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Underground Coal Mine Production Planning using Technological Similarity Algorithm

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Abstract—**Underground coal mines have to do business with respect to customer's requirements (called technological requirements) especially if they supply a local heating plants. They are primary related to the quantity and heating value of the coal. In this paper, algorithm of production planning is developed to organize mining to meet requirements in the best way possible. Using technological similarity function algorithm continuously measure the distance between current and required state of outputs and select the best schedule of mining to achieve given values. Algorithm produces the sequence of homogeneous coal deposit parts, on the annual time span, meeting requirements with respect to the set of defined constraints.**

Keywords - underground coal mine, production planning, technological requirements, similarity algorithm

I. Introduction

Mining conditions or characteristics of coal deposit belong to the internal set of constraints that cannot be influenced. Customer's requirements belong to the set of external conditions and can be changed within limited interval which is defined by a technological process. In such environment, management of coal company must organize production in a way that will harmonize these two sets.

The most of existing models that treat a problem of underground mine production planning use different approaches to solve a such very complex problem [1,2,3,4,5,6,7,8].

Underground coal mine production planning can be represented as a sequencing of coal deposit over defined time horizon, usually on annual time span. A part of deposit that should be mined for one year is called annual mining cut and is composed of adequate number of blocks. Total number of annual mining cuts equals total number of planned years of mining.

Creation of annual mining cut is based on algorithm that represents an iterative procedure in which the current iteration uses updated information from previous one. Using technological similarity function algorithm continuously measure the distance between current and required state of mining cut and select the best schedule of mining to meet customer's requirements (technological requirements). Technological requirements are: annual quantity and average heating value of coal. Forming the mining cut equals the growing of initial block by adding one in every successive iteration with respect to given requirements, spatial constraints and error of similarity. Spatial constraints concern the way of growing the mining cut.

II. Algorithm of Production Planning

A. Problem definition

The traditional block model of deposit means the deposit is divided into adequate number of blocks having the same size. Such model is created using the data obtained from exploration drilling and geostatistical methods. Suppose what portion of the deposit is defined to be mined by adequate mining method in economical way (mineable reserves), that is, ultimate number of mineable blocks is defined.

Underground coal mine production planning can be represented as a sequencing of coal deposit over defined time horizon, usually on annual time span. Part of coal deposit mined per one year should be similarly equal to the planned annual capacity of production. We called this part as annual mining cut (*AMC*). If we take into consideration that coal deposit has to be mined over T periods than every coal deposit can be expressed as union of *AMC*s as follows:

$$CD = \bigcup_{t=1}^{T} AMC_t = AMC_1 \cup AMC_2 \cup \dots \cup AMC_t \quad (1)$$

Definition 1: Let $B = \{b_k\}_{k=1,2,\dots,K}$ be a set of mineable blocks in the coal deposit where each block is defined by the attribute vector $b_k = \{a_{i^k}\}_{i=1,2,..,N;\forall k\in K}$. A subset of $\{b_k\}_{k=1,2,\dots,K}$ is a set $AMC_t = \{b_{m^t}\}_{m<K;\forall t\in T}$.

Obviously, AMC_t represents the set of blocks that should be mined over one year.

Definition 2: Let $C = \{AMC_1, \dots, AMC_t\}$ be a set of *AMC*s. Each annual mining cut $AMC_t, t = 1,2,\dots,T$ is represented as a vector of attributes $A_t = \{a_{i^t}\}_{i=1,2,\dots,N;\forall t\in T}$. If there are no changes on the set of attributes over time, than index t can be omitted.

Definition 3: Let $X_t = \{x_{i^t}\}_{i=1,2,\dots,N;\forall t\in T}$ be the set of attribute's values of *AMC* for every year of mining.

Definition 4: Let $Y_t = \{y_{i^t}\}_{i=1,2,\dots,N;\forall t\in T}$ be the set of required technological attribute's values of *AMC* for every year of mining.

Definition 5: Let $B = \{b_k\}_{k=1,2,\dots,K}$ be a set of mineable blocks in the coal then subset $W = \{w_j\}_{j=1,2,\dots,J}$ is a set composed of outer blocks. Outer block is a block which has at least one common edge with waste.

Definition 6: Let $x_{i^t}, i = 1,2,\dots,N; \forall t \in T$ be the current value of attribute and $y_{i^t}, i = 1,2,\dots,N; \forall t \in T$ be the required value of attribute, then $\varepsilon_t, \forall t \in T$ is aggregated error of similarity. It is calculated as follows:

$$\varepsilon_t = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{y_{i^t} - x_{i^t}}{y_{i^t}}\right|, \forall t \in T \quad (2)$$

It is necessary to define value of aggregated error of similarity (threshold value) which is reasonable in order to verify efficiency of obtained result; $\varepsilon_t \le \varepsilon_t^v, \forall t \in T$.

The problem of underground coal mine production planning can be defined as follows:

Determine the number of mineable blocks, $AMC_t = \{b_{m^t}\}_{m<K;\forall t\in T}$*, that should be mined every year such that similarity between sets* X_t *and* Y_t *is maximized with respect to the spatial connectivity constraints and given error.*

B. Production planning algorithm

The goal of algorithm is to partition coal deposit into T annual mining cuts $CD = \{AMC_1, \dots, AMC_T\}$, where $AMC_t \ne \emptyset$; $AMC_i \cap AMC_j = \emptyset$; $CD = AMC_1 \cup AMC_2 \cup \dots \cup AMC_t$; i=1,2,…,T; j=1,2,..,T; $i \ne j$. This algorithm is an iterative procedure in which the current iteration uses updated information from previous iteration. From initial state, in every step, AMC_t is growing up by adding only and only one block and after that we calculate the similarity between current technological state of AMC_t and required technological state with respect to the given constraints and threshold value. The calculation will be repeated until no more free mineable blocks in coal deposit. The concept of algorithm is developed on the basis of greedy algorithms such as Kruskal's algorithm, Prim's algorithm and Dijkstra's algorithm [9,10,11] and constrained polygonal clustering algorithm [12].

Technological similarity algorithm is defined as follows:

Input: set of mineable blocks with attributes, set of required values, time periods, set of constraints, objective function, value of error

Output: number of blocks to be mined in every year

Step 1. Select the initial block: $b_t^{initial}, t = 1$

Step 2. Define a set of mineable blocks that can be added to the mining cut; $\{b_l\}_{l=1,2,\dots,L}$

Step 3. Calculate the objective function $F(b_l) = S(b_l) + P(b_l), \forall l \in L$

Step 4. Select the best block, $maxF(b_l)$

Step 5. Create new $AMC_{t,j}$ by adding the best block, j is iteration index, j=1,2,…,K-1

Step 6. Update $AMC_{t,j}$ state

Step 7. Calculate the aggregated error of similarity

Step 8. If $\varepsilon_t > \varepsilon_t^v$ go to Step 2

Step 9. If $\varepsilon_t \le \varepsilon_t^v$ form the final AMC_t and go to Step 2 and repeat for t+1

End while no free blocks in the coal deposit

Set of blocks is represented by *Definition* 1 with following vector of attributes, $b_k =$

$\{a_{ik}\}_{i=1,2,3;\forall k\in K}$ where: a_{1k} is tonnage of block, a_{2k} is heating value of coal in the block and a_{3k} is *x* and *y* coordinate of block center.

Set of required technological attribute's values of AMC_t for every year of mining is $Y_t = \{y_{it}\}_{i=1,2;\forall t\in T}$ where y_{1t} is accumulated annual capacity of production and y_{2t} is average heating value of the AMC_t. Accumulated annual capacity of production is defined by the following sequence:

$$Y_1^{(1)}(t) = \left\{y_1^{(1)}(1), y_1^{(1)}(2), \dots, y_1^{(1)}(t)\right\}, t \geq 2 \quad (3)$$

where

$$y_1^{(1)}(m) = \sum_{j=1}^{m} y_1(j)\,, m = 1,2,\dots,t \quad (4)$$

This approach is adopted from Grey system theory [13]. Average heating value of the AMC_t is calculated as follows:

$$y_{2t} = \frac{1}{K}\sum_{k=1}^{K} a_{2k} \quad (5)$$

This value is constant over time span.

Set of constraints is related to spatial requirements and it is divided in two main groups: constraints concerning the AMC_t level and constraint concerning the mineable block level.

Spatial constraints concerning the AMC_t level are: *spatial constraint* 1: AMC_t must not be divided in two or more parts, i.e. AMC_t must be always homogeneous; *spatial constraint* 2: AMC_t must not divide coal deposit in two or more unmined parts, i.e. the rest of unmined coal deposit must be always homogeneous. By these two constraints and penalty function we realize the concentration of production. Spatial constraint concerning the mineable block level is *spatial constraint* 3: only blocks having at least one common edge with current AMC_t can be added to the cut.

The objective function *F* is defined as a sum of S_t and P_t, where S_t is technological similarity function and P_t is penalty function.

We define technological similarity function as follows:

$$S_t(Y_t, X_t) = \frac{1}{d(Y_t,X_t)}, \forall t \in T \quad (6)$$

where

$$d(Y_t, X_t) = \sqrt{\sum_{i=1}^{N}(y_{it} - x_{it})^2}\,, \forall t \in T \quad (7)$$

is the Euclidean distance between two *N*-dimensional attribute vectors Y_t and X_t.

If we want to keep compactness of the growing AMC_t as more as possible we add penalty function $P_t(C_t^{AMC}, C_t^b)$ to the technological similarity function $S_t(Y_t, X_t)$. Penalty function is defined as follows:

$$P_t(C_t^{AMC}, C_t^b) = \frac{1}{d(C_t^{AMC},C_t^b)}, \forall t \in T \quad (8)$$

where

$$d(C_t^{AMC}, C_t^b) = \sqrt{(x_t^{AMC} - x_t^b)^2 - (y_t^{AMC} - y_t^b)^2}, \forall t \in T \quad (9)$$

is the Euclidean distance between center of the current AMC_t and center of the block being added. Finally, the objective function *F* is of the following form:

$$F = S_t + P_t, \forall t \in T \quad (11)$$

Objective function should be maximized.

Selection of initial block i.e. AMC_1 can be done in two ways: using expert's knowledge to select one outer block from the set *W* with respect to the mineral deposit characteristics and select one outer block from the set *W* with larger $S_t(Y_t, X_t), t = 1$.

Set of mineable blocks that can be added to the AMC_t is created with respect to the spatial constraints. It means the block violating these constraints cannot be the member of the set *L*.

Updating the state of the AMC_t, after adding the new block, has three components: updating the tonnage; updating the heating value and updating the center of the AMC_t. First two updating are related to the technological state of the AMC_t while third to the compactness of mining.

Updating the tonnage of AMC_t is performed simply by adding the tonnage of new block to the tonnage of the current cut. It is necessary to emphasize that this updating is done continuously over time, not for every year separately, otherwise it would be very difficult to define initial block for $t = 2,3,\dots,T$. For these reasons technological attribute concerning the annual capacity of production is defined as accumulated sequence. Updating the heating value is performed by averaging over the set composed of previously blocks plus new one. It is done as updating the tonnage. Updating the center of AMC_t is performed by averaging over the set composed of previously blocks plus new one with respect to x and y coordinates. It is done also as two previously updating.

III. Numerical Example

Small hypothetical coal deposit is used to test the developed algorithm. Block model of coal deposit has been created on the basis of exploration drilling and geostatistical methods. Room and pillar method is selected as a way of mining the coal deposit. The input parameters needed for testing the algorithm are given in Fig. 1, Table 1 and Table 2.

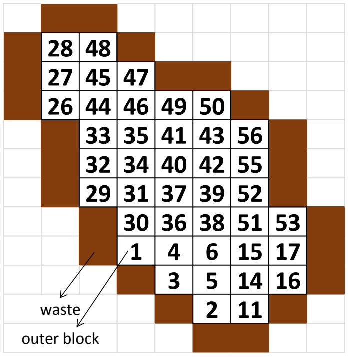

Figure 1. Block model of coal deposit

TABLE I. Value of block attributes

Block	Tonnage (t)	Heating value (kJ/kg)	*x*	*y*	Block	Tonnage (t)	Heating value (kJ/kg)	*x*	*y*
B53	12569	27492	162.50	87.50	B32	9781	26609	37.50	137.50
B17	11253	29077	162.50	62.50	B34	11380	27655	62.50	137.50
B15	9457	25488	137.50	62.50	B40	11632	26794	87.50	137.50
B51	11728	27822	137.50	87.50	B42	11427	30454	112.50	137.50
B6	10070	25508	112.50	62.50	B55	11162	24879	137.50	137.50
B38	11892	31474	112.50	87.50	B56	9853	25032	137.50	162.50
B4	9364	27377	87.50	62.50	B43	10326	27356	112.50	162.50
B36	11404	23780	87.50	87.50	B41	10619	31242	87.50	162.50
B1	6272	30346	62.50	62.50	B35	10586	24960	62.50	162.50
B30	9859	28196	62.50	87.50	B33	10718	22221	37.50	162.50
B3	8273	28751	87.50	37.50	B50	6909	24536	112.50	187.50
B5	11368	30009	112.50	37.50	B49	7281	28453	87.50	187.50
B14	11280	27002	137.50	37.50	B46	8695	24286	62.50	187.50
B16	12386	29200	162.50	37.50	B44	10635	27366	37.50	187.50
B2	8300	24778	112.50	12.50	B26	6117	24495	12.50	187.50
B11	9674	26811	137.50	12.50	B47	7602	31652	62.50	212.50
B31	10446	25136	62.50	112.50	B45	10179	30032	37.50	212.50
B37	11210	23343	87.50	112.50	B27	7376	24762	12.50	212.50
B39	11030	26472	112.50	112.50	B48	6960	28567	37.50	237.50
B52	10519	30458	137.50	112.50	B28	5563	31034	12.50	237.50
B29	7990	22853	37.50	112.50					

TABLE II. Input parameters and technological requirements

Parameter	Value
Number of blocks	41
Block dimension	25×25×5 m
Required heating value	27165 kJ/kg
Required accumulated capacity	
Year 1	80228 t
Year 2	160457 t
Year 3	240685 t
Year 4	320913 t
Year 5	401141 t
Time periods	5
Threshold value ε_t^v	0.1
Number of iterations	40

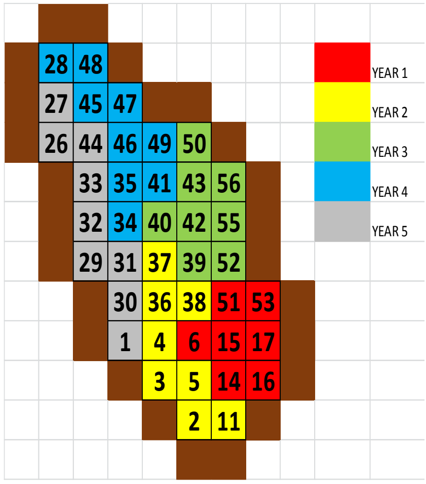

Figure 2. Plan of production

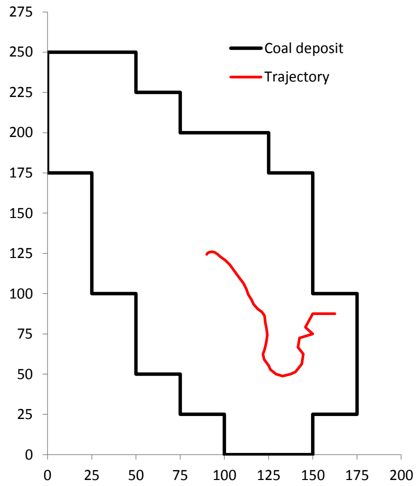

Figure 3. Trajectory of mining cut center

Block 53 was selected as initial block according to expert's knowledge. Following plan of production is obtained by applying the developed algorithm (see Fig. 2 and Table 3).

TABLE III. SUMMARY RESULTS

Year	Annual capacity (t/year)	Average heating value (kJ/kg)
1	78744	27370
2	81483	27040
3	82857	26998
4	78864	28653
5	79139	25776

Process of updating the center of AMC_t is represented by Fig. 3. No matter from which point updating is started, the process always convergence to the center of coal deposit.

Efficiency of the algorithm with respect to the given threshold value is represented in Table 4. It can be seen the efficiency is very high.

TABLE IV. ERROR OF ALGORITHM

Year	Annual capacity (t/year)	Error	Average heating value (kJ/kg)	Error	Aggregated error
Accumulated time span					
1	78744	0.01850	27370	0.00755	0.01302
1+2	160227	0.00143	27194	0.00108	0.00126
1+2+3	243084	0.00997	27126	0.00144	0.00570
1+2+3+4	321948	0.00323	27555	0.01438	0.00880
Annual time span					
1	78744	0.01850	27370	0.00755	0.01302
2	81483	0.01564	27040	0.00458	0.01011
3	82857	0.03277	26998	0.00616	0.01946
4	78864	0.01700	28653	0.05480	0.03590
5	79193	0.01290	25776	0.05113	0.03201

IV. CONCLUSION

This paper deals with an underground coal mine production planning problem that takes into account requirements of customer, called technological requirements. The problem was treated as an iterative algorithm that creates sequence of coal deposit parts that should be mined over defined time span. Coal deposit part called annual mining cut is composed of set of mineable blocks mined every year with respect to given requirements, spatial constraints and error of similarity. Algorithm allows initial annual mining cut to grow until reach the desired state on annual time span. Spatial constraints define the way of growing the annual mining cut.

Using technological similarity function algorithm continuously measure the distance between current and required state of annual mining cut and select the best schedule of mining to meet requirements.

Future research will be focus on including more technological requirements such as ash and sulfur content and including economic aspects of planning.

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Mathematical Modeling of Hybrid Renewable Energy System

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Abstract—**One of the major worldwide concerns is to reduce the emissions from traditional power plants by using renewable energy and to reduce the high cost of supplying electricity to remote areas. Hybrid energy systems can provide a good solution for such problems. Hybrid systems are characterized by containing two or more technologies of electrical generation, in order to optimize global efficiency of the processes. Combining multiple renewable energy sources can be a possible solution to overcome defects, which not only provides reliable power but also leads to reduction in required storage capacity. An oversized hybrid system satisfies the load demand, but it can be unnecessarily expensive. An undersized hybrid system is economical, but may not be able to meet the load demand. The optimal sizing of the renewable energy power system depends on the mathematical model of system components. Focusing on the three most used renewable energy sources, a summary of mathematical modeling of various renewable power systems is presented in this paper. More precisely, a general methodology for mathematical modeling of a small hydro-solar-wind power system is described.**

Keywords – mathematical modeling, hybrid renewable energy system, photovoltaic, wind power, hydro power

I. INTRODUCTION

Energy plays an important role in all types of development, including economic development. The world total energy annual consumption generally increases, with the vast majority of energy being produced by fossil fuels such as coal, oil and natural gas. At present fossil fuels contribute as the world's major energy sources. Along with the increasing demand for energy on a global scale, there is a continuously increasing negative impact on the environment, as energy is most often obtained from fossil fuels. Renewable energy is still more expensive than the energy generated by conventional sources - fossil or nuclear fuel, but has many advantages: reducing the impact of the energy sector on the environment, accessibility, creating jobs and developing the local economy. For these reasons, renewable energy sources are increasingly becoming a realistic perspective. It is a fact that renewable energy sources, energy efficiency and cleaner production are three basic elements on which sustainable energy development is based.

The renewable energy sources in comparison to conventional energy sources are less competitive due to their uncertainty, intermittency due to dependence on weather, and high initial cost. Recently, extensive research on renewable energy technology has been conducted worldwide which resulted in significant development in the renewable energy materials, decline in the cost of renewable energy technology, and increase in their efficiency. Due to intermittent nature of the renewable energy sources, system using single renewable energy source leads to oversized components and unnecessary operational and lifecycle cost. To overcome the intermittency and uncertainty of renewable sources and to provide an economic, reliable, and sustained supply of electricity, two or more forms of energy sources can be combined to form a hybrid energy system that complements the drawbacks in each individual energy source. The energy from renewable sources is available in abundance but intermittent in nature, hybrid combination and integration of two or more renewable sources make best utilize of their operating characteristics and improve the system performance and efficiency. Therefore, the design goals for hybrid power system are the minimization of power production cost, minimization of power purchase from grid (if it is connected to grid), reduction in emission, reduction of the total lifecycle cost and increase in reliability of the power generation of system.

Hybrid Renewable Energy Systems (HRES) are composed of one renewable and one conventional energy source or more than one renewable with or without conventional energy sources. A HRES can be standalone or grid connected. In a grid connected system, the size of storage device can be relatively smaller because deficient power can be obtained from the grid. A grid connected HRES can supply electricity to both load and the grid. However, when connected to grid, proper power electronic controllers are required. Based on the type of HRES, the operating mode of HRES can be classified into island mode where the generated electricity is consumed locally and grid connected mode where the renewable energy source is connected to the grid. Hybridization of different alternative energy sources can complement each other to some extent and achieve higher total energy efficiency than that could be obtained from a single renewable source. Multi source hybrid renewable energy systems, with proper control, have great potential to provide higher quality and more reliable power to customers than a system based on a single source. Due to this feature, hybrid energy systems have caught worldwide research attention.

II. MATHEMATICAL MODELING

A hybrid energy system may consist of various renewable energy conversion components such as wind turbines, PV arrays and hydro turbines, as well as conventional non-renewable generators such as diesel generators, micro turbines and storage device like battery. A hybrid energy system could have all these components or only a part of them. In order to make the correct selection of components and subsystems for optimal sizing of the entire system, the first step is modeling the individual components.

Very good mathematical models have been derived by many researchers to model hydro turbine/generator, solar cells, wind turbine/generator, diesel engine, battery storage banks, fuel cells. The performance of the individual component is either modeled by deterministic or probabilistic approaches. The purpose of each model or approach is to look for an accurate mathematical model that more closely represents the final model. When an approximate mathematical model is available it is easier to test the system for suitability without spending money prior to the fabrication. The modeling process allows identification and better understanding the characteristics of the components and it provides support in decision-making. The detail modeling reflects by correct performance prediction, but the design of the perfect model is too complex or extremely time consuming. A sufficiently appropriate model should be between complexity and accuracy.

From mathematical model, the next step is to develop the computer simulation model to test the system outputs under various input conditions, as well as to test the system for stability. These computer simulations can be used for further analysis or to change various components or to redesign the system for optimized it before fabricating the final prototype model.

A general methodology for mathematical modeling of a small hydro-solar-wind power system is described below.

A. PV System

Power output of a PV array is based on solar irradiance and ambient temperature. The power output is calculated as

$$P_{pv} = \eta_{pvg} A_{pvg} G_t \ , \qquad (1)$$

where η_{pvg} is PV generation efficiency, A_{pvg} is PV generator area (m^2), and G_t is solar irradiation in tilted module plane (W/m^2). Further, η_{pvg} is defined as

$$\eta_{pvg} = \eta_r \eta_{pc} [1 - \beta (T_c - T_{c\,\mathrm{ref}})] \ , \qquad (2)$$

where η_r is the reference module efficiency, η_{pc} is power conditioning efficiency, β is temperature coefficient ((0.004-0.006) per ^{0}C), and $T_{c\,\mathrm{ref}}$ is reference cell temperature in ^{0}C. The cell temperature T_c can be obtained by relation

$$T_c = T_a + \frac{NOCT - 20}{800} G_t \ , \qquad (3)$$

where T_a is ambient temperature in ^{0}C, $NOCT$ is nominal operating cell temperature in ^{0}C, and G_t is solar irradiation in tilted module plane (W/m^2).

The total radiation in the solar cell considering normal and diffuse solar radiation can be estimated as

$$I_T = I_b R_b + I_d R_d + (I_b + I_b) R_r \ . \qquad (4)$$

Small solar cell is the basic building blocks of PV array system. PV cells are interconnected in series-parallel configuration to form a PV array. An ideal solar cell can be considered as a current source wherein the current produce is proportional to the solar irradiation intensity. Using ideal single diode (Fig. 1) for an array with N_s series connected cells and N_p parallel connected cells, the array current may be related to the array voltage as

$$I = N_P \left[I_{ph} - I_{rs} \exp\left(\frac{q(V+IR_S)}{AKTN_s} - 1 \right) \right], \quad (5)$$

where q is the electron charge (1.6×10^{-9}C), K is Boltzmann's constant, A is the diode ideality factor, T is the cell temperature (K), I_{rs} is the cell reverse saturation current at T,

$$I_{rs} = I_{rr} \left(\frac{T}{T_r} \right)^3 \exp\left[\frac{E_G}{AK} \left(\frac{1}{T_r} - \frac{1}{T} \right) \right], \quad (6)$$

T_r is the cell referred temperature, I_{rr} is the reverse saturation current at T_r, E_G is the band gap energy of the semiconductor used in the cell. The photo current I_{ph} varies with the cell's temperature and radiation as follows

$$I_{ph} = I_{SCR} + k_i (T - T_r) \frac{S}{100}, \quad (7)$$

where I_{SCR} is cell short circuit current at reference temperature and radiation, k_i is the short circuit current temperature coefficient and S is the solar radiation in (mW/cm^2).

There are two models that are generally used to model solar cell: a **single diode circuit model** (Fig.2), and a **double diode circuit model** (Fig.3).

Single diode circuit model uses an additional shunt resistance in parallel to ideal diode model. *I-V* characteristic of PV cell using one diode model can be derived as

$$I = I_{ph} - I_D, \quad (8)$$

$$I = I_{ph} - I_0 \left[\exp\left(\frac{q(V+R_S I)}{AKT} - 1 \right) - \frac{V+R_S I}{R_{sh}} \right], \quad (9)$$

where I_{ph} is photo current (A), I_D is the diode current (A), I_0 is the inverse saturation current (A), A is the diode constant, q is the charge of the electron (1.6×10^{-9}C), K is Boltzmann's constant, T is the cell temperature (^{0}C), R_s is the series resistance (Ohm), R_{sh} is the shunt resistance (Ohm), I is the cell current (A), and V is cell voltage (V).

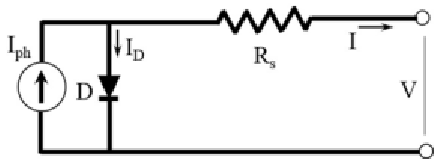

Figure 1. Ideal single diode PV cell model.

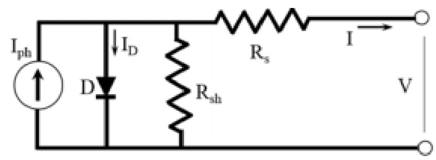

Figure 2. Single diode PV cell model.

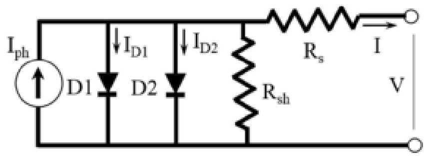

Figure 3. Double diode PV cell model.

I-V characteristic of PV cell using **two diode circuit model** can be described as

$$I = I_{PV} - I_{D1} - I_{D2} - \frac{V+IR_S}{R_{SH}}, \quad (10)$$

where

$$I_{D1} = I_{01} \left[\exp\left(\frac{V+IR_S}{a_1 V_{T1}} \right) - 1 \right], \quad (11)$$

$$I_{D2} = I_{02} \left[\exp\left(\frac{V+IR_S}{a_2 V_{T2}} \right) - 1 \right], \quad (12)$$

I_{01} and I_{02} are reverse saturation current of diode 1 and diode 2, respectively, V_{T1} and V_{T2} are thermal voltage of respective diode, a_1 and a_2 represent the diode ideality constants.

The maximum power output of a single PV module is given by

$$P_{\max} = \frac{\frac{V_{OC}}{cK\,T/q} - \ln\left(\frac{V_{OC}}{cK\,T/q} + 0{,}72\right)}{\left(1 + \frac{V_{OC}}{nK\,T/q}\right)} \left(1 - \frac{R_S}{V_{OC}/I_{SC}}\right)\left(\frac{V_{OC0}}{1 + \beta \ln \frac{G_0}{G}}\right)\left(\frac{T_0}{T}\right)^{\gamma} I_{sc0}\left(\frac{G}{G_0}\right)^{\alpha}, \quad (13)$$

where V_{oc} is the open-circuit voltage, n is the ideality factor ($1 < n < 2$), K is the Boltzmann constant, T is the PV module temperature (K), q is the electron charge, α is the factor responsible for all the non-linear effects that the photocurrent depends on, β is a PV module technology specific-related dimensionless coefficient, and γ is the factor considering all the non-linear temperature-voltage effects.

A real system consists of the number of PV modules connected in series and parallel. The total power output for an array with N_s series connected cells and N_p parallel-connected cells with P_M power of each module will be

$$P_{array} = N_s N_p P_M \quad . \qquad (14)$$

B. Wind Power System

The fundamental equation governing the mechanical power of the wind turbine is given by

$$P_w = \frac{1}{2} C_p(\lambda, \beta) \rho A v^3 \,, \qquad (15)$$

where C_p is power coefficient, ρ is air density (kg/m^3), A is intercepting area of the rotor blades (m^2), v is average wind speed (m/s), λ is tip speed ratio. The theoretical maximum value of the power coefficient C_p is 0.593, also known as Betz's coefficient.

The Tip Speed Ratio (TSR) for wind turbine is defined as the ratio of rotational speed of the tip of a blade to the wind velocity, i.e.

$$\lambda = \frac{R\omega}{v} \,, \qquad (16)$$

$$P_w(v) = \begin{cases} \frac{v^k - v_C^k}{v_R^k - v_C^k} P_R & v_C \le v \le v_R \\ P_R & v_R \le v \le v_F \\ 0 & v \le v_C \text{ and } v \ge v_F \end{cases} \,, \qquad (17)$$

where P_R is rated power, v_C is cut-in wind speed, v_R is rated wind speed, v_F is rated cut-out speed, and k is the Weibull shape factor. In literature there are authors that use the value of k as 1, or k as 2, or take the value as 3. *Cut-in speed* is a very low wind speed at which the turbine first starts to rotate and generate power. *Cut-out speed* is the high wind speed at which the forces on the turbine structure are high as a result there is a risk of the damage to the rotor. To prevent damage, braking system is employed to bring the rotor to stand-still. *Rated output speed* is the wind speed between cut-in speed and cut-out speed where the power output reaches the maximum limit that the electrical generator is capable of and is called rated power output.

Drive train transfers high aerodynamic torque at rotor to low speed shaft of generator through gearbox. Some generators are directly coupled with the rotor to reduce complexity so they do not need modeling of this part.

Drive train can be modeled using one mass model and two mass model. Developed mathematical model is based on the torsional multi-body dynamic model

$$\begin{bmatrix} \dot{\omega}_t \\ \dot{\omega}_g \\ \dot{T}_{ls} \end{bmatrix} = \begin{bmatrix} -\frac{K_t}{J_t} & 0 & -\frac{1}{J_t} \\ 0 & -\frac{K_g}{J_g} & \frac{1}{n_g J_g} \\ \left(B_{ls} - \frac{K_{ls} K_r}{J_r}\right) & \frac{1}{n_g}\left(\frac{K_{ls} K_r}{J_g} - B_{ls}\right) & -K_{ls}\frac{J_r + n_g^2 J_g}{n_g^2 J_g J_r} \end{bmatrix} \begin{bmatrix} \omega_t \\ \omega_g \\ T_{ls} \end{bmatrix} + \begin{bmatrix} \frac{1}{J_r} \\ 0 \\ \frac{K_{ls}}{J_r} \end{bmatrix} T_m + \begin{bmatrix} 0 \\ -\frac{1}{J_g} \\ \frac{K_{ls}}{n_g J_g} \end{bmatrix} T_g \quad . \qquad (18)$$

If a perfectly rigid low-speed shaft is assumed, a **single mass model** (Fig. 4) of the turbine can be considered.

The rotor side inertia for a single mass wind turbine model is given by

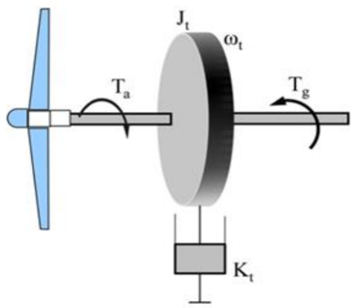

Figure 4. One mass model of wind turbine system.

$$J_t\dot{\omega}_t = T_a - K_t\omega_t - T_g \ , \qquad (19)$$

and

$$J_t = J_r + n_g^2 J_g \ ,$$
$$K_t = K_r + n_g^2 K_g \ , \qquad (20)$$
$$T_g = n_g T_{em} \ ,$$

where J_t is the turbine rotor moment of inertia [kgm^2], ω_t is low shaft angular speed [radsec^{-2}], K_t is the turbine damping coefficient [Nm rad^{-1} sec^{-1}], representing aerodynamic resistance, and K_g is generator damping coefficient, [Nm rad^{-1} sec^{-1}], representing mechanical friction.

The schematic presentation of **two mass model of wind turbine system** is given in Fig.5.

If the ideal gearbox with ratio n is assumed, then

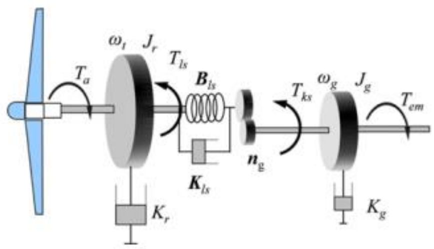

Figure 5. Two mass model of wind turbine system.

$$n = \frac{T_{ls}}{T_{hs}} = \frac{\omega_g}{\omega_t} = \frac{\theta_g}{\theta_{ls}} \ , \qquad (21)$$

The rotor side inertia J_r for the two mass wind turbine model is given by

$$J_r \frac{d\omega_t}{dt} = T_m - T_{ls} - K_r\omega_t \ , \qquad (22)$$

The low speed shaft torque is given by

$$T_{ls} = B_{ls}(\theta_t - \theta_{ls}) + K_{ls}(\omega_t - \omega_{ls}) \ , \qquad (23)$$

The generator inertia J_g is driven by the high speed shaft and braked by the electromagnetic torque T_g of the generator

$$J_g \frac{d\omega_g}{dt} = T_{hs} - K_g\omega_g - T_g \ . \qquad (24)$$

After eliminating T_{ls} time derivative from (23) and using (22) and (24), following dynamical system is derived

$$\frac{dT_{ls}}{dt} = \left(B_{ls} - \frac{K_{ls}K_t}{Jt}\right)\omega_t + \frac{1}{n}\left(\frac{K_{ls}K_t}{Jg} - B_{ls}\right)\omega_g - K_{ls}\frac{Jt + n^2 Jg}{n^2 JtJg}T_{ls} + \frac{K_{ls}}{Jt}T_a + \frac{K_{ls}}{nJg}T_g \ , \qquad (25)$$

where

$$K_{ls} = IG/L_{ls} \ ,$$

$$D_{ls} = \xi D_s \ ,$$

$$\xi = \sqrt{1 - \left(\frac{\omega}{\omega_n}\right)^2} \ , \qquad (26)$$

$$D_s = 2\sqrt{K_{ls}m} \ , \qquad (27)$$

and ω/ω_n is ratio of shaft frequency of oscillation to the un-damped natural frequency of shaft, m is mass of shaft, I is second momentum of area about the axis of rotation, L_{ls} is shaft length, G is modulus of rigidity, D_S is critical damping of shaft, and ξ is damping ratio of shaft.

The output power and torque of turbine (T_t) in terms of rotational speed can be obtained by substituting (16) in (15).

$$P_w = \frac{1}{2}\rho A C_p(\lambda, \beta)\left(\frac{R\omega_{opt}}{\lambda_{opt}}\right)^3 \ , \qquad (28)$$

$$T_t = \frac{1}{2}\rho A C_p(\lambda, \beta)\left(\frac{R}{\lambda_{opt}}\right)^3 \omega_{opt} \ . \qquad (29)$$

C. Hydro Power System

The first step in hydro modeling is to calculate the flow rate. The flow rate can be calculated if the catchment area of river is known in addition to the rainfall data (monthly, daily, and hourly). Catchment areas are the areas from which rain water flows into the river. The above procedure is for run off river type of hydro system. The hydro potential of a site is given by

$$Q_{site} = K\frac{A_{site}}{A_{gauge}}Q_{gauge} \ , \qquad (30)$$

where A_{site} is catchment area of power plant (m^2), A_{gauge} is catchment area of gauge (m^2), Q_{site} is discharge at site (m^3/s), Q_{gauge} is discharge at gauge (m^3/s), and K is scaling constant or function.

The mechanical power generated by the turbine is given by

$$P = \eta_{total} \rho g Q H \quad , \qquad (31)$$

where P is mechanical power output produced at the turbine, η_{total} is hydraulic efficiency of the turbine, ρ is density of water (1000 kg/m^3), g is acceleration due to gravity (9.81 m/s^2), and H is effective pressure head (m).

III. CONTROL OF HYBRID ENERGY SYSTEM

Hybrid energy system has complex control system due to integration of two or more different power sources. The dynamic interaction between the power electronic interface of renewable energy sources leads to problems of stability and power quality in the system, which makes the control difficult and complex.

Because of the nonlinear power characteristics, wind and PV system require special techniques to extract maximum power. Hence, the complexity of HES control system increases with maximum power point tracking (MPPT) techniques employed in their subsystems. MPPT tracking has to be done for individual subsystems. The performance analysis of HES can only be evaluated after performance analysis of individual system.

A HES can be standalone or grid connected. Standalone systems, besides the generation capacity, need to have additional storage capacity large enough to handle the load. In a grid connected system, the storage device can be relatively smaller as deficient power can be obtained from the grid. A grid connected HES can supply electricity to both load and the utility grid. However, when connected to grid, proper power electronic controllers are required to control voltage, frequency and harmonic regulations, and load sharing.

During operation hybrid wind-solar system is subjected to fluctuating wind speeds and solar insolation as well as to varying load demand. Hence a controller is essential to determine how much energy is available from each component and how much to use of it. The operation policy for standalone wind-solar hybrid system should employ the available energy from the wind turbine and solar panel in each sub-period to use first and excess energy to be stored in batteries. If the renewable energy is not sufficient to supply the load in a given sub-period, then energy is drawn from battery storage first and then through diesel generator (if available). In case of systems where diesel generator is available, batteries act as fuel saver and they are used prior to diesel engine. The operation policy in case of grid connected hybrid system should exploit renewable energy first and excess energy if available should be stored in batteries. However, if excess energy is still available, then it should be sold to the grid. If renewable energy is not sufficient to supply the load in a given sub-period, then batteries should be employed first and grid electricity should be used if deficiency still exists. The battery in grid connected system store the surplus power from power generation system, so only small power from the grid is needed.

The operation of hybrid hydro-wind power system enables the accumulation of electricity generated by the wind turbine/generator in the form of potential water energy in the accumulation and at the required moment of conversion of that energy back to the electric power. This conversion does not occur in reality, but energy is stored as a potential energy of water in the accumulation at the expense of a reduced production of a hydro power plant in the period when there is enough energy from the wind.

In hydro-pumped energy system (HPES), the same system can work as motor to pumped water to the reservoirs, or it can work as generator depending on the energy generated by the other systems. When the solar PV system and wind turbine system generate more than requirement, the HPES will work as motor to pumped water from low reservoir to upper reservoir, i.e. as a hydro energy storage system (HESS). When the energy generated from solar PV system and wind system is less than load demand, the HPES will work as generator. The water stored in upper reservoir will be move to lower reservoir making the HPES system to work in generating mode.

IV. CONCLUSION

Approximately one-fifth of the global populations are living without electricity in the world. In developing countries, it is estimated that almost one third of total population are deprived of electricity. An alternative to the grid connected power is the renewable energy based off-grid power system.

Due to intermittent nature of the renewable energy sources, system using single renewable source leads to oversized components and unnecessary operational and lifecycle cost. To overcome the intermittency and uncertainty of renewable sources and to provide an economic, reliable, and sustained supply of electricity, two or more forms of energy sources can be combined to form a hybrid energy system that complements the drawbacks in each individual energy source.

Hydro-pumped energy system is most promising upcoming technology to increase the renewable energy deployment. Globally there are 270 HPES working and under construction with combine generating capacity of 127,000MW. Variable speed system is preferable for HPES because the parameters like power is varies due to which it must run at optimal speed for maximum output, so Doubly Fed Induction Machines precede among other available system.

The energy from renewable sources is available in abundance but intermittent in nature, hybrid combination and integration of two or more renewable sources make best utilize of their operating characteristics and improve the system performance and efficiency. Therefore, the design goals for hybrid power system are the minimization of power production cost, minimization of power purchase from grid (if it is connected to grid), reduction in emission, reduction of the total lifecycle cost and increase in reliability of the power generation of system. In order to make the correct selection of components and subsystems for optimal sizing of the entire system, the first step is modeling the individual components.

Focusing on the three most used renewable energy sources, a summary of mathematical modeling of various renewable power systems is presented in this paper. More precisely, a general methodology for mathematical modeling of a small hydro-solar-wind power system is described.

From mathematical model, the next step is to develop the computer simulation model to test the system outputs under various input conditions, as well as to test the system for stability. These computer simulations can be used for further analysis or to change various components or to redesign the system for optimized it before fabricating the final prototype model.

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Management of the Environmental Protection System in the Energy Industry

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Abstract — **Implementation of modern environmental protection systems improves the use of preventive measures and the procedures that eliminate the negative effects caused by mining and energy complexes. Modern-day safety systems include the analysis of the state of the environment and the monitoring of the impact of open-pit mining, coal combustion, and the associated technological processes, which are necessary for the system that transforms energy from coal to function. Environmental protection system management in the energy industry plays a key role in preserving the quality of air, water, and soil.**

Keywords – energy, environment, project management, sustainable development

I. Introduction

In the United States during the 1960s, a method was developed that analyzes a product during its entire life cycle. The method was initially used within global energy modeling and assessment, but was later included in other fields that monitor materials, energy, pollutant emissions, and waste from the manufacturing process. Life cycle analysis (LCA) [1] is used in all engineering fields. LCA procedures and methods were agreed upon at the conference of the Society of Environmental Toxicology and Chemistry (SETAC) in 1992 [2].

LCA-based modeling of the environmental management system (EMS) leaves room for decision making according to relevant information, which is necessary for the management of an organization and the monitoring of the state of the maintenance and purification system.

LCA is a method that can be implemented in modern-day EMS, because it analyzes the environmental impact during the entire life cycle of a product. It requires a comprehensive analysis of the impact, from tailings removal to ash and slag disposal. Collection of data on the impact of open-pit mines and thermal power plants on the quality of air, water [3], and soil is necessary for the LCA of coal and the creation of guidelines for resolving priority environmental issues.

Coal LCA is performed only after the subject and system boundaries have been established [4]. The subject of coal LCA is the impact analysis of coal mining and combustion, in order to create a database required for EMS modeling in mining and energy complexes.

The analyzed processes should be presented in detail and the significance of the processes outside the system (which are not analyzed due to their complexity) should be stressed. The processes of goal generation and distribution of electricity fall outside the system boundaries, because they go beyond the needs for studying the state in mining and energy complexes.

II. Energy System Analysis

Setting the boundaries of the system for assessing the complex life cycle of coal allows the scope and aim of analysis to be defined. The aim of analysis is to determine pollution sources and to timely detect the exceeded values of pollutant emissions. The scope of analysis includes the analyzed processes (open-pit mining, coal and tailings transport, coal combustion, and disposal of tailings, ash, and slag).

LCA involves the definition of analysis aim, analysis scope, data collection procedures, and life cycle assessment.

The first stage of LCA involves the definition of the aim and methods. The aim of analysis (Table I) is defined by means of a functional unit, which, for the purpose of coal LCA, is one tone of coal. The methods of analysis are also defined in the first stage of LCA. In this case, the real impact assessment can be determined based on environmental monitoring results and the selected indicators of sustainable development.

TABLE I. AIM OF EMS ANALYSIS

AIM OF ANALYSIS
-Examination of the environmental impact of mining and energy complexes
-Definition of EMS requirements
-Adherence to the principles of sustainable development
-Prediction of the environmental impact of the process and the reaction of the public

Boundaries should be set at the very beginning of the first stage of coal LCA (Table II). This paper analyzes the combustion process in detail.

TABLE II. DEFINITION OF THE SCOPE OF ANALYSIS

SCOPE OF ANALYSIS
-Setting the boundaries for the system of mining and energy complexes and their surroundings
-Efficient use of raw material (coal) and energy
-Emission of pollutants and the amount of solid waste
-Planning of sustainable open-pit mining
- Planning of sustainable combustion process
-Proposal for a sustainable manner of coal mining and combustion

The characteristics of the combustion process are not affected by the person who uses the results of mining and energy complex EMS modeling to manage the environmental protection system.

However, proper maintenance of the boiler heating surfaces and the purification system is essential to the mitigation of environmental impact of combustion, so their impact is considered here.

Realization of a preset goal implies detailed preparation for the creation of up-to-date environmental protection systems in mining and energy complexes.

The second stage of coal LCA involves data collection (Table III), using the existing reports on pollutant emissions [5], data on the amount of excavated and burned coal, deposited tailings, and the area of land occupied. It is very important, not only for this stage but also for the entire LCA, to have reliable data, which requires special attention.

The Report on Emissions by the Mining Institute and the Report on the State of the Environment by the Environmental Protection Agency are valid and acceptable sources of information to be used for impact analysis. Detailed analysis of existing results is aimed at determining parameters whose values exceed the limit values. Comparative analyses of available data provide an accurate picture of the actual state. Depending on the observed system, relevant indicators of the energy industry are considered, while taking into account specific environmental indicators [6], (transport indicators and indicators of air, water, and soil pollution).

TABLE III. COLLECTION OF DATA ON THE IMPACT OF THE THERMAL POWER FACILITY

DATA COLLECTION
-Causes of environmental disturbance
-Effects of the operation of mining and energy complexes
-Review of previous domestic and foreign research
-Analysis of domestic and foreign research
-Studies that can be applied to the conditions of Serbian mines
-Formation of a monitoring system and collection of input data

The third stage of coal LCA allows the assessment of coal life cycle (Table IV) and of the impact of mining and energy complexes on air, water, and soil quality based on the data collected in the previous stage (reduced to the functional unit). This stage also enables the assessment of the impact of coal mining and combustion on global environmental changes, such as shortages of coal reserves (non-renewable energy source), acid rain, global warming, and occupation of agricultural land.

TABLE IV. COAL LIFE CYCLE ASSESSMENT

LIFE CYCLE ASSESSMENT
-Result analysis
-Evaluation of the environmental impact of open-pit mining
- Evaluation of the environmental impact of combustion
- Evaluation of the environmental impact of tailings and ash holes
-Reduction of results to the same unit
-Proposal for improving the process

The fourth stage of LCA depends on the previous stages. Interpretation of results (Table V, VI) largely depends on life cycle assessment, but data still have to be collected properly (from coal open-pit mining to the use of ash for industry purposes or dispersal of solid particles form the ash hole, which will eventually reach the human food chain).

TABLE V. INTERPRETATION OF ANALYSIS RESULTS

INTERPRETATION OF RESULTS
-Showcasing of environmental impacts of specific parts of the cycle
-Selection of environmental and energy efficiency indicators for coal life cycle assessment
-Recommendations on how to resolve the issue

TABLE VI. GUIDELINES OF ISO 140001 STANDARDS IN THE SYSTEM OF ENVIRONMENTAL MANAGEMENT AND ENERGY TRANSFORMATIONS IN MINING AND ENERGY COMPLEX INTERPRETATION OF ANALYSIS RESULTS [7]

REVIEWING MANAGEMENT SYSTEM IMPROVEMENTS INTERPRETATION OF RESULTS
Reviving of environmental management system in mining and energy complex
-Identifying areas for improving the functioning of the management system
-Taking measures to improve the environmental management system
General and specific objectives of environmental protection and mining and energy complex programs
Environmental management system programs
Internal audits of application of prescribed measures for environmental protection
Training of workers for environmental protection

III. EVALUATION OF THE IMPACT OF THE ENERGY INDUSTRY ON ENVIRONMENTAL QUALITY

Use of LCA in environmental protection system modeling for mining and energy complexes requires analyses of a number of independent and interdependent processes. The result of an entire life cycle of coal would be to join the individual results into a functional whole.

Using LCA to evaluate the impact of mining and energy complexes and the state of the environment is crucial for the harmonization of the operation of mining and energy complexes with the principles of sustainable development.

Mining and energy complex management based on coal LCA and implementation of up-to-date methods of environmental management (AHP and BSC) is a step toward resolving ecological issues created by coal mining and combustion. Using the BSC in management procedures forms a basic for improvement of the existing EMS of for establishment of a parallel management system [8]. Systematic approach to environmental management planning for mining and energy complex, based on the application of AHP method in combination with BSC method, provides an opportunity for a more realistic view of the situation and mitigates the subjective attitudes in decision-making [9]. In addition to environmental preservation, achieving economic gain is also very important. Implementation of up-to-date environmental protection systems and EMS modeling helps with the accomplishment of sustainable development goals and the functioning of mining and energy complexes in accordance with Serbian legislation and EU requirements.

Data collection plays an important role in EMS modeling. It involves the analysis of values of emission and immission concentrations and sets the foundation for: data processing and numeric representation of relevant inputs (matter and energy); and outputs (products, energy, and pollutant emissions). Data are collected for the purpose of selecting environmental indicators and creating an EMS model. Implementation of coal life cycle assessment, as the following stage, depends on the collected data, which in fact represent the input for the third stage of the cycle.

Inputs and outputs, characteristic for specific processes, should be viewed as the source of data for every elementary process. Limitations in data collection are possible, but they are not disregarded in the modeling stage if they are relevant for the mining and energy complexes EMS model design.

IV. ENVIRONMENTAL MANAGEMENT

A network planning technique is a starting point for project management. Application of the critical path method (CPM) and precisely defined activity durations allows [10] the creation of the mining and energy complexes EMS model (Table VII).

TABLE VII. MANAGEMENT MODEL CREATION

CREATION OF AN EMS MODEL
-Creation of a model for a concrete example from the EMS structure
-Concrete model checking
-Checking for a number of different conditions using parameters
-Determination of regularities based on several instances of model checking
-Model checking for specified conditions
-Evaluation of model universality with proof analysis

Defined activities form the basis for the realization of the management program [11], by applying the software package MS Project (Table VIII).

TABLE VIII. A LIST OF PROJECT MANAGEMENT ACTIVITIES

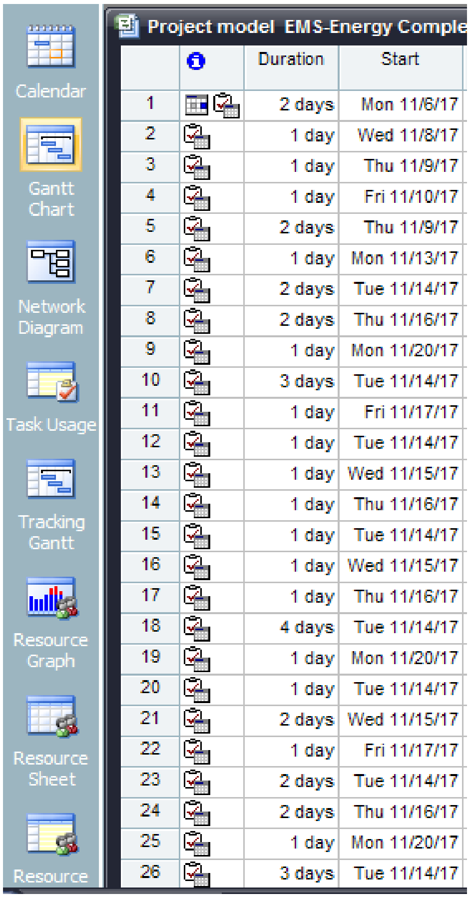
No.	POJECT MANAGEMENT ACTIVITIES
1	Defining real possibilities for improving Management of the Environmental Protection System in the Energy Industry (MEPSEI)
2	Selecting multidisciplinary team members
3	Defining key problems in the functioning of MEPSEI
4	Defining the impact of energy complex operation
5	Analyzing and applying the principles of sustainable development
6	Selecting the basic principles of sustainable development
7	Investigating air quality effects of coal dust
8	Investigating air quality effects of emitted ash and gaseous products
9	Establishing ratios for concentrations
10	Investigating the effects of untreated mine wastewater, landfill leachate, and ash
11	Establishing ratios for concentrations of heavy metals
12	Investigating the effects of surface exploitation on the humus layer destruction of abandoned areas and on the quality of agricultural land
13	Investigating the effects of ash disposal on the humus layer destruction of abandoned areas and on the quality of agricultural land
14	Establishing ratios for concentrations of heavy metals in soil and their acceptable values
15	Identifying vulnerabilities in the application of applicable laws
16	Identifying vulnerabilities in the application of EU directives
17	Considering opportunities for active environmental protection
18	Identifying gaps in the preventive safety measures
19	Considering causes of threats to the environment
20	Identifying causes of the adverse effects caused by operations
21	Identifying opportunities for eliminating causes of the adverse effects caused by operations
22	Considering the need for environmental education
23	Analyzing studies on the country's energy potential
24	Considering coal reserves
25	Identifying opportunities for rational consumption of coal
26	Analyzing the annual level of coal exploitation
27	Analyzing data on GDP per unit of consumption
28	Analyzing and assessing harmful consequences of coal mining and combustion
29	Creating amendment proposals on the adopted short- and long-term goals of environmental protection
30	Identifying opportunities for rationalization of coal consumption
31	Predicting risks to human health and the state of the environment
32	Creating amendment proposals on the adopted environmental policy
33	Analyzing energy consumption
34	Establishing procedures to stop disregarding the importance of environmental degradation

35	Establishing procedures and compliance with EU standards
36	Preparing the documentation for timely risk identification
37	Proposing the implementation of sustainable development principles

Activity durations are shown in Fig. 1.

Fig. 1 shows that most activities are planned to be completed in one day. Identifying gaps in the preventive safety measures (18) is very important for the improvement of the environmental protection system, so the activity duration is set at four workdays.

This fact is highly significant, especially when dealing with a wide-scope research, which is necessary for EMS modeling of complex technological processes.

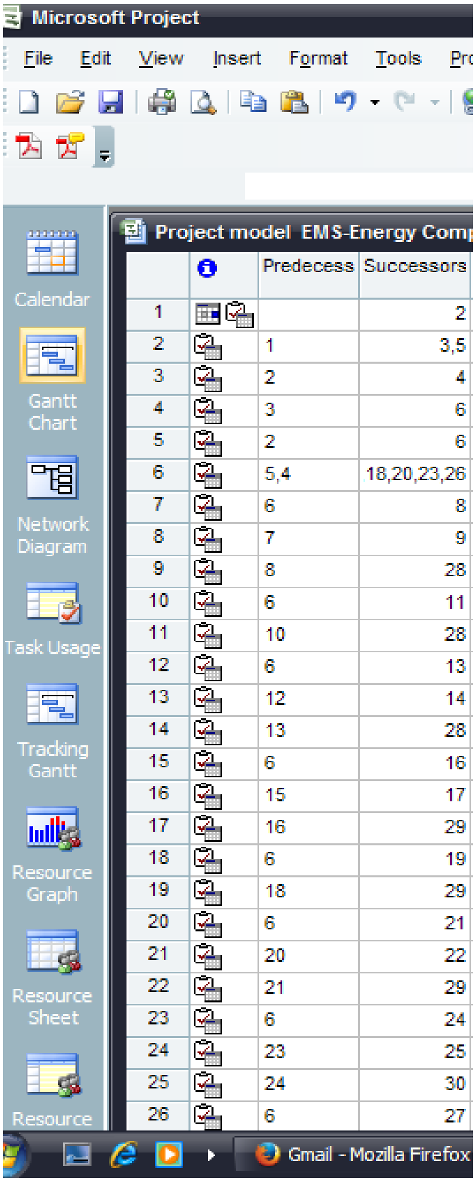


	Duration	Start
1	2 days	Mon 11/6/17
2	1 day	Wed 11/8/17
3	1 day	Thu 11/9/17
4	1 day	Fri 11/10/17
5	2 days	Thu 11/9/17
6	1 day	Mon 11/13/17
7	2 days	Tue 11/14/17
8	2 days	Thu 11/16/17
9	1 day	Mon 11/20/17
10	3 days	Tue 11/14/17
11	1 day	Fri 11/17/17
12	1 day	Tue 11/14/17
13	1 day	Wed 11/15/17
14	1 day	Thu 11/16/17
15	1 day	Tue 11/14/17
16	1 day	Wed 11/15/17
17	1 day	Thu 11/16/17
18	4 days	Tue 11/14/17
19	1 day	Mon 11/20/17
20	1 day	Tue 11/14/17
21	2 days	Wed 11/15/17
22	1 day	Fri 11/17/17
23	2 days	Tue 11/14/17
24	2 days	Thu 11/16/17
25	1 day	Mon 11/20/17
26	3 days	Tue 11/14/17

Figure 1. Duration of activities

Fig. 2 shows the order of execution of project activities to improve the MEPSEI.

It can be seen that activities such as identifying gaps in the preventive safety measures (18), identifying causes of adverse effects (20), or analyzing the country’s energy potential (23), and analyzing the annual level of coal exploitation (26) depend on the possibility of applying the principles of sustainable development in the energy industry.



	Predecess	Successors
1		2
2	1	3,5
3	2	4
4	3	6
5	2	6
6	5,4	18,20,23,26
7	6	8
8	7	9
9	8	28
10	6	11
11	10	28
12	6	13
13	12	14
14	13	28
15	6	16
16	15	17
17	16	29
18	6	19
19	18	29
20	6	21
21	20	22
22	21	29
23	6	24
24	23	25
25	24	30
26	6	27

Figure 2. Order of execution of activities

It can be seen that activities such as identifying gaps in the preventive safety measures (18), identifying causes of adverse effects (20), or analyzing the country's energy potential (23), and analyzing the annual level of coal exploitation (26) depend on the possibility of applying the principles of sustainable development in the energy industry.

Fig. 3 clearly shows that investigating air quality effects of coal dust (7) and the effects of untreated mine wastewater, landfill leachate, and ash (10) depend on the selection of the basic

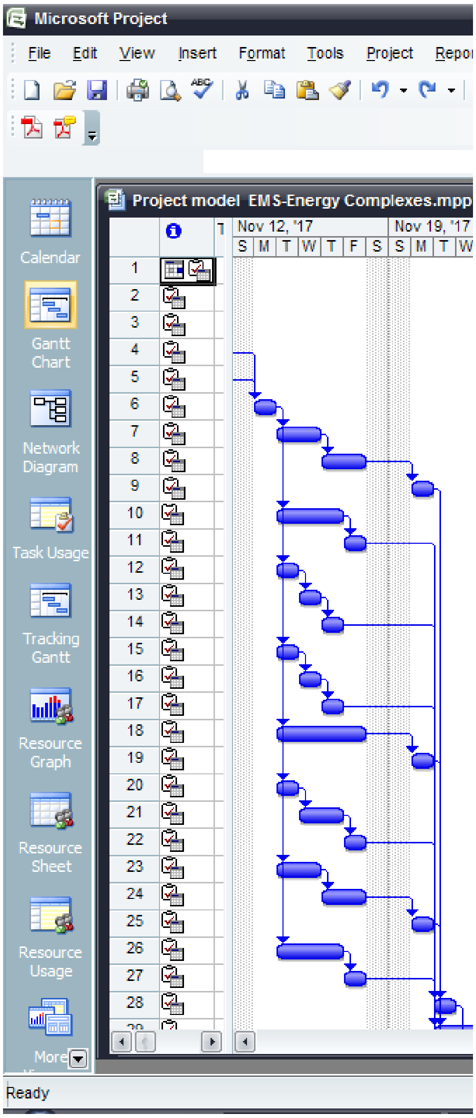


Figure 3. Illustrative part of gantographic display of branched structure of the project to improve the MEPSEI

principles of sustainable development (6) and on the aims of MEPSEI system improvement. Investigating the effects of surface exploitation on the humus layer destruction and on the quality of agricultural land (12) as well as the effects of ash disposal (13) are activities of great importance for proper determination of ratios for concentrations of heavy metals in soil and their acceptable values (14). Identifying vulnerabilities in the application of applicable environmental laws (15), causes of adverse effects (20), and the annual level of coal exploitation (26) are key activities for analyzing and assessing harmful consequences of coal mining and combustion (28).

Fig. 4 shows a portion of the calendar of activities.

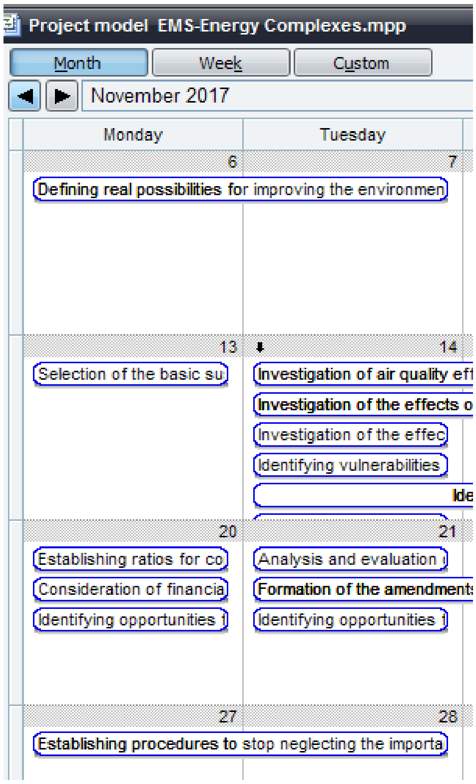


Figure 4. Calendar of activities planned in the management project

It can be seen that the beginning of the workweek in the observed period involves the following activities:

- defining real possibilities for improving MEPSEI (1),

- selecting the basic principles of sustainable development on which process management will be based (6),

- considering the financial and technical reasons for environmental endangerment (20),

- identifying opportunities for eliminating causes of the adverse effects (21), and

- establishing procedures to determine the real value of the effects of mining and energy complex operations (34).

Based on the analysis of activity duration we determined the critical path (Fig. 5). It represents a chain of interrelated activities that have the same earliest and latest time durations. It stretches between the initial and the final event.

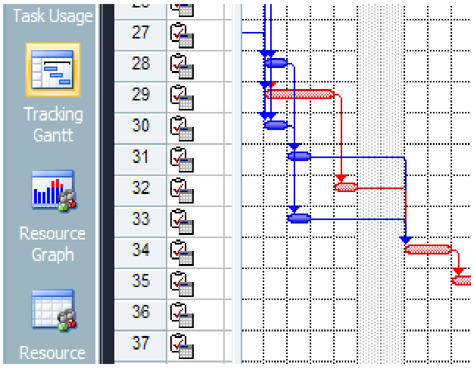


Figure 5. Partial representation of the critical MECEMS management project

Analysis of activities in the critical path (Fig. 5) reveals that special attention should be given to the creation of amendment proposals on the adopted short- and long-term goals of environmental protection (29) and on the adopted environmental policy (32), but also to the establishment of procedures that will stop the disregard of implementation of safety measures and operational procedures, reduce the level of environmental pollution, and comply with EU standards.

The system of environmental protection management enables the implementation of environmental policy by achieving required standards, respecting legal norms and adopted regulations [12].

V. Conclusion

Management of the environmental protection system in mining and energy complexes is a key task for the functioning of the energy sector in keeping with the principles of sustainable development. Use of coal life cycle analysis is the basis for identifying problems in the functioning of the safety system and corrective environmental protection measures.

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Financing of Energy Saving Renovation of Housing Real Estates: Best Practices

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Abstract — **The article considers energy efficiency as a topical scientific problem. One of the solutions to this problem can be the renovation of housing real estates, related to the improvement of energy efficiency. It is proved that the main problem of this renovation is the need for significant financing. The best practices of financing such renovations are considered.**

Keywords: energy efficiency renovation, housing real estates, financing of renovation

I. Introduction

The growth of the population of the planet leads to an increase in energy consumption. The increase of the number of powerful industries, electric transport and cars, road and city lighting, various electrical household appliances also lead to an increase of the energy consumption. Therefore, energy saving is an important scientific problem. Scientists around the world offer various solutions to this problem. According to the authors, one of the solutions to this problem may be the renovation of housing real estates, based on improving energy efficiency. Various technologies and materials capable of conserving energy may be applied for this renovation. The article will consider the best practices for financing such renovation.

II. Materials and methods

The author uses methods of statistical and economic analysis, sociological research and the method of expert evaluations.

III. Relevance of the research

The modern consumer society is based on the principal of maximal satisfaction of material needs. This principle results in unlimited growth of production. As an outcome a disbalance between sustainable development and economic processes is observed. Natural-resources potential which has been stored for hundreds of years can be exhausted during several decades; therefore, ecological problems connected with self-preservation of the human and human civilization are becoming all the more prominent. The major ecological objective is preservation of biosphere and minimization of damage brought about by unsustainable economic activity.

The scale of world production and consumption has led to disastrous imbalance between nature and social systems and exceeded capabilities of environment to cope with the results of human activity. Such situation is considered to be a global environmental crisis.

Existence of such problems imposes restrictions onto world economy. In the last decades, acceleration and extension of economic globalization have been observed and the major negative result of it appears to be aggravation and intensification of environmental problems: pollution of the environment, destruction of its components and scarcity of resources for economic activity [1].

Recently, most of the countries in the world have been giving a lot of attention to ecological politics:

- The USA Senate is considering the Clean Energy and Safety Act according to which emissions are to be reduced by 17 % in 2020 and by 83 % by 2050 compared to emissions of 2005;
- Sweden is planning to become the 1st country in the world having abandoned oil as an energy source by 2020;
- Japan adopted National Development Plan in 2010 which is based on development of

renewable sources of energy, ecological market and preservation of the environment.

International issues related to provision of countries with affordable energy and its sustainable utilization, energy and environmental safety are of the highest priority at the moment. Buildings are considered to be the major consumers of energy resources thought in spite of this they possess considerable potential in terms of energy conservation. Buildings are responsible for about 30 % of global greenhouse gas emissions and 40 % of energy consumption in Europe.

IV. SOLUTION TO THE PROBLEM

The authors of the article suggest considering renovation of housing real estates stock based on the enhancement of energy efficiency one of the possible solutions to the given problems. Renovation of residential housing and, namely reduction of heat loss through enhancement of insulation, is considered to be one of the effective measures to conserve energy resources.

International practices indicate that energy saving renovation allows:

- increasing energy efficiency in buildings;
- reducing consumption of energy resources;
- providing comfortable climatic conditions;
- improving ecological situation in the world by means of reducing emissions of carbon dioxide into the air.

For example, renovation of the European Union’s building stock in terms of its energy efficiency is to have saved from €80 to €153 billion of investment costs into the block’s power system by 2050 [2]. Buildings have the potential to reach a 90 % reduction in their greenhouse gas emissions by 2050 [3]. The full costs of installation and maintenance of the building systems are to be offset by 10 % increase in productivity [4].

Practices of the recent years have proved that housing sector is rather vulnerable to measures of state policy aimed at increasing of energy efficiency. In the period between 2000-2015 in Russia specific power consumption per m^2 of the living floor space regarding equatable weather conditions reduced by 20 %. This can be considered a breakthrough for energy consumption in Russia for the last 10 years have stabilized and started to decrease slightly while the floor space has increased by 25 % over the same period. The number of multistoried houses, equipped with metering devices and quantity of energy efficiently bulbs have considerably increased as well, however, average consumption of electrical energy by new types of fridges and other household appliances has decreased.

According to the report Promotion of healthy and energy efficient buildings in the European Union [5], substantial health benefits from improved indoor climate resulting from energy efficient renovation of buildings are estimated at €33–73 billion annually by 2020 in the low energy efficiency scenario and at €64–140 billion in the high energy efficiency scenario due to improved life quality, less public health expenses and fewer days missed at work. These figures are the same as those estimated when considering the energy efficiency alone. Unused potentials of energy efficiency should be further exploited in the European and world legislation based on a system-approach to the building. This means that the building’s envelope and its insulation, use of daylight, demand-controlled ventilation, heat recovery through mechanical ventilation systems, installations to avoid overheating such as ventilative cooling and solar shading (e.g. by overhangs, louvers and awnings) are to be analyzed and optimized in a systematic way in order to achieve the highest energy saving possible. One of affordable ways of increasing energy efficiency in buildings is the insulation whereby conservation of energy resources is achieved.

It is obvious that energy saving renovation of housing real estates benefit the government and citizens of different countries. However, the main problem is financing such programmes. The further analysis of best world practices in renovation justifies their relevancy and effectiveness.

V. GERMANY

Germany creates conditions for stimulation of energy efficient renovation through cooperation with KfW Bank of Development. Two thirds of all residential buildings had been constructed before the first Act on thermal insulation entered into force in 1977, and are therefore considered old buildings from an energy perspective. The same is true for the majority of about 300,000 buildings of municipal and public infrastructure in Germany. Residential housing alone accounts for about

40 % of total energy use in Germany [6]. The potential for making improvements in terms of energy is enormous.

KfW is supporting the energy shift over the next five years with more than €100 billion, making a crucial contribution to restructuring of the energy supply. KfW Bank under the guidance of German government pays subsidies and issues loans for reconstruction of residential buildings with flexible credit payment terms up to 30 years. This system allows every resident regardless their social status to improve their housing conditions. The major objective of KfW Bank is to initiate a massive expansion of electricity and heat energy generated by renewable sources, including the electricity grids required to transport it, also focusing on developing energy storage systems and highly efficient technologies such as gas-fired power stations.

Using a variety of promotional products, KfW helps residents and tenants, municipalities, small and medium-sized enterprises reduce their energy consumption, also safely implement energy efficiency measures for buildings during an economic crisis. Efficiency measures generally pay off economically in the medium-term. They contribute directly to climate protection.

Private households, municipalities and public institutions can use energy more efficiently, while companies can push ahead with technological innovations for climate protection. This not only protects the environment, but also safeguards the country's technological edge, employment and prosperity.

The activity of KfW also affects economy and labour market. Investments into renovation of houses benefit small and medium-size enterprises such as development and construction companies. Approximately 300 000 of work places were provided in the period of one year [Table I]. Federal Government of Germany equally benefits from tax revenue, social security contributions and low expenses on unemployment.

With «KfW Efficiency House», KfW established a uniform standard for buildings recognized throughout the real estate sector. A «KfW Efficiency House-55», for example, needs only 55 % of the primary energy of a new building constructed in accordance with the Energy Saving Act (EnEV) due to modern heating technologies based on renewable energies as well as very efficient heat insulation.

41 % of all new-built houses in Germany now meet one of the «KfW Efficiency House» standards.

TABLE I. IMPACT OF KFW «ENERGY EFFICIENT CONSTRUCTION AND REFURBISHMENT» PROGRAMMES

Indicator	2009	2010	2011	2012
Commitment volume (€ in billions) – of which funding of Federal Government (€ in billions)	9,0 2,04	8,9 1,37	6,6 0,93	10,1 1,42
Investments financed (€ in billions)	18,6	21,5	18,6	27,3
Housing units financed, in thousands	617	953	282	358
Reduced greenhouse gas emissions (CO2 equivalent) (per year, in thousand tones)	1212	1039	577	832
Jobs secured (for one year, in thousands)	262	289	253	373

By providing low-interest loans and terms of up to 30 years, KfW helps municipalities reduce their deficiencies in the energy-efficient refurbishment of schools, nurseries or community buildings. According to estimates by the Bremer Energy Institute these are to require at least €75 billion by 2020. Additional savings potential is exploited with promotional products for the energy efficiency rehabilitation of town districts and the modernization of street lighting.

The funds invested in 2011 in Energy Efficient Construction and Energy Efficient Refurbishment of residential buildings and municipalities totaling €6.6 billion reduced the emission of greenhouse gases by 576,800 tons per year.

VI. ESTONIA

Estonia offers its way of funding renovation. Residential housing stock was built mainly in the 1980s when issues of energy efficiency and energy conservation were not paid attention to. Two thirds of the stock are represented by multi-storeyed buildings, one third of it is composed of detached houses. The research shows that the average age of detached houses exceeds 50 years' mark while multi-storeyed buildings are about 25–30 years old. The age of the rest of the housing stock varies greatly reaching 100 years for some houses in old areas [7]. Therefore, owners of these houses have to pay ever-greater attention to maintenance of their property taking into consideration energy efficient renovation and life.

The average annual heating energy used in the residential housing of Estonia is 200-400 kWh/m2 compared to the figure in industrial nations with a similar climate which is only 150–230 kWh/m2. According to the information from the Ministry of the Environment of Finland, Estonia uses 2 to 3 times more energy than the Nordic countries combined even though the average temperature is higher. Thus, Estonians consume more energy and also pay quite a lot for it. Rapidly rising energy prices do not only lead residents to supplement the heating insulation of the buildings, but they are forced to. Above all, additional insulation is a way of saving equally on a personal and on a national scale. The microclimate of the rooms can be improved by the insulation. In addition, the less energy is used the less the environment is damaged.

Based on the EU Directive on energy efficiency for buildings [8], Estonia has the obligation to develop and implement measures to make the use of energy more efficient in existing buildings. Due to this Estonian Government decided to create a loans fund (average rate of interest from 3,5 % to 4 %) in order to encourage an increase in energy efficiency of the housing stock through grants, subsidies and loans. In Estonia technical aspects of renovation of every building depend on the results of the building's examination and energy audit. Generally, renovation involves insulation work, installation of new windows and doors and adjustment of renewable energy devices.

Residents of multi-storeyed buildings usually cannot afford funding major renovation activities. Therefore, in some houses there is a house reparation contribution fund and residents are to contribute money into it. Unfortunately, collection of a necessary sum for a major renovation activity can take a lot of time and the amount of renovation work can increase many-fold as well as its cost.

Contributing money to house reparation contribution fund, residents have to wait for a considerable amount of time before the renovation activities commence. Another option for the residents is to take a loan in a bank and invest money into a total renovation of the house. The example of residents having taken the loan clearly demonstrates that their monthly expenses decrease due to savings evoked by smaller heating bills after the renovation. Therefore, in terms of expenditure there is no considerable difference for residents how to pay for renovation activities contributing to a house reparation fund or taking a loan from the bank.

Loan interest rates for energy efficient renovation of multi-storeyed housing vary from 5 to 7 % and, as a rule, banks do not demand any pawning of property. Furthermore, the activities having been paid for earlier by residents from their own assets are also considered to be loan payments. In case a pawn is required or the loan is taken by a community of residents the guarantee of payment issued by "KredEx" (a financial organization dealing with giving loans, guarantees and grants to execute decision in the field of energy efficiency improvement) is used. Finally, the state promotes renovation activities (excluding reparation of heating, water supply, sewage systems) equal to the amount of 10 % from the cost of the work performed through "KredEx". Such assistance can be granted to houses built not later that in 1990. "KredEx" assists with expert evaluation of the building and energy audit and reimburses 50 % of the expenses.

VII. LATVIA

Lately, the condition of Latvian residential housing is attracting more and more attention of the Government and expert community in general. One of the most topical questions is the question about energy efficiency of residential multi-storeyed buildings along with the whole infrastructure ensuring how efficiently residential, social and commercial buildings function. Considering the fact that the predominant number (80 %) of multi-storeyed buildings had been built before 1991 the housing stock depreciation issue is acute. In some cases depreciation has reached the point of being physically dangerous for people. Therefore, the options offered are to aim at solving the depreciation problem, of improving energy efficiency and initiation of economic growth [9].

According to Central statistical administration of Latvia common living space corresponding to 1 person comprises on average 38 m2 as of 2015. Therefore, 72 % of population abides in typical multi-storeyed houses.

Consequently, major interest for the research present those particular houses which were built according to a mass production plan in the period of the former Soviet Union. There are 39,1 thousand multi-storeyed buildings in Latvia. Riga holds 11900 residential buildings which comprises about 30 % of Latvia's total amount of housing.

As reported by "Altum" (a government corporation which deals with financing of projects energy saving renovation of multi-storeyed housing at European funds' expenses) there are approximately 10000 houses in Latvia which are in critical condition [10]. In accordance with Riga Energy Agency there are about 6000 multi-storeyed buildings (total floor area is 12 mln m2 requiring urgent renovation.

In the estimation of Latvian Ministry of Economy total investment costs of the whole Latvian housing stock renovation is about €3,5 billion although experts of non-governmental organization «Ēku saglabāšanas un energotaupības birojs» (ESEB) name €8 billion as a sufficient amount of money necessary for renovation which is particularly important for Riga. Experts estimate that on average a full renovation cost of 1 m2 amounts to €100 – €170. Taking the data issued by Riga Energy Agency into consideration there are 6000 multi-storeyed houses in Riga requiring urgent renovation with total floor space of 12 mln m2 which amounts to €1,2 – €1,6 billion necessary for renovation solely in Riga.

Since the state program of co-funding European funds' assets was initiated "Energy Efficiency in Multi-Apartment Buildings programme conditions (DME) " came into being. Since March 2016 Riga self-government increases provision of projects in energy efficient renovation of housing real estates. It provides:

- free of charge counselling on the questions of energy efficiency conducted by Riga Energy Agency (REA);
- co-funding (up to 80 %) of energy audit activities (not more than €427 for one house);
- discount on property tax (to 90 %) for residential buildings which completed the renovation through the program of energy efficiency.

VIII. THE NETHERLANDS

The Netherlands is the country of modest climate. Housing real estates is mostly old; the majority of buildings was built in 1950-1970s and lacks necessary insulation which results in considerably high energy consumption during winter months. The main aim for the Netherlands is to renovate 111000 residential buildings so that they could receive Energy Efficiency Class "B" by 2020. The key objective is to renovate majority of buildings so that they obtained Energy Efficiency Class "0" (A++) by means of "Rapids" system.

Zero energy consumption is planned to be achieved through minimization of heat losses, implementation of insulating materials and adjustment of renewable energy equipment. The difference between regular reconstructions and energy saving renovation based on "Rapids" system lies in the fact that all major activities for "Rapids" are conducted at a plant and work force is needed only at the final stage. Funding of the program is to be provided by the state and private investors.

IX. RUSSIA

The main part of the housing real estates stock in Russia is the buildings built in 1970-1990. Therefore, energy saving renovation of housing real estates is one of the most effective energy saving measures. In Russia, there are 3,5 billion m2 of housing, of which about 50 % (1,8 billion m2) is relatively high-quality.

For 35 % of residential real estate needs major repairs and another 20 % - maintenance. The dilapidated housing is 2,7 % (90 million m2), the emergency housing is 0,3 % (11 million m2).

Most (2 billion m2 or 57 %) are prefabricated houses built before 1991 and with the expired capital repair period. Annual repair from these volumes is only 0,3 % (10-11 million m2) with a standard of 5 % (170 million m2). The consumption of heat in panel houses is several times higher than in the EU, and the deterioration of the infrastructure is 80% [11].

Capital repair of buildings will reduce energy consumption in them to regulatory requirements for new construction. And due to the reconstruction of buildings, which include a number of measures for insulation, a huge reserve of energy savings is achieved. Despite the fact that there are many barriers to the renovation of buildings, there are many examples of how they can be overcome.

1) Financing energy saving renovation of housing real estates can carry out through subsidies from budgets of different levels.

Budget subsidies for energy saving renovation of housing real estates are to be given solely for compound renovation and the amount of the subsidy is to depend on engineering estimate of the energy efficient outcome (50 % of the total sum) and reached level of energy saving (other 50 % of sum).

2) State-private partnership

Financing is administered basing on common interests of the state and the private sector. Such cooperation is gaining major popularity in Russia.

3) Private investments

Energy saving renovation of housing real estates is in most cases a feasible project as the recoupment period is comparatively short. In Russia it is connected with high heat and electricity prices though after the renovation consumption of the resources is to be considerably lower.

4) Concessional lending on energy saving renovation

Development of this measure requires governmental support of banks in development and implementation of lending banking products in energy efficient housing renovation project.

5) Tax incentives

As a means of support for renovation projects it is required to reduce rates of value-added tax by 10 % for activities and building materials used for increasing thermal protection of buildings including insulation materials, building and installation work, expendable materials, energy efficient windows with heat transmission resistance not less than 0,95 kWh/m2. Moreover, it is essential to introduce amendments to Internal Revenue Code on tax loans for energy efficient construction materials manufacturers.

X. Results

In 2018-2050 additional costs for all scenarios with measures to improve energy efficiency and development of renewable energy sources in buildings are €1000 billion (in prices of 2016). These costs constitute less than 10 % of base construction costs, major overhaul of residential buildings and for purchase of household appliances in 2018-2050, which are equal €15170 billion (in prices of 2016). A part of the incremental cost to improve energy efficiency of buildings in the process of new construction and major repairs does not exceed 7 % of base costs for new construction and major renovation.

As research shows, reduce energy consumption in the real estate sector in Russia perhaps more than in 2 times even when doubling area of real estate by 2050.

In the implementation of all energy saving renovation by 2050, divided in different scenarios, in Russia:

- will be received the total energy savings for 2014-2050 in 2677 million tons of fuel equivalent, which is 3 times the final energy consumption by all sectors of the Russian economy in 2013;
- will be received a total saving of natural gas in 2014-2050 size 3272 billion m3, which is 7 times higher than the natural gas consumption in Russia in 2013;
- reduced natural gas emissions by 50 % compared to 2013;
- reducing mortality of more than 1 million people by reducing emissions of harmful substances into the atmosphere in 2014-2050;
- reducing mortality and morbidity of 1,2 million people by improving thermal comfort;
- energy costs of buildings in 2017-2050 will decrease by €50 billion (in prices of 2016);
- budget expenses for energy supply of buildings in 2017-2050 will decrease by €100 billion (in prices of 2016);
- will create 540 thousand jobs in construction and about 1 million jobs throughout the economy.

Thus, the conducted study allowed to identify various options for financing energy efficient renovation of the housing stock in various countries of Europe. It should be noted that without state support and creation of special funds financing, the residents will not be able to solve this problem themselves.

XI. THE APPLICATION OF RESEARCH RESULTS

The materials of this article can be used by public authorities and commercial enterprises, as well as by individuals and their associations. Considered by the authors of the best practices for the financing of energy conservation, renovation of housing real estates will allow us to take a broad look at this problem. Scientists who research the problem of energy saving can use materials.

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AHP Application on Circuit Breakers

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Abstract—**In this paper an Analytic Hierarchy Process (AHP) is applied as multi-criteria decision making tool for determination of the best strategy of electrical equipment maintenance in order to increase electrical system reliability and safety. Analysis was made at six circuit breakers installed in different substations in electrical energy system in Serbia. These breakers have been operating for a different period and electrical facilities with different importance concerning the category and number of customers they supplied.**

Keywords–AHP,decision making, maintenance, circuit breaker, reliability, safety.

I. INTRODUCTION

Circuit breaker is an electrical device that has an essential role in the electrical energy system. When a fault occurs, fault current must be interrupted quickly and reliably in order to avoid human injuries and minimize equipment damage. Absence of fault current interruption results to a damage that can be very serious. During its service life, a circuit breaker must be constantly prepared to operate properly and his replacement must be performed after it is damaged or its life's cycle ends. Proper maintenance leads to the electrical energy system's reliability increase [1-2].

Electrical, thermal, mechanical and ambient conditions represent factors which have significant influence on circuit breaker's ageing. Electrical field strength in the breaker's insulation is one of the reason of its electrical ageing. Temperature increase can cause chemical, physical and thermal-dynamic changes on circuit breaker. Forces that affect the circuit breaker during its transportation, installation and operation lead to the mechanical ageing. The ambient conditions that cause circuit breaker's ageing are humidity, air, pollution, radiation, etc. Therefore, there are many reasons for regular tests and proper maintenance of circuit breakers. Reference [3] presents ultrasound tools for testing of insulation and infrared term scanning method which detects an abnormality of circuit breaker's temperature increase.

Maintenance techniques that can be applied for circuit breakers are Condition-Based Maintenance (CBM), Reliability Centered Maintenance (RCM) and Reliability Centered Asset Management (RCAM). These techniques are presented in [4-7].

In this paper the emphasis is placed on application of one of multi-criteria decision making methods to electrical circuit breakers in electrical energy system. The chosen method is Analytic Hierarchy Process (AHP) developed by American researcher Saaty T. L. This method is used to determine which circuit breaker should stop being used and replaced by another new one, based on presented criterions. Circuit breakers which were analyzed are installed in electrical substations in different regions in Serbian electrical energy system (EES).

II. THEORETICAL BACKGROUND

A. *Failure Rates*

The failure rate of a circuit breaker at time t is the probability of a component failing at time t if the component is still functioning at time t [8].

Recently installed circuit breakers have relatively high failure rate due to the possibility that they have manufacturing flaws, or they were damaged during shipping or installation, or they were installed incorrectly. This period of high failure rate is declared as *infant mortality period*. If circuit breaker "survives" infant mortality period, than it enters to the period referred to as

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its useful life, characterized by a nearly constant failure rate. As the useful life of circuit breaker comes to the end, the previously constant failure rate will start to increase. This is the time when *wear out* period starts. During the wear out period, the failure rate increases exponentially until the breaker fails.

A graph that is commonly used to represent how a circuit breaker's failure rate changes in time is the bathtub curve shown in Fig. 1. The bathtub curve begins with a high failure rate (infant mortality), lowers to a constant failure rate (useful life), and then increases again (wear out).

A more detailed curve used to represent circuit breaker's failure function is the saw tooth bathtub curve shown in Fig. 2. Instead of using a constant failure rate during the useful life period,

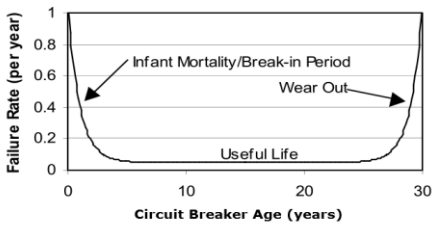

Figure 1. Bathtub [8]

this curve uses an increasing failure rate. This increase is attributed to normal wear, and can be mitigated by periodic maintenance. This is analogues to changing the oil in an automobile. If performing maintenance to the component reduces the failure rate to the same level every time, it is referred to as perfect maintenance.

Maintenance is rarely perfect. Reliability of the component will usually be slightly worse than the last time maintenance was performed. Another complication is that failure rate after maintenance increases temporary. This happens

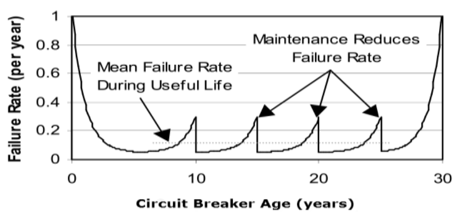

Figure 2. Sawtooth bathtub curve [8]

because there are some situations that can cause improper maintenance (maintenance crews can cause damage, errors can happen during re-assembly, tools can be left inside the equipment etc.). If the maintained circuit breaker survives for a short period of time after performed maintenance, the maintenance was probably performed properly and therefore failure rate decreases.

A detailed properly maintenance's failure function is shown in Fig. 3. When maintenance is performed at hour 100 the failure rate is relatively high. Failure rate is reduced to zero during maintenance, and then suddenly grows to a very high level due to the possibility of mistakes happened during the maintenance process. Failure rate quickly decreases to a level that was in the pre-maintenance period, and then gradually rises until the time predicted for next maintenance.

B. *Weibull Distribution*

Weibull distribution is a function of two parameters: a scale parameter α and a shape

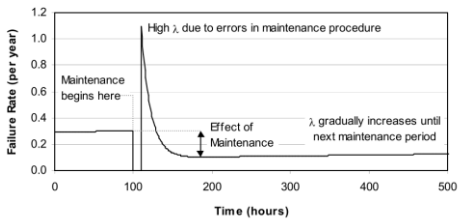

Figure 3. Detailed maintenance interval failure function[8]

parameter β. It is able to assume various shapes to fit varying data sets. It has the additional advantages of having a closed-form cumulative distribution function and a closed-form failure function. Equations which describe Weibull distribution are: density function shown in (1), cumulative distribution function shown in (2) and failure function shown in (3).

$$f(x) = \frac{\beta \cdot x^{\beta-1}}{\alpha^{\beta}} \exp\left[-\left(\frac{x}{\alpha}\right)^{\beta}\right] \quad (1)$$

$$F(x) = 1 - \exp\left[-\left(\frac{x}{\alpha}\right)^{\beta}\right] \quad (2)$$

$$\lambda(x) = \frac{\beta \cdot x^{\beta-1}}{a^{\beta}} \quad (3)$$

Three examples of Weibull distributions are shown in Fig. 4. The left graph represents an exponentially decaying density curve, the middle graph shows a density curve that is distorted to the left, and the right graph shows a density curve distorted to the right. $\beta < 1$ corresponds to a decreasing failure function and $\beta > 1$ corresponds to an increasing failure function. $\beta = 1$ (not shown) corresponds to a constant failure function equivalent to an exponential distribution with $\lambda = 1/\alpha$.

C. Analytic Hierachy Process

The Analytic Hierarchy Process (AHP) is an effective mathematical tool used for solving the complex decision making problems [9]. It is one of the most widely used multiplied criteria decision making tools. The AHP is technique that allows decision makers to model complex problem based on mathematics and human psychology. It is the subjective judgment of decision makers. In order to make a good decision, the decision maker must define: the problem, the need and the purpose of the decision, the criteria and sub criteria for evaluation of alternatives, the alternative actions that should be taken, and stakeholders and groups affected [9].

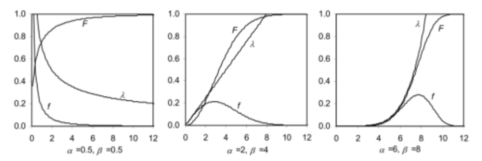

Figure 4. Three different Weibull distributions [8]

The AHP decomposes the complex problem into a hierarchy of subproblems in order to evaluate the relative importance of each criterion. The hierarchical structure is constructed by the goal on the top, criterions in the middle and alternatives at the bottom of the structure and they are all related each other. The hierarchical structure is shown in Fig. 5.

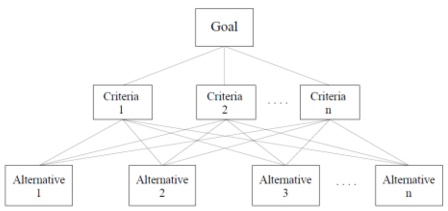

Figure 5. Hierarchical structure [9]

The values of criterions/alternatives are set by pairwise comparison using Saaty Ranking Scale, which is shown in the Table I. The pairwise comparison is evaluated and represented by a matrix, which is named pairwise comparison matrix. This matrix specifies the relative importance of the criterions/alternatives. Then, these values are computed to find the ranks among the criterions/alternatives. According to these rank's values the decisions are taken.

TABLE I. SAATY RATING SCALE [10]

Intensity of importance	***Definition***
1	Equal importance
3	Weak importance
5	Essential or strong importance
7	Demonstrated importance
9	Absolute importance
2,4,6,8	Intermediate values between the two adjacent judgments

The application of AHP to a decision-making problem consists of following steps:

Step No. 1: identification of the problem and determination of the desired solution.

Step No. 2: decomposition of the problem and creation of a hierarchical model. The hierarchical model consists of different levels. Hierarchical structure begins with a common goal followed by criteria and possible alternatives.

Step No. 3: definition of the comparison matrix of the criteria. Matrix is generated by using of Saaty's Rating Scale. The comparison is made through a scale to show how many times more important or dominant one element is over another element with respect to the criterion or property by which they are compared [11]. Comparison matrix is squared and it is shown in (4), where is the row's and j is the column's index number and the values of elements a_{ij} indicates what extend object x_i is being compared preferred to object x_j. For elements located in the diagonal of matrix A, where is i=j the numerical values are $a_{ij}=1$.

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \cdots & 1 \end{bmatrix} \quad (4)$$

Step No. 4: determination of the relative weight of criteria.

First, it is necessary to summarize values of all elements in every row in the matrix. It is going to be performed by Equation shown in (5), where n is the total number of rows and columns.

$$S_{ri} = \sum_{j=1}^{n} a_{ij} \quad (5)$$

Thereafter, it is necessary to calculate the total value of matrix T, shown in(6).

$$T = \sum_{i}^{n} S_{ri} \quad (6)$$

Then, the sum of each row calculated by (5), is dividing by total value of matrix calculated by (6), in order to obtain normalized value. This Equation is shown in (7).

$$N_i = \frac{S_i}{T} \quad (7)$$

Normalized values of each row form eigenvector which presents the weight of each criterion. Presented process is going to be repeated until the eigenvector of the matrix stops being changed.

Step No. 5: determination of the decision criteria matrix's consistency factor.

In the beginning it is necessary to calculate the consistency index shown in (8), where λ_{max} is the highest matrix eigenvalue.

$$CI = \frac{\lambda_{\max} - n}{n-1} \quad (8)$$

Thereafter, it is necessary to calculate consistency ratio. This is presented in (9), where RI represents random index that is obtained for different values of the criteria number. Those RI values are presented in Table II.

$$CR = \frac{CI}{RI} \quad (9)$$

TABLE II. RANDOM INDEX (RI)

n	2	3	4	5	6	7	8	..
RI	0	0.58	0.9	1.12	1.24	1.32	1.41	..

It is assumed that the comparison will be internally coherent when CR≤0.1. Otherwise, it must be considered that inconsistency has occurred during the comparison process, and therefore the comparison process must be repeated.

Step No. 6: definition of comparison matrixes of alternatives based on criterions.

Step No. 7: determination of relative weight of alternatives following step No. 4 and creation of priority vector of alternatives.

Step No. 8: determination of decision alternatives matrixes consistency factors following in step No. 5.

Step No. 9: creation of the priority matrix of alternatives P which consists of priority vector of alternatives for each of all alternatives.

Step No. 10: decision making. The optimal alternative $A_{opt}$is presented in (10) and it is calculated by multiplication priority matrix of alternatives Pby priority vector of criteria *y*. Now, the highest value should be chosen and it represents the best solution.

$$A_{opt} = [y] \cdot [P] \quad (10)$$

III. PRACTICAL APPLICATION OF AHP

One of very important goals for every electrical energy system (EES) is increase of its safety and reliability. One of methods that can be used for this goal achieving is proper maintenance of electrical equipment. In this paper AHP will be applied for determination of circuit breakers optimal manner of maintenance. Actually, using AHP it is going to be decided which of chosen six breakers from Serbia's EES should be withdrawn from service first and replaced with the new one. Circuit breakers that are considered in this analysis are located in following electrical substations: Knjazevac III, Sokobanja, Knjazevac I, Boljevac, Salaš, Kladovo III. Main performances of these circuit breakers are presented in following:

B1 – circuit breaker installed in substation Knjazevac III supplies one factory and it has been in operation since 1971.

B2 – circuit breaker installed in substation Sokobanja supplies a mine and it has been in operation since 1986.

B3 – circuit breaker installed in substation Knjazevac I supplies water supply system and it has been in operation since1981.

B4 – circuit breaker installed in substation Boljevac supplies suburb and it has been in operation since 1974.

B5 – circuit breaker installed in substation Salaš supplies one factory and it has been in operation since 1997.

B6 – circuit breaker installed in substation Kladovo III supplies heavy industry and it has been in operation since 1977.

Each of these circuit breakers represents one of alternatives in AHP model.

The next step is definition of criterions that will be used for circuit breakers comparison. These criterions are based on:

A1 – failure probability distribution,

A2 – reliability,

A3 – importance in supplying,

A4 – costs.

F/S histogram is based on previous measurement and experience about failure time of circuit breakers and it is presented in Fig. 6. The previous experience indicates that for one circuit breaker the usual failure time is in period of 24 to 36 life age. According to previous experience, greater significance will be given to circuit breaker which life age is 24-36.

Reliability in supplying of consumer decreases with ageing of circuit breakers and this dependence is presented in Fig. 7. According to this criterion, greater significance will be given to older circuit breaker.

Circuit breakers are located in different electrical substations that supply customers of different importance. In accordance with this initial condition, it is necessary to give greater significance to circuit breaker which has greater importance in electrical energy supplying.

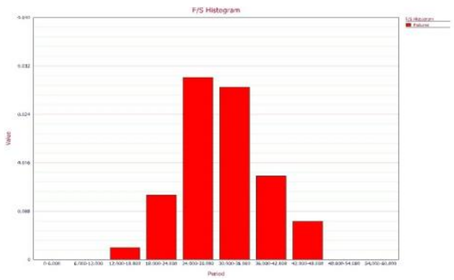

Figure 6. F/S histogram

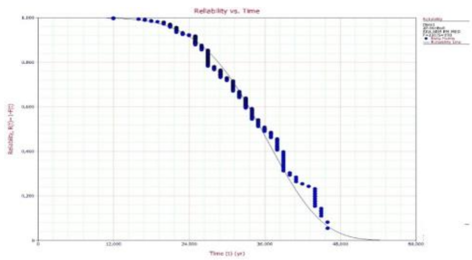

Figure 7. Realiability depending on the time

Costs are unavoidable factor when it is necessary to compare any of electrical elements. In this case, total costs consist of maintenance costs, work costs and replacement costs. According to this factor, greater significance will be given to older circuit breaker because its costs are higher.

AHP starts with comparison of criterions based on Saaty Rating Scale and with the creation of matrix of the criterions shown in Table III.

TABLE III. MATRIX OF CRITERIONS

	A1	***A2***	***A3***	***A4***
A1	1	2	0.2	0.25
A2	0.5	1	0.25	0.33
A3	5	4	1	2
A4	4	3	0.3	1

The weights of criterions are given by subjective feeling and therefore, importance in supplying has the greatest significance followed by costs, and criterions which depend on circuit breaker life age, respectively. Performing calculations described in previous chapter, the priority vector of criterions is obtained and presented in (11).

$$[y] = \begin{bmatrix} 0.1129 \\ 0.0895 \\ 0,4901 \\ 0.3075 \end{bmatrix} \quad (11)$$

According to calculated weights presented in the priority vector of criterions, it can be concluded that criteria A3 has the highest importance. Thereafter, it is necessary to compare alternatives based on criterions and create matrix of alternatives for each criterion. Those matrices are presented in Tables IV - VII.

TABLE IV. MATRIX OF ALTERNATIVES BASED ON CRITERION A1

	B1	***B2***	***B3***	***B4***	***B5***	***B6***	***Weight***
B1	1	0.2	0.2	1	0.5	0.33	0.0549
B2	5	1	1	5	4	3	0.3286
B3	5	1	1	5	4	3	0.3286
B4	1	0.2	0.2	1	0.5	0.33	0.0549
B5	2	0.25	0.25	2	1	0.5	0.0898
B6	3	0.33	0.33	3	2	1	0.1432

TABLE V. MATRIX OF ALTERNATIVES BASED ON CRITERION A2

	B1	***B2***	***B3***	***B4***	***B5***	***B6***	***Weight***
B1	1	4	3	1	5	2	0.2960
B2	0.25	1	0.5	0.25	2	0.33	0.0701
B3	0.33	2	1	0.33	3	0.5	0.1113
B4	1	4	3	1	5	2	0.2960
B5	0.2	0.5	0.33	0.2	1	0.25	0.0464
B6	0.5	3	2	0.5	4	1	0.1802

TABLE VI. MATRIX OF ALTERNATIVES BASED ON CRITERION A3

	B1	***B2***	***B3***	***B4***	***B5***	***B6***	***Weight***
B1	1	0.33	0.33	3	3	1	0.1289
B2	3	1	1	5	5	3	0.3188
B3	3	1	1	5	5	3	0.3188
B4	0.33	0.2	0.2	1	1	0.33	0.0523
B5	0.33	0.2	0.2	1	1	0.33	0.0523
B6	1	0.33	0.33	3	3	1	0.1289

TABLE VII. MATRIX OF ALTERNATIVES BASED ON CRITERION A4

	B1	***B2***	***B3***	***B4***	***B5***	***B6***	***Weight***
B1	1	5	4	2	6	3	0.3826
B2	0.2	1	0.5	0.25	2	0.33	0.0641
B3	0.25	2	1	0.33	3	0.5	0.1006
B4	0.5	4	3	1	5	2	0.2504
B5	0.17	0.5	0.33	0.2	1	0.25	0.0430
B6	0.33	3	2	0.5	4	1	0.1595

The following obtained result is priority matrix of alternatives shown in (12).

$$[P] = \begin{bmatrix} 0.0549 & 0.2960 & 0.1289 & 0.3826 \\ 0.3286 & 0.0701 & 0.3188 & 0.0641 \\ 0.3286 & 0.1113 & 0.3188 & 0.1006 \\ 0.0549 & 0.2960 & 0.0523 & 0.2504 \\ 0.0898 & 0.0464 & 0.0523 & 0.0430 \\ 0.1432 & 0.1802 & 0.1289 & 0.1595 \end{bmatrix} \quad (12)$$

Finally, vector of optimal alterative (A_{opt}) shown in (13) is calculated by multiplication of priority matrix of alternative by priority vector of criteria and the highest value is chosen as the best solution.

$$A_{opt} = \begin{bmatrix} 0.2135 \\ 0.2193 \\ 0.2342 \\ 0.1353 \\ 0.0531 \\ 0.1445 \end{bmatrix} \quad (13)$$

The highest value from vector of optimal alternatives is 0.2342 and it refers to circuit breaker installed in substation Knjazevac I. Therefore, it can be concluded that this circuit breaker should be withdrawn from operation and first replaced by the new one.

IV. CONCLUSION

In this paper application of Analytic Hierarchy Process (AHP) at example from practice was presented. At this example AHP methodology helped to make a good decision in order to achieve optimal maintenance of electrical equipment (circuit breakers, concretely) and therefore, to increase reliability and safety of EES in Serbia.

In future research this methodology can be applied to a larger number of circuit breakers from different electrical energy systems what would lead to even better results or to other electrical elements such as: supplying or measuring transformers, switches and etc. All obtained results could be useful in the area of safety and reliability of electrical energy systems.

ACKNOWLEDGMENT

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Forecasting Energy Consumption in Serbia using ARIMA Model

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Abstract— **Energy consumption is a key factor for healthy economic growth. Therefore, to be able to plan the economic growth and efficiently utilize power sources, accurate prediction of energy demand needs to be made. This paper presents the forecast of energy demand in Serbia for the period of 2016 to 2027. The ARIMA model was used for analyzing the effect of independent variables such as GDP per capita, GNI per capita and population growth on dependent variables such as energy consumption, natural gas consumption, oil consumption and renewables consumption. The results show that, in the following years, an increase can be expected in demand for oils and renewables, while there will be some decrease in demand for natural gas and electricity.**

Keywords – energy, demand, arima

I. Introduction

Forecasting energy demand is one of the primary issues of modern world. Developing economies are constantly trying to meet the demand for electricity in order to provide social welfare. Better and faster economic development is the key for a healthy economy. Energy consumption is one of the most crucial indicators of economic growth, hence it is the vital part of economy and social development [1]. Irrational energy consumption is one of the most important reasons of bad economy, extensive use of renewable resources and pollution [2] [3].

Energy can be found in different forms and from different sources. Some sources include fossil energy, renewable energy and fissile energy [3]. In 1970, the world was affected by the energy crises which eventually led to an increased attention on energy management and usage of alternative energy sources, in particular biomass and fuelwood [4].Various researchers used time series for exploring the relationship between energy consumption and economic development [5]. Energy resources have major impact on economic growth [6] [7].

Energy consumption may be affected by many factors, but this study is going to focus on population growth rate, gross national income (GNI) and gross domestic product (GDP) in Serbia. The main objective of this study is to evaluate how these factors influence energy consumption in Serbia and what are the future predictions of energy, oil, renewables and natural gas consumption. This study may help the government, organizations and individuals to realize how important energy consumption is for the country, as well as to shred lite on renewable energy and its benefits. Also, the findings in this paper can be used for creating better environmental-friendly policies. The next part of the paper presents methodology of research, followed by results and discussion.

II. Methodology

Precisely forecasting energy demand may be of critical importance for developing countries, because wrong estimation may cause insufficiency and additional costs that influence economic progress. A country like Serbia does not have enough resources to cover such costs, so the importance of energy forecasting is even higher. Energy demand forecasting can be used by the government to create additional plans in order to meet that demand. Also, by comparing energy demands of various countries, economic progress can be observed.

There are various forecasting techniques that can be used for prediction, from regression techniques to hybrid models [8], but ne of the most used analysis is time series analysis. A time series method uses past values to forecast the future [9]. This technique is based on the assumption that future values of one variable are related to past values of the same variable [10] [11]. Time series analysis is simple, but it doesn't explain the causal relation of the prediction [8].

TABLE I. DATASET FOR THE PERIOD FROM 1997 TO 2015

Year	Population growth (%)	GDP PPP (USD)	GNI per capita (USD)
1997	-0.28	3178.83	2850
1998	-0.38	2416.07	2800
1999	-0.36	2441.43	2390
2000	-0.32	870.14	1530
2001	-0.17	1634.88	1450
2002	-0.09	2149.91	1430
2003	-0.21	2832.49	2260
2004	-0.23	3331.23	3070
2005	-0.30	3528.13	3630
2006	-0.39	4129.76	3970
2007	-0.41	5458.12	4580
2008	-0.43	6701.77	5650
2009	-0.40	5821.31	6040
2010	-0.40	5411.88	5850
2011	-0.79	6423.29	5910
2012	-0.49	5659.38	5700
2013	-0.49	6353.83	6050
2014	-0.47	6200.17	5840
2015	-0.49	5237.26	5540

Probably the most used technique for time series analysis is ARIMA. ARIMA derived from autoregressive model (AR), the moving average model (MA) and the comination of the augoregressive and the moving average models (ARMA) [12] [13], therefore ARIMA technique is based on Box-Jenkins autoregressive integrated moving average analysis [14]. The technique includes three stages: (1) identification, (2) estimation, (3) diagnostic checking [15]. The model describes the process of data change through time for which it uses lag term and random error term of a variable to explain variables and predict the future [16].

For the purpose of this research, IBM SPSS software was used. Forecasting analysis was conducted for time series model. Here, independent variables such as gross domestic product per capita, gross national income per capita and population growth were used in order to increase the accuracy of the model. This data is given in Table 1 [17].

III. RESULTS AND DISCUSSION

The main feature of development of any country is effective and efficient energy supply. Figure 1 presents the trends of independent variables population, gross domestic product per capita and gross national income per capita. Based on these figures, it can be seen that population had a decreasing trend in the past years, from 7.6 millions in 1997 to 7.1 millions in 2015. The gross domestic product per capita had an increasing trend, from 3178.33 USD in 1997 to 5237.26 USD in 2015. The gross national income per capita had the same trend, increasing from 2850 USD in 1997 to 5540 USD in 2015. The same results can be observed in Table 1.

Energy sectors that were included in the analysis are presented in table 2, as well as their final consumption values. Here, EFC stands for Electricity final consumption, NGFC stands for natural gas final consumption, OFC stands for oil final consumption and RFC stands for renewables final consumption.

The results presented here show the energy projections for the period from 2016 to 2027 based on the data from 1997 to 2015. Table 3 shows the forecasted data for the period from 2016 to 2027. Based on this data, it can be observed that in 2027 the final consumption of electricity will be 26600.73 gigawatt hours, the final consumption of natural gas will be 26641.42 terajoules, the final consumption of oil will be 3,405,900 tones, while the final consumption of renewables will be 56447.65 terajoules.

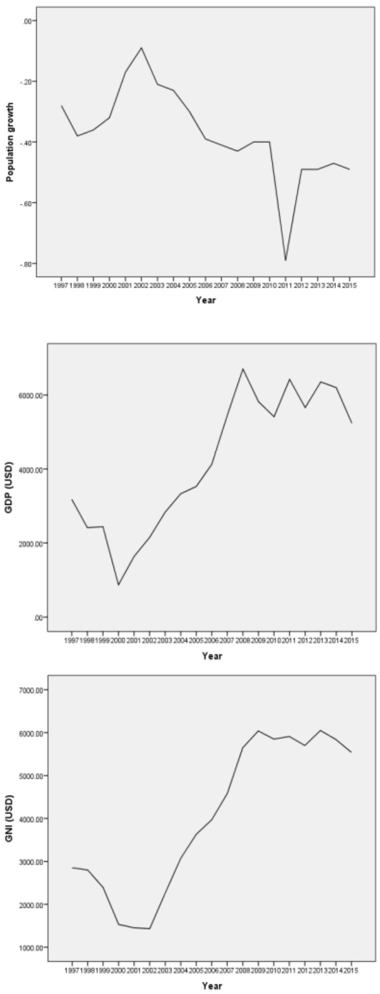

Figure 1. Trends of population growth, GDP and GNI per capita (1997-2015)

TABLE II. CONSUMPTION FROM 1997 TO 2015

Year	EFC (GWh)	NGFC (TJ)	OFC (1000 tones)	RFC (TJ)
1997	27691	75507	3562	30800
1998	27787	70336	2790	30800
1999	25751	51122	1469	30800
2000	27297	53937	1049	33600
2001	28789	58272	1968	33600
2002	29055	51631	2604	33600
2003	28057	53992	2854	33600
2004	28479	68571	3397	33600
2005	25663	57587	3118	33600
2006	26253	65067	3335	33545
2007	26519	61633	3082	33490
2008	27258	66070	3102	33652
2009	26810	41015	2742	44333
2010	27569	53374	2864	43139
2011	27991	52771	2877	42984
2012	27167	43540	2522	43096
2013	26903	46619	2668	43357
2014	26158	35663	2557	43285
2015	27073	40446	2568	43493

TABLE III. FORECASTED CONSUMPTION VALUES FOR THE PERIOD FROM 2016 TO 2027

Year	EFC	NGFC	OFC	RFC
2016	26818.50	35586.09	2641.23	45169.70
2017	26847.67	36470.26	2703.88	45831.94
2018	26811.73	26811.73	2767.09	46893.03
2019	26790.73	26790.73	2831.70	47834.17
2020	26766.33	32675.62	2897.81	48847.29
2021	26742.74	31860.01	2965.47	49862.29
2022	26718.99	30861.15	3034.70	50905.59
2023	26695.30	29998.33	3105.56	51968.07
2024	26671.63	29105.40	3178.06	53053.69
2025	26647.97	28267.03	3252.26	54161.64
2026	26624.34	37438.35	3328.20	55292.86
2027	26600.73	26641.42	3405.90	56447.65

The predicted values were compared to the true values, and the absolute error was calculated. Based on the absolute error, relative error was calculated next. Table 4 presents the error estimates for electricity final consumption and natural gas final consumption. The average relative error for electricity demand is 0.18%, and for natural gas demand 3.21%, hence the error is small and prediction is good.

TABLE IV. ABSOLUTE ERROR AND RELATIVE ERROR FOR ELECTRICITY AND NATURAL GAS FINAL CONSUMPTION

Year	Electricity final consumption		Natural gas final consumption	
	AE	RE	AE	RE
1997	0		0	
1998	-44.34	-0.16%	3123.86	4.44%
1999	2127.83	8.26%	19387.56	37.92%
2000	-991.54	-3.63%	3807.79	7.06%
2001	-1795.56	-6.24%	-6777.03	-11.63%
2002	-579.28	-1.99%	6208.76	12.03%
2003	982.43	3.50%	2839.99	5.26%
2004	-233.57	-0.82%	-15968.6	-23.29%
2005	2636.47	10.27%	402.15	0.70%
2006	13.05	0.05%	-4604.38	-7.08%
2007	-380.08	-1.43%	-1205.46	-1.96%
2008	-831.57	-3.05%	-2367.81	-3.58%
2009	62.11	0.23%	18546.21	45.22%
2010	-910.94	-3.30%	-6153.17	-11.53%
2011	-461.29	-1.65%	-9528.06	-18.06%
2012	678.06	2.50%	5929.88	13.62%
2013	340.27	1.26%	-1666.17	-3.57%
2014	703.2	2.69%	6767.13	18.98%
2015	-859.5	-3.17%	-2698.98	-6.67%

Absolute and relative errors were also compared for oils final consumption and renewables final consumption (table 5). Here, the average relative error for oils demand is 5.64%, and for renewables demand 0.42%.

TABLE V. ABSOLUTE ERROR AND RELATIVE ERROR FOR OILS AND RENEWABLES FINAL CONSUMPTION

Year	Oils final consumption		Renewables final consumption	
	AE	RE	AE	RE
1997	0		0	
1998	319.83	11.46%	669.91	2.18%
1999	1138.21	77.48%	28.77	0.09%
2000	124.9	11.91%	-2215.15	-6.59%
2001	-825.66	-41.95%	-369.5	-1.10%
2002	53.15	2.04%	300.3	0.89%
2003	210.11	7.36%	80.92	0.24%
2004	-176.94	-5.21%	1052.6	3.13%
2005	376.55	12.08%	1926.82	5.73%
2006	-240.24	-7.20%	1161.69	3.46%
2007	737.08	23.92%	-145.14	-0.43%
2008	561.46	18.10%	-365.64	-1.09%
2009	376.22	13.72%	-7948.13	-17.93%
2010	-222.17	-7.76%	1970.6	4.57%
2011	-573.49	-19.93%	-560.03	-1.30%
2012	264.52	10.49%	813.97	1.89%
2013	-99.35	-3.72%	1716.49	3.96%
2014	235.57	9.21%	1718.85	3.97%
2015	-270.02	-10.51%	2556.76	5.88%

Next, the trends in demand for electricity, natural gas, oils and renewables from 1997 to 2027 can be observed (Fig. 2).

It can be seen that the final consumption of electricity will have a decreasing trend, as well as the consumption of natural gas. On the other hand, the final consumption of oils and renewables will have an increasing trend.

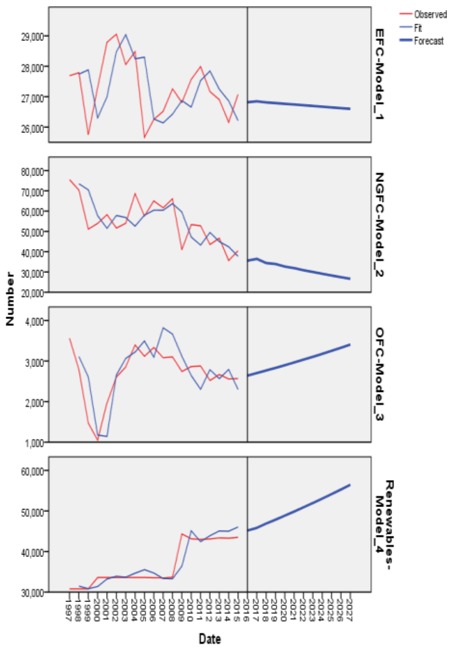

Figure 2. Trends of population growth, GDP and GNI per capita (1997-2027)

The prediction results show that the energy demand will decrease for 1.75% in 2027 comparing to 2015. Natural gas demand will also decrease for 34.13% in 2027. On the other hand, the demand for oils will increase in 2027 for 32.63% comparing to 2015. Lastly, the demand for renewables will increase for 29.79% in 2027.

IV. CONCLUSION

Forecasting energy demand is an important factor for planning economic growth. Various factors may influence the economy, among them energy consumption. This paper presents the future predictions of energy demand in Serbia based on the values of population growth, gross domestic product per capita and gross national income per capita. The forecast shows there will be a decrease in demand for electricity and natural gas, and an increase in demand for oils and renewables. This indicates that new sectors will be developed, and more cleaner renewable energy will be used, such as oils, primary solid biofuels, biogases, geothermal, solar power and hydroelectricity.

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Energy and Environmental Impact due to Energy and CO_2 Embodied in the Construction Materials of Typical Hellenic Dwellings

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Abstract—**Energy consumption in the building sector is crucial, both for the depletion of natural resources and the associated environmental impact. The scope for research in this area is wide and much needs to be done either in the construction of new buildings or in energy conservation measures for the older ones. In the era of sustainability, more emphasis is given to minimize building energy consumption and environmental impact during its life cycle. This consists of the building Operational Energy (OE) and Embodied Energy (EE), which are in direct relationship with Operational (OCO_2) and Embodied CO_2 (ECO_2) emissions contributing to the greenhouse effect. The main objective of this paper is to quantify EE and ECO_2 of typical Hellenic dwellings. Through the use of four case studies, the basic construction materials of typical Hellenic dwellings are identified and their contribution in terms of EE and ECO_2 is estimated. While material analysis is the strong point of the methodology, EE and ECO_2 analysis are not rigorous since, in the absence of a comprehensive Hellenic database, data from an international database have been utilized. However, practical values are obtained and baseline indicators are extracted concerning the EE and ECO_2 contribution of the whole building and its dominant materials.**

Keywords - Embodied energy, embodied CO_2, building materials, Hellenic dwelling.

I. Introduction

About 40% of the total energy consumption in Europe corresponds to energy consumed in the building section and, accordingly, about 45% of the CO_2 emissions in the atmosphere which is accountable for the greenhouse effect [1]. Building life cycle consists of three stages; the initial, the operational and final ones. Total energy consumed during building life cycle consists of two parts, namely the Operational Energy (OE) and the Embodied Energy (EE). OE refers to the energy consumed for the various building services, e.g. heating, cooling, ventilation, lighting, hot water, appliances, etc. The building EE refers to the energy used for the building materials at three stages of its life. First, it accounts for the energy used for the extraction of raw materials, transportation to the factory and manufacturing processes, transportation to the building construction site and installation. During the operational stage of the building life, the building EE accounts for maintenance, repair and replacement actions with respect to building materials and equipment. Finally, during the final stage, it accounts for the energy used for building demolition, deconstruction and waste or recycling/reuse of its materials. All these three EE amounts can then be gathered into two distinct components, namely the direct EE and the indirect EE. Direct EE is the energy consumed for the transportation and installation of building materials and products to the building site. Indirect EE is consumed for acquiring, processing and manufacturing building materials, including any transportation related to these activities prior to their transportation and installation on site or after that, during its

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operational stage of life. Indirect EE can be further divided into initial and recurring EE. Initial EE is the energy consumed for the acquisition, transportation and processing of raw materials to create a product from cradle (raw material) to the factory gate (ready to be used). Recurring EE is related to the energy consumed in the maintenance, repair and replacement of a product during its service life. The above definitions, as well as those concerning the corresponding Operational and Embodied CO_2 (ECO_2) emissions can be found for example in [2].

The European Directive on the energy performance of buildings (EPBD recast Directive 2010/31/EC) is the main legislative tool for improving energy efficiency of the European building stock. National efforts focus towards the concept of Nearly Zero Energy Buildings (NZEB) by the end of the decade by means of reducing OE in conjunction with the on-site use of renewable energy sources. Furthermore, current research focuses on Life Cycle Zero Energy Building (LCZEB) [3], where Life Cycle Assessment (LCA) is implemented as a basic tool; EE is an essential ingredient of building LCA. Furthermore, EE can be used to assess various energy conservation measures implemented in existing buildings.

The EE value per unit mass varies not only from material to material, but also from country to country for the same material. Unfortunately, EE databases suffer from problems of variation and incompatibility. According to Dixit et al. [2], most of the previous studies either followed the International LCA standards, or they did not follow any standards, so the authors therein referred to the necessity of the development of a global database. They compiled a list of parameters that are responsible for the lack of such a global database, like the methods of EE estimation, the building design, the construction methods, the kind and quantity of the construction materials, the system boundaries and the geographical locations. According to the literature [4], the basic methods used for the calculation of EE are the process method, the input-output method and the hybrid method. The latter utilizes the advantages of both other approaches to facilitate more comprehensive and accurate analysis. In order to estimate the total EE of a building, a good material analysis, i.e. breakdown of the various building components to their constitutive materials is required.

Various studies are available in the literature, concerning the calculation of EE and/or ECO_2 in buildings. Venkatarama et al. [5] estimated the energy consumed for the production, transportation and installation on-site of a number of traditional construction materials and concluded that an important amount of energy is used for their manufacture and transportation. Shams et al. [6] studied a typical, multi-floor residence and assessed the EE and the associated ECO_2 emissions corresponding to the use of different construction material, estimating the building EE to be 4,273.90 MJ/m^2 and ECO_2 to be 343.55 $kgCO_2/m^2$. They demonstrated a reduction of 52% in EE and 45% in ECO_2 by replacing principal materials (cement concrete, mortar) with other like (fly-ash or blast furnace slag), as well as they estimated that the use of bricks instead of ceramics would reduce ECO_2 by one third. Xing et al. [7] compared steel and aluminum with concrete terms of EE and ECO_2 in residential buildings and concluded that concrete exhibits lower energy consumption than steel or aluminum in the building life cycle. In all of their studies they found that concrete dominates in terms of mass, while steel and aluminum dominates in terms of EE and ECO_2 due to the corresponding high values of EE and ECO_2 per material mass. Monahan et al. [8] compared various building practices, in terms of their ECO_2 and EE impact. By studying a timber framed low energy building of 83 m^2 in UK with 405 kgCO2/m^2 ECO2 and 5962 MJ/m^2 EE, they considered two different scenarios. The first one considered a building with timber frame and brick cladding resulting to an increase of 32% in ECO_2 and 35% in EE compared to the initial scenario. The second scenario considered a building with timber frame and conventional cavity walls resulting to an increase of 51% for ECO_2 and 35% for EE compared to the initial scenario.

Previous work by the authors considered the basic construction materials in four typical Hellenic dwellings [9-10]. The work presented detailed calculations of the material mass quantities and focused on quantifying their environmental impact in terms of initial ECO_2 [9] and in terms of initial EE [10], providing practical information for the contribution of the dominant building construction materials in terms of mass and ECO_2. According to the main findings, it was concluded that concrete is the dominant material in terms of mass, while steel dominates with respect to EE and ECO_2. In one case, the materials of the major electro-mechanical building installations were also considered. However, their contribution in terms of EE proved to be very low compared to that of the construction materials. The work also calculated the EE and ECO_2 payback times in order to assess various energy conservation measures implemented in existing buildings.

In this paper, the results of [9], [10] are summarized both in terms of EE and ECO_2. Dominant materials in terms of mass, EE and ECO_2 are identified. The new analysis of the available data derives correlations and extracts further information in the form of indicative benchmarks.

II. METHODOLOGY AND CASE STUDIES

The three-step methodology presented in [9] is followed in this work. Each step is briefly elaborated in the following sections.

a) Material analysis: Analyze the Set of materials and equipment into their constitutive materials. To this end, the Set is divided into Groups of major components in the form of a tree, each Group is then analyzed to its constitutive main items and these are continuously split into sub-items till reaching the lower level of entities that cannot be further split into sub-items. Upon completion of the material analysis, each constitutive single material of the Set was identified and recorded. Regarding the Set of construction materials of a typical Hellenic dwelling, the following five Groups were considered [11]: Bearing structure, Masonry and Coatings, Insulation, Flooring and Covering, Material integration.
b) Mass analysis: Calculate the mass of each of the materials that has been recorded in the previous step.
c) Embodied Energy and Embodied CO_2 analysis: Transform the mass values (kg) to EE (MJ) and ECO_2 ($kgCO_2$) by means of appropriate EE (MJ/kg) and ECO_2 ($kgCO_2$/kg) coefficients. Although, the latter are nationally dependent parameters, due to the lack of a comprehensive Hellenic database, values from the Inventory of Carbon and Energy (ICE) database were used [12].

The identification of the specific materials for each case study and the estimation of their quantities were extracted from the technical drawings of the buildings under consideration. The strong point of the method is material and mass analysis. The weak point is the lack of national EE and ECO_2 coefficients and recognizing that the boundaries within the ICE database are cradle-to-gate.

Four typical Hellenic dwellings were selected as case studies [11]; cases A and B are Multi-Family Dwellings (MFD) (Fig. 1), while cases C and D are Single-Family Dwellings (SFD) (Fig. 2). They are all located in Athens (same climatic zone B of Greece) and constructed during the same decade (2000-2010). In particular, case A is a three storey MFD with a basement (88.40 m^2) and tilted roof, each floor (87.30 m^2) having an apartment (70.48 m^2) and a common staircase (16.82 m^2). Case B is a three storey MFD with a basement (81.50 m^2). Each floor (82.25 m^2) has an apartment (70.00 m^2) and a common staircase (12.25 m^2). Case C is a SFD with a floor area (112.35 m^2) and a basement (112.35 m^2). Case D is a two level (maisonette) SFD with a ground floor area (83.00 m^2), an upper level (53.00 m^2) with an internal wooden staircase and a basement (52.50 m^2).

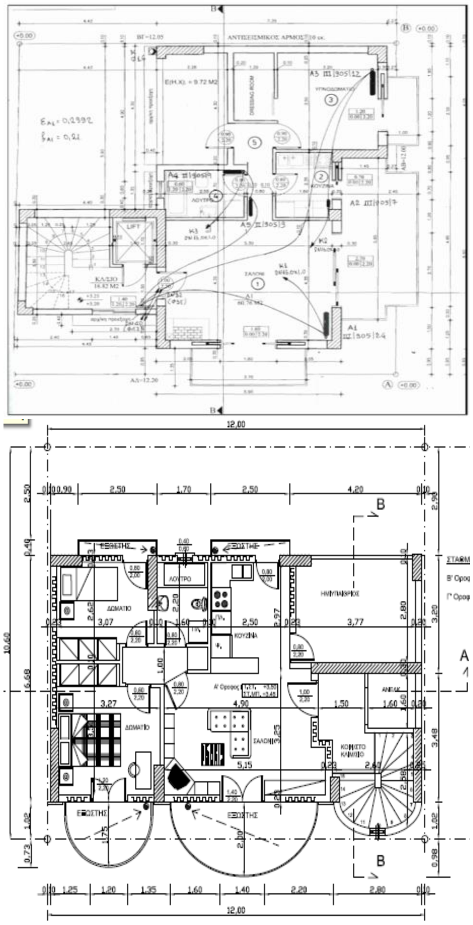

Figure 1. Floor plans for the MFD cases A (upper) and B (lower).

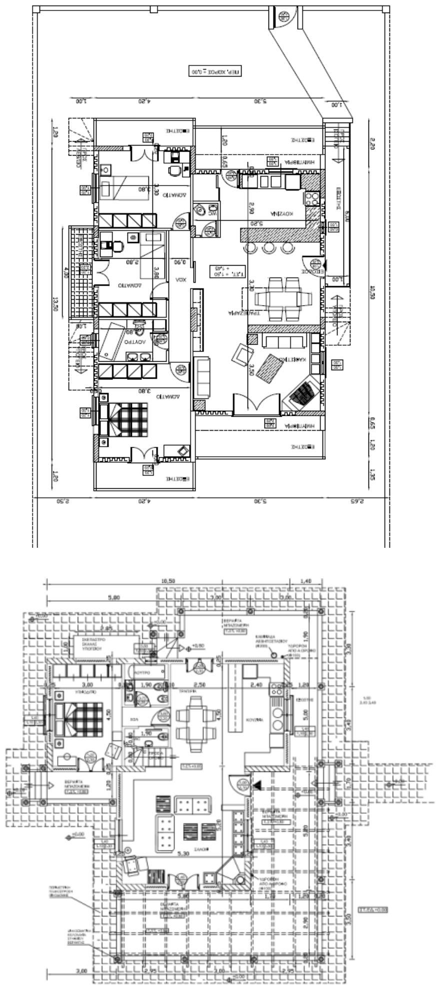

Figure 2. Floor plans for the SFD cases A (upper) and B (lower).

III. RESULTS AND DISCUSSION

Table I summarizes the detailed floor areas for the four case studies. These areas are expressed either in terms of total building area or as heated area. In addition, the ratio of the heated to the total floor area for each case is included.

TABLE I. SUMMARY OF DATA CONCERNING THE AREAS IN THE FOUR CASE STUDIES

Case Study	*A*	*B*	*C*	*D*
Total Area [m^2]	438.0	410.5	231.6	188.0
Heated Area [m^2]	182.3	169.5	112.4	135.5
Heated/Total	0.4	0.4	0.5	0.7

Table II summarizes dimensional values of Mass, EE and ECO_2 for the four case studies, as well as their averages and standard deviations. Furthermore, the calculated specific Mass, EE and ECO_2 values are also presented. These correspond to values per unit mass of the whole set of construction materials. According to the results, total Mass values in cases A and B are close to each other since they are buildings of similar type (MFD). Similarly, the Mass values of C and D are similar since they are SFD buildings. Mass values of A and B are greater than those of C and D, since MFB are buildings with larger dimensions containing higher amounts of construction materials than SFD. As expected, the EE and environmental impact (ECO_2) of MFD buildings are greater than that the corresponding values of SFD due to their higher mass content.

Concerning the specific EE values, MFD cases are characterized by a value of about 3 MJ/kg, while SFD ones by a value of about 2.5 MJ/kg, averaging a value of about 2.8 MJ/kg for all cases. In terms of specific ECO_2 values, MFD cases are characterized by a value of about 0.26 $kgCO_2$/kg, while the value for SFD ones is about 0.24 $kgCO_2$/kg, averaging a value of 0.25 $kgCO_2$/kg. Such findings could be considered as baseline indicators that could be used, in a first approach, for estimating the initial EE and ECO_2 of Hellenic dwellings due to their construction materials. Apparently, such an approach is relevant to buildings with similar characteristics as the ones described herein and requires knowledge of their total mass value.

TABLE II. SUMMARY OF MASS, EE AND ECO_2 RESULTS FOR THE CONSTRUCTION MATERIALS IN THE FOUR CASE STUDIES

Case Study	***Mass (tn)***	***EE (GJ)***	***ECO_2 ($tnCO_2$)***	***Specific EE (MJ/kg)***	***Specific ECO_2 ($kgCO_2$/kg)***
A	1,209	3,789	328	3.13	0.27
B	1,005	2,962	252	2.95	0.25
C	887	2,118	203	2.40	0.23
D	679	1,699	164	2.50	0.24
Avg.				2.75	0.25
Std. Dev.				0.24	0.02

Table III summarizes results in terms of Mass, EE and ECO_2 intensity values, i.e. corresponding values normalized per unit floor area. These values have been calculated in two

TABLE III. SUMMARY OF RESULTS IN TERMS OF MASS, EE AND ECO_2 INTENSITIES IN THE FOUR CASE STUDIES

Case Study	Per unit of total area			Per unit of heated area		
	Mass intensity (kg/m^2)	*EE intensity (MJ/m^2)*	*ECO_2 intensity ($kgCO_2/m^2$)*	*Mass intensity (kg/m^2)*	*EE intensity (MJ/m^2)*	*ECO_2 intensity ($kgCO_2/m^2$)*
A	2,761	8,651	748	6,633	20,785	1,797
B	2,449	7,216	615	5,930	17,476	1,489
C	3,828	9,145	876	7,887	18,843	1,805
D	3,612	9,036	871	5,012	12,538	1,208
Average	3,162	8,512	777	6,366	17,411	1,575
Standard deviation	663	651	124	1,213	3,521	285

ways for each quantity; in the first one, the total floor area has been considered, while the second concerns only the heated floor area. Mass intensity values per total floor area of A and B are comparable, since they MFD of similar size. The same holds for C and D that are SFD. The former values are lower than the latter ones due to their larger floor areas. The average of MFD is different than the SFD average. Looking at the corresponding intensity values per heated floor area, the average value of 6,366 kg/m^2 is a more representative quantity independent of the building typology (MFD or SFD). Similarly, the average values of 17,411 MJ/m^2 for EE and 1,575 kg $CO2/m^2$ can be considered as baseline indicators that could be used for estimating the initial EE and ECO_2 of Hellenic dwellings due to their construction materials, provided that their heated area is known.

Table IV presents average percentage contribution (among the four cases) for the top-eight dominant materials of the construction materials.

TABLE IV. AVERAGE PERCENTAGE CONTRIBUTION (AMONG THE FOUR CASES) FOR THE TOP-EIGHT DOMINANT MATERIALS OF THE CONSTRUCTION MATERIALS (CEE AND $CECO_2$ ARE THE EE AND ECO_2 COEFFICIENTS [12]).

Material	***Mass (%)***	***EE (%)***	***ECO_2 (%)***	***C_{EE} (MJ/kg)***	***C_{ECO2} ($kgCO_2/kg$)***
Concrete	59.2	16.1	24.4	0.74	0.14
Bricks	16.4	18.0	15.1	3	0.23
Plaster	7.0	4.6	3.4	1.8	0.12
Steel	2.8	30.0	29.3	29.2	2.29
Lime	2.3	4.5	7.1	5.3	0.76
Tiles	2.2	8.7	5.7	12	0.74
Wood	1.1	3.1	4.4	11	0.72
Aluminum	0.1	6.0	3.6	154	8.16
(Total)	(91.1)	(91.1)	(93.0)		

In all cases, the basic construction materials are concrete, bricks, plaster, steel, lime, ceramic tiles, wood and aluminum. Either in terms of Mass or EE or ECO_2, these eight materials represent slightly over 90% of the total. If one considers the materials with a contribution greater than 10%, there are two such materials (concrete, bricks) in the Mass list, summing about 76% of total Mass. Three such materials (steel, bricks, concrete) exist in the EE list representing about 64% of total EE and the same three materials exist in the EE list that sum up to about 69% of total ECO_2.

Concrete dominates in terms of mass in all cases (60% in average). However, steel dominates both in terms of EE and ECO_2 (30% in average), due to its high EE content. Bricks follow next in the EE list, mainly due to their high mass value as their EE content is not high, while in the ECO_2 list, concrete is the second item. The ranked lists for mass, EE and ECO_2 are not the same, since the contribution of each material is different. The cases of aluminum and steel are indicative examples, e.g. of materials that ranked in a higher position in the EE or ECO2 lists compared to their position in the mass list. Concrete and steel are characteristic examples of the influence of EE per unit material mass (CEE). Furthermore, the distribution of EE and ECO2 values is more widespread than that of mass values, due to the fact that even if some materials are encountered in small quantities they have significant EE and ECO2 coefficients.

IV. CONCLUSIONS

Assessment of the Initial EE and ECO_2 of the construction materials of typical Hellenic dwellings was carried out based on the analysis of four case studies. The buildings were intentionally chosen to be located in the same climatic zone of Greece and of the same construction period in order to have comparable characteristics. A three-step methodology consisting of material, mass and EE / ECO_2 analysis was performed for each case and the basic construction materials were identified (concrete, bricks, plaster, steel, lime, ceramic tiles, wood, aluminum). In the absence of national EE and ECO_2 coefficients, available values from an international database were used. Concrete was found to dominate in terms of mass (60%), while steel dominated in terms of EE and ECO_2 (30%). The contribution of each material in terms of mass, EE and ECO_2 is different. Materials with a low mass percentage but with high EE and ECO_2 coefficients, can have a significant combined contribution to the embodied energy and emissions in the overall construction. An average value of 2.8 MJ/kg was found to correlate the total building mass to the initial embodied energy of the building construction materials. The corresponding value of 0.25 $kgCO_2$/kg was extracted for the embodied emissions. Similarly, indicative values were calculated for EE and ECO_2 in terms of total or heated floor area of typical residential buildings.

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Optimal Location and Sizing of Distributed Generators

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Abstract—**In this paper, an algorithm was developed for determining the optimal rated power of the distributed generators (DG), at predetermined locations (nodes) in power system, so that power losses are minimal, using the search method of alternatives. This algorithm requires the calculation of power flow and voltages in the power network, and for these purposes was used Newton - Raphson iterative procedure. The algorithm was tested on the real 35 kV radial power distribution network.**

Keywords – distributed generation, optimal location, optimal sizing

I. INTRODUCTION

The degree and quality of the influence of DGs on the operation of the system depends on its power, type and location. The purpose of site and power optimization of DGs is to increase the positive and reduce the negative effects that they have on the operation of the power distribution network. Accordingly, the choice of objective function depends of the desired goal. These are usually the following goals:

- Minimization of power and energy losses;
- Improving the power network voltage profile, ie minimizing voltage deviations;
- Increasing the availability of system elements;
- Increased reliability of consumer supply;
- Minimizing the short-circuit current;
- Minimization of harmonic distortions;
- Minimizing total costs associated with power network operation (equipment installation, energy purchase, losses, power outages);
- Minimization of investments, procurement and connection of power distributed generators, etc.

In terms of determining the location and power, DGs can be divided in two groups. In the first group, locations and power are mostly determined by geographical, hydrological and meteorological factors (small hydropower plants, wind generators). In this case, it is possible to talk about optimizing the connection point to the existing power distribution network only if a set of nodes is assigned which a DG can be connected to. It is possible to look for optimal solutions in the planning phase of a completely new or reconstruction of the existing network in the given (geographic and meteorological) tolerable area. In the second group can be classified all DG with predictable output (microturbines, fuel cells, etc.) which can be connected to any point of the distribution network.

II. APPLICATION OF NEWTON RAPHSON'S THE PROCEDURE FOR CALCULATE POWER FLOW

Application of Newton - Raphson's method for the calculation of power flows is based on the equations for active and reactive power injection in hybrid form. With number 1 is marked balance node, numbers from 2 to $N - N_{PQ}$, PU (voltage controlled) nodes, and with number from $N - N_{PQ}+1$ to N is marked PQ (consumer) nodes. Accordingly, vector of unknown variables is:

$$\vec{X} = \begin{bmatrix} \vec{\theta} \\ \vec{U} \end{bmatrix}, \qquad (1)$$

where :

$\vec{\theta} = [\theta_2 \quad \theta_3 \quad \cdots \quad \theta_N]^T$ – vector of unknown voltage angles

$\vec{U} = \left[U_{N-N_{PQ}+1} \quad U_{N-N_{PQ}+2} \quad \cdots \quad U_N\right]^T$ - vector of unknown voltage modules

In order to determine the values of unknown variables, it is necessary to create a system of $N - 1 + N_{PQ}$ equations, which are simultaneously solved. For the creation of this equation, equations for the active and reactive power injection in hybrid form are used:

$$P_i(\vec{X}) = U_i^2 G_{ii} + U_i \sum_{\substack{k=1 \\ k\neq i}}^{N} U_k (G_{ik} \cos(\theta_i - \theta_k) + B_{ik} \sin(\theta_i - \theta_k)) \qquad (2)$$

$$Q_i(\vec{X}) = -U_i^2 B_{ii} + U_i \sum_{\substack{k=1 \\ k\neq i}}^{N} U_k (G_{ik} \sin(\theta_i - \theta_k) - B_{ik} \cos(\theta_i - \theta_k)) \qquad (3)$$

The symbols $P_i(\vec{X})$ and $Q_i(\vec{X})$ in relations (2) and (3) indicate that the expressions for the active and reactive power of injection in the nodes and the functions of the vector are variable. In the generator nodes, active power injection are known, and in consumer and active and reactive power injection. These known active and reactive injected powers for the node i, will be marked with P_i^{sp} and Q_i^{sp}, respectively. Now, for a node i, the following equations can be written:

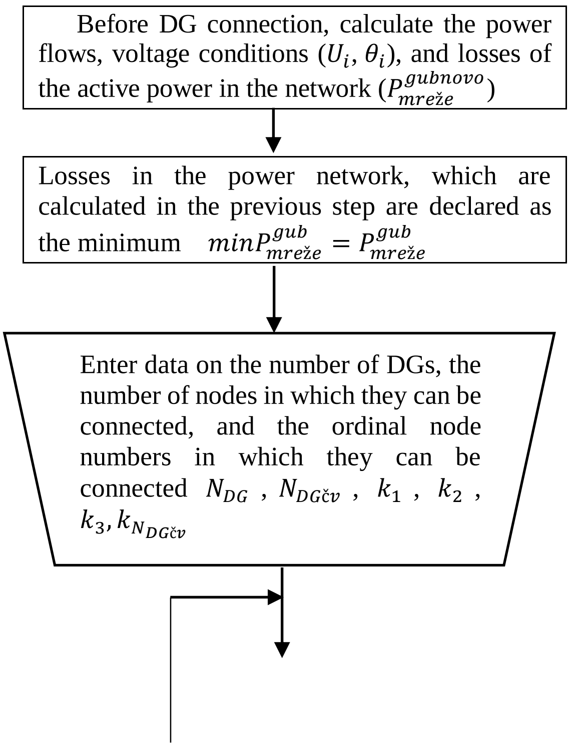
$$P_i^{sp} - U_i^2 G_{ii} - U_i \sum_{\substack{k=1 \\ k\neq i}}^{N} U_k (G_{ik} \cos(\theta_i - \theta_k) + B_{ik} \sin(\theta_i - \theta_k)) = 0 \qquad (4)$$

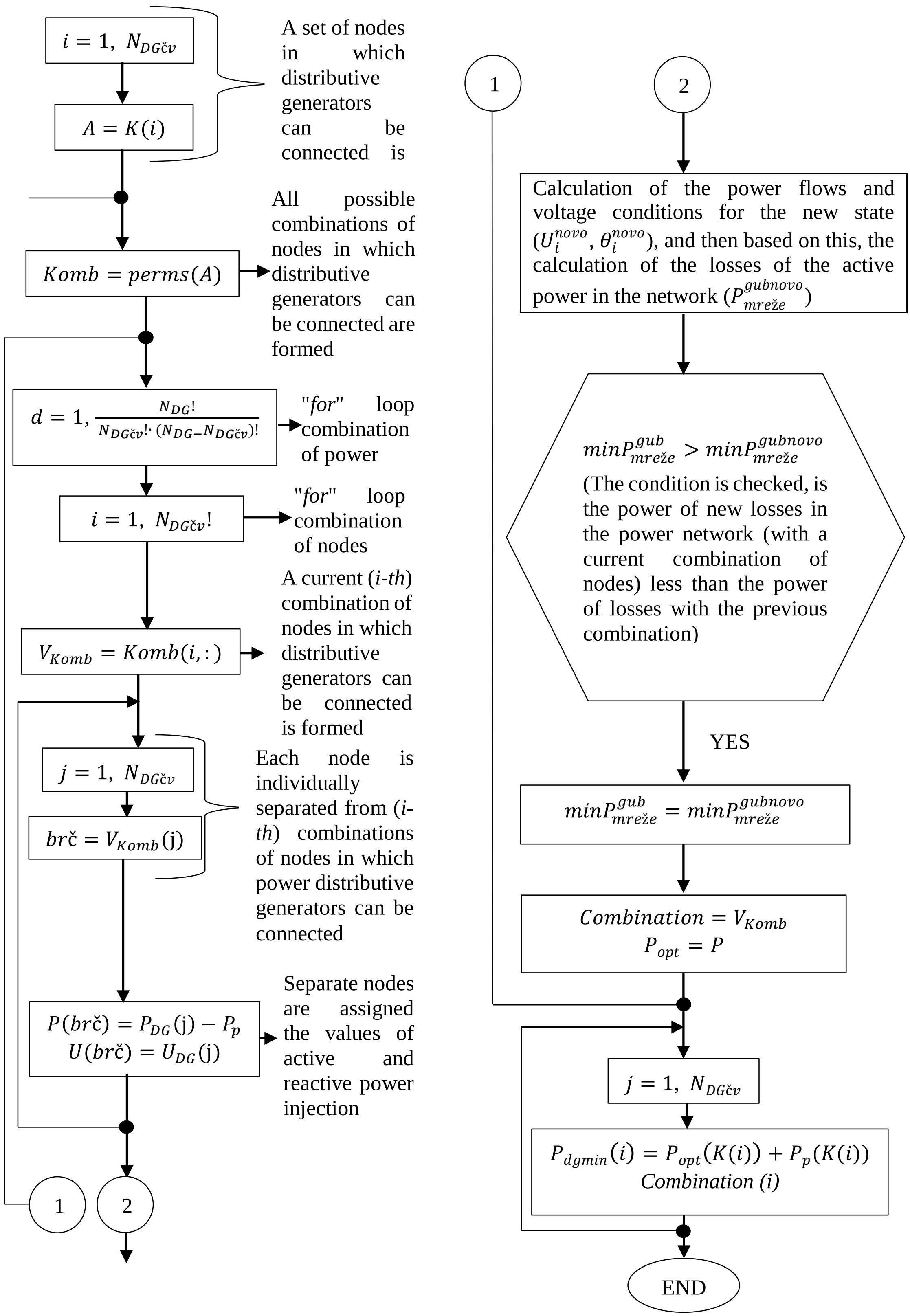
$$Q_i^{sp} + U_i^2 B_{ii} - U_i \sum_{\substack{k=1 \\ k\neq i}}^{N} U_k (G_{ik} \sin(\theta_i - \theta_k) - B_{ik} \cos(\theta_i - \theta_k)) = 0 \qquad (5)$$

Equation (4) applies to all generating and consumer nodes, and the equation (5) on the consumer nodes, so that the N-1 + N_{PQ} equation is obtained. By solving equations (4) and (5), unknown nodes voltages and unknown angles of the voltage phase are determined.

III. Algorithm for Determining Optimal Location and Power of Distribution Generators

The idea of this algorithm is reduced to a "brute force" variant search that implies the calculation of the active loss power for each combination of DG power and location. By comparing the power loss values for each combination, the optimal solution is determined. Each variant involves one calculation of power flows and voltage nodes. The number of possible combinations can be very large, so certain information about the actual operation of the system can reduce this number. For these purposes among other things, information of potential nodes to which DG can be connected, as well as their available power. Potential nodes in which DGs can be connected are selected based on the energy potential of the place where they are located. However, nodes that are farther away from the reference node were generally chosen because in this case, in radial power networks losses are reduced and improved voltage conditions. On the basis of the previously presented, an algorithm is given that determines the optimal locations and power of the distribution generator:




$i = 1,\ N_{DGčv}$
$A = K(i)$
A set of nodes in which distributive generators can be connected is
$Komb = perms(A)$
All possible combinations of nodes in which distributive generators can be connected are formed
$d = 1, \frac{N_{DG}!}{N_{DGčv}! \cdot (N_{DG} - N_{DGčv})!}$
"*for*" loop combination of power
$i = 1,\ N_{DGčv}!$
"*for*" loop combination of nodes
$V_{Komb} = Komb(i,:)$
A current (*i-th*) combination of nodes in which distributive generators can be connected is formed
$j = 1,\ N_{DGčv}$
$brč = V_{Komb}(j)$
Each node is individually separated from (*i-th*) combinations of nodes in which power distributive generators can be connected
$P(brč) = P_{DG}(j) - P_p$
$U(brč) = U_{DG}(j)$
Separate nodes are assigned the values of active and reactive power injection
1
2
1
2
Calculation of the power flows and voltage conditions for the new state (U_i^{novo}, θ_i^{novo}), and then based on this, the calculation of the losses of the active power in the network ($P_{mreže}^{gubnovo}$)
$minP_{mreže}^{gub} > minP_{mreže}^{gubnovo}$
(The condition is checked, is the power of new losses in the power network (with a current combination of nodes) less than the power of losses with the previous combination)
YES
$minP_{mreže}^{gub} = minP_{mreže}^{gubnovo}$
$Combination = V_{Komb}$
$P_{opt} = P$
$j = 1,\ N_{DGčv}$
$P_{dgmin}(i) = P_{opt}(K(i)) + P_p(K(i))$
Combination (i)
END

IV. Test power distribution network "ED Leskovac"

The previous algorithm will be applied to the power distribution network 35 kV ED Leskovac.

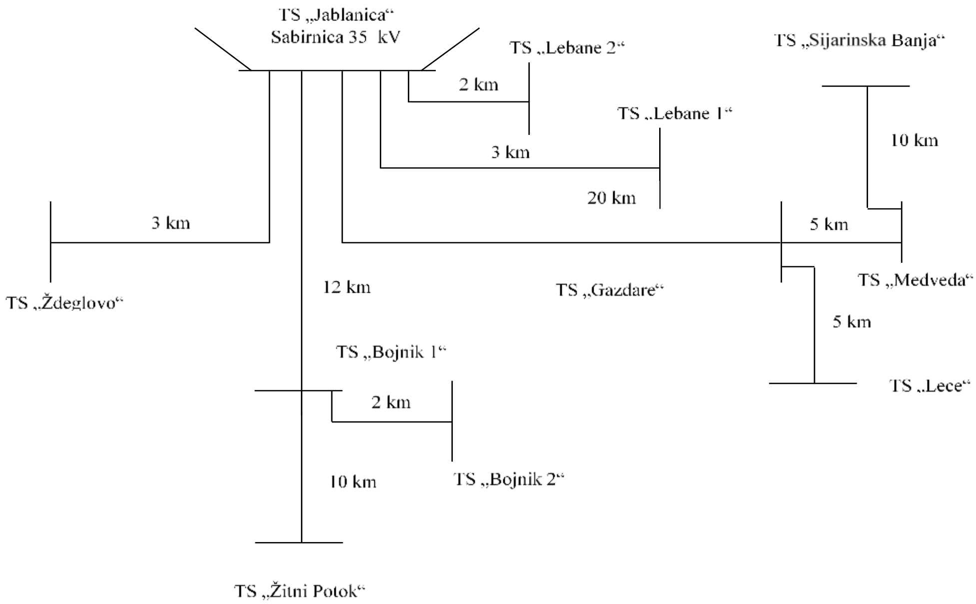


Figure 1. Power distribution network 35 kV ED Leskovac

This system includes all 35 kV nodes (total 11), at the substation 110/35 kV/kV „Jablanica", while all nodes of lower voltage levels are ignored. The active and reactive power consumption of individual nodes were modeled by constant active and reactive power consumption in these nodes and their average real value occurring in exploitation. The powerlines in the mentioned system are aluminum-steel overhead lines, cross section $3 \times \mathrm{Al/Fe}\ 95/15\ mm^2$. For For aluminum-steel ropes $95/15\ mm^2$, longitudinal resistance is $r = 0{,}31\ \Omega/km$. For a longitudinal reactance, it is usually assumed in the calculations that it is $x = 0{,}4\ \Omega/km$, so the longitudinal impedance will be $\underline{z} = (0{,}31 + j0{,}4)\ \Omega/km$. The lengths of the powerlines are shown in the figure 1. Given that the powerlines are relatively short and that it is a medium voltage level, the branches to the ground can be ignored, so that the longitudinal susceptance is approximately equal to zero.

TABLE I. The data about the nodes power distribution network

No	Names substation	$U\ [kV]$	P_G $[MW]$	P_p $[MW]$	Q_p $[MW]$
1	„Jablanica"	36,75	0	0	0
2	„Lebane 1"	-	0	2,5	1,25
3	„Lebane 2"	-	0	2,5	1,25
4	„Zdeglovo"	-	0	2	1
5	„Bojnik 1"	-	0	2	1
6	**„Gazdare"**	-		1,5	0,75
7	„Bojnik 2"	-	0	2	1
8	**„Zitni Potok"**	-		1	0,5
9	„Medveđa"	-	0	2,5	1,5
10	**„Sijarinska Banja"**	-		1	0,5
11	„Lece"	-	0	1,5	0,75

Data about DGs are given in Table II DGs are disposable with active power change in range $0{,}5\,[MW] \leq P_{DG} \leq 4[MW]$ with a step from $1[MW]$ and reactive power change in the range $0{,}25\,[MVAr] \leq Q_{DG} \leq 2[MVAr]$ with a step from $1[MVAr]$. These generators can be connected to busbars 6 (“Gazdare”), 8 (“Zitni Potok”) and 10 (“Sijarinska Banja”).

TABLE II. THE DATA ABOUT DISTRIBUTIVE GENERATORS

Generator	Active power of generator $[MW]$	Reactive power of generator $[MVAr]$
G1	0,5	0,25
G2	1,5	0,75
G3	2,5	1,25
G4	3,5	1,75
G5	4	2

It is necessary to determine which generators need to be connected to the individual nodes of the power network that are available so that the losses in the power network are minimal.

The application of the previously exposed algorithm gives the nodes in which the corresponding generators need to be connected. The result is shown in the table III.

TABLE III. THE DATA ABOUT THE GENERATORS AND POWER DISTRIBUTION NETWORK

Node	Names substation	G	Active power of generator $[MW]$	Reactive power of generator $[MVAr]$
6	„Gazdare“	G4	3,5	1,75
8	„Zitni Potok“	G3	2,5	1,25
10	„Sijarinska Banja“	G2	1,5	0,75

It can be noted that in the previous algorithm there are needs for the calculation of power flows and voltage conditions. In this paper, Newton-Raphson's iterative procedure was applied for the calculation of voltage conditions. The voltages of nodes with and without power distributed generators are shown in Table 4.

From Table 4 it can be noticed that the voltage conditions have improved the most in the nodes in which power distributive generators are connected and in the nodes near the power distribution generators.

TABLE IV. THE DATA ABOUT THE GENERATORS AND POWER DISTRIBUTION NETWORK

No	Names substation	Voltage nodes without generator $\boldsymbol{U}\,[\boldsymbol{kV}]$	Voltage nodes without generator $\boldsymbol{U}\,[\boldsymbol{kV}]$	Voltage difference with and without generator $U\,[kV]$
1	„Jablanica“	36,7500	36,7500	0
2	„Lebane 1“	36,6630	36,6518	0,0112
3	„Lebane 2“	36,6688	36,6583	0,0105
4	„Zdeglovo“	36,6665	36,6557	0,0108
5	„Bojnik 1“	35,8937	36,2261	0,3324
6	**„Gazdare“**	35,4671	35,8530	0,3859
7	„Bojnik 2“	35,8367	36,1624	0,3257
8	**„Zitni Potok“**	35,7510	36,4278	0,6768
9	„Medveđa“	35,4001	35,8043	0,4042
10	**„Sijarinska Banja“**	35,5544	36,0292	0,4748
11	„Lece“	35,2499	35,6382	0,3883

V. CONCLUSION

With the proper combination of nodes with connected DGs and their connected power, losses in power network can be minimized. The loss reduction is a logical consequence of the fact that due to the influence of DGs, the power is transmitted locally to a particular peripheral node, while without them the total power is transferred only from one (balancing-reference) feeder node, so the higher power passes through several lines, creating power losses. In the radial network, in order to minimize losses, DGs need to be connected to nodes that are farther away from the feeder node. It is noted that voltage conditions have improved most in nodes with DG connected, and then in nodes that are adjacent to them.

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An Integrated Computational Approach for the Assessment of Nearshore Wind Farms: Case of a Tropical Island

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Abstract – **This paper discusses about the assessment of a nearshore wind farm using an integrated computational approach. The wind flow patterns over the selected wind farm region is generated using a Computational Fluid Dynamics (CFD) model and the wind farm layout evaluated using the Park Optimizer algorithm. A typical nearshore wind farm case study is considered for a tropical island and the impact of increasing the number of turbines is also examined. The methods discussed in this article can be used as an initial assessment of resources for the design and set up of any nearshore wind farm project, especially for small island developing states (SIDS).**

Keywords- Nearshore wind farm, wind resource assessment, Computational Fluid Dynamics (CFD), wind flow patterns, turbine placement optimization.

I. INTRODUCTION

As the threats of an energy crisis and climate change effects are becoming more evident, countries around the world are striving to adopt renewable sources of energy. Their aim is to stave off the 1.5 °C increase in temperatures of the planet from pre-industrial levels [1]. Hence, strategic roadmaps are being developed to achieve the targeted percentage of renewable energy (RE) use. One main component of the roadmaps is the assessment of the RE resources. For many countries, the shift is towards wind and solar [2]. In this article, the focus is on wind energy (assessment, implementation and economic analysis).

Wind energy has been exploited by mankind for more than 2000 years and represents a reliable source of RE [3]. In the present days, the wind energy technologies have reached such a mature level that it is being used as one of the main sources of electricity production in many countries including Germany, Spain, United States, China and India [4, 5]. In nations without enough buildable land, such as small island developing states (SIDS), the constructions of wind power stations at sea are being envisioned. Near-shore/Offshore wind farming is a new emerging technology in the field of renewable energies. It is becoming more feasible as multiple wind farms have been successfully installed around Europe [6]. The attractiveness of offshore wind farms lies in the fact that, as compared to onshore farming, they can be subjected to stronger wind velocities and have fewer fluctuations since there are no physical barriers to the incoming winds such as mountains, high rise buildings and so on [7-8].

However, there are many challenges facing the deployment of offshore/nearshore wind farms (WF). Hence, a reliable and robust assessment method is required to assess such projects. Moreover, the layout of a WF is a challenging job since many factors such as multiple wake phenomena need to be considered. In large WF, wake effects lead to considerable power lost. Hence it is desirable to determine the optimal locations of wind turbines on the chosen site such that maximum power can be extracted [9]. Several optimization algorithms are available in the literature that use very simple rules to find the appropriate turbine positioning (WF layout). A review of these algorithms is beyond the scope of this paper and the interested reader is referred to [10-13] among others.

This paper discusses about an integrated computational approach to assess wind power potential for wind farming and optimizing the number of wind turbines that can be installed. Although the method can be employed to both onshore and offshore WF, the focus is on nearshore.

II. MODELLING WIND FLOW PATTERNS

To characterize the wind resources of a given region, long term wind measured data are usually utilized to assess the wind variability from a probability distribution. In wind energy studies, the interest is in wind data at hub heights of wind turbines (typically between 60 to 110 metres above ground level – m.a.g.l), while measurements are performed at a different height ($Z_{ref} \approx 10$ m.a.g.l). Therefore, the log-law which is given in the following equation:

$$V(Z) = V_{ref} \frac{\ln(Z / Z_0)}{\ln(Z_{ref} / Z_0)} . \qquad (1)$$

is used to estimate the wind speed V at height Z. In equation (1), V_{ref} is the measured wind speed and Z_0 is the surface roughness. One drawback of this approach is that the measured wind speed data is generally not obtained at the proposed wind farm location and the equation is valid only if the atmosphere is neutrally stable [14].

In [15] the use of Computational Fluid Dynamics (CFD) has been proposed as a reliable method to model multi-level wind flow patterns over a given area. In the CFD model, the flow was assumed to be incompressible, steady and turbulent. The flow variables that are solved are pressure, velocity components, turbulent kinetic energy and the turbulent dissipation rate. The full numerical models (WindSim software) were already explained and validated in [15] over a large range of data and need not be repeated here. The resulting wind patterns could be overlaid over geographical information system (GIS) and bathymetry datasets of the area to select regions over which nearshore wind farms could be erected.

There are multiple factors which must be taken into consideration before erecting a wind farm. Closer spacing of wind turbines may allow more wind turbines on the site, but will reduce the average energy captured from each turbine in the wind farm. The extraction of energy by those wind turbines that are upwind of other turbines can result in decreased wind speeds at the downwind turbines and increased turbulence due to wake effects which will subsequently result in a decrease of energy production.

An integrated computational approach is therefore proposed in this work in which a Park Optimizer (PO) module is linked to the WindSim CFD model to optimized wind turbine placement in the form. The module has been

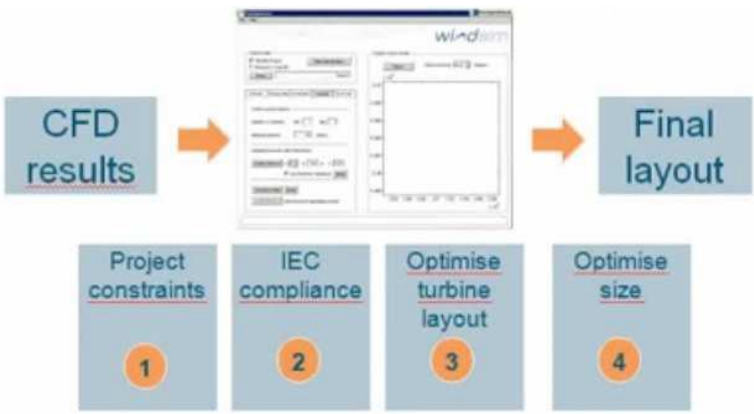


Figure 1. The Park Optimizer (PO) module (Adapted from [16]).

rigorously tested and validated by [16]. As illustrated in Figure 1, the PO module uses as input the CFD results obtained for the wind farms and it takes into consideration the following constraints before giving the final layout of the turbine placement as output:

1. Project Constraints. This takes into consideration forbidden zones for wind farming (natural preservation parks, shipping lanes etc.).
2. IEC compliance, which takes into account the minimum and maximum limits of shear, extreme speeds, flow inclination and turbulence intensity with respect to a wind turbine.
3. Optimized turbine layout displays the multiple arrays which are possible for the incoming wind direction. It also indicates which array is best suited.
4. Optimized turbine size gives an indication of the number of wind turbines that can be erected on the region of interest while respecting all other constrains including the wake effects in the farm. It provides graphs of energy against number of turbines as well as the Net Present Value (NPV) to indicate the economic benefits for such a wind farm.

III. THE STUDY AREA AND ITS WIND CLIMATE

As a case study, the implementation of a nearshore wind farm for the island of Mauritius (latitude 20° 17’ South and longitude 57° 50’ East), which is situated in the tropical South West Indian Ocean (SWIO) region, is considered. Figure 1 depicts the topography of the island which spans over a range of 60 km in the North-South direction and some 45 km in the East-West direction. The highest part of the island, the Central Plateau is at around 500 m above sea level. Some of the non-populated islets of Mauritius are also shown in the figure: Ile-aux- Benitiers (South West), Gunners Guoin and Flat island (North), Ile aux Aigrettes (South East), Ile-D’Ambre (North East) and Ile-aux-Cerfs (East). As the name suggests Flat Island is low lying with a measurement of 253 hectares and a maximum height of 15 m. The south-western part of the islet however has a high ridge of 102 m with an automated lighthouse at the top. Round Island is 22.5 km to the North of

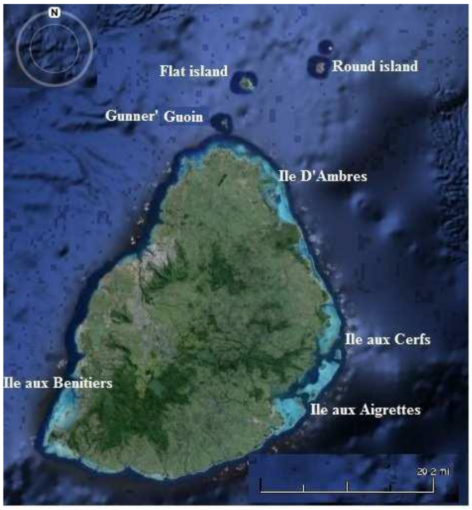


Figure 2. A map of Mauritius showing some of its islets [17].

Mauritius has a maximum elevation of 280 m and an area of 1.69 km^2. Gunner’s Quoin measures only 65 hectares with a maximum height of 76 m, lies 8 km to the north of Mauritius.

Mostly year round, Mauritius is influenced by the South-East Trade Winds whose speed is higher. The flow of the trade winds is mostly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere, strengthening during the winter and when the Arctic oscillation is in its warm phase. At 1000 m, the trade winds attain their highest average value during the months of August and September, though their strength in the whole of winter is high compared to summer. (It has also been noted that some Easterlies during the months of September and October and June to August are present) [18].

IV. VALIDATION OF MODEL RESULTS

Validations of the model results require measurement data obtained from sufficiently long sampling periods [19]. Two wind-measuring instruments were located on Round Island (stations M1 and M2) on a pole at a height of 60 m and one at 100 m. At Pamplemousses which is on mainland Mauritius), a third wind-measuring equipment was installed (station M3) at 10 m. Stations M1, M2 and M3 all have 1.5 years of measured data recorded with a cup anemometer.

TABLE I. M1 STATION DATA (ROUND ISLAND)

Inlet wind direction (degrees)	Wind speed (m/s)		%diff
	CFD	Measured	
85	6.0	6.4	6.25
90	6.7	6.5	3.08
100	6.1	6.3	3.17
105	5.9	6.2	4.84
110	7.9	7.6	3.95
120	6.1	6.4	4.69
150	6.7	6.5	3.08
		RMSE	0.28

TABLE II. M2 STATION DATA (ROUND ISLAND)

Inlet wind direction (degrees)	Wind speed (m/s)		%diff
	CFD	Measured	
85	5.7	5.4	5.56
90	4.9	4.6	6.52
100	5.4	5.2	3.85
105	5.1	5.3	3.77
110	5.0	4.8	4.17
120	5.2	5.5	5.45
150	7.2	6.9	4.35
		RMSE	0.26

The recorded data were averaged over 10 minute-periods for mean wind speed and wind direction. It should be noted that only data with U_{thr} greater than 4 m/s were retained, in an attempt to exclude measurements value which were affected by thermal effects; [20] stated that this threshold is considered sufficiently high. This is crucial as these measurements will be used for CFD corroboration and the CFD simulations will be performed for neutral atmospheric boundary layers and isothermal conditions.

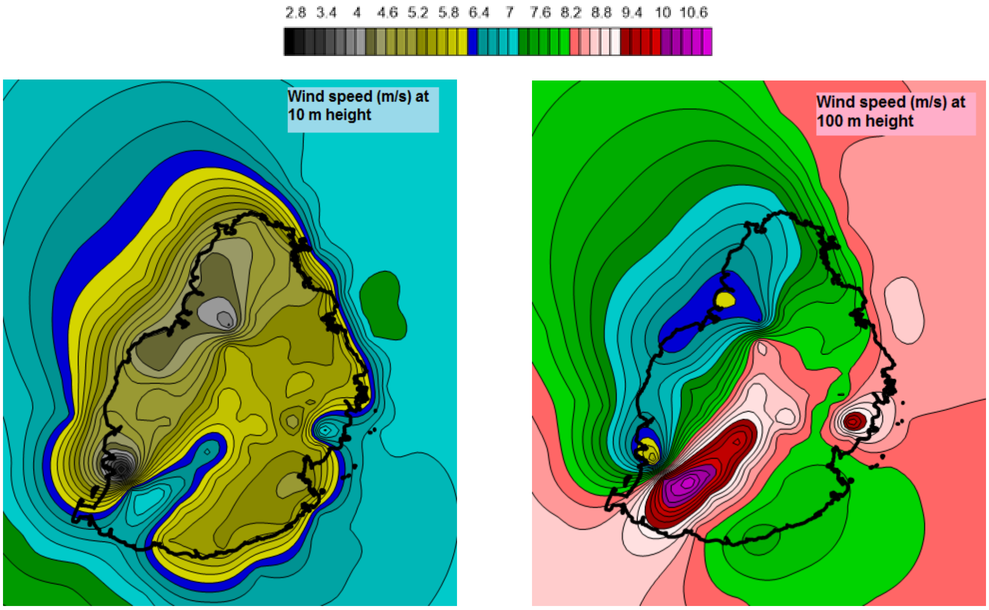
Data sets of measured wind speed and wind direction compared with numerical ones were displayed for an important variety of reference wind directions at the 3 stations and are given in Tables I to III. The percentage difference (%diff) between the values as well as the root mean square error (RMSE) are displayed. Note that there were no recorded data in the west direction because no measurements with $U_{thr} > 4$ m/s were recorded. The tables show a fair agreement for the reference wind directions with the measured ones in all cases. The results of this validation process imply that the simulations are regarded as amply accurate and that the equivalent level of geometrical illustration and the same physical models can be retained for the remaining CFD simulations in this case study.

TABLE III. M3 STATION (PAMPLEMOUSSES)

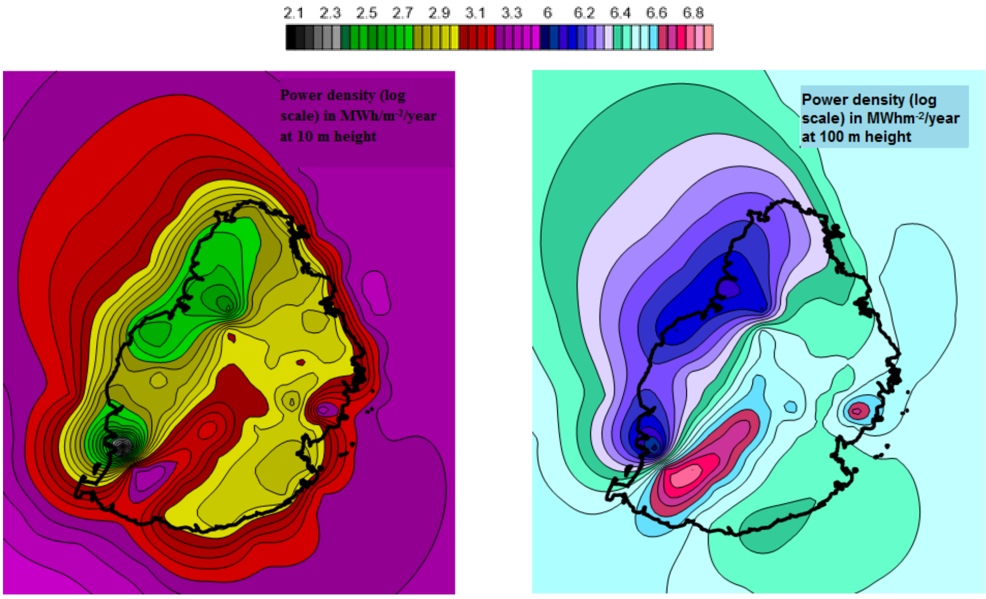
Inlet wind direction (degrees)	Wind speed (m/s)		% diff
	CFD	Measured	
85	3.9	4.2	7.14
90	4.7	4.5	4.44
105	4.3	4.5	4.44
100	4.0	4.4	9.09
110	4.6	4.4	4.55
120	5.2	5.1	1.96
150	5.2	4.8	8.33
		RMSE	0.28

V. WIND AND POWER MAPS FOR THE ISLAND

Yearly mean geographical distribution of wind speed and wind power density at the heights of 10 m and 100 m above sea level are displayed in Figure 3. It is observed that at higher altitudes, over most part of the island, the wind is around three times stronger than at lower altitudes. At 10 m, the East coast and South West part of the island have mean wind speed in the vicinity of 5 m/s while at 100 m the mean wind speed is around 8 m/s. The near-shore regions of Mauritius have the presence of high wind speeds (at 100 m height) in the whole southern segment. Wind speeds of 7.4 m/s in the North part of the near shore, surrounding Mauritius, between 7.8



(a) Yearly mean wind speed in m/s



(b)Yearly mean wind power density (log scale) in MWhm^{-2}/year

Figure 3. Wind maps generated using the WindSim CFD software.

m/s and 9.2 m/s on the North-East coast, in the South-East coast between 8.0 m/s and 9.2 m/s and 7.4 m/s to 8.4 m/s in the South West shore. In the West and North-West parts of the island, wind speed has a moderate value in between 6.6 m/s and 7.2 m/s.

It is interesting to note that at 100 m the yearly mean wind power density over most part of the country is around 1600 kWh/m^2/year. Concerning nearshore wind power, in the northern segment the power density averages between 3000 to 4200 kWh/m^2/year and near 4200 kWh/m^2/year in the eastern region. The

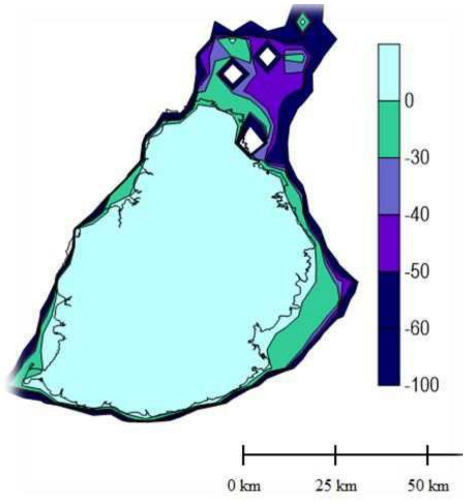


Figure 4. Bathymetry of Mauritius (North is upward). The colour scale represents depth in metres.

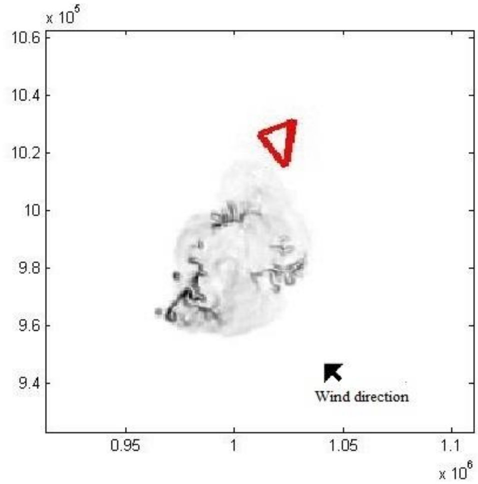


Figure 5. Location of a proposed nearshore wind farm (in red color) (The *x* and *y* axes show the longitudes and latitudes in metres in UTM coordinates).

power density in South eastern region fluctuates around 3000 kWh/m^2/year while for the entire western part it ranges moderately between 1400 to 2200 kWh/m^2/year.

To analyze the appropriate regions for nearshore wind farming, the availability and suitability at those locations need to be studied in detail. For instance, in the North part of the island, there is a ridge of depth in the ranges of 10 m to 50 m (see figure 4), which extends several kilometers in the ocean. On this part the wind speed is greater than 8.0 m/s, which indicates a good location for the placement of a nearshore WF. Furthermore, an exclusion analysis has eliminated the Northwest, East and South near-shores of the island due to constraints such as maritime navigation routes, nautical sports and airport buffer zones. Therefore, it is inferred that the North part of the island has good wind potential as well as coherent bathymetry for nearshore wind farming.

VI. Optimization of Wind Turbine Placements in the WF and Costing

The location of a proposed nearshore WF is shown in Figure 5. The PO module was applied to find the locations and layout that maximizes the power efficiency of the wind farm in the selected region. Given that the island benefits mostly from the South East trade winds year round, only a wind direction of 150 degrees was considered. It is also assumed that the Siemens 2.3 MW wind turbines, 80 m rotor diameter are installed at hub height of 100 m in this region. Detailed characteristics of this wind turbine are given in [21]. Figure 6 shows how 200 such turbines (circles in the diagram) are optimally arranged in the farm area using the PO module. Figures 7(a) and 7(b) display the variation of energy output of the turbines and the *NPV* (in MEuro) as a function of number of installed turbines (n).

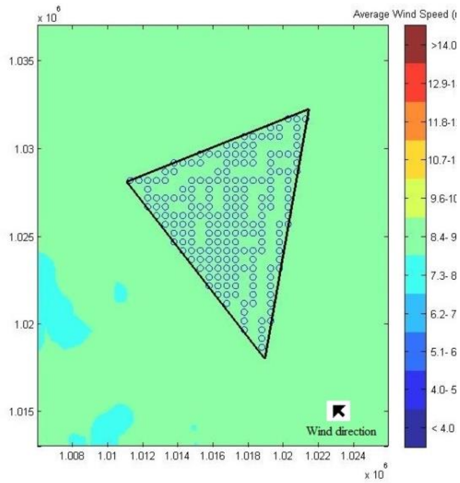
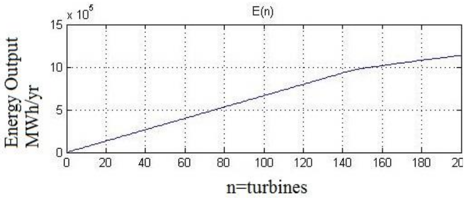
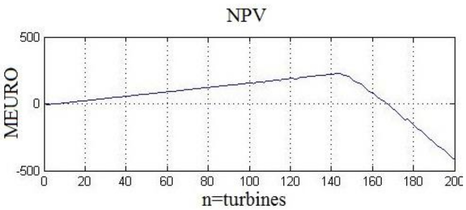


Figure 6. Optimized array arrangement of 200 Siemens 2.3 MW wind turbines in the farm area according to the PO module (The *x* and *y* axes show the longitudes and latitudes in metres in UTM coordinates).



(a) Energy output



(b) Profitability Curve, NPV (n)

Figure 7. Energy output and Profitability curves versus number of turbines n for an offshore wind farm in the Northern region of the island.

The economic optimization is performed by maximizing the Net Present Value (NPV) over n=1 to N and the Present Value Cost (PVC) as given below:

$$NPV = -C_0 - C_1 - C_2 - C_3 P_n + \sum_{t=1}^{T} (1+r)^{-t} E(n)(p_t + s_t - oc(n)) \times 10^{-6} \quad (2)$$

where C_0 is the fixed cost of site, C_1 is the cost of site infrastructure roads/ internal cables etc, C_2 is the investment transformers connection, C_3 is the investment cost of turbines, s_t is the subsidy level, oc(n) is the operational cost, P_n is the installed capacity, r is the interest rate and $E(n)$ is the Energy yield.

$$PVC = I + C\left(\frac{1+i}{r-i}\right) \times \left[1 - \left(\frac{1+i}{1+r}\right)^t\right] - S\left(\frac{1+i}{1+r}\right)^t \quad (3)$$

where PVC is the present value costs, I is the initial total capital, C is the operation, maintenance and repair cost which is assumed to be 25% of the annual cost of the turbines, t is the lifetime (20 years), i and r are the interest and inflation rates for Mauritius, which are 5% and 3.5% respectively and S is the scrap value which is taken to be 10% of the turbine price and civil work. The above assumptions are similar to those used in [22, 23].

It can be seen from figure 7(b) that the profitability curve peaks around 250 MEuro for 145 turbines and decreases rapidly towards high loss (≈ -500 MEuro) for 200 turbines although the energy output for this amount of turbine is around 1100 GWh/year. Correspondingly, with more than 145 turbines installed on the chosen site, the gradient of the energy output curve decreases. This can be attributed to the effects of intensified wake. The intensified wake significantly lowers the power production of the downstream wind turbines.

VII. Conclusion

This study has demonstrated how a computational algorithm integrating Computational Fluid Dynamics and Park Optimizer module can be used to assess nearshore wind energy for a small island. Future work will address a detailed economic analysis of implementing such a WF.

Ackowledgment

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Numerical Simulation of Wind Flow Influence on Heat Island Temperature Characteristics in Urban City Area

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Abstract— **The main aim of this paper is three-dimensional (CFD) simulation of turbulent wind flow around realistic block of buildings located in city center in Belgrade, Serbia. Two different cases for different inlet wind directions were simulated. The first one in which wind flows from eastern direction, and the second one in which wind flows from southern direction. All input wind parameters (velocity magnitude, velocity direction, air temperature, outdoor radiative temperature) were obtained from complex measuring campaign performed in this area. The obtained results showed deep insight in velocity field, vortex structure and their influence on temperature increase of analyzed block of buildings area. It was shown that the main causes for the observed temperature increase are developed horizontal standing vortex structures. It was also shown that this negative effect is to some extent retarded by the presence of vertical recirculation zones which enhance heat transfer away from inner area of block of buildings. Influence of “Venturi effect” of narrow passage on low altitude wind speed increase was also determined. It was concluded that temperature increase is present in the both investigated cases. However, this temperature increase is significantly lower in the second case which was chosen as a more favorable.**

Keywords - wind flow, Computational Fluid Dynamics (CFD), urban heat island (UHI)

I. INTRODUCTION

Expected continuation of urbanization as well as its speed can be based on the extrapolation of the statistical trends recorded over the past century. In 1900, only 10% of the world's population lived in cities, while now that number is increased to more than 50% [1]. Considering this fact it is natural and necessary to study the characteristics of the microclimate of our urban areas. Some cities have been successful in understanding the challenges of the 21st century, but there is clearly no routine or consistency in the application of environmental policies across the world as well as the proper design and planning of the urban environments. The growth of urbanization has turned cities in dense inhabited urban areas with decreasing number of green areas and with growing number of impervious surfaces. It is expected that temperature changes in urban areas caused by global warming and urbanization effects will affect human health directly and indirectly [2]. According to the US National Academy of Sciences and Royal Society (2014), a small increase of global temperature may result in widespread changes in regional temperature with increases in heat stress in local areas. The regional temperature changes increase the risks of heat wave events, which represent a serious public health concern [3]. Urban thermal issues related to the climate change are often neglected in urban planning [4]. A consequence of neglecting these issues in urban planning could increase inhabitants’ mortality and morbidity rate. These consequences have already been reported during the 2003 European heat wave [4].The urban heat island (UHI) is the most prevalent and among the most serious climatic manifestations of urbanization [5].

Oke [6] in his paper defined the most frequent causes of increasing UHI intensities.

Their relative importance was determined in numerous follow-up studies: trapping of short and long-wave radiation in between buildings, decreased long-wave radiative heat losses due to reduced sky-view factors, increased storage of sensible heat in the construction materials, anthropogenic heat released from combustion of fuels (domestic heating, traffic), reduced potential for evaporation, which implies that energy is converted into sensible rather than latent heat, and reduced convective heat removal due to the reduction of wind speed.

The effect of UHI has become one of the most significant concerns and challenges for planners and designers of urban areas. Wind velocity can reduce the heat island effect, leading to comfortable outdoor temperatures and lower pollutants' emissions [7]. Recent studies in this field showed that wind may bring significant improvements to urban thermal environments [8-10]. However, there are multiple necessary wind conditions which must be met so that wind flow can diminish negative UHI effects. Among these the most important are wind strength and wind direction. Under proper wind conditions heat can be removed away from its urban source points by advection and natural convection. In this way wind may help to prevent local heat accumulation and negative UHI effects.

However, positive wind effects depend not only of wind characteristics, but to the large extent they depend of local building areas design, building arrangement inside single blocks of buildings, building height, etc… One of the more significant problems that occur in the city environments is the areas in blocks of buildings which are impermeable or have low permeability for wind flow. Consequently, wind velocity in such areas is very low which decreases positive wind flow effects. The most common negative manifestation in these buildings' structures, caused by their impermeability, is standing vortexes development. Frequent appearance of standing vortexes leads to an increase in the outside temperature and consequently to a local negative UHI impacts on thermal heat comfort.

The wind flow pattern around a building is schematically indicated in Fig. 1. The approaching wind is partly guided over the building (1,3), partly around the vertical edges (2,4), but the largest part is deviated to the ground-level, where a standing vortex develops (6) that subsequently wraps around the corners (8) and joins the overall flow around the building at a ground level (9). The typical problematic areas where high wind speed occurs are the standing vortex areas and the corner streams. Further upstream, a stagnation region with low wind speeds develops (7). Downstream of the building, complex and strongly transient wind-velocity patterns develop, but these are generally associated with lower wind speed values and are of less concern (10 –16).

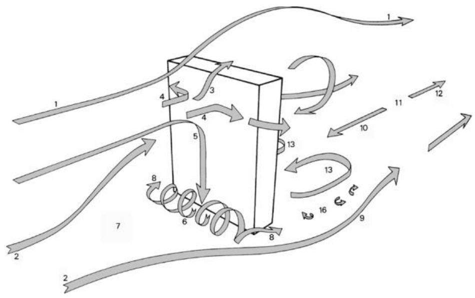


Figure 1 Schematic representation of wind flow pattern around a high-rise building [12].

Nowadays, many urban authorities neglect outdoor thermal comfort requirements and grant a building permit for a new building as well as block of buildings, without proper documentation which would incorporate in-depth building thermal performance analysis. Many studies about urban area outdoor thermal comfort indicated possible negative consequences for inhabitants. Moreover, these studies underlined need for use of modern tools which would enable detailed buildings and urban area performance analysis.

The main objective of this study computational fluid dynamics (CFD) simulation of complex turbulent wind flow field and temperature distribution in block of buildings located in city center of Belgrade. The main aim of this study is to perform in-depth analysis, based on the obtained numerical results, of flow field patterns and temperature distribution inside inner area of the block of buildings and to asses possible standing vortex zone. Furthermore, this study aims to determine standing vortex characteristics: their number, size, velocity magnitude, and position. Based on these data assessment of standing vortex and wind flow characteristics influence on temperature increase in the block of buildings area is defined.

II. EXPERIMENTAL INVESTIGATION

A. Study site

The study site in this research work is buildings block, Fig. 2, located near city center of Belgrade, Serbia.

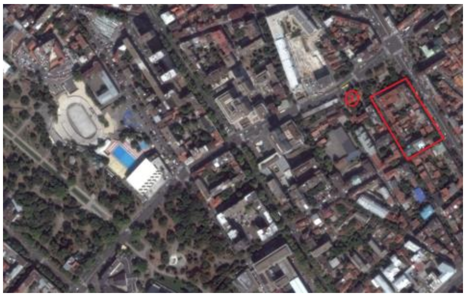


Figure 2. Building block part of Belgrade [Google map (http://maps.google.com)]

B. Local Climatology

In order to provide locally reliable data of wind climatology, the local meteorological mast has been installed on the roof of buildings near the observation block (location 1 of Fig.2; N 44º48 ’37.87’’, E 20º28 ’42.43’’). The data of 10 minutes averaged wind velocity and direction, as well air temperature and relative humidity have been continuously monitored in the period of 20.03.2015 to 27.09.2015. The summary of gathered data is presented on Fig. 3 – 4, as well as in Tab. 1.

TABLE I. SUMMARY OF GATHERED DATA

Tabulated Wind Climatology of Belgrade Center (Height = 10 m, a.g.l.)				
Dir.	A	k	*Va*	f
0	1.3	1.91	1.14	14
30	1.3	1.7	1.16	11
60	1	1.73	0.87	7
90	1.1	1.94	0.95	7
120	1.5	2.22	1.36	13
150	1.9	2	1.69	16
180	1.5	2.08	1.29	4
210	1.4	2.15	1.24	7
240	1.5	2.17	1.31	10
270	1.2	1.91	1.05	2
300	1.5	2.52	1.29	4
330	1.2	2.03	1.08	5
Total	1.4	1.91	1.28	100

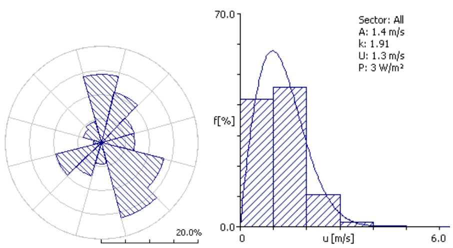


Figure 3. Wind Climatology of Belgrade Centre

III. CFD SIMULATIONS

A. Solver outline

General CFD code ANSYS FLUENT 13.0 coupled with user defined functions (UDFs) was used for all numerical simulations of realistic block of buildings located in city center of Belgrade, Serbia. Computational grid was constructed dividing geometrical domain in a finite number of control volumes using pre-processor ANSYS GAMBIT 2.4.0. Main flow field transport equations for: mass, momentum, turbulence, temperature and radiation were discretized on the generated finite volume grid using a co-located scheme, in which pressure and velocity are both stored at cell centers. Second order upwind scheme was used for spatial discretization of equation convective terms. Least squares cell-based method was used for evaluation of all gradients and derivatives in transport equations. FLUENT uses scalar algebraic multigrid AMG solver for

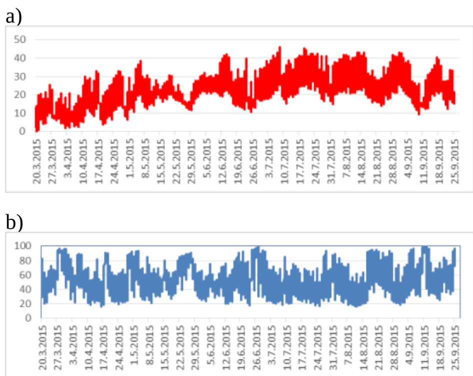


Figure 4. a) Air temperature and b) Relative Humidity (%) of Belgrade Centre.

the solution of linear systems obtained from the discretization of the individual transport equations with using either the Gauss-Seidel smoother [12].

B. *Computational domain and computational grid generation*

Computational domain has hexagonal shape with block of buildings positioned in its center. Buildings' geometry was imported into GAMBIT pre-processor from external 3d drawing, Fig. 5. Computational domain completion and grid generation were than performed inside GAMBIT pre-processor. The main domain dimensions are: 620 m in *x*-direction, 700 m in *y*-direction, and 124 m in *z*-direction, Fig. 6. These dimensions are adopted according recommendations given for flow

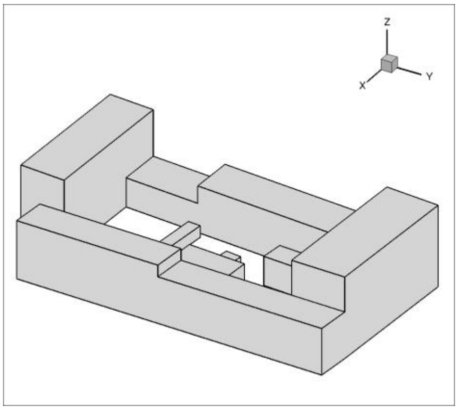


Figure 5. Geometry of investigated block of buildings in Belgrade centre, Serbia

around buildings in [13].

Generated computational grid consists of all hexagonal elements, as can be seen in Fig. 6. Semi-automatic hybrid grids, often consisting mainly of tetrahedral elements, are generally easier and less time consuming to generate compared with grids consisting of only hexagonal elements. However, great effort was taken in order to construct hexagonal grid in order to decrease numerical diffusivity and allow use of relatively simple and robust discretization schemes with satisfying accuracy [14]. Average cell size was determined according to guidelines given in [15]. Computational cells on building walls, and inner area of block of buildings have average size of 0.5 m in order to properly resolve wind effects in this region. Cell size increases for 20% in the cell layers near to the building walls until it reaches approximately 1.2 m. Cell size than

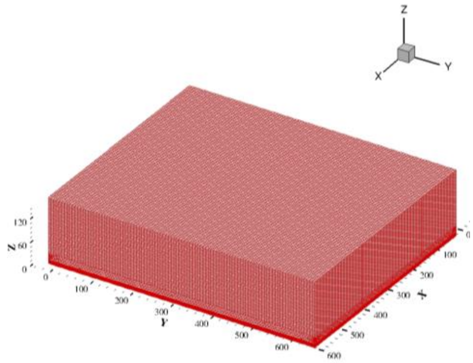


Figure 6. Finite volume grid of computational domain with main dimensions

gradually increases to 6 m at domain boundaries.

C. *Grid independence study*

The four different meshes were constructed in order to investigate solution dependence of mesh finesses. Course grid consisting of 1935287 finite volumes, medium grid consisting of 2998277 finite volumes, fine grid consisting of 6002350 control volumes, and very fine grid consisting of 8267158 finite volumes. The first case (with air inlet positioned on east domain boundary) was used to test solution – grid dependence. Case was calculated on all four meshes, and change in wind velocity magnitude in vertical $x = constant$ plane, positioned in the middle of block of buildings was monitored. Values of calculated velocity magnitude stopped changing from fine to very fine mesh, and thus solution was adopted as grid independent, Fig. 7. Based on this fine mesh was adopted for all numerical simulations performed in the scope of this work. Detail view, showing part of adopted computational mesh near region of interest (block of buildings), is shown in Fig. 8.

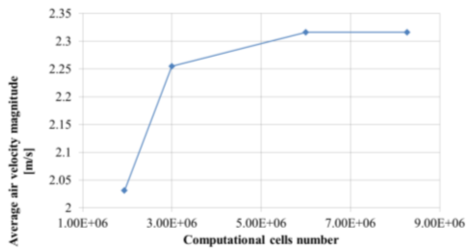


Figure 7. Results of grid independence study

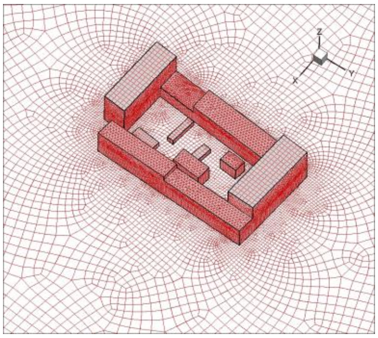


Figure 8. Part of fine computational mesh near block of buildings

D. Governing equations

Governing equations describing three-dimensional, turbulent air flow with heat transfer shown in differential form are:

- continuity equation:

$$\frac{\partial(\rho f)}{\partial t} + \frac{\partial(\rho u_j f)}{\partial x_j} = \frac{\partial S_j}{\partial x_j} + S_\Phi$$

$$\frac{\partial u_j}{\partial x_j} = 0 \quad (1)$$

- momentum equation:

$$\frac{\partial \rho u_i u_j}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left[(\mu + \mu_t)\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i}\right)\right] + \rho_{ref}\, g_i \beta\left(T - T_{ref}\right) \quad (2)$$

- energy (sensible enthalpy) equation

$$\frac{\partial \rho u_j h}{\partial x_j} = \frac{\partial}{\partial x_j}\left[(\lambda + \lambda_t)\left(\frac{\partial T}{\partial x_j}\right)\right] + \tau_{ij}\frac{\partial u_j}{\partial x_i} + S_{rad} \quad (3)$$

E. Turbulence modeling

Realizable *k*-*ε* turbulence model [16] was chosen for turbulence modeling in this work over more robust, and traditionally used standard *k*-*ε* model [17]. This choice is based on the fact that realizable *k*-*ε* turbulence model is able to more accurately predict flows involving swirling, boundary layer flows, strong, pressure gradients, and recirculation [12]. The modeled transport equations for *k* and *ε* in the realizable *k*-*ε* model are:

- $$\frac{\partial \rho u_j k}{\partial x_j} = \mu_t S^2 - \rho\varepsilon + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\left(\frac{\partial k}{\partial x_j}\right)\right] \quad (4)$$

- $$\frac{\partial \rho u_j \varepsilon}{\partial x_j} = C_1 S\,\rho\varepsilon - C_2\frac{\rho\varepsilon^2}{k+\sqrt{\nu\varepsilon}} + \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon}\right)\left(\frac{\partial \varepsilon}{\partial x_j}\right)\right] \quad (5)$$

It is important to mention that system of equations (1-5) is derived assuming turbulent, incompressible flow of Newtonian fluid.

F. Radiation modeling

Discrete ordinates (DO) model was used for radiation modeling, mainly due its ability to accurately predict radiative heat fluxes in cases involving complex geometries and strong curvatures. The discrete ordinates (DO) radiation model solves the radiative transfer equation (RTE) for a finite number of discrete solid angles, each associated with a vector in the global Cartesian system. The DO model transforms RTE into a transport for radiation intensity in the spatial coordinates (*x*, *y*, *z*). In this way solution of radiation heat transfer is calculated in the same manner as solution for the fluid flow and energy equations. Equal quadrature divisions in all four directions (4 × 4) were set to solve the DO equation. Equation for radiation intensity is solved at every 10 flow field iterations.

G. Boundary conditions

Dirichlet boundary condition was applied to all variables at the domain inlet using °heric boundary layer (ABL) assumption [18] Velocity magnitude, turbulent kinetic energy, turbulent dissipation rate, and air temperature values at inlet are defined by the following profiles according to ABL approximation:

- inlet velocity magnitude:

$$u_{inlet} = \frac{u^*}{K} ln\left(\frac{z+z_0}{z_0}\right) \quad (6)$$

- inlet turbulent kinetic energy:

$$k_{inlet} = \frac{u^{*2}}{\sqrt{C_\mu}} \quad (7)$$

- inlet turbulent dissipation rate:

$$\varepsilon_{inlet} = \frac{u^{*3}}{K(z+z_0)} \quad (8)$$

- inlet temperature:

$$T_{inlet} = T_{z_0} - 0.009775 \cdot z \quad (9)$$

Friction velocity u^* can be determined from the following equation:

$$u^* = \frac{Ku_h}{ln\left(\frac{z+z_0}{z_0}\right)} \quad (10)$$

Friction velocity is computed, according to ABL assumption, using value of velocity magnitude u_h = 1.5 m/s measured at reference height h = 10 m. K is von Karman's constant, $K \approx 0.4$. z_0 is roughness height, taken from recommendation for urban city centers with residential and commercial buildings with different heights, z_0 = 2 m [19]. Value of temperature measured at reference height, h, was $T_h = 30\ °C$.

Dirichlet boundary condition was applied for static pressure, turbulent kinetic energy, turbulent dissipation rate, and temperature at the outlet boundary opposite of inlet surface in flow direction. Dirichlet boundary condition for normal velocity vector component equal to zero was set to the rest of domain boundaries. Neumann boundary condition with zero gradient was set for all other variables at the above defined boundary surfaces.

Material transport and thermal properties

All material properties necessary for flow field and heat transfer calculations are given in Tab. 2.

TABLE II. MATERIAL PROPERTIES

Material transport and thermal properties			
Property	**Fluid**	**Building**	**Ground**
Material	**Air**	**Brick**	**Asphalt**
Density [kg/m3]	1.225	1400	2360
Specific heat [J/kgK)]	1006.43	900	920
Thermal conductivity [W/mK]	0.0242	1.7	0.75
Viscosity [kg/ms]	1.7894e10^{-5}	-	-
Absorption coefficient [1/m]	0.19	0.75	0.9
Scattering coefficient [1/m]	0	0	-10
Refractive index [-]	1	1.7	1.92
Internal emissivity [-]	0.9	0.88	0.95

External air emissivity was set to 0.05, free stream radiative temperature was set to measured value of 38 $°C$, while convective heat transfer coefficient for building surfaces was calculated according to the following expression defined in [20]:

$$h_{building} = 5.7 + 3.8u_{surf} \quad (11)$$

where u_{surf} is velocity magnitude at boundary face of finite volume of corresponding building surface.

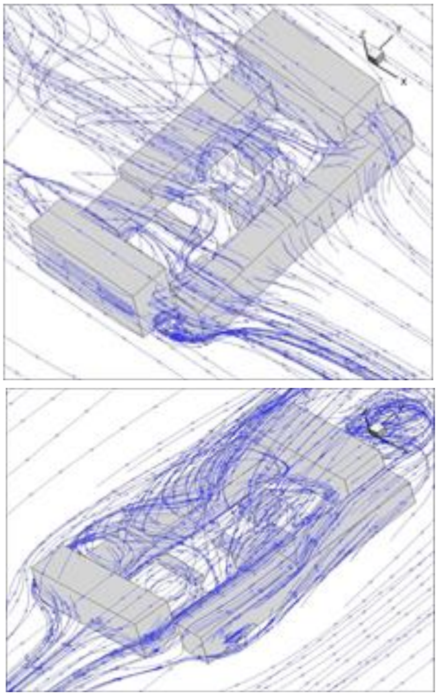
IV. RESULTS AND DISSCUSSION

Velocity stream lines for calculated cases are shown in Fig. 9. It can be seen that, for the case 1 in which wind comes to the block of buildings from the eastern direction, significant portion of wind is directed over the buildings. This part of wind flow forms vertical vortex zones located in inner area between bounding buildings. However, major part of wind flow is directed towards ground level where it wraps round buildings' corners. The opening between bounding buildings located in the southern-eastern corner of building blocks leads to "Venturi effect" and consequently redirects significant portion of wind flow into inner area between bounding buildings which makes favorable conditions for closed vortex zones formation. Smaller part of wind, near ground level forms complex wind-velocity structures at the outer eastern building surfaces. However, since this is only small portion of total wind flow and since it is characterized by low velocity magnitudes it has only minor influence and it is of less concern, Fig. 9 a).

Velocity streamlines for the case 2, in which wind comes to the block of buildings from southern direction is shown in Fig. 9 b). It can be seen that overall velocity field structure is quite different compared with the previous case. Namely, wind flow is directed to the highest building in the block and thus the biggest portion of wind is directed not over, but around southern side of buildings. Part of wind flow directed to the western side of block of buildings than flows over lower height buildings and forms strong vertical vortex zone. The other part of wind flow, directed to the eastern part of building block encounters narrow passage between buildings. This narrow passage again (similarly as in previous case) produces "Venturi effect" increasing wind speed, and forms closed vortex zone in near ground horizontal plane.

Deeper insight into wind patterns and vortex structure can be seen from the Fig. 10. and Fig. 11.

Velocity magnitude for case 1 at horizontal cross-section at 1.5 m from ground level is shown in Fig. 10. It can be seen that two major closed vortex zones are formed in northern and central inner area of block of buildings. These zones are characterized by very low velocity magnitude, between 0.04 m/s and 0.2 m/s and thus it is expected that heat will accumulate in this zones leading to increased temperature values which intensify urban heat island impact and consequently have negative implications for human comfort and urban design. Third closed vortex zone is formed near southern part of block of buildings. However, this zone has higher velocity magnitude, compared with the previous two, between 0.12 m/s and 0.36 m/s and thus it is expected that temperature increase in this zone will be lower than in the other two closed vortex zones. Higher velocities present in the southern closed vortex zone may be explained by the effect of narrow passage between buildings which increases wind speed.



a)

b)

Figure 9. Velocity streamlines in vicinity of block of buildings: a) case 1 – wind inlet located at the eastern domain boundary, b) case 2 – wind inlet located at the southern domain boundary.

However, in order to form clearer picture of vortex structure in building of blocks, flow patterns in vertical planes will be also part of analysis in this work.

Velocity magnitude for case 2 at horizontal cross-section at 1.5 m from ground level is shown in Fig. 11. It can be seen that average velocity in inner area of building blocks is much higher in this case compared with the previous case. Two closed zones vortex zones are formed in middle and in southern part of inner building of blocks area. The middle closed zone is characterized by quite low velocity magnitude values. Minimal velocity magnitude values are in range of 0.4 m/s – 0.8 m/s (which are still much higher than in previous case). However, size of this zone is quite small and thus it is expected that it will have somewhat limited influence on temperature increase and urban heat island impact. On the other hand the southern closed vortex zone has much bigger size, but it is also characterized by higher

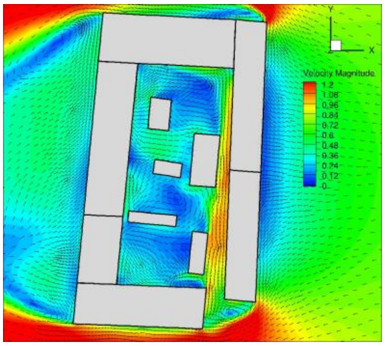


Figure 10. Case 1 – velocity magnitude with velocity vectors in horizontal cross-section at 1.5 m from the ground level

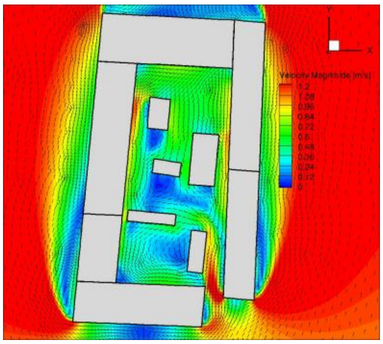


Figure 11. Case 2 – velocity magnitude with velocity vectors in horizontal cross-section at 1.5 m from the ground level

velocity magnitudes, up to 0.6 m/s. Again, due to complex vortex size further analysis of calculated results is necessary in order to clarify their influence on temperature field in inner zone of analyzed block of buildings.

Velocity magnitude with velocity vectors in the middle vertical cross-section *x* = *const*. for case 1 are shown in Fig. 12. It can be seen that wind portion directed over the buildings together with natural convective flow leads to the formation of vertical vortex zones. Three of these zones are formed in the inner part of building block. The importance of these zones is in the fact that they are in the contact with air at higher altitudes, which together with the quite high velocity magnitudes of this zones (up to 1.2 m/s) enhances heat transfer in the direction away from the inner buildings' zone. This should have positive impact on urban heat island characteristics, somewhat limiting negative influence of closed horizontal vortex zones.

Velocity magnitude with velocity vectors in the middle vertical cross-section *x* = *const*. for case 2 are shown in Fig. 12. It can be seen that change of inlet wind direction form eastern in case 1 to southern in case 2 led to overall increase of velocity magnitude in inner buildings' zone. Vertical vortex zones formed by the portion of wind coming from the left side where lower bounding buildings are located (Fig. 9. b) contributes to this velocity magnitude

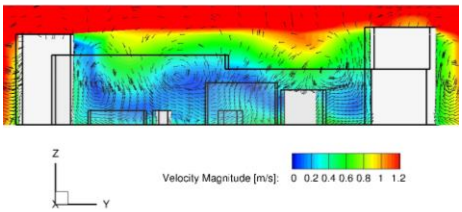


Figure 12. Case 1 – velocity magnitude with velocity vectors in the middle vertical cross-section *x* = *const*.

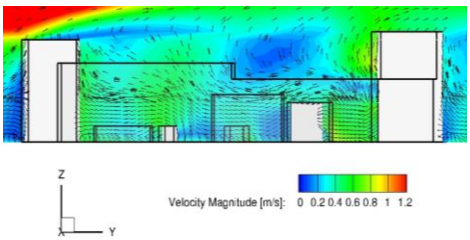


Figure 13. Case 2 – velocity magnitude with velocity vectors in the middle vertical cross-section *x* = *const*.

increase at higher altitudes. Moreover, velocity magnitude is also increased in near ground levels compared with the pervious case. This increase can be explained by the narrow passage between buildings which induces "Venturi effect". Influence of "Venturi effect" is more intensive in case 2 than it was in case 1 due to the fact that in the case 2 passage direction is aligned with incoming wind direction. It can be seen that minimum velocity magnitude

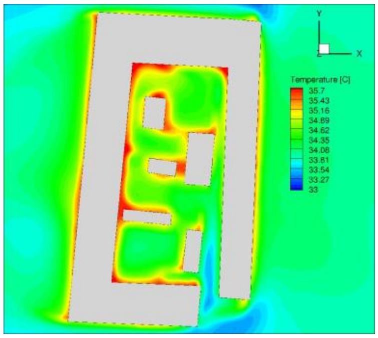


Figure 14. Case 1 – temperature distribution in horizontal cross-section at 1.5 m from the ground level

increased from the about 0.2 m/s to more than 0.4 m/s changing wind direction. Stronger vertical recirculation will intensify heat transfer out of the inner buildings' are. Because of this it is expected that temperature increase in inner buildings' area will be less pronounced in case 2 than in case 1, which would also limit negative effects of urban heat island.

Temperature distribution in horizontal cross-section at 1.5 m from the ground level for case 1 is shown in Fig. 14. It can be seen that minimal increase in temperature compared with bulk flow temperature is about 3.5 °*C*. Moreover, developed stagnant horizontal vortex zones negatively influence heat convection and lead to further increase in temperature in the inner buildings' zone, up to more than 5 °*C*. This quite big temperature increase is present in almost all parts of inner buildings' zone, and it is in range of 4.5 °*C* to 4.8 °*C* in average.

Temperature distribution in horizontal cross-section at 1.5 m from the ground level for case 2 is shown in Fig. 15. It can be seen that minimal increase in temperature compared with bulk flow temperature is lowered to about 3 °*C* compared to the previous case. More importantly, this zone with lower temperatures, between 3 °*C* and 3.5 °*C* are present in almost one third of inner buildings' zone (in its northern part). Average temperature increase is also lower in almost all other parts of inner buildings' area to 3.9 °*C*. Only exception is the most southern part of this area in which presence of closed vortex zone leads to increase in temperature to about 4.5 °*C*. However, it may be concluded that case 2 is more favorable than case 1 since temperature values are lower in almost all parts of inner buildings' area, as well as because temperature distribution is more uniform. The above mentioned facts limit negative influence of urban heat island, although it is clear that it cannot be neglected.

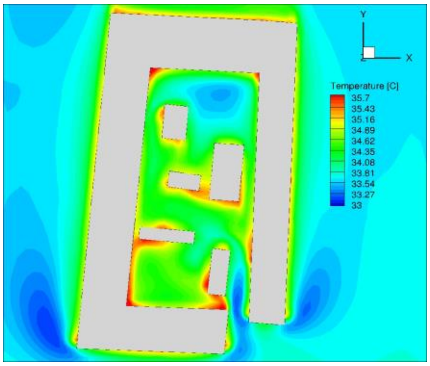


Figure 15. Case 2 – temperature distribution in horizontal cross-section at 1.5 m from the ground level

V. CONCLUSIONS

- Detailed three-dimensional simulation of turbulent wind flow with heat transfer around realistic block of buildings in city center of Belgrade city Serbia was conducted in order to determine possible causes for temperature increase and negative urban heat island effect on outdoor thermal comfort.
- CFD simulations were performed for two most frequent wind flow directions: from eastern and from southern sides.
- Results analysis offered detailed view into flow field inside inner area of the block of buildings. It was shown that the most prevailing negative effect which causes temperature increase in the buildings' block is development of standing vortex horizontal structures.
- It was also shown that development of vertical vortex zones, caused by the presence of buildings with lower height and by the presence of narrow passage between two buildings has opposite effect. Namely, their presence intensifies heat transfer from lower altitudes near ground levels to higher air altitudes and significantly lower negative effects caused by the above mentioned standing vortex structures.
- Standing vortex structures are more numerous with lower velocity magnitudes in the first case leading to the higher temperature increase inside inner area of the considered block of buildings.
- Standing vortex structure and their number changes with wind direction change in the second scenario, in which only one closed horizontal vortex zone is developed. Moreover, wind velocity in this standing zone is higher than in the first case. These phenomena lead to visibly lower temperature increase.
- It is planned to further develop current CFD model in order to include other important effects, such as influence of gaseous species with greenhouse effect, influence of traffic, and vegetation.
- Future CFD simulation will be also performed for larger urban areas consisting of more blocks of buildings in order to determine their possible relations.

ACKNOWLEDGMENTS

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Conditions for Efficiency of Open Pit Medium Voltage Power Transformers

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***Abstract*—A quality solution for electric current supply is one of the basic conditions for maximum exploitation of the chosen equipment and technologies in open pit mines. Prolonging the life cycle of power transformers, together with obtaining the highest possible economic effect, is the priority of any electro-energetic system. This paper analyses the technical lifespan of transformers from the aspect of overload. The results for transformers of specific nominal power, and for the given number of operating hours are provided in the form of diagram for two characteristic environment temperatures.**

Keywords - power transformer, insulation, overload, ageing

I. Introduction

Any electro-energetic system which supplies mining equipment in open pit mines under specific conditions, which are determined by the adopted technology in yards, should provide reliable and constant power supply, and at the same time, meet the requirements of efficiency, enable the simplest manner of exploitation and provide maximum service safety.

The basic characteristic of exploitation in open pit mines in the electro-energetic domain is deconcentration of power consumers, as well as engaging high power machines. Apart from this, mining electro-equipment is often obsolete and inadequately maintained, poorly protected from atmospheric impact, exposed to various kinds of mechanical strain and is constantly moved together with mining manufacturing plants, according to the adopted technological process.

Thus, safety and cost-effectiveness of an electro-energetic system of an open pit mine are not guaranteed but require constant attention. The complexity, structure and frequently significant rise in power consumption, require a well-designed approach to managing and investing in the maintenance and development of the network.

The total financial input into the electro-energetic network of a specific open pit mine includes the costs of electric power networks maintenance and the investment costs which should be sufficient enough to enable safe and reliable supply of consumers with quality power, given the expected increase in the power consumption.

One of the ways of solving the problem of power sources energy efficiency relates to improving the elements of distribution network, which leads to the increase in their efficiency, and ultimately the efficiency of the entire system.

Distribution medium voltage transformers of 10/0.4 kV represent a considerable portion of an electro-energetic system and require most investments. Despite the fact that transformers have the efficiency of 96 – 99%, considerable savings in power can be obtained by planning the optimum development of the distributive network development by finding the minimum cost function, that is by analyzing the conditions for transformer optimum exploitation [1, 2].

The estimate of the remaining transformer lifespan is carried out based on its load during operation and measurement of certain oil temperatures so as to establish the diagram of the hot-spot temperature during transformer operation, or by following the processes which affect the condition of the insulation system and operative condition of transformers, based on the analysis of electric and chemical features of the insulation system

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II. TRANSFORMER ECONOMIC OPERATION

Total operating costs of transformers consist of permanent annual costs and proportional annual costs. Permanent annual costs comprise the investment cost and the cost of transformer iron loss. Proportional annual costs of transformers depend on the costs of transformer copper loss, transformer maximum load for the annual operating hours [1].

The comparative diagrams of the dependence of the relative annual cost of medium voltage 10/0.4 kV transformer upon the load, for five different values of rated power: 50, 100, 160, 250 and 400 kVA are presented in Fig. 1, 2, 3 and 4. The diagrams have been made for 3000 annual operating hours, given the fact that the largest number of distributive transformers operate in the scope of 2 000 – 4 500 h annually, and it is shown that transformers can operate efficiently even with loads larger than nominal [1, 3]. The

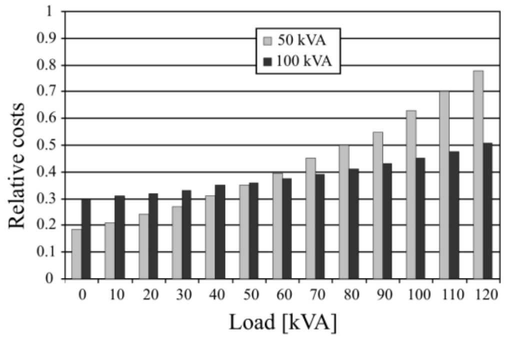

Figure 1. The annual costs of 10/0.4 kV transformers depending on the load for 50 kVA and 100 kVA.

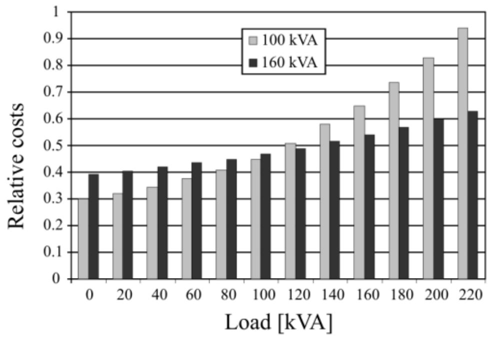

Figure 2. The annual costs of 10/0.4 kV transformers depending on the load for 100 kVA and 160 kVA.

limits of economic operation are determined by the points of leveling of the two transformer types relative annual costs.

In the case of 50 kVA and 110 kVA this limit is approximately 50-60 kVA, with 100 kVA and 160 kVA transformers the limit is approximately 110 kVA, with 160 kVA and 250 kVA transformers the limit is approximately 180 kVA, with 250 kVA and 400 kVA transformers the limit is 260-270 kVA.

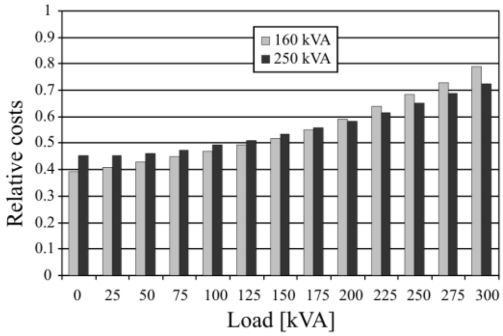

Figure 3. The annual costs of 10/0.4 kV transformers depending on the load for 160 kVA and 250 kVA.

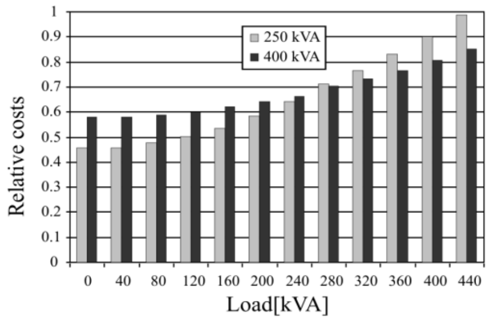

Figure 4. The annual costs of 10/0.4 kV transformers depending on the load for 250 kVA and 400 kVA.

In a such a way we can establish to which extent transformers can be used in an economic way, even if the load is greater than the rated. However, transformer overload causes overheating and decreasing of the transformer technical lifetime and it is important to bear in mind the transformer loss-of-life analysis [4].

III. TRANSFORMERS AGEING MECHANISM

The transformers' ageing is mainly determined by its insulation characteristics, which are continuously changing during a transformer operation. These changes are the result of the electrical, thermal and mechanical stresses, and their interaction [5, 6].

Ageing mechanism of the transformer insulation is a complex process, and it can be represented as in Fig. 5.

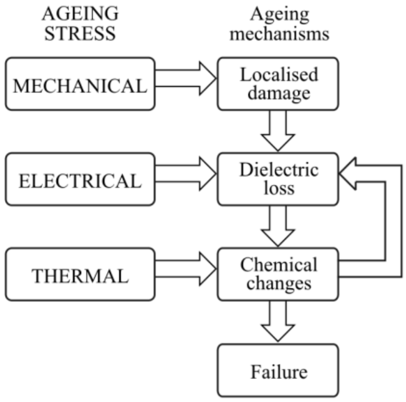

Figure 5. Transformer ageing mechanism.

A. Mechanical ageing

Mechanical ageing occurs due to: the fatigue of insulation parts caused by s number of mild strain occurrences, as the consequence of thermomechanical strain due to heat strain and contractions, breaking of insulation parts due to severe mechanical strain, displacement of insulation parts caused by electric, thermal or mechanical strains. In case of repeated mechanical strains, mechanical ageing depends on the frequency of this repetition as well.

Transformer windings are exposed to mechanical strain in the event of short circuits in the network, sudden overload or the occurrence of vibrations due to magnetostriction. The result of this is the decrease of winding resistance to the short circuit forces, and the abruption and sudden ageing of the paper, which significantly shortens the transformer lifetime.

B. Electrical ageing

Electrical transformer ageing is determined by the power of the electrical field, where oil presents the weakest link of the insulation system. Electric strain, which exists in the insulation system, is in inverse proportion to the dielectric constant. Electrical transformer ageing can be the consequence of: tracking, electrolysis, the existence of electricity or elevated temperatures, caused by dielectric loss.

Transformer ageing as the result of electrical strain can lead to dielectric losses and final failure, that is dielectric breakdown. In all kinds of insulation oils, dielectric breakdown occurs at approximately 60–70 kV. The limit of dielectric breakdown is considerably lower due to the presence of water or gases (for example, with 100 ppm of water, dielectric breakdown of mineral oil falls to 10–20 kV), and even more so due to the existence of different contributing factors such as dust and different particles combined with water. The conclusion regarding electrical strain is that the necessary condition for a long-term and reliable transformer operation is maintaining a clean production process.

C. Thermal ageing

Thermal load depends on the temperature of the coil and its duration, and predominantly effects chemical changes in the transformer insulation system. The data used for calculating the transformer thermal ageing are: manner of cooling, operating conditions of the environment, as well as the history of load, with relevant coil and oil temperatures and environment temperature.

The possibility of load, that is, intensity of the ageing process is conditioned by the permissible transformer insulation temperature [7]. Nowadays usually used criteria of the insulation's end of life are established on Montsinger relation:

$$D = D_0 \cdot e^{-0.69 p \cdot (\vartheta - \vartheta_0)}, \qquad (1)$$

where D is the expected transformer life, p is the material constant, ϑ is insulation temperature in degrees Celsius and D_0 is the lifetime a transformer has at hot spot temperature ϑ_0 (the highest insulation temperature).

Instead of the expected transformer life, commonly the inverse function, relative thermal ageing V is used, which represents the ratio between transformer lifetime at hot spot temperature, and lifetime at rated load:

$$V = e^{0.69 (\vartheta - \vartheta_0)/\Delta_0}, \qquad (2)$$

where Δ_0 is temperature decrease at which transformer lifetime is doubled**.** In the referent literature, the value Δ_0 is within the range of 6 –10 ºC, and according to IEC specification [8, 9] it is adopted that $\Delta_0 = 6$ ºC.

Under ideal conditions, the winding hottest-spot temperature is considered to be ranging between 98°C and 110°C for different ways of thermal upgrading insulation process [10].

The average daily temperature is not always 20 ºC, so the hottest spot of the winding is not constant, and transformer exploitation U_D is introduced, in relation to one year, day or hour, as the percentage ratio:

$$U_D = \frac{1}{D_0} e^{0.69(\vartheta - 98)/6}. \quad (3)$$

In American recommendations $\Delta_0 = 8.6$ºC and the transformer life time exploitation per hour can be given by the equation:

$$U_D = 0.0025 \cdot e^{0.69(\vartheta - 110)/8.06}. \quad (4)$$

Transformer lifetime of 5.4 years, obtained for the winding temperature of 110 ºC, matches a lifetime exploitation of 0.0025% per hour that is a slightly shorter lifetime of 4.5 years.

In our country, the standards define the thermal ageing on the basis of IEC specification. Transformers are designed for continuous operation at up to 55°C or 65°C rise above ambient temperature as determined by average winding resistance.

During a continuous load, heat losses cause the temperature of the winding to increase, and the heat is transferred to the surrounding oil.

The winding hottest-spot temperature is determined as the sum of the ambient temperature (cooling medium) ϑ_a, top-oil rise over ambient temperature $\Delta\vartheta_{oil}$, and the copper hottest-spot rise over oil temperature $\Delta\vartheta_{Cu\text{-}oil}$.

The permissible loading of transformers depends on the design characteristics of the transformer, cooling system employed, duration of changed load, and cooling system employed, in which case the convection heat transfer characteristics are determined by heat transfer theory for transformers with forced air flow and by the corresponding thermal models for transformer with natural oil flow [11].

The optimum transformer load is the one at which its economic and technical lifetime are equal.

IV. TRANSFORMER OVERLOAD

Despite the fact that insulation ageing is the result of complex electric, thermal and mechanical processes, in calculations, ageing is exclusively treated as a thermally dependent function, according to IEC standard.

According to IEC specifications [8, 9], the hot-spot temperature must not be higher than 140°C, and the top-oil temperature must not exceed 105°C. Based on the highest temperatures of copper and oil in transformers of 10/0.4 kV, with the nominal power of 50-400 kVA, presented as relative to their load, for a specific number of operating hours, and an adopted average temperature of the surrounding air, it is possible to calculate transformer border loads [12, 13].

Fig. 6 and 7 present transformers maximum loads S_{max} relative to the rated load S_n depending on the number of operating hours.

Transformer maximum loads are given for two average yearly air temperatures, namely +20°C for the summer period and 0°C for the winter period.

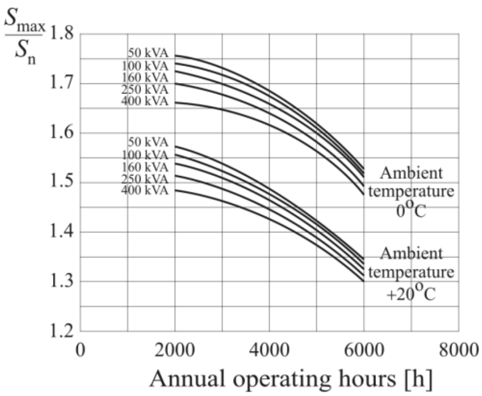

Figure 6. Allowed power of transformers 10/0.4 kV the life time exploitation of which is 0.017%/day.

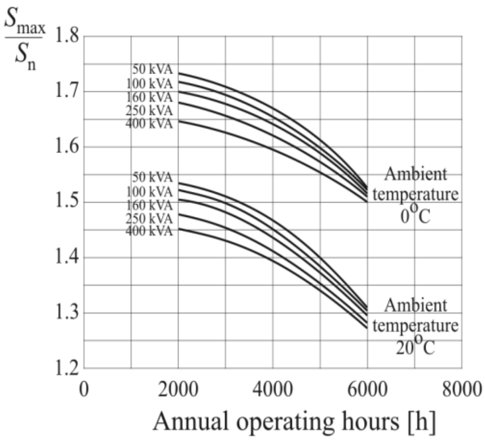

Figure 7. Allowed power of transformers 10/0.4 kV the life time exploitation of which is 0.014%/day.

Fig. 6 shows graphic representations of transformers loads, the lifespan exploitation of which is 0.017% per day, whereas the technical life span would be 16.5 years, which equals the lifespan calculated based on practice.

Fig. 7 contains curves of transformer load, the lifespan exploitation of which is 0.014% per day, that is the lifespan is 20 years long, which is quite efficient

Based on Fig. 6 and 7 it is evident that transformer operating loads can be considerably larger than the transformer nominal power (in summer from 30 to 60%), with the transformer lifespan still remaining normal.

Table I contains the calculated permitted operating loads for a 10/0.4 kV transformer, with the power of 50 kVA, for 3000 h operating hours annually and the temperature of +20°C.

The permitted loads have been calculated to show that average daily lifespan exploitation during one week is 0.017% per day.

A conclusion can be made based on Table I, that border temperature of the coil hot-spot is reached if the transformer load is slightly greater than $1.57 \times S_n$, i.e. with this ratio against operating load, the transformer lifespan will not be fully used and consumption will be negligible.

TABLE I. PERMITED OPERATING LOADS FOR 10/0.4KV TRASNSFORMER

$\frac{S_{max}}{S_n}$	Temperature of the copper [°C]
1.15	151
1.22	150
1.31	150
1.40	149
1.50	146
1.57	138
1.62	128

The second reason for the poor exploitation of transformer lifespan is the yearly rise in the maximum loads of transformer stations.

Transformer uses its lifespan only during its last year before substitution, since the insulation due to thermal load has not been wasted before that.

V. CONCLUSION

Medium voltage power transformers are the most important and critical components of the open-pit mine distribution power systems. In order to achieve a more cost effective power delivery system, the paper deals with the conditions and the parameters limiting transformer optimum exploitation. The transformer economic operation is analyzed, as well as overload capacity and extension of transformer lifetime. The mechanisms influencing the transformer insulation ageing are identified, followed by appropriate examples.

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Biodiesel Production from Mixture of Oils – a Review

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Abstract—**Effective production of Biodiesel from non-edible oils is one of the challenging issues for researchers. There are various production methods which can be used, but the non-edible vegetable oils contain high level of free fatty acid which make it difficult to produce biodiesel from it. In this review, it is reported that biodiesel produced from a mixture of oils is one of the best methods to improve the properties of biodiesel produced and also its yields.**

Keywords - Biodiesel, Mixture of oils, Production

I. INTRODUCTION

Biodiesel is a mono-alkyl esters of long chain fatty acids, which is derived from renewable sources. It is an oxygenated fuel derived from renewable biological sources and it may be used in diesel engines without any modifications in diesel engine [1]. Biodiesel is highly biodegradable and has decreased levels of toxicity. Biodiesel emits a very less quantity of harmful emissions like carbon monoxide, particulate matters, smoke, hydrocarbon emission. Biodiesel does not emit sulphur and net carbon dioxide [2-3].

II. IMPORTANCE OF BIODIESEL

Fossil fuel reserves are limited in earth and its consumption is a major concern because of its limited availability in the world. Exhaustive uses of fossil fuels in industrial, transportation, farming and domestic sectors may cause its depletion rapidly. Its use also deteriorates the atmosphere, passing on harmful emissions. This trouble can be solved with the increase in the role of alternative fuel in automotive engines. A number of alternative fuels has been recognised such as biodiesel, bio-alcohol, non-fossil natural gas, hydrogen, vegetable oils etc. But biodiesel is found to be more popular alternative fuel in various cases of diesel engines.

4.1 billion tons of Carbon Dioxide will be passed off to the atmosphere from 2007 to 2020. In addition, 8.6 billion metric tons of carbon dioxide will be passed off to the atmosphere from 2020 to 2035 [2]. Peaceful existence of the world is threatened by Global warming and the energy crisis. This trouble can be solved with the increase in the role of alternative fuel and energy loss minimization in automotive engines. The role of substitute fuels in automotive engines increases in recent years due to hike in prices of liquid hydrocarbon day by day [4].

In a single decade, there is seven fold expansion of biodiesel sectors from 2000 to 2015 at an annual growth of 23% in biodiesel production globally. There is a need to increase the biodiesel production dramatically with strong policy directive, subsidies and trade policies in favour of agricultural interests, rural economic development, energy security and climate [5].

Energy resources will take on an important part in future. In some of the developing countries, 90% of total rural energy is provided by Bioenergy. Various biofuels are being used for Bioenergy conversion with advanced technologies in developed nations to make it competitive with fossil fuels costwise. If renewable energy projects are designed and planned carefully with local input and support, it will facilitate economic and social development in local residential areas. Sustainability, greenhouse gas emissions reduction, regional growth, social structure and agriculture are some of the advantages which may be achieved with the biofuels use. The need to get carbon neutral renewable energy goes up to mitigate the greenhouse gas effect [6]. 88% of primary energy consumption is accounted for fossil fuels with a percentage of 35% oil, 29% coal, 24% natural gas, 5% nuclear energy and 6% hydroelectricity. Economic development may be affirmed with the growth of alternative energy resources as traditional fossil fuel resources are defined. Cetane number, energy content, viscosity and phase changes are some of the characteristics of biodiesel which is comparable to diesel. Biodiesel does not contain any type of petroleum product. Biodiesel can be mixed with diesel at any proportions. Biodiesel can be brought about by various biolipids. Climate, local soil conditions and accessibility are some of the important elements for a region on which choice of feedstock for biodiesel depends. Hence, different types of oils are being focused by different areas. Biodiesel has good lubricity, higher cetane number and a higher flash point as compared to that of diesel. Edible oils used for the production of biodiesel causes increase in cost and food security problems. In view of these problems, alternative feedstocks such as used cooking oils, various animal fats, waste restaurant greases, non-edible vegetable oils and microorganisms such as algae are being explored [7].

III. VARIOUS VEGETABLE OILS FOR BIODIESEL

Brazil is the second largest producer of Soybean in the world. Brazil utilises Soybean, Bovine lard and Cottonseed oil for production of biodiesel. Soybean is utilised to produce 80% of biodiesel in Brazil in spite of its 18% low oil content. In 2011, 2.6 million m^3, 3.7 million m^3, 2.8 million m^3 and 2.7 million m^3 of Biodiesel was produced in Brazil, USA, Germany and Argentina respectively. Any material which contains fatty acids may be utilised for biodiesel production e.g. vegetable fats and oils, waste fats and animal fats can be used for production of biodiesel. At present, 95% of biodiesel is produced from edible oils e.g. Soybean, Palm, Sunflower and Rapeseed in the world [8]. 84% of biodiesel is made globally by rapeseed oil, which is an edible oil. Similarly Sunflower oil, Palm oil and Soybean oil are as well used for biodiesel production in a significant way. As edible oils are used for 95% of biodiesel production, it is reported that it is the transition of food into fuel, which results in food starvation [9].

In developing countries, edible oils can not be employed as fuel because it may cause food scarcity and other environmental problems by utilising arable land. Thus, non-edible vegetable oils are getting more attractive for biodiesel production. Non-edible oilseed crops such as Jatropha curcus, Madhuca indica (mahua), Pongamia pinnata (Karanja), Camelina sativa (Camelina), Cotton seed (Gossypium hirsutum), Cumaru, Cynara cardunculus, Abutilon muticum, neem (Azadirachta indica), jojoba (Simmondsia chinensis), Passion seed (passiflora edulis), Moringa (Moringa oleifera), Tobacco seed, Rubber seed tree (Hevca brasiliensis), Salmon oil, Tall (Carnegiea gigantean), Coffee Ground (Coffea arabica), Nagchampa (Calophyllum inophyllum) , Croton megalocarpus, Pachira glabra, Aleurites moluccana, Terminalia belerica may be used for biodiesel production [2]. Developing rural areas in India can create renewable energy from non-edible oils such as Karanja, Jatropha and Linseed oil in an efficacious and economical manner [10].

IV. PROBLEM ASSOCIATED WITH SINGLE VEGETABLE OIL

The biodiesel production from non-edible oils are the challenging topic for researchers. There are various production methods which can be used for biodiesel production.

First generation biodiesel is produced from edible vegetable oils. In the world, edible oils contributes to 95% of biodiesel production such as Sunflower oil (13%), Rapeseed oil (84%), Palm oil (1%), Soybean Oil and other (2%) at present. Only the economic consumption of edible oil as biodiesel raises many problems connected with food versus fuel crisis, destruction of vital soil resources, deforestation and arable land uses. Cost of vegetable oil plants has been increased in the last 10 years which will strike the economic feasibility of the biodiesel industry [2]. The main biodiesel feedstocks are shown in Table I.

Second generation biodiesel produced from non-edible plants can be grown in semi or non-arable lands which results in higher revenue collection for under-utilised lands. Non-edible oil resources are easily usable in many regions of the globe. They are not desirable for food crops, no food competition, reduction of deforestation rate, more environmentally friendly, produce useful byproducts and above all, they are economical as compared to edible oils. These feedstocks are relatively cheaper thereby reducing the cost of biodiesel production.

TABLE I MAIN BIODIESEL FEEDSTOCKS [2, 11]

Edible oils	Non-edible oils
Soybeans	Jatropha curcus
Rapeseed	Mahua
Safflower	Karanja
Rice bran oil	Camelina
Barley	Cotton seed
Sesame	Cumaru
Groundnut	Cynara cardunculus
Wheat	Neem
Corn	Jojoba
Coconut	Passion seed
Canola	Moringa
Peanut	Terminalia belerica
Palm	Linseed
Palm	Pachira glabra
Sunflower	Croton megalocarpus
Cottonseed oil	Tall
Castor	
Mustard	

Scientific knowledge for these feedstocks are unfortunately not sufficient, resulting in a lot of challenges for their development [12].

Non-edible oil crops can be cultivated on waste lands in remote areas and forests. Boundaries of agricultural areas, irrigation channels and road sides can be practiced to produce these crops [13, 14]. Several non-edible oils shall be explored to use for biodiesel production, which is one of the best solution to bring down the economic consumption of edible oil for biodiesel production. Waste oils, greases and animal fats such as beef tallow, poultry fat and pork lard are also regarded as second generation feedstocks. Animal fats also contain high quantity of saturated fatty acid, which make it difficult for transesterification process [2]. Non-edible oils generally contains high level of free fatty acids which make it difficult to produce biodiesel from it [15]. The current potential biodiesel feedstocks of the various countries are shown in Table II.

TABLE II CURRENT POTENTIAL BIODIESEL FEEDSTOCKS [2]

Country	Feedstock
USA	Soybean,waste oil, peanut
Mexico	Waste oil , Animal fat
Canada	Reapeseed oil, animal fat, soybeans,yellow grease, tallow, mustard
Germany	Rapeseed
Mexico	Animal fats, waste oil
Italy	Sunflower, Rapeseed
France	Sunflower, Rapeseed
Spain	Linseed oil, sunflower
UK	Rapeseed, waste cooking oil
Sweden	Rapeseed
India	Jatropha, Karanja
Malaysia	Palm Oil
Indonesia	Palm oil, Jatropha, Coconut
Singapore	Palm oil
Philippines	Coconut, Jatropha
Thailand	Palm, jatropha, coconut
China	Jatropha, waste cooking oil, rapeseed
Brazil	Soybean, palm, castor, cotton oil

V. MIX OIL BIODIESEL

Mahua oil and Simaouba oil with FFA levels of 13% and 1.43% respectively were mixed in equal proportions to scale down the uptake of methanol in the yield of biodiesel. The FFA of mixed oil was noted as 7.19%. A two step procedure, an acid pre treatment followed by base transesterification was followed to bring down the FFA level at about 1% to produce biodiesel [16]. The biodiesel yield obtained from the base –catalysed transesterification of mixtures of Castor oil and Soybean oil in the presence of ethanol increased as the proportion of Castor oil decreased. Ethanolysis of mixtures of vegetable oil containing up to 25 wt% of

Castor oil yielded biodiesels that were more easily purified than those obtained from neat Castor oil and hence, relatively high process yields could be obtained [17]. Possibility to use hybrid feedstocks has been explored due to limitations of feedstock availability. Hazelnut oil and Sunflower oil have high free fatty acid content and therefore its mixture (50:50 v/v) also has high free fatty acid content. The biodiesel produced from the mixture of these oils was found to have fuel properties which are comparable to ASTM D 6751 and EN 14214 biodiesel standards [18]. Researchers proposed a production method with different proportions of Methanol, Sodium Hydroxide, variation in reaction time and reaction temperature to optimise experimental conditions for maximum yield of biodiesel. They used acid base catalysed transesterification with variation in methanol concentration from 20 to 40%, 0.5 to 2.5% NaOH concentration, 30 to 65^0C reaction temperature and 50 to 120 minutes reaction time. They found maximum yield of biodiesel as 95% for process variable of 35% of Methanol, 1.5% of Sodium Hydroxide at 65^0C reaction temperature with 90 minutes reaction time. They found yield of biodiesel in the range of 75-95%. It was informed that biodiesel made by two step acid transesterification from a mixture of Karanja oils and Jatropha oils can meet the requirements of diesel fuels in the near future [19]. Researchers produced biodiesel from a mixture of high free fatty acid Polanga, Karanja and Jatropha oils by acid base catalysed transesterification. Biodiesel was found to meet ASTM D 6751 biodiesel standards [20]. The researchers proposed a faster and non-corrosive biodiesel production method from the mixture of Karanja and Linseed oils. They achieved biodiesel yields in the range of 68.2% to 78.9% with the change in different parameters [21].

VI. CONCLUSION

It may be concluded from this review that biodiesel can be produced from the mixture of non-edible oils to improve the properties of biodiesel produced from it and also its yields.

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Perspectives of Small, Water Related, Decentralized Energy-Generation Systems

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Abstract— **In the last decade of the 20th century, a clear consensus between researchers has been made: there is significantly increased energy demand but classic energy sources are decreasing and alternative energy sources are strongly encouraged. Following these ideas, with respect to both national energy management policies and European praxis, a strong impetus to alternative energy sources in Serbia is given. Among them, according to the authors of this paper, particular attention should be given to decentralized energy generation (DEG) systems. Within DEG systems, a widespread possibility is identified in the small hydro-power plant (SHPP) sector for generating hydroelectric power. Bearing these facts in mind, the authors were also motivated by the fact that the SHP sector in the Republic of Serbia has not been subjected to such analysis. In this paper, the application points of small-hydro generation have been defined as objectives of study, together with detailed reviews related to applicable environmental impact assessment. The authors also considered a list of factors influencing the techno-economic viability of electricity generation in such systems, including the influence on water quality. Major results obtained by this research could be divided in three groups: 1. extended knowledge about the equipment needed, operation, and maintenance of these systems; 2. the abovementioned DEG systems could play a more significant role in the Serbian energy market by increasing a total number of installed and operational generators; 3. efficiency of small operational DEG systems could be significantly improved by coupling them with intelligent monitoring and control systems.**

This research clearly indicates a necessity of hydro-economic models application: instead of building new energy sources, it is better to upgrade existing ones. The authors list limitations of contemporary energy policy in Serbia, recommend way of policy improvement, and suggest directions of future work. The aim of this paper is directed to analysis of the SHPP application in context of renewable energy sources (RES) design as the possible model of engineering measures facing increased energy demand. The research is grounded on representing the types of SHPP which exist and operates, as well as the manner in which they are build and maintained. The importance of SHPP facilities is explained both in solving problems related to increased energy demand and possible offer of new working places, i.e. job offer. At the end of the presented research, the examples from the world and Serbia are presented, which further confirm the importance of implementation of SHPP facilities in the world, as well as in our country. The conclusion summarizes the most important preventive activities to be undertaken in sense of environmental impact assessment, ecological risk prediction and mitigation.

Keywords – national energy balance, small hydro-power plants, environental impact assessment

I. INTRODUCTION

The turn of the 21st century was marked by both significant scientific discoveries and the realisation of the fact that energy demands are ever-increasing, with the existing energy sources having various limitations. The altered global energy conditions, especially the rise in petroleum products prices and intensified exploitation of coal and other fossil fuels in thermal power plants and heating plants, which were predominantly responsible for a series of environmental issues, both globally and locally, are forcing us to seek out new solutions in terms of renewable energy sources. Renewable energy sources include hydropower, wind energy, solar energy, biomass energy, geothermal energy, etc. It is to be expected that all countries in the world will need to fully resort to using renewable sources of electric energy.

This paper focuses on small, decentralized systems of hydroelectric energy generation within the existing small water courses. The introductory part analyzes the possibility of using hydro energy on small watercourses because the operating principles of all hydroelectric power plants are the same, whereas the central part of the paper is dedicated to small hydroelectric power plants (hereinafter SHPP), which represent a particularly interesanting case. Accordingly, anything that applies to SHPP on small watercourses also applies to those in large water streems, only in such cases, there will be fewer problems in resolving water intake (less construction work, lower installation prices, etc.) [1].

As regards the utilization of the hydropower potential, it can be concluded that large hydropower facilities were usually built in all the places where it was economically viable. One should also consider that investing in SHPP cannot solve the problem of insufficient electric energy without investing in other sources but it can certainly alleviate it in an eco-friendly manner [2].

Apart from this primary reason of building SHPP, there are also secondary reasons, such as construction of roads to less accessible areas, development of tourism, light industry, etc. The advantages and downsides of building SHPP can usually be viewed from the perspective of financing as a key aspect, especially in middle-income and low-income developing countries. Therefore, the paper also provides an economic insight of SHPP construction. The end objective of the paper is to use the analysis to emphasise the need for a more extensive construction of such facilities in Serbia.

II. GLOBAL HYDROPOWER POTENTIAL

Of all renewable energy sources, hydropower was at the top from the very beginning of the electric power industry development in the world. From an economic perspective, the most suitable locations for building SHPP were river basins, where big hydropower potentials could be easily exploited. With this approach, technically available big hydropower potentials were exhausted rather quickly while hydropower potentials contained within smaller basins were more interesting for exploitation. It is estimated that the total global commercially usable hydropower potential amounts to ca. 15,000 TWh/year, 20% of which has already been exhausted.

Table 1 showcases the available and exhausted hydropower potentials in countries with the most hydropower [2, 3].

TABLE I. AVAILABLE AND EXHAUSTED HYDROPOWER POTENTIALS IN COUNTRIES WITH THE MOST HYDROPOWER

Country	Commer. usable, in TWh	% of globally usable	Production, in TWh	% of usage
China	1923	12.7	107	5.6
Brazil	1195	7.9	199	16.7
USA	1095	7.3	229	20.9
Canada	600	4.0	52	8.7
Russia	593	3.9	307	51.8
India	376	2.5	229	60.9
Norway	150	1.0	109	72.7
Japan	130	0.9	96	73.9
Venezu.	99	0.7	70	70.7
Germany	72	0.5	78	108.3
Globe	15099	100.0	2044	23.5

As shown in table 1, hydropower potential has an approx. 18% share in total global electric energy production. The total global electric energy production in 2002 was 16,000 TWh, of which 2,800 TWh was hydro-generated. The annual production in SHPP was estimated at ca. 100 TWh.

Based on global and local analyses it can be concluded that from the aspect of potential, the development of SHPP is both imminent and promising.

III. Hydropower Potential in Serbia

If we look at the geological and hydrological circumstances in Serbia, we can see that the total usable water potential is significant and that our country ranks high among European countries rich in water. On the other hand, our country also ranks high among European countries with a relatively low level of exploitation of the available and technically and economically usable hydropower potential. The level of exploitation is estimated at no more than 46%, which places Serbia among those countries with a perspective of substantial expansion of electric power production capacities in favor of hydropower potential.

Therefore, as the ecologically most suitable and cheapest energy source, hydropower potential is a resource of national significance, i.e. a resource which needs to play an important role in defining a national energetic development program. Considering, on the one hand, the constant increase in the electric power deficit in Serbia and, on the other hand, a lengthy period of construction of large hydropower production capacities, the hydropower potential corresponding to SHPPs becomes an important and current issue.

The total hydropower potential in Serbia is estimated at 35,000 GWh/year, of which 27,000 GWh/year are technically and economically usable according to the current situation, and the most recent technical achievements and economic criteria. Out of this value, a SHPP with installed power of up to 10 MW can yield about 2,131 GWh/year, with total installed power of ca. 650 MW. In Serbia, SHPPs potential goes up to the 4,7% of total primary energy consumption [4]. It follows that a negligibly small percent (around 1%) of the hydropower potential of small river basins is used. It can therefore be concluded that our country is somewhat irresponsible as regards the exploitation of a reusable and ecologically and economically most suitable type of energy [5]. In the early 1980s the SHPPs, as one of the best known reusable energy sources, were re-established regarding their significance. This was a logical step, as many countries had already possessed SHPPs which were ready to be restored and upgraded. Simultaneously, most developed countries began a detailed examination of all available locations (including the quite small water courses) and construction of new SHPPs at those locations.

IV. Classification of Small Hydroelectric Power Plants

A small hydroelectric power plant (SHPP) is a facility whose definition usually depends on the role and significance it is attributed when constructed [1]. Most countries have varying classifications of SHPPs because they are dependent on a number of parameters:

- A country's level of economic development,
- Development of the electric power industry,
- Available and usable water resources,
- Natural topographic, geological, and other conditions,
- Development of industry, machine engineering, electrical engineering, and hydro engineering,
- Quantity of coal, petroleum products, and other raw energy materials,
- Population density, etc.

The basic parameters to be used in SHPP classification are the following:

- Installed aggregate power,
- Aggregate type in relation to the turbine and mode of operation,
- Rotational speed,
- Mode of operation in relation to the general energy system,
- Installed drop rate, etc.

Definition and classification of SHPPs is usually based on their nominal power. Accordingly, there are different classifications and recommendations by international and national organizations that deal with the hydropower potential exploitation. For our purpose, the following standards should be accepted:

- Micro hydroelectric power plants up to 100 kW,
- Mini hydroelectric power plants from 100 kW to 1000 kW,
- Small hydroelectric power plants from 1000 kW to 10 MW.

According to this classification, HPPs which can be built in small river basins most commonly belong in the small HPP group. Depending on the presence of accumulation reservoirs which regulate inflow irregularity, there are two basic HPP types:

- Run-off, and
- Reservoir type.

Based on this division, SHPPs that are built directly on water courses belong in the group of run-off HPPs, especially in the case of river where annual volumetric flow does not vary significantly. On the other hand, SHPPs that can be built near accumulation reservoirs for urban water supply, melioration or flood defense belong in the group of reservoir HPPs.

V. Concluding Remarks

Interests for small, decentralized energy systems in Serbia are constantly increasing after years of stagnation. This urges for identification of locally available energy generation in the decentralized energy generation sense. Selection and application of the most suitable small decentralized energy generation systems largely depends not only on technological but on a series of socio-economic, environmental, and political conditions. In addition, small decentralized energy generation systems are significantly interlaced with different kinds of produced energy distribution to the end user. This implies that application of these systems has to be thoughtfully designed in order to ensure that varying needs are met, for example: satisfying energy demands, justifying initial investment and operational costs and providing income, and making effective use of hydro energy without influencing water quality. In order to achieve a better, i.e. acceptable and sustainable energy policy, Serbian institutions in charge are obligated to promote and to stimulate possible usage of small, decentralized energy systems, reorder the energy sector (in terms of national laws harmonization), and encourage further researches and commercial utilizations. Incentives related to small, decentralized energy systems are more than welcome. It is expected from the Government to provide a concrete financial impetus for decentralized energy systems promotion. According to the recent national energy efficiency strategy, this is, hopefully, going to happen in the near future. The Government's regulatory role (particularly through subsidizing) in these issues is decisive. Present situation in Serbia's decentralized energy systems sector reveals that some efforts have already been made. First results indicate that even without concrete Government support these energy production systems could work profitably. However, for a wider acceptance of small, decentralized energy systems and appropriate market development, concrete government incentives are needed.

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Methodology for the Instrumentation and Control of Prototypes, Applied in the Development of a Solar Tracker

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Abstract—**The present article proposes a methodology for the instrumentation and control of prototypes, which consists of several steps of development and documentation of the project. At the moment, this methodology is applied to the development of a solar tracking system of 2 axes in a fixed receiver solar concentrator. To achieve this goal, first, the distinct steps that involve instrumentation and control of prototypes are identified and later validated through the implementation of the solar tracker. At the end of the research, a methodology for instrumentation, prototype control and the development of a solar tracking control system is obtained as a main product, allowing its operation to be manual and automatic.**

Keywords - Stepwise Methodology, Instrumentation and Control of Prototypes, Solar Tracker

NOMENCLATURE

H – High Values

M – Medium Values

L – Low Values

IX.X. –PLC input address

OX.X. – PLC output address

I. Introduction

As a result of the effects generated by climate change, caused mainly by global warming, one of the most important subjects today is the outstanding use of solar energy, with the purpose of transforming it into electrical energy or the generation of water steam to be used in industrial processes, through collectors, concentrators and photovoltaic systems, thereby generating a replacement for fossil fuels which often incorporate solar trackers in order to more efficiently capture the solar radiation [1 and 2]. For this reason, numerous solar trackers have been developed incorporating different control systems, such as the mentioned in research presented in [3,4 and 5] to mention some, for electric power generation as shown in [6 and 7] also steam generating control systems have been developed and instrumented [8 and 9]. In regard to methodologies for documenting projects development, we have the step-by-step, sequential and cascade methodology presented by the FESTO company for the design of pneumatic circuits [10 and 11], another one developed initially for automation projects corresponding to the GEMA methodology recently presented in [12] other methodologies of controller programming such as flowcharts have been presented in [13], or the GRAFCET methodology which was presented and applied in [14 and 15] or finally the petri networks, used in the control of robust systems which was presented in [16], in spite of all these methodologies and technological developments concerning solar trackers as well as other devices, the proposed methodologies cannot be directly extrapolated to the development of prototypes used in the energy utilization that are often instrumented for the control and records of temperatures, Flows or Position.

For all of this and considering the contexts analyzed in the present document, a methodology is proposed that will serve as a guide for the development of prototypes in energy systems. Which is validated through its application for the development of a solar tracker, with the evaluation of the different alternatives for instrumentation and programming of the control system using a decision matrix.

II. Development

The main purpose of this project is to develop a methodology specifically designed for the instrumentation and control of prototypes of energy utilization systems Fig. 1 as well as their application in the design and construction process of a solar tracker.

A. *Proposed Methodology*

This section briefly mentions each step of the process. These provide a design guide in regard to the logic that develops the instrumentation and programming of control systems in prototypes.

a) Step 1: Process description

The result of this step is basically a paragraph describing in detail how the process is expected to be developed, in which the events are established sequentially without still mentioning sensors and actuators, since at this stage they are not yet incorporated. Generally, this paragraph is provided by the engineers involved in the process or, if applicable, by the people requesting the instrumentation and control of a prototype.

b) Step 2: Division of the process in sub processes.

The main result of this step is a list of the sub processes, where each of them is delimited by the specific operation, which will be delimited in each step of the project.

c) Step 3: Instrumentation of sub processes.

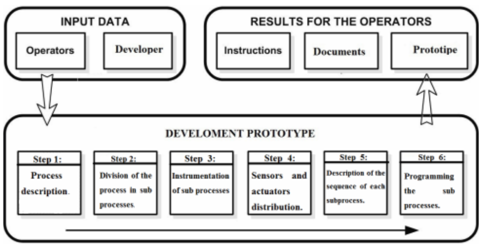


Figure 1. Project development methodology

This stage consists of the selection of instruments, using for this a matrix of comparison for the different types of instruments, operating characteristics such as: speed, cost, installation, maintenance, spare parts, and availability. The "H" evaluation criterion is applied for high values, "M" for median values and "L" for low values, and the selected instrument must be the most suitable according to the requirements and conditions of the project.

d) Step 4: Sensors and actuators distribution.

Here we define the distribution schemes of the elements that form each module. At this stage it is necessary to list the sensors and actuators, as well as their main characteristics. In addition, these sensors or actuators must have a numbering according to the other modules, as well as their connection schemes according to the case.

e) Step 5: Detailed description of the sequence of each sub process.

The result of this step are paragraphs that will form the comments of the program, which narrates in detail what happens with events and actions in time, involving the labels of the sensors and actuators previously assigned in the previous step.

f) Step 6: Programming the sub processes.

Before programming the process, a GRAFSET or flow diagram is developed with support of the detailed description of each sequence (Stage 5) and the programming of the modules that compose the system is continued, for this it is necessary to incorporate the programming language and the instructions according to the PLC model and the language that is being use.

g) Prototype and Documentation

Finally, we have as a result of applied the methodology is the prototype and documents that conform the proposal and which are what will allow implementing the control of the process or prototype, these documents are:

1. Technical specifications of sensors and instruments.

2. Scheme of the distribution of sensors and actuators.

3. Circuit connection diagram.

4. Controller Program.

5. Technical specifications of the components.

6. Detailed description of processes

B. Methodology Application

This section illustrates in a clear and systematic way the way in which the previously proposed methodology is applied. Through the development of the project "Solar tracker".

a) Step 1: Description of the process.

To follow the sun requires first locate in which part of the celestial vault is located the sun and then make a pair of movement, one in Azimuth and another in Elevation to orient the system and thus have a better radiation uptake solar, to eliminate the cosine effect of solar projection on the concentrator.

b) Step 2: Division of the process in sub processes.

The previous stage requires the design of a two-axis solar tracker in which sensing, control and displacement actuators are identified.

c) Step 3: Instrumentation of sub processes.

The technical data of the devices described in this project are in a project portfolio that can be provided at the request of the interested party.

“Sensing module”. - In order for the device to follow the path of the sun, a module is needed to indicate the intensity of its incident light and to send this information to the control unit on which position the sun is in relation to the tracking device. To meet this goal, you can take one of the following options:

TABLE I. TYPES OF SENSORS

Sensors	*Cost*	*Availability*	*Mounting*
Infrared	L	H	L
Light Dependent Resistor	L	H	M
Commercial optic	M	M	H

Being the most viable option, the infrared sensors had their high availability and operative installations of this device shown in Fig. 2. Finally, complete content and organizational editing before formatting. Please take note of the

Figure 2. Infrared Sensor

following items when proofreading spelling and grammar:

“Control module”. - This must be able to make the decisions to move the device following the path of the sun, depending on the signals received by the sensors and the logic established by a program or truth table. The options for doing this are as follows:

The most viable option is a PLC because of its high ease of installation and programming, shown in Fig. 3.

“Actuator module”. - Once the sensing signals are obtained, the control unit decides what action to take, this must be carried out through the actuators which are the devices that will physically move the device. Which can be chosen from the following types:

TABLE II. TYPES OF CONTROLLERS

Control	*Cost*	*Availability*	*Knowledge*
PLC	H	H	H
Micro controllers	M	H	L
Logic gate	M	H	L

Figure 3. Programmer or programmable logic controller

TABLE III. TYPES OF ACTUATORS

Actuator	*Cost*	*Availability*	*Maintenance*
Motor DC	M	H	L
Hydraulic engine	H	M	H
Pneumatic motor	H	M	H

It was decided by the most viable option, which is the DC motor because of its high availability and moderate cost, which is shown in Fig. 4.

Figure 4. Electric motor

d) Step 4: Sensors and actuators distribution

Due to the incorporation of the aforementioned modules and instruments into the system, the first step is to assign the location and distribution of sensors and actuators. The physical location of the sensors and actuators is shown in the following Fig. 5, 6 and 7.

e) Step 5: Detailed description of the sequence for each sub process.

For the development of the "solar tracker" project, it is expected to generate input signals from the sensors that give the necessary information to the control unit to command the

Figure 5. Acutators location (M1 y M2)

Figure 6. Sensor concentrate

actuators. The description of each module will serve as comments and basis for the development of the PLC programs, which is the control unit.

Figure 7. Sensors location

Description of the sensing module. - The sensors are located at the top of the solar reflector that is rotating so that it moves along with the path of the sun. There is a shading system, which is designed so that when any of the four sensors (S1, S2, S3 and S4) is reached by sunlight, send signals to the PLC and it is activated by the shading logic, which consists of whether 2 sensors are shaded, indicates that it correctly follows the sun on that axis, but if either sensor detects UV radiation from the sun, it indicates that the follower has to be moved in that direction until it is shaded by the actuation of a DC motor connected to a relay and thus in this way the solar tracker can change the direction of rotation or elevation according to the conditions that have.

Description of the control module. - It is in charge of making decisions based on the data obtained from the sensors plus the logic of your program and generate the control signals that indicate to the actuators the movement to be performed. This will be done through a FESTO® branded PLC

Also, as an alternative way of control is included a manual control that can be used in case of hardware, software or maintenance failures. It consists of a control box with push buttons (BV, B1, B2, B3 and B4) where the operator can control the actuators, also has two luminous indicators (LV and LR) of the follower activity.

Description of the actuators module. - Included in this module are the actuators that will move the solar tracker according to the commands given by the control module. This is done by activating and controlling the direction of rotation of the motors M1 and M2.

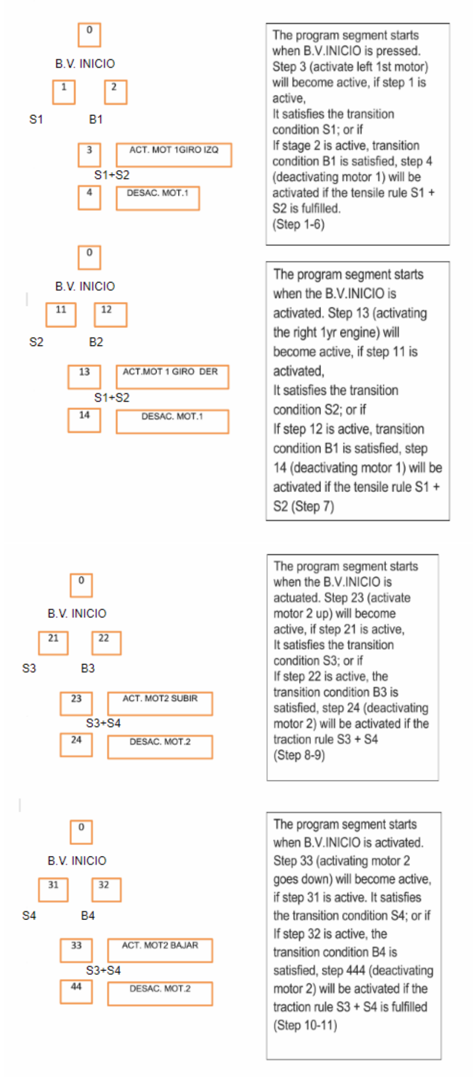


Figure 8. Functional diagram made in GRAFCET

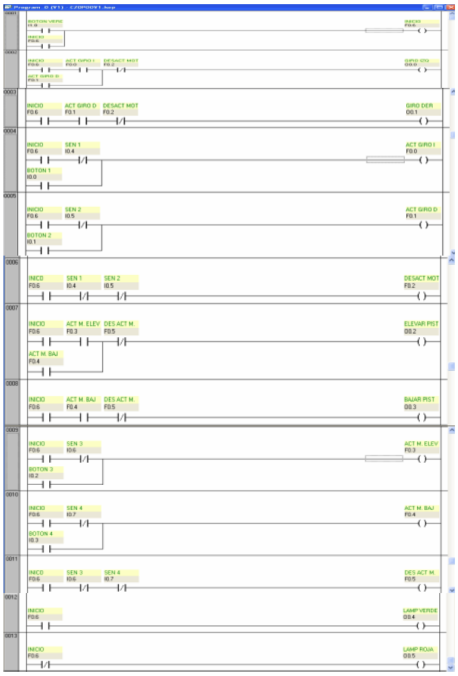


Figure 9. Program in LADDER loaded in the PLC

f) Step 6: Programming the sub processes.

The functional diagram was made through sequences made in GRAFCET to later pass it to the programming language of the Programmable Logic Controller (PLC).

TABLE IV. ASSIGNMENT OF ENTRIES

Symbol	Entry	Type	Application
BV	I1.0	Push button	Start button
S1	I0.4	Optical sensor	Detects the presence of the sun on the east side
B1	I0.0	Push button	Send signal for manual work
S2	I0.5	Optical sensor	Detects the presence of the sun on the west side
B2	I0.1	Push button	Send signal for manual work

S3	I0.6	Optical sensor	Detects the presence of the sun to raise piston
B3	I0.2	Push button	Send signal for manual work
S4	I0.7	Optical sensor	Detects the presence of the sun to lower the piston
B4	I0.3	Push button	Send signal for manual work

In this case, the programming language of the PLC, shown in Fig 9 is developed for a FESTO brand PLC, based on the previous comments and assigning an input or output depending on the sensor, using the ladder language.

g) Prototype and Documentation

Finally, the documentation of the prototype is illustrated in conjunction with the data in Table 4 and 5 as well as Figures 8-11, which illustrate the documents and diagrams which are generated according to the information of the previous stages and which forms the proposal for the development of this project.

TABLE V. OUTPUT ASSIGNMENT

Symbol	*Output*	*Type*	*Application*
M1	QO.0	Motor 24v DC	Left gear movement.
M1	Q0.1	Motor 24v DC	Right gear movements.
M2	Q0.2	Motor 24v DC	Lifting gear movements.
M2	Q0.3	Motor 24v DC	Gear movements down.
LV	Q0.4	Green lamp	Equipment working.
LR	Q0.5	Red lamp	Equipment off.

III. RESULTS

At the end of the present work we have 2 products concerning the development of a

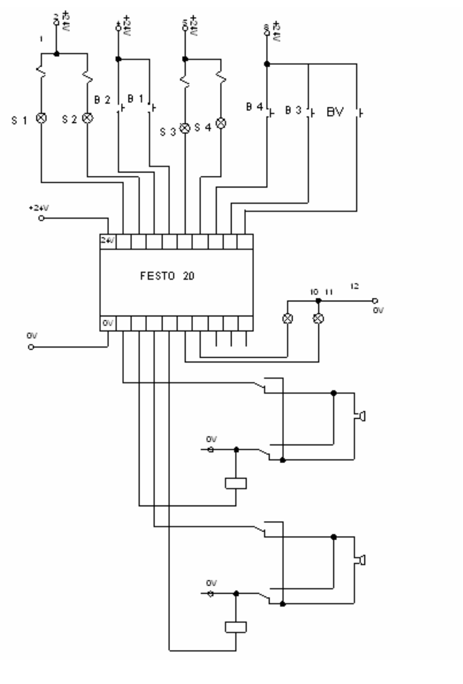
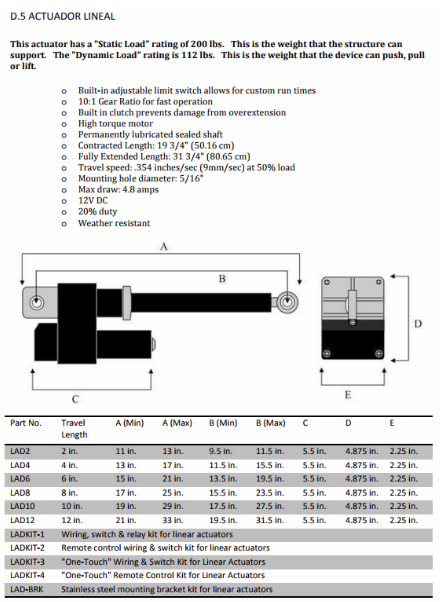


Figure 10. Solar tracking electric diagram

methodology that provides a standardized guide which allows an adequate instrumentation and basic control for prototypes, in addition to the implementation of a prototype solar tracker, which is shown in the Fig. 12. this clearly



D.5 ACTUADOR LINEAL

This actuator has a "Static Load" rating of 200 lbs. This is the weight that the structure can support. The "Dynamic Load" rating is 112 lbs. This is the weight that the device can push, pull or lift.

- Built-in adjustable limit switch allows for custom run times
- 10:1 Gear Ratio for fast operation
- Built in clutch prevents damage from overextension
- High torque motor
- Permanently lubricated sealed shaft
- Contracted Length: 19 3/4" (50.16 cm)
- Fully Extended Length: 31 3/4" (80.65 cm)
- Travel speed: .354 inches/sec (9mm/sec) at 50% load
- Mounting hole diameter: 5/16"
- Max draw: 4.8 amps
- 12V DC
- 20% duty
- Weather resistant

Part No.	Travel Length	A (Min)	A (Max)	B (Min)	B (Max)	C	D	E
LAD2	2 in.	11 in.	13 in.	9.5 in.	11.5 in.	5.5 in.	4.875 in.	2.25 in.
LAD4	4 in.	13 in.	17 in.	11.5 in.	15.5 in.	5.5 in.	4.875 in.	2.25 in.
LAD6	6 in.	15 in.	21 in.	13.5 in.	19.5 in.	5.5 in.	4.875 in.	2.25 in.
LAD8	8 in.	17 in.	25 in.	15.5 in.	23.5 in.	5.5 in.	4.875 in.	2.25 in.
LAD10	10 in.	19 in.	29 in.	17.5 in.	27.5 in.	5.5 in.	4.875 in.	2.25 in.
LAD12	12 in.	21 in.	33 in.	19.5 in.	31.5 in.	5.5 in.	4.875 in.	2.25 in.
LADKIT-1	Wiring, switch & relay kit for linear actuators							
LADKIT-2	Remote control wiring & switch kit for linear actuators							
LADKIT-3	"One-Touch" Wiring & Switch Kit for Linear Actuators							
LADKIT-4	"One-Touch" Remote Control Kit for Linear Actuators							
LAD-BRK	Stainless steel mounting bracket kit for linear actuators							

Figure 11. Documentation example of the instrumentation elements

indicates the devices that allow manual and automatic control of the solar tracker.

Figure 12. Solar tracker physically armed.

Control of the prototype solar tracker was developed for a PLC. From which a solar tracking error of 2 degrees was obtained, which can be considered as acceptable in solar concentration systems, which usually operate with tracking errors ranging from 0.5 degrees to 3 degrees.

IV. Conclusion

The step wise methodology proposed in this article constitutes a useful tool that facilitates the instrumentation and programming of controllers. That in turn allowed the development of a solar tracker with a solar tracking error of 2 degrees, which can operate manually and automatically and whose program was developed based on the GRAFCET technique.

Regarding the documentation of the prototype of solar tracker, has a description in stages that will facilitate its modification or repair for future project changes.

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Application of Deep Learning for Electrical Appliance Classification

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Abstract—**This paper focuses on the application of deep learning algorithms for electrical appliance classification. The present appliance detection and energy consumption prediction per appliance category was done using power load diagram of simulated groups of households. Multiple appliances for each category were simulated and then combined to generate synthetic household. Only the power load diagram without any feature engineering is fed into the algorithms, and their performances were assessed.**

Keywords – Electrical appliance detection, Energy efficiency, Machine learning, Synthetic data.

I. INTRODUCTION

The Energy Efficiency Directive of the European Union states the target of energy consumption reduction by a 20% by the end of 2020 and by a 30% by the end of 2030 [1]. Concerning the electrical power consumption, the demand for an increase of the appliance energy efficiency was obvious. But promoting the rational usage and smart energy management can have immediate impact on the energy consumption [2]. Households are the biggest consumers of the electrical energy in the developing countries. Its residents are usually not encouraged, or are unaware of the potential for the energy consumption reduction. Smart grids can, among other, promote better consumer profiling through smart meters, thus clearing the path for the energy consumption suggestions [3]. Relying on this solution can be problematic for the developing countries because of the smart grid cost. These countries require the immediate solution that uses the existing infrastructure, one of which is shown in [4].

The consumer profiling, through used appliance classification can be done with three different techniques or their combination:

- Intrusive Load Monitoring (ILM) refers to the set of techniques where each significant appliance is recorded using cheap sensor, and sensors are part of wired and/or wireless network infrastructure.
- Nonintrusive Load Monitoring (NILM) refers to the set of techniques where power consumption of each appliance is extrapolated from the power load diagram of the whole (e.g. house or office building)
- Usage of smart appliances that have adequate sensing and communication hardware.

Two approaches on data analysis require a data sampled in time interval of several seconds, as shown in [2], [3], [5], and [6], or high frequency sampling [7-9]. Machine learning is a preferred method in mentioned papers for appliance classification. Standard machine learning techniques usually require feature extraction from collected data. It can be an active and reactive power, first several harmonics of the signal's Fast Fourier Transform (FFT), or the information for the number of edges in the power load diagram, among other.

This paper proposes a way of electrical appliance detection and energy estimation of each appliance using deep learning algorithms. The proposed algorithms can adopt to a data generated by usually present power loggers in electrical substations. These algorithms can contribute to reduction of energy waste in several ways. First, electrical energy distributors can prioritize power supply to substations or substation feeders with more delicate appliances. Consumers can be monitored for eventual fraud detection, and synchronization of appliances usage can be directed. Inefficient or inappropriate appliances can be detected, and an appropriate replacement can be suggested.

II. MATERIALS AND METHODS

Traditional machine learning algorithms (e.g., Support Vector Machine [10], Decision Trees [7] or Shallow Artificial Neural Network [11]) are usually preferred over deep learning to address the electrical appliance classification problem for several reasons:

- labeled dataset can be several thousand times smaller,
- training of the algorithm requires cheaper hardware.

A. Data Generation for Deep Learning Algorithms

An online available data is often too small for an effective deep network training. Considering the size of the necessary training data, collection of the real data is followed with cost, privacy and practicality issues. For that reason, usage of a synthetically generated data, at least for an initial version of algorithm tests, can be a good substitute.

The synthetic data is generated using the Simulink model of a household, described in [12]. Table I presents the list of the simulated appliances.

TABLE I. SIMULATED APPLIANCES

Abbreviation	Appliance
LWH	Large water heater
SWH	Smaller water heater
ST	Stove
EL	Electronics
LI	Lights
WM	Washing machine
FR	Fridge
AC	Air condition
HE	Heater
DW	Dishwasher
CD	Clothes dryer
WT	Water pump

Each of the appliance is simulated for three different types of consumers. Energy efficiency of the appliance depends on the belonging consumer class, which can be:

- Concerned,
- Less concerned,
- Not concerned about consumption

AC is simulated for three different house sizes and for three different outdoor temperatures. The daily power diagram for each appliance is exported in .csv file format for further processing. Example of appliance power load diagram is shown in Fig. 1.

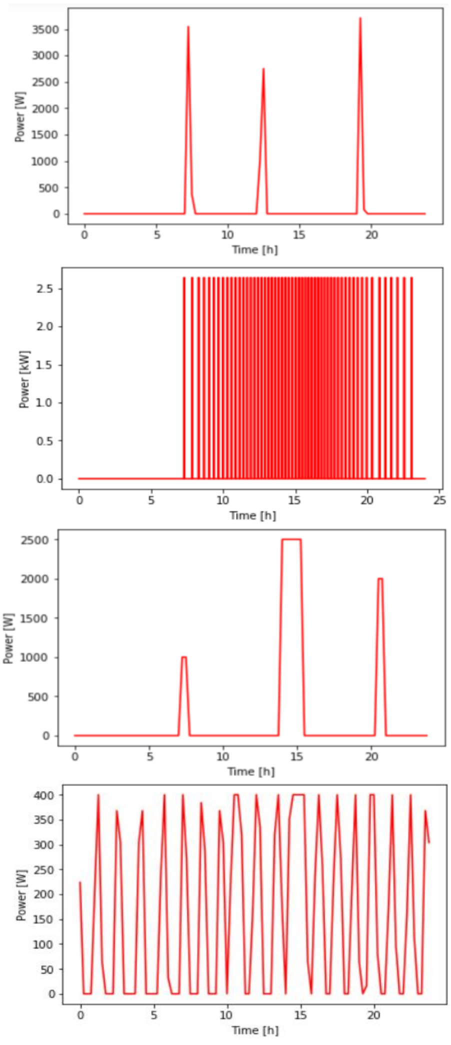

Figure 1. Simulated appliances, top to bottom: LWH, AC, ST and FR.

A user can generate numerous virtual households using the Python script in which the following can be modified:

- Share of each consumer class,
- Length of generated data in weeks,

- Probabilities for number of certain appliances in each consumer class, for working day and weekend separately,
- Probabilities for number of certain appliance usage, in each consumer class, for working day and weekend separately,
- Probabilities for days that certain appliance will be used, in each consumer class, for working day, weekend and considering outdoor temperature for AC or HE,
- Probabilities that the following week each appliance will be used on same day, day before, after, or it will be skipped,
- Probability that certain appliance will take power load diagram from corresponding class or some of other two classes, for working day and weekend separately,
- Time span up to each appliance load diagram can be shifted, by default diagram can be shifted up to an hour left or right.

All of the upper mentioned induced probabilities enable large number of different households, to prevent the deep network to learn the results by heart (data overfitting). Another script is used to combine a certain number of virtual households into a simulated transformer feeder consumption. Fig. 2 displays the combined daily power load diagram of the 36 simulated households.

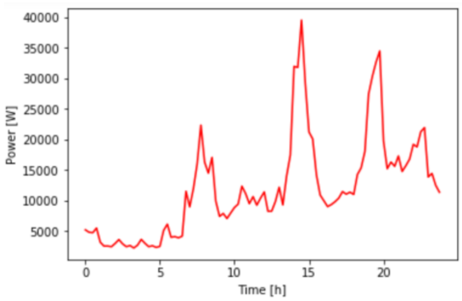

Figure 2. Combined power load diagram of generated households

The load flow diagram in Fig. 2. shows resemblance with expected power load diagram of household consumptions presented in [11].

B. *Used Algorithms for Deep Learning*

Finding the optimal number of hidden layers, numbers of artificial neurons (cells) per layer, and cell types is an iterative process.

Used cell types for experimentation:

- Plain artificial neuron and
- Long Short-Term Memory (LSTM) cell

Deep learning algorithms can have big performance boost if appropriate initialization function is used.

Used initialization functions:

- Xavier, and
- He

Activation functions used for the neurons:

- Logistic sigmoid,
- Tanh, and
- Exponential Linear Unit (ELU)

All of the input data is scaled by removing the mean and scaling to unit variance of the training data. Batch Normalization (BN) was tried for the hidden layer's inputs normalization, although similar results were obtained without any hidden layer input scaling.

Experimented regularization techniques were:

- Early Stopping and
- Dropout (with dropout rate from 5% to 50%)

Appropriate optimization algorithm can significantly speed up training process. Experimented optimization algorithms were:

- Gradient Descent,
- Momentum and
- Adam optimizer

Implementation of these algorithms was done using Google's open source software library TensorFlow [13]. Algorithms were written using Python programming language, and computation graphs created by the TensorFlow are executed on a graphics card (Nvidia Quadro M2000M).

The total number of generated synthetic households is one thousand. From those households one thousand simulated feeder power loads are generated. Number of households for each feeder is randomly generated from one to fifty households, and then appropriate number of random households is selected. Twenty percent of the generated data is put aside for the testing purposes.

First algorithm has the task of detecting the number of appliances in each category and total Number of Consumers (NoC) given the daily load diagram (total of thirteen outputs). The data sampled in fifteen-minute interval is the input of the tested algorithms.

Second algorithm has the task of calculating the total energy that will consumers spent and energy that will each appliance category spend for the determined period. The output of the second algorithm is twice the size (twenty-six) because the energy consumption is required for the period when the price per unit of energy is higher and when it is lower. The input is the data sampled in fifteen-minute interval for a week.

III. Main Results

Results that will be shown are obtained for a couple of minutes training. Early stopping was applied to all algorithms to prevent data overfitting. For each deep neural network, details of structure and one test instance will be shown.

A. *Number of Appliances and Consumers in Daily Load Diagram*

This problem was addressed using two algorithms. From the set of tested deep networks with plain neurons (PN) for this specific task, the network with the structure shown in Table II can be seen as a reasonable choice.

TABLE II. First Deep Network with Plain Neurons

Parameter	Value
Neuron type	Plain neuron
Initialization function	Xavier
Neuron activation function	ELU
Regularization	Early stopping and 10% dropout
Optimization algorithm	Adam optimizer
Learning rate	0.001
Number of inputs	96
Number of outputs	13
Number of hidden layers	5
Number of neurons per hidden layer	600, 400, 200, 100, 50
Batch size	50

Deep network structure that addresses the same issue but uses the LSTM cell can be seen in Table III.

TABLE III. First Deep Network with LSTM Cells

Parameter	Value
Neuron type	LSTM
Initialization function	He
Neuron activation function	ELU
Regularization	Early stopping and 20% dropout
Optimization algorithm	Adam optimizer
Learning rate	0.001
Number of inputs (steps)	1 (96)
Number of outputs	13
Number of hidden layers	3
Number of neurons per hidden layer	50, 50, 13
Batch size	50

Performance comparison of these two deep networks will be made using Mean Square Error (MSE) and one test instance. This comparison can be seen in Table IV.

TABLE IV. Performance Comparison

Type	Test	PN	LSTM
MSE	/	3.58	4.158
NoC	46	45	43
DW	0	1	1
SWH	26	24	23
WT	6	6	6
CD	1	2	2
AC	20	19	16
LI	0	2	2
FR	25	26	27
HE	0	0	0
WM	0	0	0
EL	0	1	1
ST	0	1	0
LWH	3	4	4

Deep network compiled of plain neurons showed better results on test data. This can be partially due to the fact that specific appliances are turned on in specific times of the day. That way connections from inputs of the specific appliance occurrence time span can be more reinforced to the output that detects that appliance. Recurrent networks usually better handle sequential data, while inputs of the traditional neural network are treated as independent of each other. Graphical representation of the output, including test data diagram can be seen in the Fig. 3.

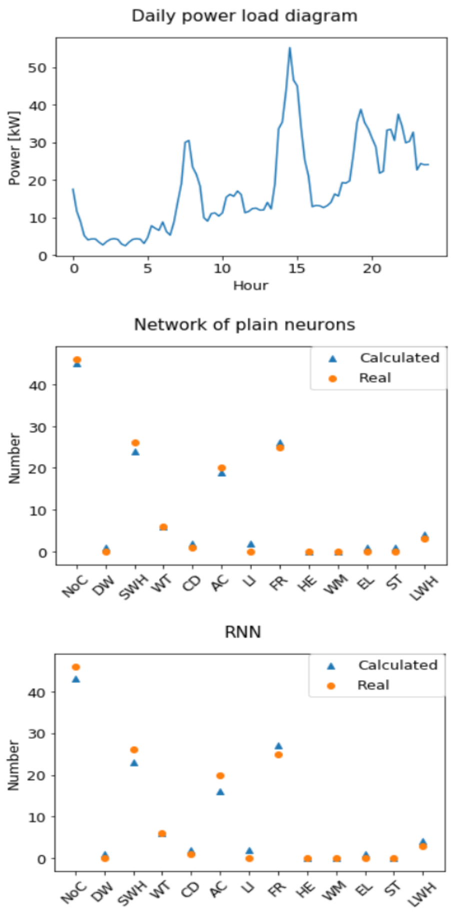

Figure 3. Deep network input test data diagram (upper), output of plain neuron network (midle) and output of LSTM network (bottom)

B. *Forecasting Energy Consumption of Each Appliance Category*

The number of inputs required for the second algorithm creates the problem for effective training of the deep recurrent neural network. Back propagation through time of the recurrent network with six hundred seventy-two steps can be very time consuming. For that reason, only the plain neural network structure is showed in Table V.

TABLE V. SECOND DEEP NETWORK WITH PLAIN NEURONS

Parameter	**Value**
Neuron type	Plain neuron
Initialization function	Xavier
Neuron activation function	ELU
Regularization	Early stopping and 10% dropout
Optimization algorithm	Adam optimizer
Learning rate	0.0007
Number of inputs	672
Number of outputs	26
Number of hidden layers	5
Number of neurons per hidden layer	1000, 600, 400, 200, 100
Batch size	50

This network has the average MSE on test data 16108 kWh. An algorithm pipelining approach, that can be seen in [14], was initially tried, where output of the previous algorithm was additional data set. This was the step of the feature extraction. But even deep network of this size showed no significant performance boost with this step, which implies that network was able to extract necessary features without a human intervention.

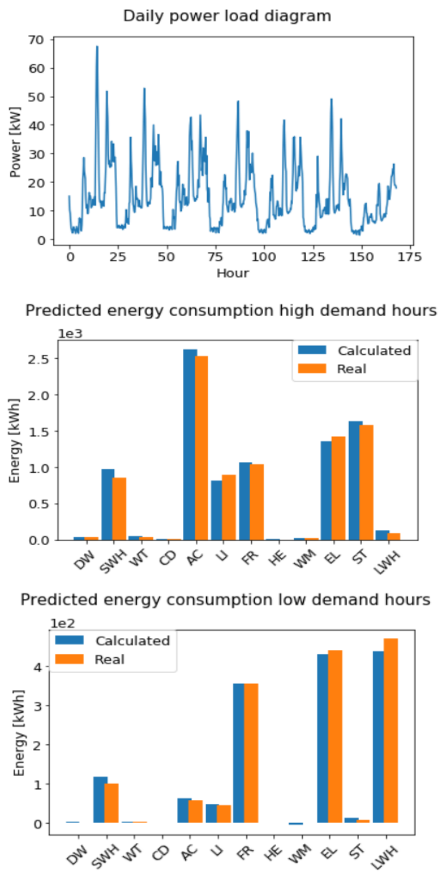

Figure 4. Deep network input test data diagram (upper), predicted energy consumption diagram (midle and bottom)

IV. CONCLUSION

This paper evaluated the ability of deep artificial neural networks for electrical appliance classification based on the power consumption diagram of simulated households. Networks were created using plain neurons and LSTM cells.

Results showed that plain neurons had smaller MSE when the number of consumers and appliances were estimated using daily power diagram. When the forecasting of electrical energy consumption for each appliance class algorithms were tested plain neurons had one advantage. They were trained in a reasonable amount of time, while RNN training was much slower.

It is reasonable to assume that deep networks can be used for real data appliance classification, given enough training data. Future work will involve a deep neural network appliance classification testing on real residential transformer feeder.

ACKNOWLEDGMENTS

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Renewable Energy and Sustainable Development - Impacts on the Path to Decarbonsation of Energy Sector

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Abstract— **Societies around the world are on the margin of a deep and urgently required transformation in the way they produce and use energy. The needed transition in the energy sector is moving the world away from the consumption of fossil fuels towards cleaner, renewable forms of energy. This paper gives an overview to the drivers behind renewable energy as being the many economic, social, political, and environmental imperatives that might motivate society to pursue this transition for a positive outcome. The rapid deployment of renewable energy has been driven mainly by a wide range of objectives (drivers), which include advancing economic development, improving energy security, enhancing energy access and mitigating climate change. Altogether, these drivers might be described as the pursuit of sustainable development, where economic prosperity is advanced around the world while negative impacts are minimized. Furthermore, the paper discusses the situation in Republic of Macedonia from this aspect.**

Keywords - renewable energy, energy decarbonisation, sustainable development

I. INTRODUCTION

The year 2015 was especially significant one for renewable energy. Important agreements were made by G7 and G20 governments aimed to accelerate access to renewable energy sources and promote energy efficiency. In their Declaration on Climate Change, the G7 countries committed to strive "for a transformation of the energy sectors by 2050". Renewables were on the G20 agenda for the first-ever. G20 Energy Ministers endorsed an 11-point Communiqué that included the adoption of a toolkit for a long-term sustainable and integrated approach to renewable energy deployment, and the Communiqué was adopted by the full G20 summit in November. The United Nations (UN) General Assembly adopted 17 Sustainable Development Goals (SDGs) containing, for the first time, a dedicated goal on sustainable energy for all. Despite the drop in prices of fossil fuels on world stock markets, the world achieved a significant increase in the renewable energy capacities. However, low prices of fossil fuels have slowed growth, especially in the heating and cooling sector.

The year culminated with the Paris Agreement. Namely, at the UN Climate Change Conference (COP21) in Paris, 195 countries agreed to limit global warming below 2 degrees Celsius and a greater number of countries committed to scaling up renewables and energy efficiency through their Intended Nationally Determined Contributions (INDCs). In an era of accelerating global change, the adoption of the Paris Agreement is a milestone in the global energy transition. The energy decarbonisation is now considered as a central element of global efforts to reduce greenhouse gas emissions.

Societies around the world are on the margin of a deep and urgently required transformation in the way they produce and use energy. The consumption of fossil fuels causes climate change and other environmental and social challenges. Thus, the needed transition in the energy sector is moving the world away from the consumption of fossil fuels towards cleaner, renewable forms of energy. Millions of people around the world are already using renewable energy to generate electricity, heat and cool buildings, prepare food, and provide transportation. Renewable energy is available on the market and it is competitive with conventional sources in many areas. The share of renewable energy was around 19% of the world's final energy demand in 2015. [1]

A significant increase in the deployment of renewable energies has already occurred. The following steps must include an increase in the share of renewable energy sources together with energy efficiency measures. This approach is also embedded in the Sustainable Development Goals, which require a significant increase of renewable energy in the global energy mix by 2030 and double the energy efficiency improvement rate.

Renewable energy is now competitive with fossil fuels in many markets and has been established around the world as the main energy source. The renewable power generating capacity has reached its highest growth so far. Modern renewable heat capacity also continues to grow, and the use of renewables is expanding in the transport sector as well. Distributed renewable energy is advancing rapidly in order to provide energy even for hard-to-reach areas.

However, in order to increase access to energy while achieving the goal of limiting global temperature rise to 2 degrees Celsius, the rest of fossil fuel reserves will need to be kept in the ground, and both renewable energy and energy efficiency will need to be increase dramatically.

Throughout the world, it has become clear that the transition to 100% renewable energy is largely a matter of political will and that the necessary technologies are already within reach. The number of governments around the world that sets ambitious targets about renewable energy is increasing, with a growing number of authorities that aiming for 100% renewable energy. In particular, local governments are pioneers in this movement and become incubators of regional best practices and policies [6].

II. IMPACTS OF RENEWABLE ENERGY

The rapid increase in the use of renewable energy sources is mainly directed towards a wide range of goals, which include the promotion of economic development, energy security improvement, increased access to energy and mitigation of climate change. Together, these objectives could be described as striving toward sustainable development, which would contribute to economic prosperity around the world with minimal negative impacts. Such assumed benefits are widely cited as key drivers in political and energy debates, but specific documentary evidence of such benefits is quite limited by several reasons, such as lack of appropriate conceptual frameworks, methodological challenges and limited access to relevant data. Realizing these goals can help fulfill the ambition of the international community to achieve sustainable development and climate change mitigation.

Worldwide, the share of energy (especially electricity) from renewable sources has increased dramatically as a response to renewable energy policies. Several authorities have already achieved the goal of 100% renewable energy, including numerous cities in Europe, three cities in the United States and several authorities in Japan and Pacific. At the end of 2015, the Lower Austria achieved the goal of generating 100% electricity from renewable sources [6].

Although the use of renewable energy is rising rapidly, the share of renewables in total final energy consumption is not growing as quickly. In developed countries, energy demand growth is slow. In developing countries, energy demand growth is rapid, and fossil fuels play a significant part in meeting this rising demand. In addition, the transition from traditional biomass for heating and cooking to modern, more efficient renewables and fossil fuels, which is in general a very positive transition, reduces overall renewable energy shares. Estimated renewable energy share of total final energy consumption, for 2015, is shown in Fig.1 [1].

The developed countries and the developing countries into which modern renewables are making inroads present different political and policy challenges, economic structures, financial needs and availability, and other factors that delay or advance renewable energy deployment.

The benefits behind renewable energy as being the many economic, social, political, and environmental imperatives might motivate society to pursue this transition for a positive outcome. The various expected benefits of the energy transition are the realized positive outcomes (positive impacts), which are presumed to be closely aligned with the drivers that motivated the transition. Drivers and benefits can be classified by the three main categories: environmental, economic, and

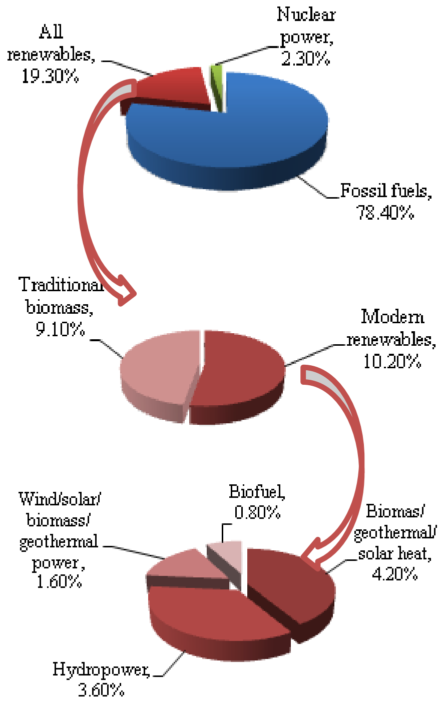

Figure 1. Estimated renewable energy share of total final energy consumption, 2015.

social/political, while it has to be noted that many benefits do not fit just one category at the exclusion of others. The benefits of improved public health arguably may be all at once: economic, social, political, and environmental.

A. Environmental Impacts

Ramping up RES is essential to meet climate goals without slowing down economic growth and reducing welfare. Renewable energy plays a key role in mitigating global greenhouse gas emissions by radically reducing emissions from the global energy system. The IRENA analysis in REmap 2030 demonstrates that doubling the share of renewables in total final energy consumption from 18% in 2010 to 36% by 2030, combined with significant improvements in energy end-use efficiency, is needed to keep global warming under 2 ° C [4].

Energy sector decarbonisation through renewable energy deployment is a key pillar of the strategies of several countries for their contribution in greenhouse gas emissions reduction in order to meet the climate goals. The use of energy accounts for just over two thirds of total annual greenhouse gas emissions. A more

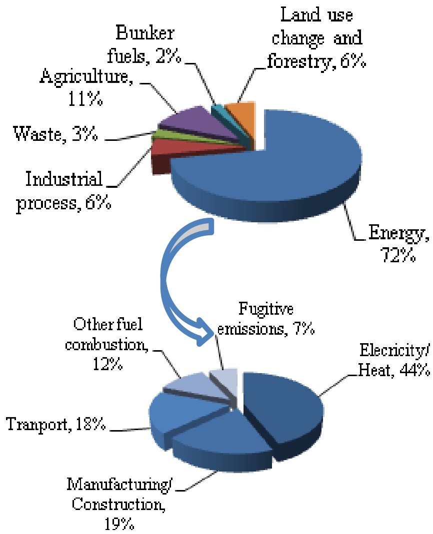

Figure 2. Global greenhouse gas emissions by sector, 2012.

detailed overview shows that power generation is responsible for greater part of these emissions, followed by manufacturing and transport (Fig. 2) [4].

Renewable energy already contributes to reducing emissions in the power sector. Renewable power plants currently account for more than 24% of total global electricity generation [1]. In 2012, about 3.1Gt of CO_2eq of emissions were avoided through the use of renewable energy, compared to emissions that would otherwise have occurred from fossil fuel-based power. These avoided emissions come primarily from hydropower, while the electricity production from wind, solar and bioenergy sources have recorded a spectacular increase over the past decade, driven by appropriate policies and significant cost reductions. Without renewable-based power generation, total emissions from the power sector would have been higher by 20% [4].

In order to limit global temperature rise, the deployment of renewable energy must be accelerated. For the electricity sector, achieving a further reduction in absolute emissions will require a significant decrease in the intensity of emissions from power generation. Additional possibilities for emission reduction can be provided from other sectors in the final energy consumption (heating/cooling and transport), which enables accelerating the energy transition.

Reduction of emissions from the deployment of renewable sources, together with the achievement of energy efficiency improvements (7.3Gt CO_2), could limit the global temperature rise below 2^0C [5]. The realization of these reductions will require substantial efforts for mobilizing investments in the renewable energy sector.

B. Economic Impacts

When assessing the economic benefits of using renewable energy sources, two different types of benefits should be distinct. Clear additional benefits such as the economic benefits of reduced emissions of air pollutants, which results in lower general health costs are one type of economic benefits. It should be noted here that the benefits associated with reduction in greenhouse gas emissions are global, while those associated with reduction in air pollution emissions are more localized. The benefits that are not necessary net additions, such as created jobs that can be realized in whole or in part at the expense of jobs in another part of the economy are the other type of economic benefits. This category is sometimes referred to as a transfer of resources, without specific characterization of net economic or social benefits.

Increased use of renewable energy has helped to reduce costs associated with the consumption of fossil fuels, including fuel imports and environmental and health impacts. In the EU, for example, demand for fossil fuels was down by 116 million tons of oil equivalent (Mtoe) during 2013, thanks to renewable energy. Avoided imported fuel costs due to increasing renewable energy production amount to an estimated EUR 30 billion annually [6].

Renewables also have helped to create jobs worldwide, with global employment in the sector (without large-scale hydropower) reaching an estimated 8.3 million in 2016 (Table 1), according to IRENA, with large-scale hydro supporting an estimated 1.5 million additional direct jobs [1]. Most jobs to date have been created in the power sector (with the largest number in solar PV, at 3.1 million) and in biofuels (1.7 million), followed by wind energy (1.2 million), the number of solar heating and cooling related jobs declined by an estimated 12% (an estimated 828,000 in 2016). The leading countries for renewable energy jobs in 2015 were China, Brazil, the United States, India, Japan, and Germany.

Citizen economic and political participation and the involvement of communities in renewable energy projects are necessary to ensure acceptance. Moreover, experience shows that adopting a people-centered approach and empowering citizens, farmers and small businesses to invest in renewable energy projects can be a powerful tool for socio-economic development and local wealth creation. Renewable energy projects also help to improve the standards of living in countries.

C. Political and Security Impacts

Energy security has both short-term and long-term aspects. The short-term aspects pertains to the capacity to cope with sudden imbalances in energy supply and demand, while the long-term aspects pertains to timely and appropriate investment in supply to meet long-term economic and environmental needs. Energy security on a local, national, or regional level may be enhanced with renewables through diversification and localization of energy supply.

Energy security fosters political and economic security, and vice versa. The conventional context for the study of this topic has been focused on fossil fuels. Increased deployment of renewable energy has been shown to improve energy security in the EU, where renewable’s substitution for natural gas accounted for 30 % of the estimated reduction in fossil fuel demand during 2013 [6].

Indeed, the increased use of renewable energy sources is not synonymous with improved energy security and reliability bearing in mind the stochastic nature of renewable energy sources. They can in the short term impair the security and reliability of the supply, if such problems are not overcome by options such as extended interconnection, use of non-variable renewable energy sources and increased storage capacity.

However, the attention to this security aspect of variable renewable energy output stands in contrast with the lack of concerted effort to measure and account for the actual beneficial role of renewable energy, and its further potential, in improving energy security, whether locally or globally, and subsequent benefits to political and economic stability.

TABLE I. ESTIMATED DIRECT AND INDIRECT JOBS IN RENEWABLE ENERGY, BY COUNTRY AND TECHNOLOGY

	World	China	Brazil	United States	India	Japan	Bang-ladesh	European Union		
								Germany	***France***	***Rest of EU***
	THOUSAND JOBS									
Solar PV	3,095	1,962	4	241.9	121	302	140	31.6	16	67
Liquid biofuels	1,724	51	783	283.7	35	3		22.8	22	48
Wind power	1,155	509	32.4	102.5	60.5	5	0.33	142.9	22	165
Solar heating/ cooling	828	690	43.4	13	13.8	0.7		9.9	5.5	20
Solid biomass	723	180		79.7	58			45.4	50	238
Biogas	333	145		7	85		15	45	4.4	15
Hydro-power (small-scale)	211	95	11.5	9.3	12		5	6.7	4	35
Geothermal energy	182			35		2		17.3	37.5	62
CSP	23	11		5.2				0.7		3
Total	8,305	3,643	875.9	777.3	385	313	162.3	334	162	667
Hydropower (large-scale)	1,519	312	183	28	236	18		6	9	46
Total (including large HP)	9,824	3,955	1,058	806	621	330	162	340	171	714

Source: IRENA

III. DECARBONISATION OF THE ENERGY SECTOR IN MACEDONIA

The most important problems that energy sector faces in Macedonia are unfavorable energy mix with high prevalence of domestic lignite, which is characterized by a low energy value; strong dependence on energy import; high dependence on imported energy fuels (50%); poor condition of the energy systems and high degree of inefficiency in energy production and use [7]. The above-mentioned problems are burdened by the need for electrical power imports for the entities that purchase the electricity on the free trade market because it is not produced in Macedonia.

The current Macedonian energy strategy is not directed towards the 100% renewable energy system, but the usage of RES is maximized in all official scenarios. According to the Macedonian energy strategy [9], planned consumption of the biomass for the combustion in 2030 is around 3000 GWh, consumption of geothermal energy is expected to be 620-730 GWh, RES for the production of electricity are planned at 4600 GWh and planned share of RES in the electricity generation in 2030 is 30%. According to the Action plan for RES of the Republic of Macedonia by 2025 with a vision of 2030, the assumptions for the share of the renewables in the final energy consumption are presented in Fig. 3 [8].

The results of analyses [7] show that the 100% renewable energy system in Macedonia is possible. However, to achieve this goal high share of biomass, wind power and solar power as well as different storage technologies are needed. Also, all analyses have been conducted with the existing technologies and with the high emphasis on the new storage technologies such as electric vehicles and heat pumps in order to increase the

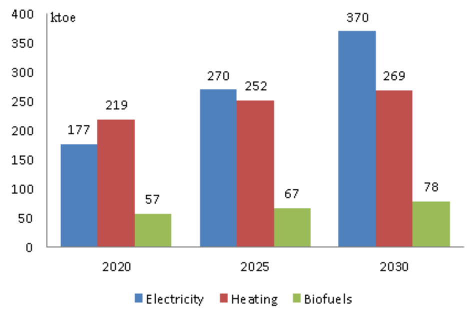

Figure 3. Share of renewables in the final energy consumption according to the Action Plan for RES, R.Macedonia.

penetration of the intermittent RES and to decrease critical excess of electricity. Additional energy efficiency measures are needed in order to decrease the biomass needs for designing the 100% renewable energy system.

Macedonia has sufficient renewable energy resources at its disposal to fully meet the needs for electricity generation without utilization of fossil fuels [11]. Accomplishing the vision to ensure the production of electricity from its own domestic (renewable) energy sources, to stop imports of electricity and energy for production and to improve the living environment of citizens is not an easy and simple task.

The obstacles that need to be overcome in making this vision come true are of different nature. Above all, they are of:

- Political nature.
- Financial nature.
- Technical nature.

The main technical barrier in greater utilization of RES in the power system comes from its stochastic manner of production. One cannot plan the production in advance and there have to be standby electricity producers whose production is not dependent on climate conditions.

The gains from the utilization of the renewable resources offer dual purpose solution i.e. to enable economic growth as well as to decarbonise the economy across the world.

A. Environmental Influences

The pollution caused by energy processes employing the combustion of fossil fuels has both global and local character. The global character refers to everybody's pollution anywhere and which, as a consequence, causes climate change. Local pollution has considerably more serious and tangible consequences compared to the global one. Moreover, main pollutants affect the quality of air and are causing a range of diseases to the respiratory organs, especially in children.

It should also be mentioned that there is pollution coming from soil, which has to be removed to reach coal and is generated during the process of the exploitation of surface mines and large dumpsites of slag and ashes. Despite the fact that the levels of radioactivity in the waste are relatively low, a number of studies in Macedonia show that they cannot be underestimated.

If no more coal is utilized to produce electricity, in the case of Macedonia it would mean that on average 7 million tons of coal will not be combusted on an annual basis. In summary, REK Bitola and TPP Oslomej contribute to environmental pollution by the following:

- Over 6.3 million tones CO_2 each year.
- Over 85 000 tones SO_2.
- Over 15 600 tones dust released in the air.

Although these figures are small compared with the emission of harmful substances by industrialized countries, they are very large for our local and immediate environment [11].

If we take into account the potential electrical powered cars offer, besides recharging their batteries during periods of greater production of electricity from renewable energy sources, there would also be a significant reduction of pollution in urban areas caused by the reduced combustion of fossil fuels in the transport sector.

B. Political and Security Impacts

Macedonia is a country dependent on imports when it comes to fuel supply. The import of fuels (liquid and gaseous fuels, quality coal) averages 48%, or almost half of total supply. Macedonia is import dependent and has limited reserves. According to the strategic documents of Macedonia, coal represents the basic fuel for electricity generation today and in the future until 2035.

The domestic generation of electrical power is meeting the needs of 95% of the low voltage user's grid, where households represent the majority of consumers. However, in accordance with the conditions prevailing in the liberal electricity market, the industry has to meet its energy needs through imports.

If Macedonia promotes the production of electricity from renewable sources, it will be free of fuel imports required for its industry, as well as free from electricity imports, which are to be imported according to documents related to the energy sector. The decline of fuel and electricity imports would result in a higher level of sovereignty for Macedonia, meaning that there would be no more opportunities to exert political pressure based on the dependency of imported energy (in all its forms).

IV. Conclusion

The rising dependency on energy imports, increase of greenhouse gas emissions and high and unstable energy prices are some of the problems that Europe is facing today. One of the most promising ways for reducing Europe's dependency on energy imports and for diversification of energy resources, which at the same time reduces GHG emissions, are renewable energy sources. Hence, the common goal of the European Union is to increase the share of RES in the final energy consumption.

By the end of 2015, humanity has bravely and ambitiously entered the energy era of the 21st century, adopting by consensus a balanced agreement to stop climate change and maintain the rise of the average global temperature below 2 degrees Celsius. As one of the potential signatories of future agreements, Macedonia faces many challenges but also threats and opportunities.

The results of analyses show that 100% renewable energy system by 2050 in Macedonia is possible. Macedonia also has sufficient renewable energy sources at its disposal to fully meet the needs for electricity generation without utilization of fossil fuels.

In order to achieve these forecasts, Macedonia has to construct all hydropower plants as projected in the Strategy for Development of the Energy Sector until 2035. The same applies to the other power plants related to the RES sector. The construction of the new plants will require big capital investments but it will also create many new jobs. The period is sufficient to achieve a phase-by-phase training of a sufficient number of qualified staff, as well as to retrain employees in sectors that will slowly disappear.

The conclusion is that there will be hindrances along the way but they are manageable. The expected gains are huge and we shouldn't miss the possibility of moving toward 100 % renewable energy system by 2050.

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The Risk Based Trial and Error Fault Location Algorithm in Distribution Network

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Abstract— **Using a trial and error method of isolating sections of the faulted feeder, crews will reclose the substation breaker to validate that the faulted feeder section is downstream from the isolation point. In this paper, a two-step algorithm for the trial and error procedure is presented, based on the risk assessment of possible scenarios. In the first step, the optimal number of crews is determined, and in the second step, the optimal strategy of section openings and crew with minimum risk is selected. The risk is defined as the product of probability of event and associated non supplied energy. The algorithm is tested on a radial distribution network with 3 sectionalizers.**

Keywords - Fault location, distribution network, crew optimization

I. Introduction

Precise fault location in distribution network plays an important role in system restoration, reducing outage time and improving system reliability. A variety of approaches for locating faults in power distribution systems can be classified in three broad categories: impedance methods that estimate the relative distance to the fault from data acquisition provided by the protection devices; travelling waves or high frequency components based methods and knowledge based methods [1-4]. Determination of fault location in distribution network is usually performed by the traditional trial and error procedure. This methodology is most often used in networks without remote fault detector units. The procedure of feeder sectionalizing starts with the opening of the line disconnector located approximately in the middle of the damaged feeder. In the case when no remote control units are available, the opening is done manually. After the disconnection of this device, two possible scenarios are possible: if the fault is upstream of the line disconnector, the feeder will be switched off again by the relay protection: if the fault is downstream of the disconnector, the healthy part of the feeder will be switched on. By the successive repetition of this procedure, the faulty section is isolated at the end.

Figure 1 represents the typical scheme of medium voltage power line. Line disconnectors are denoted with 1, 2 and 3. Concentrated loads are denoted with L1, L2 and L3. For the sake of illustration, if we start the procedure with the disconnector 1, the fault is in the zone A if the switching of the feeder remains unsuccessful.

Crews are dispatched to the faulted feeder and try to predict the fault location. Using a trial and error method of isolating sections of the faulted feeder, crews will reclose the substation breaker, or other network protective devices, such as reclosers, to validate that the faulted feeder section is downstream from the isolation point. This can create unnecessary wear on protective equipment on the feeder being tested, resulting in decreased equipment life and increased time required for maintenance. It also increases the risk of creating additional faults on the feeder as weak isolation points are stressed. Multiple faults on a feeder can create additional complexity for the crew as they try to locate the faulted section. One solution to help crews locate a fault and rule out healthy sections of a feeder is the addition of fault passage indicators (FPI) at strategically located points along a feeder. Solutions for fault passage indication exist for both overhead and underground networks. One such solution for overhead networks is FPIs that can clip-on to overhead lines. The fault isolation and restoration process was also accelerated a lot

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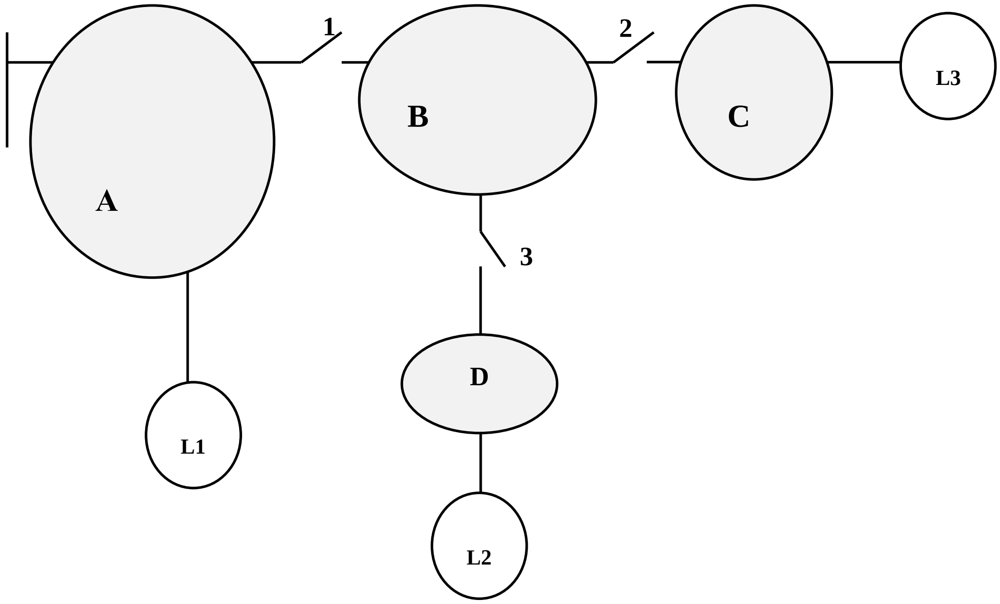

Figure 1. Radial distribution feeder with line disconnectors

by the introduction of remote control to the sectionalizing switches. In some countries these switches were in the beginning equipped with a pause switching system, which performs a step by step reclosing based on local automation.

In this paper, a two-step algorithm for the trial and error procedure is presented, based on the risk assessment of possible scenarios. In the first step, the optimal number of crews with minimum number of possible trials is determined. In the second step, the optimal strategy of line section isolation is selected, with minimum risk as a criterion. The risk is defined as the product of probability of event and associated non supplied energy. The algorithm is tested on a radial distribution network with 3 sectionalizers.

II. RISK BASED FAULT LOCATION

Since the distribution feeder is a radial network, with multiple laterals connected to the main feeder, faults at various locations may lead to the same voltages and currents observed at the substation. In other words, using the substation measurements to calculate the fault location, multiple possibilities could be obtained. As the first step, it is necessary to find all possible fault locations. This can be accomplished by searching the network and applying the fault distance algorithm on a section by section basis. Depending on the automation degree of the feeder, and the number of fault passage indicators, this process can be automatic, semi-automatic or manual, sending the crews for doing the manipulations. The optimal crew number, however, is not usually optimized simultaneously with the disconnectors or sectionalizers opening schedule.

Current studies are focusing on improving individual steps of fault management. Studies on the linkage between tasks and the impact on the overall performance of system reliability are missing. For example, the approach for crew dispatching in [4] is based on the assumption that fault analysis provides precise location and cause of fault, which does not stand for many fault location approaches. The methodology proposed in this paper consists of two consecutive steps. In the first one, the optimal number of crew is determined. The optimal number of crews is the one with the least possible number of trials, and the search algorithm takes advantage of the tree structure of the distribution feeder and tree-traverses the network for all possible fault locations. The algorithm flow for this procedure is given below, with following annotation: n – total number of sectionalizers, m – number of lateral branches, e – number of crews and p – maximal number of circuit breaker closing.

A. Algorithm flow

1: The main and lateral branches are defined. The main branch is the one with the maximal number of sectionalizers in serial. All other branches are lateral branches.

2: The number of crews is defined, according to the general condition

3: The first lateral is opened.

4: If the fault is not located, repeat the Step 3 for all laterals

5: If the fault is not located open the first main section

6: If the fault is not located, repeat the Step 5

7: Increase the number of crews e and go to 2

We can distinguish two possible cases when the general condition $e \le m$ is satisfied:

a) Odd number of sectionalizers

$$p = \frac{n+1}{2} + m - (e-1) \quad . \tag{1}$$

b) Pair number of sectionalizers

$$p = \frac{n}{2} + 1 + m - (e-1) \quad . \tag{2}$$

Results for different combinations of crew and sectionalizer quantity are presented in Table I.

TABLE I. MAXIMAL POSSIBLE NUMBER OF TRIALS WITH DIFFERENT NUMBER OF CREWS

	Number of trials				
		A (n = 3)		**B (n = 4)**	
m	**e=1**	**e=2**	**e=3**	**e=2**	**e=3**
4	7	5	4	6	5
5	8	6	5	7	6
6	9	7	6	8	7
7	10	8	7	9	8
8	11	9	8	10	9
9	12	10	9	11	10
10	13	11	10	12	11
11	14	12	11	13	12
12	15	13	12	14	13
13	16	14	13	15	14
14	17	15	14	16	15
15	18	16	15	17	16

The comparison of different crew number can be graphically presented on Figure 2.

After the determination of optimal number of crews, in the second step, we are performing the opening strategy optimization, using the minimum risk approach, when the risk is defined as the expected non supplied energy. The risk is calculated for every scenario, step by step, using the same expression (3):

$$R = P_A \cdot C_A + P_{-A} \cdot C_{-A} \quad . \tag{3}$$

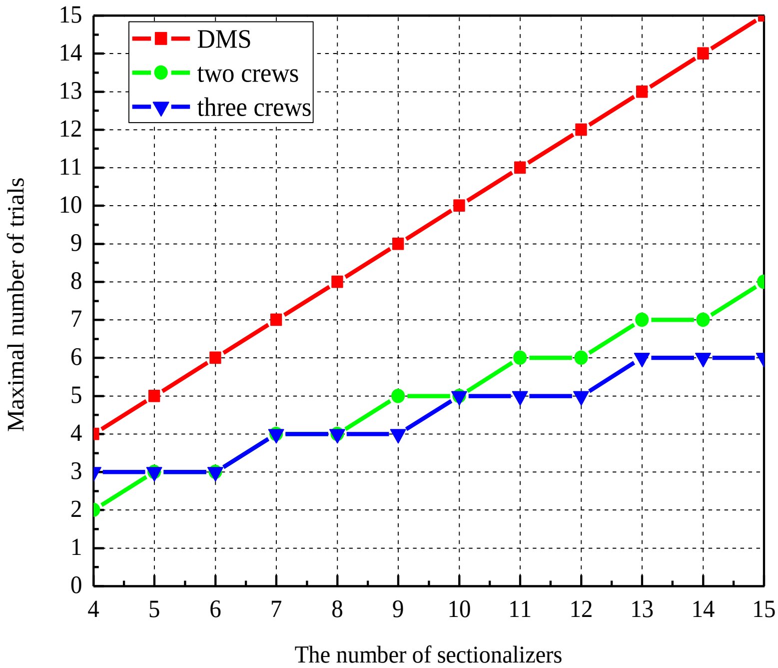

Figure 2. Maximal number of trials depending on number of sectionalizers

P_A represents the probability that the fault is within zone *A*, and can be calculated from the expression (4), under assumption that failure intensities are the same for all sections. Is this is not the case, the weighted values of lengths will be introduced.

$$P_A = \frac{total\ lenght\ of\ \ feeders\ in\ zone\ A}{total\ \ feeder\ lenght} \ . \quad (4)$$

C_A are interruption costs for the fault in zone *A*, according to expression (5).

$$C_A = L_A \cdot (t_{11} + t_r) \ . \quad (5)$$

P_{-A} is the probability that the fault outside A

$$P_{-A} = 1 - P_A \ . \quad (6)$$

C_{-A} are interruption costs for the fault in zone A

$$C_{-A} = L_A \cdot t_{11} \ , \quad (7)$$

t_{ij} stands for the traveling time from location *i* to *j*, and t_r represents the estimated repair time.

For the total of n disconnectors in the network, it is necessary to analyze n! alternatives. For the sake of illustration, we will use the feeder presented on Fig. 1 to determine the optimal crew number. Possible scenarios with one crew are: 123, 132, 213, 231, 312 and 321. In this example, after the opening of the sectionalizer 2, we repeat the procedure with updated manipulation time (t_{11}+t_{12}) by adding the time to open it. For every scenario, the risk is calculated and the one with the lowest risk has been chosen. The input data for the network presented on Fig. 1 are given in Table II.

We start with the number of mains and laterals definition. If we define zones *A*, *B* as mains, and *C*, *D* as lateral, then $m = 2$, and optimal number of crews is $e = 2$, with maximum $p = 2$ trials. Optimal strategy is to open disconnectors 2 and 3 at the same time. If we have only one available crew, the decision tree for the optimal strategy selection is presented on Figure 3.

Table II Network parameters for the example network

Zone	Network length	No. of customers	Peak power
A	1 km	2000	2 MW
B	5 km	5000	5 MW
C	10 km	2000	1 MW
D	7 km	3000	2 MW

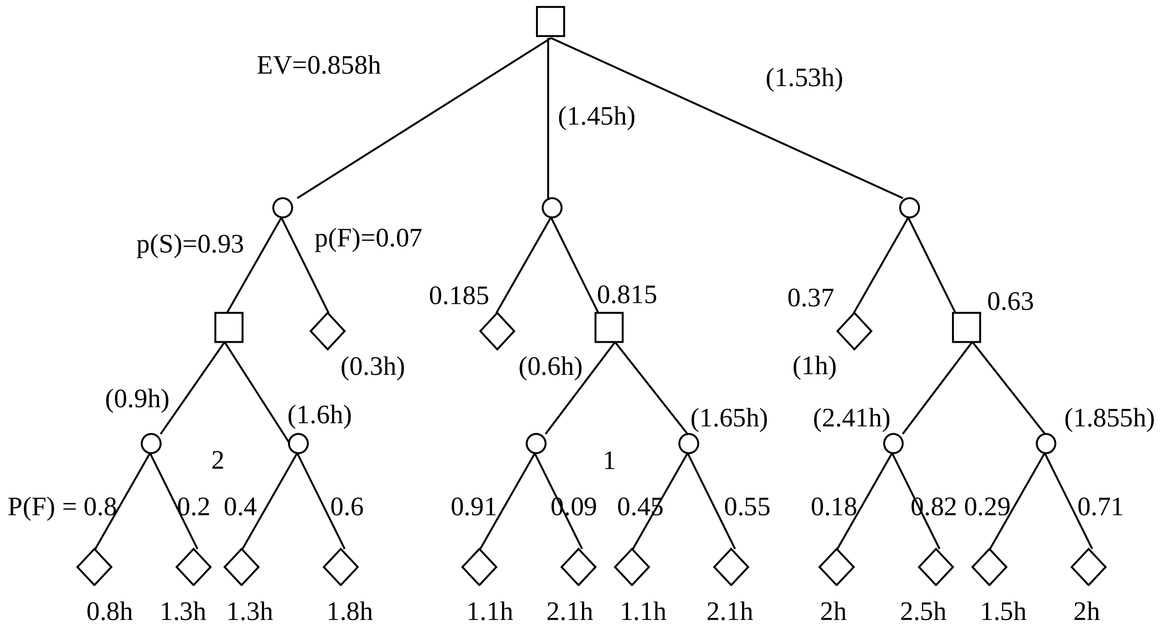

Figure 3. Decision tree for the optimal strategy selection

It can be seen that the best strategy is to go first to the disconnector 1, and in the case of unsuccessful attempt of energizing the feeder the fault location is found in zone A. Otherwise, the next step is to go to the disconnector 2, and finally, to the disconnector 3. P(F) and P(S) represent the probabilities of failure and success, respectively.

III. Conclusion

In distribution systems, fault location is estimated by trial and error method. The line is energized section by section until the protective relay trips the feeding circuit breaker and the faulty section is identified. This procedure may be repeated several times which is time consuming and also exposes additional stress on the equipment. The methodology presented in this paper reduces the possible number of trials by the optimization of both number of dispatched crews and the crew dispatching schedule. That way, fault analysis and identification can be carried out quickly for quick restoration of the system. This algorithm can be incorporated in existing Distribution Management System, with the required set of input data, including the estimated times of crew traveling, times of manipulation and the estimated non supplied energy.

Acknowledgement

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The Role and Importance of Anthracite Coal in The Energy Sector and Water Treatment

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Abstract – **Coal, as one of the most important primary fossil fuel, is the most abundant and inexpensive fossil fuel. Currently, coal account around 30% of primary energy and 41% of global electricity production worldwide. Based at available data of current production and consumption rates, proven reserves of coal have been projected to last for two centuries. Coal represents a strategically important and a significant energy resource on which is based the energy and economic development of the Republic of Serbia. In this paper is shown the role and importance of coal in the energy sector and water treatment.**

Keywords - coal, mine, anthracite, energy, water, treatment.

I. Introduction

Energy is a primary driver of economic development. Access to modern energy system is vital to social development and quality of life. Currently, the global energy system faces many challenges in the 21st century. The major challenge is providing access to affordable resources and secure energy supplies.

The International Energy Agency (IEA) estimates that over 1,030 million people will be living without electricity in 2030 [1]. Modern/advanced energy technologies are essential to meet this challenge [2].

The global primary energy consumption has been rising in the last couple of decades. The world's energy consumption is closely correlated with the global economic growth [3]. This growth has been due to several factors such as increased industrial activity, food production, transport and other services, necessitated by growth in population and urbanization [1].

According to BP's Statistical Review of World Energy, world total primary energy supply in 2016 was 13276.3 million tonnes of oil equivalent (Mtoe). From 2005 to 2016, world primary energy consumption grew at an average annual rate of 1.8 %. Global primary energy consumption increased by just 1 % in 2016, following growth of 1% in 2014 and 0.9 % in 2015 [4].

Coal, as the most widely available and one of the world's most used fossil fuel resource, is the key to the worldwide structure of energy. Based on data from BP Statistical Review of World Energy Report 2016 [5], comparative primary energy consumption over the past 15 years is shown on Fig. 1 [6].

Figure 1. Comparative primary energy consumption by fuel over the past 15 years [6]

Coal currently supplies around 30% of primary energy and 41% of global electricity generation [6].

Coal has been growing rapidly as one of the world's most used resources. It is predicted that coal will continue to play a very significant role

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in world primary energy demand well into the future.

II. WORLD COAL RESERVES, PRODUCTION AND CONSUMPITION OF COAL

A. *World coal reserves*

Coal is the most widely available fossil fuel and energy resource worldwide. Their reserves are available in almost every country, with recoverable reserves in around 70 countries. The largest reserves of coal are in the USA, China, Russia, Australia and India. Coal actively mined in around 50 countries [2].

World coal reserves are abundant; it has been estimated that there are over 1139 billion tonnes of proven coal reserves worldwide. This means that there is enough coal to last us at least 153 years at current rates of consumption [4].

Coal reserves reported by World Coal Association (WCA) are much lower – about 861 billion tonnes, equivalent to 112 years of coal output [2].

Distribution of proved coal reserves by region are shown on Fig. 2 [4].

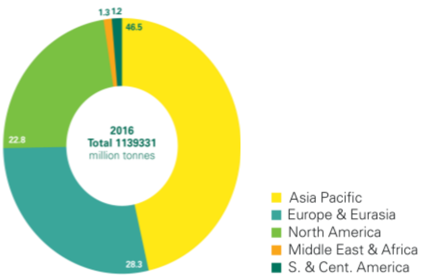

Figure 2. World proved coal reserves (in Mt) [4]

As shown in Fig. 2, the Asia Pacific region have the largest proved reserves (46.5 %), followed by the Europe and Eurasia region (28.3 %) and North America (22.8 %).

The largest coal reserves are in the USA (22.1 %), China (21.4 %), Russia (14.1 %), Australia (12.7 %) and India (8.3 %) [4], which account around 80 % of the world's recoverable coal reserves, predominantly low quality/value coals such as lignite's, subbituminous coals and high-ash bituminous coals [7].

According to BP Statistical Review data [4], total proved reserves at and 2016 are over 816 billion tonnes of anthracite and bituminous coal, and over 323 billion tonnes of sub-bituminous and lignite coal.

By rank, anthracite and bituminous coals account about 71 % of the world's proved reserves, subbituminous coal and lignite about 29 %. Anthracites and bituminous coals are adequate to meet projected growth in coal demand through to 2035 [8].

B. *World coal production*

World coal production was approximately 7,460 million tonnes (3,656 million tonnes of oil equivalent) in 2016 and it is 6.5 % lower than world coal production in 2015. Total coal production (in million tonnes) from 1986 to 2016 is shown on Fig. 3 [4].

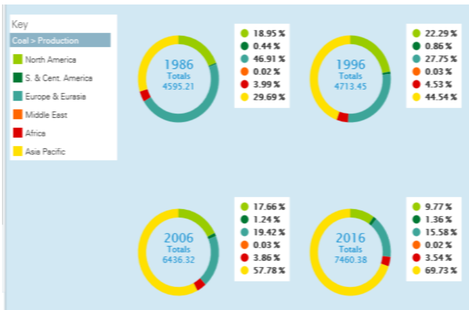

Figure 3. World coal production (in Mt) from 1986 to 2016

World coal production (in million tonnes of oil equivalent) by region is given on Fig. 4 [4].

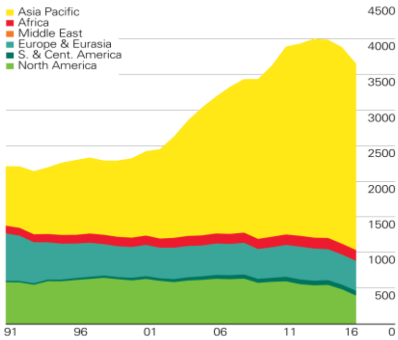

Figure 4. World coal production by region (in Mtoe) [4]

Total world coal production increased by 10 % in the period from 1992 through 2002 and by 60 % from 2002 through 2012. The maximum world's total annual production was approximately 8,274 million tonnes of coal (Mtoe) in 2013. Coal production decreased with 0.7 % in 2014 and with a further 2.8 % in 2015, making the first decline in global coal production growth since the 1990s. [4].

The largest coal producing countries are not confined to one region. Approximately 90 % of the total global coal is produced by ten countries. China was the world's largest coal producer. Other major coal producers are the USA, India, Indonesia, Australia and South Africa.

In 2016, China produced 3,411 million tonnes of coal (1,685 million tonnes of oil equivalent), accounting for 46 % of the world coal production. China's production fell by 7.9 % or 140 Mtoe.

Fig. 5 shows the historical and projected world coal production. World coal production is projected to peak in 2039, with a production level of 8,844 million tonnes [9].

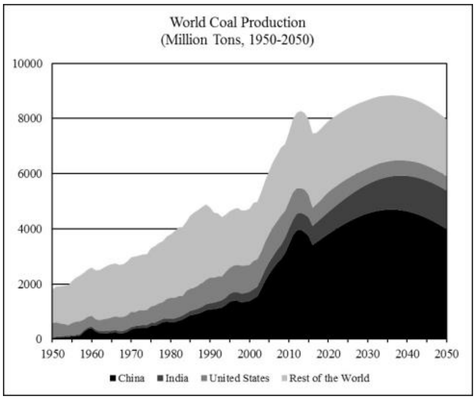

Figure 5. Historical and projected world coal production (in Mt) [9]

By comparison, in "World Energy Report 2016-2050" [10], global coal production was projected to peak in 2039, with a production level of 8,695 million tons. It is also predicted annually average increase of 1.5 %, so in twenty years it will replace oil and become the world's largest source of total energy.

C. World coal consumption

Historically, coal has been the major source of energy for the industrial advances and socio-economic well-being in the UK, Europe and the United States since the mid-18th century [1].

Coal currently fuels 40 % of the world's electricity and is forecast to continue to supply a strategic share over the next three decades [6]. The world currently consumes over 7,800 Mt of coal which is used by a variety of sectors including power generation, iron and steel production, cement manufacturing and as a liquid fuel.

According to BP's Statistical Review of World Energy 2017, total coal consumption was 3,732 million tons of oil equivalent in 2016, accounting for 28.1 % of the world energy consumption [4].

World coal consumption (in million tonnes of oil equivalent) by region is given on Fig. 6 [4].

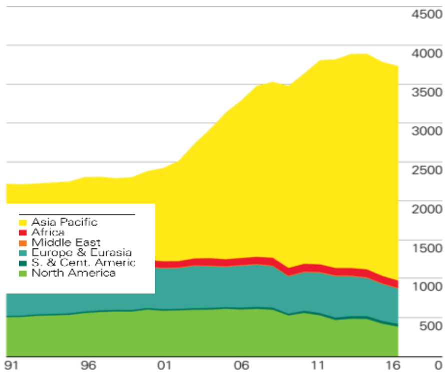

Figure 6. World coal consumption by region (in Mtoe) [4]

Many countries with significant coal reserves also have substantial coal production. Currently, five countries, namely China, the United States, Russia, India and Japan accounted for over 75% of worldwide coal consumption.

From 2005 to 2015, world coal consumption grew at an average annual rate of 1.6 %. In 2016, global consumption dropped 6.2 % or 231 million tonnes of oil equivalent (Mtoe), according to BP. China's production fell by 7.9 % or 140 Mtoe – also a record decline – while US production fell by 19 % or 85 Mtoe.

The importance of coal to electricity worldwide is set to continue. Future world energy scenarios to 2040 and beyond from the International Energy Agency (IEA) showed a marked increase of coal in world total primary energy consumption [2, 8].

Coal has a crucial and a vital role in meeting current needs mankind and it will be a resource bridge to meet economic goals into future. However, climate change mitigation demands, transition to cleaner forms of energy and increased competition from other energy resources will presenting the main challenges for the coal mining and coal industry.

III. Energy Sector of the Republic of Serbia

A. *Primary energy consumption in the Republic of Serbia*

The energy sector is one of the strategic areas for Serbia's future economic development. Basic goals of energy sector are energy security, establishment of energy market and functioning of the sector in accordance with the principles of sustainable development.

Primary energy consumption in the Republic of Serbia in 2010 was 15.531 million tonnes of oil equivalent. Structure of primary energy consumption in 2010 is given on Fig. 7 [11].

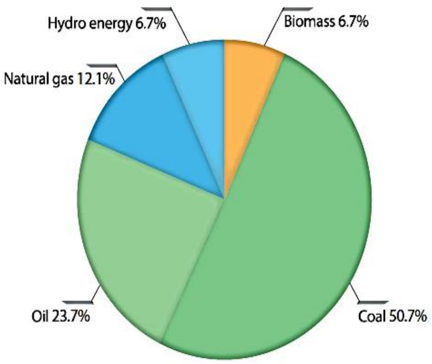

Figure 7. Primary energy consumption in the Republic of Serbia in 2010 (in Mtoe) [11]

Coal participates in the primary energy consumption with 50.7 %. Coal consumption is dominantly connected with energy generation by transformation (about 92 %) out of which the highest consumption is in thermal power plants.

In Fig. 8 is shown structure of primary energy consumption in the region in 2010 [11].

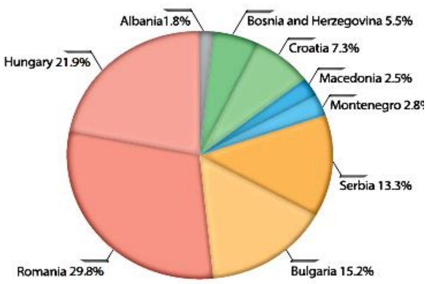

Figure 8. Structure of primary energy consumption in the region in 2010 [11]

The Republic of Serbia, with share of 13.3 % in consumption of primary energy, also has a significant role at regional energy market (Fig. 8). Also, consumption of primary energy per capita in 2010 in the Republic of Serbia was 2.14 toe which is slightly above average regional and world consumption, but it is two times less than average consumption of OECD developed countries [11].

B. *Coal resources and potentials of the Republic of Serbia*

Coal represents a strategically important and a significant energy resource on which is based the energy and economic development of the Republic of Serbia.

Coal was, is and will be most important source of primary energy in Serbia, regarding both the amounts and energy, regardless to any correction of existing reserves estimates.

The Republic of Serbia has a significant coal reserves, such as: hard, brown, brown-lignite and lignite. Total geological reserves of coal in the Republic of Serbia is given in Table 1.

TABLE I. Total geological coal reserves of the Republic of Serbia (thousands of t)

Coal	Serbia not including AP	AP Kosovo and Metohija	AP Vojvodin a	Total Republic of Serbia
Hard	8,214	0	0	8,214
Brown	111,293	0	0	111,293
Brown -lignite	536,678	0	8,729	545,407
Lignite	3,989,33 3	15,746,00 0	275,000	20,010,33 3

It can be seen from table 1 that the Republic of Serbia has a large amount of coal reserves (over 20 billion tonnes). According to the data from Energy Sector Development Strategy of the Republic of Serbia for the period by 2025 with projections by 2030 [11], more than 76 % of total coal reserves in Serbia are at the territory of Kosovo and Metohija basin.

The most important deposits of coal in the Republic of Serbia are represented by lignite and at the same time represent the largest coal complex.

Geological reserves of lignite compared to the geological reserves of all types of coal account about 97 %. Most significant reserves of lignite are in two main coal basins: Kolubara and Kostolac.

C. Coal production and exploatation in the Republic of Serbia

Production and exploitation of coal is one of the basic activities of modern society, both in the world and in our country.

According to BP data [4], Republic of Serbia produced 38.4 million tonnes of coal (7.4 million tonnes of oil equivalent) in 2016, accounting for 0.5 % of the world coal production.

Coal has long term perspective and competitive position for electricity generation as cheapest domestic primary fuel [12]. Therefore, some 90 % of overall annual coal production is used for electricity generation [12].

Coal is produced within two public enterprises and one share-holding company: Public Enterprise for Underground Coal Mining (JP PEU), Public Enterprise Electric Power Industry of Serbia (JP EPS) which consists of PD RB Kolubara and PD TE-KO Kostolac and company Rudnik Kovin AD.

The exploitation of coal in Serbia is done by open-pit (surface), underground and underwater exploitation, and within each of them there are coal preparation plants. The methods of exploitation, the different production capacities of the coal mines, as well as the different types and qualities of coal as a definite product, which are related to the mentioned methods of exploitation, are conditioned by the different processes of coal preparation.

Open-pit or surface exploitation of lignite coal is carried out by JP EPS in Kolubara and Kostolac mining basin. In 2015, it produces over 37 million tonnes of lignite annually, which is supplied to the thermal plants “Nikola Tesla” and “Morava” [13].

Analyses performed at JP EPS showed that planned overall consumption of electricity in Serbia until 2025 will increase by 1% annually [12]. Currently, coal production is stable and in the coming period it will increase in the accordance with the construction of new thermal power plants.

Underground exploitation of coal is carried out within the Public company for underground coal Resavica (JP PEU), which was formed in 1992 by consolidating nine coal mines from underground mining in a single company for coal production in the Republic of Serbia.

The Public company for underground coal Resavica (JP PEU) currently includes eight active mines, situated in eastern and central Serbia (Vrška Čuka, Rembas, Ibar mines, Soko, Bogovina, Lubnica, Jasenovac and Štavalj) and one mine (RGP Aleksinac) that was closed in the 1990s, but it also provides services for underground facilities for other mines.

JP PEU each year produces more than half a million tons of high quality coal for thermal power plants and market in Serbia. Coal producion in JP PEU Resavica from 1992 to 2015 is given on Fig. 9 [14].

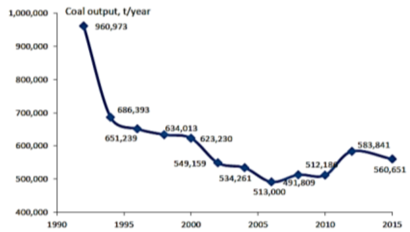

Figure 8. Coal producion in JP PEU Resavica from 1992 to 2015 [14]

It can be seen that coal production was reduced by 400,322 t or 42 % from 960,973 t of excavated coal in 1992 to 560,651 t in 2015. Top coal producers in the JP PEU are Rembas, Soko and Štavalj mines, while coal mine Vrška Čuka is on the bottom.

In the underground coal mining, most important development resources are coal reserves, equipment, technology and human resources [14]. Currently, the underground coal mining is faced with numerous problems, such as: application of low-productive digging methods, complex natural geological and mining conditions of exploitation, etc.

One of the basic preconditions for economic development in underground mines coal is in increasing the efficiency of their exploitation, better utilization of coal reserves and implementation of a number of requirements, primarily related on the environment protection.

Coal plays a significant global role in sustainable development. Whether mining or mining and coal processing is in accordance with the concept and principles of sustainable development, we will shortly show on the example at coal mine Vrška Čuka.

IV. Coal mine Vrška Čuka – past, present and future

Coal mine "Vrška Čuka" is located about 10 kilometers near Zaječar in Eastern Serbia. It is the smallest underground mine in Serbia measured in terms of level of production (about 5,000 to 7,000 tonnes of coal) and number of employees. Coal mine "Vrška Čuka" has been operating for more than 130 years with average annual production of between 10 and 12 thousand tonnes In the 1950's, this mine produced 55,000 tonnes of coal per year.

Coal mine "Vrška Čuka" is the only mine of anthracite coal in Serbia. Currently, it produces anthracite in the Mala Čuka location.

Total geological and exploitation reserves (A + B + C1 category) in the "Mala Čuka" deposit are shown in Table 2 [15].

TABLE II. Total geological and exploitation reserves in the "Mala Čuka" deposit (t)

Category	Geological reserves (t)	Exploitation reserves (t)
A	9,580	9,101
B	685,703	651,418
C_1	774,042	735,340
Total	1,469.325	1,395,859

Anthracite is the oldest, hardest and cleanest type of coal. It is commonly classified into three grades: standard grade (SG), which is used mainly in power generation, and high grade (HG) and ultrahigh grade (UHG), the principal uses of which are in the metallurgy sector.

Anthracite, as highest quality coal, has a wide range of industrial applications. It is commonly used for steel manufacturing, metals processing and to make other products such as filters for water purification or some carbon composite materials.

In the coal mine "Vrška Čuka", anthracite generates in two varieties as amorphous and crystallite anthracite [16].

Currently, in the present state of exploitation, production and marketing of anthracite from coal mine "Vrška Čuka" to consumers as an energy source, there is a question of sustainability and closure of the Mine in to future.

Based on available data and current projections into future, the sustainability of mining production is based on [17]:

- Stable exploitation with annual output of 15,000 tonnes of anthracite coal,
- The production of filter-anthracite as well as other high quality technological products into the future.

Filter-anthracite is a natural filter material, produced from crushed and sieved highest quality crystallite anthracite without chemical and thermal activation process.

Filter-anthracite is a resistant to abrasion. It is characterized by metallic-glass shine, with shell texture and inner porous structure, which makes it suitable for water filtration.

Filter-anthracite meets the requirements of the European standard EN 12909 (in accordance with ANSI/AWWA B100-09) and in terms of the controlled parameters; it is health safety and can be used in the water purification process for drinking-water (Certificate no. 178 of 11.04.2014 by Institute of Public Health "Dr. Milan Jovanovic Batut") [16-17].

Filter-anthracite® is an effective water filtration media for single - or multi-layer filtration in the open and closed filters. It is used in the water purification for drinking-water [17-18], swimming pools water and wastewater [18-20].

According to the quality and physical and chemical characteristics of anthracite coal, new, eco-friendly product, filter-anthracite with low ash content and high cost price, has made a concrete contribution to the improvement of the economic and production effects of coal mine "Vrška Čuka". All mentioned will have a wider benefit on the social, economic, regional and sustainable development of the coal mine in the future [21].

V. Conclusion

Coal is one of the most important and most used primary fossil fuels. Coal is and will be the main source for electricity production into future. Some 40 % of worldwide annual coal production is used for electricity generation; therefore coal mining production and development is connected with planning of electricity generation and consumption.

The Republic of Serbia, with a potential of about 20 billion tonnes of coal, has no dilemma whether coal will be the main energy source for both current and future electricity generation.

In order to achieve these goals, it is necessary to focus all activities on opening new mining capacities and solving the main problems contained in the triangle of energy policy goals by respecting the principles of sustainable development.

The sustainability of mining production in underground coal mine “Vrška Čuka” is based on the production of new, eco-friendly product, filter anthracite, which will be used in water treatment into the future.

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Reducing Distribution Losses by Optimal Sizing and Allocation of Distributed Generation using GA

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Abstract- **Energy policies of today put considerable pressure on operators to eliminate losses that appear in the process of delivering electricity. Together with a new view of what a distribution network should represent, classic distribution methods need to become smart grids. A system that achieves minimum operational losses becomes more and more attractive. This paper tackles the energy efficiency in distribution networks by proposing an optimum allocation and sizing of distributed generation. Using a genetic algorithm, the minimum loss allocation and sizing are determined considering key elements within the network operation.**

Keywords-- Reactive power control, Energy efficiency, Power grids, Power system planning, Power system simulation

I. INTRODUCTION

Transport and distribution of power implies, as any physical process, a loss of energy due to the irreversible thermodynamic conversions. These losses, different from the useful energy, have been referred to as technical losses [1].Network losses can be divided into technical losses, which refer to energy transformed to heat and noise during the transmission and therefore physically lost, and non-technical losses, which refer to energy delivered and consumed, but for some reason not recorded as sales. Losses in distribution networks are generally higher than in transmission grids. For example in EU member states, the average losses in transmission networks are between 1% and 2.6% while in distribution networks they are between 2.3% and 11.8% [ERGEG08]. As discussed above, the range of these values is due to the specifics of the power system of each country [2].

A distribution network that has DG units will be more efficient due to a decrease in power losses in lines and improved voltage profile. The opportunity to develop a modern distribution network with DG depends in a big way on the actual reduction in power losses. This paper tackles the issue of optimal sizing and allocation of DG units by assessing overall power losses, average voltage profile and conformity towards operational parameters. Distributed Generation generally refers to small units up to 10 MW. Being small, they can be placed closer to the consumption point, dusk decreasing the path necessary for the energy to travel to get from the point on generation to where it is used. In this category, almost all new technologies developed for small scale networks or even individual use like photovoltaic, biomass or wind turbines are included [3]. The current trend in power systems development tends to show an increase interest for smart grids. Moreover, introduction of competition between companies involved in generating, transmitting and distributing energy puts increased pressure on eliminating losses and staying competitive. On the down side, these units must be part of a reliable, functional network. This means the units must be dispatch able and perfectly integrated in the overall protection systems. Allocation and sizing of DG units is a problem that has been tackled using GA by different methods like considering it a combinatorial problem [4] or converging towards a solution considering optimal power flow [5].

The elements upon changes can be inflicted in order to reduce losses are:

$$\Delta P = 3R \cdot I^2 \cdot 10^{-3} \text{ [kW]}, \quad (1)$$

$$I^2 = \frac{S^2}{3 \cdot U^2} \text{ [A].} \qquad (2)$$

Loss reduction is based upon three main foundations (Fig. 1):

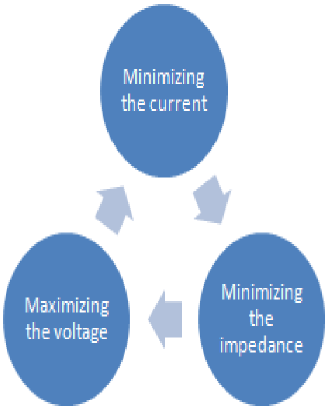

Fig.1. Loss reductions foundations

DG units allocation and sizing must be done by taking into account the real economic return. That is why the size of the capacitor bank is represented as a significant variable inside the proposed algorithm.

The paper presented relies on real world data obtained from a functional distribution network and proposes a new minimization problem based on genetic algorithm for loss reduction while maintaining a fully functional network.

II. GENETIC ALGORITHM

Genetic algorithms use terms borrowed from genetics. GA actually used to compare the similarity of two things (direct analogy). It is also used to optimize the applied solution by using the biological method it is explained by Darwin. Basically, it is used in different applications its gives an exact result compare to other methods for solving specific error using GA. In this, fitness functions are used to obtain the different possible solutions [4-5].

Inspired by natural systems and living populations, GA borrows search techniques and evolution mechanisms. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time [6]. GA Program comprises of three different phases of search [7]:

- phase 1: defining the initial population;
- phase 2: calculating the fitness function;
- phase 3: obtaining the new population.

- **Chromosome Representation.**

In each generation of the genetic algorithm, two parent chromosomes are selected based on their fitness values; these chromosomes are used by the mutation and crossover operators to produce two offspring chromosomes for the new population.

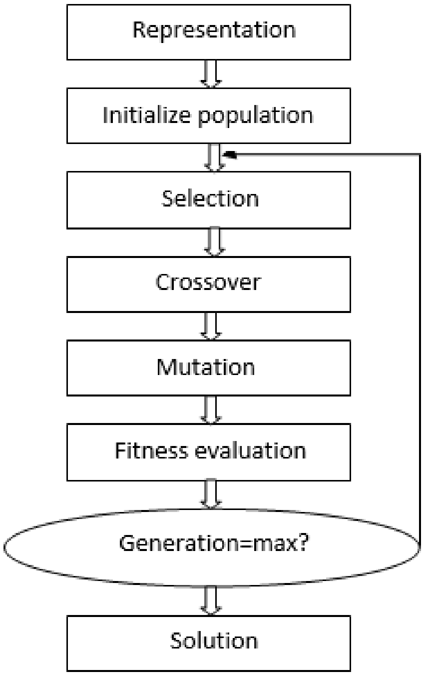

Fig. 2 Genetic Algorithm flowchart

- **Initial population**. In MATLAB environment, the initial population is 50 when the number of decision variables is less than 5. If this decision variables are more than 5 then default initial population is 200.

- **Reproduction**. At each generation, two individuals are randomly selected for reproduction. If the new chromosome, obtained with crossover and mutation, is not unique in the current population, the process is repeated.

- **Crossover** In genetic algorithms, crossover is a genetic operator used to vary the programming of a chromosome or chromosomes from one generation to the next. It is analogous to reproduction and biological crossover, upon which genetic algorithms are based. Crossover is a process of taking more than one parent solution and producing a child solution from them. There are methods for selection of the chromosomes. Those are also given below.

- **Mutation**. Mutation is a genetic operator used to maintain genetic diversity from one generation of a population of genetic algorithm chromosomes to the next. It is analogous to biological mutation. Mutation alters one or more gene values in a chromosome from its initial state. In mutation, the solution may change entirely from the previous solution. Hence GA can come to a better solution by using mutation. Mutation occurs during evolution according to a user-definable mutation probability. This probability should be set low. If it is set too high, the search will turn into a primitive random search [8].

- **Adaptive crossover and mutation**. As the generations pass and the individuals converge to the global solution, the intervals for the randomly generated variables decrease proportionally with the number of generations left to evaluate.

- **Evaluation**. For each valid configuration, the structure of the network must be tested to see if the imposed restrictions have been violated. A full load flow calculation is made and if the solution is within the limits, it tests if the power loss is less than the most suboptimal solution in the current population. If so, the new candidate solution takes its place.

- **Stopping criteria**. Algorithm is set to run until the solution found satisfies the fitness function or, given a finite number of generations is achieved, the best suitable solution is chosen.

III. PROBLEM FORMULATION

Obtaining the minimum losses within a power distribution network requires an objective function or a Fitness Function if we use a Genetic Algorithm. The FF is selected to reduce the system power losses and increase the voltage stability of the system. Different scenarios are used in this study to determine the effectiveness of the proposed. This fitness function will be optimized in the presence of constraints that need to be fulfilled in order to define the optimum distribution size and allocation. In the radial distribution system, 20/0.4 kV substations represent opportunities for installing capacitor banks. The distribution systems optimum sizing and allocation problem is to decide the position and size of the capacitor banks so as to obtain the minimum distribution losses with satisfying the constraints.

A. Constraints

a) Voltage

In order to maintain power quality, acceptable ranges must be kept in each node:

$$V_{\min} \le V_j \le V_{\max}, \forall j \in \{1,...,n\}, \quad (3)$$

where $V_{\min}$ and $V_{\max}$ are the acceptable limits for customer service voltage at node *i*.

b) Current constraints

$$i_j \le I_{\max}, \forall j \in \{1,...,n\}, \quad (4)$$

where $I_{\max}$, the maximum current that can flow through edge *j*.

c) Active and reactive power losses constraint:

The losses after capacitor banks are installed in the distribution network should be less than or equal to losses before installing them.

PL with CB ≤ PL without CB

QL with CB ≤ QL without CB

d) Size constraints

Capacitor banks size is evaluated inside the algorithm.

Loss reduction in network alteration by installing capacitor banks is formulated:

$$Min\sum_{i=0}^{n-1} r_i \frac{P_i^2 + Q_i^2}{V_i^2}, \quad (5)$$

where:

r_i - Resistance of the branch i

P_i = Real power flowing through the branch

Q_i = Reactive power flowing through the branch

V_i = Voltage at the receiving end of the branch

B. *Objective function*

The main goal of the proposed algorithm is to determine the best allocation and sizing by minimizing total active losses. The fitness should be capable of reflecting this objective and directing the search towards optimal solution. Load flow calculation is performed to obtain total active power loss. Reciprocal value of total active power loss is proposed as fitness function to obtain optimal active power loss. Maximization of the Fitness Function [F] offers the optimum network size and allocation all the while obeying all the constraints stated. The Fitness Function is determined as follows:

$$MaxF = \frac{1}{f} \cdot 100 , \qquad (6)$$

where f is developed by taking into the active and reactive power losses, voltage profile throughout the network, size of generation units and function weights that allow to prioritize the above mention variables.

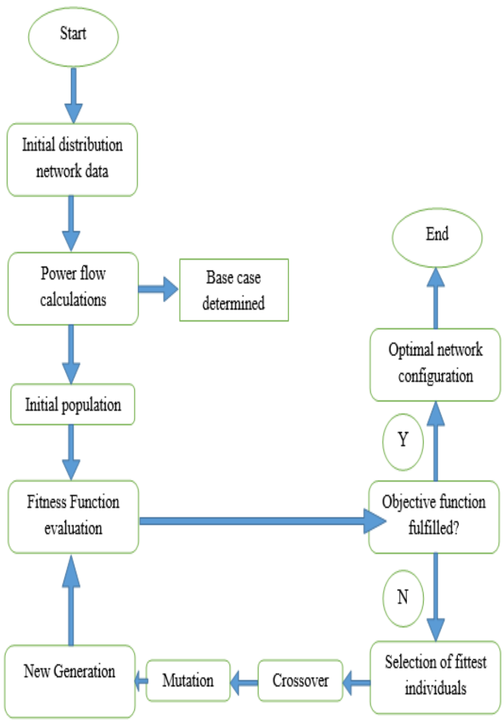

Fig.3 Proposed Genetic Algorithm

Active, reactive losses and AVP are obtained from EDSA Paladin design base load flow program. Every value is consistent to each individual scenario and obeys every constraint. After determining the base case, the power-flow program is executed and then the objective function calculated. The developed algorithm which is programmed in MATLAB reduces the computation time (Fig. 3).

C. *System description*

The distribution network has 7 20/0.4 kV substations that are supplying residential consumers as well as industrials ones. Their installed power varies from 630 kVA to 1000 kVA and their power consumption profile is shown in fig. 4. In normal operation, there are no Distributed Generation units installed. This will serve as base case scenario against which results will be compared. Electrical parameters of underground 20 kV lines are considered for power flow calculations.

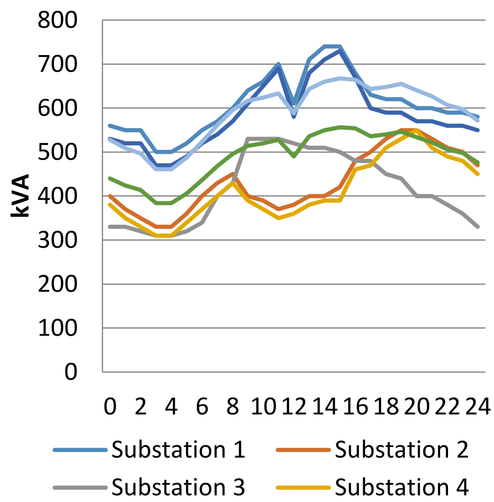

Fig.4 Load profile

Reducing losses becomes even more important as systems head towards smart power grids in which the places energy is produced and consumed, vary throughout the day. Of course, any changes to power network distribution systems must be economically viable. Therefore, a thorough cost efficient analysis must be performed. However, this is not the subject of the present article.

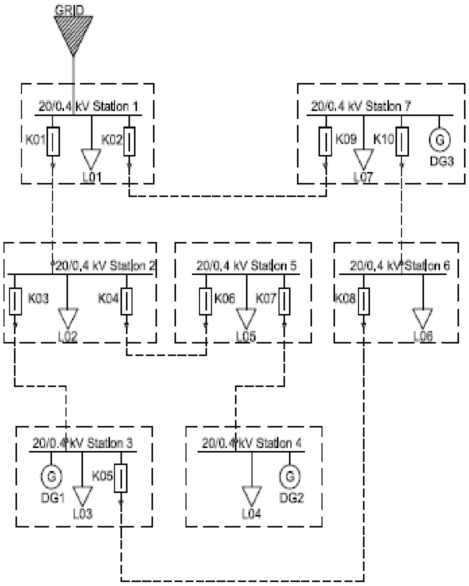

Fig. 5 Network configuration

IV. CASE STUDY

A. Base case scenario

Proving the efficiency of the proposed algorithm for sizing and allocation of DG units is done simulating and comparing different scenarios to the base case which is the current state of the distribution network. This case describes the current state of the distribution network. Power losses and voltage profile were obtained from a load flow program for different scenarios. Power flow calculations show a 0.23p.u. real power losses and 0.116 p.u. reactive power losses.

TABLE I. LOSSES WITHOUT CAPACITOR BANKS

Base Case Scenario				
Off peak				
P_{L1}	Q_{L1}	AVP	Q_{bc}	P_L Improvement
(kW)	(kVAr)	(kV)	(%)	(%)
406.8	266.6	19.2	0	-
Peak				
P_{L1}	Q_{L1}	AVP	S_{op}	P_L Improvement
(kW)	(kVAr)	(kV)	(%)	(%)
711.56	436.5	18.8	0	-

Table I shows the current state of the distribution system without any capacitor banks for reactive compensation. The active losses are around 20%. A value considered too high for modern power systems.

B. Simulation scenarios

In the first scenario, DG unit is installed in Station 3. Real power losses at peak consumption are 0.17 p.u. and AVP 0.92 wap.u. A 4% improvement can be observed compared to the base case. Fitness function value is 0.327 (Table II). In off peak condition, the algorithm reveals that optimum allocation gives overall smaller losses than a bigger generation unit.

TABLE II. LOSSES WITH CAPACITOR BANKS

Scenario	***Off peak***					
	P_{L1}	Q_{L1}	AVP	S_{op}	Fitness	P_L Improvement
	(kW)	(kVAr)	(p.u.)	-	-	(%)
1	386.4	230.4	0.922	0.5	0.327	1
2	244.1	186.5	0.94	1	0.274	8
3	162.7	123.8	0.95	0.5	0.49	12
Scenario	***Peak***					
	P_{L1}	Q_{L1}	AVP	S_{op}	Fitness	P_L Improvement
	(kW)	(kVAr)	(p.u.)	-	-	(%)
1	525.81	362.9	0.91	0.5	0.262	4
2	433.1	305.6	0.932	1	0.218	8
3	278.4	193.7	0.94	0.5	0.38	12

The second scenario analyses power losses with a DG unit in Station 5. It can be observed that active power losses are improved by 8% compared to the base case. Finally, the last case studied was proposed. Distribution Units are installed in Station 7. The fitness function value is maximum which corresponds to minimum active losses in the system while constraints are met.

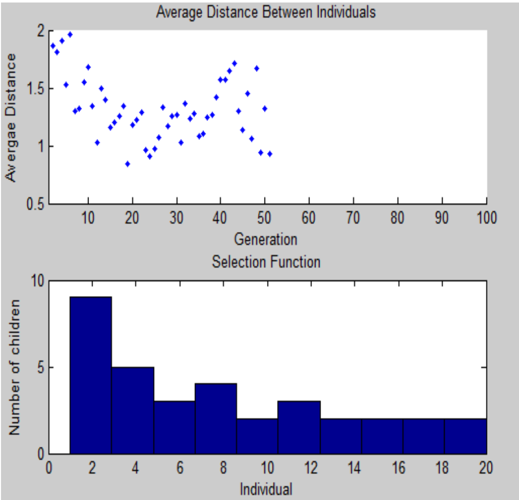

Fig. 6 GA functions

V. CONCLUSIONS

This paper proposes an optimum DG sizing and allocation algorithm based on Genetic Algorithm to minimize system losses while constraints are imposed. Only results that meet all constraints are taken into consideration. Time varying loads are an important factor in the effort to reduce losses and they need to be taken into account while searching for solutions.

The solution searches for the optimum configuration while keeping to a minimum the size of the capacitor banks needed to achieve the best case scenario. Minimizing the fitness function through GA, the optimum configuration was determined which has a 14% improvement compared to the existing network layout. The results obtained are found to be satisfactory and the use of Rowlett wheel selection demonstrates the effectiveness and applicability of the proposed methodology.

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Green ICTs: Main Concepts and Serbian Perspectives

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Abstract— **Consumption of energy in previous decades has been increased, among others, due to growing demands caused by broader application of Information and Communication Technologies (ICTs). The importance of energy efficiency in the ICT domain initiated the idea of the development of "green" ICTs. In this paper, main concepts of "greening" are presented. Also, some perspectives and possibilities of applying green ICT concepts in Serbia are considered.**

Keywords – Information and communication technology (ICT), green technologies, goals, energy consumption, eco-labeling

I. Introduction

Green development, based on sustainability premises, is one of the most important development ideas in a modern world. The need for fast economic development and large number of inhabitants has caused the development without thinking about the effects of certain phases in the process of production, transportation or use of goods and products. This has led to major pollution, irrational use of non-renewable resources and large quantities of toxic waste. Thus, the concept of "greening" everything affecting the aforementioned adverse effects is introduced.

The importance of ICT (information and communication technologies) for all aspects of a modern world is obvious. ICT is part of everyday life - education, working environment, production facilities, etc. All spheres of human activity benefit from ICT support, because it allows faster execution, communication and informing about the current situation.

During daily use of ICTs, there is little concern about the effects on the environment. ICTs and their applications can have positive and negative effects on the environment. Many people are not even aware of negative effects of ICTs on the environment, or their knowledge about that is very superficial. In this paper, basic concepts of green ICTs are presented.

II. Green ICT

Green ICT refers to environmentally sustainable use of information and communication technologies. According to OECD [1], green growth measurement framework consists of a set of indicators describing the whole lifecycle. It includes socio-economic context and the characteristics of growth, as well as economic opportunities and policy responses.

The socio-economic context describes goods production (environmental and resource productivity), goods consumption (environmental quality of life), and natural asset base. The economic opportunities and policy responses describe taxes and subsidies, regulations, investment, innovations, trade, education, training, and jobs.

Green ICT concept includes environmental sustainability aspects. It is based on efficient energy consumption and total ownership cost including removal and recycling activities. According to [2], the following main criteria for classifying policies and programmes on ICT and the environment are identified:

- Life cycle phases – research and development, design, manufacturing, distribution, use, and disposal;
- Environmental impact categories - global warming, energy use, toxicity, non-energy resource depletion, land use, water use,

ozone layer depletion, and effects on biodiversity.

The interaction between ICT and the environment consists of three different types of impacts (Fig. 1): direct, enabling, and systemic impacts [3]. They are also called “orders”, where direct impacts are the first order impacts, while systemic impacts are the third order impacts.

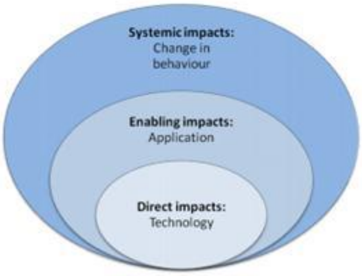

Figure 1. Layered framework for green ICT [3].

Direct (first order) impacts of ICTs on the environment are caused by physical existence of ICT products, goods, services, and related processes (Table I). They affect the natural environment during the production of ICT hardware, components and ICT services and through their operating infrastructures, offices, vehicles (energy consumption, recyclability, etc.). At the end, users affect the environment directly by means of purchase, consumption, use, and end-of-life treatment of ICT products.

TABLE I. DIFFERENT IMPACTS AND SOURCES

Impacts	Sources
Direct	ICT manufacturing and services firms, intermediate goods production companies, final consumers and users of ICTs [3].
Enabling	Resource-efficient product design, creation, use, and disposal by means of ICT application.
Systemic	The expected and unexpected consequences of wide ICT application, caused by behavioral changes of users.

Enabling impacts cause environmental impact reduction in different economic or social activities. ICTs can affect other product productions by means of optimization, dematerialization or substitution, and increasing demands for other products. It can also include some problems, when ICTs make more complicated procedures for disposal or recycling of non-ICT products (for example, machine or car parts).

Systemic impacts of ICTs and their application on the environment make behavioral changes and affect non-technological factors. The most important is acceptance among users, because some changes in their lives are needed (lifestyle changes, adjustment of individual habits). The effects are made by means of providing information, making adaptive pricing scales, optimization of demands, making technological adaptations, and initiating feedback effects [3].

There are different types or classes of environmental impacts caused by ICTs (Fig. 2). They are classified according to ISO 14042 standard on environmental management and life-cycle assessment [4], as well as EPA life-cycle principles and practice [5].

The main classes describing the ICTs “greenness” are their effects on global warming, primary energy consumption, resource depletion, environmental toxicity, land and water use during the production, and biodiversity loss.

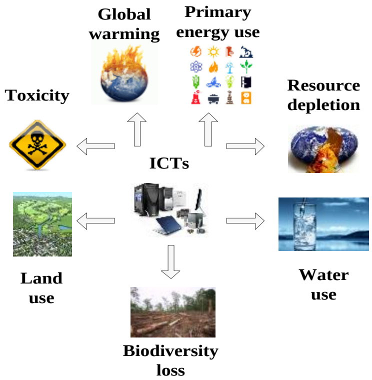

Figure 2. Different classes of ICT environmental impact.

All of these effects are observed throughout the life-cycle of ICT applications. According to the simplest waterfall model, these phases are requirement specification, analysis, design, development, testing, operation, and removal (disposal). Some savings can be achieved at each phase.

III. GREEN ICT GOALS

During the development of ICT, rare materials are used. These include, among others, gold, silver and platinum, but also cobalt, tantalum, palladium, and cadmium. Some of them have a very negative impact on humans and the environment, and it is necessary to pay special attention to their storage and after the end of using the computer components in which they are installed.

Based on these premises, as well as the need for efficient use of limited resources and energy, basic guidelines for "greening" ICTs are based on their entire life cycle (Fig. 3).

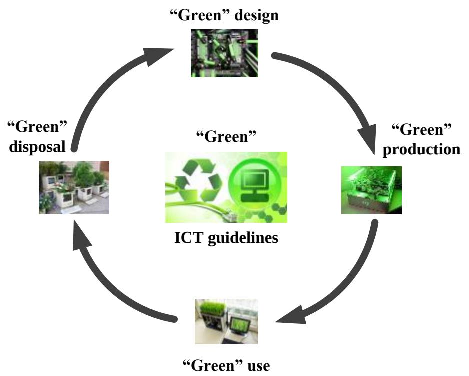

Figure 3. The guidelines for "greening" the ICTs life-cycles.

Guides are based on the application of a holistic approach throughout the entire life-cycle. It begins by designing components or systems that use energy rationally and in which rare or dangerous substances are used rationally, and ends with system or component "end-of-life", so that materials can be recycled or non-reusable material stored without further environmental pollution. The same goes for ICT services, where rational use of resources, primarily energy and communication channels, is in the foreground. The operationalization of these guidelines is shown in Table II.

TABLE II. PHASES AND "GREEN" OUTCOMES

Phase	Guidelines and outcomes
Design	Design for sustainable development, proposal of energy- and resource-efficient systems.
Production	Rational use of resources and substances, development of efficient algorithms, eco-labeling.
Use	Energy consumption control, energy-efficient computing, user-friendly applications.
Disposal	Organized collection of old equipment, responsible storage and recycling.

IV. ENERGY CONSUMPTION

An increase in the number of inhabitants and the use of various technical devices has led to an increase in the energy demand beyond the possibility of its production. Energy efficiency started to become especially important when it was concluded that the amount of certain resources (primarily oil and coal) was limited and that alternatives for their use would not be quickly found. In the coming decades, non-renewable energy sources must be replaced by renewable sources. The sun and the wind are some of these renewable energy sources. Today as the main goal in the development of all devices, and especially in the domain of ICTs, the energy efficiency, or economical use of energy, is placed at the forefront.

Energy consumption is different in different parts of a computer system from a standpoint of personal users. Some of the data concerning the energy consumption of main components of an average computer system used in 2017 are shown in Table III. The largest consumers are the central processor unit (CPU) and the graphics card. Also, a monitor, which is constantly active, has a significant influence on energy consumption. Therefore, it is very important to take into account the energy efficiency of each computing component, peripheral devices and network equipment. For example, a modem consuming 7-10 Watts per hour has a total monthly consumption of 5-6 kWh.

TABLE III. PERSONAL COMPUTER COMPONENTS AND THEIR AVERAGE CONSUMPTIONS

Component	Description
CPU	45-140 W (desktop), 17-40 W (laptop)
Monitor	35-70 W (LCD), 15-30 W (LED)
GPU	65-250 W
RAM	4-10 W per module
Disk	5-10 W (HDD), 2-4W (SSD)
Printer	30-50 W (printing), 3-5 W (standby)
Modem	2-20 W

The laptop power consumption is limited by the power of the power supply unit. This power can be from 40 W for small-screen computers (up to 12 inches), and up to 250 W for computers equipped with special graphic cards and larger screens.

The need for the allocation of energy efficient devices from others has led to the introduction of various ecological labels. These labels are mainly introduced by non-governmental organizations and engineering associations, but also by departments (Table IV). Among them, the most famous are Energy Star and TCO. They relate to different equipment, and TCO introduces elements of ergonomics in analysis.

TABLE IV. SOME GOVERNMENTAL AND NON-GOVERNMENTAL ECO-LABELS

Name	Description
80-Plus	Established by Ecos. Proposed for power-supply units (PSUs) describing their energy efficiency.
EPEAT	Electronic Product Environmental Assessment Tool, developed by the Zero Waste Alliance. Describes the usage of recyclable and biodegradable material, and product longevity.
Energy Star	It was created by the Environmental Protection Agency and the US Department of Energy. Standard for energy efficient computer products and peripheral units.
PC Green Label	Developed by PC3R Promotion Center, to reduce, reuse and recycle (3Rs) of computers and computer displays. It considers all main life-cycle phases.
TCO	Developed by TCO Development, an organization of Swedish Confederation of Professional Employees. Started with low electromagnetic emissions of displays.

Many researchers stated important effects of eco-labeling on energy efficiency and reduction of energy consumption.

V. GREEN ICT PERSPECTIVES IN SERBIA

According to the data of the Statistical Office of the Republic of Serbia, in 2015 almost 99.3% of households had TV, 90.3% cell phones, 53.6% cable TV, and 39% laptops [6]. Personal computers had 64.4% households, Internet used 63.8%, and 56% broadband Internet. Almost 95% of enterprises used e-government services, and 100% used computers in production or business activities. Large environmental systems, such as Danube, were monitored, to control pollution and predict larger disasters [7]. They also consume energy continuously, and can be good examples of systems oriented towards green ICTs.

The entire IT sector has a significant influence on energy consumption. As described in [8], the energy situation in Serbia is not good, and one of the unused potentials for decreasing of the energy consumption is to stimulate energy efficiency in the ICT sector. Approximately 2-3% of the energy consumed can be saved in this domain.

About 350 thousand computers are sold in Serbia annually. Nearly two million computers have been delivered in the past six years, and five years should be a replacement time. However, the lifespan of the computers has been extended, and buying low-end computers, composed of components of doubtful quality, leads to low energy efficiency. Average buyer in Serbia, when purchasing a computer, the least attention pays to energy efficiency, quality standards, and energy consumption.

VI. CONCLUSION

Energy efficiency, especially in home conditions, almost never analyzed from the point of view of ICT equipment consumption, although total consumption of a better-equipped desktop PC can be equal to yearly consumption of two fridges. It is therefore important to take into account the "greening" of ICTs, with a special emphasis on education, eco-labeling and a change in the awareness of Serbian citizens about the importance of considering the energy efficiency of the ICT equipment they buy or use.

ACKNOWLEDGMENT

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QR Codes Application for Equipment Maintenance Improvement – Case Study in Serbia's Transformer Substations

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Abstract—**This paper describes current electrical equipment maintenance practice and asset management techniques in Serbia's electrical energy system. A brief overview of maintenance concepts used in domestic and international practice is also presented. Finally, at the example of QR codes utilization for electrical equipment data storage in transformer substations, one possibility for maintenance improvement is presented.**

Keywords – maintenance, QR codes, transformer substations, improvement, electrical equipment

I. INTRODUCTION

In last few decades electrical equipment maintenance became one of most important areas in the electrical power engineering. In order to achieve a good maintenance strategy it is important to have all necessary data about electrical elements that are part of one electrical energy system. In this paper accent will be put on major electrical equipment in transformer substations that belong to Serbia's electrical energy system (EES).

Electrical devices that can be classified in transformer substation's major equipment are: distribution and measuring (current and voltage) transformers, circuit breakers, switches, surge arresters and DC voltage components (rechargeable batteries and inverters). For all these elements it is important to have information about rated values of all their electrical parameters (voltage, current, active or reactive power etc.), as well as years of their production and external conditions in which they have been operating during their lifecycles. Having these information can represent good basis for successful electrical equipment maintenance.

In this paper, QR codes application is presented, as one of methods that can help having mentioned data, and therefore, good initial conditions for introduction of efficient asset management system. Namely, in this case study is going to be shown how utilization of QR codes for all electrical elements in transformer substations will facilitate recording their necessary data (rated values of their electrical parameters, locations of stations where they are installed, ambient conditions in which they operate, number and type of failures in the point of their installation, but also their "movements", if they have been changing their installation points during their lifetimes). If would maintenance services have all these data about every significant electrical component, they could easily estimate conditions of all those components what leads to improvement of electrical equipment maintenance, in the case of applying any of the known maintenance techniques.

II. ELECTRICAL EQUIPMENT DATA STORAGE – CURRENT PRACTICE IN SERBIA'S ELECTRICAL MAINTENACE SERVICES

In order to have precise information about any of electrical elements, it is necessary to have well-conceived database, updated every time when any change happens. As it has already been mentioned, it is essential to know electrical component's "route" during its exploitation,

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from the moment of installation until the end of its lifecycle, for all major equipment elements.

However, current maintenance practice in Serbia's EES does not include database that contains all significant data about each component from the EES. Actually, at this moment there is no even database that consists of electrical component's elementary data. On the contrary, content of every transformer station is filed to the level of electrical field (switchboard). Therefore, data that could be used from existing databases can include information about transformer substation's location, its voltage level and number of transformer, measuring or transmission fields, but no detailed content of these fields, i.e. no information about electrical elements installed in them.

On the other hand, existing databases for electrical equipment have unique nomenclature system used for notation of electrical energy system assets. In the case of transformer substations, analyzed in this paper, every field in each individual substation is noted by serial number and by precisely defined string of four digits (these digits define type of electrical facility, voltage level and type of transformer station's field). Using this nomenclature system every field (switchboard) in Serbia's electrical energy system has unique label. Thereafter, it would not be a complicated task to expand this nomenclature system to the level of electrical components installed in transformer substations.

Expanding the existing nomenclature would provide new data storage system in which every individual electrical element from considered EES will have its own label (code). It would be also easier to record all necessary data about those elements by the method: one code for one element – one set of required data, listed in the previous section.

Actually, the hardest task here would be data collection for electrical equipment that is in operation (live components). In exterior conditions (transformer substations with voltage level ≥110 kV) this process can be performed by taking photos of components nameplates (nameplate contains most of component's basic information, such as: rated electrical parameters, manufacturer, type, year of production, serial number etc.). Combination of data obtained from component's nameplate with information about transformer station's location, voltage level, importance in electrical supplying and existence of failures and their causes (can be provided from

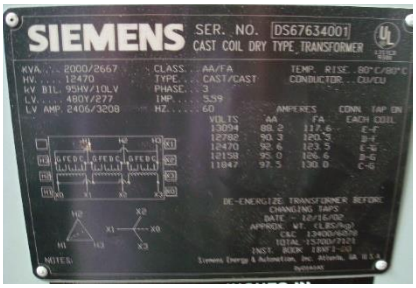

Figure 1. Photo of distribution transformer's nameplate [1]

SCADA systems installed in substations) represents excellent basis for component's condition estimation. The nameplate of one distribution transformer (11000/415 V, installed in exterior facility) that has a large amount of required data is presented in Fig. 1.

However, much bigger problem would be data collection for live components installed in electrical boards. In these situation it is not possible taking photos without substation's disconnection from the system, what is really complicated to provide, because a lot of customers could stay without electricity supplying. Only possible situations in which this can be performed are planned transformer substation's revisions, when disconnect is required. This means that it would be almost impossible to have all necessary data about every electrical component in every moment of its lifecycle. Photo of voltage measuring transformers during their operation, (installed in enclosed switchboard at 35 kV in transformer substation Niš 13) without possibility to see their nameplates is presented in Fig. 2.

Described problem will be additionally higher because, as it has already been mentioned, it is important to know the component's "route" – to know locations and conditions for all

Figure 2. Photo of volatge measuring transformers during operation – no possiblity to read their nameplates

transformer substations in which the certain component has been operating during its lifetime. Previous experience shows that maintenance services had not found yet appropriate solution for this problem. Therefore, this will be the subject of the case study which is going to be described in section 4 of the paper.

III. Maintenenance Concepts in Domestic and International Practice

Since the basic idea of analysis presented in this paper is electrical equipment maintenance improvement in Serbia's EES, it would be useful to give a short review of maintenance concepts used in domestic and international practice.

Maintenance strategy of any technical system is defined as a group of activities which main goal is to prolong equipment lifecycle and to reduce the total exploitation costs [2-3]. In general, maintenance can be classified as corrective and preventive.

Corrective maintenance is usually performed after component failure's appearance, in situations when considered element is not able to operate properly. This maintenance concept consists of damaged component's repair or of its partial or total replacement. Maintenance activities that should be taken here depend on the preventive maintenance that is (is not) performed at considered element [2-6].

Preventive maintenance includes all maintenance techniques that delay the component's failure using their preventive actions. Preventive maintenance can be classified as following:

- Time Based Maintenance (TBM) – preventive maintenance (component's repair or replacement) performed in fixed intervals
- Condition Based Maintenance (CBM)
- Reliability Centered Maintenance (RCM)
- Performance Focused Maintenance (PFM) [2, 6].

A. Time Based Maintenance (TBM)

This maintenance concept is the oldest and most widespread in electrical distribution companies in domestic and international practice. It is performed in fixed intervals that are in relation with previously used component's operation time. Maintenance plans are based on manufacturer's instructions and suggestions, standards and user's experience. In general, this is the most expensive maintenance concept, because it provides the same type of activities regardless of equipment's condition, points of installation and importance for system operation. Taking into account described maintenance concept, knowing of electrical equipment condition for its performance is not crucial. However, it would be useful to have database with information about performed maintenance at all elements in order to improve previously defined time intervals (adaptive TBM maintenance [2]), what would be less expensive maintenance concept.

B. Condition Based Maintenance (CBM)

This maintenance concept requires constant electrical equipment functionality testing and monitoring. It is necessary to know all parameters that has significant impact to equipment's lifecycle. Condition Based Maintenance defines relation: *cause-symptom-consequence* and therefore, it is easy to determine if there is a need for certain corrective activities. This concept is really technically and economically efficient, but it is also really complicated, because it requires monitoring and control systems and always updated databases. The main difference between this concept and Time Based Maintenance is possibility to delay some unnecessary activities and to reduce total amount of maintenance costs [2-4]. Actually, QR codes application, that is going to be described in following section, would have the greatest contribution in systems that use Condition Based Maintenance concept.

C. Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance represents the determination process of the most efficient maintenance program in terms of system's reliability. The main goal of this concept is to provide balance between costs caused by certain solution and savings that can be provided by its application. RCM concept is probabilistic approach that requires highly sophisticated models and absolutely precise input data (condition of equipment is crucial). This maintenance concept is usually applied in technically and technologically most developed systems, such as: airlines, nuclear power plants, spaceships etc. [2, 3]. RCM is also applied in electrical energy systems that possess precise statistics and because of its complexity it is not enough popular in domestic practice, but there is a trend to establish this concept in every system that has required technologies.

D. *Performance Focused Maintenance (PFM)*

PFM is the youngest formed maintenance concept and it includes maintenance strategy that implies detailed understanding of failure's causes, continuous measuring and parameters monitoring, precise determination of optimization intervals and updated database using. PFM concept recognizes requires for introducing a process control what can be achieved by integration of technological and business company's systems. Therefore, this concept must be supported by the top management of the company. PFM concept can provide really high level of system's reliability and availability and reduced exploitation costs. Activities that have to be performed if this concept is used are: system limits and critical functions identification, analysis of failures and their effects, knowing of elements ageing mechanism, optimization of maintenance intervals, planning and maintenance program development, measuring, maintenance documentation preparing. All listed activities indicate that this is the most complex maintenance concept [2].

Anyway, for all presented maintenance concepts (and even for TBM), necessary basis is knowing of electrical equipment's condition. In following section one method for this goal achieving is going to be presented.

IV. QR Codes Apllication for Electrical Equipment Data Storage

It has already been indicated to importance of installation positions' monitoring for every element in transformer substation (that can be classified in major electrical equipment) in previous sections. It has been emphasized that data obtained from monitoring process are necessary for any estimation of components conditions, health indices or remaining lifecycle. However, it has been explained that current practice in maintenance services in Serbia's EES does not include mentioned data, because electrical elements hadn't been listed in equipment database, but only electrical fields (switchboards) where they had been installed. Therefore, these elements had not got their inverter numbers in existing databases. Actually, every element has its own serial number, gained from its manufacturer, but these numbers haven't been used for maintenance process. In addition, at the largest number of elements it is impossible to read these numbers while the equipment is energized.

Actually, there are two problems that have to be solved here: the first that is related to precise identification of any element in exploitation and the second that is related to precise identification of the "route" for every element through its lifecycle. The first problem can be solved by data collection described in Section II, but since the equipment in transformer substations is usually energized, it is possible to read elements nameplates only during previously planned revisions. This process will require a lot of time, but this is a method by which it is possible to create appropriate database for all major equipment components.

Creation of this database will help having main data from elements nameplates, but the second problem still wouldn't be solved. Certainly, its solving is the subject analyzed in this case study.

One of methods that can be used is application of QR codes for elements notation. Great advantages of QR code's application are giving quick response (QR) and possibility to have a large amount of information. In general, maximal capacitance of one QR code is 7089 numerical, or 4096 alphanumerical characters. Using simple cellphones applications for their reading, it is possible to have a lot of element's characteristics (rated parameters from the element's nameplate; characteristics of transformer station in which the element is installed – its location, importance in supplying, number of customers; data that contains information obtained from element's testing, information about failures at the point of installation etc.), what are going to be used to describe current element's condition. In addition, web links for electrical components manufacturer catalogues can be written in one QR code, in order to achieve more information and manufacturer's manuals. In this way it is possible to have detailed information about one element in any moment of its lifecycle. If the certain element changes its installation point in one moment (after failure it can be replaced with another one and thereafter repaired and installed in transformer substation with different characteristics), data can easily be updated and the certain element can have new QR code.

Another very important advantage is reading accessibility of QR codes. The best method is to set QR code at every element from the group of major equipment (in the case of exterior facility) or at the door of enclosed switchboard for all important electrical elements installed in it (in the case of interior substation). Especially for these enclosed equipment QR codes application would be useful, because, as it has already been explained, the only way to read nameplates for enclosed elements are during substations revisions. For the first level of data collection, rated data could be read from component's nameplate and thereafter written in QR code and in that way stored for the rest of component's lifecycle. Certainly, information about ambient conditions for considered element could be changed using previously described process.

As example, generated QR code for necessary data of one distribution transformer installed in transformer substation 110/35/10 kV "Niš 13" is presented in Fig. 3 and data read from this code are shown in Fig. 4. Presented data include rated values of distribution transformer, read from its nameplate (easily taken photo at the site), transformer's manufacturer, type, name and location of the substation. Of course, the amount of information in the code can be increased (substations characteristics, test reports, links to manufacturer's manual, reports of all maintenance activities performed at the considered component etc.) or decreased (if maintenance services have required data in database and decide to use QR code just for written component's inventory number).

At the first site, this procedure can seems really complicated, but it can be significantly

Figure 3. QR code for distribution transformer installed in transformer substation 110/35/10 kV "Niš

DISTRIBUTION TRANSFORMER DATA: Unique inventory number: 307514; Element number:/; Region: Nis; Substation (number and name of substation): 0001 TS 110/35/10 kV "Nis 13"; Manufacturer: MINEL; Type: TP-8214-31.5; Serial Number (optional): 9821783; Year of production: 1984; Regulation (number of steps): 21; Rated power [kVA]: 31500; Rated primary voltage [kV] : 110; Rated secondary voltage [kV]: 36.75; Rated tertiary voltage [kV]: 10.5; Rated primary current [A]: 165.3 ; Rated secondary current [A]: 494.9; Rated tertiary current [A]: 577.4; Rated frequency [Hz]: 50; Rated power factor: /; Cooling method: ONAN/ONAF; Connection: YNyn0d5; Short-circuit voltage [%]: 10.65; Transformer total weight [t]: 54.2; Transformer oil weight [t]: 13; Isolation level: Si123/Si38/Si12; Ambient temperature [°C]: /.

Figure 4. Data written in QR code presented in Fig.3 read by free cellphone aplication

simplified with the fact that in the one process of public procurement distribution companies would buy same type elements, with same characteristics. The only information that will be different between these elements would be their serial numbers. Therefore, it is possible to create one QR code for one component, and just to copy data to QR codes of same characteristics elements and change their serial numbers and data about substations in which they should be installed. For creating and printing a large number of these codes it should not use more than a few hours.

It should also notice that this method totally eliminates the need for old elements (that are a long period in exploitation) inverters number's creation. This fact is really important, because, as it was explained, current maintenance practice in Serbia does not include nomenclature to the level of electrical elements. Actually, for elements that don't have inverters number, it is possible just to create QR codes as their identifications, if there is not a possibility of nomenclature's extension.

In the process of maintenance performing, QR codes can also facilitate reports writing, because it could be provided that in work orders are just few sentences and appropriate photo of QR code of the element that was repaired (replaced). In this manner the component's "route" is monitoring and it is possible to have information about it in any moment during its lifecycle, what could represents one of solutions for the second described problem in the beginning of this paper's section.

V. Conclusion

Regarding all described advantages it can be concluded that introduction of QR codes application for electrical equipment data storage in electrical distribution companies in Serbia would significantly improve their current practice. Processes of data collection, maintenance reports creation and database updating would be greatly facilitate. Obtained data could provide information about electrical elements conditions whenever it is needed what represents perfect basis for maintenance improvement for all presented maintenance concepts. The highest improvement could be seen for maintenance concepts that are based on elements conditions (CBM and PFM).

In this paper application of QR codes is presented at case study performed for electrical equipment in transformer substations. Future analysis can be provided in any other public or industrial company's system that requires any type of maintenance, because even in a companies that have highly developed maintenance concepts, there are always possibilities for some improvements.

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Wind Energy Estimation under the Impact of Urban Morphology: Example of Beijing

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Abstract—**Wind energy is beneficial for the sustainable development of cities. With increasing new wind turbine technologies and CFD techniques, urban wind becomes to attract public attention while large-scale wind capacity installation is stabilizing. This work is trying to estimate wind energy within the angle of urban morphology. Six different urban tissues were compared and analyzed with several relevant urban morphology parameters. Numerical simulations in CFD were undertaken to visualize the outcome of wind energy of each urban tissue. The results showed that the forms with lower floor area ratio usually have the higher wind potential density, and the forms with higher porosity usually have the higher wind potential density on unit of roof surface.**

Keywords - urban wind energy, urban morphology, CFD, urban tissue

I. INTRODUCTION

Wind energy is among one of the oldest renewable energy sources and its exploitation technology is simple and cheap, compared to solar PV and some other clean energy sources. Since 2000 a golden development period was recorded and the wind industry has shown an accumulative growth of around 21% per year [1].

Small and micro-size wind turbines that can adapt to urban wind environment are increasing these years. Some turbines with special designed blades can benefit the urban turbulent environment [2-3], and some other turbines in conducted wind passages can take advantage of wind concentration effect and reduce noise or security problems [4-5].

In the literature of urban wind estimation, most of the interest rests on the environment of some simple building forms and city-scale wind source evaluation. However, very few publications were found on community scale wind estimation. In fact, because of complex urban wind environment under various barriers' interaction, community scale is more accurate than building-scale and less cumbersome than city-scale to estimate wind energy. Numerical wind simulations with 5 specific sites in Copenhagen in the scale of small community (300 m×150 m) were carried out by Beller [2]. Some interesting conceptions on the wind energy development in urban environment were given. The method of DTM (Digital Terrain Model), GIS as well as CFD (Computational Fluid Dynamics) were utilized to analyse the ventilation situation of 6 street blocks in the city of Bangkok by Srifuengfung et al. [6]. Five urban design parameters were applied to describe the urban form properties and the results found two important influential parameters.

Urban morphology is defined as the study of urban form, which is a part of generally identified urban area corresponding to a homogeneous area in morphological point of view [7]. As great urbanisation processing and complex urban system emerging, urban morphology becomes a popular and effective method in the domain of urban planning. urban form plays an important role when facing city problems like climate change [8] energy consumption and evaluation [9-10], renewable energy development and assessment [11], traffic analysis [12], wind comfort [13-14], air pollution [15]. Ng *et al.* [16] used the method of FAD (Frontal Area Density)

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maps with GIS (Geographic Information System) on the Hong Kong city to analyse the relation between the urban morphology and urban ventilation situation. It is found that for large cities with many skyscrapers the increase of urban form permeability of the podium layer (0-15 m) can improve the city's ventilation. Some propositions were also given on building dispositions which can induce favourable ventilation environment in the pedestrian level. Kitous *et al.* [17] evaluated the impact of street length and symmetry on the wind canyon effect, based on the case study of the city Ksar in Algeria.

In this paper, we are trying to estimate wind energy within the angle of urban morphology. Six typical urban tissues in Beijing were chosen and compared in urban morphology study. Several relevant urban morphology parameters and wind energy indicators were utilized. Numerical simulations in CFD were undertaken to visualize the outcome of wind energy of each urban tissue.

II. Methodology

A. Urban morphology indicator

Based on the previous research findings [18-19], we adopt the core urban form parameters and those high-correlated parameters to wind energy. They are: floor area ratio (FAR), plot ratio (PR), average building height ($\overline{H}$), standard deviation of the building heights (σ_h), mean building volume ($\overline{V_b}$), relative rugosity (R_r), porosity (P_o). Seven typical urban tissues in the same city (Beijing) will be evaluated and compared with these parameters. To facilitate the comparison, the urban tissue scale is similar, around 300m*300m. Two groups of building nature are identified: apartment building cluster and office building cluster. All of them are dense either in plot ratio or in floor area ratio.

B. CFD simulation setting

ANSYS 14.0 is used for this simulation. Autodesk CAD 2015 is used for geometry creating. Most of the detailed setting of CFD was the same as the best case of validation given by ref. [20]. As the model scale change from a building to a neighborhood (urban form), the simulation setting needs to be reviewed and modified, in presence of simulation duration, precision and validation. For the current simulations of urban tissues (around 300 m×300 m), some necessary adjustments of the CFD setting are needed and given in the Table 1.

C. Evaluation method

Most of the Urban form is greatly influenced by the local climate and socioeconomical aspects, for example, the apartment building North-South distance is demanded by the local sunlight access condition. Thus urban form should not be universal for apartment building configuration but rather for office or other public function zones. In this research, we consider the local wind rose and choose the seasonal dominant wind direction (Northwest for Beijing, see Fig. 1 [19]) as our simulation wind inlet direction in order to get a general image of the exploitable wind energy potential in Beijing urban areas.

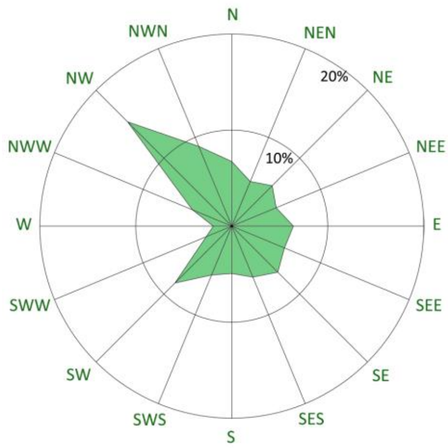

Figure 1. Annual wind rose in Beijing (data of 1995-2002 from Chaoyang Meteo).

To evaluate wind energy of an urban tissue, we continue to adopt the method of wind potential indicator of M' by ref. [21-22]:

$$M' = \left(U^3\right)_m \times A = D \times A \ . \qquad (1)$$

where A is the total area of the test surface, $(U^3)_m$ is the area-weighted average cubic velocity which can be defined and imported from the code FLUENT. As the indicator of wind potential density of a surface can be defined as D, then we can find $D = (U^3)_m$. If we compare two sites of different area, we can evaluate the general density of wind potential density in a site: $D' = M' / S$, where S is the site area. In this research, we choose those surface planes of 10 m above the exploitable roofs, which is defined to be more than 20 m in height.

TABLE I. ADDITIONAL PARAMETERS SETTING FOR URBAN FORM SIMULATION

CFD sections		**Parameter setting**
Geometry (demi-sphere domain, measured by its radius R)		800 m
Mesh	***Typical number of tetrahedral cells***	180 000 < N' < 1 500 000
	Average quality of the elements	0.61 < Q_a < 0.65
	Average skewness	0.26 < S_a < 0.27
CFD solution	***inlet conditions***	In the wind velocity estimation equation $U = U_0\left(\frac{z}{H_0}\right)^{\alpha}$, $U_0 = 3$ m/s, H_0 = 10 m and $\alpha = 0{,}25$
	Launcher option	Double Precision
	Inflation layer	L = 6 m, N = 5, T_g = 0,5 m, r_g = 1,3, T_b = 0,13 m, r_b = 1,2.
	Number of Iterations	3000 < N < 4000
	Residue	Continuity < 2×10e-5, velocity < 10e-5

III. WIND SIMULATION OF SIX URBAN TISSUES IN BEIJING

A. *Urban morphology study*

Beijing, China's capital city, is a megacity of 22 million permanent residents and has an area of 16410 km^2. The main region includes 6 districts which cover 1369 km^2 and house 12.8 million permanent residence [23].

Beijing has 3060 years of history in construction and various ethnic minorities as well as colorful urban forms in nowadays. Therefore, we selected 6 typical urban tissues in community scale in this city. They are mainly high-rise buildings clusters, which are proved to be more advantageous to develop wind energy around them than those low-rise buildings. Their morphological data can be evaluated in the Table II. Their axonometric images can be viewed in Fig. 2.

From the view of building form feature, we can see that: tissue A1, A2 and B1are mainly dot-type towers, A3 and B2 is for short bar of high-rise buildings, A4 is for continuous bar of high-rise buildings and A5 is for middle-rise buildings with short distance between each other.

In Table II, we can find the following features of these urban tissues:

- In the groups of apartment cluster (A1-A5), A3 has the most density (both in FAR and PR), A5 has high plot ratio density but relative low FAR, while the A1, A2 and A3 have similar density.
- In the groups of apartment cluster, A4 has highest $\overline{V_b}$ and R_r, A1 and A2 share similar R_r and P_o; A2 and A3 share similar $\overline{V_b}$; A3 and A5 share similar P_o.

TABLE II. URBAN FORM INFORMATION OF EACH URBAN TISSUE

Urban tissue names	**A1**	**A2**	**A3**	**A4**	**A5**	**B1**	**B2**
	Jinsong N	Jinsong S	Guoruicheng	Zhujiang DJ-A	Fengrong Garden	Jianwai SOHO	Financial street
Urban form nature	Apartment, residential area	Apartment, residential area	Apartment, residential area	Apartment, residential area	Apartment, residential area	Office, commercial center	Office, commercial center
Area	12.8 Ha	13.6 Ha	9.5 Ha	16.2 Ha	7.6 Ha	6.9 Ha	11.1 Ha
FAR	19.4%	20.1%	44.4%	27.4%	43.0%	31.2%	32.1%
PR	3.74	3.61	4.34	3.12	2.26	4.12	5.42
$\overline{H}$	60.4 m	57.0 m	31.1 m	36.84 m	17.5 m	55.5 m	63.7 m
σ_h	33 m	29.7 m	13.7 m	23.2 m	4.6 m	55.4 m	24.4 m
$\sigma_h/\overline{H}$	55 %	52 %	44 %	63 %	26 %	100 %	32 %
$\overline{V_b}$	83700 m^3	111000 m^3	101000 m^3	182000 m^3	47600 m^3	78200 m^3	283000 m^3
R_r	69600 m^3	73800 m^3	88400 m^3	379200 m^3	29800 m^3	76700 m^3	248500 m^3
P_o	80.5%	80.0%	55.6%	72.6%	57.8%	69.2%	67.9%

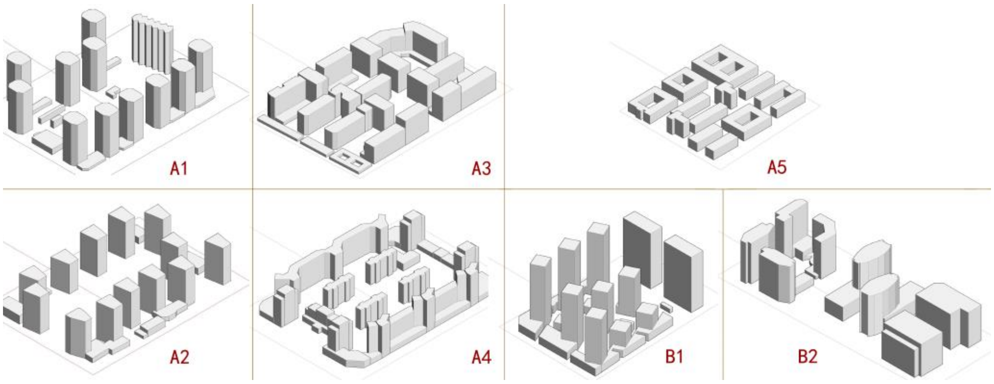

Figure 2. Axonometric views of the chosen urban tissues in Beijing.

TABLE III. WIND ENERGY DENSIGY OF EACH URBAN TISSUE

Urban tissues		A1	A2	A3	A4	A5	B1	B2
Buildings with the exploitable wind energy	Heights (m)	93	87	35-50	26-77	20	45- 127	60-92
	Total roof surface (m^2)	15429	16690	28399	23280	27018	10039	31522
	Total site area (m^2)	128200	13582 3	94736	162190	75927	68670	110904
D (m^3s^{-3}) with the exploitable wind energy (U > 3 m/s) (density by roof area)		420.4	334.7	98.0	186.5	80.3	158.4	223.1
D (m^3s^{-3}) with the exploitable wind energy (U > 2 m/s) (density by roof area)		420.4	334.7	97.5	186.1	78.8	155.4	223.1
D' (m^3s^{-3}) with the exploitable wind energy (U > 3 m/s) (density by site area)		50.6	41.1	29.4	26.8	28.6	23.2	63.4
D' (m^3s^{-3}) with the exploitable wind energy (U > 2 m/s) (density by site area)		50.6	41.1	29.2	26.7	28.1	22.7	63.4

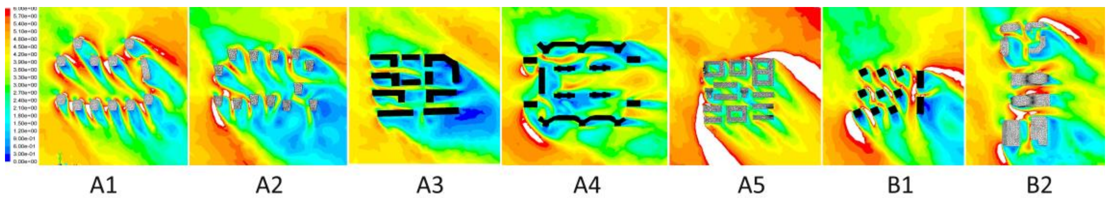

Figure 3. Wind velocity coutour lines of each urban tissue in simulation.

- In the groups of office cluster (B1-B2), they have similar FAR and P_o, but B2 has higher FAR, $\overline{V_b}$ and R_r.
- With similar density in PR, compared with B1, A3 has higher FAR, $\overline{V_b}$ and R_r, but smaller $\overline{H}$ and P_o.

B. *Wind silulation results and analysis*

General wind simulation result can be viewed in example of wind velocity contour lines on horizontal section of Z = 20 m for each model (see Fig. 3). The wind potential evaluation with two wind speed thresholds: V > 2 m/s and V > 3 m/s. All the buildings above which at *Z* = 10 m the wind speed is stronger than these thresholds were taken into consideration. The results of the seven urban tissue wind energy outcome are summarized in Table III. From this table, we can find that:

- For the wind potential density on unit of roof surface, the urban forms A1 and A2 have the highest values, then the forms A4 and B2, while A3 and A5 have the lowest outcome.

- For the wind potential density on unit of site area, the urban forms B2 has the highest value, then the forms of A1 and A2, while B1 has the lowest outcome.

If we consider the values of urban morphological parameters on Table II, along with the outcome of wind potential of simulation, we can find that:

- The forms with higher porosity usually have the higher wind potential density on unit of roof surface, e.g. the forms A1, A2.
- The forms with lower FAR usually have the higher wind potential density on unit of roof surface, e.g. the forms A1, A2 and B2.
- The forms with higher average building height usually have the higher wind potential density on unit of site area, e.g. the forms B1, A1 and A2.

If we consider the different building forms features of these seven urban forms, along with the outcome of wind potential of simulation, we can find that:

- With very similar urban morphology parameter values, the forms with round angle on building floor plans usually have the higher wind potential density (both on unit of roof surface and on unit of site area), e.g. the forms A1and A2.

IV. CONCLUSION

This paper chose seven typical urban forms from the city of Beijing and made a cross analysis of their exploitable wind potential over roof with their morphological characteristics. Wind simulation with local dominant wind direction was undertaken and wind potential of 10 m over roofs of the highest buildings in each urban form is evaluated. Some interesting relationships were found as the following:

1) The forms with lower FAR usually have the higher wind potential density on unit of roof surface.

2) The forms with higher porosity usually have the higher wind potential density on unit of roof surface.

3) The forms with higher average building height usually have the higher wind potential density on unit of site area.

With limit of time, this research is far from perfection and needs a lot of work to improve, e.g. finding some idealized urban forms (with small modification from the real ones) with some similar urban morphological parameter values, in order to facilitate the comparison among different urban forms and evaluate the impact of morphological modification over the wind potential.

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Multi-criteria GIS Analysis Model for Determining Geothermal Capacity for Heating Systems in the Urban Core of Nis

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Abstract— **Transition of heating system in individual housing stock towards renewable energy sources has a considerable potential for improvement of the overall energy efficiency in Serbian cities. In line with Sustainable Energy Action Plan (SEAP) for the city of Niš, this paper proposes a conceptual model for determining the geothermal capacity for utilization in heating systems in individual housing in the urban core of the city of Niš.**

Keywords – GIS, energy efficiency, planning, Niš

I. Introduction

UN recognized energy security and transition to renewable energy sources (RES) as one of the 17 goals as well as one of the main challenges for sustainable development [1]. The European Union states introduced the strategy to increase the share of RES up to 20% by 2020 [2]. In line with EU energy strategy, Serbia subsequently has adopted National Renewable Energy Action Plan setting the frame for affirmation and utilization of RES in the transformation of national energy system [3].

Among other means of RES, because of its multiple benefits, geothermal energy (GE) is one of the most suitable, since it is fully environmentally friendly, renews quickly, and it can be exploited directly. Thus, geothermal energy lately gains more attention, since in many countries it contributes to the energy security by offsetting dependency on imported fuels. According to World Geothermal Congresses in 2015 (WGC2015), the growing awareness of geothermal heat pumps has boosted the direct-use of geothermal energy, with an increase of the annual energy use at a compound rate of 10.3%, compared to 2010, and installed capacity growth at a compound annual rate of 8.69%. WGC2015 survey estimates that geothermal (ground-source) heat pumps have the largest energy use and installed capacity worldwide that account for 70.90% of the installed capacity and 55.15% of the annual energy use, with an approximate US$ 20 billion investments in geothermal energy by 49 countries during the period 2010–2014, for both electric power and direct-use [4].

Development of the renewable energy sector in Serbia is in its infancy. RES potential in Serbia can cover ~50% of its primary energy needs, however, utilization of that potential is currently only 18% [5]. Despite the potential of RES, current energy production in Serbia is largely based on burning of crude coal.

Considering all RES, studies show that Serbia has favorable conditions for usage of geothermal sources at first place [6]. Serbia is well known for a great number of thermo-mineral springs, both in European and world context. Due to their generous chemical structures, water temperature and their effects on human health, they have been utilized for medical purposes for a long while [7, 8].

Geothermal flow in Serbia is mostly higher than 60MW/m2, which represents the average value of flow density in Europe. Approximations show that utilization of GE sources could replace at least 500.000 tons of imported fuels annually

(~10% of today's heating system requirements) [9]. The current utilization of GE in Serbia in terms of installed capacity and annual energy use are 116.543 MWt and 1808.808 TJ/year [10]. The total output of all geothermal springs in Serbia is 4000 l/s (Bašić 2009). With the estimated geothermal potential of 800 MWt, Serbia is placed among first 36 countries worldwide [11].

However, the utilization of GE mostly narrows down to balneology and recreational purposes, and to a limited degree in agriculture and heating systems [11, 12], harvesting only about 12% of total available potential [13]. In Serbia, about 25% of the existing boreholes, with a total capacity of 19 MW, are used, while the capacity of remaining 75% unused boreholes is estimated at about 54 MW [14]. Considering that, obviously, a huge amount of energy is literally wasted.

Looking at the demand side, the building sector is one of the greatest energy consumers worldwide. According to statistics, the share of building stock in energy consumption in EU is above ~40% with an annual increase of 0.6% [15, 16]. In Serbia, buildings consume ~50% of total produced energy, mainly for heating [17].

The share of heated objects connected to district heating systems in Serbian cities is less than 30%. The Larger part of building stock relies on household small-scale central heating systems, based on electricity or firewood and natural gas as a fuel. This system is characterized as energy inefficient and environmentally adverse [18]. Obviously, the introduction of a new means of the affordable and environmentally friendly system and decarbonization of existing heating systems are main challenges ahead. Harmonization of regulation with EU binding environmental and energy directives will influence the activity towards more sustainable energy policies and in Serbia.

Not all the cities in Serbia are in the proximity to high-temperature geothermal waters, but on the other hand, many of them are in the regions with ground waters of modest temperature levels, between 10 and 30◦C [19 - 21]. Even though, due to their lower energy potential, those waters can't be used for direct heating [22, 23], but with the application of appropriate heating pumps they can be efficiently utilized [24]. Considering also a constant decrease of initial investments of geothermal heating pumps and 50% lower maintenance costs compared to conventional systems [25], this system has a potential for increasing the utilization of GE in Serbian cities and contribute to the incremental aiding of the current energy system.

Along with the above-mentioned, we need more studies on the distribution of GE in an urban context and in relation to spatial disposition and typology of the built environment. Accordingly, this paper aims to contribute methodologically to the subject matter, suggesting a conceptual model for determining the geothermal capacity for utilization in heating systems in the urban core of the city of Niš.

II. STUDY AREA

Niš is the third largest city in Serbia, and as a center of the south-eastern region of the Republic of Serbia has a considerable share in Serbian economic and social development. It has 260,037 inhabitants, out of which more than 70% live in an urbanized area [26]. The city has experienced difficulty repositioning itself during the post-socialist transition and finding alternatives to urban models imposed by market-driven development. During the last two decades, urban core went through extensive infill development without any comprehensive urban development vision and energy efficiency related regulations, both at the urban and building scale [27]; thus, adding to already largely energy-inefficient housing stock.

In recent years, city officials showed some progress regarding energy policy. Niš was the first city in Serbia that adopted Sustainable Energy Action Plan (SEAP) in 2014 under the Covenant of Mayor's initiative [28]. The plan considers inventory of RES potentials, current energy consumption, and related environmental impacts by sectors, a framework for energy management until 2020 with emission scenarios, investment plan, and regulatory aspects. Thus, city officials show the political will to move forward towards energy resilient development. However, since 2014, very little has been done in relation to the planned activities.

Similar to other Serbian cities, Niš has high a share of heating produced directly from electricity ~30%, which is almost the same as the share of heat produced in district heating system and firewood, and relatively high emissions of carbon dioxide per kWh thermal energy (393 g/kWh). Annual energy consumption related to heating in 2010, for the total heating area of 7.105.600 m2, was 662.3 GWh. The analysis of spent energy in the subsector of collective and individual housing shows that with 58, 66 %, the share of energy consumption of single-family houses was ~30% larger than multi-story buildings. On the other hand, energy consumption of public buildings, which are mostly connected to district heating system, was 39.77 GWh [28].

Obviously, the transition of heating system in individual housing stock towards RES has a large potential for improvement of the city energy efficiency. However, except some studies related to the inventory exploitation of solar energy [29, 30], studies of other means of RES is largely missing, especially when it comes to spatially explicit studies.

III. MATERIALS AND METHODS

Geographic Information System (GIS) and geospatial modeling can be applied as a suitable tool in renewable data processing. For this modeling exercise, we used open source QGIS 2.18.5 software and applied inverse distance weighting interpolation method (IDW) for modeling of the inlet and outlet temperatures and the potential energy use. IDW is a type of deterministic method for multivariate interpolation with a known scattered set of points. Data used in this model are provided by private enterprise Geoprojekt d.o.o., Niš that conducted a survey of geothermal capacity for the installation of geothermal heating pumps at several locations in Niš for the private investors in period 2013-2015.

For calculation of the installed power of geothermal energy we used following methodology [31, 32]:

$$Q = FR_{max} \times \left[T_i - T_o\right] \times 4.184 \times 10^{-3} \quad , \quad (1)$$

where

Q - is heating power (MWt)

FR_{max} - is maximal discharge (kg/s)

T_i - is inlet (ThM) water temperature (^{0}C)

T_o - is outlet (ThM) water temperature of (^{0}C)

The total energy of (ThM) waters is given by the following equation

$$E_{use} = FR_{avg} \times \left[T_i - T_o\right] \times 131.9 \times 10^{-3} \quad , \quad (2)$$

where,

Ho_{use} - is energy use (Tj/yr)

FR_{avg}- is average discharge (kg/s)

In order to juxtapose obtained geothermal potential and typology of the built environment, we overlapped resulting maps with the satellite image of the urban core of the city of Niš, where the approximation of the typology of the built environment is outlined in three proxy clusters: low-rise housing area, high-rise housing area, and mix-use area. Thus, this allowed an understanding of the distribution of potential installed capacity in respect to particular housing type and assumed demand.

IV. RESULTS AND DISCUSSION

The analysis of the inlet temperatures showed that the inlet temperatures of the boreholes within the observed area range in the interval from 18 to 21.5°C, moving from the west to the east, with a rather balanced distribution of isolines following east-west direction. The average inlet temperature in the area is 19.4 °C.

Outlet temperatures are lower compared to the inlet temperatures, as a consequence of the geothermal gradient of the inlet temperature regime. Outlet temperatures of the boreholes within the observed area fall in the range between 15 to 19°C. The average outlet temperature in the analyzed area is 17°C in total. In comparison with the inlet temperature, the distribution of the outlet temperature has a slightly polarized gradient with higher temperatures at western and eastern extremes of the area that decreases towards the central part. A large share of the central area falls within the temperature gradient between 15 and 17°C.

Apart from the analysis of temperature, another important indicator of the physical characteristics of the geothermal waters is the water discharge in the boreholes, expressed in kg/s. The quoted parameter is used for the calculation of the geothermal energy capacity, i.e. installed power (Tj/year). When it comes to the discharge properties of the analyzed locations, most of them revel moderate to significant discharge. The range of discharge shows notable variability. It spans from 1.5 to 3 kg/s, with the average discharge in the area of 1.9 kg/s.

The summarized capacity of the installed power in Tj/year in the observed area is 5.37 Tj/year. The central isoline that reveals the capacity of 2 Tj/year extends along the north-east – south-west axis and divide the area on two gradients: 1) the south-east area with decreasing of potential installed power < 2 Tj/year, and north-west area with increasing potential installed capacity > 2 Tj/year. The biggest power capacity is 1.42 Tj/year at the location in Rašićeva st. while the lowest is 0.12 Tj/year at the location in Marina Držića st.

When it comes to a typology of the built environment we can assume in broad terms three categories for this exercise: 1) the areas that dominantly consist of low-rise buildings (e.g. single family houses or low-rise apartment buildings mostly relying on its own heating systems), 2) the areas that dominantly consists high-rise buildings (e.g. multi-story apartment or commercial buildings mostly connected to district heating system), and 3) mix-use areas that consist of the combination of first two categories (with combination of heating systems).

A large part of the observed area belongs to the first category (the area south of the railway corridor between Vojvode Putnika st. and the intersection of Mediana and Zorna Đinđića Blvd, housing area around Branka Miljkovića st. at the east and area between Obilićev venac st. and Sarajevska st. at the west). This area consists mostly of single-family houses that rely on independent household small-scale central heating systems, based either on electricity or firewood.

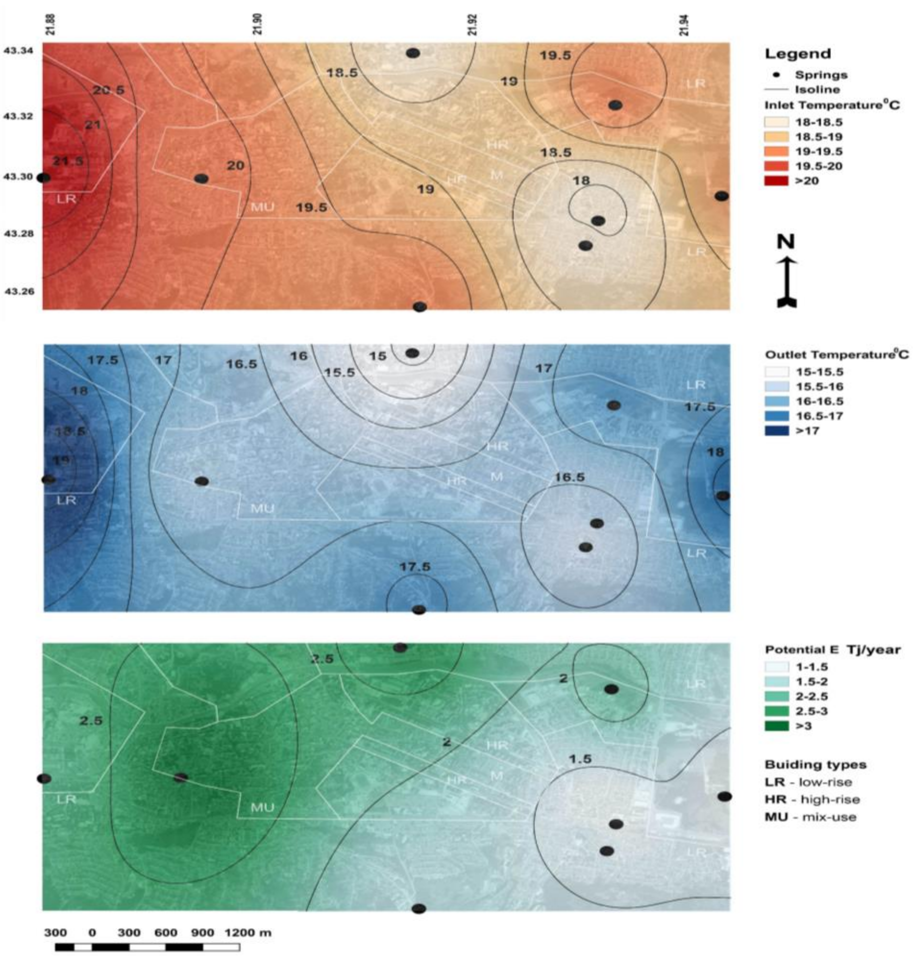

Figure 1. Dispersion of inlet and outlet temperatres and potential energy use in resepect to built environment.

According to the model, housing areas located eastwards of Kovanlučka st. (e.g. Rasadnik, Stara železnika kolonija, Kičevo, Obilićev venac) have higher GE potential raging between 2 and 2.5 2 Tj/year, in comparison with housing areas south of Dušana Popovića st. and in proximity to Branka Miljkovića st., with potential between 0.2 and 1.5 Tj/year. Potentially the highest installed capacity can be utilized in the low-rise and mix-use area with higher population density in the proximity to Obilićev venac st., with an average inlet and outlet temperature of ~ 20 °C and ~17°C. On the other hand, the model reveals the lowest capacity for the housing areas eastward of Gabrovački put, where the potential installed capacity is < 0.5 Tj/year.

When it comes to the category of the mix-use area, most of it is located in proximity to city center. It has slightly lower inlet and outlet temperature in comparison with the first category, while the potential installed capacity remains significant as in the case of the low-rise area.

Considering the fact that single-family housing sub-sector in Niš has a high share in total energy consumption for heating, it seems that large portion of it has suitable initial conditions for a transition towards geothermal heat pump system. All of the measured temperatures in the observed area belongs to the group of waters of modest temperature levels, between 10 and 30°C. Thus, different types of two-stage heat pump systems that are capable of bridging large temperature difference between the temperature of sub-geothermal water and the temperature requirement for hot-water heating will be the most convenient in this area. Study of two-stage cascade heat pump in Serbia has proved the system as satisfactory and has shown a high-grade energy efficiency [24]. Also, the same study argues for economic justification and pay-off period of 7 years of this system for an assumed intake well depth of 30m and sub-geothermal water temperature of 16°C and capacity of 218 MWh/year.

V. CONCLUDING REMARKS

The pace of transition towards RES in Niš is slow due to much financial, procedural, and political constraints. Between one-third and one-half of the total population lives in a high-density multi-story housing area that is connected to the district heating system that requires considerable investments for the transition towards RES, and thus, will highly likely remain unchanged for a long time. In this area, any adjustment of the heating system at the individual building level is hard to expect. Single-family housing sub-sector occupies the disproportionately large surface area where any large-scale extension of district heating system will be inefficient due to low population density. On the other hand, this sub-sector is suitable for interventions on the individual building level and installation of heat pump systems. Obviously, with slow-pace, this sector can on a case-by-case scenario improve its energy efficiency in this way. In order to aid this transition more structured database is needed to inform the decision of the private investors. Thus, the improvement of this kind of models is an objective need.

Given the tentative nature of the exercise, limited data sample, and fact that it is a conceptual model for determining the capacity for utilization of GE with respect to the built environment, any thorough conclusion will be highly arbitrary. However, the model generates a platform for further development since it offers an understanding of the potential for utilization of RES in an urban context linking the calculated installed capacity with potential target users. With a larger number of entry data points and finer categorization and inventory of housing types, it can provide a clear picture of the distribution of GE potential and help justification of investment at the individual level. Also, in methodological terms, it can contribute in the planning process in energy and urban design sector. Some further studies may consider the development of the model towards decision support system in this sector (e.g. in public participation process).

ACKNOWLEDGMENT

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Practical Example Of Significant Energy Savings Achieved By Optimal Reengineering In Pump Stations

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Abstract— **On the example of the small pump station "Mokra", this paper presents opportunities for significant electric energy savings, based on optimal reengineering of pump stations. Detailed description of the previous state in the pump station is given and problems identified during the initial testing of old pumps are presented. Considering collected data, appropriate pump units were chosen and installed in the pump station. After that, new testing was performed and its results clearly show that saving of almost 50% of consumed electric energy is achieved, for the same amount of transported water.**

Keywords – pumps, efficiency, reengineering, energy saving

I. INTRODUCTION

Water supply systems are usually very complex structures, containing large number of different elements built into them. It is important that all these elements are properly chosen and mutually harmonized, in order to achieve high energy efficiency of water transportation process. Beside pipelines, pump stations are the most important parts of modern water supply systems. Pumps installed in pump stations are usually driven by three phase induction motors, whose rated power can vary from several kilowatts up to several hundreds of kilowatts. Knowing that in a large system there are usually many pump stations included, it is necessary to perform system optimization in order to minimize electric energy consumption per volumetric unit of transported water.

Different types of algorithms and approaches for increasing of energy efficiency can be found in literature. In [1] and [2], authors suggest optimal reconfiguration of complex pipeline systems in order to achieve lower pressure drops and leakage reduction, considering that pump's performance curve is already properly chosen and that efficiency in the normal operating region is acceptable high. In [3], the multiobjective approach, which takes into account operation reliability and maintenance cost is presented, but again, the analysis is based upon assumption that pump's performance curves are good and equal to producer's catalogue curves.

In reality, actual performance curves can be notable different compared to those given in catalogues. The standard ISO 9906 [4] allows significant deviation from the rated performance curve, especially if pumps are classified as grade 3. Besides that, it is known from engineering practice that after long period of operation and numerous repairs performed on a pump, one can expect further deviation from the initial performance curve. As the rule, the performance curve is degraded, and the pump can't achieve values of head and flow that were available at the very beginning of exploitation. As a consequence, most of old pumps that are still in use have completely unknown performance curves and, as a rule, operate with low energy efficiency.

There are many practical examples showing that reengineering of existing pump stations, directed towards replacement of old pumps by new, appropriate chosen units, can lead to a significant increase of efficiency, as reported in [5] and [6]. In [7], we have described in details simple procedure that can be used for identification of any pump's actual performance curves and pipeline's characteristic. This can be considered as the starting point for any serious reengineering process, but also as the method for verification of gained goals in increasing of the energy efficiency. In this paper we present the application of the proposed approach in the pump station (PS) "Mokra" and the final positive results achieved by its optimal reengineering.

II. Description of the PS "Mokra"

The PS "Mokra" is located in the village of Mokra, Municipality of Bela Palanka. It was designed and built in year of 1982 to provide the needs of the Mokra village residents for water. Pumps inside the PS "Mokra" take small amount of the water flowing through the pipe connecting the capture of the Mokra spring to the main pipeline towards City of Niš. This means that there is an overpressure at the inlet side of the pumps, which is not constant but depends on actual state of the whole system. Usually, the value of the inlet overpressure varies between 1.1 *bar* and 1.4 *bar*. Water is being pushed towards the main reservoir of the village, with a total volume of 120 m^3. The PS "Mokra" is connected to the village reservoir via a pressure-distribution pipeline, which means that a part of the pumped water is directly distributed to consumers connected along the pipeline route, while the excess is stored in the reservoir. At the final part of the pipeline route (just before the flow into the reservoir), there is a branch on which a buster pump is installed with the task of pushing water towards the smaller reservoir of the second altitude zone of the village (volume of the reservoir of the second altitude zone is 15 m^3).

A. Previous state in the PS "Mokra"

The previous state of the interior of the PS Mokra is shown in Fig. 1. Until June 2017, in PS "Mokra" there were 2 pump units type VP50-3, manufactured by "Jastrebac", which were driven by three-phase induction motors with rated power of 11 *kW*. It has to be mentioned that these pumps were installed in 1982 and that they were repaired numerous times.

Figure 1. Interior of the PS "Mokra" - previous

In august 2016, authors had performed an experimental testing using methodology from [7], in order to identify actual performance curves and also the pipeline characteristic. Obtained results shown that performance curves of old pumps are extremely degraded compared to the catalogue curve, as presented in Fig. 2.

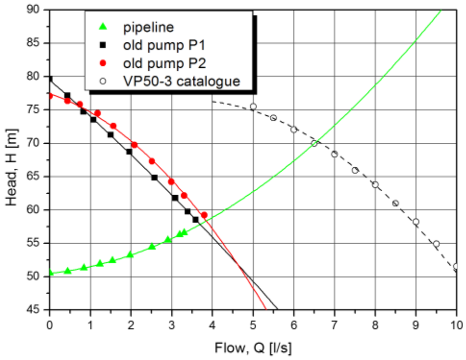

Figure 2. Performance curves of old pumps VP50-3

Calculated efficiency for both pump units (cumulative observed as pump+motor) was very low, and it did not exceed the value of 25%, even with fully opened valve at discharge side of a pump (Fig. 3).

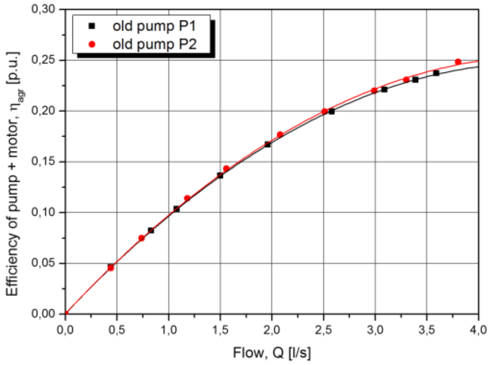

Figure 3. Efficiency of old pump units VP50-3

For purposes of analysis that is performed in section III of the paper, it is important to mention that with fully opened valve, the old pump P_1 was delivering flow of Q_{1old}=3.59 [*l/s*], consuming active electric power P_{P1old}=8.69 [*kW*]. Under the same conditions, the old pump P_2 was delivering flow of Q_{2old}=3.8 [*l/s*], consuming active electric power P_{P2old}=8.89 [*kW*].

B. *New state in the PS "Mokra"*

A detailed analysis of recorded data, including data from evidential book in the PS "Mokra", which shown that average consumption of water is 135 m^3 per day, led to the conclusion that the current needs of the Mokra village can be met with the use of pumps powered by 5.5 *kW* induction motors. The target operating point of the system with new pumps was defined as (5 *l/s*, 62.8 *m*). Two new identical pump units WILO HELIX V1607 were selected as the best solution for replacement of old pumps, and they were installed in the PS "Mokra" during the first half of June 2017. In addition, a complete reconstruction of the pump station's control and measuring system was carried out, by installing a new control cabinet with improved measurement and control functions. The new state of the interior of the PS "Mokra" is shown in Fig. 4.

Figure 4. Interior of the PS "Mokra" - new

Several days after the installation of new pumps, additional tests were carried out in order to approve that the new state, predicted through the process of optimal reengineering fulfill defined criteria. The testing procedure was identical to the one described in [7], but for the sake of better understanding of measured values, short description is given here.

The experiment was carried out in the following manner: after the pump P_1 was started, with the fully opened discharge valve, and the fully open main valve located in the PS "Mokra" yard, the gradual closing of the main valve had begun. A drain intended for chlorination of water that flows from the source of Mokra to the City of Niš was temporarily closed, so that the registered flow corresponds to the actual flow of the pump. The values of the obtained water flow $Q\ [l/s]$, the inlet pressure $p_i\ [bar]$, the discharge pressure $p_d\ [bar]$ and the active electric power taken from the electric grid $P\ [W]$ were recorded for each established stationary operating point. The experiment was interrupted after reaching the minimum flowrate Q_{min} = 1.35 *l/s*, and the main valve was returned to the fully open position. Measured results, together with the calculated values, are given in Table I.

TABLE I. VALUES FOR NEW PUMP P_1

measured				calculated		
Q [*l/s*]	p_i [*bar*]	p_d [*bar*]	P [*W*]	H [*m*]	P_h [*W*]	η_{agr} [*p.u.*]
4.95	1.05	7.3	5920	66.35	3221.9	0.544
4.35	1.05	7.95	5760	72.21	3081.3	0.535
3.72	1.05	8.5	5500	77.11	2814.0	0.511
3.25	1.05	8.9	5230	80.74	2574.1	0.492
2.42	1.05	9.4	4650	85.18	2022.3	0.435
1.81	1.05	9.6	4170	86.86	1542.4	0.370
1.35	1.05	9.6	3790	86.66	1147.7	0.303

The total head of new pump P_1 was calculated using formula

$$H\ [m]=(p_d-p_i)\cdot 10.2+H_g+\Delta H(Q), \qquad (1)$$

where H_g=-0.8 *m* represents the constant corrective factor caused by the fact that the inlet pressure sensor was placed 0.8 m above the discharge pressure sensor. The $\Delta H(Q)$ part of (1) represents the variable corrective factor dependent on flow and is defined as

$$\Delta H(Q)\approx 3.4\cdot(Q/4.95)^2\ . \qquad (2)$$

It is introduced due to local losses between the points in which the pressure was monitored, and is estimated on the basis of the known geometry of the pump station's armature, table values for local loss coefficients and information that at the flowrate of Q=4.95 *l/s*, the flow velocity through the DN100 pipe was v = 0.635 *m/s*.

Achieved hydraulic power of new pump P_1 was calculated as

$$P_h\ [W]=9.81\cdot Q[l/s]\cdot H\ [m], \qquad (3)$$

while the efficiency of a pump unit η_{agr} (pump+motor) was calculated as

$$\eta_{agr}\,[p.u.] = P_h[W] / P[W]\,. \quad (4)$$

Experimental identification of performance curves of new pump P_2 was performed in the same way, and results are presented in Table II.

TABLE II. VALUES FOR NEW PUMP P_2

measured				calculated		
Q [l/s]	p_i [bar]	p_d [bar]	P [W]	H [m]	P_h [W]	η_{agr} [$p.u.$]
4.82	1.05	7.25	5950	65.66	3104.9	0.522
4.25	1.05	7.85	5800	71.07	2962.9	0.511
3.92	1.05	8.25	5640	74.77	2875.4	0.510
3.26	1.05	8.75	5350	79.21	2533.3	0.474
2.43	1.05	9.3	4810	84.17	2006.5	0.417
2.01	1.05	9.45	4430	85.44	1684.7	0.380
1.56	1.05	9.45	4080	85.22	1304.1	0.320

III. DISCUSSION OF RESULTS

Numerical results from Tables I and II are graphically presented in Figs. 5 and 6.

Fig. 5 clearly shows that the actual performance curves of the new pump units P_1 and P_2 installed in the PS "Mokra" are approximately the same as those indicated in the manufacturer's catalogue. However, both are slightly lower than

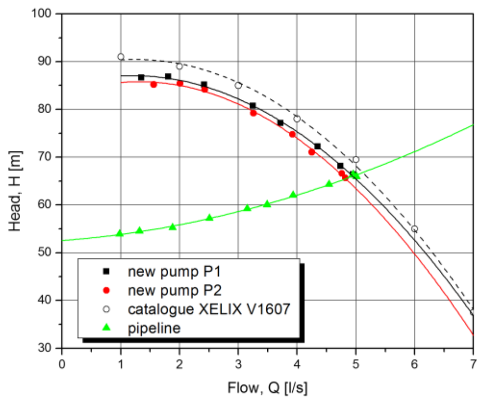

Figure 5. Performance curves of new pumps XELIX V1607

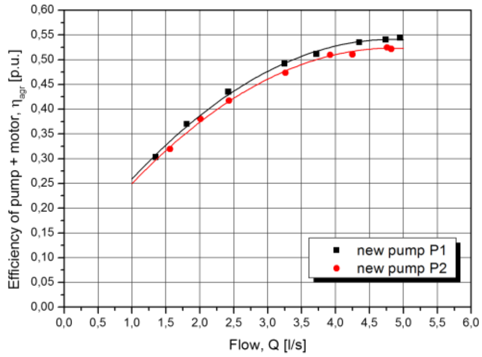

Figure 6. Efficiency curves of new pump units XELIX V1607

the expected values, which is not too surprising, knowing that the manufacturer states for these pumps that they are classified in class 3B, in accordance with standard ISO 9906. It can be noticed that the new pump P_1 has a slightly better performance curve than the new pump P_2.

The same fact can be observed in Fig. 6 which shows efficiency of both new pump units. Comparing Fig. 3 and Fig. 6, it can be noticed that significant improvement in efficiency is achieved by replacement of old pumps with new units.

The best way to perform comparison between previous and actual state in PS "Mokra" is to define specific consumption of active electric power per volumetric unit of transported water, S_c, with fully opened discharge valves (i.e. when there are no additional power losses due to partially closed discharge valve). Using data presented in section II, specific consumption of the old pumps can be calculated as

$$S_{cP1old} = \frac{P_{P1old}\,[kW]}{3.6 \cdot Q_{1old}\,[l/s]} = 0.6724\ [kWh/m^3] \quad (5)$$

and

$$S_{cP2old} = \frac{P_{P2old}\,[kW]}{3.6 \cdot Q_{2old}\,[l/s]} = 0.6499\ [kWh/m^3]\,. \quad (6)$$

Assuming that both pumps transported approximately the same amount of water (which is explained by facts that pump operation is managed by monitoring the water level in the main reservoir and that pumps are switched on alternately), the mean value of the specific consumption of the whole pump station with the old pumps can be estimated as

$$S_{c\_old} = \frac{S_{cP1old} + S_{cP2old}}{2} = 0.6612\ [kWh/m^3]\,. \quad (7)$$

Specific consumption of the new pumps can be calculated using data from Tables I and II and is defined by

$$S_{cP1new} = \frac{P_{P1new}[kW]}{3.6 \cdot Q_{1new}[l/s]} = 0.3322\ [kWh/m^3] \quad (8)$$

and

$$S_{cP2new} = \frac{P_{P2new}[kW]}{3.6 \cdot Q_{2new}[l/s]} = 0.3429\ [kWh/m^3]\,. \quad (9)$$

Further, the mean value of the specific consumption of the whole pump station with the new pumps XELIX V1607 can be estimated as

$$S_{c\_\mathrm{new}} = \frac{S_{cP1new} + S_{cP2new}}{2} = 0.3375\ [kWh/m^3]\,. \quad (10)$$

Finally, it is possible to determine ratio

$$\frac{S_{c\_new}}{S_{c\_old}} = 0.51\,, \quad (11)$$

from which is obvious that the acquisition of new pump units and their installation reduced consumption of the electricity used for the process of pumping water in PS "Mokra" to 51% of the previous one. In other words, after the process of optimal reengineering, extremely high saving in consumed electric energy is achieved. The same amount of water is being transported using 49% less electric energy than earlier.

Having in mind that average amount of pumped water in PS "Mokra" is 135 m^3 per day, annual savings of consumed active electric energy can be estimated as:

$$\Delta E = (S_{c\_old} - S_{c\_new}) \cdot 135 \cdot 365 \approx 16 MWh\,. \quad (12)$$

Such amount of savings is high enough to cover costs of performed reengineering in approximately two years, which can be considered as an extremely good investment.

IV. CONCLUSION

Presented results clearly show that the process of optimal reengineering of pump stations that are in use for the long period, can result in serious increasing of energy efficiency, and consequently, in significant savings of consumed electric energy. The amount of achieved savings can vary from one case to another, since performance curves of installed pump units are completely unknown after long period of operation. For that reason, it is proposed to perform initial testing in any pump station older than one decade, using the methodology applicable in real operating conditions. After analysis of obtained data, an optimal reengineering can be conducted, which will result in increased operational efficiency and reliability. Achieved savings in electric energy are expected to be enough high to cover costs of an investment during a period from 2 to 5 years.

ACKNOWLEDGMENT

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Calculations of Power Loss and Power Factor of Transformer on No-Load Operation

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Abstract— **This research focuses on the transformer no-load losses. Namely, when the transformer is operating at no load, the primary winding carries a small current which has a number of harmonic components. Therefore, in order to calculate the value of power and power factor it is necessary to use the appropriate mathematical analysis. This primarily refers to the harmonic analysis of both voltage and current waveforms. In this paper, the mathematical equations for active power calculations, as well as its implementation for transformer no-load loss calculations, are presented. The experimental results of both primary current and voltage waveforms are presented whereas the results of power and power factor calculations are discussed in detail.**

Keywords - transformer, no-load operation, losses, Fourier analyses.

I. INTRODUCTION

The transformers are one of the keys to allowing widespread distribution of electric power. Transformers efficiently convert electricity to higher voltage for long distance transmission and back down to low voltages suitable for customer usage [1, 2].

Transformers are basically designed to operate under rated frequency, rated voltage, and pure sinusoidal load current. However, in recent decade, changes in the type of loads, and especially increasing usage of power electronic devices, with their nonsinusoidal current waveform, have distorted the system voltage waveform as well. For that reason the impact of power electronics or nonsinusoidal current and voltage on the transformer operation has been investigate intensively in the past [3-7]. Some of papers deal with effects of current and voltage harmonics on distribution transformer losses [4-5]. On the other hand, the harmonic impact on transformer no-load losses is especially analyzed in [6-7]. The experimental study on the impact of voltage harmonics on the total harmonic distortion (THD) of current and losses of transformer is presented in [8]. General conclusion of all before mentioned paper is that the transformer efficiency decreases and transformer temperature increases with increasing harmonic distortion. Furthermore, the theoretical and experimental results presented in [3-7] clearly illustrate that the distorted supply-voltage waveform of the grid, caused by nonlinear loads, results in a notable increase of transformer no-load loss and on a significant increase of the magnetizing no-load current. The deterioration of no-load loss and magnetizing current depends not only on the amplitude of voltage harmonics but also on the phase of voltage harmonics relative to the fundamental.

However, the “nature” of transformer when operates with no-load condition also has a harmonic character. Namely, during no-load operation of transformer the primary current consists of many harmonics. This paper outlines an experiment that quantitatively analyzes the waveforms of one-phase transformer connections under steady-state no-load conditions while taking into account only ideal-sinusoidal voltage supply. Also, in this paper the comparison of power loss/power factor of transformer obtained by measurement and by computation taking into account numerical values of the phase current and voltage

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waveforms is presented. Furthermore, the impact of the phase voltage on the harmonic distortion of phase current will be, also, analyzed. It should be noted that the similar investigation are presented in [6, 9]. However, in [6, 9] the impact of the supply voltage on the harmonic distortion of the phase current is not analyzed. Also, the change of the power factor with supply voltage is not concerned in [6, 9]. On the other hand, in [9] three phase transformer is only considered.

In order to analyze the power loss of transformer at no-load condition, the mathematical calculations based on Fourier analyses need to be used [10-14]. For that reason in this paper is also given a short review about active power calculation.

This paper is organized as follows. In Section II the short description about the transformer no-load operation is given. The calculation of active power of signals which have a number of harmonic components is described in Section III. In Section IV the laboratory experimental setup, as well as experimental results of both the currents and voltages waveforms are presented. In this section the calculations of the power loss and power factor of transformer on no-load operation are also discussed. In conclusion the points of the paper are given

II. TRANSFORMER NO-LOAD OPERATION

A transformer contains two or more windings linked by a mutual field. The primary winding is connected to an alternating voltage source, which results in an alternating flux whose magnitude depends on the voltage and number of turns of the primary winding. The alternating flux links the secondary winding and induces a voltage in it with a value that depends on the number of turns of the secondary winding [1-2]. The equivalent circuit of transformer is presented in Fig. 1.

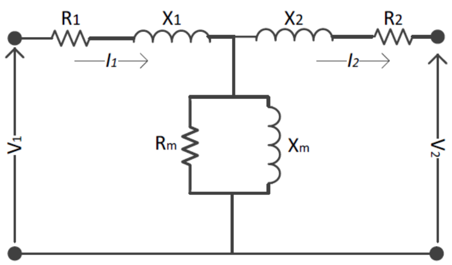

Figure 1. Equivalent circuit of transformer

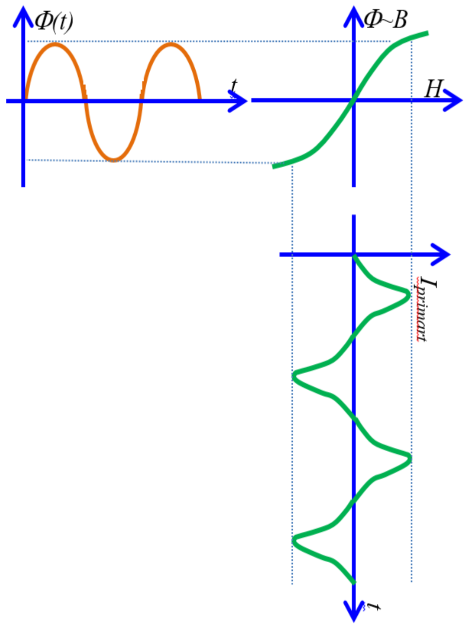

Figure 2. The flux waveform, B-H curve and primary current of transformer during no-load operation

When the transformer is operating at no load, the secondary winding is open-circuited. It means that there is no load on the secondary side of the transformer and, therefore, current in the secondary will be zero. However, the primary winding carries a small current, called no load current, which is approximately 2 to 10% of the rated current. It should be noted that this current is responsible for supplying the iron losses (hysteresis and eddy current losses) in the core and a very small amount of copper losses in the primary winding. However, at transformer no-load operation the value of the power factor is very low and varies from 0.1 to 0.15.

However, due to the nonlinearity of the B-H curve of the magnetic material, the primary current on no-load will not be a sinusoid but rather a certain distorted version, which is still periodic. Furthermore, the fundamental component of the phase current is out of phase with the applied voltage. The flux waveforms, B-H curve and primary current of transformer during no-load operation are presented in Fig. 2.

III. THE CALCULATION OF ACTIVE POWER

It is well known that quantities used in electrical power systems are defined for sinusoidal conditions [10-13]. However, active power has a clear physical meaning for sinusoidal. Namely, active power represents the average value of the instantaneous power over a fix period. On the other hand, under non sinusoidal conditions, some quantities, such as full –apparent power *S* or reactive power *Q*, can conduct to wrong interpretations [12-13].

The instant power *p(t)* for pure sinusoidal conditions is [14]:

$$p(t)=u(t)\cdot i(t), \qquad (1)$$

where *u(t)* and *i(t)* represent instant voltage and current respectively. If $u(t)=\sqrt{2}V\sin(\omega t)$ and $i(t)=\sqrt{2}I\sin(\omega t-\varphi)$, where *V* and *I* are the root mean square value of the voltage and current signals, eq. (1) can be rewritten in the following form:

$$\begin{aligned} p(t)&=u(t)\cdot i(t)\\ &=\sqrt{2}V\cdot\sin(\omega t)\cdot\sqrt{2}I\cdot\sin(\omega t-\varphi)\\ &=V\cdot I\cdot\cos(\varphi)\big(1-\cos(2\omega t)\big)+\\ &+V\cdot I\cdot\sin(\varphi)\cdot\sin(2\omega t) \end{aligned} \qquad (2)$$

The mean value of *p(t)* represents active power. The active power can be represented as:

$$\mathrm{P}=V\cdot I\cdot\cos(\varphi). \qquad (4)$$

The reactive power is defined as

$$Q=V\cdot I\cdot\sin(\varphi)\ . \qquad (5)$$

The full – apparent power represents the geometric sum of *P* and *Q*

$$S=\sqrt{P^2+Q^2}\ , \qquad (6),$$

while the power factor (cosφ) is defined as

$$\cos(\varphi)=\frac{P}{S}. \qquad (7)$$

On the other hand, if voltage and current signals contain harmonic components, then the active power can be represented by the following equation [14]:

$$P_1=\frac{1}{T}\int_0^T p(t)dt=\frac{1}{T}\int_0^T p_a(t)dt \qquad (8)$$

or

$$P=P_1+P_H. \qquad (9)$$

where p_a is part of the instantaneous power that is equal to the sum of harmonic active powers, P_1 is fundamental active power and P_h is harmonic active power [14]. The relation for power p_a is as follows:

$$P_a=V_0I_0+\sum_h V_hI_h\cos\varphi_h(1-\cos(2h\omega t-2\alpha_h)) \qquad (10)$$

where $P_h=V_hI_h\cos(\varphi_h)$ represents active harmonic power while $P_h\cos(2h\omega t-2\alpha_h)$ is intrinsic harmonic power.
On the other hand, fundamental active power is

$$P_1=\frac{1}{T}\int_0^T u_1\,i_1dt=V_1I_1\cos(\varphi_1) \qquad (11)$$

where u_1 is instantaneous voltage of fundamental component, i_1 is instantaneous voltage of fundamental component, V_1 je rms value of fundamental voltage component, I_1 is rms value of fundamental current component and $\cos\varphi_1$ is power factor of fundamental component. The harmonic power is,

$$P=V_0I_0+\sum_{h\neq 1}V_hI_h\cos\varphi_h \qquad (12)$$

In this paper, for power factor calculations we have used the method described in [15]. It method implies the usage of scalar product of arrays as follows:

$$\cos\measuredangle(U,I)=\frac{\sum_{i=1}^{n}U_iI_i}{\sqrt{\sum_{i=1}^{n}{U_i}^2}\sqrt{\sum_{i=1}^{n}{I_i}^2}} \qquad (13)$$

As the goal of this paper is to calculate the power loss of transformer during no-load condition, we will use eqs. (8-13).

IV. EXPERIMENTAL RESULTS

The laboratory experiment consists of performing the following steps: (a) record various currents and voltage waveshapes using an oscilloscope, (b) analyze the harmonic content of each waveform using a program developed in

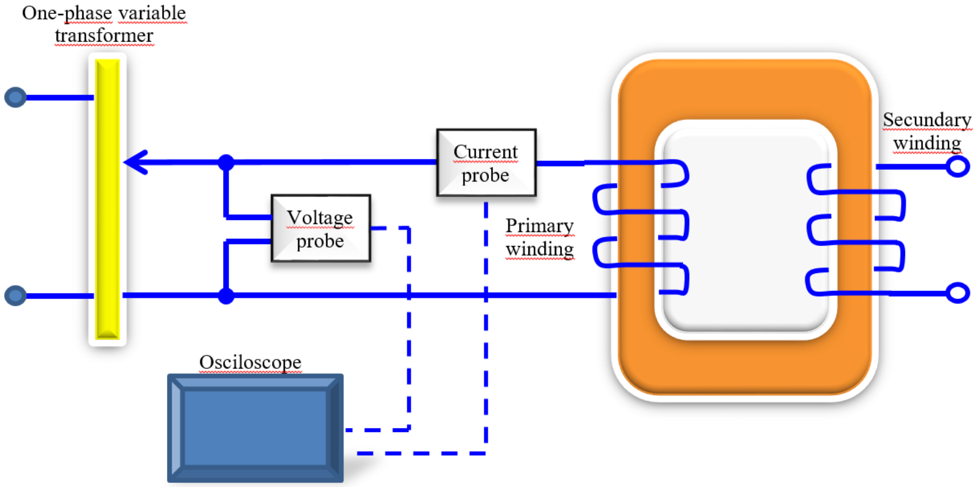

Figure 3. Block diagram of experimental setup

program package Matlab for harmonic analyzer, (c) calculation of power using eq. (13). The developed program, realized in program package Matlab, enables calculations of rms voltage, rms current, fundamental rms voltage, fundamental rms current, harmonic rms voltage, harmonic rms current, as well as of all active powers. It also enables determination of values of all harmonics of certain signal as well as their phase shift. The block diagram of the experimental setup is presented in Fig. 3, while the experimental setup is presented in Fig. 4. The experimental setup is composed of a one-phase transformer (2kVA, 220V/110V, 18A/9A), instrument Powertek ISW8001, one variable transformer (1kV, 10A), current probe, voltage probe, and an oscilloscope (Micsig tBook TO102).

The measured voltage – current characteristic of observed transformer is presented in Fig. 5a, while the measured primary voltage and primary

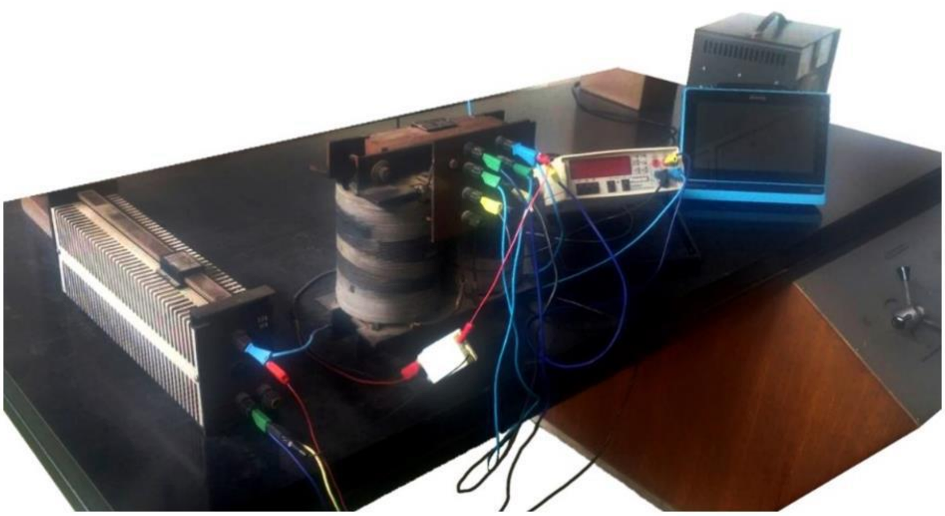

Figure 4. Experimental setup

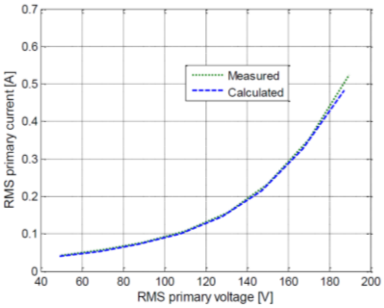

Figure 5. Measured and computed rms current-voltage characteristics of transformer on no-load

current waveforms are presented in fig 5b. In this figure is also presented computed voltage-current characteristic.

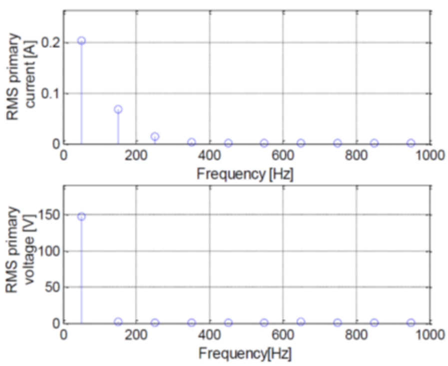

Figure 6. Harmonic content of primary current and primary voltage

As it can be seen from Fig. 5 certain deviations between measured and computed values are obvious, which is due to the fact that the measuring instrument takes into account only fundamental frequency – 50Hz. From this figure is, also, clear that the saturation of the magnetic material begins for voltage above 80V. The harmonic content of primary voltage and current, for supply rms voltage of 150V, is presented in Fig. 6. As it can be seen the primary voltage is almost without higher harmonics. However, the primary current, besides fundamental component, contains much expressed third and fifth harmonic components.

In Fig. 7, the total, fundamental and harmonic active power vs. supply voltage characteristics are presented. As it can be seen, harmonic power is very low. On the other hand, the value of harmonic power grows with increasing voltage.

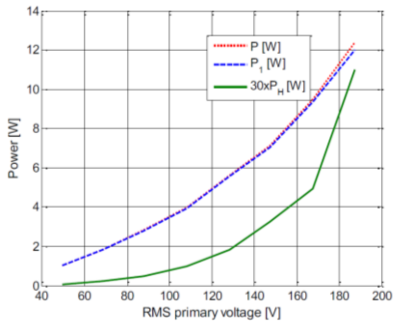

Figure 7. Total fundamental and harmonic active power vs. supply voltage

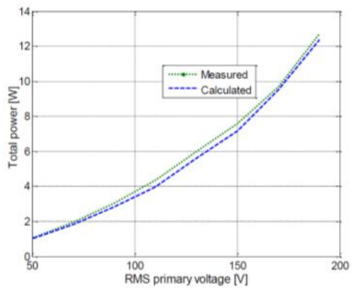

Figure 8. Comparison between the experimental-measured and calculated total no-load loss

Fig. 8 presents a comparison between the experimental-measured and calculated total no-load loss. The experimental-measured and calculated power factor vs. voltage characteristic is presented in Fig. 9. As it can be seen from Fig. 8 and Fig 9, the difference between measured and calculated power-voltage curve and power factor-voltage curve is about 8% and 0.5%, respectively. It can be concluded, even students use the instrument Powertek ISW8001 for realization of transformer no-load operation exercise, the accurate forming of no-load transformer characteristics required usage of mathematical analysis.

IV. CONCLUSIONS

In this study, a practical engineering analysis and method has been proposed for calculating the active power losses of transformer in no-load operation. The laboratory experiments enabled measuring the fundamental and harmonic power losses. It is shown that the impact of the harmonic power is very small, but for larger power transformer the special attention should be paid to that investigation.

In the future work, the primary current and voltage total harmonic distribution (THD) will be analyzed. Also, the value of the reactive power change and it harmonic content during transformer no-load operation will be discussed.

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Thermal Imaging Assessment of Energy Efficiency

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Abstract— **Modern thermal cameras with cooled detectors in the focal plane array, so-called cooled thermal cameras, have until recently only been used for military purposes. Now, however, there are increasing civilian applications. The characteristics, advantages and shortfalls of thermal cameras are presented in the paper, along with the most suitable operating modes for generating high-quality thermal images. The objective of the research is to determine their applicability for energy efficiency assessment in various industries.**

Keywords- IR thermography; Thermal image; Focal Plane Array (FPA)

I. Introduction

Although thermal cameras were originally used for military purposes, they immediately attracted interest because of their wide applicability in the construction industry, virtually all segments of manufacturing and energy, human and veterinary medicine, geology, mining, scientific studies, and even areas like cultural heritage research [1-7]. Thermal imaging is becoming increasingly important due to the constantly improving quality and affordability of thermal cameras. Of special interest are modern cameras with infrared (IR) detectors in the focal plane array (FPA), cryogenically cooled, which are often referred to as thermal cameras with cooled detectors or simply cooled thermal cameras [8]. Apart from military, research, and development applications, these cameras are becoming increasingly suitable for thermal imaging in various industries and will likely play a role in the area of energy efficiency. However, given their still extremely high cost, and in addition to assessing whether they can be used for a given purpose, it is extremely important to determine their best operating mode. In view of the fact that mostly FLIR cameras are commercially available in Serbia, a modern "non-commercial" camera of this type is used as an example to assess its applicability to energy efficiency.

II. Main distance measurement problems

The IR wavelength in the electromagnetic spectral range from 800 nm to 1000 μm, invisible to the human eye, is extremely important in science and technology because the main distance measurement problems – locating of warm objects and gases – are solved in that very range. This is the reason for the significance of conversion of spatial distribution of IR radiation into a visible (thermal) image, enabled by modern thermography. Namely, the gas composition of the Earth's atmosphere (78% nitrogen, less than 21% oxygen, and about 1% of all other gases along with aerosols and dust) is such that it absorbs and scatters nearly all IR radiation. However, there are wavelengths where the attenuation of IR radiation is poor. Better transmission of this radiation in the range 1.5–2 μm (first atmospheric window), 3–5 μm (second atmospheric window) and 8–14 μm (third atmospheric window) is attributed to the selective nature of absorption of radiation and continual scattering according to Rayleigh's law [9]. It follows from Planck's radiation law that suitable thermal imagers can be used in the first, second and third optical window to also detect bodies whose temperatures are 1100–1200ºC, 500–600ºC and 30–40ºC, respectively. This is extremely important when thermal imaging assessments are made at large distances which, depending on the requirement, can be even up to 10 km.

III. THERMAL IMAGING METHODS

Thermography is a contactless method for assessing temperatures and recording the temperature distribution on the surface of an object. The end result is a thermal image (IR frame). An example of a thermal image that shows how much a structure is heated is given in Fig. 1. The method is not intended to accurately determine the temperature of the test object, but only to provide insight into the surface temperature. Depending on the measurement approach, there is passive (qualitative) and active (quantitative) thermography. In the former case, the temperature of the test object is only compared to ambient temperature, whereas the latter involves external heating of the test object to monitor the dynamic behavior of temperature. There are numerous advantages of thermography in addition to contactless measurement, such as non-destructive testing; remote measurement; real-time measurement; two-dimensional measurement; and, in the case of the passive method, no disturbance of the heat balance.

However, the method also has certain shortfalls: dependence on the surface properties of the test object (emission, reflection, transmissivity) and the distance of the object from the camera; only surface temperature is measured; and, in the case of outdoor measurement, climate conditions (such as air temperature and humidity) are also a factor.

Figure 3. Thermal image showing the temperature of a structure [10].

IV. MODERN THERMAL CAMERAS

For temperature measurements of heated objects to be of satisfactory accuracy, in cases where the temperature gradient is not high compared to ambient temperature, the IR detectors in the FPA need to be cryogenically cooled to the temperature of liquid nitrogen. This is what makes fabrication of such thermal cameras extremely complex and costly. Quality temperature measurement in the second and particularly the third atmospheric window necessitates thermal imagers that involve cryogenics. Modern cooled cameras also include readout integrated circuits (ROIC), which enable adjustment of the integration time [11]. A short integration time, less than a microsecond, is extremely important where thermal cameras are used to monitor large temperature range fluctuations. Variation of the integration time automatically changes the temperature range. In addition, ROIC supports operation in the linear mode, which has not been the case in the past, and the main advantage of this mode is avoiding blurring of thermal images – a frequent occurrence when rapid dynamic processes, such as fast movement or vibration, are captured. In other words, thermal cameras are suitable for monitoring the development of a rapid thermal process. Namely, such cameras feature the highest sensitivity, accuracy, spatial resolution and thermal image generation speed, while the applied cutting-edge CNUC™ & Hipercal™

Figure 1. Non-commercial thermal camera FLIR SC720

technologies enable noise correction, as well as selection of a broad dynamic range.

One example of a modern non-commercial cooled thermal camera is FLIR SC720, shown in Fig. 2.

TABLE I. THERMAL CAMERA FLIR SC720

Integration Time	500 ns to Full Frame rate, with auto exposure
Accuracy	±1°C or ±1% of Reading
Standard Temperature Range	+5°C to +300°C
HD Video	DVI 1080p
Focus	Automatic or manual
Available optics	50mm - 11° x 8.8° - USL Motorized
Camera f/#	3.0 for X6540sc
Weight w/o Lens	5.05 kg
Filtering	4× Position Motorized, with drift compensation and automatic identification
Synchronization	Modes IRIG-B; Sync In, Trigger In
Command and Control	Gigabit Ethernet, Camera Link, Detachable LCD Display, WiFi
Digital Data Streaming	Simultaneous Gigabit Ethernet and Camera Link Base Camera Link Medium
Thermal sensitivity (NETD)	<25 mK
Integration time	160 ns to 20ms
Field of view	Depend on lens 12mm-44°x34°-USL Motorized 25mm - 22° x 17° - USL Motorized 50mm - 11° x 8.8° - USL Motorized 100mm - 5.5° x 4.4° - USL Motorized 200mm-2.75°x2.2°- USL Motorized Close up x3 - 3.2 x 2.6m
External trigger	Manual or Auto (USL mechanism)
Interfaces	WiFi, GigE, Camera link, DVI, BNC
Resolution	640 x 512 Pixels
Frame Rate	Up tp 355 Hz (Full Frame Mode) Up to 4500 Hz with Windowing (320 x 8 Pixels)
Temperature Range	-40 °C to +1500 °C
Spectral range	7.5 - 13 μm
Image frequency	30 Hz (60 / 120 Hz with windowing)
Focal Plane Array (FPA)	Coooled Semiconductors

Some of its most important features are presented in Table 1. This camera operates in the spectral range 1.5 – 5.1 μm and is therefore intended for the first and second atmospheric window. It is also possible to vary parameters while the camera is recording. It supports efficient assessment of temperatures from 5 to 300^{o}C. The cryogenic technology allows cooling of IR detectors with 50 mm optics and 11° × 8.8° field of view. The integration time can be varied from 3 μs to 20 ms and it is possible to do so in 1 μs steps. The noise equivalent temperature difference (NETD) is less than 25 mK.

Apart from military uses, such as to detect troops and vehicles, these cameras are extremely suitable for scientific, research, development and industrial applications.

V. THERMAL IMAGE QUALITY

In parallel with ongoing technological advances that lead to increasing quality of thermal images (which can be in color or gray scale), attemtpts are being made to refine thermal image processing methods (analysis). High-quality thermal images can provide insight into the presence and size of defects, which are one of the most frequent causes of heat loss or breakage. For example, ASTM defines a standard thermal imaging method for locating places where there is layering of joints in materials [12]. Namely, where the surface temperature of a test object is assessed by active thermography and when subsurface defects invisible to the eye are detected (which as a rule lead to the loss/release of heat), after the object is heated the thermal images show for a while the defects responsible for heat loss. However, the number of frames that show a defect and the sharpness of its contour are determined by both the characteristics of the camera and adequate selection of parameters. The decisive parameters are generation frequency and integration time. Several recording sessions should be undertaken in identical experimental conditions, but at different integration times, in order to compare thermal image quality or, in other words, to determine the location and size of the defects as clearly as possible [13]. The integration time is in effect the detector exposure time (the time the detector is exposed to receive signals from the environment). The integration time is directly coupled by means of software to the temperature range in which the thermal camera operates. Namely, a long integration time means that the detector will capture energy signals from the environment over a longer time period and will thus be able to detect lower temperatures. Conversely, a short integration time enables detection of higher temperatures. Therefore, in order to detect higher temperatures in the environment, the integration time needs to be shorter, and vice-versa. The integration time, temperature range and active detector surface are therefore directly coupled with the thermal imaging frequency. Other important experimental parameters in thermal imaging include the distance of the thermal camera from the test object surface, its orientation towards the object, ambient temperature, transmission, humidity and emissivity of the object.

The above mentioned thermal camera allows the active detector surface to be: 320 × 256 pixels, 160 × 128 pixels, 64 × 120 pixels or 64 × 8 pixels. An acquisition speed of 1500 Hz can be achieved by shortening the integration time and reducing the active detector surface. Even though the camera can acquire signals of 1000 Hz, it is not possible to achieve this speed at an ambient temperature of about 20^{o}C.

VI. Conclusion

Thermal imagers are widely used in the area of energy efficiency, to detect temperatures and defects in materials, as well as to monitor and support maintenance of costly manufacturing equipment. In addition to the application of existing “commercial thermal imagers”, a decrease in price will make the use of “thermal cameras with cooled FPA detectors” unavoidable. Namely, thermography, as a contactless method for remote temperature assessment of objects in real time, is increasingly used for nondestructive testing and evaluation (NDT&E) of material uniformity, as well as testing of thermal and physical properties of objects and materials.

Thermal cameras with cooled FPA detectors are of special interest as they are intended to operate in the third atmospheric window (i.e. spectral range from 8 – 12 μm), where the temperature gradient between the ambient temperature and the temperature of the test object is extremely small. These thermal cameras are the most sensitive to temperature differences which are sometimes equivalent to noise in that range.

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Analysis of a Survey on Energy Efficiency, Case Study - City of Niš

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***Abstract*—The average energy consumption in residential buildings in Serbia is higher than in developed European countries. Final energy consumption in the Republic of Serbia tends towards scenario which involves application of energy efficiency measures. The survey was conducted with purpose to analyze public awareness of: the importance of energy efficiency; the possibility of financing activities related to energy efficiency; the importance of energy savings and ways that lead to savings and about the impact of energy efficiency on the environment, and to motivate the respondents for better energy saving**

Keywords- energy efficiency, survey, energy savings

I. INTRODUCTION

The average energy consumption in residential buildings in Serbia is over 150 $kWhm^{-2}$ per year, while in developed European countries it is about 50 $kWhm^{-2}$ per year [1]. This fact forces Republic of Serbia to intensify activities on achieving the standards that apply in the European Union. Technology development has enabled more efficient use of energy and consequently proactive approach to solving the problem of energy efficiency. The term energy efficiency implies using the smaller amount of energy (energy sources) for completing the same function (heating or cooling the space, lightning, production, vehicles etc.). It is important to emphasize that energy efficiency doesn't mean energy saving. Namely, saving implies certain giving up, while efficient use of energy never disrupts working and living conditions [2]. Today the world faces two major energy problems. The first is the energy deficiency and uncertainty in supply and other is the environment pollution and climate change caused by irrational energy consumption. Today, energy is mostly derived from non-renewable energy sources. The world is facing energy source depletion, which in turn increases the price of energy sources and the degree of pollution of the environment [3]. Monitoring of the parameters of electric energy consumption and managing the operation of electric devices present a great potential for reducing the consumption of electric energy. Final energy consumption in the Republic of Serbia tends towards scenario which involves application of energy efficiency measures. It is expected that economic development of the country, including the anticipated reindustrialization will inevitably lead to increased energy demand. Therefore, it is necessary to ensure that energy intensity indicators aim at European Union countries average values through intensive application of measures and procedures for increasing energy efficiency [4].

Focus of the research was on: public awareness of the importance of energy efficiency; public awareness of the possibility of financing activities related to energy efficiency; user knowledge about the importance of energy savings and ways that lead to savings; user knowledge about the impact of energy efficiency on the environment and motivating the respondents for better energy saving.

The aims of the research were: to develop a mechanism that would provide permanent reduce of energy consumption in households through new designs and application of new systems of energy consumption control and management, to evaluate the public knowledge of the specified area and the possibility of placement a new product -home automation.

II. Methodology of the Research

In this research, the questioning method was used as a way of collecting primary data and information (motives and opinions). The main subjects in the questioning were the respondent and the examiner [5,6].

A combination of personal communication, using the technique of individual testing, that is, structured personal communication and correspondence communications was used. The respondent filled out the printed questionnaire in the presence of an examiner who, in cases where necessary, provided additional explanations. For questions of closed type, previously prepared answers were offered, providing respondents the possibility of multiple choices. Also, a certain number of questionnaires were distributed by intermediators to respondents from higher education institutions (students and teaching staff).

The survey was conducted on a representative sample consisting of 101 people from the territory of the city of Niš: 40 adult women and 61 adult men. Among the respondents, the largest percentage were young people aged 20-30 (77.23%), and a significantly lower percentage of respondents were "middle" and "older" persons of male and female gender.

Respondents were answering the following 19 questions:

Question no. 1. Gender

Question no. 2. How old are you?

Question no. 3: Do you know the meaning of the term "energy efficiency"?

Question no. 4: Is energy efficiency personally important to you?

Question no. 5: Do you take care of energy savings?

Question no. 6: Are you trying to save energy in your household and reduce costs?

Question no. 7: Do you know how you can reduce energy costs in your household?

Question no. 8: Is energy efficiency related to environmental protection?

Question no. 9: Please evaluate your contribution to energy efficiency and environmental protection

Question no. 10: Effective energy efficiency measures

Question no. 11: In your opinion, to what extent does your home meet the criteria of energy efficiency?

Question no. 12: Do you know what the energy class of an electrical device is and how it is checked?

Question no. 13: Do you use some energy saving measures in your household?

Question no. 14: What types of renewable energy sources are you familiar with?

Question no. 15: In your opinion, which of the listed factors has the greatest impact on energy efficiency (peoples' habits; laws and standards; technology and technical solutions of processes or financial support)?

Question no. 16: In your opinion, what is the average return period for investments in measures for increase in energy efficiency?

Question no. 17: If there are any, what are the reasons that prevent you from saving energy?

Question no. 18: To what extent did this survey motivate you to save energy in your household?

Question no. 19: In the future, will you continue to save energy in every possible way?

III. Results and Discussion

The results of the study showed that the majority (65.35%) of the total number of respondents felt that they fully understood the meaning of the term "energy efficiency." Male respondents in higher percentage (70.49 %) declared that they fully understood the meaning of this term. Respondents, both male and female, were familiar but still insufficiently with the term of energy efficiency and this insufficient knowledge of the respondents indicated that they could not determine which answer to choose.

For most respondents (63.37% of the total number), energy efficiency wais important or partially important, while the percentage of respondents who considered this problem to be irrelevant was negligible. There were no significant differences at the gender level. A large percentage of the total number of respondents (78.22%) thought that they took care of energy savings, from which 87.50% women pleaded to have considered savings while the percentage of men with such an opinion was 72.13%. A significant percentage of the total number of respondents (87.13%) made efforts to save energy and thus reduced costs in their home budget, where female respondents were in the forefront in saving efforts. An extensive awareness of measures for energy savings and energy saving effects, which will lead to an even higher percentage of energy-dependent respondents is needed.

As an answer to the question "Do you know how to reduce the energy costs in your household?" relatively small percentage of the total number of respondents (32.67%) said they knew precisely in which ways it was possible to increase energy efficiency, that is, to reduce energy costs in their households. Male are somewhat less informed in compare to female respondents and have given unreliable answers such as they “think they knew” what ways could be applied in order to increase energy efficiency. This result clearly indicated that the respondents were familiar with certain savings measures, but also that they were uncertain about their knowledge of energy savings in general.

On the other hand, the respondents understood the ecological principles and the natural relationship between energy efficiency and environmental protection. The results obtained among both genders showed a high level of certainty that energy efficiency is related to environmental protection, with exception of one male respondent who considered that there was no connection. When assessing their contribution to energy efficiency and environmental protection, the results showed almost no difference between the genders. The largest percentage of the total number of respondents (52.48%) considered their contribution to energy efficiency increase to be partial, while a significant percentage (25.74%) considered it insufficient. It is obvious that the public self-critically accessed the subject matter. Therefore, it is necessary through an educational approach, to increase the percentage of those who can significantly contribute the increase of energy efficiency and environmental protection.

By ranging offered answers to the question of efficiency measures by energy saving effects, obtained results indicated the importance of each energy efficiency category (Table 1, Table 2).

TABLE I. RANGING OF ANSWERS ON EFFICIENCY MEASURES BY SAVING EFFECTS FOR MEN

measure / grade	heating of object	quality joinery	the use of EE devices	the use of EE boilers	The use of LED lightning	Implementation of home
1	4	19	2	3	12	14
2	8	9	6	8	12	12
3	9	5	15	13	7	8
4	17	7	16	10	6	7
5	15	10	5	12	12	4
6	12	4	11	10	6	11

TABLE II. RANGING OF ANSWERS ON EFFICIENCY MEASURES BY SAVING EFFECTS FOR WOMEN

measure / grade	heating of object	quality joinery	the use of EE devices	the use of EE boilers	The use of LED lightning	Implementation of home
1	3	13	1	2	13	6
2	7	5	7	3	7	9
3	4	5	7	10	9	4
4	9	3	11	7	1	6
5	2	8	8	10	6	6
6	13	5	5	4	3	7

Responders were quite insecure regarding to the most significant measures for energy saving. There were no major deviations in gender-level ranking. It is noteworthy that the measure of introduction of a home automation system was at second place by importance, after the measures for improving the heating of the building. This data was obtained by rating the measures based on the number of highest grades, taking into account the responses of all respondents, both male and female. For the purpose of better informing of the public, it is necessary to systematize the public knowledge about the significance of the measures taken to increase the energy efficiency in facilities and to explicate the information placed to the public from different sources. That way it would be possible to enlarge the potential market for the introduction of the concept of "smart home".

Regarding the respondents' opinion on the extent to which their homes meet the energy efficiency criteria, majority of the total number of respondents (60.39%) thought that their homes are partially energy efficient, but there was also a significant number of those (21.78%) who thought that their homes are inefficient or not effective at all (6.93%). The public should be met with the importance of applying different energy saving measures and the effects of their implementation, as well as different forms of financial support, in order to use public image on this issue.

Analysis of the survey showed that it is essential to educate respondents about energy classes and the significance of the use of energy efficient devices. The knowledge of respondents about the energy classes of the device showed that a higher percentage of respondents of both gender (57.43%) didn't not know the meaning of a term nor how to check the energy class of an electrical device.

The majority of respondents both male and female stated that they applied turning off lighting and electrical devices as a primary measure of energy saving in their homes, followed by monitoring the daily electricity tariffs, which are traditionally effective but also the simplest measures. It is important to note that a higher percent of men (57.38%) than women (27.50%) recognized isolation of the building as a saving measure.

The respondents of both genders almost equally gave answers about the different types of renewable energy sources. The public is generally well aware of the different types of renewable energy sources. The obtained results showed that the solar energy was the most famous renewable source of energy, followed by wind energy and hydropower, then geothermal sources and biomass.

It is important to analyze the opinions of the respondents about the factors that affect the energy efficiency the most. The highest percentage (44.68%) of female respondents thought that people's habits are the factor that has the greatest impact on energy efficiency, which is, right after, in their opinion equally affected by technology and financial incentives. Male respondents (28.99%) considered financial incentives and people's habits equally important. There were no major differences between genders when it comes to laws and standards as well as technology and technical process solutions as factors. When compared to a survey from 2013 [7], majority of respondents believed that the investment in technology and changing people's habits may contribute the energy efficiency in Republic of Serbia, while most respondents had no knowledge of existing funds for financing projects for improvements in energy efficiency. It is necessary to present to the public the possibilities of technological solutions in increasing energy efficiency, the possible ways of financing and the positive effects of the implemented measures.

In addition, it necessary to present to the public various forms of investment and time periods in which it is possible to recover the invested funds as well as the effects of the measures taken in future. Special attention should be paid to the possibility of introducing home automation and all the benefits provided by the concept of "smart home", especially emphasizing the fact that the investment return period in this case is the shortest (1-2 years).

The largest percentage of the total number of respondents (39.60%) believed that the average investment return period of implemented measures for increasing energy efficiency was 4-7 years, which was the optimal period. A significant number of male respondents (34.43%) thought that this period was longer (7-10 years) while a significant number of women (30.77%) thought that the invested funds could be recovered in a shorter period (2-4 years).

What prevents people to save? The answers to this question by male and female showed significant difference when the first two options were in question (30.19% of male respondents from the total number of male respondents and

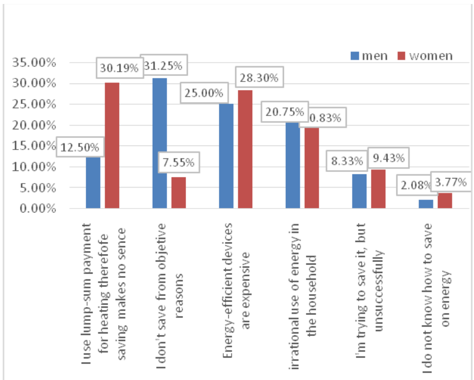

Figure 1. Graphic presentation of answers on question no. 17.

12.50% of women in relation to the total number of women), while in others there were no major deviations between genders (Fig. 1). It is significant that more than a quarter of the total number of respondents considered that one of the reasons they didn't save energy was that energy efficient devices were expensive. The percentage of respondents who did not know how to save energy was negligible. Educational and promotional campaigns which emphasize all technological possibilities of today should be brought closer to the public, thus explaining that their reasons for not saving energy are not always objective.

Using targeted and well thought-out questions it is possible to further motivate the public about energy savings in their household. The highest percentage of the total number of respondents (65.35%) believed that they were saving energy, but after the survey, they would save energy more consciously. Just over a quarter (27.72%) of respondents were not motivated by the survey to save energy, while 6.93% of respondents were not even thinking about energy savings before the survey. There were no significant differences between genders. In order to increase the consciousness and knowledge of the public in the field of energy efficiency, it is necessary to significantly increase the implementation of such actions at all levels (local self-government, non-governmental sector, clusters, associations, economic entities, etc). This is supported by the fact that a large percentage of the total number of respondents declared that they would continue to save energy in every possible way (69.15%) or at least in some (29.21%) in the future. This attitude is almost equally shared by the respondents of both genders.

IV. CONCLUSIONS

Respondents generally stated that energy efficiency in the house was something very important (63.66%), or partially important (32.67%) for them and had a general idea of how to increase it, but unfortunately, only declaratively, because only 28.57% were compelled to take appropriate measures and only few of them actually applied them.

Surprisingly, there is a lack of knowledge among young people (students) about the benefits of energy efficiency in the country and its impact on the environment. There is some passivity and indifference about the future by the younger population. The reason may be the lack in educational system and the lack in a strategy of governmental and non-governmental organizations for work with youth on the topic of energy efficiency.

The survey reveals that the lack of knowledge about the benefits and effects of energy efficiency in homes make people passive in seeking information about different forms of efficient heating, lighting, cooling, etc. Indicative is the fact that most people make efforts to save energy, but only half of them will do it in ways that do not require higher funding. Despite the existence of an incentive program by the central government and other financial resources, a large percentage of people in these regions were not aware of its existence.

People understood the importance of energy efficiency and were aware that they should do something about it, but the opinions and ideas of how to implement it differ. Education is needed on how to achieve better results with less financial resources. All population categories in the city of Niš need more knowledge and consulting help in order to be able to work out multiple problems of poor design and obsolete technology in their home and the limited financial resources they have.

However, the general impression is that most respondents do not consider the issues of energy efficiency to be the priority, and in most cases, they are not able to specify the key parameters related to the energy they use in their homes. According to observers in the field, only 4-5 for every 20 respondents showed closer interest in energy efficiency issues, demonstrated knowledge on this topic and pay attention to specific parameters related to the use of energy in their homes.

Most respondents clearly showed interest in solving energy efficiency problems in terms of improving the current picture of energy use, especially in the buildings they live in. This in fact shows that most consumers believed that increase of personal actions will lead to improved energy efficiency in their homes.

Lack of knowledge about the main energy parameters among respondents resulted in longer duration of individual interviews and data verification.

During the field work, a significant number of sustained respondents were noted, which required more time for the interviewers to verify that the respondents would provide the answers to a questionnaire. This behavior was probably caused by a lower interest of certain categories of respondents in energy efficiency issues, and therefore a reduced attention to the details defined in the questions prepared in the questionnaire.

The final analysis of the survey, however, showed that the issue of energy efficiency in the territory of the city of Niš is current and that in the future citizens will start to actively manage the use of energy, and consequently, begin to pay attention to each specific energy parameter.

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Risk Management in Market Operations of Electrical Industry

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Abstract—**Altogether dissertation is a modest contribution to risk management, which is a central issue of the practice of engineering, business. The electricity market business brings new uncertainties and risks. Shareholders have various interests and see risks differently. There are many debates on the financial risk, but it is important to also talk about the risks in immeasurable monetary units. To understand the problem of multiple criteria, various tools and techniques were used in order to solve the problem of power system planning, concept of optimization is conflated with the concept of compromise.**

What in fact is the risk?

The risk is the danger which may be exposed due to the uncertainty. The risk is also related to the decision. Where there is uncertainty and there are no alternatives, there is no risk, for example, there is no risk of death, because death is inevitable and nothing can be done so that it does not happen. But, time, place and the way of death are uncertain.

The choices we make can affect the uncertainty and may reduce or eliminate hazards. Some of these risks include economic components, e.g. compensation costs due to premature death in a car accident. For other hazards, economic aspects are secondary. For example, lifestyle will reduce the risk of immobility in a hopeless state when recovery is impossible.

Surely we can talk about uncertainties. What can be said and what it means depends on the uncertainties and their impact. The largest number of power system analysis is based on a probabilistic or unknown, but well limited model. The third model that is completely unknown is also important. The following figure shows the probabilistic model of the transmission capacity between the two regions. The diagram is based on the simulation of production and network status.

Keywords - risk, robustness, probability, exposure, regret, uncertainty, quantifying the risk

I. INTRODUCTION

Robustness, a basic measure of risk, is probability that we will not regret because of the certain decision. Robustness can be imagined as a feature of choice in a game of two persons. Naturally, one player selects a certain way of playing assuming that in this way he avoids (more or less) uncertainty or that he is ready to adequately respond to a specific set of uncertainties. If the selection of the way of the game is optimal in term of minimum costs for players, or, for example, achieving maximum profits, while uncertainties that occur in that way of playing do not affect the end result, we can say that the selected way of the game is robust. Exposure is a measure of the loss that occurs as a consequence of the uncertainty effect on a player, or on some system, with selected modules of work or chosen way of the game. Sometimes exposure to uncertainty and risk is measured by monetary units, and sometimes it is not. Namely, the risk can also be measured qualitatively, e.g. exposure to loss of health due to polluted environment is large or small, or in terms of some match, exposure to risk of creating the riot is small or quite large, etc.

The analysis takes into account the case of necessity of generating 1.700 MW in EES [1].

It is necessary to generate the power of 1700 MW in EES, but in the way to reduce the risk and include less uncertainty in the planning of the power system.

We have available three groups of sources for adding total of 1.700MW in EPS:

- TPP-1 capacity of 100-900 MW, with 100 MW step
- Disperse-generators DG-2 with a capacity of 500-1300 MW with step 100 MW
- Hydroelectric power plant - HPP3 300-1200 MW capacity with step 100 MW

The analysis takes into account the following factors:

- economic conditions (strong, medium, weak)
- environmental-ecological conditions (strong, medium, weak)

Evaluating the quality of individual plans for various scenarios in considered case will be done on the basis of the following criteria:

- the price of electricity
- the profit
- environmental index

A. *Defining the issues*

If we take the economic conditions (electricity price and the profit) and environmental restrictions (environmental index), we can formulate nine scenarios, given in Table I.

Available sources are TPP-1, DG-2 and HPP-3 and it is possible to create 54 plans in the

TABLE I. SCENARIOS

Scenario	Economic Conditions	Environmental Restrictions
Sc_1	Weak	Weak
Sc_2	Middle	Weak
Sc_3	Strong	Weak
Sc_4	Weak	Middle
Sc_5	Middle	Middle
Sc_6	Strong	Middle
Sc_7	Weak	Strong
Sc_8	Middle	Strong
Sc_9	Strong	Strong

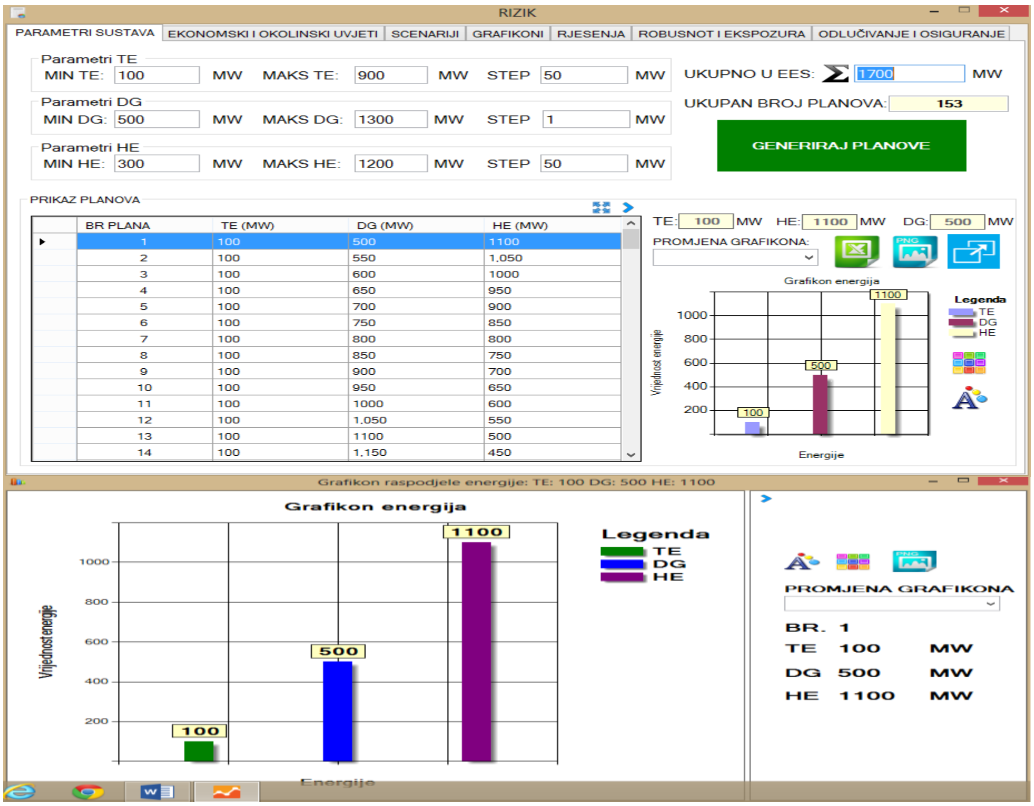


Figure 1. Plans in the planning of the EPS

planning of the EPS and the same are shown in Fig. 1.

During the planning of EEP, the following three factors must be taken into account:

- criteria which are opposed to each other (e.g. minimization of costs, minimal environmental impacts and maximizing reliability)
- a set of options, which include the traditional reinforcements in the manufacture and network, but also are temporary at the side of the load, uncertainty

Lately, for understanding the problem of more criteria, we came to the use of various tools and techniques in order to solve the problem of planning of the power system, so that the concept of optimization is in the line with the concept of compromise [2].

Risk management involves the following three risks:

1. quantitative risk
2. determination of risk reduction measures
3. justification of acceptable level of risk

II. Problem Solution

The problem is set up as a problem of generating $P = 1.700$ MW in power system taking into account the three above-mentioned criteria, a final decision will be implemented through eight steps.

A. *Step No. 1: Calculation of the objective function*

The objective function for all criteria, scenarios and plans is calculated according to the following formula:

$$F^{k}{}_{j,k} = a^{i}{}_{j} \cdot + DSM_{k} + b^{i}{}_{j} \cdot PDG_{k} + c^{i}{}_{j} \cdot UG_{k} \quad (1)$$

$i = 1,....,ns$; $j = 1,....,na,$; $k = 1,....,np,$

where:

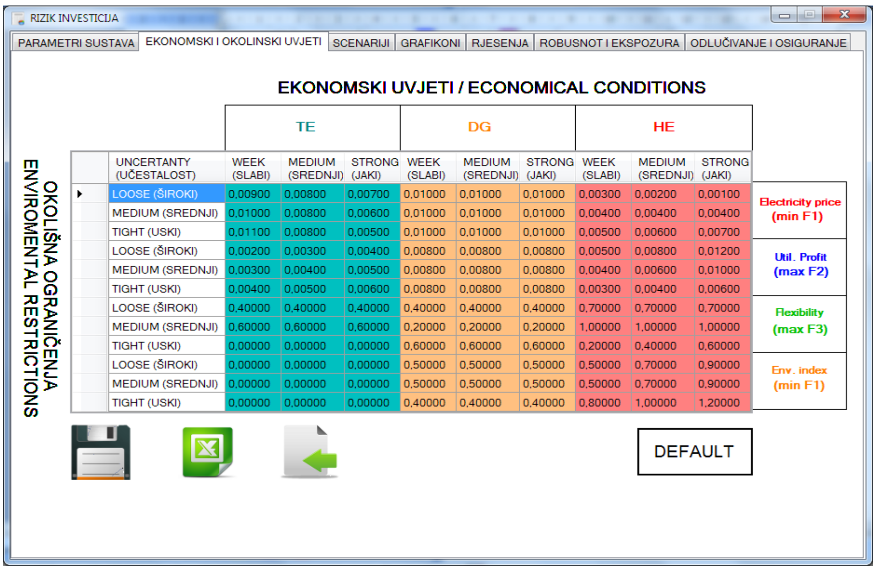
ns = 9 - number of scenarios

to = 3 - number of criteria

n = 54 - the number of plans

Based on the above equation (1.0) we calculate the cost of the objective function for all criteria, scenarios and plans. First, we calculate the objective functions (3 functions) for scenario 1, for each of the 54 possible plans. In the same way, we calculate the objective function for all other scenarios and plans, taking into account each of the three stated criteria.

The coefficients a, b and c are the objective functions for all criteria and scenarios, and they are determined based on engineering experience and their values are given in Fig. 2.



	TE			DG			HE			
UNCERTANTY (UČESTALOST)	WEEK (SLABI)	MEDIUM (SREDNJI)	STRONG (JAKI)	WEEK (SLABI)	MEDIUM (SREDNJI)	STRONG (JAKI)	WEEK (SLABI)	MEDIUM (SREDNJI)	STRONG (JAKI)	
LOOSE (ŠIROKI)	0,00900	0,00800	0,00700	0,01000	0,01000	0,01000	0,00300	0,00200	0,00100	Electricity price (min F1)
MEDIUM (SREDNJI)	0,01000	0,00800	0,00600	0,01000	0,01000	0,01000	0,00400	0,00400	0,00400	
TIGHT (USKI)	0,01100	0,00800	0,00500	0,01000	0,01000	0,01000	0,00500	0,00600	0,00700	
LOOSE (ŠIROKI)	0,00200	0,00300	0,00400	0,00800	0,00800	0,00800	0,00500	0,00800	0,01200	Util. Profit (max F2)
MEDIUM (SREDNJI)	0,00300	0,00400	0,00500	0,00800	0,00800	0,00800	0,00400	0,00600	0,01000	
TIGHT (USKI)	0,00400	0,00500	0,00600	0,00800	0,00800	0,00800	0,00300	0,00400	0,00600	
LOOSE (ŠIROKI)	0,40000	0,40000	0,40000	0,40000	0,40000	0,40000	0,70000	0,70000	0,70000	Flexibility (max F3)
MEDIUM (SREDNJI)	0,60000	0,60000	0,60000	0,20000	0,20000	0,20000	1,00000	1,00000	1,00000	
TIGHT (USKI)	0,00000	0,00000	0,00000	0,60000	0,60000	0,60000	0,20000	0,40000	0,60000	
LOOSE (ŠIROKI)	0,00000	0,00000	0,00000	0,50000	0,50000	0,50000	0,50000	0,70000	0,90000	Env. index (min F1)
MEDIUM (SREDNJI)	0,00000	0,00000	0,00000	0,50000	0,50000	0,50000	0,50000	0,70000	0,90000	
TIGHT (USKI)	0,00000	0,00000	0,00000	0,40000	0,40000	0,40000	0,80000	1,00000	1,20000	

Figure 2. Coefficients values

B. Step No. 2: Normalization

In the case of a large discrepancy between the calculated values of the objective functions for the corresponding criteria, then the normalization of the objective function values is done. In the particular considered problem, it is necessary to normalize (divide with 80) the objective function F3 for all nine scenarios.

C. Step No. 3: The optimal solution to the given criteria

Optimal solutions to the given criteria are minimum of functions F1 (Electricity price) and F3norm (environmental index) and maximum of function F2 (profits). Minimum and maximum values of the objective function for all criteria and scenarios are given in Fig. 3. The table has been prepared on the basis of all the scenarios that are available (9) and are given in the appendix.

Optimal values of the objective function for all criteria and scenarios are shown in the last column of Fig. 3.

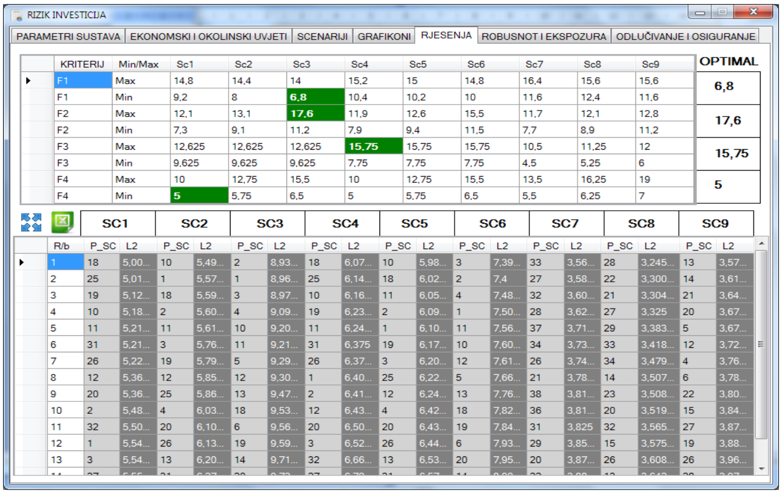
It is generally accepted that the most interesting solutions (from the point of view of the person who decides) are those closest to the ideal solution.

Minimization of the distance (difference) between the calculated value of the objective functions (F1, F2 and F3) and ideal values (minimum F1min and F3min or maximum F2max) of objective functions are calculated according to the Euclidian form:

$$L_2 = \sqrt{\left(F_{A,k} - F_{1,\min}\right)^2 + \left(F_{2,k} - F_{2,\max}\right)^2 + \left(F_{3,k} - F_{3,\min}\right)^2}\,, \quad (2)$$

$k = 1,.....,54$

Possible solutions of the problem with multiple criteria with two objective functions are shown in Figs. 1-2 for each scenario.



KRITERIJ	Min/Max	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	OPTIMAL
F1	Max	14,8	14,4	14	15,2	15	14,8	16,4	15,6	15,6	6,8
F1	Min	9,2	8	6,8	10,4	10,2	10	11,6	12,4	11,6	
F2	Max	12,1	13,1	17,6	11,9	12,6	15,5	11,7	12,1	12,8	17,6
F2	Min	7,3	9,1	11,2	7,9	9,4	11,5	7,7	8,9	11,2	
F3	Max	12,625	12,625	12,625	15,75	15,75	15,75	10,5	11,25	12	15,75
F3	Min	9,625	9,625	9,625	7,75	7,75	7,75	4,5	5,25	6	
F4	Max	10	12,75	15,5	10	12,75	15,5	13,5	16,25	19	5
F4	Min	5	5,75	6,5	5	5,75	6,5	5,5	6,25	7	

	SC1		SC2		SC3		SC4		SC5		SC6		SC7		SC8		SC9	
R/b	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2
1	18	5,00...	10	5,49...	2	8,93...	18	6,07...	10	5,98...	3	7,39...	33	3,56...	28	3,245...	13	3,57...
2	25	5,01...	1	5,57...	1	8,96...	25	6,14...	18	6,02...	2	7,4	27	3,58...	22	3,300...	14	3,61...
3	19	5,12...	18	5,59...	3	8,97...	10	6,16...	11	6,05...	4	7,48...	32	3,60...	21	3,304...	21	3,64...
4	10	5,18...	2	5,60...	4	9,09...	19	6,23...	2	6,09...	1	7,50...	28	3,62...	27	3,325	20	3,67...
5	11	5,21...	11	5,61...	10	9,20...	11	6,24...	1	6,10...	11	7,56...	37	3,71...	29	3,383...	5	3,67...
6	31	5,21...	3	5,76...	11	9,21...	31	6,375	19	6,17...	10	7,60...	34	3,73...	33	3,418...	12	3,72...
7	26	5,22...	19	5,79...	5	9,29...	26	6,37...	3	6,20...	12	7,61...	26	3,74...	34	3,479...	4	3,76...
8	12	5,36...	12	5,85...	12	9,30...	1	6,40...	25	6,22...	5	7,66...	21	3,78...	14	3,507...	6	3,78...
9	20	5,36...	25	5,86...	13	9,47...	2	6,41...	12	6,24...	13	7,76...	38	3,81...	23	3,508...	22	3,80...
10	2	5,48...	4	6,03...	18	9,53...	12	6,43...	4	6,42...	18	7,82...	36	3,81...	20	3,519...	15	3,84...
11	32	5,50...	20	6,10...	6	9,56...	20	6,50...	20	6,43...	19	7,84...	31	3,825	32	3,565...	27	3,87...
12	1	5,54...	26	6,13...	19	9,59...	3	6,52...	26	6,44...	6	7,93...	29	3,85...	15	3,575...	19	3,88...
13	3	5,54...	13	6,20...	14	9,71...	32	6,66...	13	6,53...	20	7,95...	20	3,87...	26	3,608...	26	3,96...

Figure 3. Minimum and maximum values of the objective function for all criteria and scenarios

D. Step No. 4: The most interesting solutions

If the given problem has multiple criteria, such as in this case, there is no only one solution, which optimizes all the criteria, because inevitably "good" solution by one criterion leads to “bad" solution by other criteria. Therefore, a compromise is needed ("trade off" - exchange) between the criteria, and the conducted analysis in this case will be called "trade-off" analysis.

Possible solution of the problem with multiple criteria with two objective functions (maximum profit and minimum environmental index) is shown in the Fig. 4.

Solution of the problem with multiple criteria and two objective functions (minimum electricity price and maximum profit) is shown in Fig. 5.

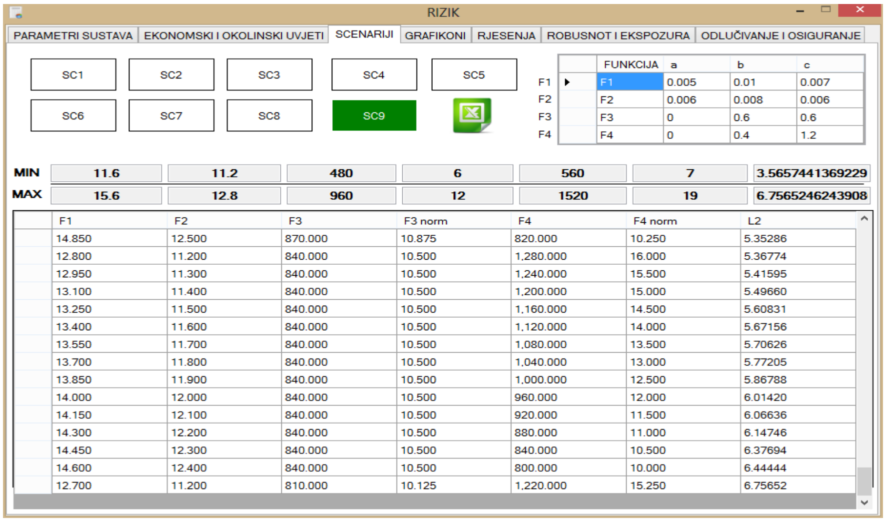


Figure 4. Possible solution of the problem with multiple criteria with two objective functions (maximum profit and minimum environmental index)

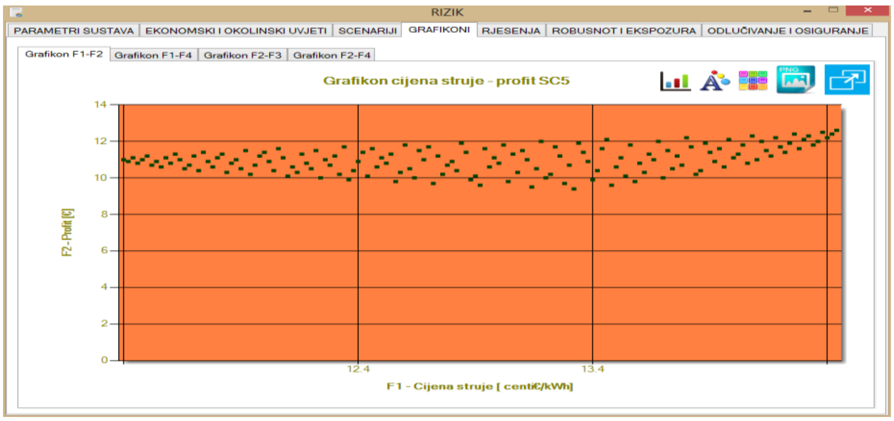
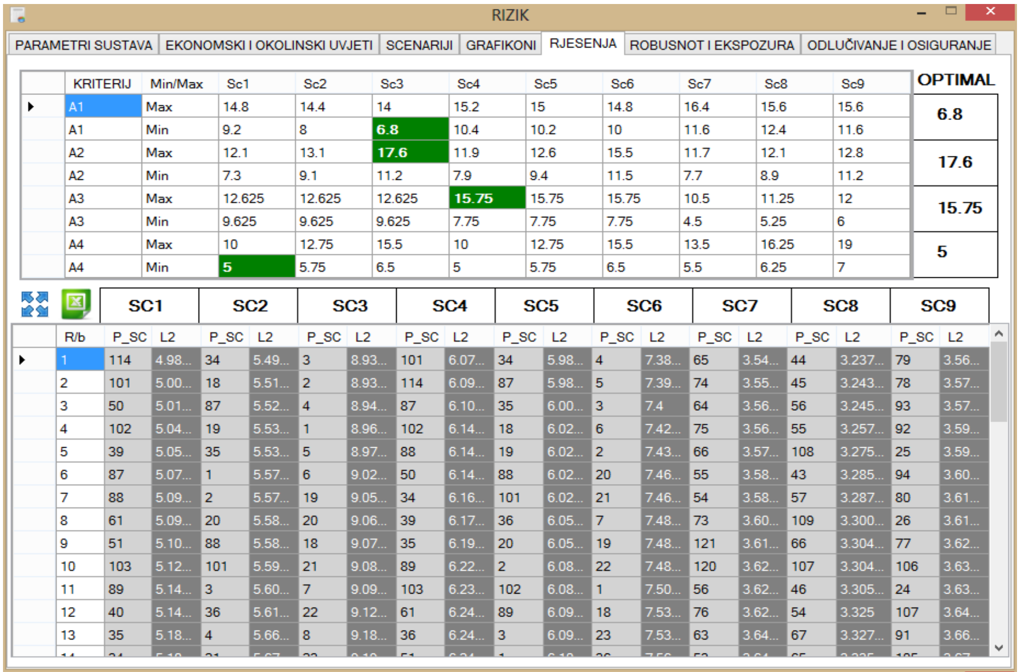


Figure 5. Solution of the problem with multiple criteria and two objective functions (minimum electricity price and maximum profit)

From the Fig. 3 it can be concluded that the ideal solutions are optimal values of objective functions F1, F2 and F3 (5.90, 18.00, 4.00) for all criteria, plans and scenarios. Distance between the calculated values of the objective functions and optimal solutions (ideal points) for all criteria are minimized based on Euclidian form, given by the expression (1).

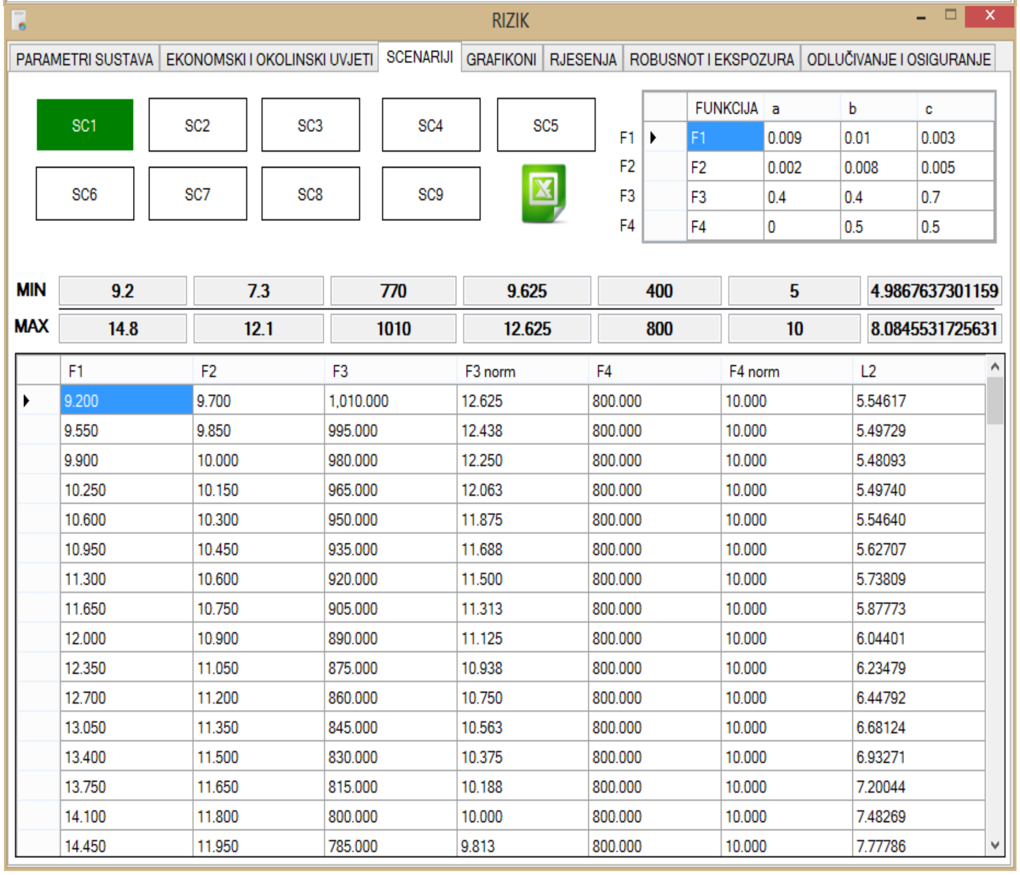
E. Step No. 5: Establishment of a global set of solutions

Based on the given values of the power sources (TPP-1, DG-2 and HPP-3) for the 54 plans and criteria for adding them in the planning of the power system, values of the objective functions have been calculated for all criteria, plans and scenarios. In order to make decision, it is necessary to establish a set of solutions (10-15 best solutions), which have the smallest difference between the calculated values, objective functions and ideal solutions.



KRITERIJ	Min/Max	Sc1	Sc2	Sc3	Sc4	Sc5	Sc6	Sc7	Sc8	Sc9	OPTIMAL
A1	Max	14.8	14.4	14	15.2	15	14.8	16.4	15.6	15.6	6.8
A1	Min	9.2	8	6.8	10.4	10.2	10	11.6	12.4	11.6	
A2	Max	12.1	13.1	17.6	11.9	12.6	15.5	11.7	12.1	12.8	17.6
A2	Min	7.3	9.1	11.2	7.9	9.4	11.5	7.7	8.9	11.2	
A3	Max	12.625	12.625	12.625	15.75	15.75	15.75	10.5	11.25	12	15.75
A3	Min	9.625	9.625	9.625	7.75	7.75	7.75	4.5	5.25	6	
A4	Max	10	12.75	15.5	10	12.75	15.5	13.5	16.25	19	5
A4	Min	5	5.75	6.5	5	5.75	6.5	5.5	6.25	7	

	SC1		SC2		SC3		SC4		SC5		SC6		SC7		SC8		SC9	
R/b	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2	P_SC	L2
1	114	4.98...	34	5.49...	3	8.93...	101	6.07...	34	5.98...	4	7.38...	65	3.54...	44	3.237...	79	3.56...
2	101	5.00...	18	5.51...	2	8.93...	114	6.09...	87	5.98...	5	7.39...	74	3.55...	45	3.243...	78	3.57...
3	50	5.01...	87	5.52...	4	8.94...	87	6.10...	35	6.00...	3	7.4	64	3.56...	56	3.245...	93	3.57...
4	102	5.04...	19	5.53...	1	8.96...	102	6.14...	18	6.02...	6	7.42...	75	3.56...	55	3.257...	92	3.59...
5	39	5.05...	35	5.53...	5	8.97...	88	6.14...	19	6.02...	2	7.43...	66	3.57...	108	3.275...	25	3.59...
6	87	5.07...	1	5.57...	6	9.02...	50	6.14...	88	6.02...	20	7.46...	55	3.58...	43	3.285...	94	3.60...
7	88	5.09...	2	5.57...	19	9.05...	34	6.16...	101	6.02...	21	7.46...	54	3.58...	57	3.287...	80	3.61...
8	61	5.09...	20	5.58...	20	9.06...	39	6.17...	36	6.05...	7	7.48...	73	3.60...	109	3.300...	26	3.61...
9	51	5.10...	88	5.58...	18	9.07...	35	6.19...	20	6.05...	19	7.48...	121	3.61...	66	3.304...	77	3.62...
10	103	5.12...	101	5.59...	21	9.08...	89	6.22...	2	6.08...	22	7.48...	120	3.62...	107	3.304...	106	3.63...
11	89	5.14...	3	5.60...	7	9.09...	103	6.23...	102	6.08...	1	7.50...	56	3.62...	46	3.305...	24	3.63...
12	40	5.14...	36	5.61...	22	9.12...	61	6.24...	89	6.09...	18	7.53...	76	3.62...	54	3.325	107	3.64...
13	35	5.18...	4	5.66...	8	9.18...	36	6.24...	3	6.09...	23	7.53...	63	3.64...	67	3.327...	91	3.66...



	FUNKCIJA	a	b	c
F1	F1	0.009	0.01	0.003
F2	F2	0.002	0.008	0.005
F3	F3	0.4	0.4	0.7
F4	F4	0	0.5	0.5

MIN	9.2	7.3	770	9.625	400	5	4.9867637301159
MAX	14.8	12.1	1010	12.625	800	10	8.0845531725631

F1	F2	F3	F3 norm	F4	F4 norm	L2
9.200	9.700	1,010.000	12.625	800.000	10.000	5.54617
9.550	9.850	995.000	12.438	800.000	10.000	5.49729
9.900	10.000	980.000	12.250	800.000	10.000	5.48093
10.250	10.150	965.000	12.063	800.000	10.000	5.49740
10.600	10.300	950.000	11.875	800.000	10.000	5.54640
10.950	10.450	935.000	11.688	800.000	10.000	5.62707
11.300	10.600	920.000	11.500	800.000	10.000	5.73809
11.650	10.750	905.000	11.313	800.000	10.000	5.87773
12.000	10.900	890.000	11.125	800.000	10.000	6.04401
12.350	11.050	875.000	10.938	800.000	10.000	6.23479
12.700	11.200	860.000	10.750	800.000	10.000	6.44792
13.050	11.350	845.000	10.563	800.000	10.000	6.68124
13.400	11.500	830.000	10.375	800.000	10.000	6.93271
13.750	11.650	815.000	10.188	800.000	10.000	7.20044
14.100	11.800	800.000	10.000	800.000	10.000	7.48269
14.450	11.950	785.000	9.813	800.000	10.000	7.77786

Figure 6. Best solutions - example

example, of which values are given in Fig. 6. [3].

F. Step No. 6: Defining the robustness and exposure

Robustness is a measure of safety or reduction of the risk in making of decision, which in fact represents the stability of a particular plan. Robustness gives an answer based on which cases for which the individual who decides will have the least regret are selected. Probability of robustness of some plan (which belongs to the better plans) is defined by a number of scenarios for which the plan is in good relation with the total number of scenarios (in this case 9).

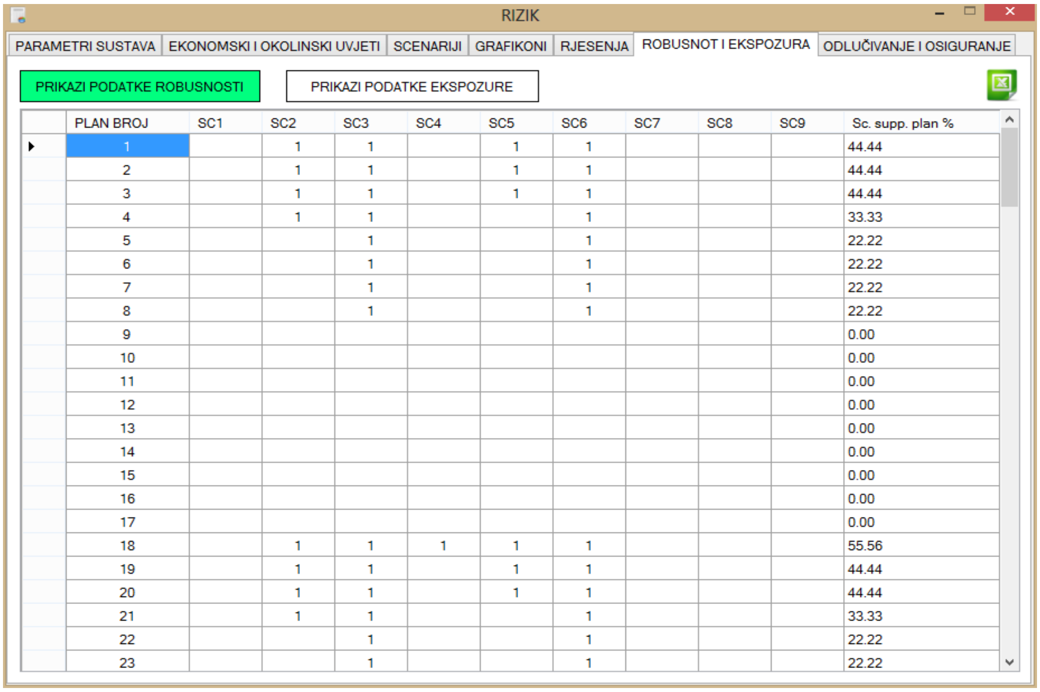
The plan is 100 % robust, which means the robustness of the plan has a probability of 1, if it is determined (set) for all scenarios, which means that a robust solution leads to minimization (reduction) of a risk. A plan that is robust for all scenarios does not lead to regrets, however if the plan is not fully robust, then we can regret for the decision made by the individual, and the cause of regret will be the scenario for which the plan is not robust.

Fig. 7 shows the robustness of individual plans. The results are consistent with the results from Fig. 6.

From the Fig. 7 it can be concluded that four plans (1, 2, 4, and 5) have the best robustness and are supported with 8 out of 9 possible scenarios, and their robustness is 88.88%.

“Exposure” is measure, which determines the degree of regret for choosing a specific plan, or how some plan is liable (prone) to the risk. As in the analysed example, none of the plans are fully robust (a probability of 100%), the individual who makes the decision takes the risk, which measure is the equivalent to the degree of regret. Exposures to particular plans for each scenario and for all criteria are given in Fig. 7.

In this example, plans 1, 2, 4 and 5 are supported for each scenario, except for scenario 7 (economic conditions - poor, environmental restrictions - strong), and these plans have the same exposure.



PLAN BROJ	SC1	SC2	SC3	SC4	SC5	SC6	SC7	SC8	SC9	Sc. supp. plan %
1		1	1		1	1				44.44
2		1	1		1	1				44.44
3		1	1		1	1				44.44
4		1	1			1				33.33
5			1			1				22.22
6			1			1				22.22
7			1			1				22.22
8			1			1				22.22
9										0.00
10										0.00
11										0.00
12										0.00
13										0.00
14										0.00
15										0.00
16										0.00
17										0.00
18		1	1	1	1	1				55.56
19		1	1		1	1				44.44
20		1	1		1	1				44.44
21		1	1			1				33.33
22			1			1				22.22
23			1			1				22.22

Figure 7. Robustness of individual plans

G. *Step No. 7: Deciding*

Deciding for some of the plans with less exposure can be with or without probability for each of the scenario.

a) Deciding without probability

Analysis of plans in the previous step showed that the plans 1, 2, 4 and 5 are the most robust, or they have the lowest exposure. The above plans are exposure for scenario 7. An individual who decides (makes the decision) can notice that scenario 9 (economic conditions - strong environmental restrictions - strong) is almost impossible scenario by the scenario analysis. So an individual can make a decision between the four specified plans.

In accordance with the most robust plans, adding of 1.700 MW power source shall be done as follows:

• Plan 1: TPP - 1 = 900 MW, DG - 2 = 500 MW and HPP - 3 = 300 MW

• Plan 2: TPP - 1 = 800 MW, DG - 2 = 600 MW and HPP - 3 = 300 MW

• Plan 4: TPP - 1 = 600 MW, DG - 2 = 800 MW and HPP - 3 = 300 MW

• Plan 5: TPP - 1 = 500 MW, DG - 2 = 900 MW and HPP - 3 = 300 MW

TABLE II. VALUES OF PROBABILITYS[1]

		Economic Conditions			
		Weak	Medium	Strong	∑
Limitations of environment	Weak	**0,1125 (Sc1)**	**0,0800 (Sc2)**	**0,0700 (Sc3)**	0,2625
	Medium	**0,1125 (Sc4)**	**0,2400 (Sc5)**	**0,1750 (Sc6)**	0,5275
	Strong	**0,0250 (Sc7)**	**0,0800 (Sc8)**	**0,1050 (Sc9)**	0,2100
	∑	**0,25**	**0,4**	**0,35**	1

The final decision that needs to be made, however, is a decision that will made by the individual with the least of regret (with the least of risk) and it is based on his knowledge and feeling about the scenario which is most likely to happen in the future. A final decision is one that is not mathematically clear -it is neutral and based on the decision of the individual who conducted the assessment.

b) Deciding with probability

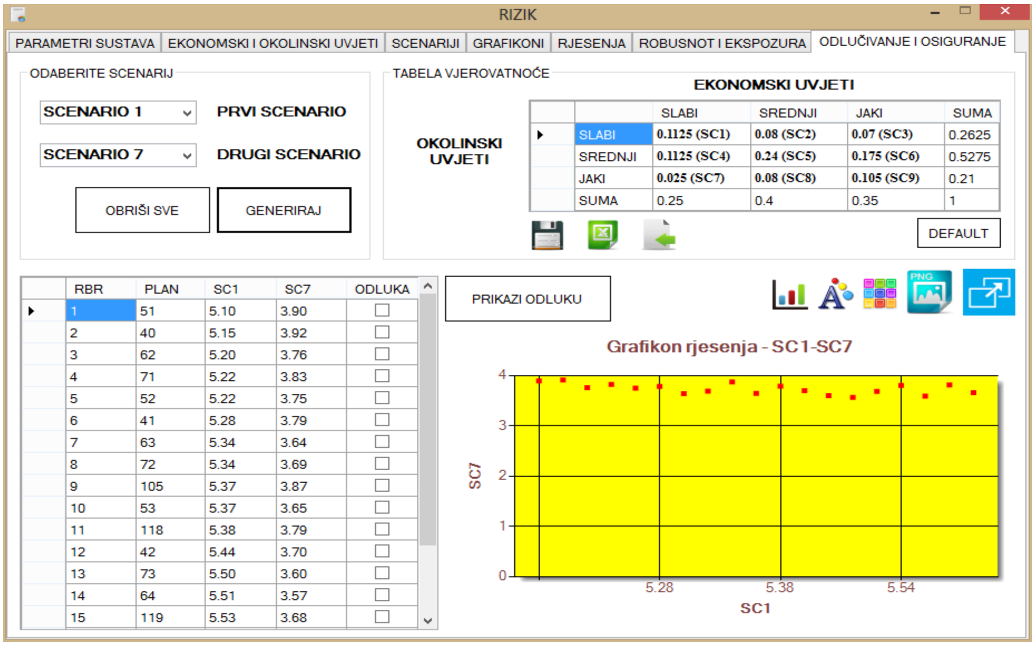
Using the probability when deciding will reduce the regret over decision made by the individual. Values of probability, which depend on economic conditions and environmental restrictions for each scenario are shown in Table II.

From Table II, scenario 2 will be selected (economic conditions - middle, weak environmental constraints) as well as scenario 5 (economic conditions - middle, environmental restrictions - medium). In order to choose the plan that will be chosen as the solution according to scenario 2 and scenario 5, the common plans for both scenarios will be compared (Table III) and diagram S_{C2} = f (S_{C5}) will be drawn, which is shown in Fig 8.

TABLE III. SCENARIO COMPARISON

Plan	S_{c2}	S_{c5}	
1	3,382	4,835	Decision 1
2	3,426	4,484	
3	3,586	4,398	
4	3,945	5,174	
5	4,325	4,331	Decision 2
6	4,034	5,217	
7	4,592	4,517	
8	4,071	5,347	
13	4,776	4,780	
15	3,709	4,652	Decision 3

[1] Table II was created on the basis of engineering experience (assessment by individual).



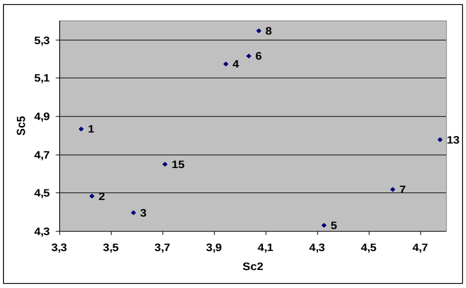


Figure 8. Diagram S_{C2} = f (S_{C5})

According to the Fig. 8, the most attractive plans for scenario 2 and scenario 5 are 1.5 and 15. For consideration of the best solution, sources (TPP-1, DG-2 and HPP-3) of selected plans are given in Table IV.

TABLE IV. BEST SOLUTION, SOURCES (TPP-1, DG-2 AND HPP-3) OF SELECTED PLANS

Plans	TPP-1	DG-2	HPP-3
1	900	500	300
5	500	900	300
15	400	900	400

H. Step No. 8: "Hedging" (Insurance)

"Hedging" in some way represents insurance. In the specific case, 'hedging' implies adding 100 MW of sources UG in the power system, as can be seen from Table V.

This means that we provide an additional 100 MW for electrical power system by using sources UG.

TABLE V. "HEDGING"

Plans	TPP-1	DG-2	HPP-3
1	900	500	300
5	**500**	**900**	300
15	400	900	**400**

III. CONCLUDING REMARKS AND NOTES

Based on all the above stated and conducted considerations we can conclude that in the end the individual, on the basis of his experience and feelings to predict events in the future, will make the final decision for which he will have minimum regret, and he always tries to put the risk to minimum by his own decision. The decision that an individual makes is with or without probability. If the decision is made without probability, then we choose those plans which have a maximum of robustness, or at least exposure, because in this case the risk is minimized. From the above analysed plans in this case, in my opinion minimum regret will occur by choosing the plan 5, which is the exposure only for scenario 7.

If the decision is made with probability, then there is a possibility of ‘’hedging’’ (insurance), which for the most attractive plans in the analysed case is 100 MW from source HPP-3.

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