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Electricity Storage in the Optimization of Energy Supply Systems

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INTRODUCTION

In the context of distributed energy resources, energy storage can play an important role and is widely accepted as the appropriate complement to the uncertainties (variability and intermittency) associated with renewable energy. Energy storage is employed to stabilize and help intermittent renewable technologies become more competitive, where that surplus energy can be stored and consumed later when its use or cost is more beneficial (Kousksou et al., 2014; Romero, 2016; Zubi et al., 2018; Fernandez et al., 2019).

The complexity, which is inherent to spatial and temporal interdependencies, is a significant challenge in the synthesis of renewable energy. Due to the high degree of integration and coupling, determining the optimal configuration and design of a polygeneration energy system is quite a challenging task, and there are still complex problems that have not been adequately confronted as of yet (Romero; Carvalho; Millar, 2016; Delgado et al., 2018), such as the integration with renewable energy technologies and energy storage.

The multifaceted nature of polygeneration systems (multiple energy resources, multiple energy products, multiple technology options) requires a design procedure that provides flexible, efficient, and reliable energy systems.

OBJECTIVE

The objective of this study is to adapt a model of electric storage and introduce it within a mathematical model based on Mixed Integer Linear Programming (MILP) that optimizes the supply of energy (in all forms) to a tertiary sector building.

MATERIALS AND METHODS

MILP is an example of mathematical programming that utilizes binary and integer variables to express quantity, decision, and logical relations. MILP consists of three steps [9]: establishment of a superstructure of available equipment and resources (representation of all possible alternatives); formulation of a mathematical model that represents all possible forms of operation through discrete variables and continuous; and determination of the optimized solution, from the resolution of the mathematical model.

The case study is a 420-bed hospital, with an area of 49.000 m², located in João Pessoa, Northeast Brazil. The study extended over one year, where each month was represented by two typical days (working day and weekend), each divided into 24 hourly periods, resulting in 576 different operation periods. The annual energy demands are 2791 MWh for electricity, 1947 MWh for hot water (direct use and laundry), 138 MWh for steam (sterilization), and 2309 MWh for cooling.

All technologies and equipment considered in the optimization are commercially available, where the technical information was obtained from the manufacturers' catalogs, and their prices were obtained through direct consultation.

The current electricity tariff (2019) currently considers a value throughout the day (R$ 190/MWh), with a peak value between 18h and 21h (R$ 298/MWh). The natural gas tariff has a fixed value (R$ 398/MWh). The diesel tariff considered was R$ 290/MWh. Biomass (sugarcane bagasse) is a locally available energy resource (R$ 52/MWh). The solar energy resource considered herein is restricted to photovoltaic panels (1.64 m² each) for the production of electricity, following to the Brazilian legal scenario, which enables the exports of self-generated electricity through credit compensation scheme established. Regarding the economic and financial scenario, considering a 15-year lifetime for the system and an interest rate of 10% y^{-1}, a depreciation factor (FAM) of 0.13 y^{-1} was obtained.

The problem to be solved consists of two simultaneous steps: selection of equipment and operation mode during each of the defined time intervals, throughout the year. An economic objective function was defined to consider the annual cost minimization, which includes fixed costs (investment in equipment and storage) and variable costs (purchase of energy utilities, and maintenance and operating costs). The solver employed in the optimization procedure was LINGO.

$$\text{Annual Cost} = (\text{Fixed costs}) + (\text{Variable costs}) \quad (1)$$

$$\text{Fixedcosts}=\text{FAM}\cdot[(\text{FCI}\cdot\textstyle\sum_i \text{CINV}_i) + \text{Cost of PV panels} + \text{Cost of storage}] \quad (2)$$

$$\text{Variable Costs} = (\text{Cost of natural gas}) + (\text{Cost of electricity imports}) - (\text{Credit due to electricity exports}) + (\text{Cost of diesel}) + (\text{Cost of biomass}) + (\text{Operation and Maintenance}) \quad (3)$$

$CINV_i$ is the number of equipment installed for each technology i multiplied by the individual cost, FAM is the depreciation factor, and FCI accounts for indirect costs involved in transportation, assembly, installation, supervision, engineering, service charges, and contingency, totaling 15% of equipment investment costs. These costs are already included for solar panels and electricity storage. In (2), the cost of storage is expressed as:

$$(\text{Cost of storage}_{ee}) = (\text{Fixed cost})_{sto\ ee} + (\text{Variable cost})_{sto\ ee} \quad (4)$$

$$(\text{Fixed cost})_{sto\ ee} = \text{BSTEE} \quad (5)$$

$$(\text{Variable cost})_{sto\ ee} = \text{STEE} \cdot c_{var} \quad (6)$$

Equation (4) is linear and includes a fixed cost that is independent of the size of the battery bank to be installed and grows according to the variable cost, which depends mostly on the installed storage capacity.

Equation (5) defines the fixed cost of storage from the binary variable BSTEE, which defines the presence or not of electrical energy storage systems. BSTEE is multiplied by the cost of installation of the battery bank c_fix, which includes inverters.

With consideration of electricity storage, the energy balance for electricity (j = ee) is:

$$\text{Production}_{ee} - \text{Consumption}_{ee} + \text{Purchase}_{ee} - \text{Export}_{ee} - \text{Demand}_{ee} + \text{EEPV}_{ee} \pm \text{Storage}_{ee} = 0 \quad (7)$$

Fig. 1 shows the possibilities of electricity flows in the system, including storage.

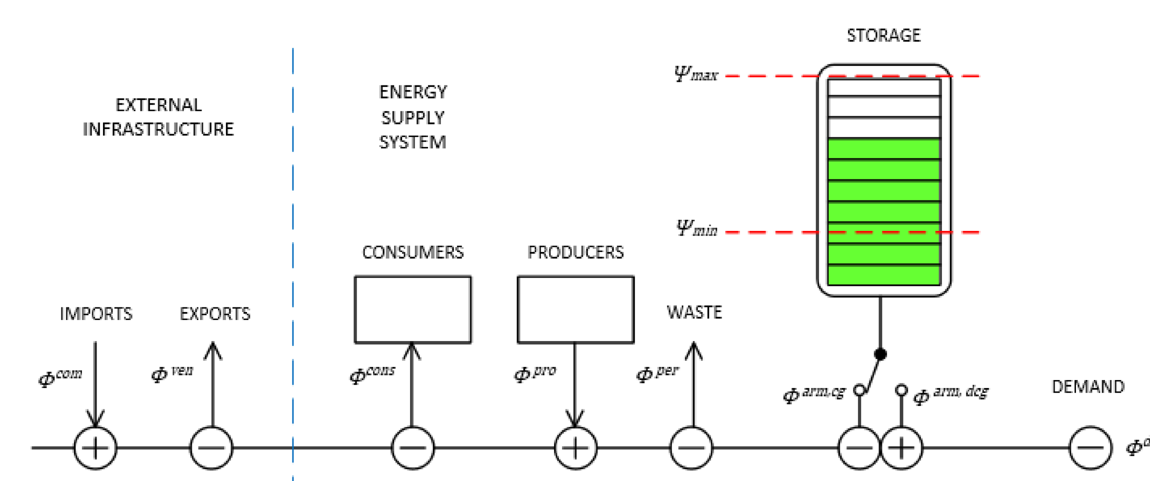

Figure 1 - Storage scheme implemented in the optimization (Translated from Romero, 2016).

RESULTS AND DISCUSSION

A reference system was defined, where energy demands were satisfied conventionally, excluding the possibilities of cogeneration and the use of renewable energy sources. The economic optimal was obtained by solving the optimization model, minimizing the annual cost, with free selection of technologies and installation of 200 PV panels (area available). Table 1 shows the configuration and energy flows for the reference system and the economic optimal.

	Reference system	Economic optimal
Composition of system	Number (installed power)	Number (installed power)
Steam boil (BM)	0 (0 MW)	1 (0.250 MW)
Steam boil (EE)	1 (0.150 MW)	0 (0 MW)
HX (VA-HW)	1 (0.400 MW)	1 (0.400 MW)
Hot water boil (BM)	0 (0 MW)	3 (0.510 MW)
Hot water boil (EE)	4 (0.600 MW)	0 (0 MW)
Mechanical chiller	3 (0.810 MW)	3 (0.810 MW)
Cooling Tower	1 (1.000 MW)	1 (1.000 MW)
Photovoltaic panels	--	200 units
Storage (EE)	--	0 MWh
Electricity imports	5676 MWh/year	3226 MWh/year
Biomass imports	0 MWh/year	2635 MWh/year
Capital costs	R$ 971,060	R$ 1,507,167
Annual cost of electricity imports	R$/year 1,174,722	R$/year 663,451
Annual cost of biomass imports	R$/year --	R$/year 137,045
Operation and maintenance costs	R$/year 41,585	R$/year 54,170
Annual cost of equipment *	R$/year 126,238	R$/year 195,932
TOTAL annual cost	R$/year 1,342,545	R$/year 1,050,598

Table 1 - Solutions for the reference and economic optimal systems.

There was an increase in capital cost (55.20%) in the optimal economic system, but there is a considerable annual benefit where 21.75 % is saved per year regarding energy resource acquisition and system operation and maintenance costs. The optimal economic solution did not include electricity storage. A sensitivity analysis verified that electricity storage was only installed when its variable costs were reduced by almost 70%. Likewise, photovoltaic panels are only included spontaneously in the optimal configuration when capital costs are reduced by more than half or when the tariff of electricity imported increases considerably.

CONCLUSIONS

The incorporation of storage equipment and renewable energies required the development of a more complex and specific model. Considering complementary or competing uses of renewable and stored energy increased the size of the optimization model significantly.

The ideal economical solution installed 200 photovoltaic panels and used biomass to power the boilers, but did not install electricity storage. When comparing the optimal economic solution with the reference system, the main modification the utilization of biomass boilers instead of electric boilers (benefiting from the technical and economic feasibility of this energy resource, considered very cheap and able to meet the energy demands). The optimal economic solution presented annual cost 22% lower than the reference system.

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