Optimal Allocation of Sectionalizing Switches in Smart Grid: A Problem-Solving Framework

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Abstract

Reliability improvement of electricity supply represents one of the mandatory objectives of the future Smart Grid (SG) concept. In this paper, problem-solving frameworks for optimal allocation of Sectionalizing Switches (SS) in Distribution System (DS) are analyzed. The diversity of protection components available for SG with Distributed Generation (DG) is highlighted. The unique classification of input data sets for SS optimal allocation is proposed. Specific guidelines are recommended for the creation of a generalized problem-solving framework.

Introduction

The selection of an adequate number of SS and their locations is a difficult task in DS planning [1]. This task requires solving a combinatorial constrained problem described by a nonlinear objective function [2,3].

Heuristic algorithms are used widely in the literature to solve the optimal switch placement problem. Since heuristic algorithms explore only a narrow region of the search space and tend to get stuck into locally optimal solutions [4], the mathematical optimization method mixed-integer linear programming (MILP) is proposed [5]. The optimal solution of SS allocation problem depends on both, economic and technical considerations. The objective is to minimize the overall costs, improve reliability indices, and satisfy all technical constraints at the same time.

- Consideration of SS additional possible locations on laterals is proposed recently [6]. Simultaneous placement of fault indicators (FI) and SS in DS is proposed in [7].
- The impact of distributed generation (DG) is landing capabilities on the SS allocation problem is analyzed in [8-10].
- Malfunction probability of SS is considered in [11].

A large diversity of the existing problem-solving frameworks in literature could be confusing, thus aggravating future research.
The **main objective of the paper** is an attempt to create the guidelines towards a simple, clarified, and ultimate problem-solving framework, which would be based on the summary of all existing problem-solving frameworks.

Allocation of protection components in DS

Protection component is a device capable to cause a reconfiguration of DS.
The example of modern DS with the existing protection components and possible locations of SS is presented in Figure 1.

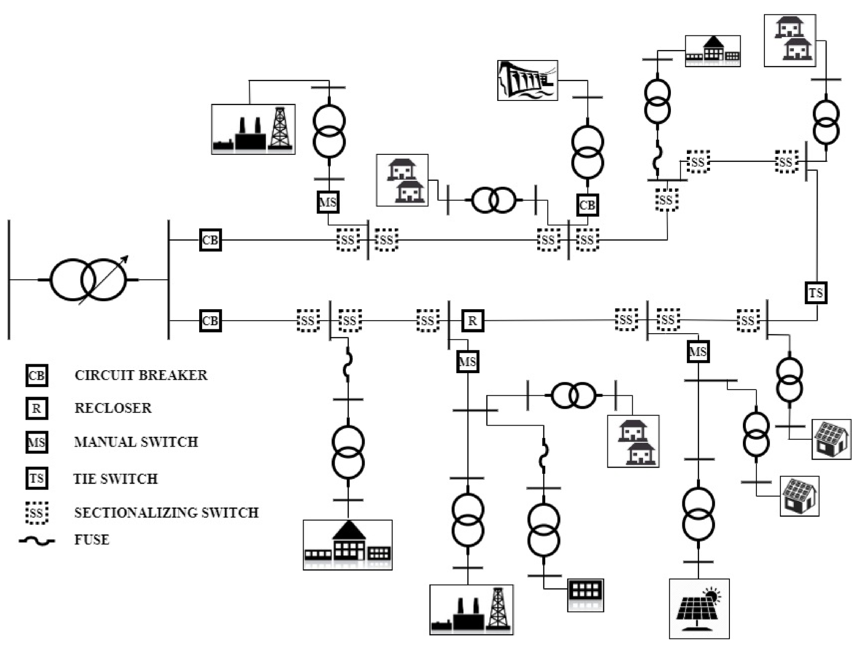

Figure 1: Protection components and possible locations of SS in distribution network with DG

- Reclosers are commonly used for fast restoration of power supply in the case of transient faults.
- In the case of a permanent fault, the main protection objective is to isolate the faulted component from the rest of the DS.
- Deployment of SS in main feeders enables the isolation of smaller DS area in the case of permanent faults
- Optimal SS allocation should be determined to meet DS's economical and technical requirements

Input data and guidelines for solving generalized SS allocation problem

The first step towards generalized problem-solving framework definition is input data availability and range analysis. Input data sets required for optimal allocation of SS problem solving are presented in Figure 2.

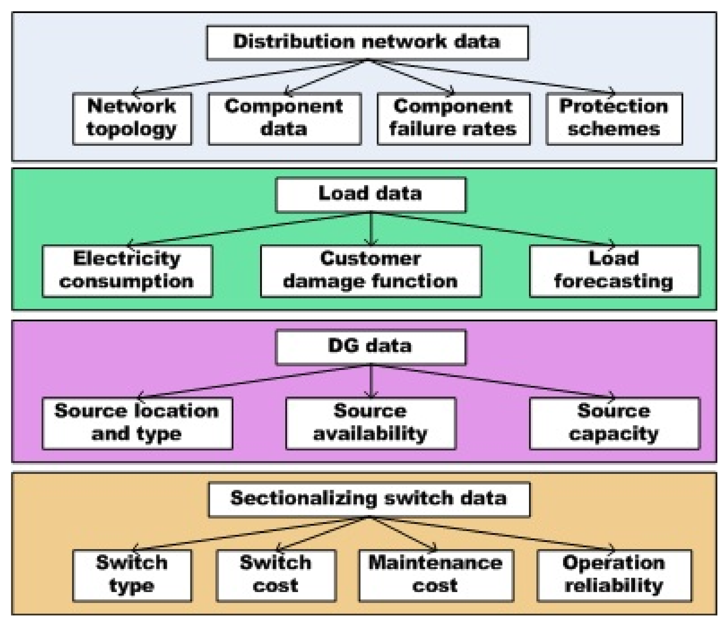

Figure 2: Input data sets required for SS optimal allocation problem solving

Since there are many SS allocation problem-solving frameworks, there is a need to identify and clarify relevant guidelines and methodology steps towards a generalized framework. The most relevant guidelines for solving of SS allocation problem are summarized in the form of a generalized framework prototype, which is presented in Figure 3.

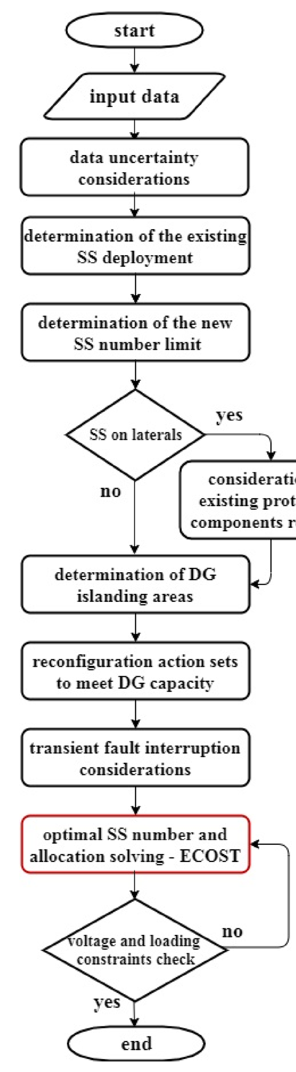

Figure 3: Generalized SS optimal allocation problem-solving framework prototype based on selected guidelines

Reliability indicators and objective function

In early research stages on SS optimal allocations, the following reliability indicators were used:

- System Average Interruption Frequency Index (SAIFI): $\mathrm{SAIFI} = \frac{\sum_i \lambda_i N_i}{\sum_i N_i}$
- System Average Interruption Duration Index (SAIDI): $\mathrm{SAIDI} = \frac{\sum_i U_i N_i}{N_T}$

where i is customer's location, N_i is the number of customers at location i, λ_i is the failure rate related to location i, U_i is the annual outage time for location i and N_T is the total number of customers served.

The best way to quantify customer outage costs is the usage of ECOST [1]:

$$\mathrm{ECOST} = \sum_{i=1}^{N_i}\sum_{j=1}^{N_j}\sum_{k=1}^{N_k} \lambda_i \times \mathrm{CDF_{i,j,k}} \times L_{j,k},$$

where N_i is the total number of possible fault locations, N_j is the total number of load points, N_k is the total number of customer types, λ_i is an average failure rate of network component i, $L_{j,k}$ is the average load of the kth-type customers located at the jth load point and $\mathrm{CDF_{i,j,k}}$ is customer damage function.

The cost of SS can be quantified by the following equation [5]:

$$\mathrm{SSCOST} = \sum_{s=1}^{N_s} (\mathrm{CI_s} + \mathrm{IC_s} + \mathrm{MC_s}) \times X_s,$$

where N_s is the number of SS, $\mathrm{CI_s}$ is the SS capital investment cost, $\mathrm{IC_s}$ is the SS installation cost, $\mathrm{MC_s}$ is SS maintenance cost and X_s is a binary variable representing SS existence.

The proposed MILP formulation for the SS optimal allocation in DS is defined as follows [5]:

$$\min \left[\sum_{t=1}^{N_t}\sum_{f=1}^{N_f} \left(\frac{(1+q)^{t-1}}{(1+\mathrm{DR})^t} \times \mathrm{ECOST} + \frac{1}{(1+\mathrm{DR})^t} \right) \right],$$

where N_t is the number of years, N_f is the number of feeders, q is the annual load increase rate and DR is the annual discount rate.

To account for transient (temporary) faults it is necessary to additionally include the corresponding interruption costs [9]:

$$\mathrm{ICT} = \sum_{i=1}^{N_i}\sum_{j=1}^{N_j}\sum_{k=1}^{N_k} \lambda_i^T \times \mathrm{CDF}_{i,j,k}^T \times L_{j,k},$$

where λ_i^T is temporary failure rate of network component i and $\mathrm{CDF}_{i,j,k}^T$ is customer damage function of temporary faults.

Conclusion

SS optimal allocation is one of the most important problems that should be analyzed in future DS since it has the potential to significantly improve reliability, which is the mandatory task in the SG concept. The complexity of DS protection with various types of protection components is emphasized in this paper. The obtained research results can be useful to DS planning departments considering the future SS investments and also to the research community attempting to create an ultimate problem-solving framework for SS optimal allocation.

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