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A review of the optimal allocation of distributed generation: Objectives, constraints, methods, and algorithms

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ABSTRACT

Distributed generation, with respect to its ability in utilizing the alternative resources of energy, provides a promising future for power generation in electric networks. Distributed generators contribution to power systems include improvement in energy efficiency and power quality to reliability and security. These benefits are only achievable with optimal allocation of distributed resources that considers the objective function, constraints, and employs suitable optimization algorithm. In this paper, a comprehensive review on the optimal allocation of distributed generators was carried out for different objectives, constraints, and algorithms. Current review highlights how the methods and algorithms for optimal distributed generation allocation play an important role in improving the accuracy and efficiency of the results.

1. Introduction

Unlike the traditional centralized generation, distributed generation refers to a method in which a part of the electric power is generated and delivered to customers with small generation units placed close to the end users. The distributed generation can also be addressed as dispersed generation, embedded generation, or decentralized generation. Distributed generation covers a wide range of locally installed power generation units which can be of both renewable and conventional types. Nowadays, with respect to the technical developments, enormous benefits can be achieved from Distributed Generators (DGs) in economical, technical, and environmental fields [1–3]. Those advantages could be earned by optimal selection, sizing, and placement of DGs in power systems.

There are technical and environmental restrictions in the conventional power plants' expansion. Moreover, unsecure fossil fuel market has led the electricity market towards new energy resources. In this way, there are a number of incentives for encouraging network planners to use combined heat power (CHP) resources in distribution networks. Some of the issues which can be addressed by DG integration in distributed networks are: power losses, voltage control, reliability, stability, and fault level [3–11]. Since the DG installation in power networks changes the network characteristics and the nature of the electricity market [12,13], proper legislative regulations for the electricity sector are being introduced at the same time. A comprehensive review on above matters, including the distributed power generation resources, regulation, and integration arrangement, has been carried out in Ref. [14].

Distributed Generation Allocation (DGA) can also include Distributed Generation Planning (DGP). Since the objectives, constraints, and optimization approaches are common in either DGA or DGP, most of the studies which have been reviewed in this article focused on distributed generation allocation as well as planning. According to the selected objectives and the operation constraints, the utilized method in DGA can be categorized with respect to their approaches for optimization such as normal search methods, intelligent methods, or fuzzy set based methods. An extensive review on the technical aspects of optimal distributed generation planning was done in Ref. [15]. In current study, optimal DG allocation has been reviewed and presented with focus on mathematical models and employed solutions. A brief review was also carried out on the related studies with respect to their objectives and constraints as follows:

Single or multi-objective functions are considered to maximize the benefits of DG due to the considered constraints. Normally, the real power loss [16–37] and the voltage profile [36–47] are the base objectives. Some other objectives may accompany this base objective such as reactive power minimization [48], DG capacity maximization [49–61], or economy oriented objectives [62–75]. Other than the above, multi-objectives models including various type of objectives [76–103] have also been implemented in DGA formulations. There are

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also studies on the influence of DG on supply system security and reliability, which clarified that these parameters could be improved by means of a proper DGA [104–110]. Technical issues of variable DGs (e.g. wind turbines) derived from time varying nature [14] and integrated in distribution networks using suitable DGA approaches are also investigated in Refs. [25,50,88,111–115]. A wide range of constraints has been selected for optimal DGA fitness functions of either single or multi objectives. These constraints can be categorized into two main classes: power systems conservation constraints and utilities capacity limitations. However, other constraints including power exchange between areas [17], voltage step [51], and short circuit level and ratio (SCL & SCR) [52] are also discussed in the literatures. The following sections discuss the objectives and constraints in DGA studies and presents the methods and algorithms for optimal DGA.

2. Selected objectives for optimal DGA

Most of the DGA studies were done with the objective of real power loss minimization. Besides that, the reactive power loss, voltage profile, the current reduction in weak lines, spinning reserve power, and network MVA capacity are also take in to account. Normally, the real power loss is selected as the base objective index and other objectives are used to form single or multi objective fitness functions for optimization. The most common combinations are explained in the following sub-sections and summarized in Fig. 1.

2.1. Power loss minimization

In this scheme, optimal location of DG units has been investigated by minimizing active power loss in the lines through DGA [16,17,33,41,42,116–121]. The formulation was done by assuming that the summation of the total injected power on all nodes could represent the network losses. The aforementioned formula for power losses has been extended according to the second order technique in Refs. [16] and [17] based on the Newton's method and genetic algorithm, respectively. In addition, in Ref. [17], the objective function has been expressed for each load level by total cost of the losses for that specific load level. Furthermore, the loadability has been improved by optimal allocation of DG units and by minimizing the total reactive power losses in Ref. [18]. In another study, the total line losses has been minimized to investigate the impact of DG on voltage stability and power transfer capacity of distribution network [19]. It has been understood that due to the injection of the active power, overall impact of DG installation is positive. Later on, the power loss has been minimized by focusing on the transmission losses to determine the installation bus and size of a type-3 DG (induction generator empowered by wind turbine) in Ref. [36]. On the other hand, the authors in Ref. [20], have expressed the total power loss as a function of the injected current to the network branches.

The majority of researches only focused on total real losses in power systems (exact losses) [21–26], while, the total energy loss and energy loss for 24 h are chosen to minimize the power losses in Refs. [27] and [28], respectively. Moreover, the total power losses has been represented by the annual energy losses in the number of studies [29–31]. The annual energy loss is minimized by optimal DGA in Ref. [29] using biomass and wind DGs in combination or as a single source. They were installed in both dispatchable and nondispatchable forms. Same objective is minimized by optimal DGA of 3 wind turbines [30]. The trend was followed by optimization of hybrid DG unit comprising solar, wind, and non-renewable DG [31]. In addition, the power losses was

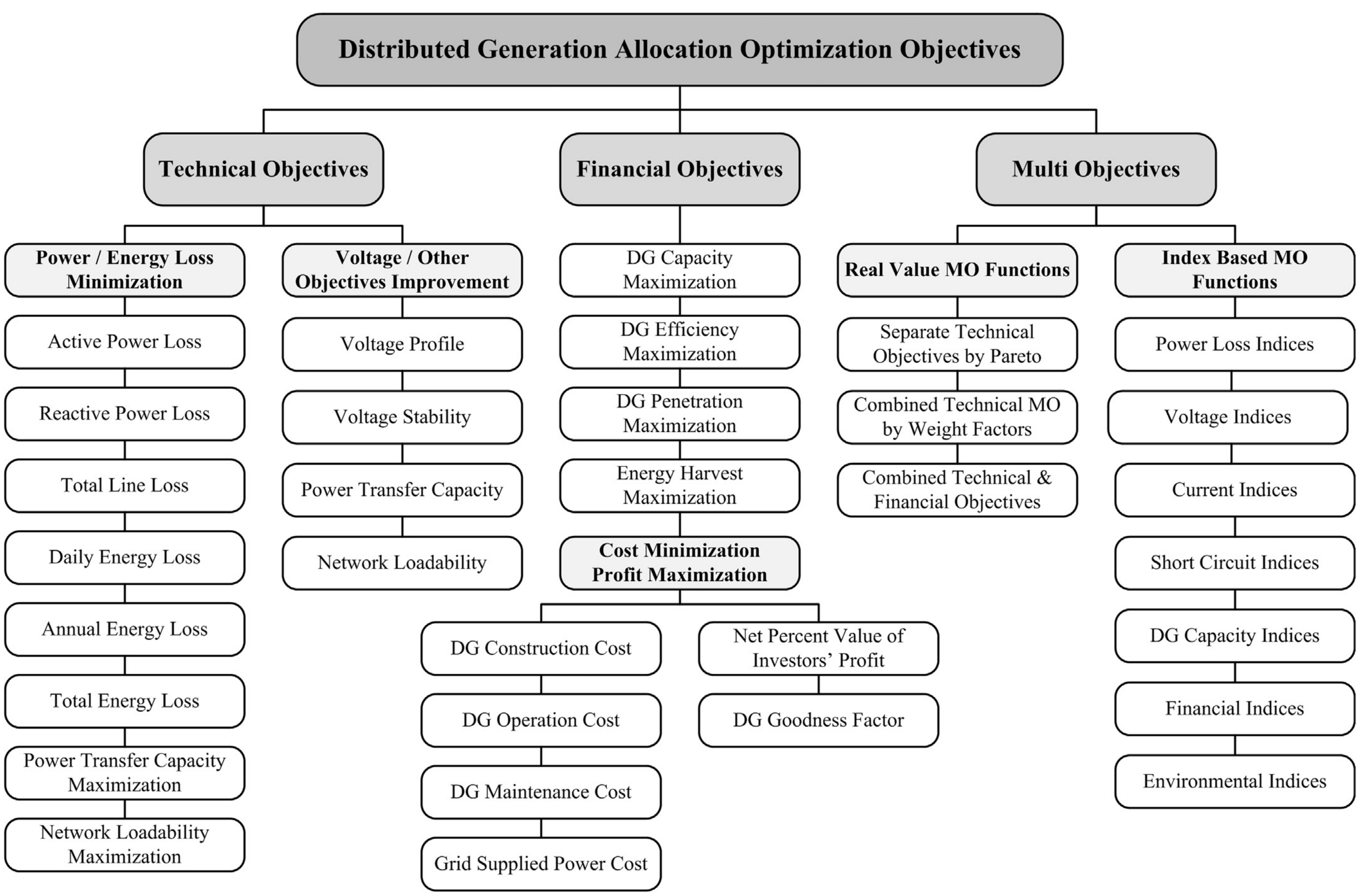

Fig. 1. Selected objectives in distributed generation allocation.

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