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Long-term multi-objective distribution network planning by DG allocation and feeders' reconfiguration

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ABSTRACT

This paper proposes a long-term planning method to maximize the benefits of network reconfiguration and distributed generation (DG) allocation in distribution networks. The proposed method handles long-term yearly load increase and seeks to define the reinforcements (i.e., line upgrades, network reconfiguration, and DG integration) and when and where they are required to meet the load rise with minimal cost and acceptable quality standards. The objectives considered in this paper are: economic (costs of line upgrades, energy losses, switching operations, and DG capital, operation and maintenance costs) and environmental (emissions from grid and DG units). The proposed method takes into consideration the uncertainty related to renewable DG output power and the load variability. The long-term planning problem is defined as multi-objective nonlinear mixed integer programming. The outcomes of the planning problem are the Pareto front, which represents different optimum operating system points. Finally, the local distribution company (LDC) can choose the system operating point based on its preferences.

1. Introduction

With the challenges facing electricity generation due to the limitation of fossil fuels, renewable based distributed generation (DG) units (i.e., wind power, photovoltaic, biogas, and fuel cells) become a dominant choice in power systems. These renewable energy sources promise an improvement on the power supply reliability due to their inexhaustible nature, and a reduction in greenhouse gas emissions because they are nonpolluting [1]. Installation of DG units in distribution systems has several benefits such as reducing system losses, enhancing voltage profile, shaving peak demand, relieving overloaded distribution lines, reducing environmental impacts, increasing overall energy efficiency, and deferring investments to upgrade existing power systems [2].

Network reconfiguration is a vital function in distribution automation (DA), which is generally used for loss reduction and system security improvement. The reconfiguration problem is to find the best configuration of the distribution system that gives minimum energy loss while satisfying the imposed operating constraints. This process is normally achieved by opening the normally closed sectionalizing switches and closing the normally opened tie switches [3–5]. Since network reconfiguration and DG allocation are complex combinatorial optimization problems, several algorithms are proposed in the literature [1–8] to solve those problems. Further, the continuous load demand growth may lead to system feeders' overloading and/or voltage constraints violation, where installing DG units can be beneficial. A review of the literature shows that most of the published work has considered DG allocation and reconfiguration problems independently [2,6]. Thus, DG units have been allocated in an individual network configuration that could be considered as original configuration [6].

A review of the literature also reveals that few studies have considered DG allocation and network reconfiguration simultaneously [1–3,6–8]. A GA to solve the expansion planning problem in distribution systems is proposed in [1]. The authors did not propose a new reconfiguration algorithm but used a heuristic algorithm from a previous work. Also, their work did not take into consideration the gas emissions and the multi-year load growth. Harmony search algorithm to solve the network reconfiguration problem in presence of DG units with an objective of minimizing the real power losses only was introduced in [2]. The simulation results were based on the assumption that the load is fixed. This assumption may lead to sub-optimal solution because of the time-varying nature of loads in distribution systems. Also the work considered only dispatchable DG units. Since the thermal and voltage constraints can limit DG penetration, a GA based reconfiguration method to maximize allowable DG penetration at given nodes was presented in [3]. In [6], DG allocation and network reconfiguration were achieved simultaneously. In both [3,6], authors did not, however, consider load variation or variable DG output in their investigation. In [7], the effect of coordinating network reconfiguration and voltage control

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on increasing the maximum allowable DG penetration at a given node was presented. The work covered only wind-based DG units.

From the above discussion, it is obvious that sufficient work has been done with respect to DG allocation and network reconfiguration problems independently, yet fewer publications have addressed the two problems simultaneously. Moreover, the gas emissions, multi-year load growth, and the uncertainty associated with renewable DG units and load variations were not considered in most studies. However, the planning of DG integration together with network reconfiguration is a requirement for the modern active distribution networks in order to maximize the benefits as much as possible. This paper, therefore proposes a planning method based on non-dominated sorting genetic algorithms (NDSGA) for distribution systems by feeders reconfiguration and DG allocation. The algorithm takes the following into consideration:

- Uncertainty associated with renewable DG units' output power.
- Load variation and customer sector type.
- Different types of DG units (gas turbine, wind, photovoltaic) which are the most commonly used types.

The main contribution of this paper is twofold:

- The paper proposes a multi-year multi-objective joint reconfiguration and DG allocation. The considered objectives are: economic (costs of line upgrades, energy losses, switching operations, and DG capital, operation and maintenance costs) and environmental (emissions from grid and DG units).
- Unlike the previous work on joint reconfiguration and DG allocation that considered fixed load or used one year only, the stochastic nature associated with renewable DG output power, load variability, and load growth across the planning horizon have been considered in evaluating the different planning objectives.

The remainder of this paper is organized as follows: Section 2 presents the problem description. Section 3 presents the models used for the system components. The problem formulation is explained in Section 4. Sections 5 and 6 detail the test results, and Section 7 presents the conclusions.

2. Problem description

Distribution companies seek optimal configuration to minimize energy losses in their distribution networks. For practical application of network reconfiguration in real systems, the time varying nature of loads and DG units should be considered [9]. Unlike the previous work, a joint optimization algorithm has been proposed for combining of the DG allocation and network reconfiguration problems. This is because these two problems have an inherent coupling relationship, and therefore, considering them simultaneously is more effective than considering them separately. Fig. 1 summarizes the proposed method. It starts by modeling the load and DG generation with consideration of the probabilistic nature of renewable DGs. Then, the planning problem is formulated, with an objective function of minimizing the overall cost and the gas emissions.

3. Modeling of loads and DG units

In this paper, the types of DG units considered are photovoltaic (PV) modules, wind turbines (WT), and gas turbines (GT). Other DG types can be modeled with similar approaches [10]. In this work, the hourly average load, wind speed, and solar irradiance are considered and the variations within the hour are neglected. Also, the wind-based and solar-based DG output powers and load are modeled as multi-state variables. The number of states is a trade-off between accuracy and problem's complexity.

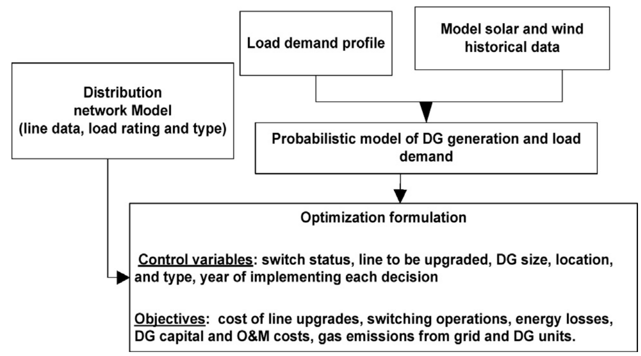

Fig. 1. A brief description for the planning problem.

3.1. Renewable generation modeling

For this research, the wind speed and solar irradiance for each hour of the day are modeled by Weibull and Beta probability density functions (PDFs), respectively, using historical data [11]. The probabilistic models for both wind and PV-based DG units' output power are described as follows [10,11]:

- The entire year is divided into 12 months, and each month is being represented by one day, which is subdivided into 24 h segments [10,11].
- The mean and standard deviation for each time segment are calculated utilizing the historical wind speed and solar irradiance data [10,11].
- The Weibull and Beta PDFs are generated for each hour using the mean and standard deviation for each segment [10,11].
- In order to integrate the output power of wind turbines and PV modules as multi-state, the continuous PDF of each is divided into a proper number of states. Then the probability of each wind speed and irradiance state is calculated [10,11].
- The corresponding output power of the wind turbine and PV module in each state are calculated using the wind turbine and PV module characteristics [11].

Therefore, these wind and solar generation states (PDFs) which calculated based on the historical data for the site under study remain the same after the year of DG installation.

3.2. Gas turbine and load modeling

The gas turbines generators are assumed to be firm generators without uncertainty (i.e., constant output power at its rated value), which is the typical model in this type of studies [10,11]. The load is assumed to be categorized into three types, which are residential, commercial, and industrial. Historical data of load demand is utilized to calculate the probability of each load state during each hour. In this work a definite number of states are chosen to represent each type of load, and the states values are calculated based on the central centroid sorting process developed in [12]. These load states are updated every year based on the load growth rate.

3.3. Combined generation-load model

The generation-load model describes all the system states and their probabilities of occurrence. The year is divided into 12 months; further each month is modeled by 24 h. Therefore, each load state or generation state has a probability of occurrence in