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Multiple-distributed generation planning under load uncertainty and different penetration levels

Faruk Ugranlı, Engin Karatepe *

Department of Electrical and Electronics Engineering, Engineering Faculty, Ege University, 35100 Bornova, Izmir, Turkey

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ABSTRACT

The penetration of distributed generation (DG) in power system is continually increasing. Hence, there is a need to investigate the potential benefits and drawbacks of DGs when integrating DG units in existing networks. The challenge of identifying the optimal locations and sizes has triggered research interest and many studies have been presented in this purpose. Different analytical techniques have been developed to minimize power losses for single-DG unit integration. If DG units are integrated at nonoptimal locations, the power losses increase, resulting in increased cost of energy. The novelty of this paper lies in studying the optimal placement of multiple-DG units in order to minimize power losses. In this study, an optimality criterion is investigated to minimize losses by including load uncertainty, different DG penetration levels and reactive power of multiple-DG concept. The simulation results show that it is not possible to form an analytical equation for optimum planning of DG in terms of load distribution, penetration level and reactive power. Due to the complexity of the multiple-DG concept, artificial neural network based optimal DG placement and size method is developed. The proposed method is implemented to the IEEE-30 bus test network and the results are presented and discussed. The results show that the proposed method can be applied to a power network for all possible scenarios.

1. Introduction

Because of the major development of energy technologies in recent years, the power systems have been evolved rapidly. The future grids become a complex system in terms of operation and coordination by integrating more distributed generation (DG) units [1,2]. Distributed generations or dispersed generations are small sized electricity generation units. Although the capacities of DG units increase up to 50 or 100 MW [3,4], it is difficult to define an exact capacity and optimum location due to the specific structural features of power networks. DG concept allows the usage of different renewable and conventional power sources [5,6]. DGs have huge scopes for technical, economical, and environmental benefits such as postponement of transmission and distribution lines upgrades investments [7], improvement of the voltage profile, reducing power losses, and line loading. Integration of DG can change the characteristic and the operation of power systems. DGs can trigger bidirectional power flow, which can affect power losses and voltage profile. For this reason, the problems of DG allocation and sizing are quite important to take the advantages of DG integration [8]. An inappropriate allocation of DG units causes bad turn in terms of reliability and system efficiency, especially at high penetration levels. In this respect, it is crucial to define some principles of DG allocations. Therefore, impacts of DGs on power system performance are widely studied for getting basic principles [9–12].

Many different techniques were developed and reported in the literature for problem of optimum size and location of DG units. It is noticed that there is no strict way to handle this problem. Minimizing the power losses and improving the voltage profiles are main objective functions for the problem of DG integration [13–21]. Different analytical techniques have been developed for minimizing power losses for single-DG unit integration [22,23]. The integration of multiple-DG units cannot be handled simply as well as single-DG because of the complex structures of power networks, despite of these different techniques. For this reason, researchers have started to use intelligent techniques. Genetic algorithm, simulated annealing, particle swarm optimization, fuzzy logic, fuzzy wavelet network, and artificial neural networks (ANN) are some methods used for power system problems [24–27]. While solving the optimum size and location problems by means of these methods, researchers make some assumptions in their studies. DG units can be modeled as active power sources although many kinds of DGs are capable of injecting and/or absorbing the reactive power [28–31]. In some studies, reactive powers of DGs are included into the problems [32–34]. Ugranlı et al. investigated the impact of

* Corresponding author. Tel.: +90 232 3115243; fax: +90 232 3886024.
E-mail addresses: faruk.ugranli@ege.edu.tr (F. Ugranlı), engin.karatepe@ege.edu.tr (E. Karatepe).

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reactive power fluctuations of DG on the voltage profiles and ANN based DG allocation method is proposed to reduce the voltage variations [32]. When including reactive power of DG into the optimization problems, the modeling of DG can be categorized into four groups: the reactive power is formulated according to the real power of DG unit [35]; the output power of DG is taken as the predefined active-reactive data pairs [36]; the reactive power of DG is included as a constraint variable in the optimization problem [37,38]; and DG unit is assumed to have fixed power factor [9,39]. The last approach is chosen in this study, because it is assumed that the power factor of all DG types can be controlled by using advanced control strategies and power electronic interfaces [40].

In general, some DGs such as wind turbine and photovoltaic have intermittent characteristics, thus they are not dispatchable sources. However, research efforts have been made towards enhancing the dispatchability of DG systems by forecasting the weather and the output power of generation [41,42]. Moreover, micro-turbines and synchronous based DGs can be forced to operate at an adequate size level to reduce power losses and improve the power quality [43]. The maximum size of DG to be connected to a bus can be varied according to the existing infrastructure of a power system [3]. The penetration level is defined as the output active power of total capacity of DG divided by the total network load on a power network. Since each power network has different active power load, the penetration level of DG is a relative term [3]. Here, maximum total DG capacity is assumed to be 50 MW according to the medium category of distributed generation in [3]. This size is considerably high penetration level for the IEEE-30 bus test network which is used in this paper.

As far as multiple-DG units are considered, the structure of the power network will become more complex. In order to ensure the optimum operation and coordination of the power systems, the units should be communicated to each other. In addition, they should be coordinated by management centers [44]. The coordination can be performed by using intelligent methods. The load data are available instantaneously in a power system [45]. By using these data, the optimal size and placement of multiple-DG units can be determined. However, it is very difficult to derive an analytical equation which represents the relationships between optimum allocation of multiple-DG units and load profile. Hence, an intelligent tool is needed to be developed to map this kind of nonlinear relationships. In this study, ANN is utilized to overcome these difficulties. The proposed method can be used easily in planning and management stages for multiple-DG concept when the load data is available for a power network. Elnashar et al. present an ANN based optimal distributed resources allocation method in order to estimate the weighting factors and these factors are voltage level, power losses, and short circuit level [46]. While other authors have studied single-DG connections schemes for a specific load condition, this paper proposes a study of multiple-DG concept and load uncertainty for a given power network. Furthermore, the exhaustive repetitive power flow analysis is not required in the proposed ANN method. The number of candidate DG buses is also not restricted in the problem formulation, so the proposed method can be applied to a power network for all possible scenarios. Optimal DG location and size can be determined quickly among the selected buses.

In this paper, firstly the behaviors of the multiple-DG integrated power system are analyzed in detail. Because of the complexity of the power systems, an ANN based optimal DG placement and size approach is proposed to minimize total power losses including uncertainties of the load. Synchronous machine based DGs are considered in this study. The proposed method is implemented to the IEEE-30 bus test network and the results are presented.

2. Problem formulation

DG can be powered by both conventional and renewable energy sources [3]. Acharya et al. consider DGs as an active power source [22]. It means that considered DG can be any type of DG technology which is operated at unity power factor. In [23], DGs are assumed to be operated at unity power factor in the planning formulation. Different power factors can be dealt with by considering the reactive power of DGs in power networks. In [39], it is assumed that DG operates at determined constant power factor without mentioning the types of DG. Olamaei et al. propose a planning formulation by considering DGs as both active and reactive power sources [24]. In this study, synchronous machine based DGs are considered in the problem formulation. Thus, DGs are assumed to be dispatchable because synchronous machine based DGs are considered. Not only the active powers of DG units but also reactive powers of them are included in the planning of DG allocation and size.

2.1. Load representation

In power networks, loads are highly distributed and quite variable, thus detailed modeling is impossible. The power loads always change with time in a real system. Data collection and forecasting methodologies for reliability evaluation are complementary activities. However, it is often very expensive and impractical to collect and analyze the load data for the entire network. Therefore the mathematical methods can be used for the estimation of loads at unmetered points on the systems [47]. For this reason, the load variations can be included by using randomly generated series within a reasonable range in power flow analysis [48]. The load models are provided from the statistically independent random value generating process in this study. The original load values of the power network are selected as their mean values. The following equation is used to include the load variations for each load bus

$$P^i_{load} = P^i_{mean} + P^i_{mean} \cdot \alpha \cdot random(z) \quad \text{for } i = 1, 2, \ldots, N_{bus} \tag{1}$$

$$P^{total}_{load} = \sum_{i=1}^{N_{bus}} P^i_{load} \tag{2}$$

where P^i_{load} is the randomly generated load powers for ith bus, P^i_{mean} is mean value of the power for ith bus, N_{bus} is number of the buses, and α is the deviation factor. The deviation factor is commonly used to calculate the load profile in the literature [48]. To obtain the load profile, their mean values are assumed to be equal to base case loads. Their standard deviations are calculated by multiplying the mean value of power and deviation factor. So that, deviation factor (α), which is chosen 10% in this study, is a parameter to calculate the standard deviation of load profile. By using this factor, standard deviation of the loads can be calculated by multiplying P^i_{mean} and α as in (1) [48]. The random function generates a random vector with length z which is number of the load cases. This function generates normally distributed random numbers in the range of -1 and +1.

2.2. The finding the optimal size and placement of multiple-DG units

In this study, optimality criteria will be investigated to minimize total losses by including load variations, different penetration levels and reactive power for multiple-DG concepts.

The general expression for the objective function of this study

$$Minimize \quad P_{loss} = \sum_{i=1}^{N_{line}} \left(I^{flow}_i\right)^2 R_i \tag{3}$$

where N_{line} is number of the lines which also include transformers, P_{loss} is the total power losses, I^{flow}_i and R_i are the current and