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Long term scheduling for optimal allocation and sizing of DG unit considering load variations and DG type

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ABSTRACT

This paper proposes a new long term scheduling for optimal allocation and sizing of different types of Distributed Generation (DG) units in the distribution networks in order to minimize power losses. The optimization process is implemented by continuously changing the load of the system in the planning time horizon. In order to make the analysis more practical, the loads are linearly changed in small steps of 1% from 50% to 150% of the actual value. In each load step, the optimal size and location for different types of DG units are evaluated. The proposed approach will help the distribution network operators (DNOs) to have a long term planning for the optimal management of DG units and reach the maximum efficiency. On the other hand, since the optimization process is implemented for the entire time period, the short term scheduling is also possible. The proposed method is applied to IEEE 33-bus test system using both the analytical approach and particle swarm optimization (PSO) algorithm. The simulation results show the effectiveness and acceptable performance of the proposed method.

1. Introduction

The most of distribution networks have been planned as passive radial networks with unidirectional power flow. However, considering DG units in the distribution network, changes these networks to active ones with bidirectional power flow. The utilization of DG units in the system can yield many benefits such as power losses reduction, decreasing congestion in feeders, stability enhancement, environmental sustainability, voltage profile improvement, power quality improvement, capability of peak shaving, investment risk reduction, capital and operational expenditure reduction, deferral of expansion plans, reliability and security improvement [1–3]. According to the statistics, the amounts of power losses are different in various countries. This value in USA was estimated at 6.5% in 2007 [4]. Studies shows that distribution system power losses are about 70% of the total losses of power systems [5]. From the utility point of view, the real power losses have direct effect on the efficiency. Nevertheless, the value of the reactive power flow in feeders should be limited to a certain value to keep the voltage in acceptable range and release the transmission capacity [6]. Both of above mentioned targets can be achieved through the optimal DG operation management in the distribution system. However, the main challenging issue in DG applications is to find the optimal location and size considering utility constraints. According to recent researches, the imprecise usage of DG in the network can reverse the power flow in feeders such that high power losses and overload conditions may occur in the system [7,8]. Moreover, the high penetration of DGs in the system will reduce the coincidence between the power generation and consumption which can result in higher losses [9].

In the distribution systems, power losses reduction is one of the significant factors to improve the overall efficiency of the power delivery. In this regard, the optimal capacitor placement, reconfiguration and DG allocation are among the most well-known methods. Conventionally, based on the background of the passive distribution network, DG is installed with a “fit and forget” approach. In this situation, the DG power rating is not considerable in comparison with the system generation while it can replace the energy generated by centralized units [10]. However, in the recent years, many studies have been carried out to present new methodologies in DG allocation and sizing. Most of them are analytical methods or heuristic and metaheuristic approaches. In [11], a new analytical method has been proposed to solve the optimal DG allocation in radial distribution networks. In [12], a loss sensitivity factor method based on the equivalent current injection has been employed to determine the optimal size and location of DGs. The objective function was total power losses which should be minimized by an analytical method and without using the admittance matrix. In [7], the exact losses equation has been utilized to calculate the optimal size of the DG unit (which is capable of only P

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injection). Similar work has been expanded and applied to another type of DG considering the effect of the power factor [13]. Also, this method has been developed in [14] for multiple DG unit placement to achieve a higher loss reduction. In [15], the power loss sensitivity technique has been employed to determine the suitable size, location and operating point of DG units. In [16], a new analytical approach has been proposed for DG placement for power losses minimization. The candidate location for DG placement has been determined based on novel power stability index. In [17], loss sensitivity factor and Simulated Annealing (SA) technique has been deployed for optimal placement and sizing of DGs in order to minimize power losses and improve the voltage stability. Also, various methods have been proposed in the artificial intelligence field. In [18], bee colony algorithm has been employed to determine the optimal location, size and power factor (PF) of DG units in order to minimize power losses. In [19], a GA-based algorithm has been presented for DG placement to reduce power losses and voltage profile and reliability improvement. In [20], a GA-based OPF has been presented for optimal placement of DG units in order to minimize active and reactive power cost. In [21], a combined method based on improved PSO and Monte Carlo simulation has been proposed for optimal allocation of DG units in order to minimize the costs of power losses and to improve the voltage profile and reliability. In [22], a new method based on modified teaching–learning optimization algorithm has been suggested for finding the optimal location and size of DG units in order to power losses minimization. In [23], an Evolutionary Programming (EP) based methodology for optimal allocation of WT and PV array has been suggested to minimize active power losses. This study also considers the uncertainties associated with loads and renewable recourses. In [24], a combined solution based on GA and PSO has been proposed for DRG allocation in order to minimize power losses, improve voltage stability, and enhance voltage regulation that considering security constraints. In [25], a Cuckoo Search Algorithm (CSA) has been deployed for DG placement considering loss reduction and voltage profile improvement. Also nonlinear programming and OPF has been deployed for solving the DG allocation problem. In [26], a combined solution based on OPF and discrete form of PSO has been used for DG allocation to reduce losses and maximize DG capacities. In [27], an ordinal optimization method has been proposed by using OPF to achieve a tradeoff between loss minimization and maximization of installed capacity of DGs. In [8], a probabilistic-based method has been proposed for renewable DG units in order to minimize annual energy losses and considering uncertainties without violating system constraints. In [28], a multi-period AC OPF technique has been proposed to achieve the optimal allocation of the renewable DG units for loss minimization in a future smart grid. In [29], has been proposed a dynamic programming for multi objective DG allocation for power losses minimization, voltage profile improvement and reliability enhancement. In [30], the simple conventional iterative search method has been combined with the NR load-flow for optimal allocation of DG units in order to simultaneously reduce losses and total cost. Finally, the comprehensive overviews on different methods of the optimal DG allocation have been presented in [31–33].

In this area, the most of studies have focused their research on the peak load level and so the load variations have not been considered. However, in the time horizon of a day, a month or a year, the active and reactive load values may experience severe changes and the operator have to consider these variations. As a result of uncertainty associated with the system loads, the operation and control of distribution networks are very complex and can be modeled as a nonlinear optimization problem. In other words, considering the variations of loads during the day, a fixed value/size for the DG rating cannot guarantee the optimal power losses in the system. So considering the multi-level load analysis will change the optimal sizes and locations of DGs in the network. Therefore, the problem should be solved considering the multi-level load model such that the maximum efficiency is achieved and some unexpected issues such as feeders overload and power losses increase would not occur. This situation shows the importance of an accurate analysis for optimal siting and sizing DG of units [1]. According to the above discussion, in this work, the network load is linearly changed from 50% to 150% of its nominal value in 1% steps. At each step, the optimal size and location of DGs units are calculated. By using the curve fitting technique, the optimal size of DG per load level is formulated in the form of a simple equation. The proposed method allows the DNOs to select DG units with a wide range of power generation. In this case, the power generation can be changed and we can be sure for the loss minimization. Also, DNOs can have both long-term and short-term planning such that the system would continuously operate in its optimal condition. The main advantage of this method is its simplicity and its applicability for different loading levels. The feasibility and effectiveness of the proposed method is investigated in a standard test system.

The rest of this paper is organized as follows: In Section 2, the modeling and formulation are described. Section 3 presents the proposed PSO algorithm and analytical approach. The simulation results are discussed in Section 4. Finally, in Section 5, the main conclusions and remarks are drawn and summarized.

2. Problem modeling and formulation

2.1. DG model

DG units, considering their types, operation mode and network connection method can be modeled as PV or PQ bus [34]. In the inverter-based DG units, the convertor control method determines modeling type, while in machine-based DG units, machine operation mode determines the modeling type. A DG modeled as a PQ bus, may be modeled in three different types. In the first modeling type, DG units have a constant P and Q generation and modeled as a negative load [35]. In the second modeling type, DG units have a specified value of P and PF and modeled as a constant power factor machine [35] and in the third modeling type, DG units are modeled as a variable Q generator [35] (like a induction machine based wind farm). When DG is modeled as a PV bus, DG units have specified output real power and bus voltage magnitude [35]. Also, DG units are modeled as a PV node using a dummy bus and dummy branch which injects reactive power to the specified bus to maintain the voltage in the specified value [36]. Since DGs are, normally, smaller in size (compared with the conventional power sources) the constant PQ model is found to be sufficient for the distribution system load flow analysis [36–39]. In this paper, the DG is modeled as a negative load [39].

2.2. Load model

In power system studies, according to the static characteristics of the load, three well established models has been proposed for modeling the behavior of loads that are as follows [36,17]:

- *Constant power:* In which the *P* & *Q* are independent from the voltage changes.
- *Constant current:* In which the *P* & *Q* are directly proportional to the bus voltage.
- *Constant impedance:* Wherein the *P* & *Q* are directly proportional to square bus voltage.