ORIGINAL RESEARCH ARTICLE

Optimal placement and sizing of distributed generators for voltage-dependent load model in radial distribution system

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The power demand is expanding consistently, which results in the increment of power losses and dropped voltage of the distribution system. Integrating distributed generation (DG) substantially reduces the power loss and increases the voltage profile. In order to get maximum compensation from DG, it ought to be coordinated with optimal placement and sizing. In this paper, an extensive investigation is exhibited for the optimal placement and sizing of different types of one and multiple DGs with existing and increased loads. Electrical load growth is modelled for the base year and next three years with the predetermined load growth. In practice, the distribution system has different types of consumers, assuming constant power load model will lead to inappropriate results. Thus, five different types of load models such as constant, residential, industrial, commercial and mixed loads are considered. Three distinct sorts of DGs were chosen for this study, that is, active, reactive and combination of active–reactive power DG. The proposed study has been applied to the IEEE 33 radial distribution system with basic particle swarm optimization (PSO) algorithm. The results reveal that combination of active–reactive power DG is giving better results for power loss reduction and voltage profile improvement, compared to the other DG types.

Keywords: Distributed generation, Voltage-dependent load model, Particle swarm optimization, Distribution system

Introduction

Power utilities are facing huge challenges, as electricity demand is increasing speedily every year. Adding more power capacity to the transmission lines can undermine the security and stability of the power system. In the present trend, it is obligatory either to invest in the transmission line infrastructure or to work on the power transporting locally. Incorporating small power generators called the distributed generation (DG) to the distribution system has overall positive impact. The decision for DG location depends on stockholders, site of fuel availability, land right of way, and climate conditions, so in some extents, the distribution network operator (DNO) has no control on its placement and sizing [1]. Placement and sizing of the DG in the distribution system have large impacts on the power system. Whereas, inappropriate placement and sizing will worsen the existing situation [2–4].

Several methods such as the analytical method, numerical programming method, heuristic method, and iterative based optimization algorithms have been introduced for the proper placement and sizing of the DG in the distribution system. Among them, the 2/3 analytical method for the power loss reduction was introduced by [5]. According to this method, the best DG size can be 2/3 of the feeder load if it is placed at 2/3 of distance from the feeder. This method is based on approximation and it is only suitable for the radial system. The limitation of this method is it cannot be applied directly to the distribution system with different types of loads

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such increasing load or non-uniform loads. Author [6] derived two analytical expressions; one for the radial system and another for the meshed network. The main purpose was to minimize power losses with the unity power factor for different types of loads.

An analytical method based on the exact loss formula was used for the optimal placement and sizing of a single DG unit in the primary distribution system [7]. The results were compared with the exhaustive load flow and loss sensitivity factor. The analytical method for the optimum placement and sizing based on equivalent current injection proposed by [8] is quite simplified and there was no need to work on the admittance matrix or inverse admittance matrix or Jacobean matrix for power loss reduction. Author [9] proposed analytical expression for the different types of real and reactive power DG. The optimal location was found for minimizing power loss. The impact of the power factor of the DG units when they were placed at various locations with different sizes to provide power loss reduction and improvement in voltage profile with and without optimal power factor has been investigated by [10–12].

Linear and non-linear programming method were used for the optimal DG placement and to yield the maximum amount of energy in [13,14] considering financial and technical constraints. The optimal sitting and sizing of DG considering multi-constraints with single or multi-objective using GA have been used by [15,16]. The power loss minimization using PSO for only constant power load has been presented in [17–19] for optimal placement and sizing of DG. So far, three different types of DG with five different types of voltage-dependent load models for the base year and upto next three years load growth for short term planning of distribution system has not been reported in the literature.

Hence, the contribution of this paper is to investigate the optimal placement and sizing of DG problem for various types of DGs such as the active, reactive and the combination of active–reactive power source DG respectively. The electricity demand is increasing every year so with the predetermined load growth, the load growth for the base year and next three years is predicted. This paper also divides the loads into different categories; constant power, residential, industrial, commercial and mixed loads. The main reason for different types of loads is to observe the active and reactive power requirements of the system. Moreover, single and multi DG (from one to five numbers) were used to see the impact on power loss and voltage profile on each load types. The author believes that this paper will not only help to DNO but also help researchers and consultants to understand the behaviour of the DG in the distribution system.

The rest of the paper is organized as follows. 'Load modelling' section presents the load modelling and problem formulation, 'Optimal DG placement and sizing problem with PSO' section presents the problem formulation and optimization algorithm. 'Simulation results and discussion' presents the different case studies and finally conclusions are reported in 'Conclusion' section.

Load modelling

In most of the load flow studies, it was assumed that the load of system is constant. However, the distribution system is mainly comprises of three types of the loads such as domestic, commercial and industrial loads. The active and reactive power requirements for these types of loads are dependent on voltage and frequency of the system. Changing the load characteristic, changes the load flow analysis and its convergence [20]. The fact, the frequency of the system cannot be controlled locally so managing load voltage will improve overall active–reactive power requirement. Hence, this paper considers the voltage-dependent load model as taken from IEEE Task Force [21].

$$P_L(i) = P_{Lo}(i)(V)^p \tag{1}$$

$$Q_L(i) = Q_{Lo}(i)(V)^q \tag{2}$$

$P_L(i)$ and $Q_L(i)$ are the active and reactive power demand of the bus i, and p and q are the exponents of the voltage-dependent loads. Table 1 presents the exponential values of p and q for different category of loads.

Practically, the distribution system loads are not explicitly residential, industrial, and commercial.

The load buses may be assigned to different loads or it may be a combination of mixed loads. In this paper, the mixed load is also considered and assumed as:

The total distribution system comprises residential, commercial and industrial load types respectively.

From the simulation, the random percent value of each type of the load was taken and their total sum was 100 percent.

From each random percent value, the random bus numbers were taken from the existing distribution system and the active and reactive power loads were assigned. Finally, the voltage-dependent mixed load model was modelled from the following equation:

$$P_L = \sum_{i=1}^{\rho} P_{L0} V^{\alpha} + \sum_{i=1}^{\sigma} P_{L0} V^{\alpha} + \sum_{i=1}^{\tau} P_{L0} V^{\alpha} \tag{3}$$

$$Q_L = \sum_{i=1}^{\rho} Q_{L0} V^{\alpha} + \sum_{i=1}^{\sigma} Q_{L0} V^{\alpha} + \sum_{i=1}^{\tau} Q_{L0} V^{\alpha} \tag{4}$$

where ρ, σ and τ are the bus numbers of industrial, residential and commercial loads.

The simulation $[2, 11, 4, 20, 29, 17, 16, 10, 7, 6]$ buses were suggested as the commercial load, $[9, 21, 15, 12, 31, 28, 19]$ buses as industrial load and $[3, 5, 8, 13, 14, 18, 22, 23, 24, 25, 26, 27, 30, 32]$ buses as residential load, respectively.

The distribution system active and reactive power load demand with its load growth for k years was presented by [22,23].

$$PL(k) = PL(0)(1+g)^k \tag{5}$$

$$QL(k) = QL(0)(1+g)^k \tag{6}$$

where $P_L(0)$ and $Q_L(0)$ are the active and reactive power load at the base year, $P_L(k)$ and $Q_L(k)$ are the real and reactive power load in k year, k is the number of year, and g is the annual growth. It is worth mentioning here that the annual load growth is generally taken from the historical data of the particular distribution system under study. The load growth for this paper was taken as 7.5% for all types of loads [22,23].

TABLE 1

Load types and its exponent values.

No.	Load types	α	β
1	Constant	0	0
2	Industrial	0.18	6.00
3	Residential	0.92	4.04
4	Commercial	1.51	3.40