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A novel approach to identify optimal access point and capacity of multiple DGs in a small, medium and large scale radial distribution systems

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ABSTRACT

Distributed generation (DG) sources are predicated to play major role in distribution systems due to the demand growth for electrical energy. Location and sizing of DG sources found to be important on the system losses and voltage stability in a distribution network. In this paper an efficient technique is presented for optimal placement and sizing of DGs in a large scale radial distribution system. The main objective is to minimize network power losses and to improve the voltage stability. A detailed performance analysis is carried out on 33-bus, 69-bus and 118-bus large scale radial distribution systems to demonstrate the effectiveness of the proposed technique. Performing multiple power flow analysis on 118-bus system, the effect of DG sources on the most sensitive buses to voltage collapse is also carried out.

1. Introduction

The features like radial structure, high R/X ratio and unbalanced loads make radial distribution systems special. High R/X ratios in distribution lines result in large voltage drops, low voltage stability and high power losses. Traditional methods such as Newton Raphson and Fast Decoupled Power Flow are effective for "well conditioned" power systems but tend to encounter convergence problems with distribution systems due to above mentioned features. A more suitable algorithm for distribution systems such as ladder technique (backward–forward sweep) or power summation must be used. The radial distribution system (RDS) experiences sudden voltage collapse due to the low value of voltage stability index at most of its nodes under critical loading conditions in certain industrial areas. Recently, DGs are becoming increasingly attractive to utilities and consumers because these units produce energy close to the load, and are more efficient (less losses), easier to site and have less environmental impact. DGs are primarily installed on the distribution and sub transmission level networks. Their main technical benefits include [1]:

- Reduced line losses.
- Voltage profile improvement.
- Improved reliability and security.
- Reduced GHG emissions from central power plants.
- Relieved T&D congestion.

Several optimization studies have been performed to quantify these benefits and identify DG penetration threshold limits by optimally locating and sizing DGs to improve a particular objective, or a combination of objectives.

Authors in [2], considered an analytical expression to calculate the optimal size and an effective methodology to identify the corresponding optimum location for DG placement for minimizing the total power losses in primary distribution systems. Authors in [3], considered a simple method for optimal sizing and placement of DGs. A simple conventional iterative search technique along with Newton Raphson method of load flow study is implemented. Authors in [4], were to quantify the effect of DG on system reliability improvements, but did not use this to specifically allocate DG optimally. In [5], author fixed the DG candidate locations, number of available DGs, and total DG capacity before optimally allocating binary encoded DGs of a predefined size to minimize real power loss only. Authors in [6] combined two optimization methods, a discrete form of PSO and GA operators, to perform optimal DG allocation using technical objectives but assigned costs to the objectives. But considering cost function in finding optimal location and DG size may deviate from the original problem. Author in [7], used the Harmony Search Algorithm as a new approach; however, the optimal penetration limit for DG is set by the user before running the optimal allocation routine. Hung et al. in [8], combined the loss sensitivity concept with optimal siting and sizing, but only

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Table 1
Summary of DG types [17].

DG type	p.f	Capable of injecting	Example
1	$0 < p.f_{DG} < 1$	Real power and reactive power	Synchronous generator
2	$0 < p.f_{DG} < 1$	Real power but consuming reactive power	Wind turbine
3	$p.f_{DG} = 1$	Real power only	PV, MT and FC with PE interface
4	$p.f_{DG} = 0$	Reactive power only	Synchronous compensator

studies the real and reactive power loss reduction objectives. However, the authors did execute a rigorous comparison of the IA method with the bench mark ELF method lending credibility to their work. Authors in [9], used an energy savings goal based on emission reduction, which are typically highly specific to the region and power supply mix, and can be difficult to quantify accurately. In [10], a GA based algorithm was used to determine the optimum size and location of multiple DGs to minimize the losses and the power supplied by the grid. In [11], DGs were placed as at the most sensitive buses to voltage collapse. The DGs had the same capacity and were placed one by one. In [12], a GA–PSO based algorithm was presented to find optimal location and sizing of multiple DGs to minimize multi objective function. All mentioned research installing DGs with unity power factor in small and medium distribution systems. And many authors did not mention the run time of implemented methods. In [13], a PSO–GA was used to find the optimal location of a fixed number of DGs with specific total capacity such that the real power loss of the system is minimized and the operational constraints of the system are satisfied. In this paper fast and novel computation technique is proposed to evaluate the optimal siting and sizing of multiple DGs with unspecified power factor (p.f) in a large scale radial distribution system with an objective of minimizing real power loss and improvement in voltage profile. The first stage in the technique presented in this paper is optimal siting by applying the loss sensitivity factor (LSF). The advantage of relieving SA from determination of optimal location of DGs is to reduce the search space and to improve convergence characteristics and less computation time. The top most nodes are ranked to create a candidate nodes list, and within this list the top ranked index values represented optimal DG locations after which optimal sizing was then performed using Simulated Annealing. The proposed technique was applied to large scale 118-bus radial distribution system [14] without tie-lines. It is capable of finding optimum solution with in very short simulation time, in the range of a few seconds. A multiple power flow analysis is carried out to determine the effect of DGs on the voltage stability. The entire technique is built in MATLAB platform.

2. Load model

Distribution system loads are characterized by voltage sensitivity, and most distribution load flow programs offer the following standard models:

- Constant Power – The real and reactive power stays constant as the voltage changes.
- Constant Current – The current stays constant as the voltage changes.
- Constant Impedance – The impedance is constant as the voltage changes.

In short feeders' power loss is of great concern and for large feeders voltage stability is great importance. Modeling all loads as constant current is a good approximation for many circuits while modeling all loads as constant power is conservative for voltage profile analysis [15,16]. In this context it is more relevant to assume all loads are constant power loads.

3. Types of distributed generation

Table 1 gives information about various types of DGs. It should be noted that although utilities, manufacturers and the researchers agree that reactive power support is useful by-product of DG installation. If utilities infrastructure is equipped with two-way communication between small DG and utility's control operations center, then it is easy to manage reactive power. Therefore, the current practice is to maintain DG at unity power factor. The developed algorithm can handle all types of DG at various load levels. The present studies were run with Type 1 (0.866 p.f) and Type 3 (Unity p.f) DGs only.

4. Problem formation

Optimal DG placement in a radial distribution system is to find best locations of radial network that gives minimum power loss while satisfying certain operating constraints. The operating constraints are voltage profile of the system, current capacity of the feeder and radial structure of the distribution system. The objective function for the minimization of power loss is described as follows:

$$F = \min(P_{T,Loss}) \ldots \text{ with DGs}$$

Subjected to:
Power balance constraint:

$$P_{DGi} = P_{Di} + P_{Loss} \tag{1}$$

Voltage limits:

$$V_{i\min} \leqslant V_i \leqslant V_{i\max} \tag{2}$$

Thermal limit:

$$I_{i,i+1} \leqslant I_{i,i+1\max} \tag{3}$$

Real power generation limits

$$P_{DGi\min} \leqslant P_{DGi} \leqslant P_{DGi\max} \tag{4}$$

Reactive power generation limits

$$Q_{DGi\min} \leqslant Q_{DGi} \leqslant Q_{DGi\max} \tag{5}$$

where V_i is the voltage magnitude of bus i, $V_{\min}$ and $V_{\max}$ are bus minimum and maximum voltage limits, respectively. $I_{i,i+1\max}$ is the maximum loading on branch i, $i+1$. I_i is the current flowing through the ith branch, which is dependent on the locations and sizes of the DGs. A set of simplified feeder-line flow formulations is employed. Considering the single-line diagram depicted in Fig. 1, the recursive Eqs. (6)–(8) are used to compute the power flow.

Because of the complexity of the large scale distribution system, network is normally assumed as symmetrical system and constant loads. Therefore, the distribution lines are represented as series impedances of the value ($Z_{i,i+1} = R_{i,i+1} + jX_{i,i+1}$) and load demand as constant and balanced power sinks $S_L = P_L + jQ_L$.

The real and reactive power flows at the receiving end of branch $i+1$, P_{i+1}, and Q_{i+1}, and the voltage magnitude at the receiving end, $|V_{i+1}|$ is expressed by the following set of recursive equations:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1} \cdot \frac{P_i^2 + Q_i^2}{|V_i|^2} \tag{6}$$