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A Review of Optimal DG Allocation in Distribution System for Loss Minimization

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Abstract: *Distributed Generation (DG) also known as dispersed generation is small scale generation units directly coupled with the distributed system. There has been great interest in the installation of distributed generation sources close to the consumer load centre. The DG technologies comprise of both conventional and non-conventional sources of energy to generate power in order to satisfy the demand of ever rising energy demand. Optimum position and size of DG units can aid the performance of active power system network. Integration of DG units of optimum capacity at ideal locations improves the voltage profile of the system and minimizes the active and reactive losses of the system. In this paper, state of the art techniques for optimum placement and sizing of DG have been suggested. The paper provides an overview of the various methods implemented for determining optimal location and capacity of DG units to maximize the benefits of DG units in the system network.*

Keywords: *Distributed Generation, Loss Minimization, Optimum Location, Optimization Techniques, Voltage Profile Improvement*

I. Introduction

The deregulation of the electricity sector has created many opportunities to develop new technologies. Dispersed generation is one of those technologies to meet the ever increasing demand of electricity. The term "Dispersed Generation" refers to small-scale electric generation units close to the point of consumption. The advantages could be maximized by proper positioning of DG units at optimum location with ideal capacity and suitable type of DG unit. Distribution generation allows collection of energy from many sources and may give lower environmental impacts and improved security of supply.The benefits of integrating DG are segregated into technical, economical and environmental benefits. Technical advantages comprise of voltage improvement, minimization of real and reactive power losses, enhancement of system efficiency, increase in system reliability, improving power factor of the system and therefore improving power quality of the system.

The economical benefits include the reduction of transmission and distribution congestion, decrease in electricity transmission pricing and better performance of network system in deregulated utilities. The environmental benefits constitute the reduction in the emission of pollutants, less noise pollution and extra saving of fuel [1-5]. Several researchers have been working this area to avail the maximum benefits from the integration of DG units in the power system. With the deregulation of the power system network, it is important for the electrical utilities to maximize the positive effects of DG [6]. Numerous methods have been proposed to determine the optimum location and size of DG in order to improve the voltage level and for loss minimization. Improper location and non-optimum capacity of the DG unit can have negative impact on the active power system network. It may cause the voltage to rise above a pre-determined voltage level, increase of fault current in the system, poor efficiency and elevation of system losses. Therefore, it is necessary to find out the optimum location and size of DG units along with its type to enhance the working and planning of active network. This paper suggests various techniques to determine the ideal location and optimum size of DG units for voltage level improvement and loss minimization

II. Different Dg Technologies

Different DG technologies are available in the market today. DG size ranges from a few kilowatts to less that 10 Megawatts. Distributed generation resources (DER) can be classified into renewable DG resources and conventional DG resources. Several DG technologies along with their size and applications are shown in Table 1.

Table 1: DG Technologies and its application

No.	DG Type	Size	Application
1	Micro-Turbines	A few kW to several hundred MW	Peak load saving.
2	Fuel cells	A few tens of kW to a few MW	Base load applications, used as a module to serve large loads.
3	Photovoltaic cells	A few W to several hundred Kw	Stand alone and base load applications.
4	Wind turbines	A few hundred W to a few hundred MW	Remote homes, farms, industry application.
5	Combustion diesel engines	A few hundred MW	Peak load saving and backup operation

III. Problem Formulation

The problem of optimum allocation and size of distributed generation units comprise of various parameters. The objective functions and operation constraints should be well defined in order to attain maximum benefits by integrating DG units in the system network

A. Objective Function

The problem objective of optimum placement and sizing of DG can be single or multi objective. The single objective functions could be real loss minimization, reactive loss minimization, voltage level enhancement, maximization of DG capacity, reduction of cost of generation and minimization of voltage deviations. Multi objective functions are attained by combining single objective functions using weighting factors.

The optimal sizing and placement of DG results in minimum loss in the distribution system [7].The total real Loss in a distribution system is given by:

$$\mathbf{P}_{losses} = \sum_{i=1}^{N} \left|\mathbf{I}_i^2\right| R_i \tag{1}$$

where I_i is the current magnitude of each branch and R_i is the resistance of ith branch. considering N bus distribution systems, the loss minimization may be formulated as given below:

$$\text{Minimize } \mathbf{P}_1 = \sum_{i}^{N}\sum_{j}^{N}\left[\alpha_{ij}\left(\mathbf{P}_i\mathbf{P}_j + Q_iQ_j\right) + \beta_{ij}\left(Q_i\mathbf{P}_j - \mathbf{P}_iQ_j\right)\right] \tag{2}$$

where $$\alpha_{ij} = \frac{R_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right) \tag{3}$$

$$\beta_{ij} = \frac{R_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \tag{4}$$

and $$Z_{ij} = R_{ij} + X_{ij} \tag{5}$$

where

Z_{ij} is the impedance of the line between bus i and bus j;

R_{ij} is the resistance of the line between bus i and bus j;

V_i is the voltage magnitude at bus i;

V_j is the voltage magnitude at bus j;

δ_i is the voltage angle at bus i ;

δ_j is the voltage angle at bus j;

P_i and Q_i is the active and reactive power injection at bus i;

P_j and Q_j is the active and reactive power injection at bus j;

B. Constraints

The most popular constraints to solve the problem of sizing and location of DG units are voltage limits, real power limits, reactive power limits, power flow limits, short circuit level ratio limits, maximum number of DG units and size of DG units.

Equality Constrain: For each bus, to meet demand and supply the following load balance equation (6) should be Satisfied

$$\sum_{i=1}^{n} P_{DGi} \leq \sum_{i=1}^{n} P_{Di} \quad (6)$$

In Equality constrain: Voltage limits for each bus, there should be an upper and lower voltage bounds in equation (7)

$$|V_i|^{min} \leq |V_i| \leq |V_i|^{max} \quad (7)$$

$$0.93_{p.u} \leq V_i \leq 1.07_{p.u}$$

Where V_{min} is the minimum bus voltage and V_{max} is the maximum bus voltage

C. Number of DG units

The problem of sizing and placement of distributed generators is categorized into single DG unit and multiple DG units.

D. Types of DG units

DG can be classified into four major types based on their terminal characteristics in terms of real and reactive power delivering capability as follows:

1) Type 1: DG capable of injecting P only.
2) Type 2: DG capable of injecting Q only.
3) Type 3: DG capable of injecting both P and Q.
4) Type 4: DG capable of injecting P but consuming Q.

Photovoltaic, micro turbines, fuel cells, which are integrated to the main grid with the help of converters/inverters are good examples of Type 1. Type 2 could be synchronous compensators such as gas turbines. DG units that are based on synchronous machine (cogeneration, gas turbine, etc.) fall in Type 3. Type 4 is mainly induction generators that are used in wind farms.

IV. Methods For Optimum Location And Sizing Of Dg Units

There are numerous methods invented to determine the optimum location and size of DG units for voltage profile improvement and loss minimization. However, other objectives like reliability, maximization of DG capacity, cost minimization have also been discussed in many research papers. Fig.1 shows the classification of different techniques for solving the problem of allocation and sizing of DG units in the network system.

4.1 Load Flow Based Methods

The load flow or power flow problem consists in finding the steady-state operating point of an electric power system. More specifically, given the load demanded at consumption buses and the power supplied by generators, the aim is to obtain all bus voltages and complex power flowing through all network components**.**

During the daily grid operation, the load flow constitutes the basic tool for security analysis, by identifying unacceptable voltage deviations or potential component overloading, as a consequence of both natural load evolution and sudden structural changes. It also allows the planning engineer to simulate different future scenarios that may arise for a forecasted demand.

4.1.1 Newton Raphson

Newton Raphson method is a simple load flow based method is used to solve the problem of optimal location of a single DG unit which is delivering only real power in the system [8]. A load flow based method for optimal location of dispersed generation unit delivering only real power for voltage profile improvement has presented in [9]. A load flow based approach for optimum allocation of DG units for voltage profile improvement and loss minimization has suggested in [10]. A Newton Raphson load flow method for optimal sizing and placement of DG units using weighting factors has proposed in [11]. The cost and loss factor minimization are also discussed in this paper.

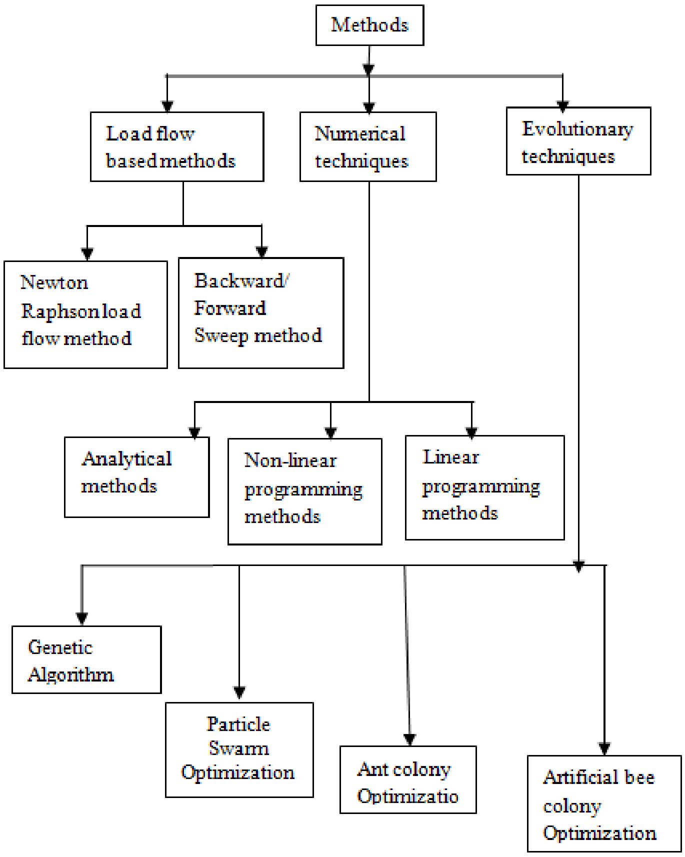
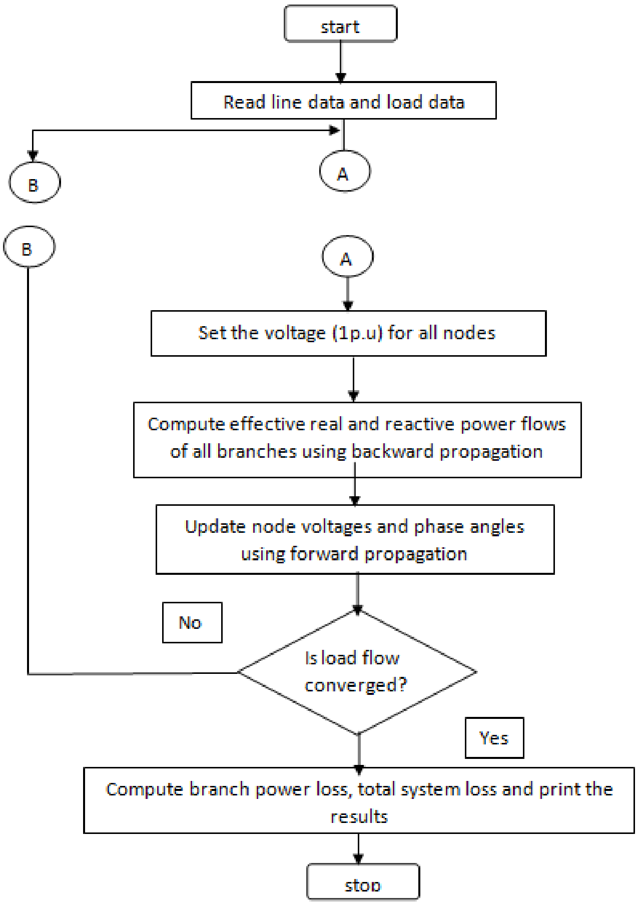


Fig.1 Methods for optimum allocation and sizing of units

4.1.2 Forward/Backward load flow method

A Forward/backward sweep method for load flow is an iterative technique in which, at each iteration two computational stages are performed. With the aid of two sets of recursive equations, load flow of a single source network can be solved iteratively. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in backward direction towards the root node. The second set of equations is used for calculation of the voltage magnitude and phase angle of each node starting from the root node and proceeding in the forward direction towards the last node. A forward/backward load flow technique for optimal placement of DG units has presented in [12]. An approach for optimal allocation and sizing of DG units using forward/backward sweep method has presented in [13].Flow chart for this method is shown below.



4.2 Numerical Techniques
4.2.1 Analytical techniques

The 2/3 rule has proposed to determine the optimum location and size of radial feeder with uniformly distributed load in [14]. An analytical technique based on exact loss formula has suggested in [15]. Three analytical approaches using different power loss expressions to determine optimal size and power factors have proposed in [16]. A loss sensitivity calculation based approach to determine optimal location of DG units has presented in [17]. And finding the optimal location of DG by using minimum loss as a constraint following algorithm should be followed.

Step 1: For the given test system without DG run the Load Flow and find out the voltage at each bus and by using power loss equation calculate the total losses.
Step 2: Select any bus as a new DG location and consider the remaining buses (except substation & the load bus on which DG is installed) as load buses.
Step 3: Now run the load flow for the case with DG installed at the new position and find out the voltage at each bus.
Step 4: By applying power loss equation calculate both active as well as reactive power losses.
Step 5: Now select all next buses individually as new DG location & repeat the steps from 2-4.
Step 6: Rank the buses in ascending order as per the amount of losses encountered at that location.
Step 7: Consider the top ranking bus as the best location for DG allocation.
Step 8: Find the required DG Capacity at that location.
Step 9: Now Install a DG on the selected location and run the Load Flow and find out the voltages at each bus.
Step 10: Examine the stability of the system by using Voltage Stability Index, L.
Step 11: If L will decrease then repeat the steps 2 to 10 to find the next best location for DG allocation.
Step 12: Increase the number of DG installation in the system till L is decreasing; if L starts increasing then stop addition of DG in the system.

4.2.2 Non-linear programming methods

A mixed integer non-linear programming method for optimal placement of DG units has presented in [18]. A non-linear programming method has employed for optimal allocation of different types of DG units considering electricity market fluctuations in [19].

4.2.3 Linear programming methods

A linear programming method has used to solve the problem of optimal placement and sizing of DG units to attain maximum DG energy harvesting has proposed in [20]. Linear programming is perhaps the most widely applied mathematical programming technique. Simply stated, linear programming seeks to find the optimum value of a linear objective function while meeting a set of linear.

4.3 Evolutionary Algorithms

4.3.1 Genetic Algorithm

The genetic algorithm is a robust optimization technique based on natural selection. The basic goal of GA is to optimize functions called fitness functions. It is an artificial intelligence technique which has been applied in various optimization problems such optimal DG placement. The Genetic Algorithm (GA) is an optimization technique based on natural selection and genetics [21]. In case of DG placement, fitness function can be loss minimization, voltage profile improvement and cost reduction. A combined GA and tabu search is suggested in [22]. Genetic algorithm is a robust optimization technique for load shedding in micro grids has discussed in [30]. The GA for handling the target problem primarily includes the following steps.

Step 1): Initially, a set of chromosomes is created in a random fashion.

Step 2): The fitness of each chromosome is evaluated based on the objective function defined.

Step 3):Based on the fitness value of each chromosome, different genetic operators including reproduction, crossover, and mutation are applied in the entire population in order to produce the next generation of chromosomes.

Step 4): Repeat steps 2 and 3 until any stopping criterion is satisfied. The chromosome with the highest fitness value is the final solution to the target problem.

4.3.2 Particle Swarm Optimization

Kennedy and Eberhart proposed the first Particle Swarm Optimization (PSO) in 1995 [23]. Applications, developments of PSO method have suggested in [24]. A PSO based method with variable load models for optimal allocation of different types of DG units has discussed in [25]. An improved PSO and clonal algorithm based method for optimum allocation of DG units has explained in [26]. In PSO, a swarm of n individuals communicate either directly or indirectly with one another search directions. PSO is a simple but powerful search technique. A hybrid GA and PSO is suggested in [27]. The (original) process for implementing the global

version of **PSO** is as follows:

Step 1: Initialize a population (array) of particles with random positions and velocities on ***d*** dimensions in the problem space.

Step 2: For each particle, evaluate the desired optimization fitness function in d variables.

Step 3: Compare particle's fitness evaluation with particle's pbest. If current value is better than pbest, then set pbest value equal to the current value, and the pbest location equal to the current location in d-dimensional space.

Step 4: Compare fitness evaluation with the population's overall previous best. If current value is better than gbest, then reset gbest to the current particle's array index and value.

Step 5: Update the position and velocity of each particle with respect to the gbest.

Step 6: Repeat Step 3 & 4 till the optimum solution is reached.

Step 7: gbestat the end of the last iteration gives the optimized value.

Step 8: Compute the Duty-cycle.

4.3.3 Ant Colony Optimization

Ant colony optimization is a technique for optimization that was introduced in the early 1990's. The inspiring source of ant colony optimization is the foraging behavior of real ant colonies. This behavior is exploited in artificial ant colonies for the search of approximate solutions to discrete optimization problems, to continuous optimization problems, and to important problems in telecommunications, such as routing and load balancing. It is an optimization technique obtained from the behavior of real ants. The procedure of the Ant Colony algorithm controls the scheduling of three activities. The first step comprises of initialization of the pheromone trail. In second step, each ant constructs a complete solution to the problem according to a probabilistic state transition rule. The third step updates quantity of pheromone. This process is iterated until a stopping criterion is obtained. An ant colony algorithm has proposed to solve the optimum placement and optimum sizing of DG units in radial distribution system network in [28].

4.3.4 Artificial Bee Colony Algorithm

Artificial Bee Colony (ABC) algorithm is one of the most recently introduced swarm-based algorithms. ABC simulates the intelligent foraging behavior of a honeybee swarm. It is a new meta-heuristic technique introduced by Karaboga in 2005. An extended version of the Artificial Bee Colony Algorithm has proposed in [29]. An Artificial Bee Colony algorithm to find the optimum placement of DG units has suggested in [29].

V. Conclusion

This paper has suggested an overview of state of the art techniques implemented to solve the problem of sizing and position of DG units in the network system. The solution methodology implemented to solve the problem of optimal allocation and size of DG units are categorized as load flow based techniques, numerical methods, analytical methods, evolutionary algorithms such as GA, PSO etc. This problem may include various objective functions, numerous constraints to solve the location issues of DG units. The most common objective function is the reduction of real losses, reactive power losses and voltage profile improvement. It can be concluded that the numerical and analytical methods are time consuming and not very efficient to solve the problem of placement and size of DG sources in the system. Evolutionary algorithms such as PSO, GA, Ant Colony Optimization etc are very feasible and easy to implement.

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