Optimal Generators Placement Techniques in Distribution Networks: A Review

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***Abstract* – To reduce power disruptions in power distribution systems, it is important to install distributed generation (DG) in the distribution systems. DG in distribution systems help to improve power quality and reliability of the networks, provided the DG units are placed at the best location with required size. There are various DG placement techniques that can be used to determine optimal location and size of DG in a distribution network. In this paper an extensive review of the art models and methods of existing optimal DG placement based on analytical optimization and heuristic optimization have been discussed. The algorithm, description, advantages, disadvantages and applications of optimization techniques have been discussed with a comparison between analytical and heuristic technique.**

***Index Terms*— Distribution systems, distributed generation, optimal DG placement.**

I. Introduction

To design a stable and reliable distribution network, DG is expected to play an important role in the future grids. In a distribution network, DG can be distinct as small or medium scale sources of power generation units located close to the load centers. To reduce the economic and environmental impact of large power stations, DG is a smart choice now a days [1].

DG comes from a variety of sources such as the renewable energy sources, diesel generator or storage devices. DG from renewable energy sources are increasing dramatically and a number of countries are aiming to increase their share of renewable energy sources to minimize the effects of greenhouse gas emissions from fossil fuels [2]. Apart from the environmental benefits, DG contributes to generate electricity with or without the grid connection (as microgrid). DG can reduce transmission and distribution cost of generation and support the consumption of energy during the peak periods increasing the quality and reliability of power system.

To get the maximum benefit from DG units in power system distribution networks, the placement and sizing of the DG units need to be done correctly. The location of DG installation is chosen by the clients or investors considering the climatic conditions, size, location and availability of resources [3]. DG placement has direct effects on the operation of power distribution networks, as inappropriate placement of DG may lead to system loss, increases the capital and operating cost with possible instability in the system [4].

However, the proper placement of DG can improve the power quality in terms of voltage profile, reduce harmonics and minimize system losses [1].

In this paper, a review of existing DG placement techniques are discussed utilizing the algorithm flowchart that will guide the power system engineers on existing DG placement techniques in a brief.

II. Optimization Techniques/Methods for DG Placement

A. Analytical Optimization Technique

Analytical optimization technique is well known as the concept of “2/3 rule”. This rule has been discussed in [5] that proposes to connect a DG to a network with 2/3 size of incoming generation at 2/3 length of the line. This technique is effective for uniformly distributed loads. Two different algorithms have been proposed by Wang and Nehrir based on the 2/3 rule of analytical techniques to use in the radial feeder network and mesh network respectively [6]. This research has connected a DG in a location indicated by X_o in Fig. 1, for a radial network using (1).

$$\frac{d\overline{P}_{loss}(x_0)}{dx_0} \tag{1}$$

Where $\overline{P}_{loss}$ is the average power loss in a given time period.

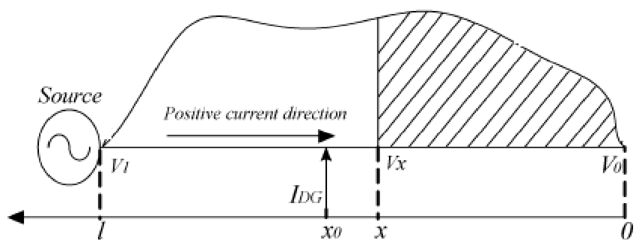

Figure 1. Radial Feeder with Distributed Load [6].

The algorithm used to determine the location of DG on a radial distributed network is shown in Fig. 2. This research also states that there might be a time when all node voltages will not fall in range regardless of moving DG location slightly. In that case, the DG size should be increased or multiple DG's should be used.

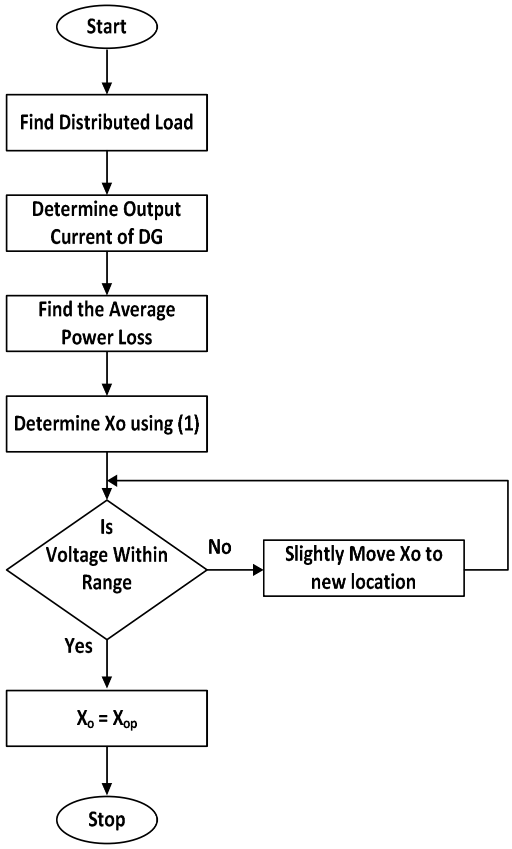

Figure 2. Optimal placement of DG on Radial Network [6].

For optimal location of DG placement on mesh network, new bus admittance matrix and corresponding impedance matrix need to be calculated in this method as shown in Fig. 3, where an additional DG is connected to Bus *j*.

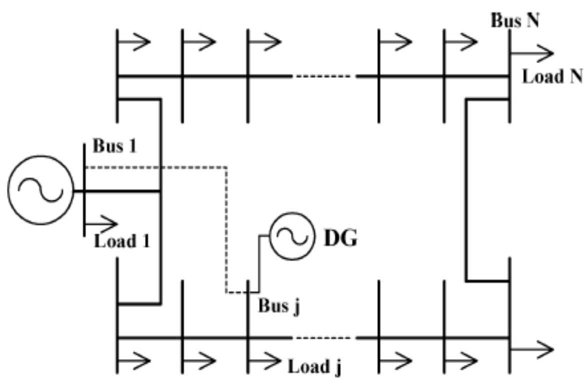

Figure 3. Mesh network with optimal DG location [6].

The procedure to determine the optimal location to connect the DG in mesh network is shown in Fig. 4. If none of the DG locations are able to satisfy the voltage rule, then DG size should be increased or multiple DG connections should be done similar to the radial network. In addition, an objective function is set to determine the optimal DG location in mesh network. When the objective function reaches its minimum value, the optimal bus to connect the DG will be found.

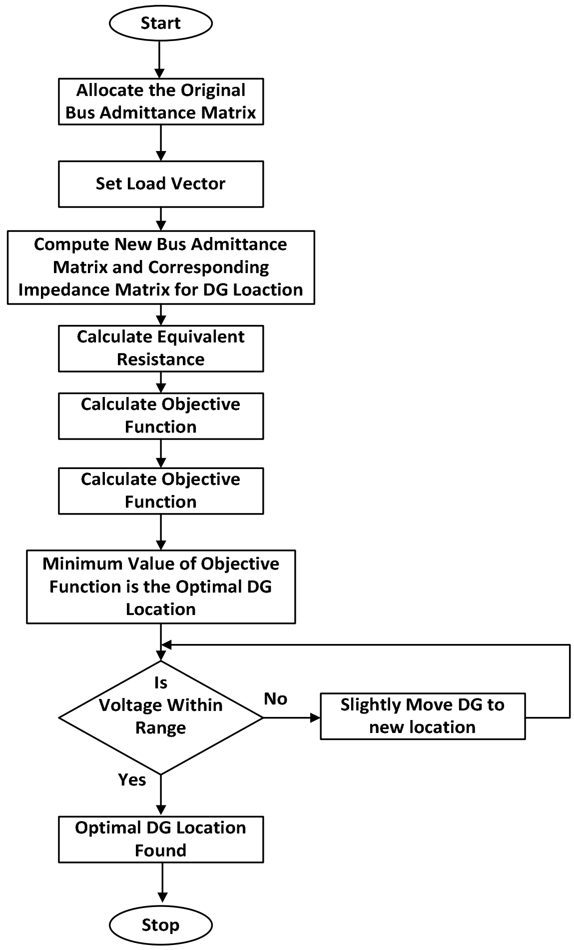

Figure 4. Procedure for optimal DG placement on mesh network [6].

Based on the exact loss formula a comprehensive analytical optimization technique has been proposed by Acharya, Mahat, and Mithulananthan [7]. This method aims to determine the optimal DG placement location with minimum loss occurring at the network. The procedure of this technique is shown in Fig. 5.

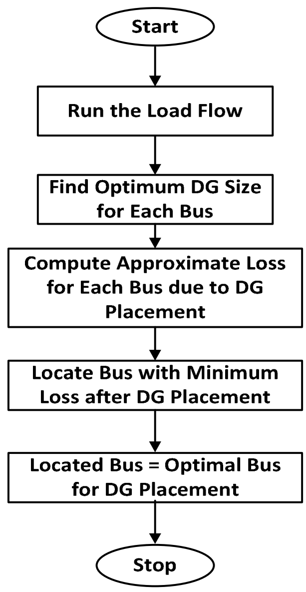

Figure 5. Exact loss based optimal location for DG placement.

Similar approach has been discussed in [8] based on the loss sensitivity factor to determine the optimal size and location of DG. Analytical technique to determine the optimal size and location for multiple DG's has been discussed in [9] and [10].

B. *Heuristic Optimization Technique*

A number of research has been conducted on heuristic techniques over the years to provide the optimal location of DG. The most commonly used heuristic techniques are: harmony search, tabu search, simulated annealing, and ant colony search algorithm. Evolutionary computation techniques are also commonly used as heuristic techniques which include genetic algorithm, differential evolution, and particle swarm optimization and others. A summary of popular heuristic optimization techniques has been given below.

1) *Harmony Search*

Harmony search algorithm is originated from the musician's behavior where they collectively play musical instruments to come up with a pleasing harmony [11]-[13]. This technique is known to be simple in concept, uses less parameters and is easy to implement. The optimal DG placement location is determined based on the loss sensitivity factor, whereas the optimal DG size is found using the harmonic search algorithm. The flowchart of harmony search algorithm is shown in Fig. 6.

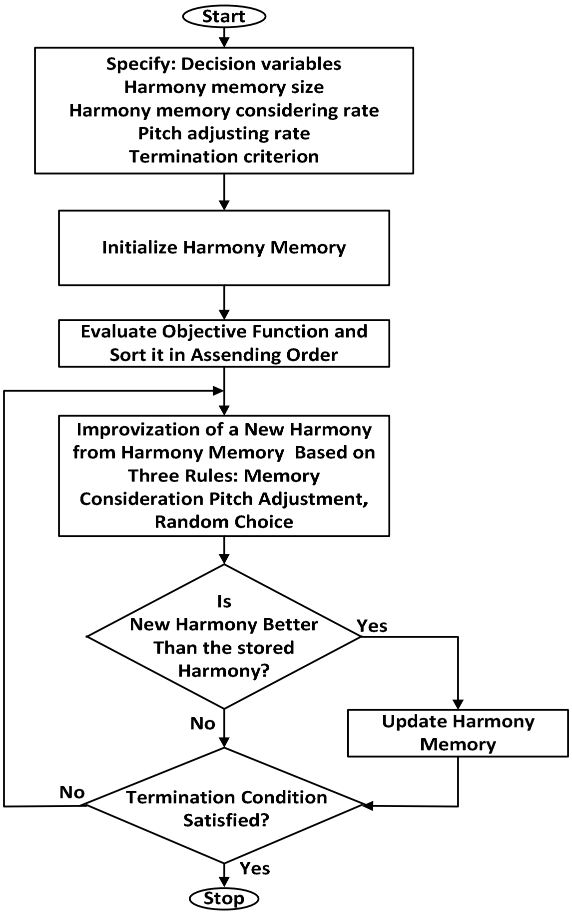

Figure 6. Flowchart of Harmony Search algorithm [11].

2) *Tabu Search*

A tabu search is also called gradient-decent search with memory that recalls number of previously visited states together with the number of states that might be considered unwanted. This information is stored in a tabu list through the help of the memory. Some of the parameters of tabu search are the definition of states, area around the state, length of the tabu list, aspiration and diversification [14]. A tabu search is useful when the loads are uniformly distributed [15]. Tabu search algorithm can be simultaneously used to solve optimal distribution generation placement and optimal placement of reactive power sources [16]. The flowchart of tabu search algorithm is shown in Fig. 7 [17].

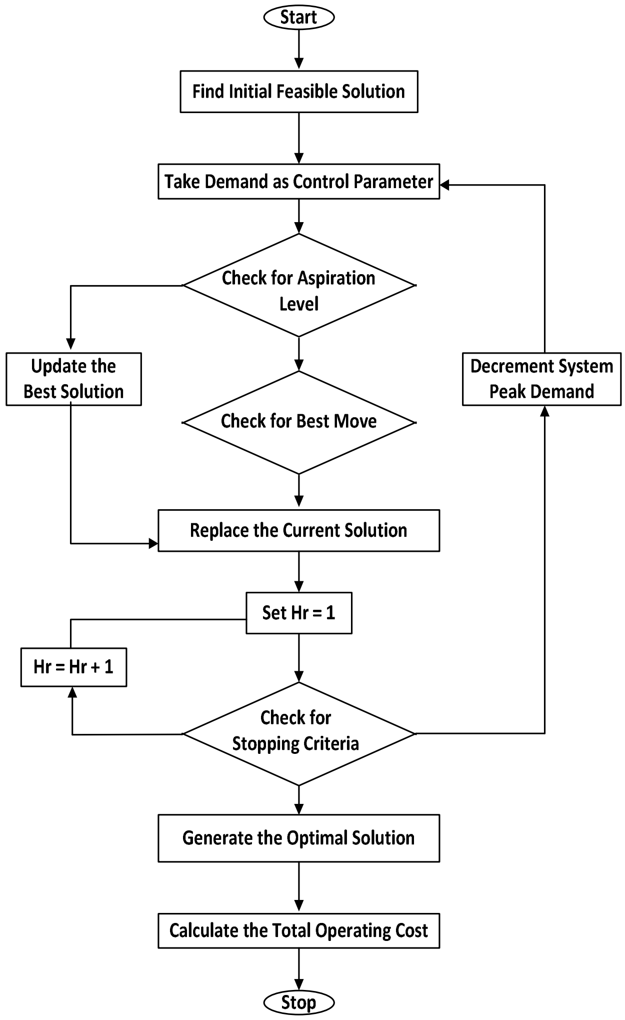

Figure 7. Flowchart of Tabu Search algorithm [17].

3) *Simulated Annealing*

Simulated annealing technique is originated from the analogy with the physical process of solids [18]. The concept is based on the manner in which liquids freeze or metals recrystallize in an annealing process. According to the authors of [19-23], simulated annealing is one of the strongest general purpose optimization techniques that can ideally converge asymptotically to a global optimum solution but it is time consuming. The flowchart of simulated annealing technique is shown in Fig. 8.

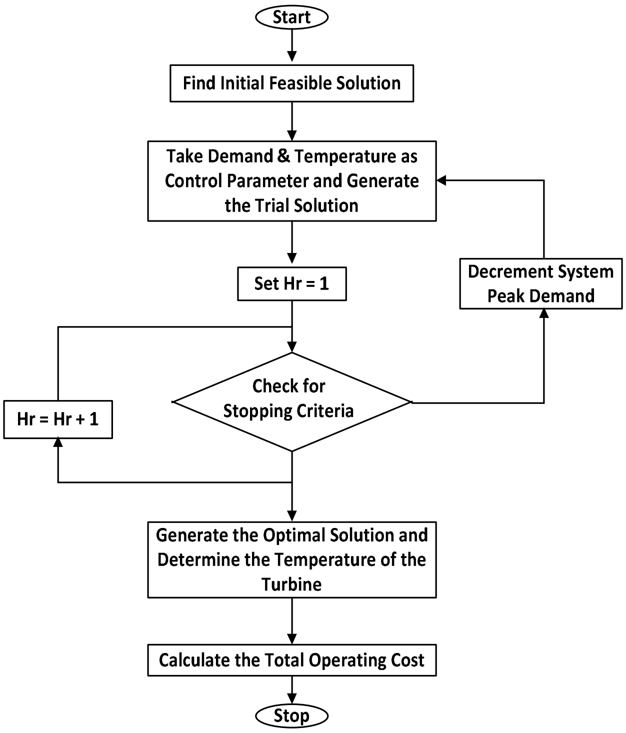

Figure 8. Flowchart of Simulated Annealing technique [17].

4) Ant Colony Optimization Technique

Ant colony optimization technique is inspired by the behavior of ants trying to find the shortest route from nest to the food springs using a chemical substance called pheromone [24], [25]. Ant colony optimization is proposed in [26] to solve the optimal distribution generation placement problems.

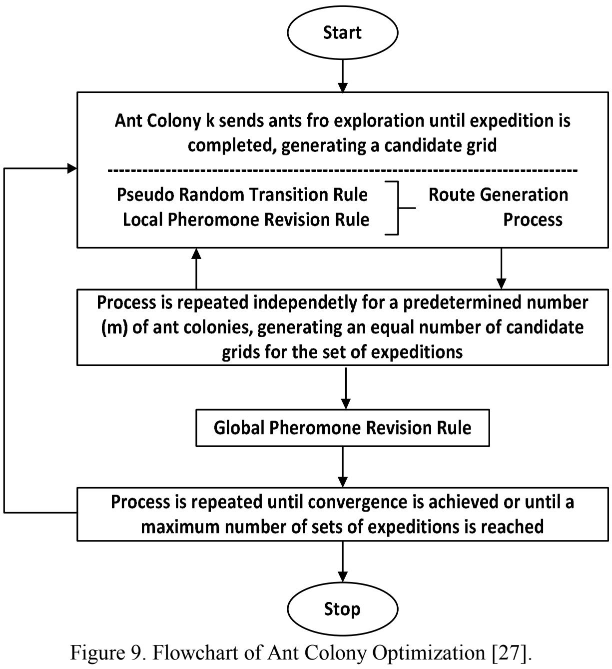

Figure 9. Flowchart of Ant Colony Optimization [27].

5) Evolutionary Computation Techniques

There are many existing evolutionary computational optimization techniques. The evolutionary computation techniques are introduced on the principle of evolution and they initiate based on natural phenomena [28], [29]. In this paper, genetic algorithm, differential evolution, and particle swarm optimization are discussed.

a) Genetic Algorithm

Genetic algorithms are used as an optimization technique which is inspired from the mechanism of biological selection and biological genetics [30]. Genetic algorithm can be used to solve problems with optimal DG placement for networks with variable power concentrated loads, distribution loads and constant power concentrated loads [31-35]. A modified genetic algorithm technique for distribution generation placement that minimizes the total real power loss in the system is proposed in [36], which optimize allocation of renewable DG units in the network. The flowchart of genetic algorithm is shown in Fig. 10. Genetic algorithm technique starts with random control variables and after that, process goes through a crossover and mutation of control variables and generates a set of solutions. Among the solutions the best possible solution is identified as the choice for the solution of a given optimization problem.

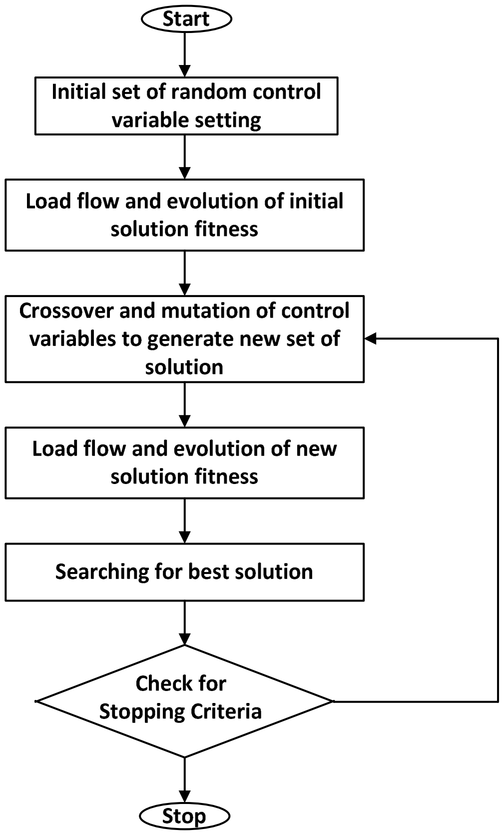

Figure 10. Flowchart of Genetic Algorithm [37].

b) Differential Evolution

Differential evolution optimization technique uses the alterations of randomly sampled pairs of objective vectors for mutation process. Differential evolution technique is mostly found to be accurate, fast and robust. Differential evolution is known to be the simplest technique that minimizes the optimization process, thus it is easy to use for solving optimization problems [38-42]. The flowchart of differential evolution technique is show in Fig. 11.

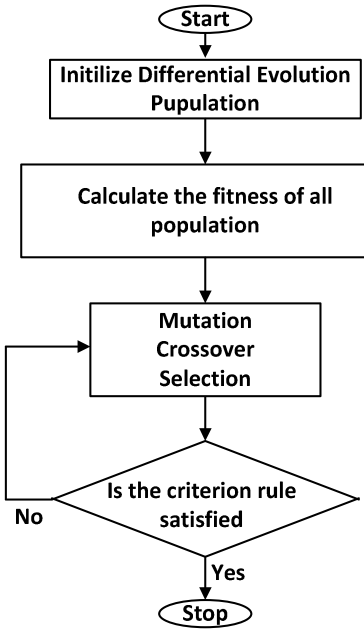

Figure 11. Flowchart of Differential Evolution [43].

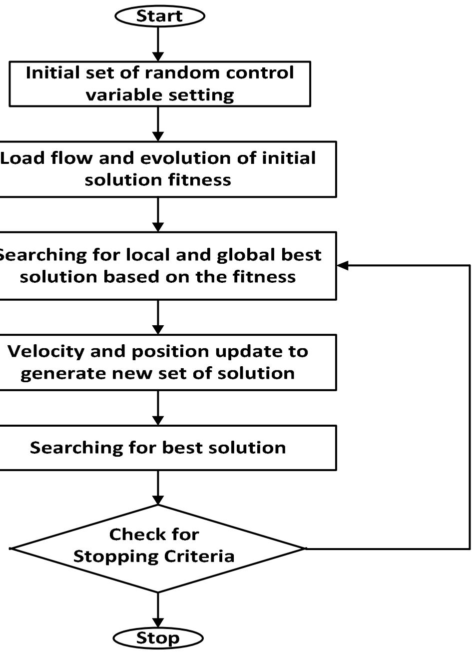

Figure 12. Flowchart of PSO Technique [52].

c) Particle Swarm Optimization (PSO)

PSO technique is inspired by the fundamental disciplines of social science and computer science that uses swarm intelligence principle as discussed in [44-47]. PSO is initiated to effectively overcome large scale non-linear optimization problems. This technique is easier to implement and is known to be more efficient [48]. Over the past years a number of researchers have made efforts to improve the PSO technique. A hybrid PSO technique has been proposed that aimed to increase the diversity of optimization problem [49-51]. A combination of genetic algorithm and PSO technique is proposed in [52] that helps minimize network's power losses with better voltage regulation and improve the voltage stability. The flowchart of PSO technique is shown in Fig. 12.

III. COMPARISON OF ANALYTICAL AND HEURISTIC OPTIMIZATION TECHNIQUES

Analytical optimization techniques are found to be simple and easy to implement to find out the optimal placement of DG. The simplicity of the algorithm makes the optimization process faster. The analytical technique works on simple assumptions therefore the result of this technique is indicative [5], [6]. While using analytical optimization technique to determine the correct location of DG, one needs to consider the transmission and distribution effects because the net thermal loss that arises from different placement varies significantly [53].

Heuristic optimization techniques mostly provide accurate optimal placement solution and are reliable and robust optimization techniques [3]. These optimization techniques can be effectively used for large-scale and complex networks. The only limitation of Heuristic optimization is that it requires high computational efforts while solving DG optimal placement problems.

IV. CONCLUSION

This paper has presented a review on the existing optimization techniques that can be used to identify the optimal location for DG. The two commonly used optimization techniques; analytical optimization and heuristic optimization are discussed in this paper. Several heuristic optimization techniques such as harmony search, tabu search, simulated annealing, and ant colony search algorithm and evolutionary computation technique has been deliberated. The most frequently used is the genetic algorithm optimization technique and other heuristic techniques such as PSO. However, this research will provide a comprehensive guide for the power system distribution network engineers to place the DG in a best possible location.

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