International Journal of Current Research and Modern Education (IJCRME)
ISSN (Online): 2455 – 5428 & Impact Factor: 3.165
Special Issue, NCFTCCPS - 2016

A COMPREHENSIVE SURVEY OF OPTIMIZATION TECHNIQUES USED FOR DISTRIBUTED GENERATOR SITING AND SIZING

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Abstract:

Distributed Generation (DG) resources have gained a lot of attention in recent times due to their positive impact on distribution system. Optimal planning of distribution system with distributed generation resources is not only concerned with the sizing of distributed generators but gives due weightage to the placement of generators as well. The installation of DG at optimum location boosts the performance of distribution system as well as presents a cost effective solution thus giving a new dimension to distribution system planning. The positive impacts of optimal distributed generator placement are reflected in terms of improved distribution system reliability, reduced customer interruption costs, reduction in losses and improvement in voltage profile as well as power quality at the consumer terminal. In order to enable electric utilities to obtain maximum benefits, the placement problem calls for state of art optimization techniques capable of handling multiple objective simultaneously in order to present the best feasible solution. This paper aims at providing an overview of several methodologies which have been adopted for finding out optimal location of distributed Generator in distribution system in order to maximize benefits.

Key Words: Distributed Generation, Heuristic and Meta heuristic techniques, Multi objective optimization & Reliability

1. Introduction:

Distributed Generation (DG) by definition is a small power source (roughly 10 MW or less) connected at the substation, distribution feeder or at the consumer terminals [1]. In the present deregulated environment, it is predicted to play an important role in the near future. The primary objective of power system has been to ensure a reliable and economic supply of electric energy to their consumers. Distributed Generators offer a lot of advantages on distribution system performance [2-11]. The benefits of Distributed Generation can be classified into following categories:

A. Technical Benefits:

- Reduction in line losses.
- Improvement in voltage profile.
- Improved Power Quality.
- Enhancement in system reliability and security.

B. Economic Benefits:

- Deferred investments for upgrades of facilities.
- Reduced O&M costs of some DG technologies.
- Enhanced productivity.
- Reduced health care costs due to improved environment.
- Reduced fuel costs due to increased overall efficiency.

- Reduced reserve requirements and the associated costs.
- Lower operating costs due to peak shaving.

C. Environmental Benefits:

- Reduced emissions of pollutants.
- Encouragement to renewable energy based generation.

However DG can have both negative and beneficial impact, depending on their size and location.

With the advent of restructuring and performance based rates, it is critical for utilities to minimize the negative impact and maximize the positive impacts of DG [12]. N. Acharya et al [14] have analyzed that inclusion of Distributed Generator beyond a particular capacity and at an unsuitable location can have a reverse impact on losses. Similarly, the effect of adding DG on network security and reliability will vary depending on its type and position and load at the connection point. Consequently, one or more sites on a given network may be optimal. Other technical, economic and environmental benefits also seek optimum siting and sizing of DG. In addition, optimal resource integration and utilization should allow distributed generators to best compete in the market. It implies that the cost of incorporating distributed generation into power system, the cost of outages and the cost of maintenance should be taken into account. Thus implementing DG in the distribution network does offer lots of benefits, but at the same time it faces many restrictions and limitations. Installing DG in the distribution system will increase the system planning problem complexity. DG has to be adequately studied, installed and coordinated with the existing protective devices and schemes. These limitations and problems must be solved before choosing DG as a planning option [15].

Hence, it becomes necessary to investigate where DG capability and placement could be used to enhance distribution network planning and operation. This paper reviews various optimization techniques used for tracking optimal location of Distributed Generators.

2. Analytical Techniques:

Analytical techniques represent the system by a mathematical model and evaluate it using direct numerical solution [16]. Analytical techniques offer the advantage of short computing time. However when the problem becomes complex, the assumptions used in order to simplify the problem may override the accuracy of the solution. Wang and Nehrir [17] have presented an analytical approach to determine the optimal location for placing DG in both radial and networked systems for minimization of power losses subjected to voltage constraints. The proposed approach is not iterative algorithm like power flow programs. Therefore, there is no convergence problems involved, and results could be obtained very quickly. However the author does not take into account the impact of sizing of DG. Tuba GÖZEL et al [18] have considered the impact of sizing of DG as well on the minimization of losses. Besides ref.17 does not take into account the variation of distribution system loads and has modeled load as unity power factor loads. Reference 18 considers the fact that distribution systems loads are uncontrolled and thus problem is parametrically analyzed by giving particular emphasis to the effects of load models. Bhowmik et al. [19] have developed closed-form equations for determining allowable penetration levels of distributed generation resources subjected to non-violation of harmonic limits as per IEEE standard [19]. The developed analytical technique is suitable for many typical radial distribution feeders with uniform, linearly increasing, or linearly decreasing load patterns.

M.A. Kashem et al. have proposed technique for minimization of power losses in a distribution feeder by optimizing DG model in terms of size, location and operating point. Sensitivity analysis for power losses in terms of DG size and DG operating point has been performed. The authors have developed the methods considering constant impedance and constant current model, separately [20]. Griffin T. et al. [21] have made use of loss sensitive factor for finding appropriate location of DG. This method tackles the siting issue first and then comes down to sizing which may not yield accurate results always since the variation in losses follow a parabolic pattern and it can so happen that with variation in size, some other bus might prove to be a better location for allocation of DG[14]. Thus in order to handle this issue Griffin has included the variation of size as well, but the method is computationally very demanding. However Acharya et al. [14] have proposed a technique which is also based on loss sensitivity factor yet computationally less cumbersome and thus can yield faster result.

3. Heuristic Techniques:

A heuristic is an algorithm that locates optimal or near optimal solutions to a problem without concern for whether the solution can be proven to be correct [23]. Heuristic methods trade off concerns such as precision, quality, and accuracy in favor of computational effort (space and time efficiency). Heuristics are deterministic in nature. Griffin et al.[21] have proposed a simple heuristic iterative approach for DG placement with objective of loss minimization using B loss coefficient. El-Khattam et al have employed the iterative technique for minimization of investments and operation costs [26]. The advantage of heuristic approach is its simplicity. They are easy to implement in comparison with analytical approaches. However the drawback is that it does not always guarantee the best solution.

4. Meta-Heuristic Techniques:

A meta-heuristic is an iterative generation process which can act as a guide for its subordinate heuristics to efficiently find the optimal or near optimal solutions of the optimization problem [22].There is only a very slight difference between the heuristics and meta-heuristics. Meta-heuristic may be considered a general algorithmic framework that can be applied to different optimization problems with relative few modifications in Heuristics to make them adapted to a specific problem [24, 25]. Meta-heuristics are intended to extend the capabilities of heuristics by combining one or more heuristic methods (referred to as procedures) using a higher-level strategy.

Some of the algorithms adopting meta-heuristic approach include Tabu Search, Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization etc.

A. Tabu Search:

Tabu search is a meta-heuristic approach which has dramatically changed the ability to solve a host of optimization problems. Tabu search was proposed by fred Glover in 1986 to allow local search methods to overcome the local optima. The algorithm is a heuristic neighborhood search in which optimal solution determination process is oriented using intelligent mechanisms. A distinguishing feature of Tabu search is embodied in its exploitation of adaptive forms of memory, which equips it to penetrate complexities that often confound alternative approaches. It is based on the premise that problem solving, in order to qualify as intelligent, must incorporate adaptive memory and responsive exploration. The adaptive memory feature of TS allows the implementation of procedures that are capable of searching the solution space economically and effectively. Nara et al and Golshan and Arefifar have used TS for optimization of DG size and location. The approach extensively explores its memory structures to effectively and economically direct the search to attractive regions in the solution space [27, 28]. A multi-objective Tabu search algorithm has been depicted in [29] by Maciel and Padilha. In ref 29 Multi objective Tabu search has been compared with NSGA-II. Using NSGA-II as a reference method, MOTS presented a considerable superior result concerning the processing time, what is a desirable feature, especially in more complex analysis where time requirements become critical.

B. Particle Swarm Optimization:

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995, inspired by social behaviour of bird flocking or fish schooling.

PSO shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optima by updating generations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In PSO, the potential solutions, called particles, fly through the problem space by following the current optimum particles. However compared to GA, PSO is quiet simplified and has few parameters to adjust. Beromi et al. [30] used PSO for finding out suitable DG size and location with the objective of improving voltage profile, minimizing losses, reduction of THD at the same time dealing with the costs. The results were compared with GA and PSO was found to give the better characteristics particularly in terms of solution quality and number of iterations. Taher Niknam [31] has used the method for optimal operation and management of distribution networks and have compared the results with GA and have reached to the following conclusions:

1. The execution time of PSO is sufficiently short in comparison with GA and the method can be implemented without any restriction in realistic networks.
2. The method can be applied to a wide variety of similar optimization problems.
3. Objective function value and active power losses in the PSO is less than GA.

Thus PSO presents a better performance in comparison with GA.

P. Ajay-D-Vimal Raj [32] et al. has used particle swarm optimization to identify the optimum generation capacity of the DG and its location to provide maximum power quality. The improvement in system line voltage stability after connecting a DG is identified by a line voltage stability indicator which takes into effect both the real and reactive power of the system. L. Y. Wong et al [33] have implemented the PSO for reduction in power losses subjected to the constraints of voltage limits.

C. Ant Colony Optimization:

Ant colony algorithms are based on the behavior of social insects with an exceptional ability to find the shortest paths from the nest to the food sources using a chemical substance called pheromone [34]. Hamid Falaghi et al [35] have presented a model to determine optimal location and size of DGs in a distribution system which is solved using ant colony optimization (ACO) as the optimization tool. In this reference DGs are considered as constant power sources. Therefore, distribution system operator can only turn on or off the DG sources and cannot change their power productions.

Lingfeng Wang et al.[36] have used ant colony system algorithm to derive the optimal recloser and DG placement scheme for radial distribution networks. A composite reliability index is used as the objective function in the optimization procedure. The author has utilized ACS algorithm for this application considering its ability to handle discrete optimization problems. It was found that the proposed ACS method outperforms the GA method in terms of solution quality and also its computational efficiency is significantly higher than that of GA. It may take a longer time for the ACS to converge because more potential solutions are to be evaluated. But the extra time needed is not as significant as that in analytical methods, since its computational efficiency is relatively insensitive to system complexity and size.

D. Simulated Annealing:

Simulated Annealing (SA) is a generic probabilistic meta-heuristic for the global optimization problem which locates a good approximation to the global optimum of a given function in a large search space. It is often used when the search space is discrete. The natural process of optimization that takes place in a slowly cooling metal (annealing) guarantees that the structure of the metal reaches the crystal structure corresponding to the minimum energy [44]. The method was independently described by Scott Kirkpatrick, C. Daniel Gelatt and Mario P. Vecchi in 1983 and by Vlado Černý in 1985. The main key to obtain good solution in the usage of SA is the cooling criterion. Question such as what should be the initial temperature and what should the cooling procedure are of paramount important for the good use of SA.

T. Sutthibun and P. Bhasaputra [45] have shown that the SA can find the optimal location and size with the less computing time than genetic algorithm and Tabu search as well as the result of multi-objective problem can conclude that the DGs placing in the optimal location are indeed capable of obtaining higher quality solution efficiently comparing with single objective.

5. Genetic Algorithm:

Genetic Algorithms (GA) have become increasingly popular in the recent times. Genetic algorithms belong to the larger class of evolutionary algorithms (EA), which generate solutions to optimization problems using techniques inspired by natural evolution, such as inheritance, mutation, selection, and crossover. In a genetic algorithm, a population of strings (called chromosomes or the genotype of the genome), which encode candidate solutions (called individuals, creatures, or phenotypes) to an optimization problem, evolves toward better solutions. Traditionally, solutions are represented in binary as strings of 0s and 1s, but other encodings are also possible. The evolution usually starts from a population of randomly generated individuals and happens in generations. In each generation, the fitness of every individual in the population is evaluated, multiple individuals are stochastically selected from the current population (based on their fitness), and modified (recombined and possibly randomly mutated) to form a new population. The new population is then used in the next iteration of the algorithm. Commonly, the algorithm terminates when either a maximum number of generations has been produced, or a satisfactory fitness level has been reached for the population. If the algorithm has terminated due to a maximum number of generations, a satisfactory solution may or may not have been reached.

Deependra Singh et al [38] have used a GA based approach for sizing and placement of DG keeping in view of system power loss minimization in different loading conditions. DGs are usually placed at substations for convenience. This reference suggests that placing a DG further out on the system as opposed to locating the DG at the substation can reduce power losses. Also in industry, decisions are based on power flow analysis run for the peak load. However this may not provide the best location for minimum loss. Thus analysis as per different loading conditions is a must. A.A. Abou El-Ela et al.[39] have presented an optimal proposed approach (OPA) to determine the optimal sitting and sizing of DG with multi-system constraints to achieve a single or multi-objectives using genetic algorithm (GA). The linear programming (LP) is used not only to confirm the optimization results obtained by GA but also to investigate the influences of varying ratings and locations of DG on the objective functions. Fatemeh Afsari[40] has proposed a multi-objective optimization model simultaneously minimizing the system expansion costs while achieving the best reliability. Pareto-optimum models have been used to find the suitable curve of non-dominated solutions, composed of a high number of solutions. The multi-objective optimization model contemplates non linear objective function of economic costs and an objective function representing the reliability. I. Pisică et al [41] have suggested that even though the location is optimal, the size of DG influences the power losses. The optimization procedure proposed in this paper also takes into account the investment costs, and therefore the GA has chosen a smaller size, as the power losses improvements when upgrading to larger sizes are insignificant. Borges and Falcao [42] have presented a method for optimal DG units allocation and sizing in order to maximize a benefit/cost relation, where the benefit is measured by the reduction of electrical losses and the cost is dependent on investment and installation. Constraints to guarantee acceptable reliability level and voltage profile along the feeders are incorporated. G. Celli et al. [43]have implemented genetic algorithm applying the ε-constrained technique to obtain a compromised non-inferior solution.

6. Genetic Algorithm Hybrid Approach:

Genetic Algorithm has been found to be very effective in area of DG allocation; however it is not very efficient in determining the absolute optimum. Therefore it is not the obvious choice when the high quality solutions are desired. To overcome this drawback, GA is combined with other techniques in order to improve its efficiency. Gandomkar et al.[46] have used GA in conjunction with simulated annealing and have demonstrated its ability to produce high class solutions in comparison with classic genetic algorithm. In order to overcome the defects of existing simple Genetic Algorithm (SGA), Hereford Ranch Algorithm (HRA), has been used by M. Gandomkar et al .[47] and J.O. Kim et al.[48] to search optimal site and size of DG in distribution feeders. HRA uses sexual differentiation and selective breeding in choosing parents for genetic string. Phan Thi Thanh Binh et al. [49] have solved the multi-objective problems using GA and fuzzy logic considering also the different weights of objective function.

Researchers have improvised combination of GA with various other techniques in order to attain the better solutions.

7. Miscellaneous Approaches:

Classical second order approach has been used by Narayan S. Rau et al [50]. The reference identifies optimal locations of distributed resources in a network to minimize losses, line loadings, and reactive power requirement. The convergence properties of the proposed algorithm have been examined with a six-bus test system. The authors report that the reduced gradient method did not converge for small nodal injections. Second order methods with proposed transformation of variables speedily yielded convergence to the global minimum. Other approaches which have been used to solve the siting and sizing problem of Distributed Generation include Primal Dual interior point method [51-52], Linear programming[53],Decision theory approach [54,55] and Double trade-off method[56].

8. Conclusion:

This paper has presented a critical review of various techniques which have been employed to address the issue of Distributed generation siting and sizing with respect to various objectives. A summarized comparison of various techniques has been presented in Appendix. The study revealed that while dealing with the multi-objective combinatorial optimization problems with several local optima, there is a possibility of getting trapped into one. A compromise has to be made between accuracy, reliability and computational time. Based upon this review it is concluded that analytical techniques might not be suitable for complex problems, meta-heuristic and heuristic approaches offer a more feasible and simplified solution. However this may lead to a compromise in solution quality and computational time. A hybrid of two or more approaches can however offer a better option by incorporating the benefits of approaches and discarding the drawbacks.

Appendix

Comparison of Various Techniques

Optimization Approach	Benefits	Drawbacks
Analytical Technique	Computing time is short.	When the problem becomes complex, the assumptions used
	Easy to implement.	in order to simplify the problem may override the accuracy
	Non -iterative in nature.	of the solution.
	Unlike other techniques, does not	
	pose convergence problems	Lacks Robustness.
Genetic Algorithm	Can rapidly locate solutions, even	Repeated fitness function evaluation for large and complex
	for large search spaces.	problems may be time consuming.
	Works with discrete and	May not suggest the best solution always, possibility of
	continuous parameters.	trapping into local optima.
	Bad proposals do not affect the end	Lack of accuracy, not suitable when a high quality solution
	solution negatively as they are	is required.
	discarded.	
	Very useful for complex and	
	loosely defined problems.	
	No derivatives needed.	
Tabu Search	Has explicit memory.	Too many parameters to be determined
	Allows non-improving solution to	Number of iterations could be very large
	be accepted in order to escape	Global optimum may not be found, depends on parameter
	from a local optimum	Settings
	Can be applied to both discrete and	
	continuous solution spaces	
	For larger and more difficult	
	problems Tabu search obtains	
	solution, that rival and often	

	surpass the best solutions	
	previously found by other	
	approaches.	
Particle Swarm Optimization	No overlapping and mutation.	Can not work out the problems of scattering and
	Simplified calculation.	optimization.
	Adopts the real number code, and it	
	is decided directly by the solution.	
Ant Colony Algorithm	Inherent parallelism.	Theoretical analysis is difficult
	Positive Feedback accounts for	Sequences of random decisions (not
	rapid	independent)
	discovery of good solutions.	Probability distribution changes by iteration
		Research is experimental rather than
		theoretical
		Time to convergence uncertain (but
		convergence is guaranteed)
Simulated Annealing	Ease of implementation	Large computing time
	Ability to provide reasonably good	
	solutions for many combinatorial	
	problems	
	Robustness	

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