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Review of Distributed Generation Objectives and Optimization Techniques

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Abstract— The Distributed Generation (DG) which are now used popularly have a positive impact on distribution system. The DG connected in the system are more beneficial only if its optimal size and site are considered i.e. they are placed at appropriate position with suitable size and their technology customs conventional and non-conventional energy sources to generate power. Installing the DG at optimum location enhances the system performance as well as provides cost effective solution as it improves the reliability of distribution system, lessen the losses, and improves the voltage profile and power quality of the system. This paper reviews the objectives along with optimization techniques to present best solution in order to gain maximum benefits.

Key words: Distributed Generation, Optimal Location, Power Loss, PSO, GA

I. INTRODUCTION

Distributed generation units is emerging massively in the electric power system infrastructure and growing market in recent years. It is small-scale generating power facility installed in the distribution system, value typically less than 10 MW. It is a technique that reduces the power loss in transmission lines as the required generation of energy is closer to the load center and places of consumption. In present times, use of DG systems in large amounts in the different power distribution systems have become very popular and is growing on with fast speed [1].

The distributed generation, also termed as embedded generation or dispersed generation or decentralized generation, has been defined as electric power source connected directly to the distribution network or on the customer site of the meter [2]. The emergence of new technological alternatives allows the DG technologies in distribution network to achieve immense technical, economic and environmental benefits [3]. These benefits could be maximized by placement of DGs at optimum locations with suitable size and type. The power system operations aim is to fulfill the demands at all locations of the network economically and in a reliable manner.

Existing sources of DGs in the system are photovoltaic cells, wind turbines, solar cell, fuel cells, fossil fuels, geothermal power, micro-gas turbines, etc. The characteristics of the network is basically changed by the DGs. The different characteristics like minimization of transmission losses, maximizing supply reliability and profit of companies are to be taken into consideration. Some of the positive impacts of connecting DGs are listed below:

- Upgrading the reliability
- Voltage profile improvement
- Decreasing power losses
- Power quality enhancement
- Less polluting emissions [4]
- Improved security
- Reduced on-peak operating cost

However DG can have both positive and undesirable impact subject to their size and location. Some undesirable ones are protection coordination, dynamic stability and islanding. The DG size and allocation should be appropriately considered, else they may degrade the power quality, reliability, and control of the utility system as well as increase system losses and operational cost. Addition of DGs also causes system planning complexity and has impacts on the power flow and voltage conditions of the system.

The detailed study has reviewed various objective functions to achieve maximum benefit of DGs without violating equality and inequality constraints of the system. The equality constraints is power conservation limit and inequality constraints are thermal limit of feeder, power limit of transformer and DG, short circuit level, intertie power and voltage step constraints. The possible objectives is to minimize total power losses, minimize real and reactive power losses or to maximize DG capacity or to increase the social welfare and profit.

Several solution techniques have been evolving to investigate DG capability and its placement to boost the distribution network operation. Different mathematical and computational methods are developed such as Conventional Methods – Linear Programming, Non-linear Programming; Intelligent search Methods – Simulated Annealing, Evolutionary Algorithm, Genetic Algorithm, Tabu Search, Heuristic algorithms and Analytical based methods.

This paper reviews Objectives in section 2 and different Intelligent based optimization techniques in section 3 for DG planning in system. Section 4 presents the conclusion.

II. DISTRIBUTED GENERATION OBJECTIVES

The basic and major objective of Distribution Generation Planning was to reduce real power losses. In addition to this other objective functions are reactive power loss, voltage profile, total spinning reserve, power flow reduction in the lines used for optimization

A. *Diminish the Power Loss:*

DG are connected optimally to achieve maximum benefits by diminishing the total power losses in the system. The base formula to reduce real power loss was presented by summing all the nodal injection of power in the network, where its objective function f was expressed as

$$f = \sum_{i=1}^{n} P_i \qquad (1)$$

Where P_i is nodal injection of power at ith bus and n total number of buses[5]. Further the formulation was changed using Newton's Second order method and Genetic Algorithm.

Later, the objective function (f) was expressed by summation of the energy loss costs for each load which as

$$f = K_e \sum_{i=0}^{nl} T^i P_{loss}^i \qquad (2)$$

Where K_e is constant of energy, P_{loss}^i power loss of load level i and T^i is time duration, nl number of load levels[6].

To find the optimal location of DG at bus j, the new expression was presented considering the resistances and complex power, as given below

$$f_j = \sum_{i=1}^{j-1} R_{1i}(j)\,|S_{Li}|^2 + \sum_{i=j+1}^{N} R_{1i}(j)|S_{Li}|^2 \ , \qquad (3)$$

Where $j=2, 3, \ldots N$; $R_{1i}(j)$ is equivalent resistance of bus 1 and bus i , S_{Li} is complex power[7]. The values of resistance is the real part of impedances between bus 1 and bus i.

The effect of DG, studied, on the distribution network to transfer the power and on voltage stability is overall a positive one as active power is injected to minimize the losses. The total real power loss (P_L) is expressed in equation 4, which is known as 'exact loss formula' [8]

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}\left[X_{ij}\left(P_iP_j + Q_iQ_j\right) + Y_{ij}\left(P_iP_j - Q_iQ_j\right)\right] \qquad (4)$$

Where,

$$X_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right), \quad Y_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right)$$

$r_{ij} + x_{ij} = z_{ij}$ are the ijth element of impedance matrix [Z_{bus}], V_i and V_j are ith & jth bus voltages respectively, P_i is active power at ith bus, P_j is active power at jth bus whereas Q_i is reactive power injection at ith bus and Q_j is reactive power injection at jth bus, N is number of buses, δ_i , δ_j phase angle at ith and jth buses respectively.

The total power loss P expressed as function of branch injection current is given as

$$P = \sum_{i=1}^{b} |B_i|^2 . R_i \qquad (5)$$

Where, R_i is ith branch resistance, b is number of branches and B_i is bus injection in branch current matrix except the reference bus.

B. *Enhance the Capacity of DG:*

Studies have been done and it shows that increasing the capacity of Distributed Generation is one of the objectives for its optimal location in the system. While allocating the DG across the buses care is taken that the constraints are not broken through. The objective function is presented as

$$f = \sum_{i=1}^{L} P_{Gi} \qquad (6)$$

Where P_{Gi} capacity of DG at ith bus and L is the number of possible locations. Further it was assumed that at each bus there is a single generator and also the load was considered to be stable in that particular region hence function to maximize the ability of DG is expressed as

$$\mathrm{f} = \sum_{\mathrm{i}=1}^{\mathrm{dn}} (\mathrm{P_{DGi}} + \mathrm{jQ_{DGi}}) \qquad (7)$$

Where dn is number of DG nodes, P_{DGi} and Q_{DGi} are real and reactive power injections at node i.

The advanced research to maximize the DG capacity shows that by using the most of currently available assets and energy resources, amount of power generation can be increased. Also price variation at each node and sensitivity of line are other criteria considered to find proper DG location and its number in proper region using a non-linear programming method. The main function was to decrease the cost of conventional fuel resources and DG sources along with total line losses in the system. The maximum DG capacity has been determined by modeling DG as generators with negative cost coefficients. By means of minimalizing the cost of these generators, the advantages of DG capacity were better.

C. Profit Growth and Auxiliary Objectives:

The problem associated with increasing cost deals with the objective to settle the difference between consumers cost and total production cost. It is formulated as difference between quadratic arch acquiesced by the customer (X_iP_i) , quadratic arch delivered by the supplier (Y_iP_i) and quadratic cost function by the DG owner (CP_{DGi}).

$$f = \sum_{i=1}^{N} (X_iP_i - Y_iP_i - CP_{DGi}) \qquad (8)$$

The widespread objectives aims to reduce different cost of components such as DGs investment cost, operation cost and compensation of the total losses. The total investment objective function is built on the supply chain model design. It aims to curtail the investment and operating costs of local DGs, expenses of purchasing the extra power by the DISCO, expense toward loss compensation services and also the investment cost of other picked new facilities for different situations. The DISCO may have other options to serve its demand growth by - Procuring the required additional power from the main grid and passing it to the distribution system through its junction substation which is connected to the main grid or Procuring the additional power from an present intertie and supplying it to its distribution network space or Capitalize in DG as an substitute for cracking the issues coming in distribution system planning (DSP) without the need for feeder advancement. As there was development, it emphasized on complete distributed generation planning including reactive sources, distributed generation and network formation planning as well as the goodness factor of the DG units which is based on calculation of the incremental contribution of a DG unit to distribution system losses. The disco's objective functions which have been framed are different for disco-owned DG and investor-owned DG [9].

The main objective of the power flow solution has been directed towards optimization of the objective function (OF) as follows, using N-R method for power flow solution,

$$OF = C(P_{DG}) + W \times E \qquad (9)$$

Where, $C(P_{DG}) = a_{DG} + b_{DG}P_{DG} + c_{DG}\,(P_{DG})^2$, $C(P_{DG})$ is total cost of DG as a function of DG rating (P_{DG}), W is weighting factor, E is total active loss and. a_{DG} , b_{DG} , and c_{DG} are the quadratic cost coefficients of specified distributed generation[10]. For the best distributed generation planning multi-objective is approved consisting of various objectives. It permits better simulation of real world, which is characterized by contrasting goals and gives the best capable solution from comprehensive range of appropriate solutions on the basis of individual view of planner.

III. OPTIMIZATION TECHNIQUES

This section describes the intelligent-search based methods to solve local problems and deal with the uncertainties. A heuristic is an algorithm that traces best or near to the best solutions to any problem without fear for whether the solution can be proven to be precise. A simple heuristic approach for placement of DG with objective of minimization of loss using B loss coefficient, minimization of investments and operation costs is studied. The advantage of heuristic approach is its simplicity to implement. However the drawback is that it does not always promise the best solution. A meta-heuristic is an iterative process which can perform as a director for its secondary heuristics to proficiently find the optimal or near optimal solutions of the optimization problem. Meta-heuristic possibly be reflected to common algorithmic framework that can be applied to different optimization problems with hardly any modifications to make them adapted to a specific problem. These methods are also being clubbed with other conventional optimization techniques to resolve the problems.

Some of the algorithms adopting meta-heuristic also known as intelligent-search based approach include Tabu Search, Simulated Annealing, Ant Colony Optimization, Particle Swarm Optimization, Genetic Algorithm-Evolutionary Algorithm, etc.

A. Simulated Annealing (SA):

Simulated Annealing was introduced independently by Scott Kirkpatrick, C. Daniel Gelatt and Mario P. Vecchi in 1983 and by Vlado Černý in 1985 and it kept developing due to its simple implementation and good results. It is a broad, probabilistic and a meta-heuristic method for the worldwide optimization difficulties which traces a good estimate to the global optimum of a given function in a large search space (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 [11]. It is capable of integrating a probability function to find new solutions and using SA as optimization means optimal location, size of DG can be determined to reduce the losses, emission and survive in uncertainties. To get the best results by means of SA the preliminary temperature and cooling criteria are dominantly important. The SA can find the optimal location and size of DG to be connected in the system with the less computing time than other algorithm as well as the result of multi-objective problem which results that the DGs being placed in the optimal location are undeniably capable of attaining higher quality solution proficiently than with single objective. Based on similarity with statistical mechanics, SA can be inferred as a form of controlled random walk in the space of possible solutions.

B. Tabu Search (TS):

Tabu Search technique is a Meta-Heuristic approach, i.e. a general scheme for regulating and controlling “inner” heuristics precisely tailored to the problems at hand. Fred Glover and Hansen in 1986 projected this new approach, called Tabu Search, to allow Local Search methods to overcome local bests. The basic principle of TS is to track Local Search if it encounters a local finest by allowing non-improving moves; cycling back to formerly visited solutions is disallowed by the use of memories, called tabu lists, which records the latest history of the search and this is key notion that can be linked to Artificial Intelligence conceptions. A simple TS algorithm at times can successfully solve difficult problems with added elements to make it fully effective. It is an effective combinatorial method that can attain an optimal or suboptimal solution with very short duration of time and it has minimum number of iteration that counts to gain better solution. TS algorithm is based on intermediate concepts such as moves, neighborhood, tabu list, constraint relaxation aspiration, intensification and diversification.

Nara and Golshan and Arefifar have used TS for optimization of DG location with its appropriate size at appropriate place, operation of Distributed generation resources and reactive power sources in a system along with tap positions of voltage regulators and network outline. The approach directs the search to best prominent zone in the set of solutions to explore its memory structures efficiently and economically. The algorithm was simplified after coordination and decomposition method was introduced in it.

C. Particle Swarm Optimization (PSO):

Encouraged by the flocking behavior of birds and schooling patterns of fish, Particle Swarm Optimization was originally invented by Russell Eberhart and James Kennedy in 1995. It is a computational, population based optimization method in which the potential solutions, called particles, fly through the problem space by following the current optimum particles. Particle Swarm Optimization is a very simple algorithm, iteratively solving, where a group of variables have their values adjusted closer to the member whose value is closest to the objective at any given instant.

The algorithm always keeps tracks of three global variables:

- Target value or condition,
- Global best (gBest) value indicating which particle's data is currently closest to the Target
- Stopping value indicating when the algorithm should stop if the Target isn't found.

Each particle's pBest value only indicates the closest the data has ever come to the target since the algorithm started. The gBest value only changes when any particle's pBest value comes closer to the target than gBest. However comparing to Genetic Algorithm (GA), PSO is simplified, has few parameters to adjust and gives characteristics particularly, the solution quality and number of iterations better than GA. The performance time of PSO is satisfactorily short in comparison with GA and the method can be applied in realistic networks without any limitations. P. Ajay-D-Vimal Raj [12] et al. has used particle swarm optimization to identify the optimum generation capacity of the DG and its location to provide maximum power quality. This technique was also implemented to determine the optimal location and sizes of multi-DGs to minimize the total real power loss of the systems [13]. A two stage methodology was also applied to locate the optimum position and size of DG in which at initial stage fuzzy approach/genetic algorithm is used for searching best place location for DG and at second stage PSO technique finds the corresponding size of the DG to be connected across the distribution system.

D. Evolutinary Algorithm (EA):

Evolutionary Algorithm varies from conventional methods of optimization, as the cost function and constraints do not differ in this. Genetic Algorithm (GA) is one of the artificial intelligent-search based method which gives solutions to optimization problems using techniques stimulated by natural evolution, such as mutation, recombination, crossover, reproduction, selection etc. Mutation randomly perturbs a candidate solution; recombination randomly mixes their parts to form a novel solution; crossover involves choosing a random position in the two strings and swapping the bits that occur after this position; reproduction replicates the most successful solutions found in a population; whereas selection purges poor solutions from a population [14]. In a genetic algorithm, a population of strings (called chromosomes or the genotype of the genome), which encrypt participant solutions (called individuals, creatures, or phenotypes) to an optimization problem which progresses towards better solutions. The evolution usually starts from a population of randomly generated individuals who are then mutated randomly to form a new population. In each generation, the fitness of every individual in the population is different. The new population is then used in the next iteration of the algorithm, which terminates when a certain fitness level is reached among the individuals.

GA was also one of the methods used for sizing and placement of DG resourcefully in the system, with an aim to diminish power loss in different loading conditions and is demonstrated. The possibility of handling single objective and multi-objective model with ε-constraint technique for solving DGP issues was presented in (Singh *et al,* 2009). GA based approach have also been demonstrated to estimate the DG impact on reliability with DG planning in (Teng *et al*, 2002; Borges *et al*, 2006) and it is pooled with OPF that provide the finest combination of sites within a distribution network for connecting a predefined number of DGs in (Harrison *et al*, 2008). Borges and Falcao [15] have presented a method for optimal DG units' allocation and sizing with a purpose to maximize a benefit/cost relation, where the benefit is measured by the depletion of electrical losses and the cost is dependent on investment and installation.

E. Ant Colony Optimization (ACO):

Ant colony algorithms are grounded 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 [16]. In literature, a model to determine optimal location and size of DGs in a distribution system is presented, which is solved using ant colony optimization (ACO) as tool wherein DGs are assumed as constant power sources. Hence, only the DG sources can be turned ON or OFF and cannot alter their power productions. In (Wang *et al*, 2008) [17], authors used ACS algorithm to optimize the re-closer (or DG) placement for a fixed DG (or re-closer) allocation to enhance the reliability and suggested that idea can be extended to the simultaneous placement of both re-closers and DGs.

IV. CONCLUSION

This paper has presented overall perspective, objectives and solution algorithms of Distributed Generation Planning (DGP) with a critical review of various techniques employed to state the issue of Distributed generation siting and sizing. Based upon this review it is concluded that meta-heuristic and heuristic approaches are more feasible and simple solution techniques than the conventional ones. However solution quality and computational time have been compromised. A hybrid of two or more approaches can contribute a better option by integrating the benefits and discarding the shortcomings. However optimization techniques can be further explored and enhanced considering performance on various systems with their upgraded versions.

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