OPTIMAL PLANNING OF DISTRIBUTED GENERATION IN DISTRIBUTION SYSTEM

Ph.D. THESIS

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ABSTRACT

The power system operation, in general, intends to satisfy the load demand at all the locations within the power network involving the considerations of economy of operation, system reliability, system security, and emission control in the generation in a convincing way. Due to drastic growth in the demand, there is a need to upgrade/add the capacity of generation and transmission system. However, due to increased transmission and distribution costs, global exhaustion of fossil fuels, deregulation trends, advancement in technologies and concern about the environmental impacts, installation of adequate number of small scale generation units rather than few large central generation units is emerging as an effective solution to meet the load growth.

Such small scale generation is commonly referred to as distributed generation (DG) or dispersed generation, provides electrical power near the premises of consumers and is connected to the distribution or sub-transmission system to curtail the cost of service. The size of DG usually ranges from few kW to several MW. Today, there are many DG technologies in trend covering conventional (such as micro turbines, combustion turbine, combined cycle, internal combustion engines etc.) to non-conventional (such as wind, photovoltaic solar, fuel cell, ocean, and geothermal etc.) technologies. DG provides a lot of benefits to utilities and consumers such as reduction in power losses; enhancement in voltage profile; power quality & reliability improvement; deferral of system upgrades; reactive power support; standby generation and peak shaving. However, DG may degrade the performance of the distribution system, if it is not planned carefully. In order to achieve the aforesaid benefits, optimal planning of DG units are essential. Therefore, in this thesis, efforts have been made to develop few methodologies for integrating DG into the existing distribution networks so as enhance its performance.

Under optimal planning of DG, determination of its optimal size and location is the most notable and promising aspect to avail the prospective benefits. Selection of the best location and size of DG, out of the different possibilities requires computationally laborious efforts for even a small system. Most of the existing work on DG siting and sizing considered various issues, such as power loss minimization; voltage profile; stability; reliability; and loading margin improvement; harmonic pollution reduction;

investment minimization or profit maximization; loading margin etc., by formulating single or multi-objective problems. Different optimization techniques/methods used for solving these problems can be categorized as index based techniques, analytical approaches, classical approaches, and Artificial Intelligence (AI) based approaches. Index based methods for DG allocation provide approximate solution with comparatively less computational time. On the other hand, analytical approach based methods typically produce closed-form solutions in terms of algebraic expressions that can be analyzed for DG allocation and planning studies. Classical approaches are suitable in finding the optimal solution of continuous and differentiable functions. These approaches have tendency to stuck at local optimal point and hence, have limited scope in practical applications. AI based methods cover Genetic algorithms (GA), Particle Swarm optimization (PSO), Tabu search, Artificial Bee colony (ABC) algorithm, Harmony Search Algorithm (HSA), Ant Colony, Simulated Annealing (SA), GA-fuzzy logic, Bacterial Foraging with PSO, plant growth simulation algorithm (PGSA), Immune algorithm, Evolutionary Programming (EP), Differential Evolution etc. These techniques are being used extensively in DG planning problems with satisfactory performance.

Analytical approaches are emerging as one of the attractive options for solving DG siting and sizing problems as these approaches achieve an optimal or near-optimal solution with less computational efforts. Most of the analytical approaches for DG siting and sizing available in literature use exact loss formula and require the formulation of the bus impedance matrix (Z_{BUS}). Due to negligible shunt charging admittance of the distribution lines in comparison to transmission lines and mostly radial structure of distribution network, Z_{BUS} cannot be formulated and hence, the aforementioned techniques are not well suited for radial distribution network. Moreover, different analytical approaches available in the literature for DG allocation attempt to minimize the active power losses only.

In this work, an analytical approach based methodology for optimal sizing and siting of single as well as multiple DGs is presented for active, reactive and apparent power loss minimization in distribution system. To meet this objective, suitable analytical expressions have been developed, which are based on change in real and imaginary components of branch currents due to DG placement. Further, a procedure is developed for computing the DG size, location, and power factor. This procedure initially determines a set of locations for DG placement and then, the optimum size and power

factor of DG at each locations are computed using developed expressions. The developed methodology has been tested on two test systems, namely, 33-bus and 69-bus radial distribution networks. The results obtained by the developed method are compared in terms of size, location, and loss reduction with those by other methods available in the literature. By comparison of the results, it is concluded that the proposed analytical method produces better loss savings as compared to other methods.

Various analytical approaches for DG allocations addressed in the literature consider only single load level for obtaining the size of DG. However, in actual practice, the load demand varies over a wide range. The variations in load level can be considered by performing as many load flows as the number of load levels. This Repeated Load Flow (RPLF) is computationally exhausting and time consuming especially for large number of load levels. Hence, there is a need to develop an efficient and simple method for DG allocation accommodating the variation in load level of the distribution network. Further, few researchers have used Interval Arithmetic (IA) in order to consider the variation in line parameters and load values ,while solving load flow problem of distribution system. To the best of author's knowledge, no literature is found so far on the application of IA in solving DG sizing and siting problems.

Therefore, in this thesis to address this gap, an IA based method has been developed for DG sizing and siting in a balanced radial distribution system so as to take the variations in load level into account. In this developed method, the variations in apparent power of load and DG current are represented by complex interval variables. First, suitable expressions to compute the apparent power loss saving in the system in terms of real and imaginary components of DG current are derived, then, the loss saving is maximized in order to obtain the real and imaginary components of DG currents. A method is also developed to calculate the optimal size and location of DG considering the variations in load values. This method first identifies a set of suitable locations and then computes the operating range of each DG in terms of interval. INTerval LABoratory (INTLAB) tool box under MATLAB environment is used to implement the developed algorithm for solving DG sizing and siting problem. The developed method is tested on 33-bus and 69-bus radial distribution networks. Optimal DG sizing and siting has been obtained to keep the system loss at a minimum level. The results obtained by developed method are compared with those by RPLF method for validation purpose.

Due to sincere concern about global warming issue, significant attention is being paid worldwide on generation of electricity through renewable energy resources. Among various renewable energy resources, wind and solar are the promising ones as these resources are available naturally without any cost. However, intermittent nature of these resources makes the output from such resources based DGs non-dispatchable. In the literature, the uncertainties in power output from such renewable DG units have been handled using probabilistic and statistical analysis based methods. These techniques need large quantum of renewable resources and hence the computational procedures involved in these become complicated.

Thus, in thesis, an approach based on Interval Programming (IvP) and Binary Particle Swarm Optimization (BPSO) has been developed for allocating the wind-based DG units in distribution network. The problem has been formulated for minimization of annual energy loss considering the constraints on bus voltage magnitude; thermal loading limits of lines; penetration of wind power into the system; and active and reactive power balance equation. The uncertainties associated with the output from wind-based DG and loads are modeled using IvP technique. A BPSO algorithm has been used to find an optimal solution. The proposed method has been applied to 33-bus and 69-bus test distribution systems. The results obtained by the proposed method show significant reduction in energy losses and improvement in system voltage profile.

Apart from analytical approach based methods, several Artificial Intelligence (AI) based method (as discussed above) have been employed in the last decade to solve the DG allocation problem with satisfactory performance. Recently, a new bio-inspired algorithm known as BAT algorithm (BA) has been successfully employed for solving capacitor placement problem in distribution network. However, the performance of this algorithm has not been test for solving DG siting and sizing problem.

Therefore, in this thesis, a BA based method has been developed for optimal siting and sizing of dispatchable DG units in the radial distribution network. This work aims to minimize annual capital cost of DG, O&M cost of DG, energy loss cost, imported energy cost and emission cost subject to various operational constraints i.e. limits on bus voltage magnitudes, line loading limits, total penetration of DG units, active-reactive power balance, number of DG units limit, and operating limits on DG units. Gas Turbine (GT), Micro Turbine (MT) and Fuel Cell (FC) based DG units have been considered as the candidate DG types to be allocated. The developed formulation is a Mixed Integer Non

Linear Programming (MINLP) problem and has been solved by a BA based algorithm. In order to demonstrate the effectiveness of proposed approach, it has been tested on 33-bus and 69-bus radial distribution networks. The obtained results show that due to simple evolution process, BA exhibits good behavior in terms of convergence rate and solution quality.

Conventional expansion planning of distribution network covers expansion/upgradation of existing substations or feeders/lines and addition of new substations or feeders/lines to meet the increased load demand. When DG is integrated in an existing distribution network, it postpones the efforts to be made under conventional planning to fulfill the increased load demand. In addition to DG, capacitors can also be considered as an option for expansion planning of distribution network. In the literature reviewed, very limited work has been reported on optimal expansion planning of distribution network considering DG and capacitor along with traditional planning options.

In this thesis, a comprehensive formulation for multistage expansion planning of distribution network has been presented to minimize the total cost of expansion. As planning options, installation of DGs and capacitors (both fixed and switching type) as well as reinforcement of distribution lines and substation transformer are considered with perspective of Distribution Company (DisCo). The objective function includes installation and operating costs of DGs and capacitors, cost of energy loss, cost of power purchased from grid and costs of substation and feeder upgradation. A GA and PSO based hybrid algorithm is applied for solving the developed formulation. In order to achieve optimal solution, GA is applied to 50% chromosomes/particles and PSO to the rest. To check its feasibility, the proposed approach has been tested on a 9-bus primary distribution system considering four options, namely, only conventional planning; and conventional planning along with DGs only, conventional planning along with capacitors only, and conventional planning with both DG and capacitors. From the obtained results, it is observed that consideration of conventional planning option along with DG and capacitors results the lowest cost of expansion. The results obtained by the proposed method have also been compared with those by GA and PSO based solution techniques.

Summarizing, various contributions made through this thesis work are as follows:

- A simple analytical approach based strategy has been developed to determine the optimal siting and sizing of single and multiple DG, so as to minimize the active, reactive and apparent power loss in a balanced radial distribution network. For

this purpose, suitable analytical expressions have been derived. The developed strategy requires only base case load flow results.

- A new and efficient method for solving the sizing and siting problem of DGs in balanced radial distribution network has been presented considering the variations in load demand. An IA based approach has been used for performing the load flow so as to take the variation in load demand into account.
- An approach based on IvP and BPSO for allocating the wind based DG in distribution system, has been developed. An IvP based algorithm is used for considering the variations in output from the wind DG and load. The formulated problem has been solved using a BPSO based technique.
- A new bio-inspired Bat algorithm based approach is implemented to determine the optimal size and location of distpatchable DGs in radial distribution system to minimize annual capital and O&M cost of DG, energy loss cost and emission cost subject to various operational constraints. This problem is formulated as a mixed integer non-linear programming problem.
- A formulation for multistage distribution network expansion planning considering DGs and capacitors (both fixed and switching) along with traditional planning options have been developed. The objective function reflects the total cost associated with expansion planning over planning horizon. The developed formulation has been solved by a hybrid GA-PSO based technique.