PLANNING OF DISTRIBUTION SYSTEM USING DISTRIBUTED GENERATION

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ABSTRACT

Power system operation aims to meet the electricity demand at all the locations within power network as economically and reliably as possible. Conventional power system operation is based on centralized utility control of a relatively small number of large generators, delivering power through an extensive transmission and distribution system, to meet the given demands of widely dispersed users. Nowadays, the justification for expansion/addition of large central power plants to meet the ever increasing load demand is weakening due to shortage of conventional resources, increased transmission and distribution costs, deregulation trends, heightened environmental concerns and various regulatory and technological changes. Distributed generation systems offer solution to many of these challenges.

Distributed generation (DG) can be defined as the strategic use of small generation throughout the electricity utilities service area at or near the premises of utility customers and interconnected to the distribution or sub-transmission system to lower the cost of service. DGs are typically of ratings between 5 kW to 30 MW and are situated close to a load centre or at a customer’s site. Technologies considered, particularly, suited to DG systems are: photovoltaic, wind turbines, small hydro plants, biomass, reciprocating engines, gas turbines, fuel cells and batteries. The significant benefits to the transmission and distribution systems by using DG are: reduced peak current flow, reduced line losses, deferral of system upgrades, reactive power support, reduced capital risk, enhanced reliability, socio-economic opportunities, etc.

Optimal planning of DG for a distribution system is a crucial factor to achieve the above benefits. DG may degrade the performance of the distribution system, if not planned properly. Therefore, in this thesis, attempts have been made to develop some methodologies, which will be helpful for integrating DG into the existing electric power distribution systems so as to the system performance as well as to overcome energy crisis. Various issues considered in this work are outlined and discussed subsequently.

Since DG is connected to electrical power system at the distribution level, it significantly changes the performance of distribution network. Therefore, the determination of optimal size and location of DG units in the distribution system is one of

the important aspects of distribution system planning using DG in order to achieve the maximum potential benefits of DG integration. The placement of DG in a distribution system is a complex combinatorial optimization problem. As reported in the literature, loss reduction, voltage profile improvement, harmonic pollution diminution, reliability enhancement and network upgrade deferral have been the primary aim for DG placement. Researchers have included one or more of these goals in their formulations and have used different solution techniques for solving their problems. These solution techniques can be broadly classified as heuristic techniques, analytical approaches and Artificial Intelligence (AI) based optimization techniques. Heuristic methods of DG allocation include sensitivity approach based and index based method. These methods give a good but not optimal solution in a reasonably short amount of time. Analytical approaches based methods provide closed-form solutions to DG allocation problem. These approaches are suitable for DG planning studies in distribution system as these approaches could lead to an optimal or near-optimal global solution. AI based optimization techniques include Genetic algorithms, Artificial Bee colony algorithm, Tabu search, Particle Swarm optimization, Evolutionary Programming etc. These techniques are widely adapted in both operational and planning studies with satisfactory performance since many years.

Most of the index based approaches available in the literature for DG sizing and sitting assume the DG penetration level to be fixed and determine its size as well as location. The fixed value of penetration level may give erroneous DG size and site which could deteriorate the system performance. Also, available index based approaches require several load flow solutions. Therefore, determination of optimal penetration level, location and hence, the size considering the DG operation other than unity power factor needs further attention.

In this thesis work, an attempt is made to analyze the impact of penetration level and power factor of DG on the squared voltage drop in a distribution system. Also, a methodology based on voltage drop reduction has been developed to determine the optimal location and size of DG. The developed methodology has been tested on 33-bus and 69-bus distribution systems considering different power factor of DG. The obtained results show the significant voltage profile improvement and thus validate the suitability of the proposed method.

Although DG reduces system energy losses, annual energy loss in distribution networks varies as a U-shape trajectory with increase in DG penetration level. The U-shape trajectory curve is obtained by varying the DG size in a fixed step and performing load flow analysis corresponding to each step size of DG capacity. This requires several load flow solutions and hence becomes computationally demanding.

In this thesis, a methodology based on active power loss saving has been developed to quantify the impact of DG on real power loss reduction. For this purpose, a set of expressions has been derived to compute approximate active power loss saving by DG integration. The developed methodology requires only base case load flow solution to compute active power loss saving. Considering different power factor of DG, the developed methodology has been tested on 33-bus and 69-bus distribution systems. By using the developed approach, it is possible to identify the best penetration level of DG at each bus which gives maximum loss saving. The loss saving by proposed method has been compared with that of repeated load flow and it is found that the trends of loss saving by both methods are similar.

There has been an increasing interest in handling the sitting and sizing problem of DG using analytical approaches. Most of the analytical approaches available in the literature for DG sitting and sizing are based on exact loss formula and require the determination of the bus impedance matrix or inverse of bus admittance matrix or Jacobian matrix which are computationally demanding. Due to high R/X ratio of distribution lines as compared to transmission lines and negligible shunt charging admittance of the distribution network, the above methods may not be suitable.

In present work, an analytical approach for optimal sitting and sizing of DG units in radial power distribution networks to minimize real power losses and squared voltage drop has been formulated and presented. For this purpose, suitable analytical expressions have been derived which are based on change in active and reactive components of branch currents caused by the DG placement. This method first determines the DG capacity causing maximum benefit at different buses, and then selects the bus as the best location for DG placement which corresponds to highest benefit. The proposed method is applicable for allocation of single as well as multiple DG units. Moreover, the proposed method requires only the results of base case load flow to determine the optimal sizes of DGs. The proposed method is tested on 33-bus and 69-bus radial distribution test systems. The results obtained by proposed method have been compared with those by different analytical methods available in the literature to validate the suitability and importance of proposed analytical method.

Optimal allocation of DGs as well as shunt capacitors in the distribution networks for the purpose of real power loss minimization is attracting significant attention of electric power utilities in the present days. The total power flow in the distribution network is composed of two components: real power and reactive power. The former is required by the active component of load and the later is required by the reactive component of load and lines to control the system voltage. Both real and reactive power flows cause the real power losses in the network. As per practice, DG is operated close to unity power factor and mainly supplies real power to the network. Since DG owners are paid for real power only, they don't prefer to generate reactive power. Due to this fact, DG can be used for the reduction of real power flow in the lines but not for the reduction of reactive power flow. The reactive power can be compensated by the use of shunt capacitors. Apart from reduction in power losses, the shunt capacitors enhances the voltage profile, improves power factor and voltage stability of the system. In the literature, very few approaches have considered the optimal allocation of combined DG and capacitor.

A method based on analytical approach for optimal allocation of DG and capacitor with the objective to minimize the total real power loss subjected to equality and inequality constraints in the distribution network has been presented in this thesis. The sensitivity analysis techniques are used to identify the optimal candidate locations for DG and capacitor placement and then the capacity variation technique is used to determine their optimal capacity in the networks. To validate the suitability of the proposed method, it has been applied to 33-bus and 69-bus test distribution systems considering different cases of DG power factor and different combinations of DG and capacitor. The obtained results reveal that allocation of combined DG and capacitor results in significant loss reduction with improved voltage profile.

With the challenges currently faced by large thermal generation systems due to the emission of harmful pollutants, escalating price and depletion of fossil fuels, renewable energy based DG units (i.e. wind, photovoltaic, biogas, fuel cells, small hydro etc.) are emerging as alternative sources of energy. The use of renewable energy sources for power production causes the reduction in greenhouse gas emissions as they are nonpolluting. Since the power output from some renewable based DG units (i.e. wind and solar) depend upon the meteorological conditions, their output cannot be regulated and such DGs are considered as non-dispatchable. The placement of non-dispatchable DG units requires some special techniques to handle the intermittent outputs.

Sufficient work has been reported in the literature on placement of renewable resource based DG units in the distribution network considering uncertainty of DG and load. However, only few works have focused on simultaneous placement of dispatchable and non-dispatchable DGs in the distribution network. The simultaneous placement of these two DG types in the distribution network complicates the problem formulation. Further, the impact of DG placement on the emission released has been rarely considered in the problem formulation. Integration of renewable DG into the distribution networks is one of the effective ways to ensure emission reduction along with the technical and economical benefits to the system. Therefore, consideration of the emission reduction besides technical and economic benefits due to placement of DG units still requires adequate attention.

A methodology has been proposed for optimal allocation of dispatchable and non-dispatchable DG units into the distribution networks with the aim to minimize the annual capital cost, operation and maintenance costs, energy loss cost and emission cost. Wind and gas turbine based DG units have been considered as the candidate DG types to be allocated. The wind based DG unit has been considered as non-dispatchable, while the gas turbine based DG unit has been considered as dispatchable. The uncertainties associated with load and wind speed are handled by employing suitable probabilistic techniques. The developed MINLP formulation has been solved by a GA based approach. The developed approach has been applied to 33-bus and 69-bus test distribution systems. For each test system, two cases have been considered, one without considering the cost of emission and the other considering the cost of emission. For both the test systems, significant improvement in the system performance in terms of reduction in active energy loss, imported active energy from the grid and reduction of emission pollutants along with improvement in the system voltage profile has been observed.

Distribution system planners are continuously exercising to obtain optimal expansion planning strategies to meet the ever increasing load demand at minimum investment cost. The traditional strategies for expansion planning include expansion of existing substations, building new substations and adding new feeders, but are constrained by system operation and performance as well as the economic limits. Deregulation of the energy market, increased power demand load, environmental concern, constraints on building new transmission and distribution lines and technological advancement in power generation systems have accelerated the interest in the application of DG in distribution systems. In addition to DGs, capacitors being less expensive devices can also postpone the need of upgradation/reinforcement of existing substation transformer due to the load growth. The use of combined DG and capacitor for network expansion planning is rarely formulated in the literature.

In the presented work, a multistage distribution network expansion planning model has been formulated to minimize the total planning cost under the condition of load growth and electricity market price variation from the view point of Distribution Company (DisCo). Along with reinforcement/upgradation of existing substations and feeders, DG and capacitors (both fixed type and switching type) have been considered as candidates for expansion planning. The objective function includes the installation and operation costs associated with DG, installation cost of capacitor, cost of energy loss, cost of power purchased from grid, and costs of substation and feeder upgradation. The constraints on bus voltage magnitude, loading of feeder and sub-station, maximum number of DG units and capacitors to be installed in each stage/year, and balance of active and reactive power have considered. For solving the proposed planning problem, a Genetic Algorithm (GA) based method has been developed. The proposed approach is tested on a 9-bus primary distribution system to obtain distribution network expansion planning considering four scenarios. The results obtained by the proposed method reveal that considering DG and capacitors as the candidates for distribution network expansion planning along with traditional planning results into lowest planning cost, improves the system performance and defers the reinforcement of feeders and sub-station.

The various contributions, which have been made through this thesis, may be summarized as follows:

- A heuristic method for DG allocation has been presented for voltage drop reduction in distribution network. For this purpose, an expression has been derived to compute the approximate voltage drop reduction by DG integration.
- A heuristic method for DG allocation has been presented for real power loss minimization of distribution network. Suitable expression has been derived to compute the approximate active power loss saving by DG integration.
- Analytical approach for optimal allocation of single and multiple DG has been developed to minimize the real power losses and squared voltage drop.
- Optimal allocation of combined DG and capacitor for real power loss minimization based on loss sensitivity method and capacity variation technique has been presented.
- A GA based method for optimal allocation of dispatchable and non-dispatchable DG units has been presented for minimizing total annual allocation cost considering technical, economical and environmental benefits.
- A multistage distribution network expansion planning formulation for optimal allocation of combined DG and capacitor (both fixed as well as switching type) along with traditional planning alternatives has been presented for minimizing the total planning cost over the planning horizon and solved by a GA based technique.