OPTIMAL SIZING AND SITING OF DISTRIBUTED GENERATION IN DISTRIBUTION SYSTEM

Ph.D. THESIS

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MAY, 2021

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A THESIS

Submitted in partial fulfilment of the requirements for the award of the degree

of

DOCTOR OF PHILOSOPHY

in

DEPARTMENT OF HYDRO AND RENEWABLE ENERGY

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ABSTRACT

Traditional distribution systems are passive and the branch power flows are unidirectional from the sub-station to the load points. In the context of deregulation, the current trend of placing Distributed Generation (DG) within the distribution system is becoming a very promising option. The presence of DG in a distribution system makes it an active network and alters the branch power flows, hence, the branch power flow in such distribution systems is no longer unidirectional. Also, the integration of DG may impact the operation and performance of a distribution network in both beneficial and detrimental ways. Therefore, in this thesis work, attempts have been made to develop some methodologies for optimal sizing and siting of DG into the distribution networks. The developed methodologies will be helpful to the utilities for integrating DGs into the existing electric power distribution systems to improve the system performance as well as to meet the growing load demand.

An analytical approach is developed to determine the optimal size and location of dispatchable DG units in a distribution system so as to minimize its active power losses. For this purpose, suitable analytical expressions have been developed considering the change in magnitude of bus voltages due to change in the branch power flows after DG placement. The developed method has been tested on 33-bus and 69-bus radial test distribution networks. To confirm the suitability of proposed method, the obtained results by it have been compared in terms of size, location, and loss reduction with those by other methods reported in the literature. By comparison of results, it is observed that the proposed analytical method gives better loss saving as compared to other methods.

As renewable energy resources have abundant availability and have potential to offset the fossil fuels and thus to reduce the emission of green-house gases, the renewable energy resources based DGs are given high priority now-a-days. Since most of the renewable resources of energy (*i.e.*, solar radiation, wind speed, etc.) are intermittent in nature, the power generation from such DGs are also intermittent. This makes such DGs non-dispatchable, *i.e.*, it is difficult to follow a pre-defined operating strategy for such DG units. Therefore, an analytical approach is modified so as to make it applicable for optimum sizing and siting of non-dispatchable DG in the distribution system. In this work, Solar Photo-Voltaic (SPV) based generators are considered as non-dispatchable DGs. Suitable formulations have been developed to determine the optimal size and location of non-dispatchable DG units in a distribution system so as to minimize its active power losses. In the formulation, the variations in power generation from SPV based DG

and load demand has been included. An algorithm is also developed for optimum sizing and siting of non-dispatchable DG in the distribution system. The developed algorithm has been tested on 33-bus and 69-bus radial distribution networks. From the obtained results, it is observed that the DG placement using proposed method improves the performance of network in terms of loss reduction and improvement in voltage profile.

Among different approaches for optimal placement and sizing of DG in the distribution system, the heuristic approaches have attracted significant attention from researchers during last few decades over classical optimization techniques. This is due to the fact that heuristic approaches are applicable to cases where the objective function is either non-differential or non-continuous. In such cases, classical optimization techniques cannot be applied. Further, heuristic approaches have better potential to find out global optima than classical optimization techniques. Since each heuristic approach has its own strength and limitations, a mix of two or more heuristic approaches in form of a hybrid heuristic technique would combine the strength of individual techniques and mitigate the limitation of each other in arriving at the best possible solutions. Therefore, a Genetic Algorithm (GA)-Particle Swarm Optimization (PSO) based hybrid approach is developed to determine the optimal size and location of dispatchable DG units in a radial distribution system. For this purpose, suitable objective function, comprising minimization of active power losses, improvement in voltage profile and enhancement in voltage stability of the distribution system has been formulated. The developed formulation is a Mixed Integer Nonlinear Programming (MINLP) problem. The developed method has been tested on 33-bus and 69-bus test distribution networks under different scenarios. To confirm the suitability of proposed method, obtained results by it have been compared in terms of loss reduction, voltage profile improvement and voltage stability enhancement with those by GA and PSO based approaches. By comparison of results, it is observed that the GA-PSO based hybrid approach gives better results as compared to GA and PSO based approaches.

For optimum sizing and siting of non-dispatchable DG in the distribution system, Monte Carlo simulation (MCS) based method is considered as a benchmark method. However, MCS performs several time-consuming simulations to provide the solution. Therefore, exploiting Point Estimate Method (PEM), A hybrid GA-PSO based approach has been proposed for optimal placement and sizing of non-dispatchable DGs in the distribution systems. For this purpose, suitable objective function, comprising the investment, operating and maintenance costs of DG, cost of capacity adequacy and cost of total real power losses has been formulated and minimized. The uncertainties in power output from non-dispatchable DGs and load have been considered using PEM. The

developed formulation is a MINLP problem. The developed method has been tested on 33-bus and 69-bus test distribution networks under different scenarios. To confirm the suitability of PEM, the results obtained by it have been compared with those by MCS. On comparison, it has been observed that the results by PEM are very close to those by MCS. Further, to validate the hybrid GA-PSO based approach, obtained results by it have been compared with those by GA and PSO based approaches. By comparison of results, it is observed that the GA-PSO based hybrid approach gives better results as compared to GA and PSO based approaches.

The distribution network expansion planning is performed to meet the future load growth. Presently, the competitive electricity market is forcing the distribution system planners to search for economical and technically feasible options/alternatives for expansion of distribution network. The simultaneous placement of DG and capacitor has potential to defer the necessary investment towards network upgradation. Therefore, a comprehensive multi-stage formulation is developed in this work for expansion planning of distribution system with the perspective of Distribution Companies (DISCOs). The developed formulation considers installation of DGs and capacitors (both fixed as well as switching type) in addition to conventional network expansion options. The developed formulation is a MINLP problem and has been solved using a hybrid GA-PSO based approach. This approach has been applied on a 9-bus radial distribution network under four different scenarios. From the obtained results, it is observed that along with conventional network expansion options, placement of DGs and capacitors in the distribution network results the lowest planning cost and improvement in the system performance. To validate the suitability of hybrid GA-PSO based approach, the results obtained it by have been compared with those by GA and PSO based approaches.

Various contributions made by this research work can be summarized as follows:

- An analytical approach has been presented for optimal sizing and siting of single as well multiple dispatchable DG units in the distribution system with an objective to minimize system power loss. In this, suitable analytical expressions have been developed considering the change in magnitude of bus voltages due to change in the branch power flows after DG placement.
- The application of analytical approach is extended for optimal placement and sizing of non-dispatchable DG units in distribution system. In this case, the variations in power generation from non-dispatchable DG units and load demand have been considered.
- A MINLP based mathematical model is developed to determine the optimal

size and location of dispatchable DG units in a distribution system. The objective function, comprising active power losses; and improvement in voltage profile and voltage stability of the distribution system, has been formulated. The developed formulation is solved using a hybrid GA-PSO based approach.

- A MINLP based mathematical model is developed to determine the optimal size and location of non-dispatchable DG units in a distribution system. The objective function comprises cost of installation, operation and maintenance of DG, cost of capacity adequacy and cost of active power losses. The uncertainties in power output from non-dispatchable DGs and load have been considered using PEM. The developed formulation is solved using a hybrid GA-PSO based approach.
- A MINLP based mathematical model is developed for multistage distribution network expansion planning. Along with the placement of DGs and capacitors (fixed as well as switching), the traditional planning alternatives (reinforcement of feeder and sub-station transformer) have been considered. The objective function is the total planning cost over planning horizon. The developed formulation is solved using a GA-PSO based hybrid approach.