DISTRIBUTED GENERATION MODELS AND ITS OPTIMAL PLACEMENT IN POWER DISTRIBUTION NETWORKS: A REVIEW

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ABSTRACT

Distributed Generation (DG) is increasing day by day and it has become an important part of electrical generation across the world. Due to the growth of DG penetration, the nature of distribution network is altered from a passive network to an active network. The penetration of DG is beneficial if it is optimally placed. Various models of DGs are developed for optimal placement of DGs, and several methods are suggested for optimal placement of DGs. Different proposed models of DGs and methods of optimal placement of DGs are reviewed in this paper.

***Keywords:* Distributed Generation (DG), Distributed Networks, DG Models, Optimal Site, Optimal Size.**

I INTRODUCTION

Distributed generation (also called decentralized generation, dispersed generation, and embedded generation) is simply defined as any source of electrical energy of limited size that is connected directly to the distribution system of a power network. Distributed Generation (DG) is also referred as 'dispersed generation' or 'embedded generation', which refers to small scale generation that is integrated within distribution systems. Generally it is integrated close to the point of use. DG can be powered by number of sources both renewable and non-renewable such as fuel cells, photovoltaic system, wind turbines, etc. Distributed energy resources (DER) and microgrid (MG) are reviewed by Jiayiet et.al. [1] and detailed overview of DG technologies is presented by Akoredeet et. al. [2]. The development of Distributed Generation in India is reviewed by Mukhoupadhyay and Singh [3]. Mishra et.al. [4] studied impact of DG on transmission pricing and system reliability. The benefits like voltaic support, lowering of line load etc, of DG scheme are proved by by Fletcher et al. [5] by conducting experiments.

DG is placed in distribution networks at depending on site and primary fuel availability or climatic conditions and the decision of DG placement is taken by owners and investors. Although in most cases, the distribution system operator (DSO) has no control about DG location and size below a certain limit, however placement of DG critically affects the operation of the distribution network. Inappropriate DG placement may increase system losses and network capital and operating costs. If it is placed optimally network performance can improve in terms of improvement of voltage profile, reduction in flows and system losses, and improve power quality and reliability of system. The DG placement problem has therefore attracted the interest of many researchers in the last fifteen years [13-31]. For solving the optimal placement problem DGs efficient and robust three phase load flow methods taking the mathematical models of DGs into account should be developed first since voltage profiles are directly related to power quality and customer satisfaction. Various researchers had developed the mathematical models of Distributed generators [6-12]. In section 2 mathematical models of DGs are reviewed and section 3 methods of optimal placement of DG are reviewed.

II DG MODELS

Mathematical models of distributed generations was developed by Teng [6] utilizing the output power characteristics for load flow analysis. The models can be specified as constant power factor model, constant voltage model or variable reactive power model. Khushalani et al. [7] discussed various models of the Distributed Generation depending upon the control of output. The nodes with small DG are modeled as PQ nodes and large output DG are modeled as constant PV nodes. Various mathematical relations are derived by Losi and Russo [8] to model asynchronous DGs, synchronous DGs and DGs connected to distribution system by power converter. Chen et al. [9] modeled the DGs based on the control of excitation. They modeled synchronous DGs as PV nodes, PQ nodes as well as static voltage characteristic model. Divya and Rao [10] developed mathematical models of wind turbine generating systems and modeled wind DGs as PQ nodes for use in load flow studies. Fejoo and Cidras [11] modeled the wind farms in two forms namely PQ and RX models for load flow analysis of the system. The models are based on steady state behavior of induction generators. Various DG models were presented by Tafreshi and Mashhour [12] with respect to DG and its connection to grid. The DGs with generators directly connected to grid are modeled as PV nodes, PQ nodes or SVCM nodes while DGs connected through power electronic interfaces are modeled as either PV node or PQ node depending upon the control. Table 1 shows briefly the various types of DGs and their connection methods to the grid as well as their suitable models for load flow studies.

Table 1. DG Technologies Models and interconnection type to grid

DG Type	Electric Machine	Utility Interface	Suitable Model for DGs	Explanations
Internal Combustion Engines	Synchronous Generator	Directly	PQ node	Regulating excitation voltage in power factor mode
			Static Voltage Characteristic Model (SVCM)	Fixed excitation voltage
			PV node	Regulating exciting voltage in voltage control mode
	Squirrel Cage Induction Generator	Directly	PQ node or Static Voltage Characteristic Model (SVCM)	----------

Gas Turbines	Synchronous Generator	Directly	PQ node	Regulating excitation voltage in power factor mode
			Static Voltage Characteristic Model (SVCM)	Fixed excitation voltage
			PV node	Regulating exciting voltage in voltage control mode
Micro Turbines	Permanent Magnet Synchronous Generator	Rectifier+ Inverter or AC/AC Converter	PQ node	Control circuit of converter controls independently P and Q
			PV node	Control circuit of converter controls independently P and V
	Squirrel Cage Induction Generator	Directly	PQ node or Static Voltage Characteristic Model (SVCM)	-------
Photovoltaic	------	Inverter	PQ node	Control circuit of converter controls independently P and Q
			PV node	Control circuit of converter controls independently P and V
Wind	Doubly fed Induction Generator	Rectifier+ Inverter	PQ node	Control circuit of converter controls independently P and Q
			PV node	Control circuit of converter controls independently P and V
	Conventional or Permanent Magnet Synchronous Generator	Rectifier+ Inverter	PQ node	Control circuit of converter controls independently P and Q
			PV node	Control circuit of converter controls independently P and V
Fuel cell	------	Inverter	PQ node	Control circuit of converter controls independently P and Q
			PV node	Control circuit of converter controls independently P and V

III METHODS FOR OPTIMAL PLACEMENT OF DG

The operation of DG can provide benefits to distribution networks such as reduction of power losses and/or deferment of investments for network enforcing, etc. only if it is allocated properly otherwise it can cause degradation of power quality, increase losses, reliability, and control etc. For benefits and foreseeable large use of DG in future attention on the sizing and siting of DGs has been paid by many researchers [13-31]. The objectives for placement of DG are minimization of energy losses, power losses, voltage variations, cost, and maximization of DG capacity. The problem of optimal placement of DG can be single objective or multi-objective which can be solved by analytical method and meta-heuristic approaches.

3.1 Single Objective Optimal Placement of DG

3.1.1 Analytical Approach

An analytical technique based on exact loss formula was used by Acharya et. al. [13] to find size and site of DG so as to minimize power losses. Optimal power factor, size and site of DG found by Hung et. al. [14] using analytical expressions. Gözel and Hocaoglu [15] found optimal placement of DG to minimize total power losses by equivalent current injection based analytical method. Hung et. al. [16] developed three analytical approaches using three different power loss expressions to identify the optimal sizes and power factors of DG units at various locations for minimizing power losses and a methodology to identify the best location. Wallance and Harrison [17] presented the optimal power flow based technique that provides a means of determining the maximum capacity of generation that may be accommodated in a network.

3.1.2 Meta-Heuristic Approach

A Genetic Algorithm (GA) based approach was used by Singh et. al. [18] to find best size and location of DG so as to minimize system power losses in different loading conditions. The optimal DG location and size found using maximum power stability index (MPSI) with particle swarm optimization (PSO) to reduce active power losses by Ishak et. al.[19]. Modified Teaching–Learning Based Optimization (MTLBO) algorithm proposed by García and Mena [20] for optimal DG in distribution systems to minimize total electrical power losses. Kaur et. al. [21] used Mixed Integer Non-Linear Programming (MINLP) based formulation to find optimal size and site of multiple DGs for loss minimization. A hybrid method employing Genetic Algorithms and Optimal power flow is presented by Gareth P. Harrison et.al [22] to find the best combination of site with a distribution network for connecting a pre defined number of DGs. Optimal size of DG found by Dasan and Devi [23] by implementing fuzzy adaptation of evolutionary programming. A new population-based ABC has been proposed by Abu-mouti El-Hawary [24] to solve to optimally place DG by minimizing the total system real power loss subject to equality and inequality constraints

3.2 Multi Objective Optimal Placement of DG

3.2.1 Analytical Approach

Optimal size and power factor of DG determined by Hung and Mithulananthan [25] using a new multiobjective index (IMO) based analytical approach for reducing power losses and enhancing loadability. Multiobjective index is defined as a combination of active and reactive power loss indices by optimally assigning a weight to each index such that the IMO can reach a minimum level. At this level, the optimal location and weights are identified.

3.2.2 Meta-Heuristic Approach

For power loss reduction and voltage stability improvement of radial distribution system a new constrained multi-objective Particle Swarm Optimization (PSO) approach for finding best location and size of DG based on Wind Turbine Generation Unit (WTGU) and photovoltaic (PV) array developed by Kayal and Chanda [26], while Injeti and Kumar [27] used a technique based on combination of Loss Sensitivity Factor (LSF) and Simulated Annealing (SA) used to solve optimal siting and sizing problem of DGs to minimize losses and voltage stability improvement. An algorithm based on Tabu Search is proposed by Golshan and Arefifar [28] to solve planning problem which determines installation locations sizes and operation of DGRs and RPSs in a distribution system along with the Tap positions of VRs and networks reconfigurations so as to minimize cost of power and energy losses and total required reactive power during planning period. El-Ela et al.[29] 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). A new method of optimization algorithms PCLONALG which is combination of PSO and CLONALG, is proposed by Sedighizadeh et. al. [30] to minimize active losses of feeders and improve voltage profile by placing multiple DGs. An optimal placement of DG on the power system network is proposed by Phonrattanasak [31] using multiobjective particle swarm optimization (MPSO) to minimize economic and emission costs of overall system.

IV CONCLUSION

The paper has discussed about Distributed Generation models reported in literature for the integration of DGs in distribution system. It is concluded that DGs are generally modeled as PQ and PV nodes in load flow calculations and summary of models of DG based on various technologies is presented. Also, review of optimal placement of DG is presented. It is concluded that improper allocation of DG distribution system would increase power or energy losses and endangers the system operation. For finding optimal site and size of DG various objectives i.e. single objective and multiobjective, are identified by researchers and imposed constraints. It is also identified that most common objective is the minimization of the total power loss and improvement of system voltage. The methods of optimal placement of DG can be categorized as analytical, numerical and heuristic methods and commonly used techniques for the genetic algorithm and swarm optimization. Also it is found that all these methods are applicable to single objective problems while multiobjective problem are solved mainly by genetic algorithms and particle swarm optimization technique.

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