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Optimal Configuration of DG in Distribution System: An Overview

Kumar Mahesh[1], Perumal Nallagownden[1a], Irraivan Elamvazuthi[1]

[1]Electrical and Electronics Engineering, Universiti Teknologi PETRONAS, 32610 Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia.

Abstract. Distributed generation (DG) has increased ever attention in the distribution system from last few years. The main reason for DG in distribution system is increasing electric demand, deregulated power system and congested transmission network, which eventually declines the system performance. There is also increasing pressure of greenhouse gas emissions. For proper utilization of DG, the optimal placement and sizing is of main concern. Because improper DG location and size will increase the losses and decrease the system performance than existing. On the contrary, proper placement will maintain voltage profile, reduce power loss, and increase voltage stability in the distribution system. This paper presents overview of DG, the advances in DG technology and different optimization methods used for optimal placement and sizing problem. The key issues and challenges offered in the development of DG is also presented in this paper.

1 Introduction

Power utilities are facing major challenges in constantly increasing power demands, fossil fuel depletion and environmental concern. The electrical energy is usually supplied through transmission and distribution network, which are operating on maximum allowable limits. Further increase in load causes to reduce the voltage profile and increase the power losses. The main cause for voltage drop and power loss reduction are high resistance in distribution lines and insufficient reactive power requirement [1, 2]. If at certain loading this voltage drop not maintain, this will cause voltage instability and blackout [3]. From last few years, number of blackout has been observed globally. Thus to improve voltage profile, power loss, enhancing voltage stability and power quality is highly required. To improve aforementioned parameter power system needs to build large centralize power plants to accommodate this increasing demand. Transporting the power on aged and congested transmission network will threatens the security and stability of power system. On the other hand generating large power station or upgrading transmission network either is not suitable due to economic and environmental concern. The efficient and reliable power delivery has forced power utilities to work on distribution system in order to reduce the system losses[4]. Many arrangements can be carried out to improve system voltage profile and reduce the power losses, like placement of capacitor banks, network reinforcement and optimally distributed generator placement etc. Mainly, all these techniques reduces the electric current at transmission system by providing it locally at distribution system. Distribution system has usually included radial feeders that fed from substation and connected to the customer meter side. Hence incorporating distributed generation in it has numerous benefits than other methods. Table 1.describes the comparison among these methods with respect to loss minimization, cost saving, voltage support, demand side management, protection system, green power, load balancing and reliability of system.[5].

[a] Corresponding author: perumal@petronas.com.my

Table 1. Loss minimization Methods in distribution system.

Methods	a	b	c	d	e	F	g	h
DG allocation	√	√	√	√	√	√	√	-
Network restructuring	√	-	√	√	√	-	√	√
Capacitor Placement	√	√	√	-	-	-	-	√

a- loss minimization b- cost saving c- voltage support d-DSM e-Protection system f- green power g-load balancing h- reliability

2 Distributed Generation (DG)

“According to IEEE the DG is the source for generation of electricity by facility that are sufficiently smaller than central power station and connected at nearly any point in a power system”[6]. The distributed generation is the source of electric power connected directly to distribution network or on the customer site of the meter [2].

The distributed generation technology generally classified into two categories 1) Renewable DG i.e. wind turbine, photovoltaic cell, biomass, geo-thermal, small hydro power etc. 2) Non-renewable distributed generation i.e. diesel engine, micro turbine, gas turbine and combine heat and power (CHP) etc.[7, 8].

Previously DG was assumed as active source of power but with recent technology the DGs are available in several types such as 1) injecting active power i.e. Photovoltaic, micro turbine, fuel cell 2) injecting only reactive power i.e. capacitors, DSTATCOM 3) injecting active power and consuming reactive power i.e. induction generator, 4) injecting active and reactive power i.e. synchronous generator [9]. The recent technology in distributed generation is not only helping in technical and economic mode but also nonpolluting and sustainable. The main advantages form DGs are it can be helpful in reducing peak demand, enhancing voltage stability, improving load factor and deferral the transmission cost [10]. The technical issue related to DG connection in distribution system depends on its rating. Therefore Table 2. describes the different categories of distributed generation used in distribution system [2, 11].

Table 2. Different categories of distributed generation.

Categories	DG ratings
Micro DG	~1 W < 5 kW
Small DG	5 kW < 5 MW
Medium DG	5 MW < 50 MW
Large DG	50 MW < 300 MW

Traditional distribution was not designed to accommodate generation facility [12], but with recent research it is possible to get maximum utilizations of distribution system to provide customer load locally through DG. Today, number of power companies are investing in small scale distributed generation such as in wind turbines, solar photo voltaic cells, micro turbines, small scale hydro and/ or CHP. Distributed generation was observed in England and Wales are 1.2 GW during 1993-1994, according to [13] it reaches to 12GW recently. DG in Fenosa distribution system Spain has 2203MW connected which represents 120% of area's total peak demand. Germany installed renewable DG in south region is of 6128 MW, Italy represents highest worldwide grid connected DG of 10 GW PV and northwest Ireland has 307 Mw connected as wind DG in distribution system[14].

3 Literature Review

The DG in distribution system has been used mainly to minimize power losses, improve voltage profile, and to enhance voltage stability and reliability of system. Number of methods like analytical method, numerical method and artificial intelligence based method has been adopted to optimally configure the DG size and location which improves the system performance.

3.1 Analytical Method

Optimal placement and sizing for DG using 2/3 analytical method has been proposed by [15]. According to this method, author drives mathematical expressions for size and location of DG. Author suggests if the load is balance then at 2/3 distance from the feeder, a 2/3 size of DG will gives minimum power loss and improves the system voltage performance. The analytical method for optimal placement of DG was used by [16] for different types of load distribution with unity power factor. The main objective was to reduce the power losses of the system. An exact loss formula for optimal placement and sizing of DG has been proposed by [17, 18]. The author's man objective was to minimize the system real power loss. Author [13] Proposed a novel Power stability index (PSI) for DG placement and sizing. The objective functions was to minimize the active and reactive power losses of radial distribution system. Furthermore, the candidate bus was found by load flow analysis on standard IEEE 12 and 69 buses. Finally author suggests that active and reactive power demand locally could be significantly reduced by minimizing power losses and improving the voltage drops in the lines. . The analytical method for optimal placement and size of dispatch-able and non-dispatch (biomass & wind) DGs with power factor consideration has been studied by [19].

3.2 Numerical Method

The different techniques such as gradient search, sequential Quadratic, linear programming, nonlinear programming, dynamic programming, ordinal optimization and exhaustive search methods have been used for optimal DG placement and sizing problem. considering all, the nonlinear programming, sequential quadratic and ordinal optimization methods are most efficient [20]. DG placement problem considering voltage stability analysis, author first used model analysis and continuous power flow method to find candidate bus for DG location, then an algorithm was carried on IEEE 33 bus radial system by [3]. A fixed DG size of 40% were placed on weakest bus and achieve satisfactory results. A new approach for simultaneous placement of different types of DGs for maximization of system loadability, and corresponding minimizing power losses using HPSO (K matrix & PSO) has been presented by [9]. The author also compared the results with M.Etthadi's method and found improved results. Voltage profile and voltage stability margin (VSM) enhancement method in a distribution system with optimal DG placement and sizing have been presented by [21]. Author consider the load as IEEE RTS bus and DG (wind and solar) as variable PQ buses
Furthermore, author used candidate bus by sensitivity analysis then with mixed integer nonlinear programming the voltage stability margin has been found. The constraints were voltage limit, feeder capacity and DG penetration as constraints.

Table 3. Different types of optimization techniques used for optimal DG placement and sizing in distribution system.

Technique	Ref no.	Advantages	Disadvantages
2/3 Rule	[15]	• Simple and easy to use • Non iterative in nature • No convergence issue	• Not suitable for variable load • Approximate value
Analytical Method	[16-18, 22]	• Easy to implement • non iterative in nature • no convergence issue • Computational time efficiency	• Lack of robustness • Only consider single objective and single distributed generation can be deployed at a time
Optimal power flow	[23]	• Easy to find literature example • Computational time efficiency	• Hard to understand and implement
Mix integer nonlinear programming	[24]	• High precision factor • Computational efficiency	• Hard to understand and implement
GA	[25]	• The heuristic nature of this algorithm results in a very good convergence rate.	• This technique optimizes the DG placement at peak point. The performance of the DG degrades as the set point changes.
Evolutionary algorithm	[26]	• Efficient performance for finding the global minimum • Easy to find example from literature	• Harder to simulate, premature convergence • Low precision factor
PSO	[27, 28]	• This technique makes it yield good results for number of DG and responds well for variation. • Easy to code with few example	• The technique optimizes the placement and sizing of DG around a specific point. • Relatively lower performance for finding the global optimum.
other	[29, 30]	• Non sorting genetic algorithm • Mimetic algorithm	• Subject to successful convergence

corresponding minimizing power losses using HPSO (K matrix & PSO) has been presented by [9]. The author also compared the results with M.Etthadi's method and found improved results. Voltage profile and voltage stability margin (VSM) enhancement method in a distribution system with optimal DG placement and sizing have been presented by [21]. Author consider the load as IEEE RTS bus and DG (wind and solar) as variable PQ buses Furthermore, author used candidate bus by sensitivity analysis then with mixed integer nonlinear programming the voltage stability margin has been found. The constraints were voltage limit, feeder capacity and DG penetration as constraints.

3.3 Artificial Intelligence

Artificial intelligence is the intelligent computer programing used in vast areas of science and engineering. The main purpose in DG placement and sizing is to optimize the objective functions technically and economically. Genetic algorithm (GA), Evolutionary algorithm (EV), Differential evolution algorithm (DE) and Particle swarm optimization algorithm (PSO) etc. are used for optimal DG placement and sizing problem. A new multi-objective PSO based wind turbine and solar array generating units in radial distribution system for minimization of power losses and enhancement in voltages stability margin by [31]. According to this author, the optimal placement depends on objectives of distribution system's design. A new solution techniques for distribution expansion planning considering voltage stability, power losses and network voltage variations, the equality and inequality parameters are solved with Pareto

Frontier Differential Evaluation algorithm by [30]. Author also compares the result with GA/ PSO and concludes that PFDE technique has higher potential in discovering solution than GA/PSO. Optimal sitting and sizing problem of DG considering uncertainty in DG and in load by [8]. The objective function was to minimize the investment cost, operating cost, maintenance cost, capacity adequacy cost and network loss cost. The author used new GA-PEM method for probabilistic power flow and for optimal plan of DG. The results are compared with GA-MCS. It is conclude that GA-PEM method is seven time faster GA-MCS. Simultaneous placement of DG and capacitor in distribution network considering voltage stability index as an objective function proposed by [29]. PV curve was used to find VSI then with help of Mematic algorithm optimal DG placement has been found. Optimal placement and sizing determination of DG and DSTATCOM for minimization of power loss, voltage dip in radial distribution system by PSO based algorithm have been investigated by [32]. In this methodology it takes real power from DG and reactive power compensation by DSTATCOM using loss sensitivity factor to find possible node for placement of DG and DSTATCOM.

4 Optimization Techniques

Several optimization techniques has been used for optimal DG placement and sizing problem. Such as conventional, artificial intelligence and hybrid intelligence. The conventional technique used in where there is single objective function and it is non iterative method. Whereas artificial and hybrid intelligence method utilized the iterative process to search the location and sizes of DGs and can be used for one or more than one objective functions. The different techniques used for optimal sizing and placement with advantage and disadvantages are presented in Table 3.

5 Challenges and Research Issue

Basically distribution system is made for unidirectional power flow, incorporating DG, it become bidirectional power flow, so it bounces many complexities in the system. Actually there are two main technical and economic constraints which has to be satisfy for proper utilization of distribution system performances. The technical constraints are power losses, voltage profile, voltage stability, carbon emissions and reliability etc. Economic constraints are DGs cost, DGs installation cost and system maintenance cost etc. Hence in the literature many techniques has been used with different objective functions to optimally place and size the DG.

The thirst to use of green energy is increased all around the globe in order to decrease the oil dependency and Carbon foot prints. Many countries are taking efforts to produce electricity by distributed generation in distribution system due to its numerous advantages. The main drawback of renewable DG is uncertainty in its generation due to its prime sources, which ultimately affects the power quality. This is another complex problem to deal with modern power system for finding the optimal placement and sizing of distributed generation.

6 Conclusion

This paper offers the latest advances in DG technology, DGs benefit along with research issues. In addition, an overview of research work has been conducted for DG in distribution system. From the literature it is observed that in order to get maximum remuneration from DG, it should be optimally located with proper sitting and sizing. Different researcher has contributed in this problem with different objective functions and methods to satisfy the system constraints. The advantages and disadvantages of different method for DG placement and sizing problem is also discuss and presented. Finally challenges and research issues are conferred.

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