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A Review on Optimization Techniques of DG Allocation for Minimization of Power Losses in Radial Distributed System

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***Abstract*—Any moderate electricity generation organization that distributes electric power to a location close to the consumer load center than central station generation is called Distributed Generation (DG).The performance of active power system network can be enhanced by the optimal position and size of DG units. In power system, in appropriate placement of DG would not only become the reason for increased power or energy losses, but it can also put the operations of the system at risk. Therefore, to increase the reliability and stability in power systems, the optimal allocation of DG sources is essential. An overview is provided in this paper for different technologies implemented for recognizing optimal location and capacity of DG units to make best use of the advantages of DG units in the system network. In this paper, various DG allocation methods are studied as per their used optimization approaches, types of DG, objectives and constraints.**

***Index Terms*—Distributed Generation (DG), optimization technique, Genetic Algorithm, Particle Swarm Optimization**

I. INTRODUCTION

The term DG (Distributed Generation) refers to the use of moderate electric power generators disseminated within the distribution network level, whether situated on the utility system near consumers or at an inaccessible site not linked to the power grid [1]. DG technologies have high proficiency, e.g. 40 to 55% for fuel cells, compared to 28 to 35% for old-fashioned huge central power generators [5].

With an ever growing load demand, the current power distribution network is frequently being faced. This increasing load is causing into improved burden and decreased voltage [1]. The distinctive feature of distribution network is that the voltage at nodes diminishes if moved away from substation. This reduction in voltage is generally because of inadequate amount of reactive power. It may lead to voltage breakdown even in certain industrial area precarious loading. Thus reactive compensation is requisite to recover the voltage profile and to evade voltage collapse [1-2]. As compared to transmission levels, the X/R ratio for distribution levels is low, that causes high power damages and a drop in voltage magnitude along with radial distribution lines [1- 3]. It is well recognized that loss in a distribution networks are considerably high as compared to that in a transmission networks. Such significant losses have a straight influence on the financial problems and overall efficacy of distribution services. The requirement of enhancing the complete efficiency of power delivery has forced the power utilities to minimize the losses at distribution level. Many arrangements can be worked out to diminish these losses such as network reconfiguration, shunt capacitor placement, distributed generator placement etc. [1-3]. The distributed generators supply fragment of active power demand, in this manner decreasing the current and MVA in lines. Installation of distributed generators on distribution network will provide the advantage of reducing energy losses, peak demand losses and enhancement in the networks voltage profile, firmness of the networks and power factor of the networks.

Table I. DG category based on capacity

Categories	Ratings
Micro-distributed generation	~1 W < 5kW
Small- distributed generation	5kW< 5 MW
Medium- distributed generation	5MW<50 MW
Large- distributed generation	50MW<300 MW

Table II. DG category based on technology

Renewable DG
Modular DG
Combined Heat and Power DG

Ackermann et al. [17] recommended a common definition for DG, suggesting that the most appropriate definition would be "an electric power source connected directly to the distribution network or on the customer site of the meter". This definition however, does not discuss about any volume criterion or the skills used to build and run these sources. Thus, two supplementary categories are advised in defining as well as classifying DG. The first category classifies DG on the basis of its capacity, and the second category classifies DG based on its technology.

A. Optimal DG Allocation

- **Real and Reactive Loss Indices (ILP and ILQ)**

The active and reactive losses are critically depending on the correct location and size of the DGs. The indices are defined as

$$ILP = \left(\frac{TP^{with\ DG\ loss}}{TP^{without\ DG\ loss}}\right) \dots\dots\dots\dots\dots (1)$$

$$ILQ = \left(\frac{TQ^{with\ DG\ loss}}{TQ^{withoutDGloss}}\right) \dots\dots\dots\dots. (2)$$

Where, $TPlosswithDG$ and $TQlosswithDG$ are the real and reactive power losses of the distribution system with DG. $TPlosswithoutDG$ and $TQlosswithoutDG$ are the real and reactive power losses of the system without DG.

Voltage Profile Index (IVD) The system's voltage profile depends on the proper location and size of the DGs. The IVD is defined as

$$IVD = \max_{i=2} n \left(\frac{|V_1| - |V_i|}{|V_{1|}}\right) \dots\dots\dots\dots (3)$$

Where n is the number of busses in system. V1 is the substation bus voltage (reference voltage). Vi is the ith bus voltage.

B. Objective Function

To analyze the effect of placing and sizing the DG in all previously given system indices is the major objective of this paper. It also observes the study with renewable bus available bounds. Multi objective optimization is designed by merging all the indices with suitable weights. The multi objective function is defined as

$Objective\ Function = (w1 * ILP + w2 * ILQ + w3 * IVD$…..(4)

In this paper, the weight is considered as

$$\sum_{k=1}^{3} w_k = 1 \qquad w_k \in [0,1] \dots\dots.. (5)$$

The weights are specified to provide the equivalent significance to each impact indices for the penetration of DGs and depend on the necessary analysis. Active power losses have higher weight (0.4)in this analysis, since the main prominence is given to active power with integration of DG. The minimum weight is assigned to the IVD, since the IVD is usually small and within acceptable limits. Equality constraint is

$$p_{gs} + \sum_{DG=1}^{m} P_{DG} = p_{load} + p_{loss} \dots\dots\dots\dots. (6)$$

In equality constraint is

$$\boldsymbol{V_{imin \leq} V_i \leq V_{imax}} \dots\dots\dots\dots (\mathbf{7})$$

II. Classification of Distributed Generation

The various DG methodologies that are being organized into the power systems are Wind Turbine (WT), Micro Turbine (MT), Combined Heat & Power (CHP), Squirrel Cage Induction Generator WT (SCIG WT), Double-Fed Induction Generator WT (DFIG WT), Fuel Cells (FC), Photo Voltaic (PV) and storage devices. Generally, DGs are categorized according to their different types and operating techniques. However, to study their effect on the electric system, it is more appropriate to classify them from the electric point of view. The various classifications can be achieved to differentiate between the types of DG according to their electrical applications, supply period, generated power types, electric ratings & renewable and non-renewable technologies.

The classification of DGs from their connection & technological points of view is represented in Fig. 1.

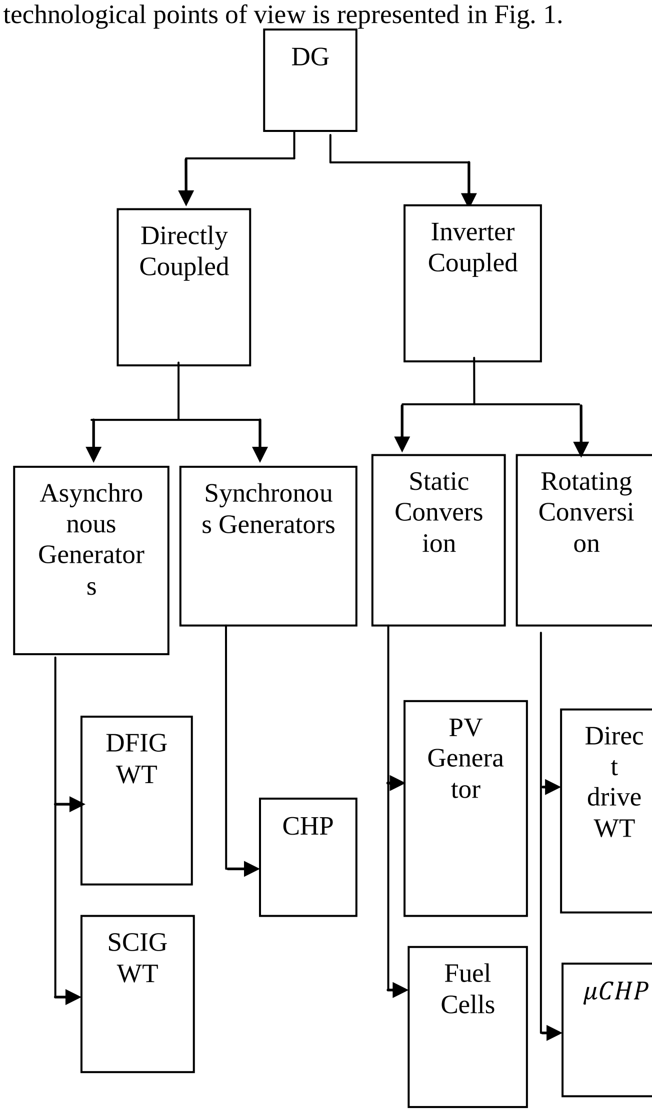

Figure 1Connection based classification of DG

1) Fuel Cells

Fuel Cells (FC) are referred to as non-traditional generators. They are known as electrochemical devices that transform chemical energy from a fuel into electrical energy directly by uniting oxygen, as an oxidant, and hydrogen, as a fuel, without combustion [6]. Generally, the hydrogen is acquired from a fossil fuel "natural gas" while air is used as a source for oxygen. The outcome of this electrochemical procedure is high-current/low voltage DC power. To associate the fuel cell to the grid, a DC/AC converter and filter system current are used to convert the output to AC power. Water (H2O) and heat are byproducts of this procedure. This heat, which frequently goes beyond 1,000 0 F, changes the water into steam, which can then be used to perform other work [5]. Irrespective of the ancillary systems, FCs has no moving parts and no combustion, making them silent devices [5]. FCs are distributed into five types depending on the chemical reaction: Alkaline (AFC), Molten Carbonate (MCFC), Phosphoric Acid (PAFC), Proton Exchange Membrane (PEMFC) and Solid Oxide (SOFC) [8].

2) Micro-turbines

Micro-turbines (MT) are small electricity generators that burn fuel such as natural gas, propane and fuel oil to generate high-speed rotation that is transmitted to an electrical generator via a main shaft. MT contains three basic components: a compressor, a turbine generator, and a recuperator [10]. In existing energy markets, MT generators are the most upgraded and most attractive devices in distributed power generation equipment [11]. Their capacity ranges from 20 kW to 500 kW and when the CHP application is used in the system; their proficiency is more than 80%. Also, the NOx emissions of MT are very low as compared to large-scale turbines [8].

3) Photovoltaic

Photovoltaic (PV) technique converts solar energy into electricity directly by using semi-conductor solar cells. These cells are manufactured in small sizes of normally around one square centimeter. When the solar cells are exposed to direct sunlight, each cell produces less than one watt of DC power, with the lowermost voltage around 0.5 V. Usually, a panel or segment can be formed by electrically joining twelve solar cell units in a series to deliver 12 V. A group of modules can be connected together in parallel in the same way to enhance the output to the desired power [5]. PV systems are categorized into three sizes on the basis of power they generate (the small size is less than 10 kW; the medium size is 10 kW to 100 kW; and the large size is more than 100 kW). The large size is suitable for the distribution network level [8]. In spite of the high initial price of PV systems (US $6,000-10,000/kW [8]), the most important features are that no fuel is required to operate them, and they are very clean and quiet [5].

4) Wind Turbines

Wind turbines are one of the most widespread renewable electrical sources in the world. At present, great number of wind turbine systems have been installed and connected to the grid, generating nearby 238,000 megawatts of electricity globally in 2011, and several new systems are being planned [12]. Wind turbines are provided by the manufacturers in a capacity range from less than 5 to over 1,000 kW [13]. Wind turbines are generally assimilated to the transmission voltage level and combined to create a wind farm. However, wind turbines are occasionally considered distributed generation, because the size and location of some small wind farms make them appropriate for association at the distribution voltage level [14] Wind turbines comprise of a rotor, turbine blades, generator, drive or coupling device, shaft and nacelle. The raw wind energy turns the blades and the common shaft, generating electrical power. Like PV systems, wind turbines need no fuel, no emissions, and generate DC power that requires AC/DC inverters to be connected to the grid. In addition, small wind turbines can be united with PV and battery systems to cover loads of 25 to 00 kW [6]. The main shortcomings of wind turbines are their high preliminary costs and irregularity of energy production. They are not well-matched to CHP applications as well [5].

III. OPTIMIZATION TECHNIQUES FOR DG ALLOCATION

Optimization is a method by using which we attempt to figure out the best solution from a set of existing alternatives. In the problem of DG allocation, DG locations and sizes must be improving in such a way that it offers most economical, effective, technically sound distribution system. In general, distribution system has several nodes and it is very tough to discover the optimal DG location and size by hand. There are multiple optimization techniques used in the literature. Among the various result approaches, deterministic algorithm such as dynamic programming, mixed integer programming, nonlinear programming and Benders decomposing have been used.

Asystematic method to decide the best location of DG is represented. However, modern studies have mostly used heuristic algorithms, such as fuzzy mathematical programming, a genetic algorithm (GA), a Tabu search (TS), an artificial immune system (AIS) and evolutionary programming, partial swarm optimization [10] [17].The benefits of population-based meta-heuristics algorithms such as GA and PSO are that a set of non-dominated solutions can be found in a single run due to their multi-point search capability. They are also less prone to dimensionality issues; however, convergence is not always assured.

Solution approaches for DG deployment can be attained via optimization techniques in order to maximize benefits of DG. Numerous optimization technologies have been offered by researchers in deciding the optimal location and size of DG. Such optimization techniques can be classified into deterministic approaches such as analytical and SQP methods and heuristic methods such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Artificial Bee Colony (ABC), etc., or into single-objective and multi-objective, based on the number of objectives. To minimize power system losses is the main aim of DG placement methods used in the literature. However, other objectives, such as refining the voltage profile and reliability and maximizing the capacity of DG and cost minimization have also been considered.

1) Genetic Algorithm

Genetic Algorithms provide a 'one size fits all' solution to the problem including search. Unlike other conservative search substitutions, GA's can be useful for most of the problems, only requiring a good function description to optimize and a good choice of representation and interpretation. Thus, coupled with the exponentially improving speed/cost ratio of computers, makes them a choice to consider for any issue related to search. Genetic Algorithms (GAs) are multipurpose exploratory hunt processes dedicated around the evolutionary thoughts of characteristic choice and genetics. A genetic algorithm is a heuristically guided random search approach that simultaneously calculates thousands of nominated solutions. Partial random selection and mixing of the evaluated searches is then carried out in order to progress towards improved solutions. The coding and manipulation of search data is based upon the process of genetic DNA and the selection method is derived from Darwin's survival of the fittest'. Search data are generally coded as binary strings known as chromosomes, which jointly form populations [5]. Over the entire population, evaluation is carried out and includes the application of complex 'fitness' operations to the string of values (genes) within individual chromosome. Normally, mixing implicates recombining the data that are held in two chromosomes that are nominated from the complete population. The outdated crossover like partly matched crossover, order crossover and cycle crossover, etc. and mutation would make some impractical solutions to be produced.

In the traditional crossover and mutation, crossover probability and mutation probability are not adaptive in nature because of having no flexibility. For this cause, when a basic GA optimization procedure surrounded in a local minima, these crossover and mutation probability cannot appear from the local minima and GA optimization provides a premature result. There are multiple adaptive techniques used in the literature [6]. On the basis of mechanism of biological DNA genetic information and evolution, an improved genetic algorithm (MDNA-GA) is suggested. The proposed adaptive mutation probability is adjusted with dynamism by considering a measure called Diversity Index (DI). It is described to point out the premature convergence degree of the population. In [7], an Improved Genetic Algorithm (IGA) is proposed. The self-adaptive operation has been employed for crossover and mutation probability in order to increase crossover and mutation quality. An Improved Genetic Algorithm (IGA) based on hormone modulation mechanism is recommended in order to create a possible solution; a new method for crossover process is adopted, named, partheno-genetic operation (PGO). The adaptive methodologies proposed for crossover and mutation operator of the GA.

The performance of genetic algorithms (GA) is exaggerated by different factors like coefficients and constants, genetic operators, parameters and some strategies. Member grouping and primary population strategies are also examples of factors. While the member grouping strategy is adopted to decrease the size of the problem, the initial population strategy has been applied to minimize the number of search to come to the optimal design in the solution space. In this analysis, two new self-adaptive member grouping schemes, and a new scheme to set the initial population have been discussed. An adaptive technique for crossover and mutation operator of the GA optimizes enterprise information system (EIS) structure based on time property has planned.

2) Particle Swarm Optimization

In 1987, a biologist named Craig Reynolds derived a formula by analyzing the social behavior of animals like flock of birds or school of fishes. On the basis of this theory, J. Kennedy and R. C. Eberhart presented an optimization technique called particle swarm optimization. Like GA, PSO also commences with random initialization of solutions called particles. These particles move around the search space with a continuous velocity based on the social psychological tendency of entities to emulate the success of other individuals. Therefore, the modification to a particle within the swarm is influenced by the experience, or knowledge of its neighbors. In order to find the best place of DG using PSO, initial populations are generated randomly with random location and size of DG in the search space (or given distribution network). Then each particle (or DG position) is tested with several operational constrictions before estimating the net cost using equation (4). If the particle is not satisfying the constraints, it is referred to as infeasible particle. After that, each particle is compared with earlier individual best and the better one is stored as Pbest along with the equivalent position of particle. Then from Pbest of all particles, overall best is stored as Gbest. Then the velocity and location of particle is updated and particles are compared to get the recent Pbest and Gbest. This process is continued until it reaches to the maximum iteration limit.

IV. RELATED WORK

Distributed Generation (DG) is one of the latest trends in power systems that are used to support the improved energy-demand. There is not a common accepted definition of DG as the idea includes many techniques and applications. Different countries use distinct notations like "embedded generation", "dispersed generation "of decentralized generation". Related work performed by various researchers is described below:

Chakravorty [1] proposed a novel voltage stability index for discovering most sensitive load on which voltage collapse was possible. New voltage stability index was provided for identifying the node that was most sensitive to voltage collapse. Composite load modeling was considered for the purpose of analysis of voltage stability.

Eminoglu [2] proposed load-flow algorithms based on the forward/backward sweeps. Their convergence capability was quantitatively computed for distinct loading conditions, R/X ratios and sub-station voltage levels. Moreover, the effects of static load modeling on the convergence features of algorithms were also examined.

Gandomkar et al. [3] used the Hereford Ranch Algorithm (HRA) to describe the DG placement and size that diminished losses of distribution power, with the condition that the number of DGs and total capacity of DGs were well-known. The parent selection algorithm for generating offspring exaggerated the capacity of GA in three aspects: finding an accurate solution for a variety of problems; preserving diversity to avoid premature convergence; and refining convergence time.

Acharya et al. [4] projected an analytical method to determine the best ability of DG. The optimal sizes corresponding to each network bus were computed using a direct equation derived from the sensitivity factor equation. Moreover, an efficient methodology based on an exact loss formula was applied to determine the optimal site of DG that reduces total power losses. The approach carried out the load flow two times, for the base case, without DG, and with DG, and considered installing only a single DG that injects active power.

Borges [5] proposed a novel methodology for optimum distributed generation allocation and sizing in distribution systems, in order to decrease the electrical network losses and to ensure acceptable reliability level and voltage profile. The optimization procedure was solved by the combination of genetic algorithms technologies with methods to analyze DG impacts in system reliability, losses and voltage profile. The losses and voltage profile evaluation were based on a power flow technique for radial networks with the representation of dispersed generators.

Le et al. [6] developed a deterministic technology based on the SQP algorithm to find out the optimal size and placement of DG in distribution systems. The authors proposed a combined objective function that aimed to minimize power loss at minimal DG cost.

Beromi et al. [7] presented a methodology for optimal allocation of DG for voltage profile enhancement and reduction of loss. GA was used as the optimization method. Load flow was applied for decision-making which suitably combined with GA.

Wu [8] suggested theoretical formulation of the forward/backward sweep with compensation power flow technique. Consequently, a new solution of unbalanced three-phase power systems based on the loop-analysis approach was developed. The proposed technique had clear theory foundation and took complete benefit of the radial (or weakly meshed) structure of distribution systems.

V. CONCLUSION AND FUTURE SCOPE

In this paper, a general idea and key concerns of various research studies for optimal allocation of DG is mentioned. The issue regarding optimal placement of DG is quite intricate. This problem may involve several objective utilities, multiple constraints to resolve the location concerns of DG units. Different optimization techniques for DG allocation such as Genetic Algorithm, Particle Swarm Optimization have also been discussed in this paper. The chief objective of this paper is minimization of power losses and voltage profile enhancement. It has been concluded that the traditional methodologies are time consuming and not very effective to solve the problem of location and size of DG sources in the system. Advanced Evolutionary optimization algorithms can be used in future because of their feasibility, easy implementation and improvise results.

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