

A Genetic Algorithm Approach for Optimal Allocation and Sizing of Distributed Generation in Distribution Networks

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Abstract

Numerous advantages attained by integrating Distributed Generation (DG) in distribution systems. These advantages include decreasing power losses and improving voltage profiles. Such benefits can be achieved and enhanced if DGs are optimally sized and located in the systems. This study presents a distributed generation (DG) allocation strategy to improve node voltage and power loss of radial distribution systems using genetic algorithm (GA). The objective is to minimize active power losses while keep the voltage profiles in the network within specified limit. In this study, the optimal DG placement and sizing problem is investigated using two approaches. First, the optimization problem is treated as single-objective optimization problem, where the system's active power losses are considered as the objective to be minimized. Secondly, the problem is tackled as a multi-objective one, focusing on total power loss as well as voltage profile of the networks. This approach finds optimal DG active power and optimal OLTC position for tap changing transformer. The simulation study is carried out on a 33-bus radial Distribution System. The results are presented, compared and analyzed in this paper.

Keywords—*Power Systems Stability, Distributed Generation, Genetic Algorithm, Distribution System*

1. INTRODUCTION

Globally increasing trends in electric power consumption, congestion in the transmission system, economic and environment concern has led the attention towards small power generation called DG, in distribution system. DG has many advantages such as it increases the power capacity in power system, it reduces the power losses in power system, and it increases the voltage profile of the distribution system as it is in radial nature [1]. DG was previously used as an active power source but today with technological advancement it is available in many forms such as: an active power source of supply (e.g. photovoltaic cell or combined heat and power (CHP)), a reactive power source (e.g. synchronous condenser,

capacitors or STATCOM), the active and reactive power requirements (e.g. synchronous machines or wind generation). It is projected that around 13% of collective power production is lost as system losses in distribution system [2].

The study reveals that an installation of DG in distribution system significantly reduces the power loss and increase the voltage profile of the system. In order to harness the optimal benefits from DG, it should have proper placement and sizing in the system. Improper placement and sizing will worsen the existing situation. There are many methods that have been used for proper placement and sizing of DG. An analytical method such as 2/3 method has been used for optimal placement and sizing of DG. According to this method, when the load is balanced then 2/3 size of DG of total incoming generation can be penetrated at 2/3 location of the feeder. However, this method is not suitable for non-uniform loads.

Linear programming method is used for optimal DG placement and to gather maximum amount of energy, considering financial and technical constraints. The probabilistic generation-load model with its all-operating condition and probabilities has been accommodated in deterministic model [2]. The optimal placement and sizing of generation units on the distribution network have been continuously studied in order to achieve different aims. The objective can be the minimization of the active losses of the feeder; or the minimization of the total network supply costs, which includes generators operation and losses compensation; or even the best utilization of the available generation capacity. As a contribution to the methodology for DG economic analysis, in this paper it is presented an algorithm for the allocation of generators in distribution networks for loss reduction in distribution network ($\text{Loss with DG} \leq \text{Loss without DG}$). The Genetic Algorithm is used as the optimization technique. The technique satisfies the power balance, bus voltage and system capacity as constraints.

2. LITERATURE REVIEW

Distributed generation means the electric power generation within distributed network to fulfil the rapid energy demand of consumers. However, distributed generation can be defined in a variety of ways.

- i. The Electric Power Research Institute (EPRI) defines distributed generation as generation from 'a few kilowatts up to 50 MW' [5].
- ii. International Energy Agency (IEA) defines distributed generation as generating plant serving a customer onsite or providing support to a distribution network, connected to the grid at distributed level voltages [6].
- iii. The International Conference on large High Voltage Electric Systems (CIGRE) defines DG as 'smaller than 50- 100 MW' [5].

Although there are variations in definitions, however, the concept is almost same. DG can be treated as small scale power generation to mitigate the consumer energy demand.

Distributed Generation can come from a variety of sources and technology. As the technical design of each distribution network is unique, therefore, it cannot be answered what should be the optimum generation capacity or rating of DG [5]. The maximum size or rating of DG which can be connected to a distribution network depends on numerous factors, such as voltage level within the distribution system, power loss profile and other technical, environmental, commercial and regulatory issues. In this paper, we will focus on the technical issues only. As DG offers lots of benefit, the penetration of DG in distribution system is increasing rapidly. Therefore, DG should be allocated in an optimal way to maximize the system efficiency.

In a distribution system power loss varies with numerous factors. Real power losses of a distribution system depend on the resistance of distribution lines, core losses of transformers and motors. As dielectric and rotational losses are so small compared with line losses, therefore, only line losses are considered in this analysis. The complex power S_{ij} from node i to j and S_{ji} from node j to i are

$$S_{ij} = V_i I_{ij}^* \quad (1)$$

$$S_{ji} = V_j I_{ji}^* \quad (2)$$

Where, V_i and V_j are the voltages at node i and j respectively. The line current I_{ij} which is measured at bus i in the positive direction of i to j and I_{ji} which is measured at bus j in the positive direction of j to i . Therefore, power loss in any line between node i and j can be written as the algebraic sum of power flows determined from (1) and (2).

$$S_{Lij} = S_{ij} + S_{ji} \quad (3)$$

After any converged load flow, power loss in any line can be calculated using (3) and taking the summation of all line losses, total power loss of the network can be calculated using equation (4) where n is the number of lines.

$$\text{Loss} = \sum_{k=1}^n S L(k) \quad (4)$$

For any distribution system, placement of any DG unit will change the power loss profile of that system. Actually, in distribution network, power loss curve with the variation of power generation at a particular location is approximately quadratic function because Line Losses $\propto I^2 R$ and $I \propto S$. Considering I is the line current, R is the resistance, and S is the apparent power flowing through the line. Therefore, as the DG size is increased in any location of a power distribution network, the total system losses are reduced to a minimum value. With further increasing of DG, losses again start to increase. This trend of losses with DG size variation is given in Figure 1 for a test case to demonstrate the sizing and location issues of DG.

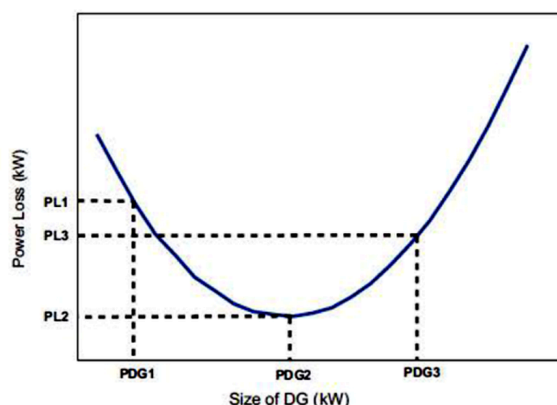


Figure 1: Power loss characteristic of distribution system with DG size variation

Here, for DG size PDG2 we get the minimum power loss which is called optimum DG size for that bus. Actually, the structure of distribution system is such that power should flow from the substation to the consumer end and conductor sizes are also decreased gradually [3]. When a DG is placed in the network, it is desirable that power should be consumed within the distribution network and thus improves power profile. Any size of DG more than the optimum size will create reverse flow of power towards distribution substation. Therefore, excessive power flow through small sized conductors towards the transmission area will increase the power losing distribution network.

In the literature, genetic algorithm has been applied to DG placement [8-10]. In all these works either sizing or location of DGs are determined by these methods. The DG placement problem has therefore attracted the interest of many research efforts in the last fifteen years [7], since it can provide DSOs, regulators, and policy makers useful input for the derivation of incentives and regulatory measures. The Clonal algorithm is a new population based meta heuristic approach inspired by Clonal principle of immune system of human body. The advantage of this algorithm is that it does not require external parameters such as selection, cross over rate and mutation rate as in case of genetic algorithm and differential evolution and it is hard to determine these parameters in prior.

However, DG placement impacts critically the operation of the distribution network. Inappropriate DG placement may increase system losses and network capital and operating costs. On the contrary, optimal DG placement (ODGP) can improve network performance in terms of voltage profile, reduce flows and system losses, and improve power quality and reliability of supply.

A. LOAD FLOW OF RADIAL DISTRIBUTION NETWORKS

A feeder brings power from substation to load points/nodes in radial distribution networks (RDN). Single or multiple radial feeders are used in this planning approach. Basically, the RDN total power losses can be minimized by minimizing the branch power flow or transported electrical power from transmission networks (i.e. some

percentage of load are locally meeting by local DG). To determine the total power loss of the network or each feeder branch and the maximum voltage deviation are determined by performing load flow. The Forward/Backward Sweep Load Flow technique is used in this case. The impedance of a feeder branch is computed by the specified resistance and reactance of the conductors used in the branch construction. The Forward/Backward Sweep Load Flow method consist two steps (i) backward sweep and (ii) forward sweep.

Backward sweep: In this step, the load current of each node of a distribution network having N number of nodes is determined as:

$$I_L - (m) = \left\{ \frac{P_L(m) - jQ_L(m)}{V^*(m)} \right\} \quad (5)$$

$$[m = 1, 2, \dots, N]$$

where, $P_L(m)$ and $Q_L(m)$ represent the active and reactive power demand at node m . Then, the current in each branch of the network is computed as:

$$I - (mn) = I - (n) + \sum_{m \in \Gamma} I_L - (m) \quad (6)$$

where, the set Γ consists of all nodes which are located beyond the node n

Forward sweep: This step is used after the backward sweep so as to determine the voltage at each node of a distribution network as follows:

$$V - (n) = V - (m) - I - (mn)Z(mn) \quad (7)$$

where, nodes n and m represent the receiving and sending end nodes, respectively for the branch mn and $Z(mn)$ is the impedance of the branch.

In this work the estimation methodology utilized within the forward/backward load flow is based on (i) equivalent current injections (ECI), (ii) the node-injection to branch current matrix (BIBC) and (iii) the branch-current to node-voltage matrix (BCBV). The relations between the node current injections and node voltages could be communicated as:

$$[\Delta V] = [BCBV]. [BIBC]. [I]$$

B. GENETIC ALGORITHMS

Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time. Generally, GA comprises three different phases of search:

Phase 1: creating an initial population;

Phase 2: evaluating a fitness function;

Phase 3: producing a new population.

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals. There are usually three operators in a typical genetic algorithm: the first is the production operator (elitism) which makes one or more copies of any individual that possess a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the 'crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the righthand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

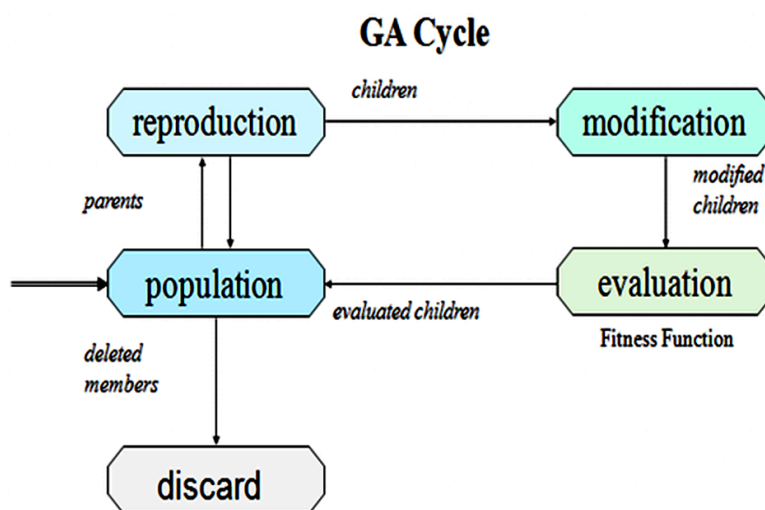


Figure 2: Genetic Algorithm Cycle

3. METHODOLOGY

The Optimal DG placement and sizing to reduce the power loss in distribution system using GA based method takes the following steps which is presented in a flowchart in Figure 3.

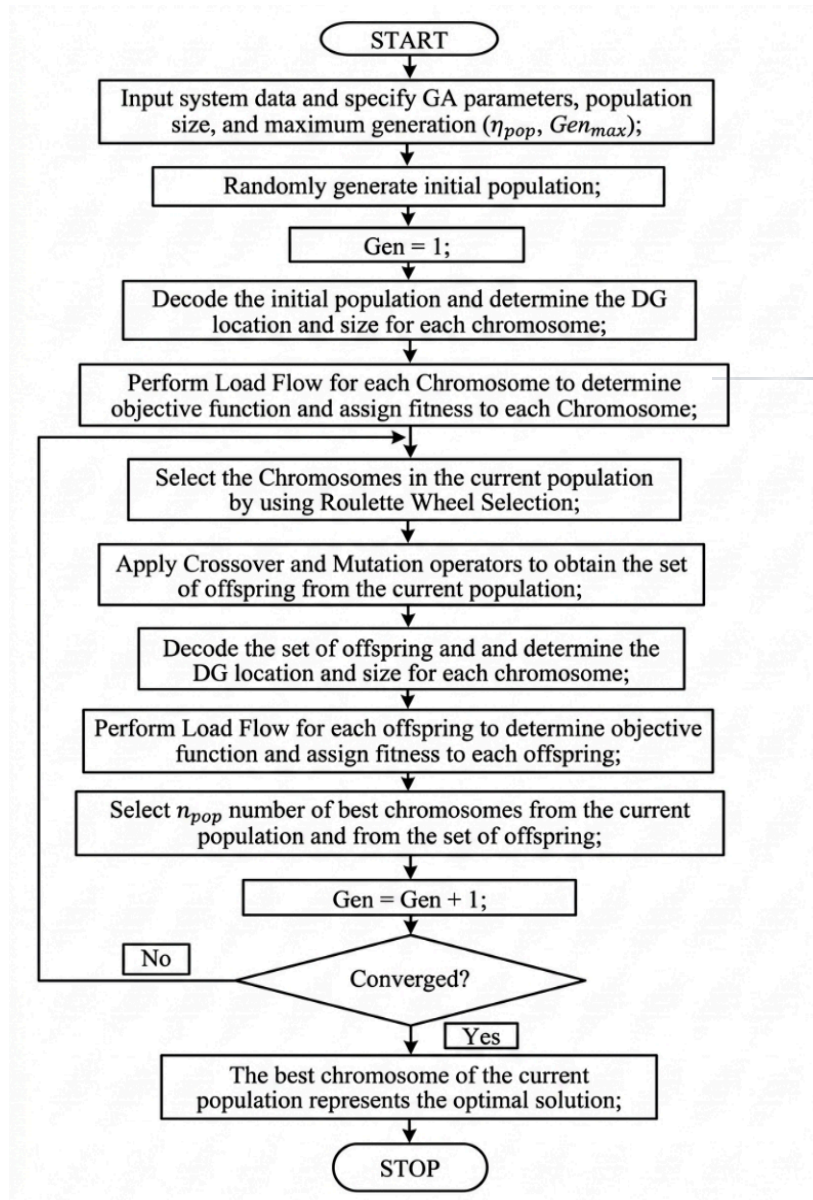


Figure 3: Methodology of the Task

A. Test System Description

To evaluate the effectiveness of the proposed approach, simulations were conducted using the standard IEEE 33-bus radial distribution test system. As illustrated in the single-line diagram (Figure 2), the network topology comprises one main feeder and

three lateral branches. The base case system parameters include a total real power demand of 3720 kW and a total reactive power demand of 2300 kVAr.

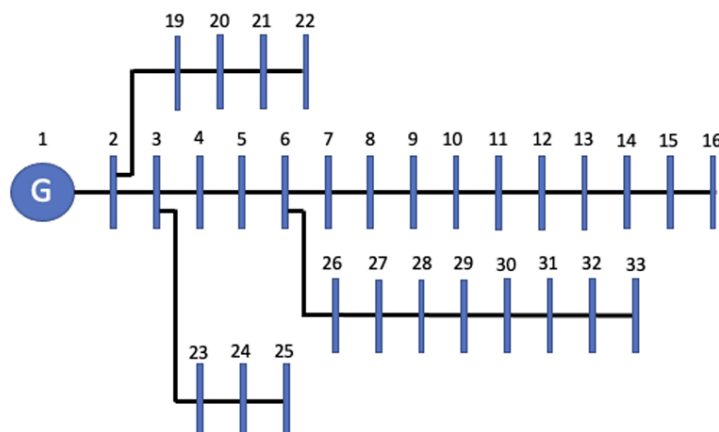


Figure 4: Single line diagram of the 33-bus test distribution system

B. Distributed Generation (DG) Modeling

The simulation framework incorporates the integration of Distributed Generation (DG) to assess its impact on the distribution network. The study categorizes and models the DG units into two distinct types based on their power injection characteristics:

Type 1 DG (Real Power Injection): These units are configured to inject only real (active) power into the grid at a unity power factor. This models the operational behavior of renewable energy sources such as photovoltaic (PV) cells and fuel cells.

Type 2 DG (Reactive Power Injection): These units are configured to supply only reactive power to the network. This represents the integration of reactive compensation devices, such as synchronous condensers or capacitor banks.

4. RESULTS AND DISCUSSION

The upper and lower limit of the voltage profile of the system are taken as 0.90 volts to 1.05 volts. Bus 1 is slack bus, which has maximum voltage for both case (Base case and after DG placement). Before installation of the DG at system, the voltage is found about 0.9038 volts at bus 18, which is minimum of all node voltage whereas after installation of type-1 DG, voltage is improved to 0.9424 volts. However, after installation of type-2 DG, voltage at bus 18 is found 0.9286 volts.

Table 1: Voltage of the system before and after DG installation

Test System		Base case		After DG placement	
		Voltage (P.U)		Voltage (P.U)	
		Min	Max	Min	Max
IEEE 33 Bus	Type 1 DG	0.9038@bus18	1.00@bus1	0.942@bus 18	1.00@bus1
	Type 2 DG	0.9038@bus 18	1.00@bus1	0.9286@bus 18	1.00 @bus1

From the analysis of table-1 it can be seen that type-1 DG gives better option for improvement of the voltage of the system than type-2 DG installed in the system.

Table 2: Optimal DG size Power loss of the system before and after DG

Test System	Base case		DG size	After DG		Loss Reduction	
	Power Loss			Power Loss			
	P_{loss} (Kw)	Q_{loss} (Kvar)	Type-1(Mw) Type-2 (Mvar)	P_{loss} (Kw)	Q_{loss} (Kvar)	P_{loss} (%)	Q_{loss} (%)
IEEE 33 Bus	211	143	Type-1(Mw) Type-2 (Mvar)	P_{loss} (Kw)	Q_{loss} (Kvar)	P_{loss} (%)	Q_{loss} (%)
Type-1 DG	211	143	2.5907@bus6	111	81.7	47.39	39.58
Type-2 DG	211	143	1.258@ bus30	170.8	118.6	19.05	17.06

Table-2 describes the optimal placement and sizing of DG with respect to real and reactive power loss for two different types of DG installation. After installation of type -1 DG, the power losses reduce from 211 kw to 111 kw which is about 47.39 % of active power loss reduction whereas the reactive power at this DG is reduced from 143 KVAR to 81.7 KVAR which is about 39.58 % of reactive loss reduction. For second type of DG, the active power loss reduces from 211 kw to 170.8 kw which is about 19.06 % of active power loss reduction whereas the reactive power at this DG is reduced from 143 KVAR to 118.6 KVAR which is about 17.06 % of reactive loss reduction. It can be noted that optimal placement of DG is bus 6 and optimal size of DG is 2.5907 Mw for DG type-1 whereas optimal placement for DG type-2 is bus 30 and optimal size is 1.258 MVAR.

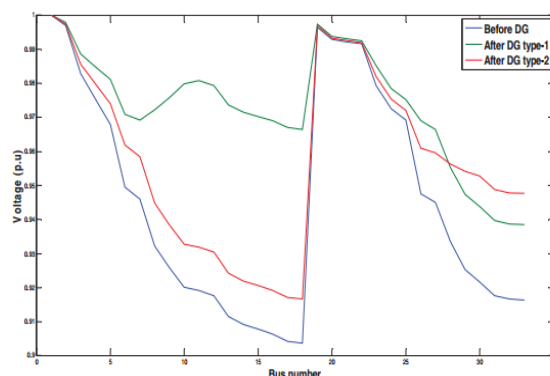


Figure 5: Voltage Profile of IEEE 33 Bus system before and after DG Installation

Figure 5 compares the voltage profile of the test system across all buses before and after integrating two types of Distributed Generation (DG). The base case without DG (blue line) experiences the most severe voltage drops, falling to nearly 0.90 p.u. around bus 18. The integration of either Type-1 (green line) or Type-2 (red line) DG significantly elevates the overall voltage levels closer to the ideal 1.0 p.u. mark across the network. Specifically, Type-1 provides superior voltage enhancement for the first half of the buses, whereas Type-2 offers slightly better voltage support at the system's terminal buses.

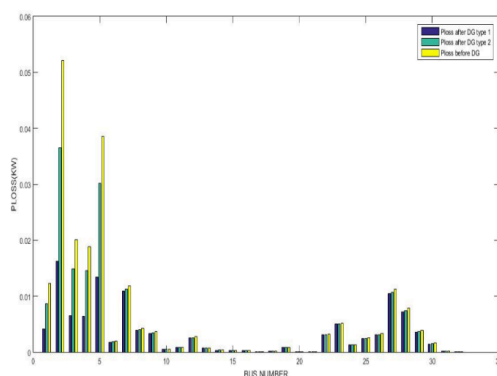


Figure 6: Real Power loss before and after DG

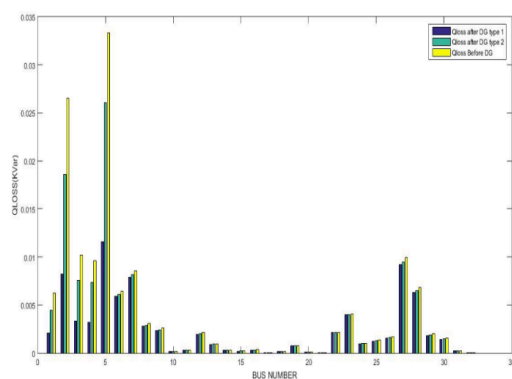


Figure 7 : Reactive Power loss before and after DG

Moreover, Figure 6 and Figure 7 are representing the real and reactive power loss on each branch of the system respectively. It can be observed on fig. 6 and fig. 7 that before DG installation the real power loss is maximum on buses 2,5,3, 4 and reactive power losses is maximum on buses 5,2,27,3 whereas after installation of different type of DG, the power losses is reduced significantly.

5. CONCLUSION

In this research, a methodology for the optimal location and sizing of DG for power loss reduction in IEEE-33 bus system using Genetic algorithms has been proposed. The programming has been done using MATLAB environment.

This study successfully implemented a Genetic Algorithm (GA) to optimize the placement and sizing of Distributed Generation (DG) units within the IEEE 33-bus distribution system. The primary objective of minimizing system power losses while enhancing the voltage profile was effectively achieved. A comparative analysis between active power (Type-1) and reactive power (Type-2) DGs revealed that Type-1 DGs yield significantly superior performance. Specifically, the integration of Type-1 DGs resulted in a 47.39% reduction in active power losses and a 4.27% improvement in the voltage profile, vastly outperforming the 19.05% loss reduction and 1.79% voltage improvement achieved by Type-2 DGs. Consequently, it is evident that Type-1 DGs are more effective in optimizing distribution network performance. Furthermore, the proposed GA methodology demonstrated a fast convergence response, confirming its computational efficiency and suitability for complex power system planning.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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