Journal of Advances in Science and Engineering 5 (2021) 20 – 36

Journal of Advances in Science and Engineering (JASE)

Journal homepage: www.sciengtexopen.org/index.php/jase

Voltage profile improvement and losses minimization for Hayin Rigasa radial network Kaduna using distributed generation

Idris A. Araga, Abel E. Airoboman *, Simon A. Auta

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna, Nigeria

ARTICLE INFO

Article history:
Received 21 May 2021
Received in revised form 21 June 2021
Accepted 29 June 2021
Available online 6 July 2021

Keywords:
Distributed generation
Genetic algorithm
Losses minimization
Optimal sizing
Radial network

ABSTRACT

This research work has presented the application of distributed generation (DG) units in a simultaneous placement approach on IEEE 33 radial test systems for validation of the technique with further implementation on 56-Bus Hayin Rigasa feeder. The genetic algorithm (GA) is employed in obtaining the optimal sizes and load loss sensitivity index for locations of the DGs for entire active and reactive power loss reduction. The voltage profile index is computed for each bus of the networks to ascertain the weakest voltage bus of the network before and after DG and circuit breaker allocation. The simultaneous placement approach of the DGs is tested with the IEEE 33-bus test networks and Hayin Rigasa feeder network and the results obtained are confirmed by comparing with the results gotten from separate DGs allocation on the networks. For IEEE 33-bus system, the simultaneous allocation of DGs and of optimal sizes 750 kW, 800 kW and at locations of buses 2 and 6 respectively, lead to a 66.49 % and 68.64 % drop in active and reactive power loss and 3.02 % improvement in voltage profile. For the 56-bus Hayin Rigasa network in Kaduna distribution network, the simultaneous placement of DGs of sizes 1,470 kW and 1490 kW at locations of bus 16 and 23 respectively, lead to a 79.54 % and 73.98 % drop in active and reactive power loss and 15.94 % improvement in voltage profile. From results comparison, it is evident that the allocation of DGs using the combination GA and load loss sensitivity index, gives an improved performance in relations to power loss reduction and voltage profile improvements of networks when compared to without DGs.

1. Introduction

Power systems are facing tremendous issues as demand grows at a rapid rate, but supply remains mainly insufficient, costly, and unreliable [1]. A few hundred-megawatt power plants were converted from minor and local power generators in order to service vast numbers of consumers near and far, thanks to the rapid growth of the power sector and industrial big machinery producing, sending, and receiving electricity. The power distribution system is constantly dealing with rising load demand, which leads to increased power consumption and significant voltage drop [1].

* Corresponding author
E-mail address: airobomanabel@nda.edu.ng
https://doi.org/10.37121/jase.v5i1.163

After over a century of human use of electrical energy, producers of the global electricity business have embraced the concept of distributed generation (DG), attempting to reduce the number of generating centers and the areas they cover on the production side. There is a pressing need to improve the total effectiveness of power distribution, which has necessitated power supply companies cutting distribution losses.

DG in the distribution network offers more assistances and efficiency for businesses, electrical customers, and the general public. DG is a system that uses small-scale technology to generate electricity close to users, minimizing line losses, improving power quality, lowering emissions, and reducing the size of the distribution and transmission systems. The application of DGs for producers and network operators has the possibility to improve voltage profile, safety and network reliability, efficiency, and security for sensitive and large loads in distribution networks.

Distribution systems (DS) generally consist of feeders (circuit breakers and lines) and distributors (Fig. 1). DS design is, preferably, the process of specifying the most economical network that will deliver the required performance goals. Consumers demanding a much higher amount of power could be connected directly to the primary distribution side [2]. Distribution systems distribute power from main part of the power systems to the customers. This is done by the distribution substations taking power from sub transmission lines to their injection stations and step-down voltages to consumer level (230/415 V) with the help of power transformers.

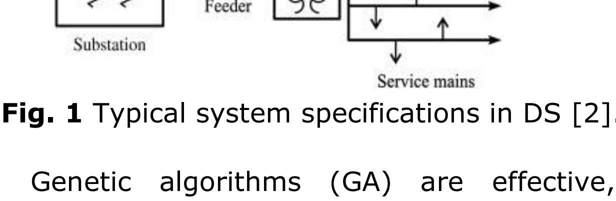

Fig. 1 Typical system specifications in DS [2].

Genetic algorithms (GA) are effective, robust, and optimizing approaches in an extensive area of search complications and inspired by Darwin's principles of survival of the fittest and natural selection. GA is a probabilistic algorithm that simulates the natural selection process of living organisms in order to arrive at a predicted solution to a problem [2].

This study presents GA as a whole unit, in which facts of this developing technology can be combined to form the structure of a design tool for manufacturing engineers. GA is used as an optimization technique toward optimizing the design process whose parameters relate in a compound style. Individuals representing diverse possible results are favorably specific according to the "gene", i.e., characteristics to future generations. Rigasa feeder emanate from the Rigasa injection substation. The network consists of a single 33/11 kV injection substation, which is being fed from a 132/33 kV Kaduna Town II Transmission station located at the northern part of Kaduna State, owned by the Kaduna Electricity Distribution Company (KEDCO). The single line diagram of the substation is shown in Fig. 2 [3]. Rigasa Injection substation has 2x15 MVA, 33/11 kV power transformers and 4x11 kV feeders. These comprises 11 kV Hayin Rigasa feeder, 11 kV Makarfi feeder, 11 kV Sabon-Gari feeder and 11 kV Asikolaye feeder.

The scope of this study, however, is limited to the 11 kV Hayin Rigasa feeder consisting of 35 buses, with 34 sectionalizing and 1-tie switch [3]. The present architecture for electricity generation, transmission and distribution in Nigeria is controlled by centralized power plants called the national grid. The power at these generating stations is normally combustion (water, natural gas, oil, and coal) or hydro generated. Centralized power networks involve transport from the generating stations, which are located far from the consumer. Existing substations can be somewhere, tens to hundreds of meters far away from the consumers of the power generated. This needs transmission across the distance to the consumer. However, the transmission lines' long structure exposes them to natural threats like strong winds and lightning, as well as human faults like overloaded trucks and vandals etc. The distance between the lines and the number of connected buses is the most common causes of power loss and drop in voltage. Moreover, the recent trend in Nigeria's deregulated energy sector, where competition is introduced at both the generation and distribution levels, is worth noting. These difficulties have provided DG requests with a highly favorable market. Individuals who are aware of the benefits of owning their own electricity producing units can do so, and the excess power created after their needs are fulfilled can be sold for a profit to everybody.

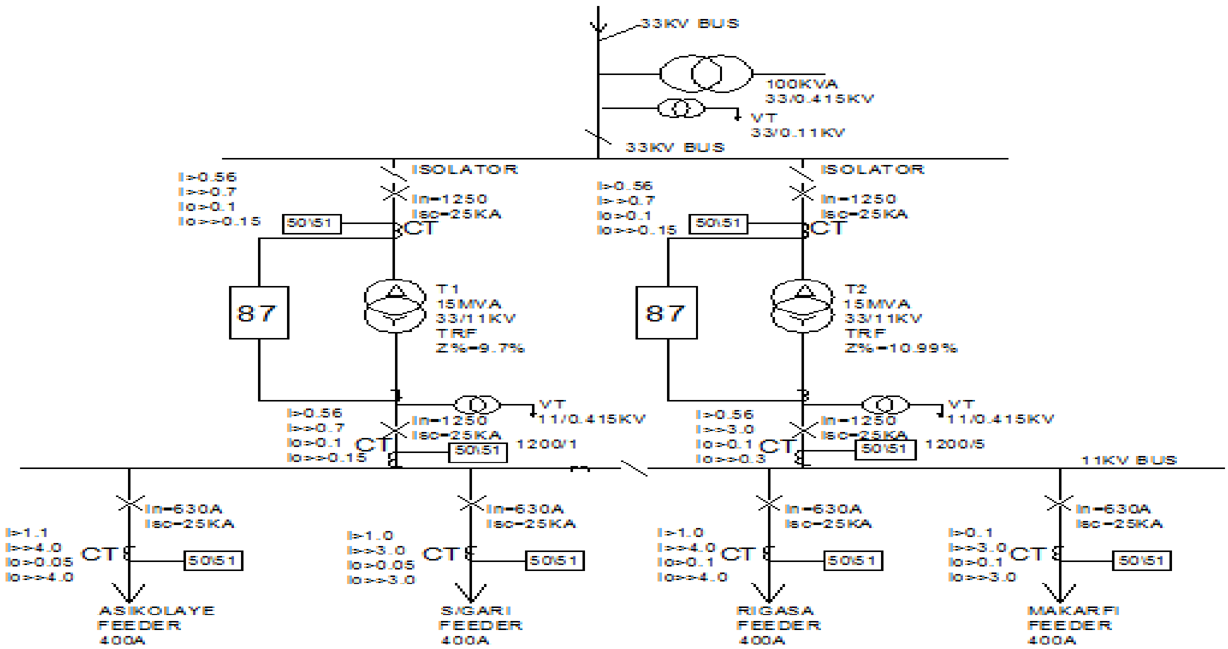

Fig. 2 Single line diagram of Rigasa injection substation fed form 132/33 kV Kaduna town II transmission station [3].

This lowers the cost of investment in the generation sector for the industry, potentially lowering electricity prices and improving the quality of power supply [4]. It's also worth noting that in the recent past, there was a drop in "economy of scale" in the electric energy generation [4]. According to a recent study [5], the charge per kWh ratio between large (conventional) and small generating (DG) units has decreased. This is due to the fact that fuel conversion, heat control or insulation, computerization, control, and thermal engineering are all improving technologically. Some DGs can be totally computerized and only need to be brought offline for maintenance once a year. Many advantages, as well as the current "environment" of the electrical industry, significantly support the use of DGs.

However, there are a number of issues to address before allowing large numbers of dispersed and distributed generators to operate in power networks. Where would the DG be put in the network for greatest technical benefits like as low losses [6], better reliability, increased loadability, and a healthier voltage profile, assuming the adoptions. Apart from these and other obstacles not mentioned, there are other issues, such as numerous stability difficulties associated with DG and the safety of DG, that must be carefully examined. Because system stability and protection issues are not part of this research, just the DG's location in the distribution network is examined to reduce total real power losses in the distribution system and enhance voltage profile.

The demand for power of electrical distribution network in Nigeria is consistently rising by the day and the ripple effect causes the rise in load burden and drop of voltage profile in other words having low voltage at the receiving end. The node voltages of distribution network drop the farther the distance from the sending (supply) substation than nodes that are close to the sending substation.

In large distribution networks, to locate best place or places for optimal placement of DG for voltage profile improvement has always remained challenging as wrong location and sizing may lead to increase in power losses and overvoltage in some cases. In most situations, the approaches involved for locating and sizing DG units in distribution system are either logical method or experimental, which are computationally thorough and optimization methods takes longer time and are characterized by slow convergence of load flow mostly when used for complex system analysis, some outcomes may be bad or poor not because the data is noisy or the used learning algorithm is weak, but as a result of weak selection of the parameters values.

This study aims to improve on the DG placement through optimization technique using GA as the optimization technique tends to offer a reduced time consumption and faster convergence of load flow analysis.

2. Review of Related Literature

According to a study by Rani and Davi [7], who used the precise loss formula approach to calculate the ideal position and amount of DG on an IEEE 33-bus network, the methodology showed that the results was able to lessen power losses while also the voltage profile of the network was improved. However, the reviewed study used the exact loss formula approach in location and siting the DG on IEEE 33-bus network, which was not tested on an existing network, so it can't be said how effective it is.

A new algorithm based on the economic dispatch approach has been created [8]. The algorithm was used to find the best size and location for the DGs in the distribution system. If the DGs are in a competitive market in Iran, the algorithm additionally considered the cost of power and the available rating (sizes). Three separate test distribution networks of various sizes were utilized to demonstrate the technique (6 buses, 18 buses, and 30 buses).

According to Khosravi [9], in ideal siting of DGs sources for loss reduction and voltage profile improvement in power distribution systems with GAs, an optimal location accepted by the DGs in a radial distribution network was proposed, and optimization parameters for DG loss reduction and voltage profile improvement were found to be trustworthy. GA used real codes and a backward-forward power-flow approach based on the distribution system to tackle the problem. The MATLAB programming tools, and the IEEE 20-bus system were used to investigate and design all of the cases. Lastly, the losses with and without DG in the network were displayed, demonstrating that the task was completed correctly. The evaluated study, on the other hand, focused on the IEEE 20-bus network. The current research consists of a single 33/11 kV injection sub-station that is fed from KEDCO 132/33 kV Kaduna town II transmission station, which is located in the northern section of Kaduna state. However, this research used a network with more nodes and higher system losses.

A decision-making method for the optimal size and positioning of DG units in distribution systems was created by Vita [10]. It provides a decision-making technique for determining the appropriate size and placement of DGs in distribution systems. The algorithm can select the ideal placement for a DG unit (of any type) and estimate the best DG size to be installed for improving voltage profiles and minimizing losses in the network's total real and reactive power, and it is very flexible to changes. The IEEE 33-bus radial distribution system was used to confirm the methodology. The resulting findings were compared to those obtained in prior experiments, demonstrating that the decision-making algorithm performs better with tolerable precision. Despite Vita's [10] outstanding performance in their research, the majority of the decision-making algorithm was focused on just the placement of DG, and several alterations and alterations were evaluated for the best site for a DG unit (of any type). However, it takes a long time to compute.

Abubakar et al. [11], focused on the appropriate placement and scale of DG in a 43-bus distribution network for voltage enhancement in his research. In 11 kV Dikko feeder, Abuja Electricity Distribution Company, Suleja, Nigeria Distribution System, power losses are linked to voltage variation, with an objective function that determines current percentage losses. Buses with a low voltage profile in the system without DG installation were found, and the best sizing and positioning of DGs was calculated, allowing losses to be controlled and power quality to be improved. For power flow analysis, Electrical transient analyzer program (ETAP) version 12.6 was utilized to generate a critical based scenario. The system's total load was taken into account. The addition of DGs to the case study has a substantial impact on the system's loss reduction. The ideal placement and size of the DG in the network were determined using GA Optimization methods built in MATLAB 2015 software. However, extracting of the load flow data to the MATLAB increases the computational time and reduces its accuracy.

Molaei et al. [12], used a GA to position and size DG units, and capacitor banks in radial distribution networks. On the IEEE -33 radial test bus, a capacitor bank and DG units were put in order to achieve the best real power losses, which the results were positive in terms of achieving the network's real power loss reduction target. However, the algorithm often converges prematurely into local optima, and the work was only validated using a medium-sized network.

Reza and Mehdi [13], presented the optimum positioning of DGs and capacitors in distribution networks using Binary particle swarm optimization (BPSO) for loss reduction, efficiency, and voltage increase. The work included a multi-objective feature that comprised a reliability index, an active power loss index, an investment cost index for DGs and capacitors, and a voltage profile index. The proposed work's efficacy was tested on IEEE 10 and 33 bus systems, with comparison tests performed before and after the installation of DGs and capacitors. BPSO, on the other hand, is prone to being stuck in local optima and thus converge prematurely to a suboptimal result. Validation was also restricted to medium-sized test networks.

Sadeghmanesh et al. [14], proposed the placement of DG units and capacitors for multi-objective optimization using genetic algorithm. Loss reduction, voltage profile enhancement, and increased usable transfer capacity were all part of the multi-objective feature. When compared to the results of Reza and Mehdi [13], validation was performed on IEEE 41, and simulation results from the work showed better results (for loss reduction and voltage profile improvement), when working with the algorithm. However, before seeing decent results, you'll need a large population and a number of generations, as well as a lot of simulation, you'll also have to wait days for a solution. Furthermore, since no index was used to determine voltage stability, the work did not resolve issues of voltage instability that may arise as a result of increased loads on a network.

Tan and Hassan [15], proposed a novel cuckoo search algorithm for optimal location and sizing of distributed generation. The research was focused on a multi-objective feature that comprised minimizing real power loss, improving voltage profiles, and increasing voltage stability margin. Two case studies on the IEEE 69 radial test bus were used to validate the system. The power factor of a single DG, on the other hand, is a property of the load, not the DG. Since most loads are inductive and use reactive power that is lagging, a single DG may be unable to satisfy the sudden and incremental demand for reactive power compensation (leading reactive power) to offset the impact of inductive loads and increase the load power factor. Furthermore, the DG sizes used violated the power balance criterion since they were larger than the network loads.

Attia et al. [16], presented a cuckoo search-based algorithm for optimal static shunt capacitors allocation in radial distribution networks. The study's objective feature was changed to reduce system peak losses, help system voltage profiles, and increase overall system power factor and make a final decision for the best location based on the number of buses nominated, the number of successful sites, and the number of injected VARs. IEEE 33- and 69-bus radial distribution systems were used for testing. However, the study only looked at one time with the highest peak losses and ignored the impact of overall average peak losses, and such will not give a true reflection of loss reduction in the networks.

Aman et al. [17], presented optimum simultaneous DG and shunt capacitor bank placement and sizing using particle swarm optimization on the basis of minimization of power system losses. Both methods were combined in the research to achieve overall low power losses and improved voltage control. IEEE 12-bus, 30-bus, 33-bus, and 69-bus radial distribution systems were tested. Since the costs of DG units and capacitor banks change over time, the approach was characterized by several assumptions about the forms, costs, and sizes of DGs and capacitor banks. Premature convergence to local optima is also a function of the optimization technique used.

Reddy and Gunaprasad [18], presented a sensitivity-based capacitor placement approach using cuckoo search algorithm for maximum annual savings. The research used a two-stage method to decide the best position and size of capacitors on radial distribution systems in order to boost the voltage profile and minimize active power loss. The loss sensitivity was calculated for each bus in the network, and the buses are rated in descending order of their values, with the buses with the highest numerical value being considered for capacitor placement. The cuckoo search algorithm was proposed to find the optimal capacitor sizes. The work was validated using IEEE 15, 34, and 69 bus radial distribution systems, and the results showed a reduction in total power loss after the capacitors were mounted. The use of loss sensitivity analysis, on the other hand, avoids a complete analysis of the buses in the networks, and consistency is presumed for the buses that are ignored. This assumption is sometimes impractical, which limits its use in online scenarios.

Yuvaraj [19] presented an effective method for solving the optimal siting and sizing problem of capacitor banks based on cuckoo search algorithm. The objective function of the study was formulated to minimize power loss and the enhancement of voltage profile and system stability. The voltage stability index

(VSI) was used to decide where the capacitors should be placed. To decide the best capacitor size, the cuckoo search algorithm was proposed. On IEEE 34 and 69 radial distribution systems with various load factors, the feasibility of the proposed method was checked. However, using VSI to determine the best position for the capacitors is a time-consuming and possibly inaccurate process.

3. Materials and Methods

The methodology adopted in carrying out this research work follows the sequence: definition of the state system model and carrying out load flow analysis to attain the steady-state base case parameters for bus voltages and line losses; thereafter, to identify the buses with low voltage profile. For each test DG, connect DG at given bus with very highest sensitivity index, carry out load flow analysis and the results are stored for each scenario. Reiterate the previous step for the next bus in the order of the bus with the next highest sensitivity index. Sort all load flow state outcomes for all DGs inserted at all buses according to minimum line losses or best voltage profile. Select a state with minimum line losses or best voltage profile for optimum DG size and location. In Fig. 3, the line diagram of the network of interest is presented.

The loss of power for line unit between buses k and k+1 can be computed as follows:

$$\boldsymbol{P_{loss}(k,k+1)} = \frac{R_k\left({P_k}^2+{Q_k}^2\right)}{{V_k}^2} \tag{1}$$

$$\boldsymbol{Q_{loss}(k,k+1)} = \frac{X_k\left({P_k}^2+{Q_k}^2\right)}{{V_k}^2} \tag{2}$$

Where, R_k (Ω) is the resistance at node '*k*', X_k (Ω) is the reactance at node '*k*', P_k (kW) is the real power that is emanating from the bus, Q_k (kW) is the reactive power that is emanating from of the bus, and V_k (kV) is the voltage at node '*k*'.

Equations (1) and (2) give the losses of real power and reactive power in line section between buses *k* and *k*+1. Now the total real power loss and total reactive loss can be calculated by summing the losses of every section of the feeder. Hence, the value of total real and reactive power loss in section of line between *k* and *k*+1 can be expressed as equations (3) and (4), respectively.

$$\boldsymbol{P_{T,loss}(k,k+1)} = \sum_{k=1}^{n} \boldsymbol{P_{loss}(k,k+1)} \tag{3}$$

$$\boldsymbol{Q_{T,loss}(k,k+1)} = \sum_{k=1}^{n} \boldsymbol{Q_{loss}(k,k+1)} \tag{4}$$

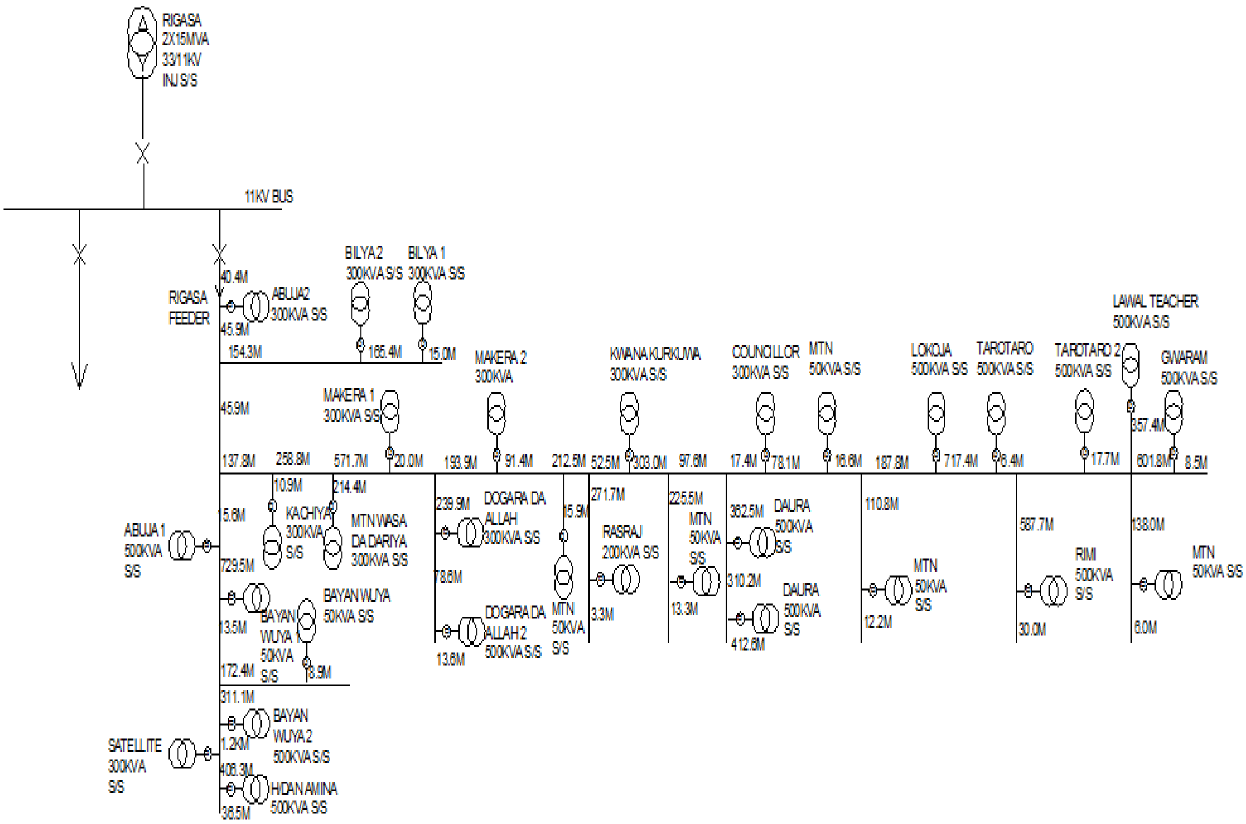

Fig. 3 Single line diagram of Hayin Rigasa network.

For the convergence analysis of iterative processes, the backward-forward method has been reformulated to perform load flow analysis. Consider a branch between nodes 'k' and 'k+1', and calculate effective power flows via backward propagation. The following equations are the effective real and reactive powers:

$$P_k = P'_{k+1} + \frac{R_k\left({P_{k+1}}^2 + {Q_{k+1}}^2\right)}{{V_{k+1}}^2} \quad (5)$$

$$Q_k = Q'_{k+1} + \frac{X_k\left({P_{k+1}}^2 + {Q_{k+1}}^2\right)}{{V_{k+1}}^2} \quad (6)$$

$$P'_{k+1} = P_{k+1} + P_{LK+1} \quad (7)$$

$$Q'_{k+1} = Q_{k+1} + Q_{LK+1} \quad (8)$$

Where, P_{k+1} is effective real power from 'k+1' node, and Q_{k+1} is effective reactive power from 'k+1' node.

Forward propagation evaluates the voltage values and voltage angles at each node. Let V_k be the voltage at node 'k' and $V_{k+1}<\delta_{k+1}$ be the voltage at node 'k+1' k+1'. The current flowing through this section with the impedance $(z_k = r_k + jx_k)$ between 'k' and 'k+1' is given as [20]:

$$I_k = \frac{V_k<\delta_k - V_{k+1}<\delta_{k+1}}{r_k + jx_k} \quad (9)$$

To find the values of voltage and the voltage angle at all nodes the recursive equations are used. Primarily assume 1.0 p. u. voltage at all node. A detailed power flow calculation operation is given by the backward-forward algorithm. The pseudo-code used in developing the algorithm for running the base case load flow analysis for the distribution systems are presented as [21]:

Step 1: Read the distribution system's bus and line data, as well as the base MVA and base kV.
Step 2: Calculate the active and reactive power injected at each node as equations (10) and (11), respectively.
Step 3: Set k=1, the iteration count.
Step 4: For convergence criterion set ε = 0.001, ΔP_{max} = 0.0 and ΔQ_{max} = 0.0.
Step 5: Evaluate the value of nodal current injection at node 'i' as equation (12).
Step 6: Apply backward sweep and calculate the branch current using KCL.
Step 7: Forward sweep is applied to calculate the voltage at each node using KVL.
Step 8: Now, calculate the power injection at node 'i' as equation (13).
Step 9: Check convergence, if $\Delta P_{max} \le \varepsilon$ and $\Delta Q_{max} \le \varepsilon$, then, go to step 11; else, step 10.
Step 10: Then set $k = k$+1 and go to step 4.
Step 11: In 'k' iteration, print that problem is converged.
Step 12: Stop.

$$P_{inj} = P_{gen} - P_{load} \quad (10)$$

$$Q_{inj} = Q_{gen} - Q_{load} \quad (11)$$

$$I_j^{(k)} = \left(\frac{S_i}{V_i^{(k-1)}}\right) \times -Y_i V_i^{(k-1)} \; for \; i = 1,2,\ldots,n \quad (12)$$

$$S_i^{(k)} = V_i^k\left(I_i^k\right) \times -Y_i\left|V_i^k\right|^2 \quad (13)$$

The most suitable sites for DG components are determined by evaluating the sensitivity factors of nodes in the network based on loss reduction. This procedure will aid in narrowing the search space for the optimization process. Based on the minimization of losses, this strategy seeks to determine optimal areas for DG sitting. The factor is named loss sensitivity factor (LSF) since it is the derivative of power loss with respect to bus load, and it can be represented as [22]:

$$LSF(i) = \frac{(\Delta P_{loss})}{\Delta P(i)} = \frac{P_{loss}(i) - P_{loss}^b}{P_{DG}^{inc}(i)} \quad (14)$$

Where, ΔP_{loss} is change in losses in the bus (kW), $\Delta P_{(i)}$ is change in power at bus 'i' (kW), P_{loss}(i) is losses after DG placement (kW), P^b_{loss} is initial power losses (kW), P^{inc}_{DG}(i) is DG size increase of bus 'i' (kW).

From equation (14), the LSFs of all buses are calculated, arranged in according to their positions order and displayed in a graph to show nodes with the highest loss sensitivity index (LSI). The nodes with the highest LSI determine the priority of buses to be considered as DG sites. The system losses are decreased if the LSF value is precisely negative; otherwise, the DG integration increases system losses. As a result, the buses with the highest LSF values are chosen for DG placement. The size of the DG can then be estimated using GA after the candidate buses have been picked. DG units are used to inject both active and reactive power, with only the reactive power being absorbed. They can boost voltage magnitude for a variety of power factors. The voltage performance index (VPI), which is computed using equation (15), is used to determine which buses are system sensitive [23].

$$VPI^{(i)} = \sum_{j=1}^{N} \frac{W_j}{2n} \left[\frac{\Delta V_j^{(i)}}{\Delta V_j^{lim}}\right]^{2n} \quad (15)$$

and

$$\Delta V_j^{(i)} = V_j^{(i)} - V_j^{lim} \quad (16)$$

Where, N is the number of system buses, W_j is the weighing factor of bus j, $2n$ is the performance index order, $V_j^{(i)}$ is the voltage at bus j with increment change in DG capacity at i^{th} bus, and V_j^{lim} is the voltage at bus j (kV)

If the voltage magnitude of all buses is within its acceptable range, the VPI value is lower, whereas it is higher in the opposite scenario. This method chooses the best DG locations to keep the voltage close to its nominal value. Based on voltage magnitude improvement, the ideal location for a DG unit is on a bus with a higher VPI value. By considering the types of DG units, the DG units in this work are modeled such as to provide active power injections. The active and reactive power supplied from the DG units to the i^{th} bus is modeled as follows [24]:

$$P_i = P_{DGi} - P_{Li} \quad (17)$$

$$Q_i = Q_{capi} - Q_{Li} \quad (18)$$

Where, P_{DGi} is the real power of the DG at bus 'i' (kW), P_{Li} is the real power of the load at bus 'i' (kW), Q_{DGi} is the reactive power of the DG at bus 'i' (kW), and Q_{Li} is the reactive power of the load at bus 'i' (kW).

Fig. 4 shows the DG on a distribution network, where, V_o and V_n are the respective sending and receiving end voltages, R_{ij} and jX_{ij} are the respective resistance and reactance at node i and j whereas the flowchart of the GA approach for optimal placement of the DG is shown in Fig. 5.

4. Results and Discussion

4.1. IEEE 33-Bus System

Initially, load flow was run on the 33-bus system to obtain the total power loss, loss sensitivity index and voltage at each bus. This is the base case voltage, loss sensitivity index and power loss (active and reactive) of the system before the integration of the DG units into the system. The base case real and reactive power loss was found to be 275 kW and 176 kVAr respectively. The base case voltage and loss sensitivity index for each bus for 33 bus system is presented in Figs. 6 – 8.

Fig. 6 shows the voltage profile of the network after load flow analysis has been carried out on the 33-bus network. The bus voltage was observed to be as low as 0.865 per unit at bus 18, which is the weakest bus, i.e., the point with the maximum voltage drops in the network. Figs. 7 – 8 show the real and reactive power on the 33-bus system with the use of load loss sensitivity index to identify the buses with the highest losses in the system. The real power loss is very high at bus 2 and bus 6, which are as high as 0.357 and 0.34.

The GA based approach was used for the optimal allocation of 2 DG units for the 33-bus system and the sizes and locations of the DGs were found to be 750 kW at bus 2 and 800 kW at bus 6 respectively. The total real and reactive power loss after DG allocation was relatively reduced to 182.85 kW and 120.82 kVAr respectively, which indicate 33.51 % and 31.35 % reduction as compared to the base case real and reactive power loss. The real power loss, voltage and loss sensitivity index for each bus for 33-bus system is presented in Figs. 9 – 11, respectively.

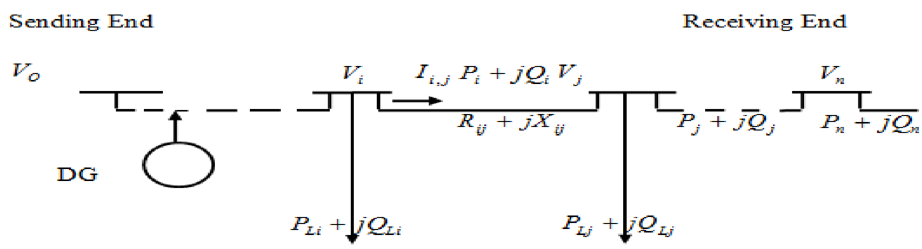

Fig. 4 Distribution system with DG unit installation at any bus.

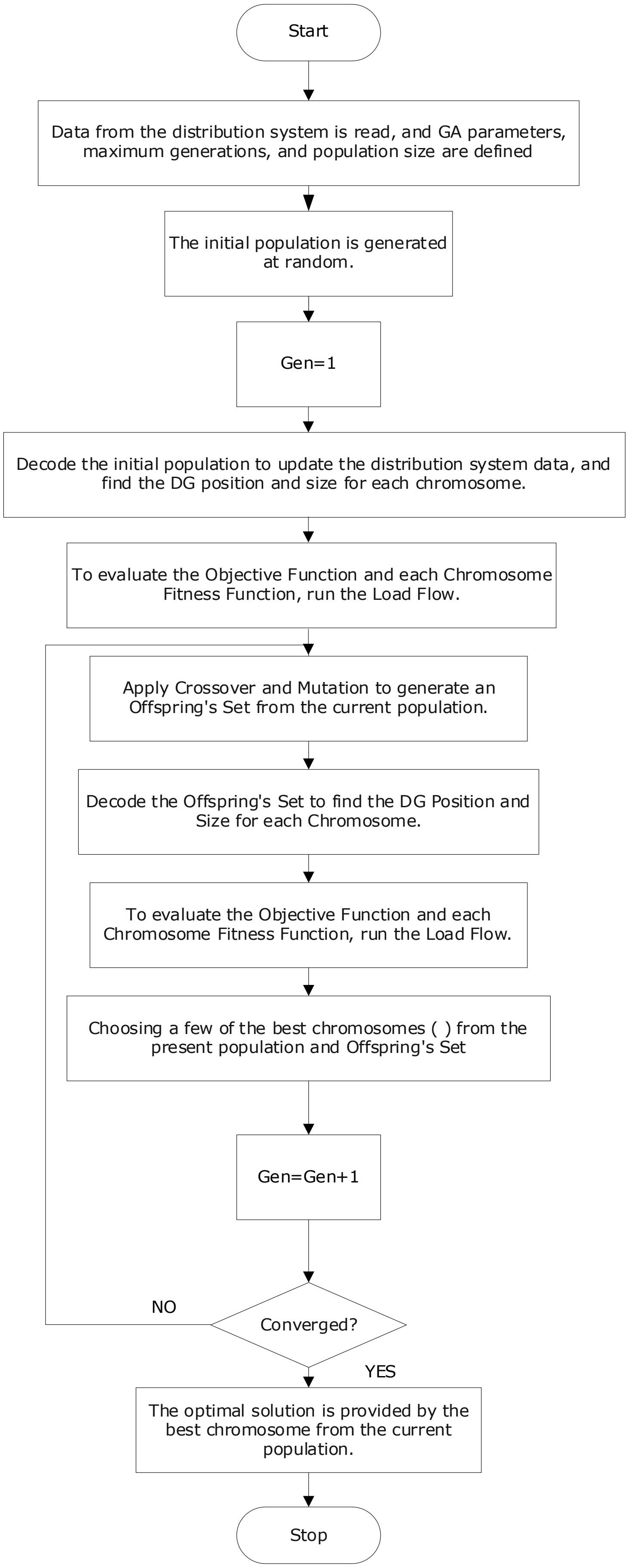

Fig. 5 Basic genetic algorithm approach for optimal placement of DG.

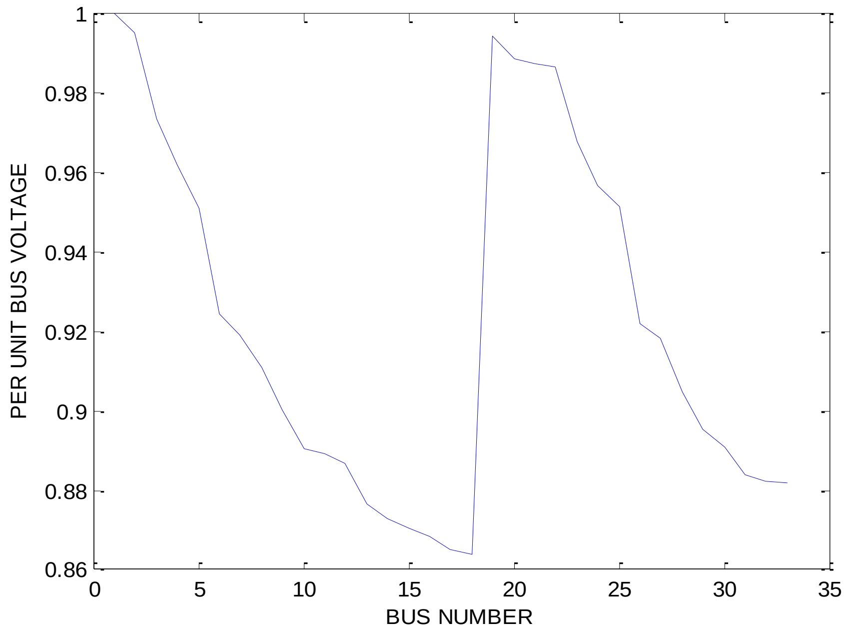

Fig. 6 Voltage profile of the 33-bus 11 kV network without DG.

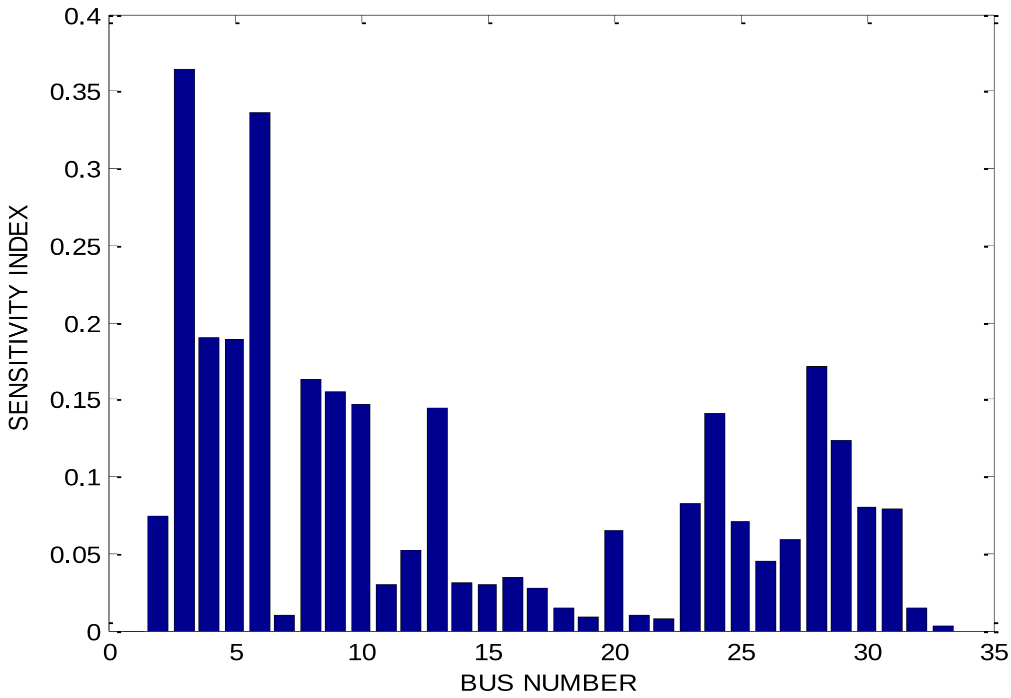

Fig. 7 Real power sensitivity index of the 33-bus 11 kV network without DG.

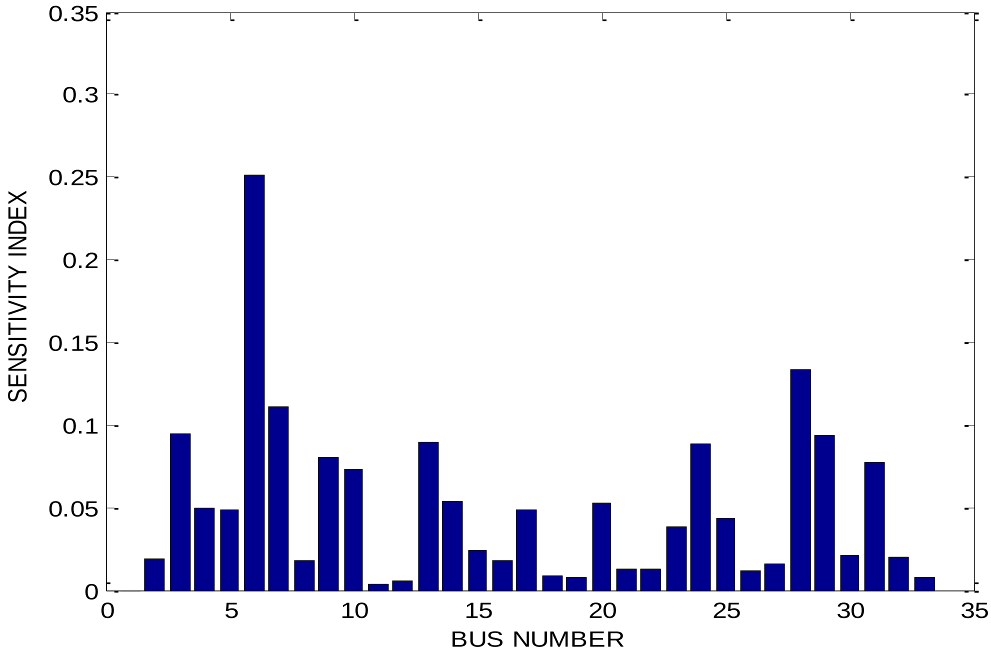

Fig. 8 Reactive power sensitivity index for a 33-bus 11 kV network without DG.

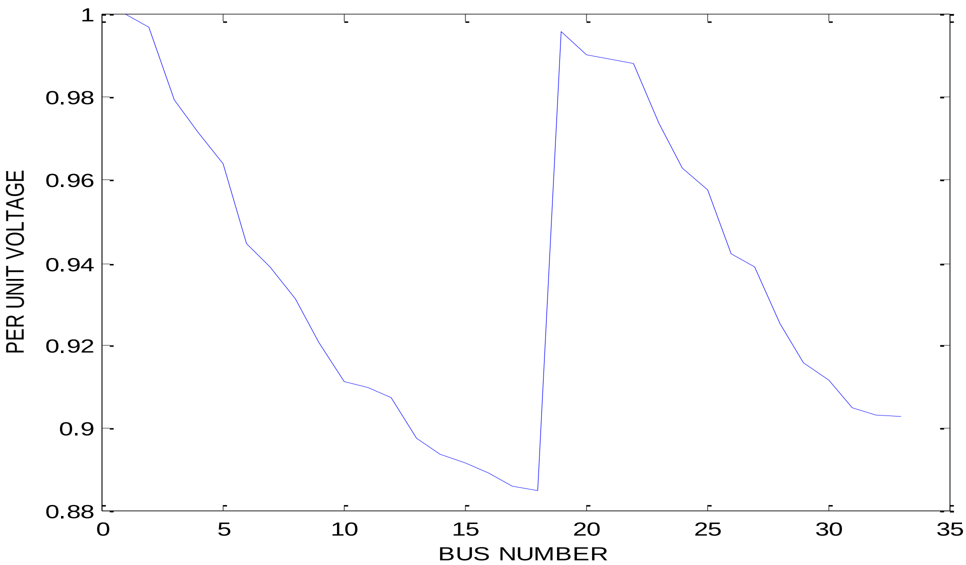

Fig. 9 Voltage profile of the 33-Bus 11 kV network with DG.

Fig. 9 shows that the allocation of the DG units has caused an improvement in the voltage profile of the 33-bus network. The bus with the lowest voltage which is bus 18 had its voltage increased from 0.865 to 0.892 per unit voltage after load flow analysis was repeated. Figs. 10 – 11, show the reduction in the losses in the 33-bus network when the load loss sensitivity index (LLSI) was repeated after the placement of DGs. It was observed before the placement of DGs, the real power losses were very high at bus 2 and bus 6, which were as high as 0.357 and 0.34. But after the placement of DGs in the 33-bus network, the real power losses were reduced to 0.28 and 0.24, respectively. The reactive power, which was at 0.25 have reduced to 0.167.

The result was compared to results from the base case and with DGs allocation on the 33-bus system to observe if there was an improvement and the result is summarized in Table 1.

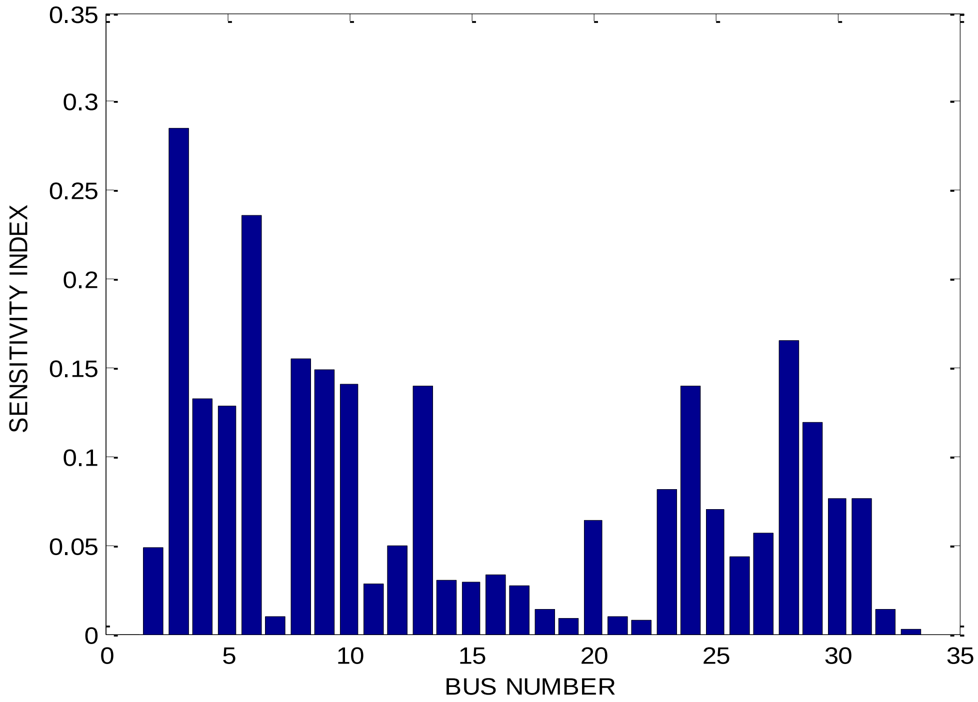

Fig. 10 Real power sensitivity index of the 33-bus 11 kV network with DG

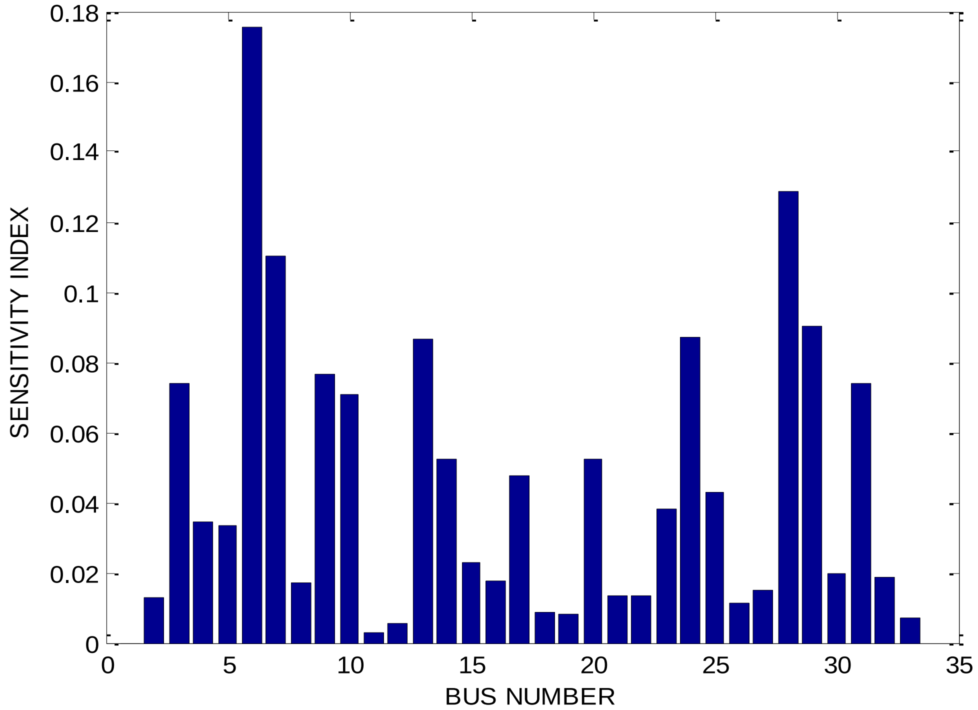

Fig. 11 Reactive power sensitivity index for a 33-bus 11 kV network with DG.

Table 1 Summary of result for 33-bus 11 kV system.

Particulars	Base Case	With DGs
P_L (active)	275 kW	182.85 kW
Q_L (reactive)	176 kVAr	120.82 kVAr
$\% P_L\ (= 100 \times (B - E)/B)$		33.51 %
$\% Q_L\ (= 100 \times (B - E)/B)$		31.35 %
$\% VPI\ (= 100 \times (B - E)/B)$		3.02 %

Where, *B* is the base case results whereas *E* is the result obtained after DG placement.

4.2. Hayin Rigasa 56-Bus System

The bus and line data for the Hayin Rigasa 56-bus feeder as shown Fig. 3 were used in modeling the system, and the base case voltage for each bus were noted. The genetic algorithm described in section 3 (Fig. 5) was used in obtaining the optimal DG siting and sizing for the 56-bus network. The bus voltages, total power loss (real and reactive), voltage profile and loss sensitivity index before and after DG placements were noted for comparison. Initially, load flow was run on the 56-bus system to get the voltage profile at each bus and the total power loss using loss sensitivity index. This is the base case voltage profile and Load loss sensitivity index (active and reactive) of the system before the integration of the DG units into the system. The base case voltages and loss sensitivity index for each bus for 56-bus 11 kV Hayin Rigasa network is presented in Figs. 12 - 14.

Fig. 12 shows the voltage profile after the load flow study has been conducted without DG. The bus voltage was observed to be as low as 0.828 per unit at bus 34, which is the weakest bus indicating the bus with the highest voltage drop.

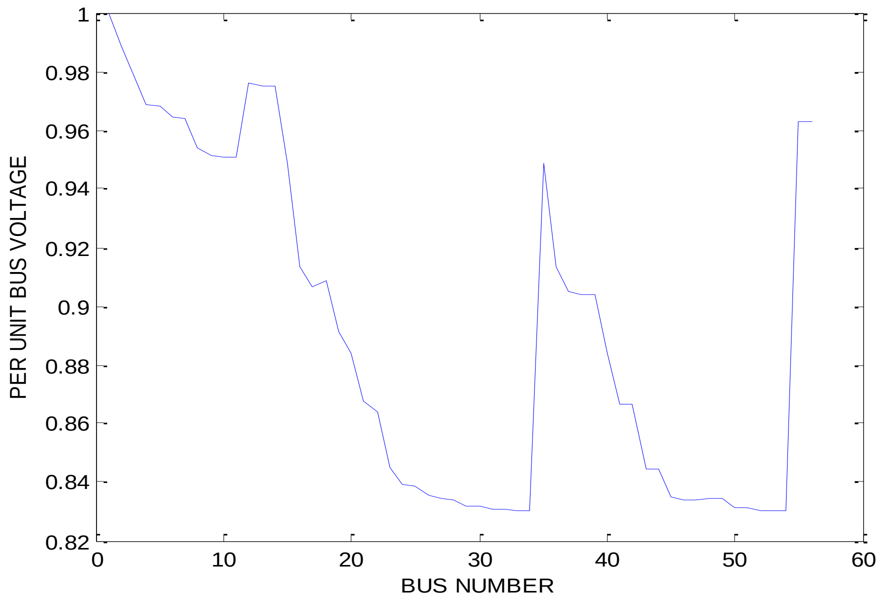

Fig. 12 Voltage profile of the 56-bus 11 kV Hayin Rigasa network without DG.

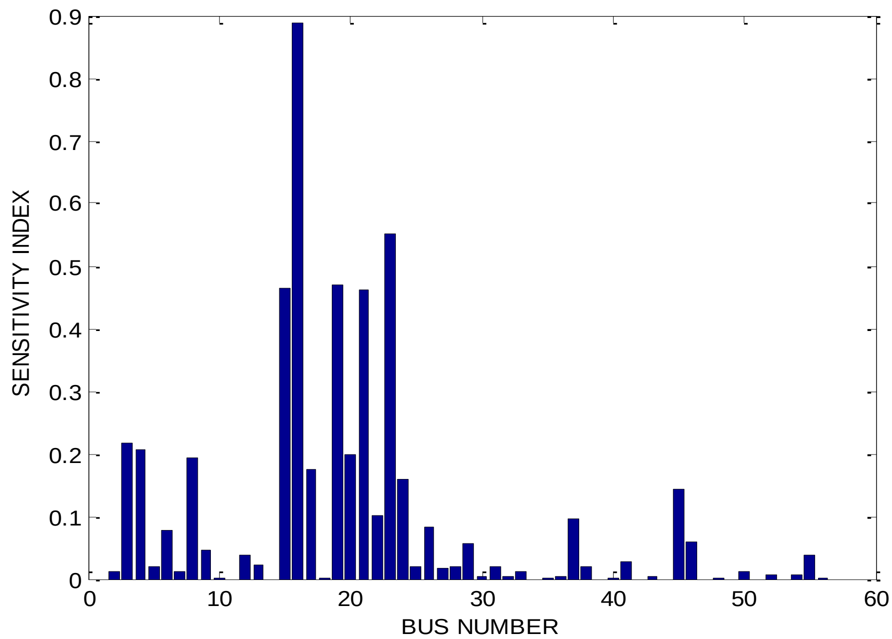

Fig. 13 Real power sensitivity index of 56-bus 11 kV Hayin Rigasa network without DG.

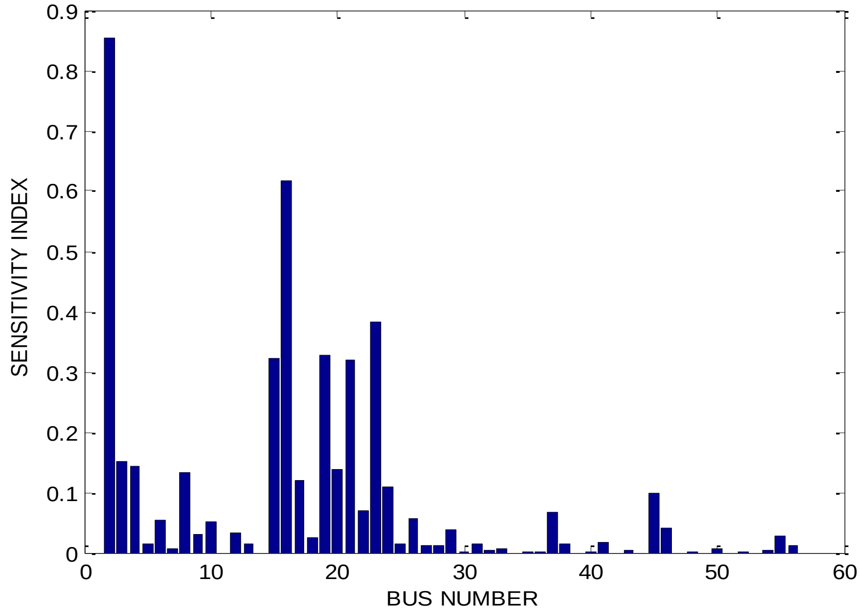

Fig. 14 Reactive power sensitivity index of 56-bus 11kV Hayin Rigasa network without DG.

Figs. 13 and 14 show the LLSI, it is observed that the base case with the most real and reactive power loss was found to be 437.27 kW and 388.44 kVAr respectively at bus 16. The GA based approach was applied for the best allocation of 2 DG units for the 56 bus Rigasa network and the sizes and locations of the DGs were found to be 1,490KW at bus 16 and 1,470 KW at bus 23 respectively. The real and reactive power loss summation after DG allocation was relatively reduced to 89.48 kW and 101.08 kVAr respectively, which indicate 79.54 % and 73.98 % actual and reactive power losses are reduced when compared to the base situation. The real and reactive power loss, voltage and loss sensitivity index for each bus for 33-bus system is presented in Figs. 15 to 17, respectively.

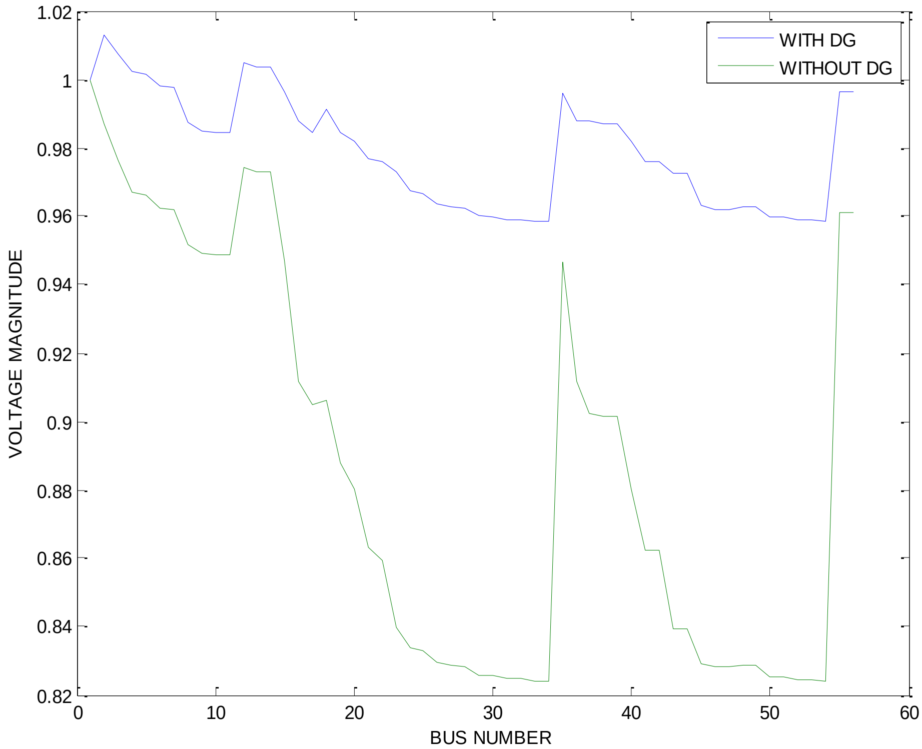

Fig. 15 Voltage profile for the 56-bus 11 kV Hayin Rigasa network with and without DG.

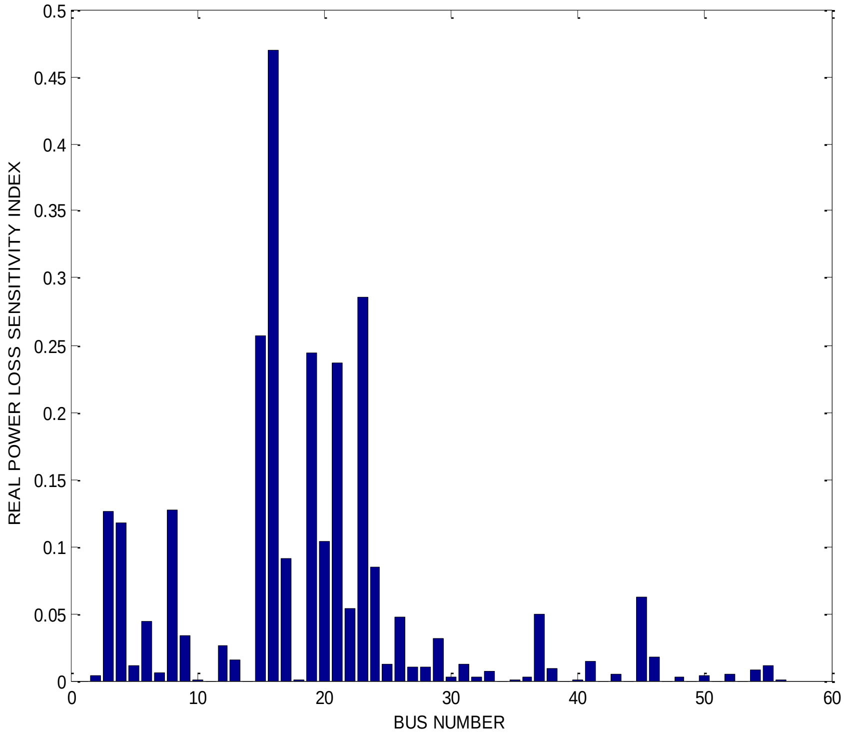

Fig. 16 Real power sensitivity index of 56-Bus 11 kV Hayin Rigasa network with DG.

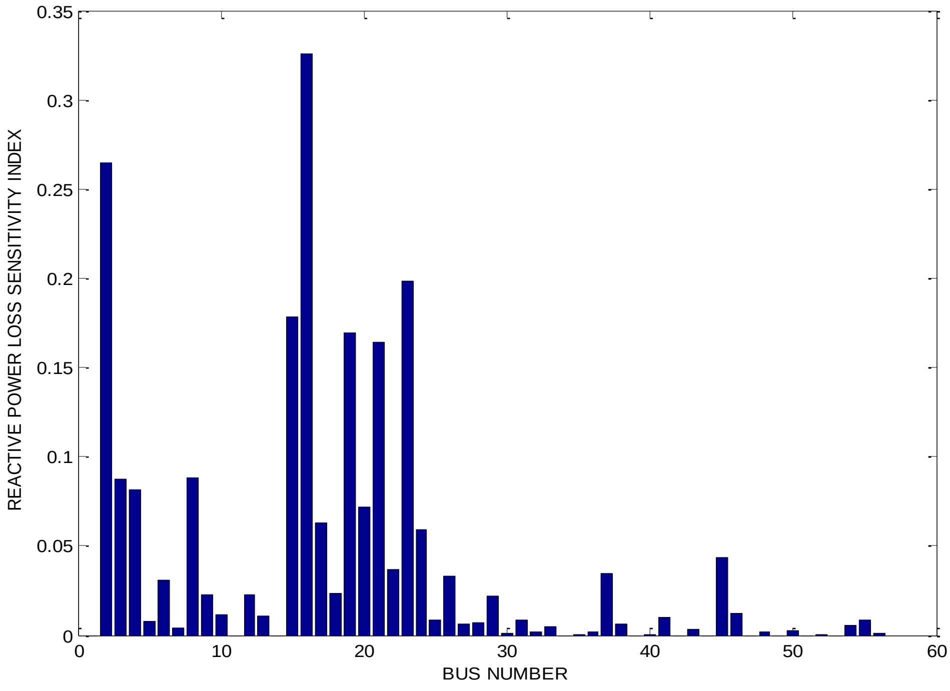

Fig. 17 Reactive power sensitivity index of 56-bus 11 kV Hayin Rigasa network with DG.

Fig. 15 shows that the allocation of the DG units has caused an improvement in the voltage profile for the Hayin Rigasa 56-bus network. The bus with the lowest voltage, which is bus 34 had its voltage increased from 0.828 to 0.96 per unit voltage.

Figs. 16 – 17 show the LLSI after the location of DGs. The losses at the real power are very high at bus 16 and bus 23 (as high as 0.89 and 0.55) are reduced to 0.457 and 0.29 respectively. The reactive power loss at bus 1 and bus 16, which was at 0.89 and 0.6 have reduced to 0.26 and 0.33 respectively. The result was compared to results from the base case and 2 DGs allocation on the Hayin Rigasa 56-bus network and the result is summarized in Table 2.

Table 2 Summary of result for 11 kV Hayin Rigasa 56-bus system.

Particulars	Base Case	Two DGs
P_L (active)	437.27 kW	89.48 kW
Q_L (reactive)	101.08 kVAr	388.44 kVAr
$\% P_L$ $(= 100 \times (B - E)/B)$		79.54 %
$\% Q_L$ $(= 100 \times (B - E)/B)$		73.98 %
$\% VPI$ $(= 100 \times (B - E)/B)$		15.94 %

Where, *B* is the base case results whereas *E* is the result obtained after DG placement.

From results comparison, it is clearly seen that the simultaneous placement of the best combination of DG units with bus 16 at Dogara da Allah 300 kVA sub-station and bus 23 at Councilor 300 kVA sub-station, gave a better performance to that obtained from the separate placements of the DG units, in terms of reduced power loss and improved voltage profile.

5. Conclusion

The task of DG location is a challenging one that necessitates the optimization of several objectives such as total power losses minimization, voltage variations, line loading, installation costs, and system stability maximization, among others. The voltages of distribution network nodes drop at a greater distance from the substation than they do at close nodes. When compared to transmission systems, distribution networks have a high X/R ratio, resulting in significant power losses and voltage reductions. In this work, loss sensitivity index was used to locate places with very high losses in the network and genetic algorithm was used as a tool of optimization to know the sizing of the DG to be put in place to enhance the voltage profile and keep as low as possible the overall system losses. For good understanding and broad approach to this research, a review of existing literature on optimization tools and various techniques for siting these DG was discussed. Furthermore, literatures on dynamic simulation and GA were discussed. The mathematical exact models of the power systems components were painstakingly formulated to achieve accurate simulation results. After wide consultations a number of software were procured through which enormous work was done to optimally site the DG. A study was done on a 33-bus system to ensure the efficiency of the optimization tool, then the work was carried out on Hayin Rigasa 56-bus network, which is located in Kaduna under KEDCO.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

ORCID

A. E. Airoboman https://orcid.org/0000-0003-2840-2506

References

[1] S. H. Horowitz, and A. G. Phadke, "Power system relaying," 2nd ed. Baldock: Research Studies Press Ltd, 2003.

[2] R. E. Brown, Electric Power Distribution Reliability, Second Edition, CRC press, Taylor & Francis group, New York, 2009.

[3] Kaduna Electric Distribution company, (KEDCO), Department of Planning and Construction, Kaduna 2015.

[4] S. G. Reddy, P. V. N. Prasad, and A. J. Laxmi, "Power quality and reliability improvement of distribution system by optimal number, location and size of DGs using particle swarm optimization," In Proceedings of the 7th IEEE International Conference on Industrial and Information Systems (ICIIS), Chennai, India, 6–9 August, 2012.

[5] V. Vita, T. Alimardan, and L. Ekonomou, "The impact of distributed generation in the distribution networks' voltage profile and energy losses," In Proceedings of the 9th IEEE European Modeling Symposium on Mathematical Modeling and Computer Simulation, Madrid, Spain, 6–8 October 2015, pp. 260–265.

[6] S. Paul, and W. Jewell, "Optimal capacitor placement and sizes for power loss reduction using combined power loss index-loss sensitivity factor and genetic algorithm," IEEE press, New York, 2012.

[7] P. S. Rani, and A. L. Davi, "Optimal sizing of DG units using exact loss formula at optimal power factor," *Int. J. Eng. Sci. Technol*., vol. 4, no. 9, pp. 4043–4050, 2012.

[8] W. Hongbin, Z. Huaidong, Z. Wei, D. Ming, "Optimal allocation of microgrid considering economic dispatch based on hybrid weighted bilevel planning method and algorithm improvement," *Int. J. Electr. Power Energy Syst*., vol. 5, pp. 28-37, 2016.

[9] M. Khosravi, "In optimal placement of distributed generation sources in order to

reduce loss and improve voltage profiles in power distribution networks using genetic algorithms," *Eur. Online J. Nat. Soc. Sci*., vol. 3, no. 3, pp. 332-342, 2014.

[10] V. Vita, "Development of a decision-making algorithm for the optimum size and placement of distributed generation units in distribution networks," ASPETE – School of Pedagogical and Technological Education, Athens, Greece, 2017.

[11] B. Abubakar, M. Uthman, F. E. Shaibu, and K. S. Oyewale, "Optimal siting and sizing of distributed generation (DG) in a 43-bus distribution system for voltage improvement," *Eur. J. Eng. Res. Sci*., vol. 4, no. 10, pp. 18-23, 2019.

[12] M. H. Molaei, M. A. Zarei, M. H. Zabihi, and A. Khodadadi, "Distributed generation and capacitor banks placement in order to achieve the optimal real power losses using GA," *Int. J. Comput. Sci. Technol*., vol. 2, pp. 400-404, 2011.

[13] B. Reza, and S. Mehdi, "Placement of distributed generation and capacitor for loss injection, reliability and voltage improvement in network using BPSO," *Int. J. Intell. Syst. Applica.*, vol 12, pp. 57-64, 2012.

[14] A. Sadeghmanesh, K. Zare, and M. Sabahi, "Distributed generation unit and capacitor placement for multi-objective optimization," *Int. J. Electr. Comput. Eng*., vol. 2, pp. 615-620, 2012.

[15] W. S. Tan, and M. Y. Hassan, "Allocation and sizing of distributed generation using cuckoo search algorithm," IEEE International Conference on Power and Energy (PEcon), 2-5 Dec. 2012 Kota Kinabalu, Malaysia.

[16] A. Attia, A. El-Fergany, and Y. Abdelaziz, "Cuckoo search-based algorithm for optimal shunt capacitors allocation in radial distribution networks," *Electr. Power Compon. Syst*., vol. 41, pp. 1567-1581, 2013.

[17] M. M. Aman, G. B. Jasmon, A. H. A Bukar, and H. Mokhlis, "Optimum simultaneous DG and shunt capacitor bank placement on the basis of minimization of power system losses," *Int. J. Comput. Electr. Eng*., vol. 5, no. 5, pp. 516-522, 2013.

[18] P. Reddy and D. Gunaprasad. "Sensitivity based capacitor placement approach using cuckoo search algorithm for maximum annual savings," *Appl. Mech. Mater*., vol. 785, pp. 24-28, 2014.

[19] T. Yuvaraj, "Optimal siting and sizing of capacitor banks in radial distribution networks using cuckoo search algorithm," *Ain Shams Eng. J.*, vol. 9, pp. 589-597, 2016.

[20] J. A. Michline Rupa, S. Ganesh, "Power flow analysis for radial distribution system using backward/forward sweep method," *Int. J. Electr. Comput. Eng*., vol. 8, no. 10, pp. 1628-1632, 2014.

[21] R. Parasher, "Load flow analysis of radial distribution network using linear data structure," arXiv preprint arXiv:1403.4702, 2014.

[22] S. Essallah, A. Bouallegue, and A. Khedher, "Optimal sizing and placement of DG units in radial distribution system," *Int. J. Renew. Energy Res*., vol. 8, no.1, pp. 166-177, 2018.

[23] V. Mithulananthan, and N. Acharya "Locating series FACTS devices for congestion management in deregulated electricity market," *Elect. Power Syst. Res*., vol. 77, pp. 352-360, 2007.

[24] M. Sedighizadeh, and A. Rezazadeh, "Using genetic algorithm for distributed generation allocation to reduce losses and improve voltage profile," *World Acad. Sci. Eng. Technol*., vol. 37, pp. 251-256, 2008.