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Investigation of Power Loss Reduction In Electrical Distribution Network With Incorporation Of Distributed Generators

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Abstract

Distributed Generators (DG) are electrical sources connected to the power network located to consumer's side but very small when compared with the centralized power plant. However, due to the unbalance operation of distribution system, installing these generators to reduce the power losses in the system requires an optimization approach so as to bring such losses to the barest minimum. This study investigated power loss reduction in electrical distribution network with the incorporation of DG using Genetic Algorithm (GA) as optimization method. In this study, DG was incorporated into existing Ladder Load Flow Algorithm for power flow analysis and optimization was performed using GA. A script was written in MATLAB/SIMULINK by developing a Graphic User Interface (GUI) model where the data value was inputted for easy output. The developed GA-DG model with GUI was tested on two distribution test feeders, IEEE 13-bus and 25-bus distribution test feeders using power loss as performance metrics. The results showed that for 13-bus system, the power losses was reduced by 1.1425 p.u, which is 68 % reduction with incorporation of DG and by 1.653 p.u, which is 99 % reduction after optimization. For 25-bus system, power losses reduced by 2.4665 p.u, that is, 55 % reduction with DG and by 4.3111 p.u, which is 96.2 % reduction after optimization. The results are in agreement with the standard IEEE test feeders. This study showed a significant reduction in the distribution network power loss after optimization with DG. Hence, optimization of DG with GA in electrical distribution system enhanced the performance of the system significantly.

Keywords: *Distributed Generators, Electrical Sources, Distribution Network, Ladder Load Flow, Genetic Algorithm, Graphic User Interface.*

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I. INTRODUCTION

Electric utilities perform the major task of satisfying customer demands by generating electricity centrally and distributing it through an extensive transmission and distribution network. As electricity demand increases, the utility generates more electricity but if the capacity of the distribution network is overcrowded, utility response to these is to build new facilities which are not economical. An alternative approach under consideration by utilities is to satisfy demand locally and incrementally by investing in Distributed Generators (DG) which is strategically sited to deliver electricity where it is needed promptly [1-3].

Distributed Generator (DG) is considered as an electrical source connected to the power network at a point very close to consumer's side which is small enough when compared with the centralized power plants. It can be in form of renewable energies, such as, wind, mini-hydro and photovoltaic system or in the form of fuel-based system such as fuel cells and micro-turbines [14], [17]. The introduction of DG sources in distribution network will aid in supply of adequate and stable electricity to consumers in terms of its socio-economic growth [6], [27].

A. Distribution Network Operation

The Distribution network is the final stage in the delivery of electric power. It carries electricity from transmission system to individual consumers as shown in Figure 1. It can be radial or networked in an open loop configuration with a single or multiple alternate sources [1], [2], [28]..

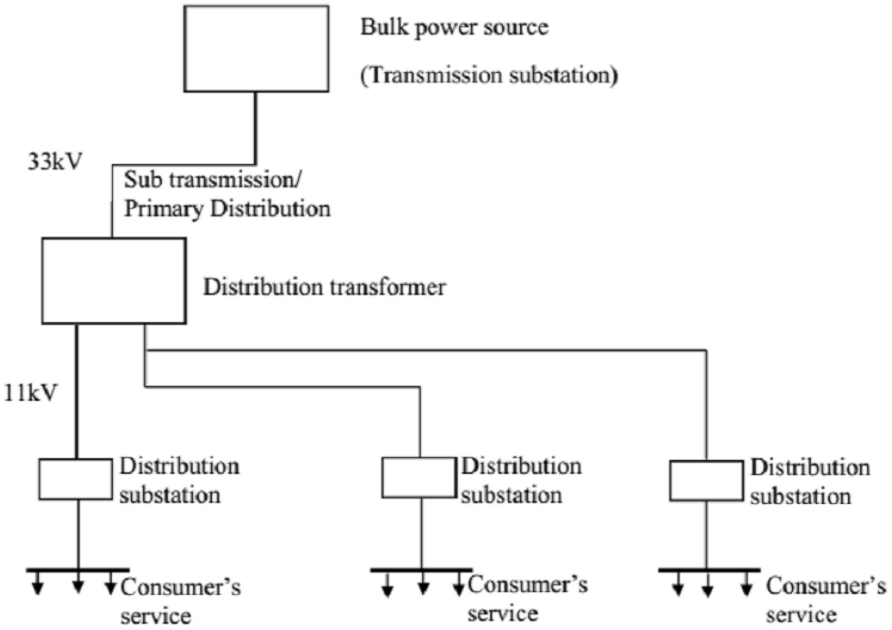


Figure 1: The Main Part of Electrical Distribution Network

B. Distribution Test Feeder

Distribution test feeders are available for the analysis of radial distribution system. They are standard feeders approved by the Institute of Electrical and Electronics Engineers Standards Association (IEEE-SA). It comprises of basic standard data such as load data, shunt capacitor data, overhead spacing data, underground spacing data, conductor data and cable data. The purpose of this data is to make available a common set of data that could be used by program developers and users to verify the correctness of their solutions [11], [24]. However, for the purpose of this study, IEEE 13-bus and 25-Bus distribution test feeders was employed and thereby discussed.

1. 13-Bus Test Feeder

This circuit model is very small and used to test common features of distribution analysis software, operating at 4.16 kV. It is characterized by being short and relatively loaded. It is a single voltage regulator at the substation, overhead and underground lines. It is a radial distribution system feeder fed at one end. The single line diagram is depicted in Figure 2 [11].

2. 25-Bus Test Feeder

It is a circuit model used to test common features of distribution analysis software, operating at 4.16 kV. It is an unbalanced radial distribution system test feeder formed as a result of two pieces of IEEE 13- bus distribution system test feeder. The single line diagram is depicted in Figure 3 [9], [20], [21], [25]..

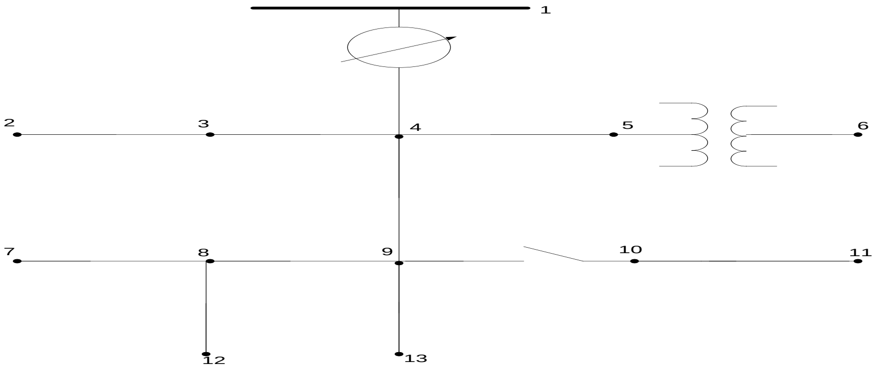


Figure 2: 13-Bus Test Feeder

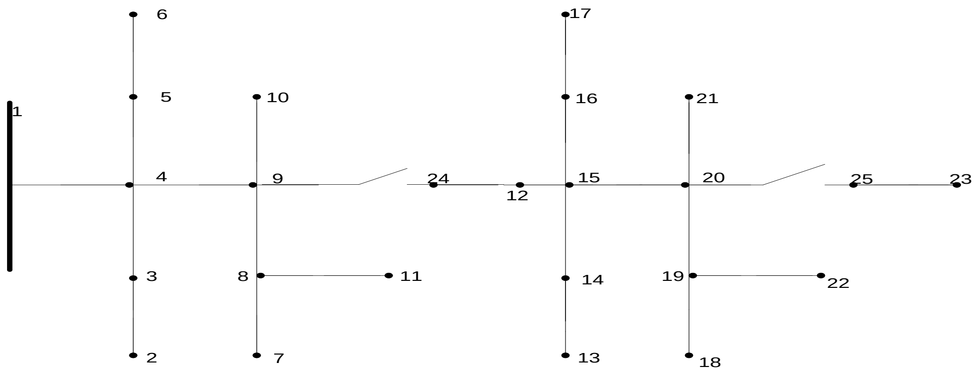


Figure 3: 25-Bus Test Feeder

C. Losses in Distribution Network

The major problem in power sector today is losses in distribution network. These losses occur in the process of supplying electrical power to consumers due to technical and commercial losses. The technical losses are due to reduction of energy in the conductors and equipment used for distribution of power. These technical losses are inherent in a system and can be reduced to a minimum level [22], [26].

D. Distributed Generation System

Distributed Generation (DG) system is one of the new trends in power systems used to support the increased energy-demand. This refers to electric generator or Distributed Generators (DG) connected at distribution level rather than transmission level. Distributed Generation also called decentralized generation, dispersed generation and embedded generation is considered as any source of electrical energy of limited size that is connected directly to the distribution system of a power network. These generators are distributed closer to the loads throughout the power system [5], [19], [28].

E. Genetic Algorithm

Genetic Algorithm (GA) is adaptive heuristic search algorithm, based on the evolutionary ideas of natural selection and genetics. GA has recently found extensive applications in solving global optimization searching problems when the closed-form optimization techniques cannot be applied. These optimization problems were made possible by the increasing availability of high performance computers at very low costs [4], [10], [16].. The optimal power flow problem is solved based on the use of a GA load flow. The advantages of using GAs are that it require no knowledge or gradient information about the response surface and can be employed for wide varieties of optimization problems [13], [23].

Mutation operation is applied for each bit in the population. After the process of selection, recombination and mutation is complete, the next population can be evaluated. The process of evaluation, selection, recombination and mutation forms one generation in execution of a Genetic Algorithm. GA works with a population of individual and each individual stands for a solution. The quality of the solution is evaluated and calculated by its fitness function. The standard GA can be represented as shown in Figure 4 [12], [18], [19],[23].

$$F = W_P \times P_L + W_q \times Q_L + W_V \times CVD \qquad (1)$$

$$CVD = \left|\sum_i^n (1 - V_i)\right| \qquad (2)$$

subject to:

$$W_P + W_q + W_V = 1 \qquad (3)$$

where; P_L is active power loss, Q_L is reactive power loss, CVD is cumulative voltage deviation, F is fitness function, W_P, $W_q$and W_V are active, reactive power losses and cumulative voltage deviation weights,n is the total number of bus and V_i is voltage magnitude at bus I [7], [8], [15]..

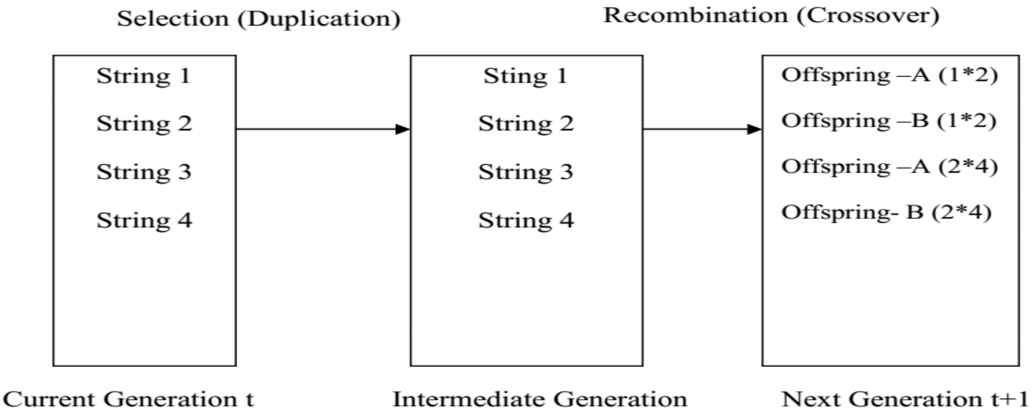


Figure 4: Genetic Algorithm Process

II. MATERIALS AND METHOD

Mathematical modeling of Ladder Load Flow with Incorporation of Distributed Generation (DG) model was developed by calculating the voltage at each distribution buses using the currents calculated in backward sweep method. Ladder Load Flow is one of the load flow methods used in radial distribution network with adequate robustness and convergence characteristics. Ladder Load Flow was employed due to the following characteristics of radial distribution networks:

i. High or large R/X ratio of the cables.
ii. Unbalance load operation.
iii. Radial or almost radial topology (weakly meshed).

By considering a balanced radial distribution network represented by an equivalent single line diagram in Figure 5 with generator arbitrarily placed at bus$(i+1)$. The line shunt capacitances at distribution voltage level are placed at the nodes of the system as reactive power injection.

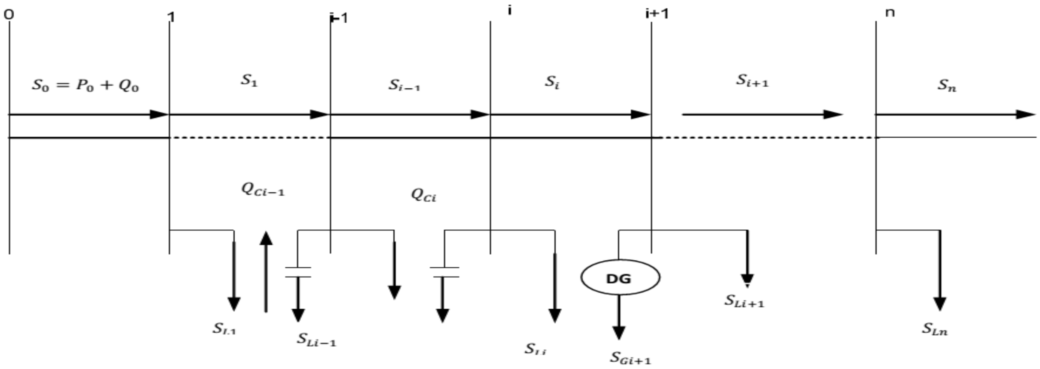


Figure 5: Single line diagram of distribution main feeder with distributed generator

From the line diagram of Figure 5, the power injected at bus $(i+1)$ when considering a ladder power flow equation is given as

$$P_{i+1} = P_i - P_{Li+1} - R_{i+1}\frac{{P_i}^2+{Q_i}^2}{|V_i|^2} + P_{Gi+1} \quad (4)$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i+1}\frac{{P_i}^2+{Q_i}^2}{|V_i|^2} + Q_{Ci+1} + Q_{Gi+1} \quad (5)$$

for$i = 0, 1, 2\ldots..\, n-1$

While voltage at receiving end is

$$|V_{i+1}|^2 = |V_i|^2 + \left({R_{i+1}}^2 + {X_{i+1}}^2\right)\frac{{P_i}^2+{Q_i}^2}{|V_i|^2} - 2(R_{i+1}P_i + X_{i+1}Q_i) \quad (6)$$

The power loss is given by:

$$P_{LOSS(i,i+1)} = R_{i,i+1}\frac{{P_i}^2+{Q_i}^2}{|V_i|^2} \quad (7)$$

Total power loss is

$$P_T^{LOSS} = \sum_{i=0}^{n-1} P_{LOSS(i,i+1)} \quad (8)$$

where: P_{i+1} is active power at bus $(i+1)$, Q_{i+1} is reactive power at bus $(i+1)$,P_i is active power at bus i, Q_i is reactive power at bus i, $|V_i|$ is voltage magnitude at bus i, $|V_{i+1}|$ is voltage magnitude at bus$(i+1)$,R_{i+1} is resistance at bus $(i+1)$, $X_{i+1}$is reactance at bus $(i+1)$, P_{Li+1} is active power loss at bus $(i+1)$, Q_{Li+1} is reactive power loss at bus $(i+1)$,P_{Gi+1}, Q_{Gi+1} is active and reactive power of DG at bus $(i+1)$,Q_{Ci+1} is reactive power injection on shunt capacitor at bus $(i+1)$

Thus, once the mathematical modeling of Ladder Load Flow with DG is developed, the power loss in the distribution system is computed using the model equations above. Then Genetic Algorithm (GA) was implemented as optimization technique to minimize the resulted power loss from Ladder Load Flow with DG model and also to optimally place the DG in an appropriate location. The main constraints in the optimization process is that, the power losses after installing DG in distribution network should be less than or equal to power losses before installing DGs.

III. SIMULATION USING GRAPHICAL USER INTERFACE

The MATLAB/SIMULINK blocks were used to develop a Graphical User Interface (GUI) where obtained data values were inputted for easy output. The line, bus, generator and load data were obtained from the Institute of Electrical and Electronics Engineers (IEEE) Distribution System Analysis Subcommittee at http/ewh.ieee.org/soc/pes/testfeeders.htm. The MATLAB 7.9.0529 environment was utilized. The developed GUI model is in two major phases. Firstly it was used to execute the distribution system with and without incorporation of DG using existing and modified Ladder Load Flow model. Secondly it was used to optimize the result of the simulation with incorporation of DG using Genetic Algorithm (GA) on standard IEEE 13- bus and 25-bus distribution test feeders.

The simulation was made using DG parameters of 5 MW with a base voltage of 13.8 kV, shunt capacitor of 200 kVar and base value of 40. The simulation of GA with DG was carried out according to the following stepwise:

Step 1: Input the system data

Step 2: Perform Ladder load flow calculation with incorporation of DG to determine initial conditions of the system.

Step 3: Select possible location of units based on areas that have large losses.

Step 4: For each selected location, recalculate system losses and record the losses.

Step 5: If the system losses is in acceptable range, stop and rank each location according to system losses else reject, then go to step 2.

The flowchart representation of the Genetic Algorithm optimization solution method with incorporation of DG is depicted in Figure 6.

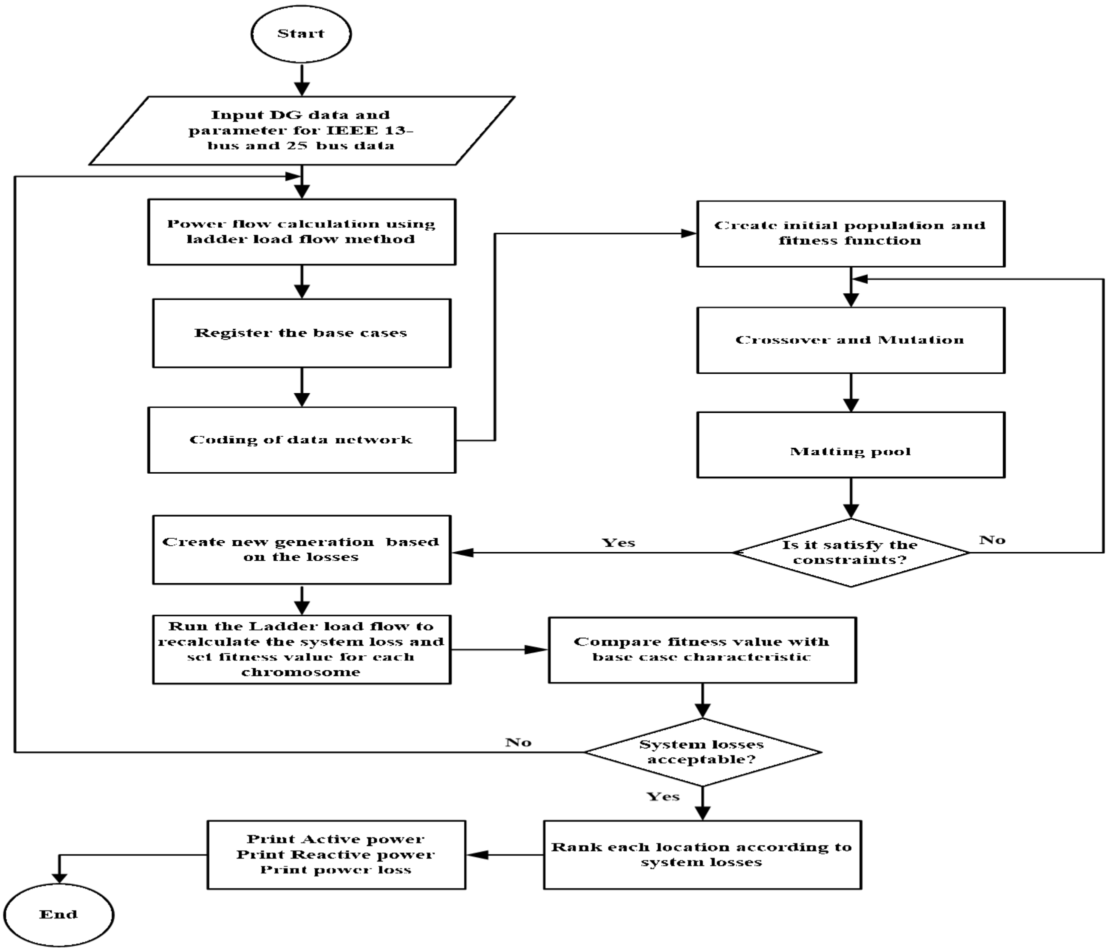


Figure 6: Flowchart of the Genetic Algorithm with Incorporation of DG

IV. RESULTS AND DISCUSSION

The objective of this study is to investigate loss reduction in electrical distribution system with incorporating Distributed Generators (DG). In a bid to achieve this objective, a Graphic User Interface (GUI) model shown in Figure 7 was developed in MATLAB/SIMULINK where the data value were inputted for easy output, the developed GUI model was used to solve the resulting GA optimization method on two distribution test feeders, IEEE 13-bus and 25-bus distribution test feeder. For 13-bus distribution test feeder, simulation was made with a pre-voltage of 4.16 kV and 100% of nominal voltage of 4.6 kV and base MVA value of 20 while the buses are configured as line number 1 to 12. For IEEE 25-bus distribution feeder, simulation was made with a pre-voltage of 4.16 kV and base MVA value of 40 while the buses are configured as line number 1 to 24. The corresponding results for two test feeders are presented in Figures 8 to 17 according to system power losses.

Figure 8 shows the variation of power loss with line numbers for 13-bus Ladder Load Flow results without DG. Lines 1, 2 and 3 recorded power loss values of 0.101, 0.1467 and 0.14 p.u. respectively which indicate an increase in power loss as the bus numbers are increased. This is due to the resistance and reactance data at each feeder. Power loss at lines 4, 5 and 6 are 0.1468, 0.1601 and 0.1035 p.u. respectively which indicate an increase in power loss but reduced at bus 6. This is also due to the resistance and reactive value at each feeder. Lines 7, 8 and 9 also recorded an increase in power losses of 0.1434, 0.1465 and 0.1510 p.u. respectively. This is due to the high reactance and reactance value at each feeder. Lines 10, 11 and 12 have the values of power loss of 0.1412, 0.141 and 0.1418 p.u respectively.

Figure 9 illustrates the correspondence between power loss and line numbers 13-Bus Ladder Load Flow results with incorporation of DG. The power loss with incorporation of DG for lines 1, 2 and 3 are 0.0687, 0.0489 and 0.0376 p.u which correspond to power loss of 0.101, 0.1467 and 0.1400 p.u. respectively without the incorporation of DG. Lines 4, 5 and 6 have values of power loss of 0.0489, 0.0508 and 0.0232 with DG which correspond to power loss of 0.1468, 0.1601 and 0.1035 p.u. respectively without incorporation of DG. The power loss with DG for lines 7, 8 and 9 are 0.041, 0.0431 and 0.0493 p.u. respectively which correspond to power loss of 0.1434, 0.1465 and 0.1510 p.u. respectively without incorporation of DG. Lines 10, bus 11 and bus 12 have the values of power loss of 0.0433, 0.0324 and 0.0356 p.u respectively with incorporation of DG.

Figure 10 depicted the variation of optimal power loss for 13-bus with incorporation of DG using GA with line numbers. The power loss with optimization for lines 1, 2 and 3 are 0.0025, 0.0012 and 0.0004 p.u respectively. Lines 4, 5 and 6 have the values of optimal power loss of 0.0007, 0.0001 and 0.0004. The power loss with optimization for lines 7, 8 and 9 are 0.0005, 0.0006 and 0 p.u. respectively. Lines 10, 11 and 12 have the values of power loss to be 0.0006, 0 and 0.0004 p.u respectively with optimization. Lines 9 and 11 appeared to have no power loss respectively for all the buses because they are voltage-controlled buses and have zero values of reactive load power. Bus 1 recorded the highest value of power loss which is due to load power at the feeder.

Figure 11 shows the variation of optimal power losses for 13-bus with incorporation of DG and power losses with incorporation of DG with the line numbers. The optimal power losses with DG for lines 1, 2 and 3 are 0.0025, 0.0012 and 0.0004 p.u. respectively which correspond to power losses of 0.0687, 0.0489 and 0.0376 p.u. respectively with DG without optimization. Lines 4, 5 and 6 have optimal power losses with DG of 0.0007, 0.0001 and 0.0004 p.u. respectively correspond to power loss of 0.0489, 0.0508 and 0.0232 respectively with DG without optimization. Lines 7, 8, and 9 have optimal power losses with DG of 0.0005, 0.00063 and 0 p.u. respectively correspond to power loss of 0.041, 0.0431 and 0.0493 p.u. respectively with DG without optimization, while lines 10, 11 and 12 have the values of optimal power losses with DG of 0.00058, 0 and 0.00037 p.u respectively which correspond to power loss of 0.041, 0.0324 and 0.0356 p.u respectively with DG without optimization. The results show that the power loss with optimization is less and better than the power loss with incorporation of DG. The result also show that the best place to install the DG is at lines 5, 6 and 3 respectively because they have least values of power losses.

The relationship between total optimal power losses for 13-bus with incorporation of DG and total power losses without and with incorporation of DG is shown in Figure 12. The total power losses without incorporation of DG were 1.663 p.u and 0.5205 p.u. having installed DG (power losses reduced by 1.1425 p.u, that is, a 68.7% reduction). The total optimal power losses with incorporation of DG is 0.01 p.u compared to total power losses of 1.663 p.u without incorporation of DG. Power loss reduced by 1.653 p.u, which is 99% reduction.

Figure 13 shows the relationship between power losses for 25-bus Ladder Load Flow results without incorporation of DG with line number. The power loss for lines 1, 2, 3 and 4 are 0.1501, 0.1567, 0.1701 and 0.1710 p.u respectively without incorporation of DG indicating an increase in power loss as bus numbers are increased. This is due to the resistance and reactance data at each feeder. Lines 5, 6, 7 and 8 have the values of power loss of 0.2145, 0.103, 0.1320 and 0.2145 p.u. respectively. Power loss without incorporating DG for lines 9, 10, 11 and 12 are 0.2145, 0.2014, 0.1845 and 0.2145 p.u. respectively while lines 13, 14, 15 and 16 have the values of power loss of 0.2132, 0.2145, 0.2145 and 0.2145 p.u respectively without incorporation of DG indicating an increase and constant in power loss. This is due to the resistance and reactance data at each feeder. Power loss for lines 17, 18, 19 and 20 are 0.2145, 0.1801, 0.2143 and 0.1124 p.u. respectively while lines 21, 22, 23 and 24 have the values of power loss of 0.2143, 0.1422, 0.2110 and 0.2070 p.u. respectively.

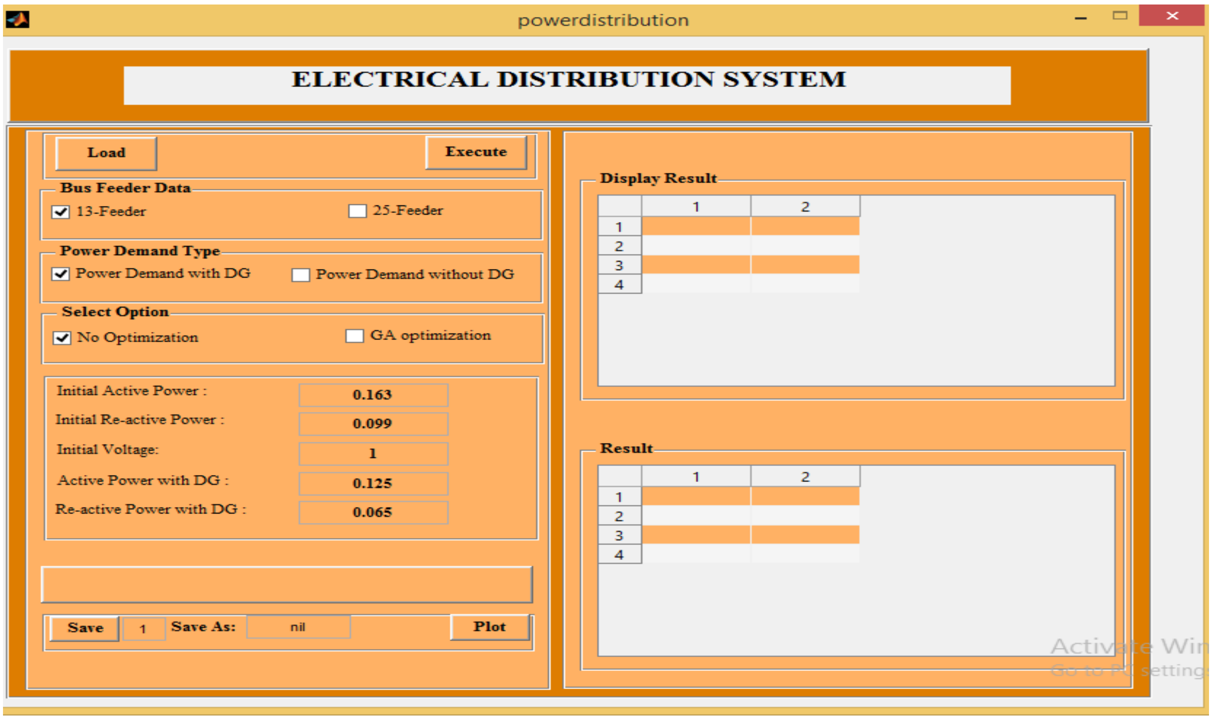
Figure 14 illustrates the correspondence between power loss and line numbers for 25-bus Ladder Load Flow results with incorporation of DG. The power loss with incorporation of DG for lines 1, 2, 3 and 4 are 0.0937, 0.0734, 0.0757 and 0.0760 p.u which correspond to power loss of 0.1501, 0.1567, 0.1701 and 0.1710 p.u respectively without the incorporation of DG. Lines 5, 6, 7 and 8 recorded an increase in power loss of 0.0925, 0.0563, 0.0710 and 0.0925 p.u. respectively when compared to power loss of 0.2145, 0.1030, 0.1320 and 0.2145 p.u. respectively without incorporation of DG. The power loss with DG for lines 9, 10, 11 and 12 are 0.0925, 0.0856, 0.0826 and 0.0922 p.u. respectively which correspond to power loss of 0.2145, 0.2014, 0.1845 and 0.2145 p.u. respectively without incorporating DG while lines 13, 14, 15 and 16 have values of power loss of 0.0917, 0.0925, 0.0925 and 0.0925 p.u respectively with incorporation of DG which correspond to power loss of 0.2132, 0.2145, 0.2145 and 0.2145 p.u respectively without incorporation of DG. The power loss for lines 17, 18, 19 and 20 are 0.0925, 0.0810, 0.0916 and 0.0602 p.u. respectively while power loss at lines 21, 22, 23 and 24 are 0.0917, 0.0710, 0.0858 and 0.0858 p.u respectively.

Figure 15 illustrates the correspondence between optimal power loss and line numbers for 25-bus with incorporation of DG. The optimal power loss with optimization for lines 1, 2, 3 and 4 are 0.0069, 0.0195, 0.0179 and 0.0188 p.u respectively. Lines 5, 6, 7 and 8 have values of optimal power loss to be 0, 0.0093, 0.0188 and 0 p.u. respectively. The optimal power loss with optimization for lines 9, 10, 11 and 12 are 0, 0, 0.0121 and 0.0192 p.u. respectively indicating a reduction in power losses when compared with the power losses of 0.2145, 0.2145, 0.2014 and 0.1845 p.u. respectively without incorporation of DG.

Figure 16 shows the variation of optimal power losses for 25-bus with DG and power losses with DG without optimization with the line numbers. The optimal power losses with DG for lines 1, 2, 3 and 4 are 0.0069, 0.0195, 0.0179 and 0.0188 p.u. which correspond to power losses of 0.0937, 0.0734, 0.0757 and 0.0760 p.u. respectively with DG without optimization. Lines 5, 6, 7 and 8 also have values of optimal power losses with DG of 0, 0.0093, 0.0188 and 0 p.u. respectively which correspond to power losses of 0.0925, 0.0563, 0.0710 and 0.0925 respectively with DG without optimization while lines 9, 10, 11 and 12 have values of optimal power loss with DG of 0, 0.0121, 0.0192 and 0 p.u. respective which correspond to power loss of 0.0925, 0.0856, 0.0922 and 0.0917 p.u. respectively with DG without optimization. The optimal power losses for lines 13, 14, 15 and 16 are 0, 0, 0 and 0 p.u respectively indicating a constant in optimal power losses. This is due to the reactive and reactance load values at the feeders. Optimal power losses with DG for lines 17, 18, 19 and 20 are 0, 0.0097, 0 and 0.0171 p.u. respectively which correspond to power losses of 0.0925, 0.0810, 0.0916 and 0.0602 p.u respectively with incorporation of DG while lines 21, 22, 23 and 24 have the values of optimal power losses with DG of 0, 0.0189, 0 and 0 p.u. respectively which correspond to power losses with DG of 0.0917, 0.0710, 0.0858 and 0.0858 p.u respectively without optimization. The results show that the power losses with optimization is less and better than the power losses with incorporation of DG. The results also show that the best place to install the DG is at lines 1, 6, 18, 10, 20, 3, 4, 7, 22, 11 and 2 respectively because they have the least values of power losses. The generator cannot be installed at lines 5, 9, 10, 12, 13, 14, 15, 16, 17, 19, 21, 23 and 24 because they are voltage- control buses.

Figure 17 shows the relationship between total optimal power losses with incorporation of DG and total power losses without and with incorporation of DG. The total power losses without introduction of DG without optimization were 4.4793 p.u and 2.0128 p.u. having installed DG (power losses reduced by 2.4665 p.u, that is, a 55.1% reduction). Total optimal power losses with introduction of DG are 0.1682 p.u compared to total power losses of 4.4793 p.u without introduction of DG (power loss reduced by 4.3111 p.u, which is 96.2% reduction).

The results also showed that the total power losses with incorporation of DG and with optimization are less than total power losses without introduction of DG. Losses along distribution lines were reduced, hence, an enhanced performance for the power infrastructure. The ladder load flow results have demonstrated the effectiveness and feasibility of the Distributed Generators power injection model. The results show an appreciable level of electrical power loss in distribution system with the incorporation of DGs.



Bus Feeder Data
☑ 13-Feeder ☐ 25-Feeder

Power Demand Type
☑ Power Demand with DG ☐ Power Demand without DG

Select Option
☑ No Optimization ☐ GA optimization

Initial Active Power : 0.163
Initial Re-active Power : 0.099
Initial Voltage: 1
Active Power with DG : 0.125
Re-active Power with DG : 0.065

Save 1 Save As: nil

Figure 7: Graphic User Interface (GUI) Model

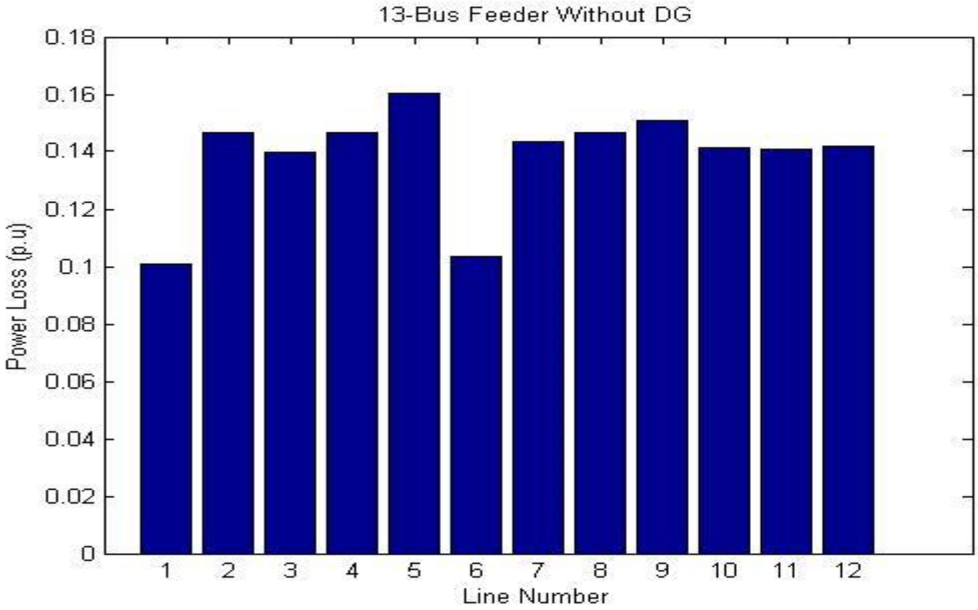


Figure 8: 13-bus Power Loss without Incorporation of DG

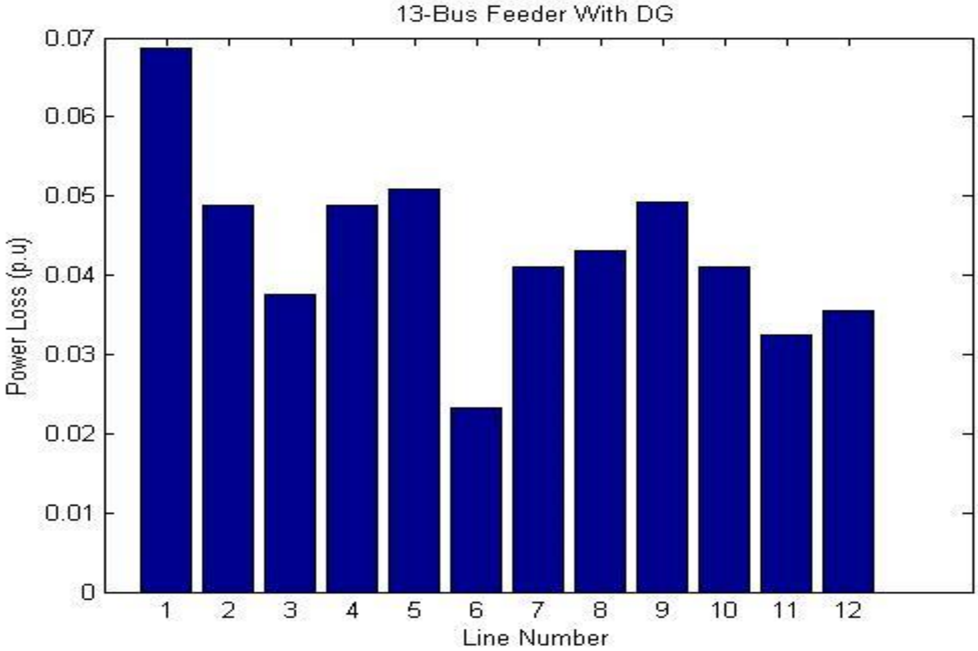


Figure 9: 13-Bus Power Loss with Incorporation of DG

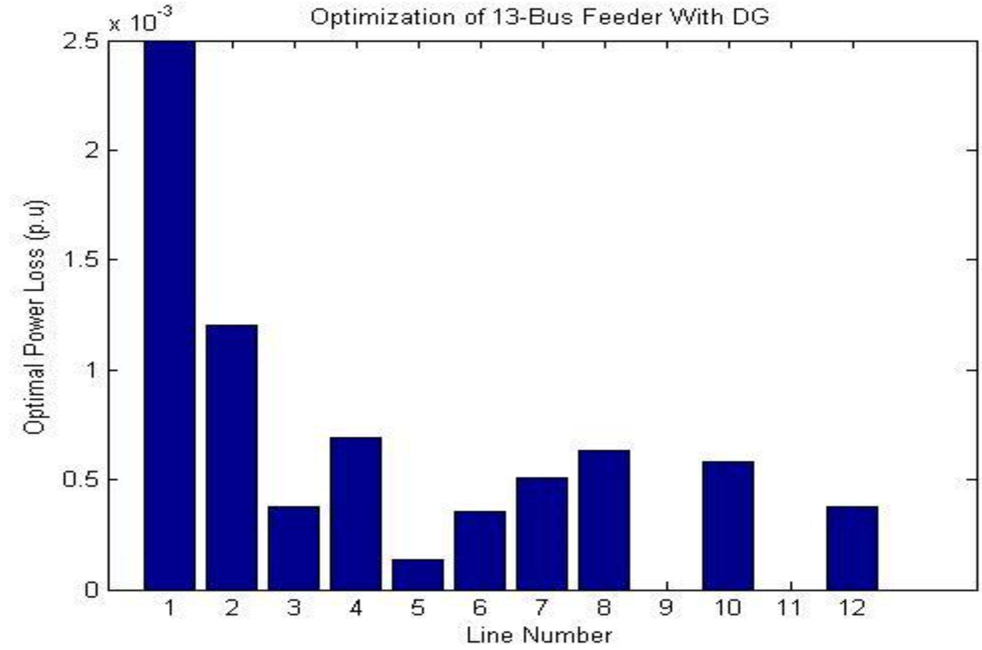


Fig 10: 13-Bus Optimal Power Loss with Incorporation of DG

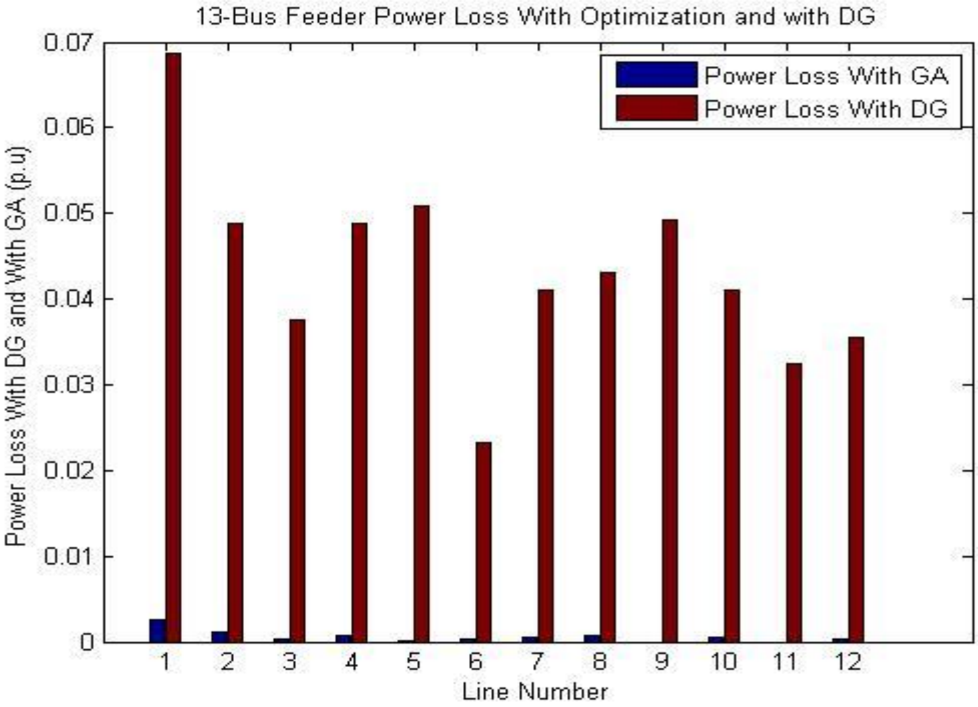


Figure 11: 13-Bus Comparison of Power Loss with Incorporation of DG and with GA

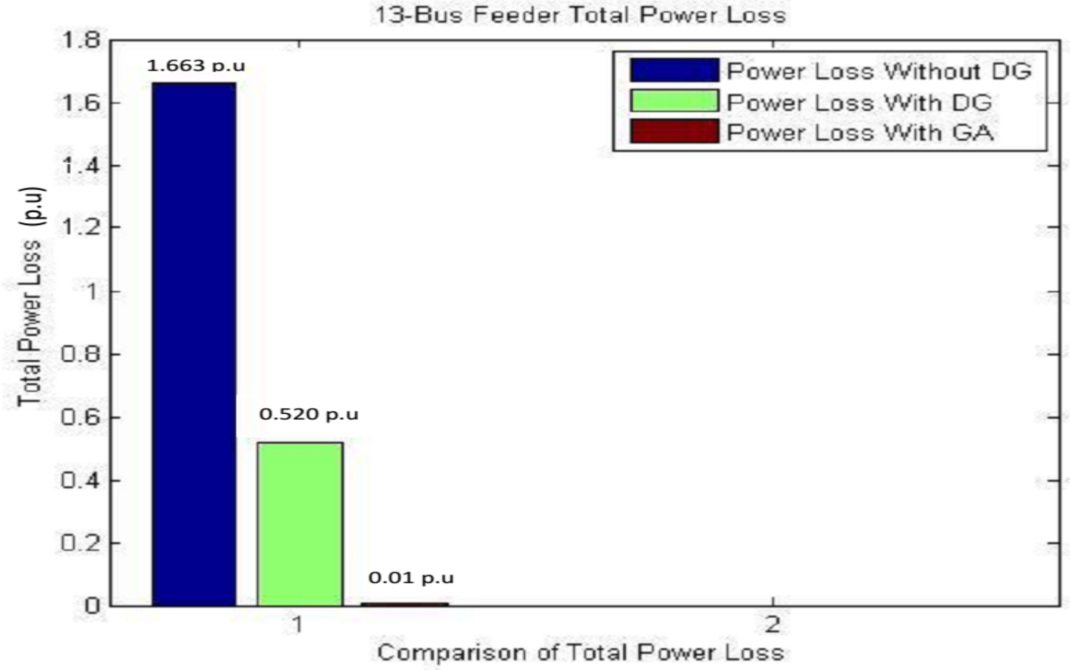


Figure 12: 13-Bus Comparison of Total Power Loss without and with DG and with GA

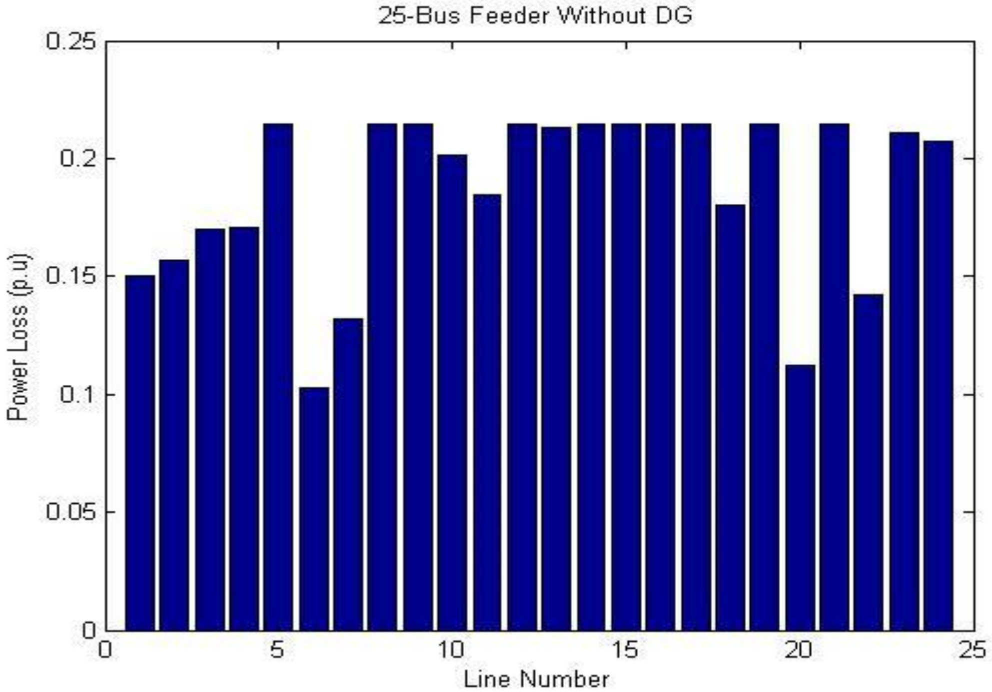


Figure 13: 25-Bus Power Loss without Incorporation of DG

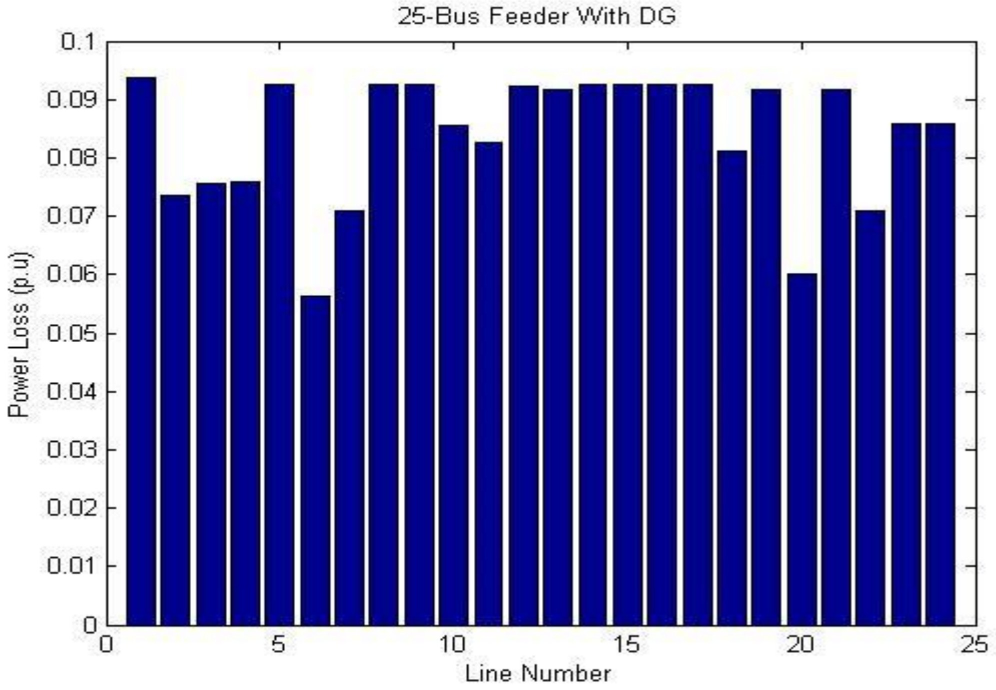


Figure 14: 25-Bus Power Loss with Incorporation of DG

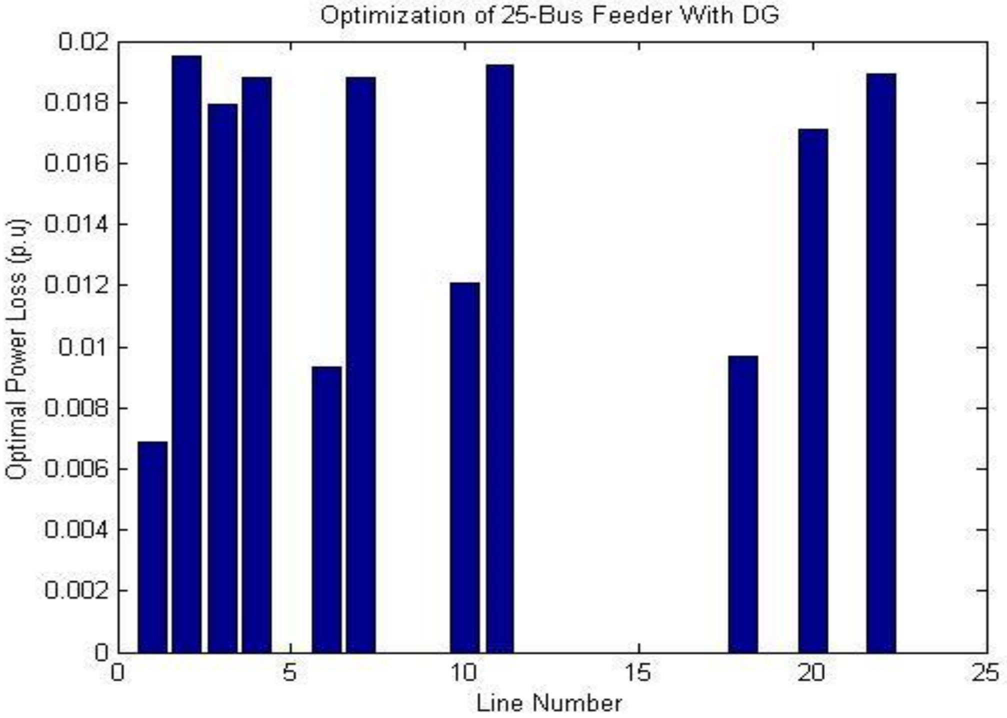


Figure 15: 25-Bus Optimal Power Loss with Incorporation of DG

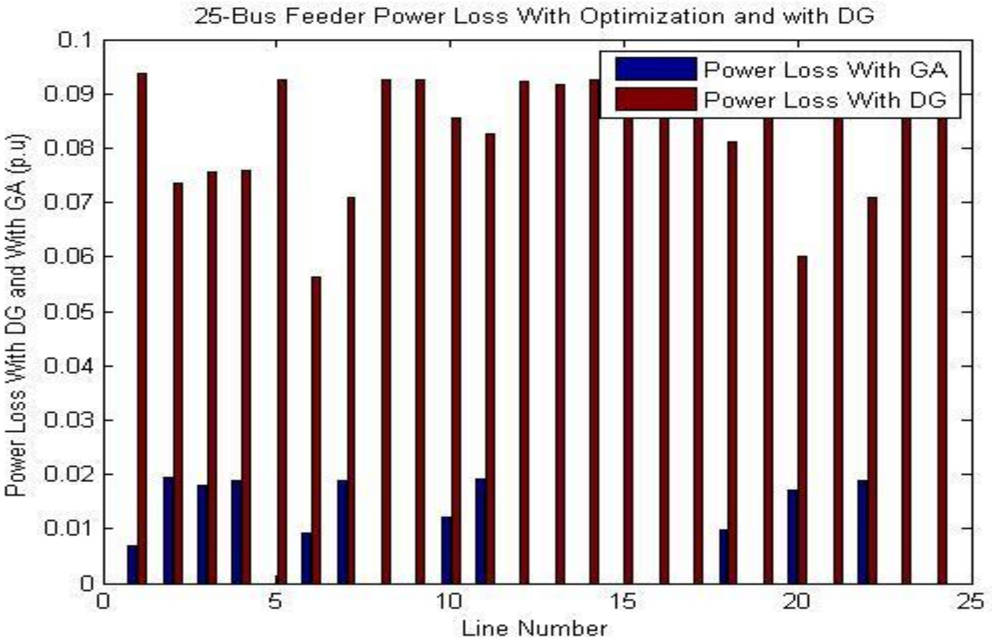


Figure 16: 25-Bus Comparison of Power Loss with DG and with GA

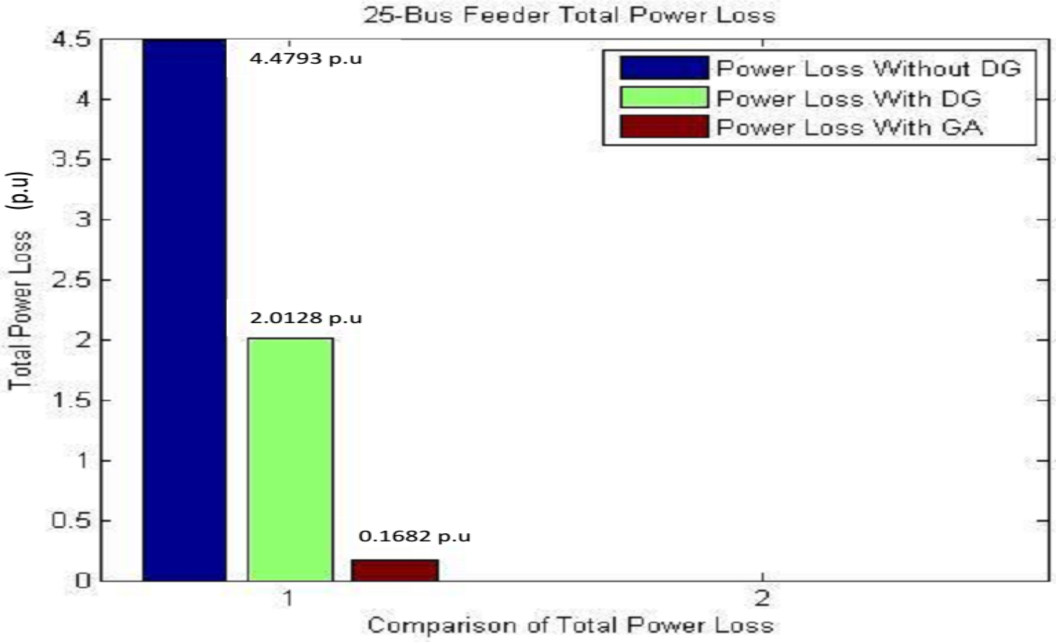


Figure 17: 25-Bus Comparison of Total Power Loss without and with DG and with

V. CONCLUSIONS

This study has investigated power loss reduction in electrical distribution system with incorporating Distributed Generators (DG) using Genetic Algorithm (GA) optimization approach on standard IEEE 13-bus and 25-bus test feeders. The study has demonstrated that incorporation of DG into the distribution network has technical benefit that compliments the distribution system performance through minimization of power losses. The study also shows that optimization of DG using GA improve electrical energy delivered to the consumers and minimize the system losses to the barest minimum. The results from the two test systems at different allocations demonstrated the applicability of the method. The results show that installing DG units at appropriate location achieved great reduction in power loss. The results also showed that the total optimal power losses with incorporation of DG were less than total power losses without and with introduction of DG.. The results show an appreciable level of electrical power loss in distribution system with optimization of DG.

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