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Power Quality Improvement of Radial Distribution System by Optimal Location and Size of Distributed Generator Using Fuzzy Genetic Algorithm

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Abstract— **Distributed Generation (DG) is becoming an increasingly attractive power generation paradigm in the field of power engineering as economic and environmental factors drive new technologies to be more efficient and less polluting than their earlier counterparts. Customers also benefit from DG in terms of better quality of supply at lower cost. Due to the installation of DG in the system, the total power loss can be reduced and voltage profile of the buses can be improved. The significant process to decrease the total power loss and to improve the power quality of the system is to identify the optimal location of DG in the radial distribution system and next stage is to find the size of the DG corresponding for maximum loss reduction. It shows the importance of installing the exact amount of DG in the best suitable location. Studies also show that if the DG units are connected at non-optimal locations or have non-optimal sizes, the system losses will increase. To accomplish the aforementioned process and to evaluate optimal location of DG and the amount of power to be generated, a new method is proposed using Fuzzy Genetic Algorithm (FGA). The proposed method is tested for IEEE 33 bus system, by connecting suitable size of DG at the optimal location of the system. The results showed a considerable reduction in the total power loss in the system and improved voltage profiles of all the buses.**

***Keywords*—DG, Fuzzy Genetic Algorithm, Power Loss, Voltage Profile**

I. Introduction

In current years, a lot of work has already been done in the electric power system infrastructure and market related to it by using Distribution Generation. Distributed Generation, is usually defined as a small-scale power generation facility that is usually connected or installed to the distribution system. While on the other hand to reduce the cost of service, the DGs usually use different modular technologies which are located around a utility's service area. Distributed generation is a technique, which minimizes the amount of power loss in transmission lines by generating the power very close to load centre.

In present times, use of DG systems in large amounts in the different power distribution systems have become very popular and is growing on with fast speed [1]. Some of the main advantages while installing DG units in distribution level are peak load saving, enhanced system security and reliability, improved voltage stability, grid strengthening, reduction in the on-peak operating cost, reduction in network loss etc. [2] [3]. The improvements in the reliability of the distribution network have come out as one of the most important benefits [4]. DGs are applied in the different power distribution systems because of energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding locations for smaller generators, shorter construction time and lower capital costs comparatively for smaller plants, and its proximity of the generation plant to heavy loads, which reduces the transmission costs [5].

Many technologies are used for DG sources such as photo voltaic cells, wind generation, combustion engines, fuel cells etc.[6][7]. Usually, DGs are attached with the already existing distribution system and lot of studies are performed to find out the best location and size of DGs to produce highest benefits [8][9]. The different characteristics that are considered to identify an optimal DG location and size are the minimization of transmission loss, maximization of supply reliability, maximization of profit of the distribution companies etc [10].

Due to wide-ranging costs, the DGs are to be allocated properly with best size to enhance the performance of the system in order to minimize the loss in the system and to improve different voltage profiles, while maintaining the stability of the system [11]. The effect of placing a DG on network indices will be different based upon its type and location and (predict) load at the connection point [12]. There are many varieties of potential benefits to DG systems both to the consumer and the electrical supplier that allow for both greater electrical flexibility and energy security [13].

In this paper, the optimal placement of DG and amount of power being generated by DG are computed using PSO and neural network. Here, a two stage PSO and one stage neural network which is used to identify the optimal placement of DG and amount of power to be generated, are presented. The rest of the paper is organized as follows: Section II briefly reviews the recent related works; Section III describes the proposed technique with sufficient mathematical models and illustrations; Section IV discusses the implementation results; and Section V concludes the paper.

II. Related Researches: A Review

Some of the latest research regarding optimal location and the reliability of distributed generator are as follows.

Amanifar *et al*. [14] have proposed a PSO algorithm that finds out the optimal placement and size of DGs and this proposed method was performed on a 15- bus test system. One of their objectives was to get some reduction by considering some functions such as total cost of the system, real power loss and the number of DGs to be connected. The objective function depends on some operating constraints. The obtained simulation results have proved that DG in optimum location and sizing can result into minimization of the fiscal cost. The number of DGs effect goodly to reduce the fiscal cost. Moreover, the result has indicated that the PSO have the potential to search for the best position and size of DGs on power system network. Also, the best DG placement and sizing result in enhancement of voltage profile, diminution of power losses and improvements are produced in power transfer capacity.

Yassami *et al*. [15] have suggested a Pareto based Multiobjective Optimization Algorithm (MOA) known as Strength Pareto Evolutionary Algorithm (SPEA) for DG planning in different distribution networks. In opposition to the conventional multi-objective optimization techniques this technique correlate different objective functions by utilizing their weighting coefficients and by creating one single objective function. In SPEA, each objective function is optimized separately. As the most of the objective functions are in contrast with each other, the SPEA produces a set of optimum solutions on the place of one single optimum one. Three different objective functions considered are: (1) minimization of power generation cost (2) minimization of active power loss (3) maximization of reliability level. The goal of this optimization is to achieve each objective function. The site and size of DG units are assumed as design variables.

Injeti *et al.* [16] have proposed a technique for optimal planning and operation of different active distribution networks regarding the location and sizing of Distributed Generators. The DG unit placement and sizing is calculated by using a fuzzy logic and an analytical method respectively. The efficiency of the proposed method is to produce a comprehensive performance analysis on 12-bus, 33-bus and 69-bus radial distribution networks.

Mohammadi *et al.* [17] have proposed an optimal DG unit placement using Genetic Algorithm (GA). The best possible size of the DG unit is calculated analytically by using approximate reasoning suitable nodes that are determined for DG unit placement. Reliability and power loss reduction indices of distribution system nodes are modeled. GA containing a set of rules is used to determine the DG unit placement. DG units are placed with the highest suitability index. Simulation results have shown the advantage of optimal DG unit placement. In comparison with the other power loss and reliability improvement techniques, it is providing very good reduction not only in power loss but also it is improving reliability improvement.

In order to produce some reductions in the real power losses and to make some enhancements in the voltage profile, Lalitha *et al*. [18] have suggested a Fuzzy and PSO technique to install DG in the radial distribution systems. A two-stage methodology has been proposed for the optimal DG placement: (1) In the first stage, the best DG location was found out by using fuzzy approach, and (2) In the second stage, the size of the DGs is found by using PSO for maximum loss reduction.

Paliwal *et al*. [19] have investigated the different impacts of DG unit's installation on different criterions such as, electric losses, reliability and voltage profile of distribution networks. Their aim of this study is to find optimal distributed generation allocation for loss reduction subjected to constraint of voltage regulation in distribution network. The system is further analyzed for different increased levels of Reliability. Distributed Generator offers the additional advantage of increasing reliability levels as suggested by the improvements in various reliability indices such as SAIDI, CAIDI and AENS. Comparative studies are carried out and related results are addressed.

A. Rezazadeh *et al*. [20] have shown the different impacts of DG on the power system transitory stability. They have used a typical 6-bus power system in their relative study of this technique. They have considered many different-2 scenarios to investigate genetic algorithm to allocate and sizing of DGs. After occurrence of a fault and tripping faulty line, power in the slack bus generator changes comprehensively in order to compensate for the losses of new power flow route. These changes of power produced in each case with no DG are calculated and compared with summation of DG sizes.

III. MATHEMATICAL FORMULATION OF OBJECTIVE FUNCTION

The objectives considered in the present study are maximization of the energy loss cost savings, minimization of line voltage drop, as well as maximization of the power transfer capability of the system. The percentage decrease in total Energy Loss Cost Savings (ELCS) when a DG is installed and run for T_d hours in a day is as given in Equation 1 . It is desired to have a DG size that maximizes this objective function when located at a particular bus.

$$\max(\mathrm{ELCS}) = \frac{C_E \sum_{M=1}^{N-1} T_d (P_{Lm}{}^{B} - P_{Lm}{}^{DG})}{C_E \sum_{M=1}^{N-1} T_d P_{Lm}{}^{B}} \quad (1)$$

Subject to

$$0 \leq \sum P_{Lm}{}^{DG} < \sum P_{Lm}{}^{B} \quad (2)$$

Where C_E is unit energy cost ($/MWh), $P_{Lm}{}^{B}$ and $P_{Lm}{}^{DG}$ are line m active power loss before and with DG installation respectively, and N is the number of buses. To improve the voltage profile of all buses, it is essential to minimize the voltage drop on all lines of the network. The total voltage drops on the system, which is a sum of the voltage drop on all the lines of the power prior to DG connection, is presented in Equation 3, where m is the line number. ΔV_m, R_m, and X_m are voltage drop, resistance, and reactance of line m respectively.

$$\sum_{m}^{N-1} \Delta V_m = \sum_{m}^{N-1} \sqrt{\frac{P_{Lm}(R_m{}^2 + X_m{}^2)}{R_m}} \quad (3)$$

Minimizing the Line Voltage Drop (LVD) is synonymous to maximizing the difference between the voltage drop on the line before and after DG connection to the network. This can be formulated in percentage form as in given in Equation 4. In other words, the highest value of the expression on the RHS of Equation 4 minimizes the LVD.

$$\min(LVD) = max\left(\frac{\sum_{m=1}^{n-1} \Delta V_m{}^{B} - \sum_{m=1}^{n-1} \Delta V_m{}^{DG}}{\sum_{m=1}^{n-1} \Delta V_m{}^{B}}\right) \quad (4)$$

The Power Transfer Capability (PTC) of a power system is the maximum power that can be transported via a power line from one point to another, without compromising the system security. DG is a viable alternative to distribution system expansion in response to the ever increasing population growth since environmental and economic constraints prohibit expansion of the existing network. The overall PTC of a distribution system could be computed from Equation 5, which is the sum of all the power transported on a line m, when P_{DG} size is connected to bus B_k.

$$\max(PTC) = \frac{(P_{DG} B_k - \sum_{m=1}^{n-1} P_{Lm}{}^{DG} + \sum_{m=1}^{n-1} P_{Lm}{}^{B})}{P_{SW} - \sum_{m=1}^{n-1} P_{Lm}{}^{B}} \quad (5)$$

Subject to the bus voltage, line thermal limit and DG capacity constraints are presented in Equation 6.

$$|V_i|_{min} \leq |V_i| \leq |V_i|_{max} , S_m \leq S_m{}^{max}$$

$$and\ P_{DG} \leq 0.4 \sum^{N}{}_{i=1} P_{Di} \quad (6)$$

The DG size is limited to 40% of the total power demand of the system to avoid power quality and protection issues, which might arise as DG size increases.

Combining these individual objectives (Eqs. 1, 4 and 5) yields the expression presented in Equation 7. In other words, the bus B_k that maximizes the objective function when P_{DG} is sited this is regarded as the optimal location in this study.

$$objfunB_k = \max(W_1 \times ELCS + W_3 \times PTC) MIN(W_2 \times LVD) \quad (7)$$

Where the weighting factors $W_1 + W_2 + W_3 = 1$. These weights are allocated by the planner to indicate the relative importance of each objective. In this work, the respective weighing factors considered are 0.4, 0.3 and 0.3.

IV. OPTIMAL PLACEMENT OF DG USING FUZZY GENETIC ALGORITHM

The flowchart shown in Fig. 1 summarizes the general procedure involved in the Genetic Algorithm (GA).

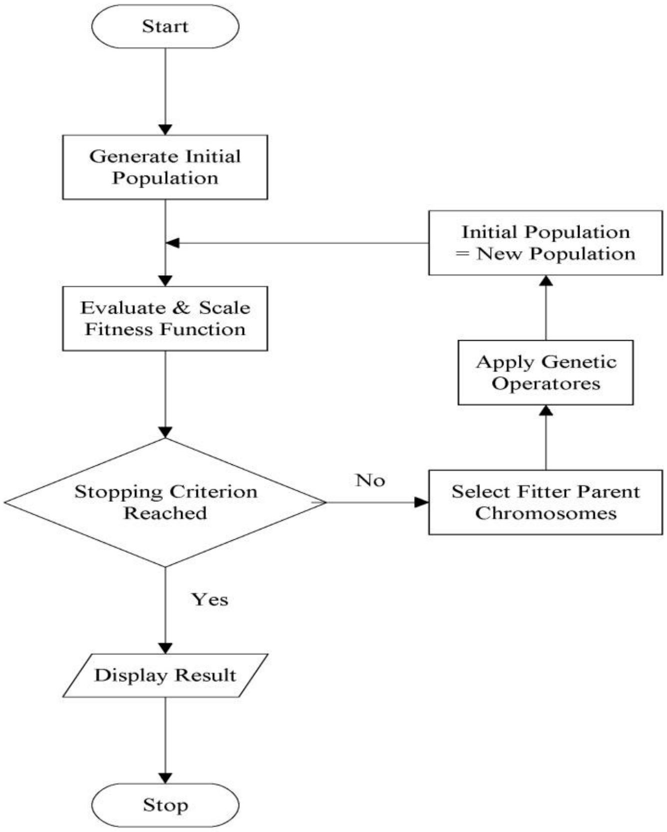

Fig. 1 General Flowchart of Genetic Algorithm

This generational process is repeated until a stopping condition has been reached.

Common terminating conditions are the following:

i) A solution that satisfies minimum criteria is found.
ii) A fixed number of generations is reached.
iii) Computation time limit is reached.
iv) No improvement in the objective function during an interval of time in seconds equal to stall time limit.
v) Combinations of the above.

The simplest form of a GA involves three types of operators as Selection, Crossover and Mutation.
The selection operator selects chromosomes in the population for reproduction. The fitter the chromosome is, the more times it is likely to be selected to reproduce; otherwise, it is eliminated from the population.

The crossover operator is used for recombination of individuals within the generation. It selects two individuals in the current generation and performs swapping at a random or fixed site in the individual string. The objective of the crossover process is to synthesize bits of knowledge from the parent chromosomes that will exhibit improved performance in the offspring. The common types of crossover are single point, two-point, uniform and arithmetic crossovers. Single point crossover, in which one crossover point is selected, then the binary string from the beginning of the chromosome to the crossover point, is copied from one parent, and the rest from the second parent, is adopted in this thesis.

The mutation operator is used to randomly flip some bits in a chromosome to explore the solution space. It introduces diversity into the population. If diversity is lost, the search convergences rapidly and some important information would be missing. After mutation, the new generation is complete and the procedure begins again with fitness evaluation of the population. The types of mutation are flip bit, boundary, nonuniform, uniform and Gaussian mutations.

GAs has certain control parameters that must be selected with maximum caution, since the performance of the GA depends largely on the values used. These parameters include population size, crossover rate and mutation rate. The choice of the control parameters, often left to the GA user, itself can be a complex non-linear optimization problem. Even though the choice of optimal parameters remains an open issue to a large extent, several researchers have proposed control parameter sets that guarantee good performance on carefully chosen test beds of objective functions. Two distinct parameter sets are proposed:

(i) Small population size, but relatively large crossover and mutation probabilities. Typical values include a population size of 30, a crossover rate of 0.9 and a mutation rate of 0.01.

ii) Larger population size, but much smaller crossover and mutation probabilities. A typical example of this includes a population size of 100, a crossover rate of 0.6 and a mutation rate of 0.001.

In real-life scenarios, the static configurations of the control parameters and encodings in GAs have some drawbacks, such as premature convergence, which usually results from rapid descending of the Population Diversity (PD), and its inability to handle fuzziness found in the fitness function. PD is the average distance between individuals in the population. A too high or too low PD would make the GA not perform well. To effectively overcome this problem, non-traditional techniques such as dynamic and adaptive strategies are employed. This would mitigate the problem by controlling the PD to maintain the proper value, thereby improving the performance of the GA. In this study, a Fuzzy Genetic Algorithm (FGA) is developed by systematically integrating fuzzy expert systems into the GA, to dynamically control the GA parameters during operation, with a

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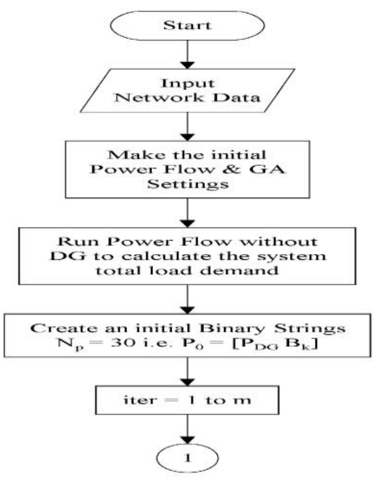
goal of achieving high performance of the algorithm. Experiments show that the FGA can search faster and more effectively than the simple GA in solving optimization problems.

The DG placement algorithm flow chart is presented in Fig. 2. The algorithm uses genetic algorithm to solve the optimization problem formulated in Equation 7. GA is a stochastic search and optimization technique based on the mechanism of natural selection and natural genetics search. Selection of appropriate GA control parameters is described as a complex optimization problem, which requires a maximum caution. The reason for this is that the performance of GA is largely dependent on these parameters. In addressing this issue, the two distinct parameter sets are identified to achieve good performance.



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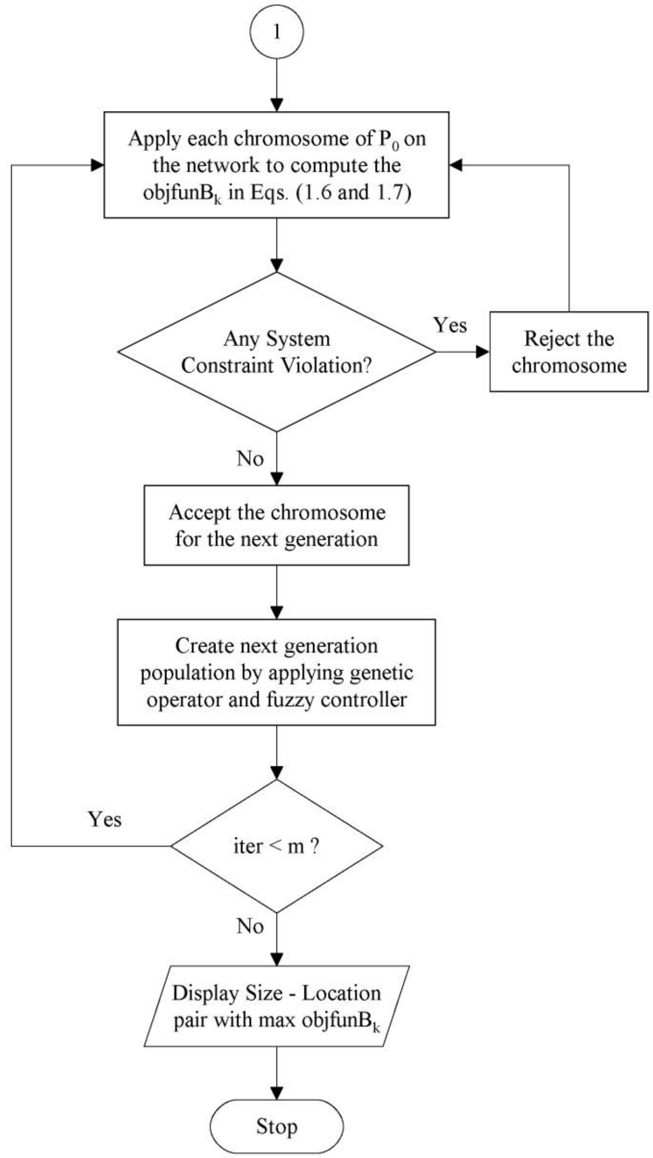

Fig. 2 Flowchart of the DG placement algorithm

The FGA convergence plot for IEEE 33 bus system displayed in Fig. 3. The developed algorithm converges faster than the same GA algorithm which was developed earlier [21] and therefore is adopted in this work.

A. *Novel Method for Solving Radial Distribution Network*

To minimize line losses of power systems, it is crucially important to define the size and location of local generation to be placed. On account of some of the inherent features of distribution systems as Radial structure, Unbalanced distributed loads and unbalanced operation, an extremely large number of branches and nodes and a wide range of X/R ratios The conventional techniques developed for transmission systems generally fail on the determination of optimum size and location of distributed generations.

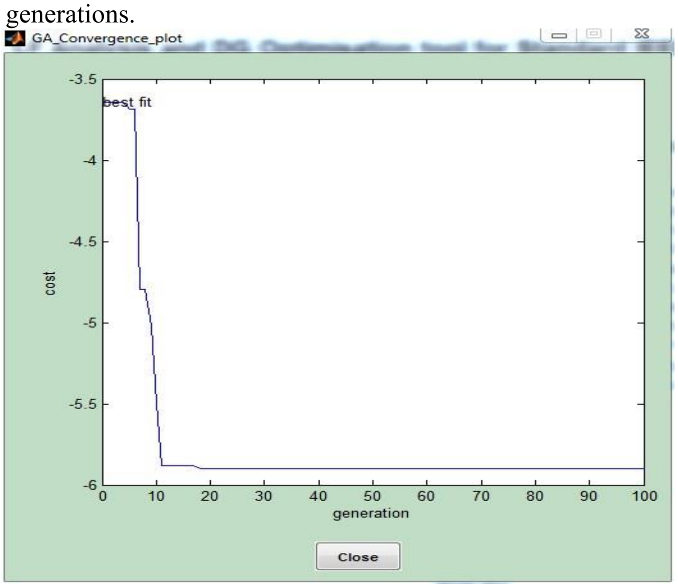

Fig. 3 Plot of FGA convergence of developed software for 33 bus RDS

In real time applications that are Supervisory Control and Data Acquisition System (SCADA), Distribution Automation (DA) for the management of Radial Distribution System (RDS) such as network optimization, VAR planning, Switching, state estimation etc. require a robust and efficient load flow method. The traditional load flow methods such as Gauss- Seidel and Newton-Raphson methods fail to meet the above requirement. Therefore, there is need to develop a load flow solutions to meet the properties of RDS with less computational time.

Load flow analysis based on the equivalent current injection techniques without use of admittance matrix, inverse of admittance matrix or Jacobian matrix which is proved to be problematic for the radial systems.

Due to the above three problems, a new approach to solve load flow problem is proposed.

B. Distribution Load Flow (DLF) Program

Therefore, a new approach load flow program is developed to solve the load flow problem in radial distribution networks is presented, in which to find optimum placement and size of DGs is based on the calculation of voltage at the buses, real and reactive power flowing through lines, real power losses and voltage deviation, using Distribution Load Flow (DLF) program. An IEEE 33-bus radial distribution test system is taken as a study system for performing the test of DLF program. The results reveal the speed and the effectiveness of the proposed method for solving the problems.

The proposed methodology is based on the equivalent current injection that uses the Bus–Injection to Branch-Current (BIBC) and Branch-Current to Bus-Voltage (BCBV) matrices which were developed based on the topological structure of the distribution systems and is implemented for the load flow analysis of the distribution systems.

V. RESULTS AND DISCUSSION

The proposed method Fuzzy Genetic Algorithm (FGA) is implemented using MATLAB 2011 and tested for distribution system reconfiguration IEEE 33-bus RDS given in Fig. 4. Substation voltage is 12.66 kV and base MVA has been taken as 100 MVA.

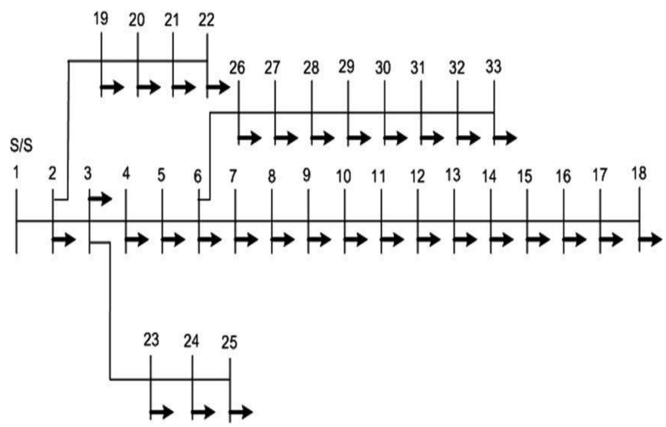

Fig. 4. IEEE 33 Bus System

The objective function and power loss plots with DG on the system with all loads modeled as constant power are shown in Fig. 5 and DG optimization details for the same test system are presented in Table I. It is visible from the figure that bus 8 is the optimal location with an optimal DG size of 1.486 MW.

The plot at bus 1 on Fig. 5 is that of the base case without DG, since generator buses are not recommended for DG connection. It should be noted from the figure that sitting DG at buses 2 and 3, 18 to 25 would amount to a great disservice to the power distribution companies as the loss incurred in each of them is higher than the standard values. They are therefore termed as critical buses where the power distribution companies must not attempt to place DG.

To reflect the voltage dependency nature of distribution systems, the loads were modeled as composite loads consisting of 45% constant power, 30% constant current and 25% constant impedance. This was run with the proposed method and results

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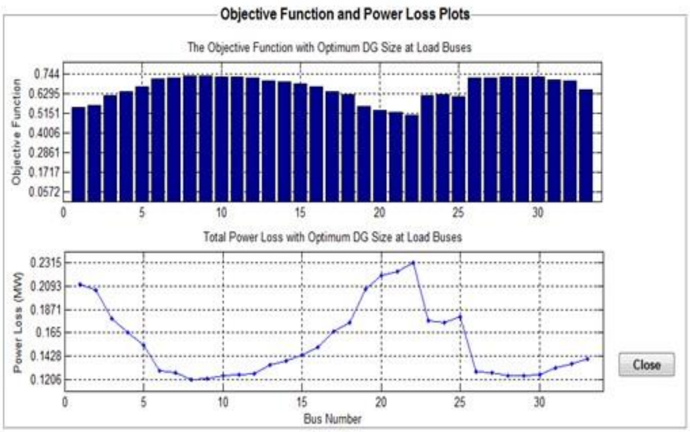

are presented in Table II, which really show the effect of the composite loads. Here the overall system power loss is less than when a constant power load model alone was considered for all loads. Adopting this, recommendation would save the power distribution companies the sum of 260.29 US $ per day, based on a unit energy cost of $120 per MWh. Table III shows the compared voltage value after and before installed DG at all the buses.

Fig. 5 Objective functions and Power loss plots with DG

Table I. DG optimization details for constant power load model

Parameter	Without DG	With DG
Active Power loss in kW	211	120.6
Reactive Power loss in kVAR	143	106.3
Minimum Voltage in Per Unit	0.90380	0.92610
Maximum Voltage in Per Unit	1.00000	1.00000
Average Voltage in Per Unit	0.94532	0.96648

Parameter	Without DG	With DG
Active Power loss in kW	189	111.6
Reactive Power loss in kVAR	127.9	100.8
Minimum Voltage in Per Unit	0.9095	0.9297
Maximum Voltage in Per Unit	1.0000	1.0000

Table II. DG optimization details for composite load model

Table III. Comparison of Voltage Profile of buses before and after DG connection

Bus No.	Per Unit Voltages at each bus	
	Without DG	With DG
1	1.00000	1.00000
2	0.99703	0.99793
3	0.98290	0.98866
4	0.97539	0.98474
5	0.96796	0.98106
6	0.94948	0.97070
7	0.94596	0.96726
8	0.93230	0.95392
9	0.92597	0.94774
10	0.92009	0.94200
11	0.91922	0.94115
12	0.91771	0.93968
13	0.91153	0.93365
14	0.90924	0.93141
15	0.90782	0.93002
16	0.90644	0.92867
17	0.90439	0.92667
18	0.90377	0.92607
19	0.99650	0.99741
20	0.99292	0.99383
21	0.99222	0.99313
22	0.99158	0.99249
23	0.97931	0.98509
24	0.97264	0.97846
25	0.96931	0.97515
26	0.94755	0.97073
27	0.94499	0.97091
28	0.93355	0.96978
29	0.92533	0.96945
30	0.92177	0.97084
31	0.91761	0.97605

32	0.91669	0.97810
33	0.91641	0.98105

From Table III, it is clear that, with optimal location of DG in the system, the voltage profile of all buses remained stable within tolerable limits.

VI. CONCLUSION

In this paper, optimal location and size of DG was identified by using Fuzzy Genetic Algorithm for a IEEE 33 bus system. The comparison was made without and with DGs in terms of total power loss and voltage profile of all the buses. The total power loss in without DG was 211 kW and after connecting DG in the system, the power loss was reduced to 120.6 kW. Thus the total loss was reduced to 57% of total power losses in the system and the voltage profile of all the buses remained stable within the tolerable limits. Hence, the power quality of the system is improved.

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