

Placement of Distributed Generator, Capacitor and DG and Capacitor in Distribution System for Loss reduction and Reliability Improvement

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Abstract— Integration of renewable energy based distributed generation (DG) units provides potential benefits to conventional distribution systems. The power injections from renewable DG units located close to the load centers provide an opportunity for system voltage support, reduction in power losses and emissions, and reliability improvement. Therefore, the allocation of DG units should be carefully determined with the consideration of different planning incentives. 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). In this paper, the distribution load flow is run initially without capacitor placement and then the size and location of capacitor in distribution systems based on GA is determined for power loss minimization and voltage profile and reliability improvement. The proposed method is tested for IEEE 33 bus system, by connecting suitable size of DG, capacitor and DG and capacitor at the optimal location of the system. The results showed a considerable reduction in the total power loss in the system, improved voltage profiles of all the buses and Reliability Indices.

Keywords—DG, Capacitor, Fuzzy Genetic Algorithm, Power Loss, Reliability Indices

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 generated by DG are computed using Fuzzy Genetic Algorithm (FGA) and optimal placement and size of capacitor computed by Genetic Algorithm (GA). The rest of the paper is organized as follows: Section II briefly reviews the recent related works; Section III and IV describe the proposed technique with sufficient mathematical models and illustrations; Section V discusses the implementation results; and Section VI concludes the paper.

II. RELATED RESEARCHES: A REVIEW

Paliwal *et al.* [14] 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. Capacitors have been widely employed in distribution systems in order to achieve different objectives. For instance, in [15] reducing active power losses is the only purpose of capacitor allocation problem. Athores in [16] determined the optimal locations and size of capacitor with an objective of improving the voltage profile and reduction of power loss in radial distribution systems. Sallam and his coauthors in [17] used shunt capacitors in distribution systems to improve the reliability indices. In [18], the authors proposed a comprehensive objective function to loss reduction and reliability enhancement in distribution network using optimal capacitor placement. For the capacitor placement problem in distribution system repeated load flow solution is required. There are a number of load flow solution techniques which are available in the text books such as Gauss-Seidel, Newton-Raphson and Fast Decoupled Load Flow method, but most of the methods have been grown up around transmission systems [19-20]. The distribution system has high R/X ratio and the conventional load flow method may not be suitable.

A number of methods have been proposed in the literature [21-27] for the distribution networks. Shirmohammadi *et al.* [21] has proposed a load flow method for distribution networks using a multi-port compensation technique and basic formulations of Kirchhoff's Laws. Rajicic and Tamura [23] has modified the fast decoupled load flow method to suit high R/X ratio nature of distribution system. Various methods [24-27] have been reported for the load flow of radial distribution system. Ghosh and Das [24] have proposed a method for the load flow of radial distribution network using the evaluation based on algebraic expression of receiving end voltage. Teng [26-27] has proposed the load flow of radial distribution system employing bus-injection to branch-current (BIBC) and branch-current to bus-voltage (BCBV) matrices.

III. MATHEMATICAL FORMULATION OF OBJECTIVE FUNCTION FOR OPTIMAL PALCEMENT OF DG

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.

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

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.

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

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.

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

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 .

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

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

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

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

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.

$$objfun_{B_k} = \max(W_1 \times ELCS + W_3 \times PTC) \text{ MIN}(W_2 \times LVD) \quad (7)$$

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.

A. Optimal Placement of DG using Fuzzy Genetic Algorithm

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

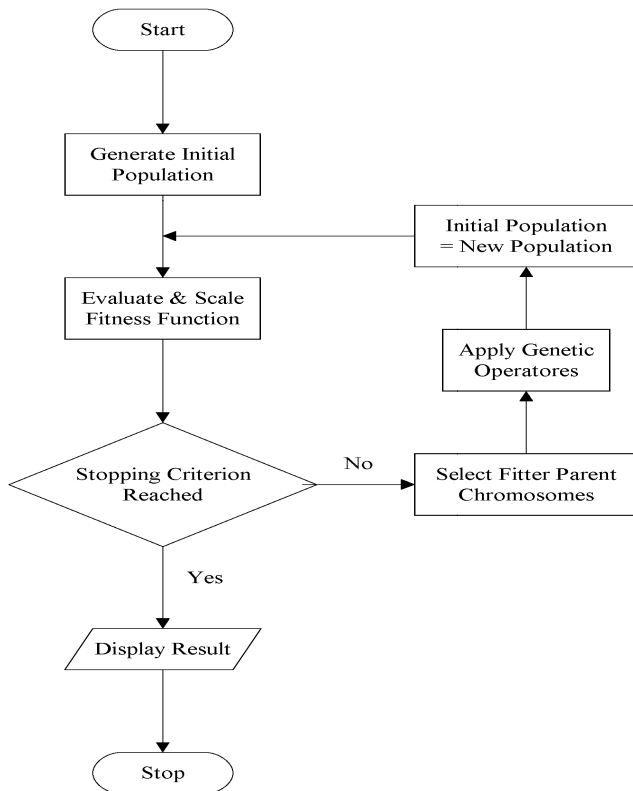


Fig. 1 General Flowchart of Genetic Algorithm

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, non-uniform, 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 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.

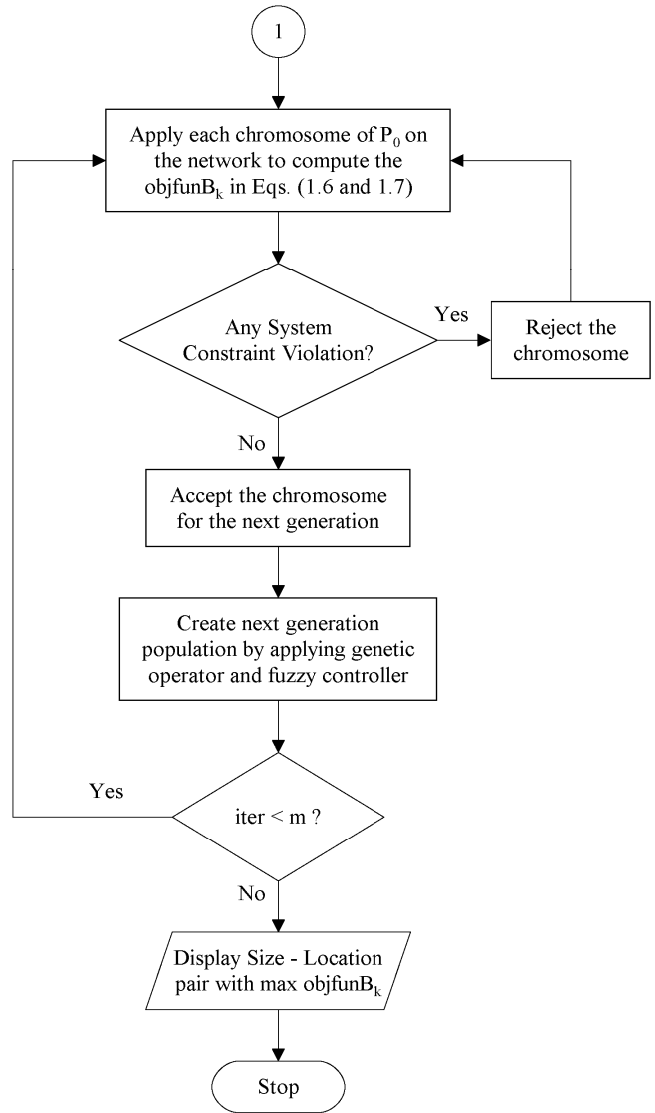
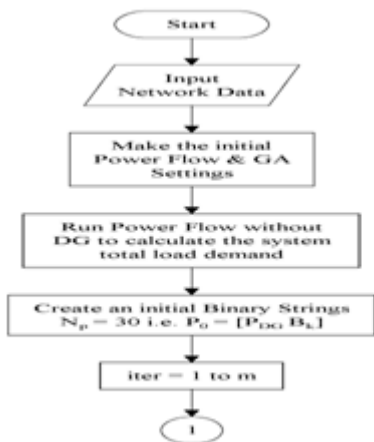


Fig. 2 Flowchart of the DG placement algorithm

The FGA convergence plot for IEEE 33 bus system displayed in Fig. 3. The developed algorithm converges faster than the same GA algorithm .

B. 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.



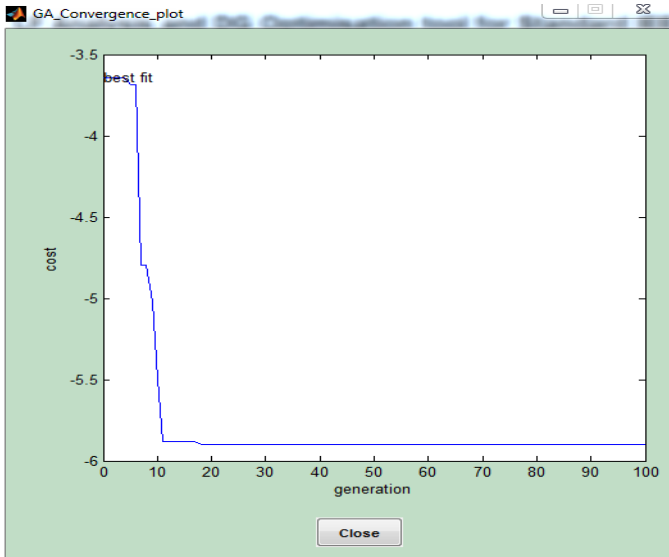


Fig. 3 Plot of FGA convergence of developed software for 33 bus RDS

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.

C. 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[26-27] 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.

IV. OPTIMAL PLACEMENT OF CAPACITOR USING GA

The developed algorithm for identifying the sizing and location is based on Genetic Algorithm (GA). A GA is an iterative procedure which begins with a randomly generated set of solutions referred as initial population. For each solution in the set, objective function and fitness are calculated. On the basis of these fitness functions, pool of selected population is formed by selection operators; the solution in this pool has better average fitness than that of initial population. The crossover and mutation operator are used to generate new solutions with the help of solution in the pool. The process is repeated iteratively while maintaining fixed number of solutions in pool of selected population, as the iteration progresses, the solution improves and optimal solution is obtained.

The success of the GA structure will lie on the coding scheme. The coding scheme and the brief discussion of various operators with reference to the problem of interest is summarized as: Here the coding scheme for 33-bus radial distribution system has been discussed. First step is to obtain the base case load flow solution for distribution system using the DLF method. Then identify the potential buses for capacitor placement by using loss sensitivity factor.

Using the loss sensitivity factor, the potential buses for shunt capacitor placement are obtained and these potential buses should be preserved.

Let the numbers of Potential Buses = [29 7 30 28 12]

Having identified the potential buses, the sizing is attempted using GA. Let the capacitor allowable range is from 100 kVAR to 1100 kVAR in step size of 50 kVAR. The respective sizes of capacitor to be installed at those potential buses are given below:

Capacitor sizes = [300 150 750 250 350]

A. Reliability Analysis of Distribution System

Most distribution systems are operated as radial networks, consequently the principles of series systems can be applied directly to them [28]. Three basic reliability indices of the system, average failure rate, λ_s , average outage time, r_s , and annual outage time U_s are given by

$$\lambda_s = \sum_i \lambda_i$$

$$U_s = \sum_i \lambda_i r_i$$

$$r_s = \frac{U_s}{\lambda_s}$$

V. RESULTS AND DISCUSSION

where λ_i , r_i and $\lambda_i r_i$ are, respectively, the average failure rate, average outage time and annual outage time of the i^{th} component.

DG placement can supply part of the reactive and active power demands, respectively. Therefore, due to the reduction of the magnitude of current, the resistive losses decrease. As a result, destructive effects of temperature on the reliability of overhead lines and underground cables are moderated. These impacts on reliability take into consideration as a failure rate reduction of distribution feeder components. Before DG placement, any feeder i has an uncompensated failure rate of $\lambda_i^{\text{uncomp}}$. If the reactive or active component of a feeder branch is fully compensated, its failure rate reduces to λ_i^{comp} . If the reactive and active components of current are not completely compensated, a failure rate is defined with linear relationship to the percentage of compensation. Thus, the compensation coefficient of the i^{th} branch is defined as:

$$\alpha_i = \frac{I_r^{\text{new}}}{I_r^{\text{old}}} * \frac{I_a^{\text{new}}}{I_a^{\text{old}}}$$

where $I_{r\text{new}}$, $I_{r\text{old}}$ and $I_{a\text{new}}$, $I_{a\text{old}}$ are the reactive and active components of the i^{th} branch current before and after compensation, respectively. The new failure rate of the i^{th} branch is computed as follows [29]:

$$\lambda_{i\text{-new}} = \alpha_i (\lambda_i^{\text{uncomp}} - \lambda_i^{\text{comp}}) + \lambda_i^{\text{comp}}$$

$\lambda_i^{\text{uncomp}}$ is assumed as 0.01 f/y and λ_i^{comp} is assumed as 0.0057 f/y for placement of DG, 0.0067 f/y for placement of capacitor and 0.0028 f/y for location of DG & Capacitor (assume both power loss and failure rate are reduced by same rate). The various customer oriented performance reliability indices are System Average Interruptions Frequency Index (SAIFI), System Average Interruptions Duration Index (SAIDI), Average Service Unavailability Index (ASUI) and one of load and energy oriented indices is Energy Not Supplied index (ENSI) explained below

$$SAIFI = \frac{\text{Total No. of Customer Interruption}}{\text{Total No. of Customers Served}} = \frac{\sum \lambda_{\text{system},i} N_i}{\sum N_i}$$

$$SAIDI = \frac{\text{Sum of Customer interruption durations}}{\text{Total no. of Customers Served}} = \frac{\sum U_{\text{system},i} N_i}{\sum N_i}$$

$$ASUI = 1 - \frac{\text{Customer hours of unavailable service}}{\text{Customer hours demanded}}$$

$$= 1 - \frac{\sum N_i * 8760 - \sum N_i U_{\text{system},i}}{\sum N_i * 8760}$$

$$ENS = \sum L_{a(i)} U_i$$

Where $L_{a(i)}$ is average load at load point L_i

The proposed method Fuzzy Genetic Algorithm (FGA) is implemented using MATLAB 2011 and tested for distribution system reconfiguration IEEE 33-bus RDS [30] given in Fig. 4. Substation voltage is 12.66 kV and base MVA has been taken as 100 MVA.

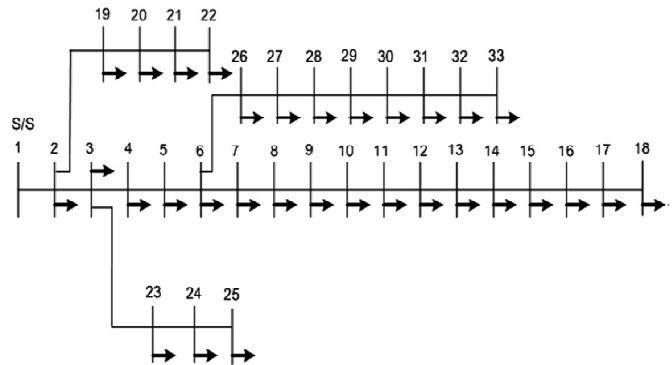


Fig. 4. IEEE 33 Bus System

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

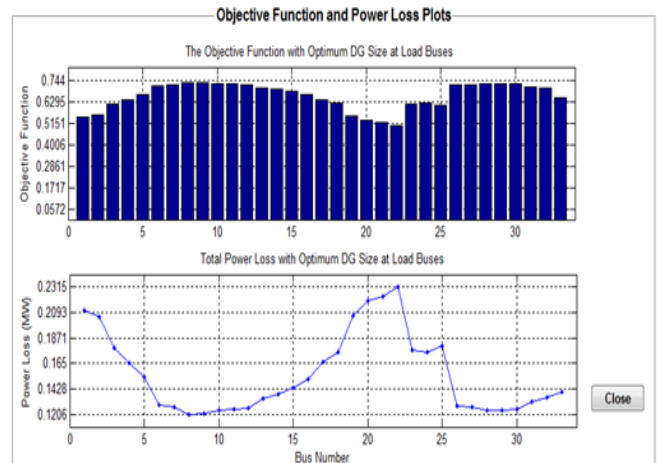


Fig. 5 Objective functions and Power loss plots with DG

DG, Capacitor, DG and capacitor placement optimization details for the same test system are presented in Table I for constant power load model.

Table I Optimization details for constant power load model for different cases

Case	Active power loss in kW	Reactive power loss in kVAR
Base case	211	143
with DG	120.6	106.3
with Capacitor	141.64	96
with DG & Capacitor	58.4	41

From the Table I, it is evident that the base case (without DG & capacitor) total real and reactive power losses are 210.99 kW and 143 kVAR respectively, whereas these losses for the optimal DG of size are 120.6 Kw and 106.3 kVAR respectively, for optimal capacitor of size and location these losses are 141.64 Kw and 96 kVAR respectively. If both DG and Capacitor placed in optimal location and size then these losses are further reduced to 58.4 kW and 41 kVAR respectively. Therefore, higher power loss reduction in distribution networks in the presence of DG and capacitor depends on the optimal size, location. Active power loss and Reactive power loss for different cases are shown in fig. 6 and fig. 7. By placing either DG or capacitor or DG and capacitor in the system the voltages profile of all the buses are improved or remained stable within tolerable limits is shown in fig. 8

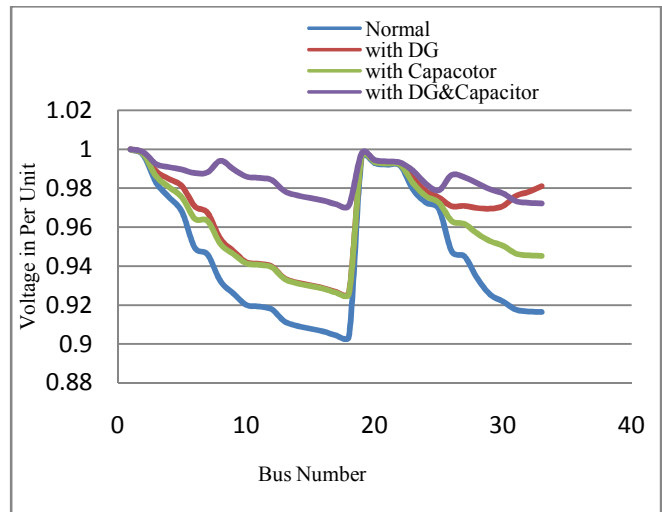


Figure 8. Per Unit Voltage of each bus for different cases

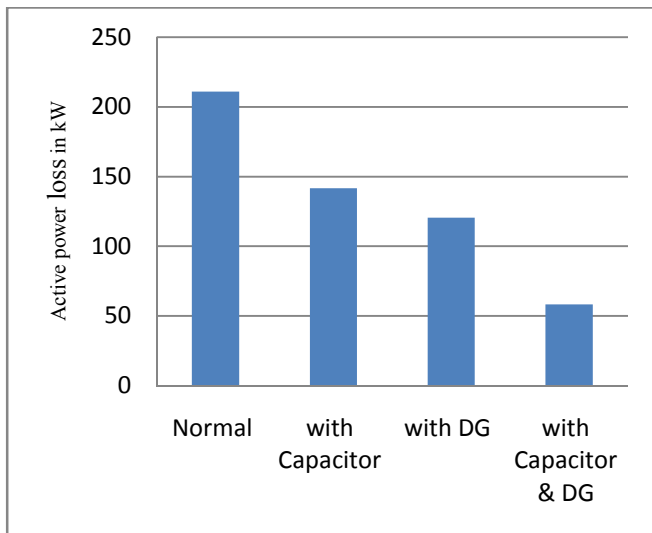


Figure 6. Active power loss for different cases

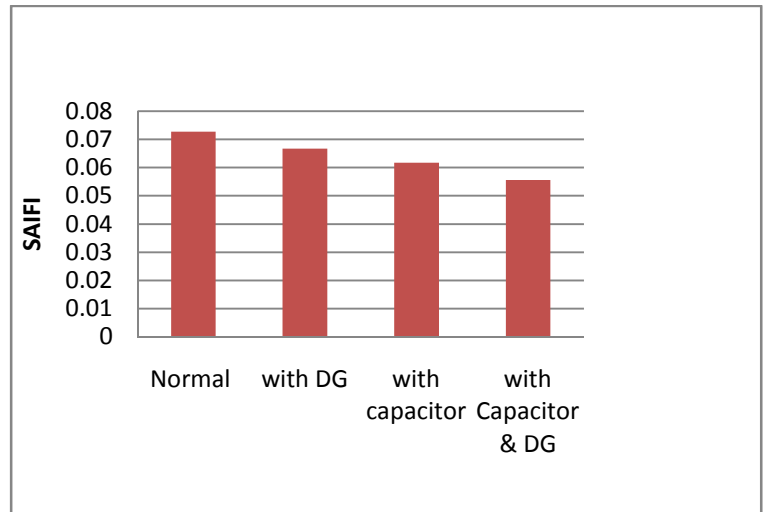


Figure 9. Improvement of SAIFI for different cases

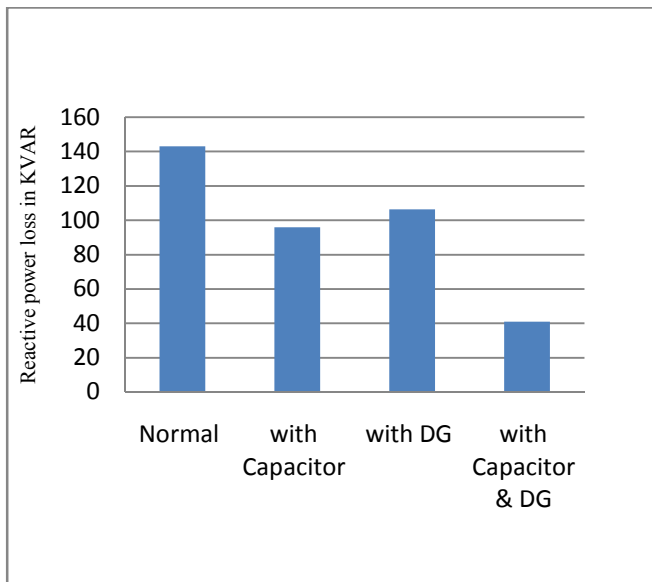


Figure 7. Reactive power loss for different cases

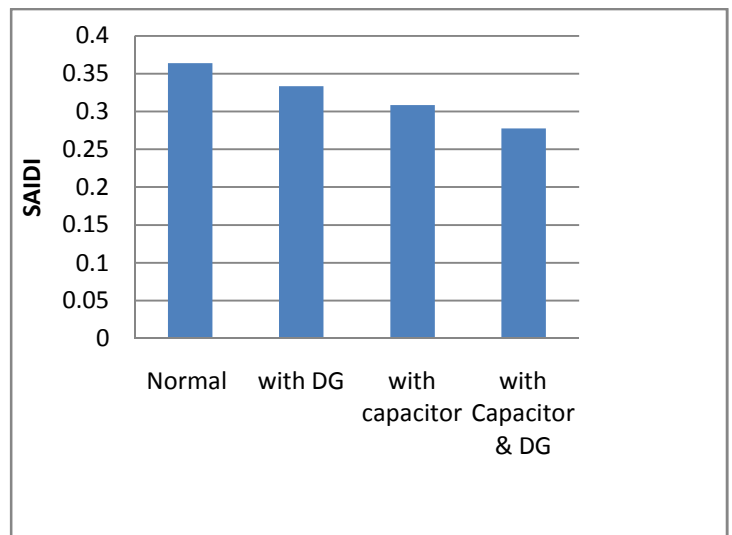


Figure 10. Improvement of SAIDI for different cases

Table II. Improvement of Performance in Reliability Indices

Parameter	Base case	With DG	With Capacitor	With DG & Capacitor
SAIDI hrs/customer in a year	0.363978	0.333683	0.308683	0.277849
SAIFI int/customer in a year	0.072769	0.06672	0.061739	0.055565
EENS kwh/year	1351	1239	1146.3	1032.42

From the Table II, it is clear that the base case (without DG & capacitor) SAIDI, SAIFI and EENS values are 0.363978 hrs/year, 0.072769 int/year and 1351 kWh/year respectively, where as optimal placement of DG or Capacitor or DG & Capacitor then there is considerable reduction in the above values. Hence, it means the reliability of the system is improved. Improvement of SAIDI, SAIFI and EENS for different cases is shown in Fig.9, Fig.10 and Fig. 11.

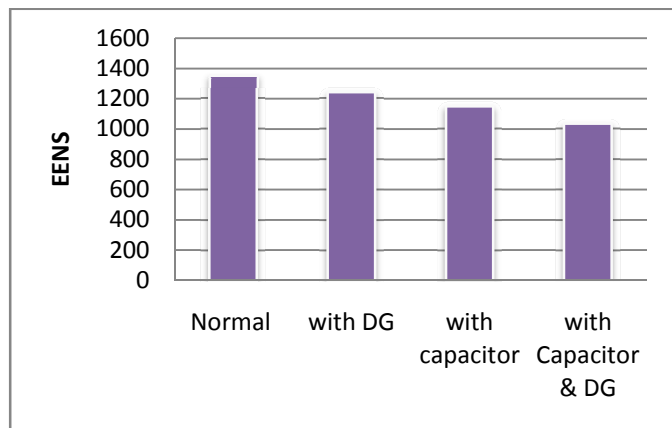


Figure 11. Improvement of EENS for different cases

VI. CONCLUSION

In this paper, optimal location and size of DG and Capacitor was identified by using Fuzzy Genetic Algorithm and genetic Algorithm respectively for IEEE 33 bus system. The comparison was made without DG & Capacitor and with DG, with Capacitor and with DG & Capacitor in terms of total power loss, voltage profile and reliability indices of the system. The total power loss without DG was 211 kW and after connecting DG & Capacitor in the system, the power loss was reduced to 58.4 kW. Thus the total loss was reduced by 72% of total power losses in the system. Reliability indices like SAIDI, SAIFI and ENS are also improved around 24.5% and the voltage profile of all the buses remained stable within the tolerable limits. Hence, the over all system power loss is reduced and reliability is improved.

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