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Optimal Nodal Power Requirements towards Loss Minimization and Stability Enhancement under Reverse Power Flow Constraint Defining DG Type

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Abstract: *Distributed systems plays a vital role in delivering power to the consumers. The goal of utility is to deliver the power of acceptable quality. Distributed Generation (DG) plays an important role in minimizing power losses in distribution network. Optimal placement of Distributed Generators (DG) finds a feasible solution for reducing the power loss and improved voltage stability and also this technical benefit of DG is ensured only on their optimal size and location. Genetic algorithm (GA) is used to define the optimal nodal power generation requirement and for the optimal number and location of nodes that yield for loss minimization and voltage stability enhancement. The objective of this proposed method is to enhance the voltage stability and minimizing the power losses in the system. This is to be achieved by ensuring the ability of the system to control the voltage after being subjected to small disturbances. The system variables are to be optimized with the above objective by using Genetic algorithm (GA) algorithm. The objective of this proposed work is to minimize the power losses and stabilized voltage. The system variables are to be optimized with the objective by using the Genetic algorithm (GA) optimization. Our approach is tested in IEEE 33 and IEEE 69-bus radial distribution systems.*

Keyword: *Distributed Generators; Genetic Algorithm (GA); Power loss; Voltage stability;*

1. INTRODUCTION

The distribution system is an important part of the total electrical network system, as it provides the final link between the bulk system and the customer. Power utilities are facing major challenges as the demand of power system is growing exponentially. The existing transmission line infra-structure is not capable to support such a huge power demand. The present need is to invest in transmission system to increase the capacity of the consumer demand locally by Distributed Generation (DG). In power system, power loss problem is one of the major drawbacks due to improper placement of DG. The optimal DG placement results in reduced distribution and transmission line losses. The existing lines should be used more efficiently for not only to reduce the losses, but also to maintain the voltage stability, reliability, security criteria and to increase the efficiency of overall system.

Distributed generation (DG) is an emerging approach for providing electric power in the heart of the power system. It mainly depends upon the installation and operation of small size, compact, and clean electric power generating units at or near an electrical

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load (customer).

DG is expected to play an increasing role in emerging electrical power systems. Studies have predicted that DG will be a significant percentage of all new generations going on lines. It is predicted that they are about 20% of the new generations being installed.

Optimal placement of DGs distribution network performance can be improved in terms of improved voltage profile, improved voltage stability, reduction in flows and power losses. DG's plays a key role in dealing with environmental concern due to their ability to produce green power and reduce the dependency on fossil fuels.

Distributed generation has meaningful effect on the network losses, voltage profile of the system, grid stability, critical loads and generation costs among others Technical literature has shown that the advantages of distributed generation can be achieved only by choosing the proper size of the DG and connecting it at the appropriate location in the power network.

2. LITERATURE REVIEW

In the competitive environment, utilities must have accurate information about the system performance to ensure that the customer expectations are to be met. The electric utility industry has developed several performance measures to evaluate the system stability performance. Power system has been providing on a stabilized and economic supply of electrical energy to their customers. In this work the technique that DG sources are becoming more prominent in distribution systems due to the incremental demands for electrical energy [1]. An optimal location and sizing of DG is initiated by particle swarm optimization (PSO) and genetic algorithm (GA). The distribution systems to minimize the network power losses, better voltage regulation and improve the voltage stability. In this work, the combined GA/PSO Optimization [2] is proposed. Separate optimization of particle swarm algorithm (PSO) is not considered.

A new hybrid method, which employs discrete particle swarm optimization (PSO) and optimal power flow (OPF) [3] used to achieve optimal site and size of distributed generation systems by computing the objective function and number of iterations a comparison between the proposed algorithm and other methods is performed. The proposed algorithm reaches a better solution than Genetic Algorithms considering similar number of evaluations. In this work, Loss minimization and enhancement of voltage stability have not been proposed. One of the significant methods for minimization of power loss in the Distribution network is improved Analytical (IA) method [4]. This method is proposed for multiple DG allocation for loss reduction in large-scale distribution systems. This method is based on IA expressions for finding the size and optimal or near optimal power factor has been also presented for placing DG units capable of delivering real and reactive power proposes the Optimal placement of different type of DG sources in distribution networks. In this work, enhancing voltage stability has not been discussed. An improved analytical (IA) expression method is proposed in this paper. This method is based on IA expressions [5] to calculate the optimal size of four different DG types and a methodology to identify the best location for DG allocation. In this technique the optimal power factor is presented for DG capable of delivering real and reactive power loss sensitivity factor (LSF) and exhaustive load flow (ELF) methods are also introduced. IA method was tested and validated on three distribution test systems with varying sizes and complexity. Results show that IA method is effective as compared with LSF and ELF solutions.

Multi objective performance index [6] is used for finding the optimal location of real power DG units and their capacities. The various impact indices such as a power loss index, line flow limit index, voltage profile index and voltage stability index are considered and are combined using weighting coefficients. The multi objective problem is solved using CABC algorithm for various types of load models. From the results, it can be concluded that the presence of DGs in optimal location reduces the real and reactive power losses and improves the voltage profile of the system.

Distributed generation (DG) is estimated to become more important in the future generation system. This paper discusses the incorporate of DG units into distribution systems can have an impact on voltage stability. Widely DG can be defined as electric power generation within distribution networks. In increasing, the terms of distributed resources, distributed capacity and distributed utility are discussed. This has been carried out on IEEE-6, IEEE-9 bus test system and PSAT [7] software results are presented. Improved and developed standard PSO optimization [8] for finding the size of different DG sizes and the best location for DG allocation. In this work, only power loss and reliability analysis was performed using improved PSO method. The authors failed to evaluate improving voltage stability.

Optimal placement of different type of DG sources in distribution networks. In this work, enhancing voltage stability has not been discussed. The proposed PSO approach for optimal placement of multiple types [9] of DGs not only reduces the line losses but also minimize the sizes of DGs with satisfaction of the permissible voltage limits. In this work the age of integrated grid, the placement and analysis of different types of DGs give guidance for optimal operation of power system has been discussed.

New hybrid method [10] which employs discrete particle swarm optimization and optimal power flow to overcome this shortcoming. The main technological constraints are imposed for utilities, to search the best sites to connect distributed generation systems in a distribution network choosing among a large number of potential combinations. In this work a fair comparison between the proposed algorithm and other methods is performed. The proposed algorithm reaches a better solution than Genetic Algorithms considering similar number of evaluations. The proposed approach is a discrete version of the PSO algorithm. It has been assessed using standard IEEE 30 bus test system. A new analytical approach [11] for DG allocation and sizing is based on a novel Power Stability Index (PSI) to determine the most voltage sensitive bus and minimum total power losses. This proposed algorithm takes less computation time by 50–60% as compared to Golden Section Search (GSS) algorithm. In this work, author failed to consider voltage stability enhancement.

Proper placement of DG in distribution system is still very challenging issue for obtaining their maximum potential benefits. Constrained multi-objective [12] a new approach of Particle Swarm Optimization (PSO) based Wind Turbine Generation Unit (WTGU) and photovoltaic (PV) array placement for voltage stability improvement and power loss reduction of radial distribution system. This proposed method targets to improve the voltage stability margin and reduce network power losses utilizing supply from DG units. In this work, optimization is carried with Particle Swarm Optimization for optimal DG placement. Finding new approach for optimal location and size of DG with an objective of minimizing network power losses, operational costs and improving voltage stability. Loss sensitivity factor [13] is used to identify the optimal locations and siting for installation of DG units. Bacterial Foraging Optimization Algorithm (BFOA) is used to find the optimal size of DG. This proposed technique is very accurate in finding the optimum solutions and this work can also be implemented for all systems with n number of buses and all types of loads. In this work, Bacterial Foraging Optimization Algorithm (BFOA) is used which takes more computational time than the GA.

Modified Teaching–Learning Based Optimization (MTLBO) algorithm [14] is proposed to determine the optimal placement and sizing of DG units in distribution systems. This algorithm permits the finding of best places to connect a number of DG units, among a large number of combinations. In this work, author failed to consider stabilizing the voltage limits in the distribution system. A simple conventional iterative search technique [15] along with Newton Raphson method of load flow study is implemented on modified bus system. Focused on optimization of weighting factor, which balances the cost and the loss factors. In this work, only cost and losses in the network has been discussed, failed to evaluate enhancing the voltage stability.

This project concentrates the enhancement of voltage stability and minimizing the power losses in the system simultaneously by the proper allocation of DGs using Genetic Algorithm. The proposed methodology is applied to 33 and 69 bus system. First the problem is to be formulated as an optimization problem with the objective of minimization of loss and voltage stability and for the enhancement of distribution network.

3. PROBLEM FORMULATION

The voltage in a distribution network at some buses causes verge of voltage collapse and also increases the active and reactive currents flowing in the branches which causes power losses in the distribution network.

3.1 Voltage stability index (VSI)

The VSI gives a significant detail about the voltage stability of the radial distribution systems. In this approach, VSI is taken as the decisive factor which variation of this value indicating the system voltage stability for the presence and absence of DGs connect to the test systems. The VSI can be defined as [7],

$$VSI(m_2) = |V(m_1)|^4 - 4.0\{P(m_2)\,x(jj) - Q(m_2)\,r(jj)\}^2 - 4.0\{P(m_2)\,r(jj) + Q(m_2)\,x(jj)\}\,|V(m_1)|^2 \quad (1)$$

Where

NB = total number of nodes;
jj = branch number;
$VSI(m_2)$ =voltage stability index of node m_2
$r(jj)$ = resistance of branch jj;
$x(jj)$ = reactance of branch jj;
$V(m_1)$ = voltage of node m_1;
$V(m_2)$ = voltage of node m_2;
$P(m_2)$ = real power load fed through node m_2;
$Q(m_2)$ = reactive power load fed through node m_2.

The intensity of stability can measure the distribution system using the VSI and thereby necessary action, possibly taken if the index indicates the instability condition of the system. The system operates at secure and stable condition the evaluated VSI values are greater than zero, otherwise instability occurs.

3.2 Power Loss Minimization

The penetration of DGs in DNs is expected to yield decreased branch currents and thus to contribute in loss reduction. The main objective function in this work is formulated by the terms of power loss minimization given as [1],

$$F_{loss} = min \sum_{\substack{i,j=1 \\ i\neq j}}^{n_l} g_{i.j} \left(V_i^2 + V_j^2 - 2V_iV_j \cos(\theta_i - \theta_j)\right) \quad (2)$$

Where

V_i is the voltage magnitude of bus i;
V_j is the voltage magnitude of bus j;

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$g_{i,j}$ is the Conductance between buses i and j;
θ_i is the voltage angle of bus i;
θ_j is the voltage angle of bus j;
n_l is total number of branches in the network;
F_{loss} is target/objective function to be minimized.

The objective function [2] is intended to be minimized under the optimal siting and sizing of DGs subject to the following constraints: Equality constraints: power flow equations satisfaction.

Inequality constraints: Inequality constraints are included basically to express capacity and operational limits of the system. The following expressions formulate the nodal voltage and branch currents constraints

$$V_i^{min} < V_i < V_i^{max} \tag{3}$$

Where $V_i^{min} and\ V_i^{max}$ the lower and upper voltage limit of each bus.

Reverse power flow constraints: The reverse power flow constraint is formulated in this work under the following expressions:

$$-P_{slackbus}^{Reverse} < \Delta P_{Slackbus}^{Optimum} \tag{4}$$

$$\left|\Delta P_{Slackbus}^{Optimum}\right| < \left|\Delta P_{Slackbus}^{initial}\right| \tag{5}$$

Where
$-P_{slackbus}^{Reverse}$ is the permissible magnitude of reverse power flow.
$\Delta P_{Slackbus}^{Optimum}$ is the difference between the injected and consumed active power at the slack bus for the final optimum solution after the sitting and sizing of DGs.
$\Delta \mathrm{P}_{\mathrm{slackbus}}^{\mathrm{initial}}$ is the difference between the injected and consumed active power at the slack bus before the DGs penetration.

DG real power generation limits: The real power generated by each DG is limited by its lower and upper limits as

$$P_{DG}^{min} \leq P_{DG} \leq P_{DG}^{max} \tag{6}$$

4. GENETIC ALGORITHM

In the proposed work the optimal location and capacity of DGs is obtained using Genetic Algorithm (GA). GA uses the concept of genetic evolution to achieve convergence and it can be utilized for both constrained and unconstrained optimization problems. GA has advantage over other conventional and modern optimization approaches is that it does not require any prior information of objective function. Also it does not deal directly with the parameters of optimization problem.GA propagates in a search space containing random sets of 'N' possible solutions, collectively called population. Each candidate solution contains a random set of 'n' possible location for DG connection and their corresponding random DG ratings, individually called genes.GA selects the candidates for operation by their biological selection of most fit candidate by the help of fitness function.GA converge the solution in iterative way by using genetic operators 'Reproduction' 'Crossover' and 'Mutation' inspired by natural evolution process. GA modifies the population of candidate solutions for every iteration as per the genetic operators; this modified population is called generation.

4.1 Population

To initialize the algorithm GA requires an initial set of probable solutions called initial population. This is completely a random group of candidate solution generated by random number generator and for these candidates no prior knowledge exists. These candidate solution consist subset consisting properties of candidate related to the DG location and sizes, known as genes.

4.2 Genetic Operators

After evaluating the fitness of each candidate using fitness function, GA converge the solution by their genetic operators which are Reproduction Selection, Crossover & Mutation. This complete evolution process is nature inspired, although it's not necessary to use all the operators. Use of operators can be modified as per requirement of the problem.

4.3 Algorithm control parameters

Control parameters are applied at every step of algorithm to control the execution of the algorithm. This is necessary to control because uncontrolled evolution may lead the algorithm towards non-optimal results or may keep algorithm unconverged.

The common parameters for the genetic algorithm are Initial population size, selection rate, crossover rate and mutation rate. Population size defines the area of search space. Large population size has the advantage of better results but may increases the time of execution.

Selection rate is defined by the fitness below which candidate marked as unfit for optimization. This helps in selection of candidate with better fitness. A higher fitness level reduces the execution time of algorithm as it selects the candidates with high value of fitness.

Crossover and Mutation are the most important steps of evolution. Crossover rate control the frequency of crossover operation whereas mutation rate controls the percentage of diversity introduced by operator in child chromosome. Higher mutation rate may distinct the child from rest of population.

5. SOLUTION METHODOLOGY

Optimization is a process by which we try to find

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out the best solution from set of available alternative. In DG allocation problem, DG locations and sizes must be optimizing in such a way that it gives most economical, efficient, technically sound distribution

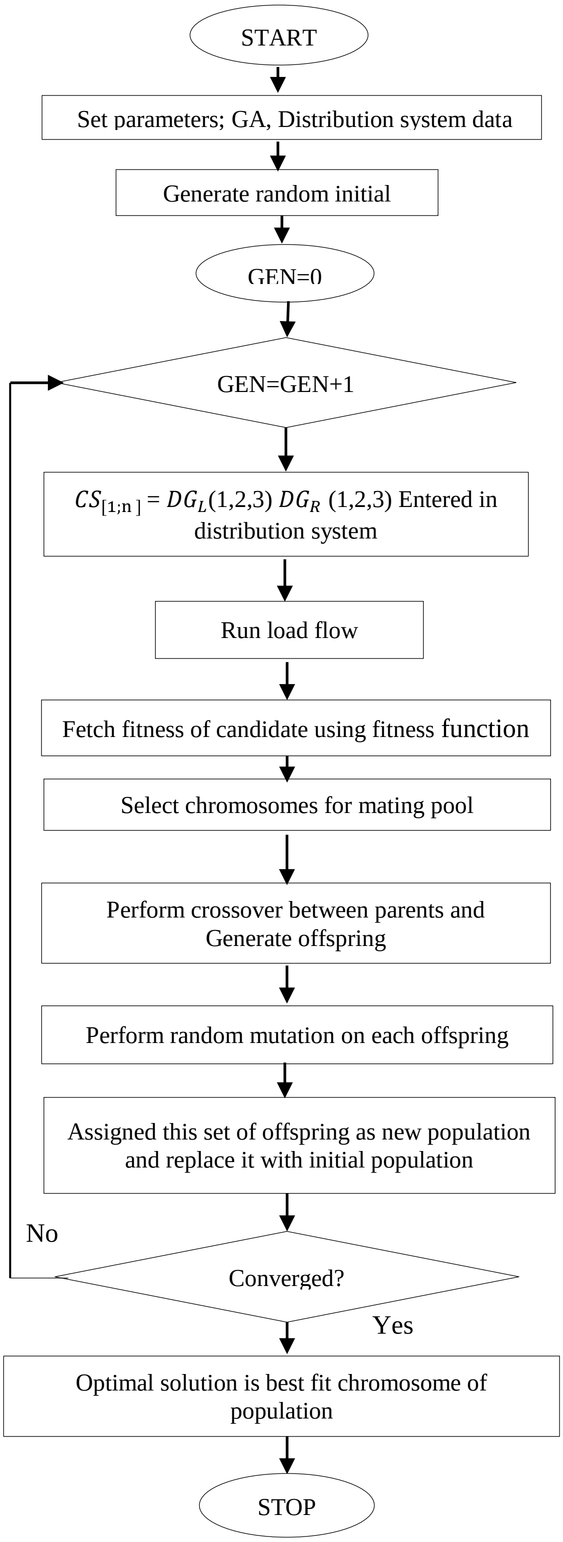

Figure 1 Flowchart of proposed method

system. There are numerous optimization approaches used in the literature. In most of the current works, population based evolutionary algorithms are used as optimization approaches. In the project work genetic algorithm is used as the solution strategy. The flow chart of the proposed method is shown in Figure.1.

Genetic Algorithms (GAs) are versatile exploratory hunt processes focused around the evolutionary ideas of characteristic choice and genetics. A genetic algorithm is analytically guided random search technique that concurrently evaluates thousands of postulated solutions. Biased random selection and mixing of the evaluated searches is then carried out in order to progress towards better solutions. The coding and manipulation of search data is based upon the operation of genetic DNA and the selection process is derived from Darwin's survival of the fittest' Search data are usually coded as binary strings called chromosomes, which collectively form populations. Typically, mixing involves recombining the data that are held in two chromosomes that are selected from the whole population.

The following steps are involved to enhance the improved voltage stability and minimized losses in distribution network of system by optimal allocation of DG using GA Optimization algorithm.

Step 1: Read the system input data, termination condition and specify the DG parameters.

Step 2: Run load flow of distribution networks, and save the all node voltage and all branch current magnitudes of the networks and total power loss and stabilized voltage. Randomly generate the initial population.

Step 3: Calculate the power losses and voltage stability index except slack bus and Evaluate the results of power losses and voltage stability index without DG placement.

Step 4: Update the population using GA optimization. Set and initialize the parameters of GA Optimal placement of DG for optimal location and sizing.

Step 5: Run the load flow of distribution networks with updated system data. Also calculate voltage stability and total power loss simultaneously for each population.

Step 6: Evaluate the objective function and the fitness value for each DG nodes. If the new solution is better than existing solutions modify the solution otherwise keep that solution.

Step 7: Print the results.

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6. RESULTS AND DISCUSSION

Programs are written in MATLAB coding for minimizing the power losses and improving the voltage stability of the network in both 33 and 69 bus systems. And then GA optimization code is written for both optimal placement and sizing of DG's simultaneously.

6.1 IEEE 33 Bus System

The tested bus is IEEE 33 and it is achieved by using the Genetic algorithm optimization. The proposed GA optimization is applied to IEEE 33–bus network for the proper allocation of location and sizing of DG by minimizing the power losses and voltage stability enhancement in Distribution Network. The proposed method is also used to find power flow, active power losses and a reactive power loss in the IEEE 33–bus system. Figure.2 shows the single line diagram of IEEE 33 bus system.

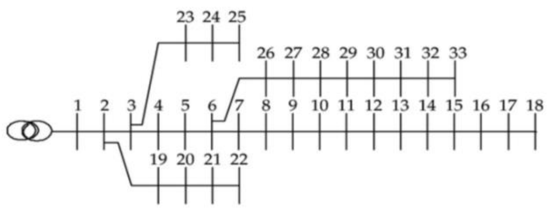

Figure.2 Single line diagram of IEEE 33 bus distribution system

This bus system has the following data:

Buses : 33
Branches : 32
Base voltage : 12.66 KV
Base MVA : 100
Total load connected: 3.715 MW and 2.3 MVar

The test system IEEE 33 bus individual real and reactive power losses of base case result at each bus system. The table I show the result of active and reactive power losses are calculated without optimal DG placement.

TABLE I LOAD FLOW FOR IEEE 33 BUS SYSTEM

Individual P loss (KW)	**Individual Q loss (KW)**	**Total Losses (KW)**
209.913	142.516	352.29

The test system IEEE 33 bus minimized individual real and reactive power losses at each bus system. The table II shows the result of the active and reactive power losses are calculated with optimal DG placement and the proposed approach reduces the losses compared with base case results.

TABLE II DG PLACEMENT RESULT FOR IEEE 33 BUS SYSTEM

Individual P loss (KW)	**Individual Q loss (KW)**	**Total Losses (KW)**
70.318	48.248	118.566

Voltage stability analysis is concerned with the calculation of how far the system is operating from the voltage collapse point using repeated load flow solutions. The VSI gives a significant detail about the voltage stability of the radial distribution systems. In this approach, VSI is taken as the decisive factor which variation of this value indicating the system voltage stability for the presence and absence of DGs connect to the 33 test bus systems.

TABLE III VOLTAGE STABILITY ANALYSIS FOR IEEE 33 BUS SYSTEM

Without DG placement		**With DG placement**	
Bus No.	**Voltage stability index (VSI)**	**Bus No.**	**Voltage stability index (VSI)**
24	-41.44	24	0.93
25	-40.95	25	0.91
08	-35.08	08	0.88
30	-9.21	30	0.83
20	-9.18	20	0.98

The table III shows the At most un-stabilized voltages in IEEE 33 buses and optimized with the Genetic algorithm for selecting optimal location and sizing of DG placement. Here, compare the both the calculated values of VSI with optimal placement of with and without DG. Obviously, the proposed approach improves the voltage stability of the distributed system. Figure.3 shows the plot of improvement in the voltage profile of 33 bus system with optimal DG allocation

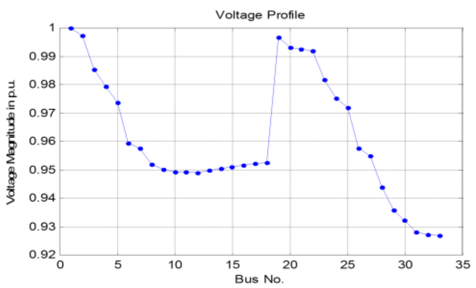

Figure 3. Plot of voltage profile improvement for IEEE 33 bus system

The system operates at secure and stable condition the evaluated VSI values are greater than zero, otherwise instability occurs.

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6.2 IEEE 69 Bus System

The tested bus is IEEE 69 and it is achieved by using the Genetic algorithm optimization. The proposed GA optimization is applied to IEEE 69–bus network for the proper allocation of location and sizing of DG by minimizing the power losses and voltage stability enhancement in Distribution Network. The proposed method is also used to find power flow, active power losses and a reactive power loss in the proposed method is tested on the 33–bus system. Figure 4 shows the single line diagram of IEEE 69 bus system.

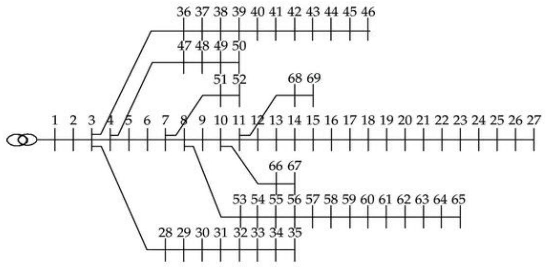

Figure.4 Single line diagram of IEEE 69 bus distribution system

This bus system has the following data:

Buses : 69
Branches : 68
Base voltage : 12.66 KV
Base MVA : 100
Total load connected: 3.80 MW and 2.69 MVar

The test system IEEE 69 bus individual real and reactive power losses of base case result at each bus system. The table IV show the result of active and reactive power losses are calculated without optimal DG placement.

TABLE IV. LOAD FLOW FOR IEEE 69 BUS SYSTEM

Individual P loss (KW)	Individual Q loss (KW)	Total Losses (KW)
224.487	101.940	326.427

TABLE V. DG PLACEMENT RESULT FOR IEEE 69 BUS SYSTEM

Individual P loss (KW)	Individual Q loss (KW)	Total Losses (KW)
155.722	70.498	226.22

The test system IEEE 69 bus minimized individual real and reactive power losses at each bus system the table V show the result of the active and reactive power losses are calculated with optimal DG placement and the proposed approach reduces the losses compared with base case results.

Voltage stability analysis is concerned with the calculation of how far the system is operating from the voltage collapse point using repeated load flow solutions. The VSI gives a significant detail about the voltage stability of the radial distribution systems. In this approach, VSI is taken as the decisive factor which variation of this value indicating the system voltage stability for the presence and absence of DGs connect to the 69 test bus systems.

TABLE VI VOLTAGE STABILITY ANALYSIS FOR IEEE 69 BUS SYSTEM

Without DG placement		With DG placement	
Bus No.	Voltage stability index (VSI)	Bus No.	Voltage stability index (VSI)
61	-93.04	61	0.73
49	-13.98	49	0.98
64	-10.85	64	0.73
12	-6.40	12	0.93
65	-2.70	65	0.74

The table VI shows the At most un-stabilized voltages in IEEE 69 buses and optimized with the Genetic algorithm for selecting optimal location and sizing of DG placement. Here, compare the both the calculated values of VSI with optimal placement of with and without DG. Obviously, the proposed approach improves the voltage stability of the distributed system. Figure.5 shows the plot of improvement in the voltage profile of 69 bus system with optimal DG allocation.

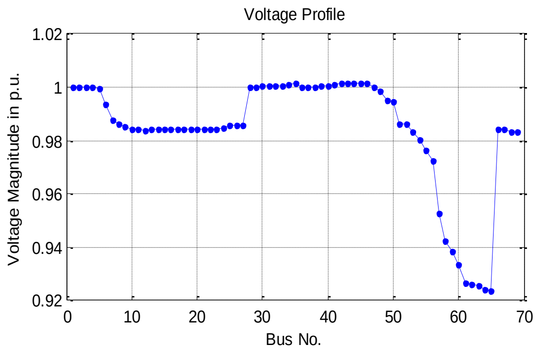

Figure 5. Plot of voltage profile improvement for IEEE 69 bus system

The system operates at secure and stable condition the evaluated VSI values are greater than zero, otherwise instability occurs. The table VII shows the comparative result analysis of objective functions for both IEEE 33 and IEEE 69 bus system. Comparing the base case results of IEEE 33 and IEEE 69 bus system with the optimal DG allocation gives better results. In this result analysis the comparison of both the power loss minimization and voltage stability enhancement by with and without DG placement.

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7. CONCLUSION

In this work Genetic Algorithm Optimization has been used for the IEEE 33 and IEEE 69 bus radial distribution systems for minimizing the power losses and to enhance the voltage stability by finding weakest voltage bus as well as due to weakest link in the system by optimal allocation and sizing of DGs in distribution network. This work concludes with the improvement of stabilized Voltage and reduced power losses in the distribution network system. Comparing the obtained results with base case values with the allocation of DGs gives better results. Obviously, this proposed approach improves the voltage stability and reduces losses in distributed system. The proposed work is implemented in MATLAB and evaluated the improved performance of objective functions.

TABLE VII COMPARATIVE RESULT ANALYSIS FOR IEEE 33 AND IEEE 69 BUS SYSTEM

Parameters	**IEEE 33**				**IEEE 69**			
	Without DG	**With DG**	**Actual Reduction**	**Reduction in %**	**Without DG**	**With DG**	**Actual Reduction**	**Reduction in %**
Total Losses (KW)	215.4935	72.9521	142.5414	66%	107.7142	73.2611	34.4531	31%
Voltage stability index (VSI)	-135.86	4.53	-140.11	100%	-126.97	4.11	-131.08	100%

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