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Placement of Distributed Generation in 33/11 kV Radial Distribution System to Minimize Power Losses, Improvement in Voltage Profile and Reliability using Genetic Algorithm

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Integration of renewable energy based distributed generation units provide 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 energy losses and reliability improvement. Therefore, the allocation of DG units should be carefully determined with the consideration of different planning incentives. In this paper, a simple method for real power loss reduction, voltage profile improvement which is based on voltage sensitivity index analysis is considered. Power flow analysis is done using the forward-backward sweep method, the placement and sizing of DG in distribution system are determined using optimization.The objective is to improve the reliability indices. The placement and size of DGs are optimized using a Genetic Algorithm. To evaluate the proposed algorithm, the 10 bus distribution feeder is used. The results illustrate the efficiency of the proposed method.

Keywords: *Distribution Generation, Distribution System, Backward-Forward Sweep,Optimization, Reliability, Genetic Algorithm, Voltage sensitivity index.*

1.0 INTRODUCTION

Due to the limitation on fossil fuel resources, alternative solutions to traditional large power stations are under high priority in recent years to meet growing energy demand of the future. Also large power stations are discovered due to many environmental concerns. On the other hand, renewable energy based electricity generated would be very small as compared to large fossil fuel based power plant. Technically they are suitable for installation at low voltage distribution system, near load centers [1].

Electric power system has been originally designed based on the unidirectional power flow, but the concept of DG has led to new consideration concerning the distribution networks [2]. The penetration of DG may impact the operation of a distribution network in both beneficial and detrimental ways. Some of the positive impacts of DG are voltage support, power loss reduction, support of ancillary services and improved reliability, where as negative ones are protection coordination, dynamic stability and islanding. In order to maximize benefits and minimize problems, technical constraints concerning the interconnection of DG units and their penetration levels are being adopted worldwide. Furthermore, the presence of DG in the deregulated market has raised new regulatory issues, concerning financial incentives, cost allocation methods, generation management techniques etc.

There are number of approaches proposed for placement and sizing of DG units [3-7]. In this

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paper, Power flow analysis is done using forward-backward sweep method [8]. Genetic algorithm [9] is proposed to usefor achieve optimal response, for loss reduction, voltage profile improvement, and improvement in reliability.Test results carried out on a 10 bus radial distribution feeder validates the suitability of this proposed method. The line and load data of the system obtained from [10].

2.0 PROBLEM FORMULATION

2.1 Load Flow Analysis

Conventional NR and Gauss Seidal methods may become inefficient in the analysis of distribution systems, due to the special features of distribution networks, i.e. radial structure, high R/X ratio and unbalanced loads etc. These features make the distribution systems power flow computations different and somewhat difficult to analyze as compared to the transmission systems. Various methods are available to carry out the analysis of balanced and unbalanced radial distribution systems and can be divided into two categories. The first type of methods is utilized by proper modification of existing methods such as NR and GS methods. On the other hand, the second group of methods is based on backward and forward sweep processes using Kirchhoff's laws. Due to its lower memory requirements, computational efficiency and robust convergence characteristic, backward and forward sweep based algorithms have gained the most popularity for distribution systems load flow analysis. In this paper, backward and forward sweep method [7] is used to find out the load flow solution.

2.2 Methodology

The method used for performing Load Flow Analysis is forward - backward sweep method for calculating voltage drops and losses of Network at different buses/nodes. The forward/backward sweep method is explained in brief as follows:

The forward-backward sweep is used as an iterative means to solve the load flow equations of radial distribution systems. The backward –forward sweep method exploits the radial topology of a distribution network. i.e., there is a unique path from any given bus to the source. There are two steps in this method, the Backward sweep, which is primarily a current summation based on the voltage updates from the far end of the feeder to the sending end and the forward sweep, mainly a voltage drop calculation from the sending end to the far end of a feeder or a lateral. By using KVL and KCL, the voltage drops can be obtained. These two steps are repeated until convergence is achieved.

The Backward sweep calculates the current injected into each branch as a function of the end node voltages. It performs a current summation while updating voltages. Bus voltages at the end nodes are initialized for the first iteration. Starting at the end buses, each branch is traversed toward the source bus updating the voltage and calculating the current injected into each bus.

These calculated currents are stored and used in the subsequent Forward sweep calculations. The Forward sweep calculates node voltages as function of the currents injected into each bus. The forward sweep is a voltage drop calculation with the constraint that the source voltage used is the specified nominal voltage at the beginning of each forward sweep. The voltage is calculated at each bus, beginning at the source bus and traversing out to the end buses using the currents calculated in the backward sweep.

Convergence is achieved when the magnitude of the voltage mismatch between the calculated source voltage in the Backward sweep and the specified source voltage is less than or equal to a specified tolerance.

The currents of all branches so calculated during the final iteration of the backward sweep are used for calculation of Power losses.

3.0 OPTIMAL LOCATION OF DG BASED ON VOLTAGE SENSITIVITY INDEX

When DG is connected at bus i, VSI for bus i is defined as

$$VSI_i = \sqrt{\frac{\sum_{k=1}^{n}(1 - V_k)^2}{n}} \quad ....(1)$$

Where V_k is voltage at k^{th} node and n is the number of nodes.

In order to restrict solution space to few buses, voltage sensitive nodes are first identified by penetrating DG with 15% of the total feeder loading capacity at each node at a time and then, calculating the voltage sensitivity index (VSI) using (1).

The node with least VSI will be picked as the best location for the DG placement.

4.0 OPTIMAL SIZE OF DG

To determine the optimal size of DG, the following steps are followed:

1. First the DG is placed at the node with least VSI
2. Keeping the power factor of DG constant, its size is varied from a minimum value to a value equal to feeder loading capacity in constant steps until the minimum system losses is found.
3. The DG size which results in minimum losses is taken as optimal.

5.0 GENETIC ALGORITHM FOR OPTIMIZATION

Due to the discrete nature of allocation and sizing problem, it undergoes a number of local minima. To deal with this a reliable optimization method is required. The optimization methods are mainly divided into analytical and heuristic methods. The analytical methods show higher accuracy compared with the heuristic methods in the smooth functions. However, the objective function in the discrete problems is non-smooth which reduce the accuracy of the analytical method and lead from occasionally to be stuck in the local minima. For optimizing this type of functions, the heuristic algorithms play an important role. They are based on the random values and if only one of these random values is located close to the global minimum, they can findacceptable solution.In this paper, Genetic Algorithm is proposed to be used to achieve optimal response. GA simulates the biological processes that allows the consecutive generations in a population to adapt to their environment. Genetic algorithm is unconstrained optimization methods, which model the evolutionary adaptation in nature. They work with a population of solutions and create new generations of solutions by appropriate genetic operators. The algorithm for the above said problem is as follows:

1. Read line data, bus data of radial distribution system.
2. Read DG sizing & identify the DG location using voltage sensitivity index.
3. Initialize GA Parameters i.e., Population Size, String Length, Probability of Cross Over and Mutation.
4. Generate initial population of chromosomes.
5. Set generation and chromosome count.
6. Decode the chromosome and calculate the actual values of DG sizing.
7. Run radial distribution system load flow by incorporating DG.
8. Calculate Active Power Loss, Voltage Sensitivity Index, and Reliability Indices.
9. Calculate the fitness function.
10. Repeat the procedure from step 6 to step 9 until chromosome count is equal to population size.
11. Terminate the algorithm if (fitness function of first chromosome – fitness function of last chromosome)≤0.000001 go to step 18.
12. Arrange chromosomes in descending order and their fitness value.
13. Elitism probability of best chromosomes is passed on to the next generation and perform Roulette Wheel Reproduction Technique for parent selection.

14. If ($r<P_c$) perform uniform cross over to obtain children of next generation, where 'r' is a random generated number between 0 and 1 and P_c is the cross over probability.
15. If ($r<P_m$) perform mutation.
16. Replace old population with new population.
17. Increment generation count. If (generation count <maximum iteration) go to step 6.
18. Print optimized value of DG sizing, Voltage magnitudes, Voltage Sensitivity Index, Power Loss, and Reliability Indices.

6.0 SIMULATION RESULTS

For simulation purpose, 10 bus radial distribution system is considered for DG installation. The presented algorithm was implemented and coded in MATLAB computing environment. In order to evaluate the proposed method the objective function is minimized using Genetic Algorithm. Optimum size and location of one DG unit is determined with the proposed method.

For the calculation of reliability indices the failure rate of the system is assumed as 0.065 f/yr, the repair and switching time is assumed as 5 hrs and 1 hrs. The substation bus voltage (bus 1) is considered as 1.0. p.u. and the lower and upper limit of voltage magnitude of buses are 0.95 to 1.05 p.u. are assumed.

The GA parameters are assumed as

Population Size = 40

String Length = 6

Probability of Cross Over = 0.8

Probability of Mutation = 0.05

7.0 TEN BUS SYSTEM

The single line diagram of 11 KV, 10bus, 10 section radial distribution system is shown in Figure 1. The total load of the system is considered as 4750KW.

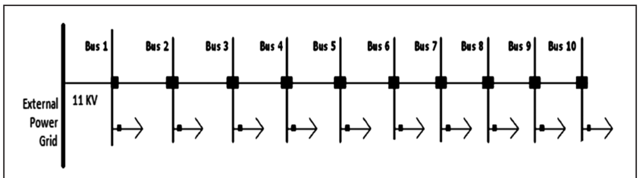

FIG.1 RADIAL DISTRIBUTION FEEDER

The optimal location and size of DG unit are given in Table 1.

TABLE 1

OPTIMUM SIZE AND LOCATION OF SINGLE DG UNIT IN 10 BUS SYSTEM

Parameter	Location	Size
DG	10	712.5 KW

In order to indicate and compare the effects of DG placement in the test system, the results are compared to the case when there is no DG in the system and results are presented in Table 2.

TABLE 2

COMPARISON OF RESULTS BEFORE AND AFTER DG IN 10 BUS SYSTEM

Param-eters	Base Case	DG with GA	% Impro vement
P LOSS (KW)	276.24	169.10	38.78
VOLTAGE (P.U.)	0.9283	0.9478	2.1
VSI	0.0503	0.0390	22.46
SAIFI	0.3710	0.3710	---
SAIDI	1.8512	0.6656	64.04
CAIDI	5.0000	1.7938	64.12
AENS	12.616	4.5261	64.12

It can be seen from the table that determination of optimum size and location of DG has a considerable effects on loss reduction, voltage and reliability improvement in the test system. It is observed that the frequency related indices remains the same, since the DG breaker is also triggered when a fault occurs in the system.

The duration related indices improves with installation, since some loads interruption duration reduces when the main supply is unavailable. The variations of these indices are shown in Figure 2. On the other hand, the DG reduces power losses significantly so that the active power loss is reduced from 276.24KW to 169.10KW as shown in the Figure 3. Moreover, VSI reduces from 0.0503 to 0.039. Therefore voltage deviations of nodes from 1.0 p.u. in the test system are reduced by DG installation.

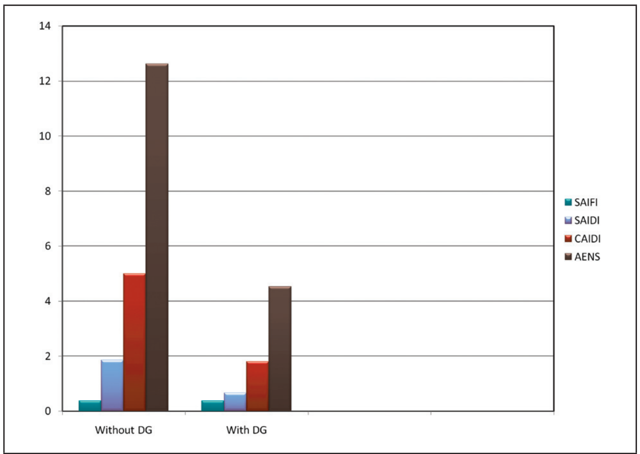

FIG. 2 VARIATION OF RELIABILITY INDICES

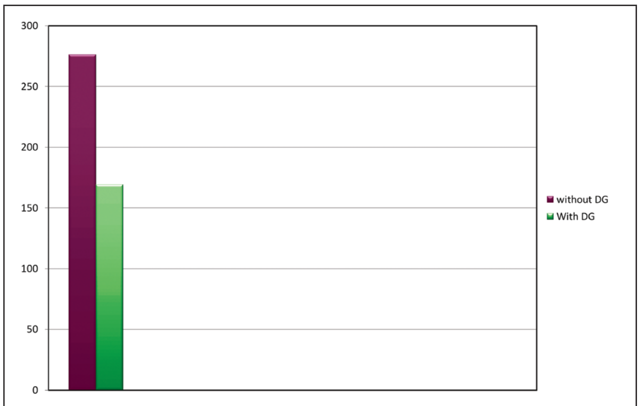

FIG. 3 VARIATION OF ACTIVE POWER LOSSES

The voltage profile of nodes before and after installation of DG in 10 bus system, shown in Figure 4. It can be seen from this figure that voltage profile of nodes improved significantly when DG are installed in the system.

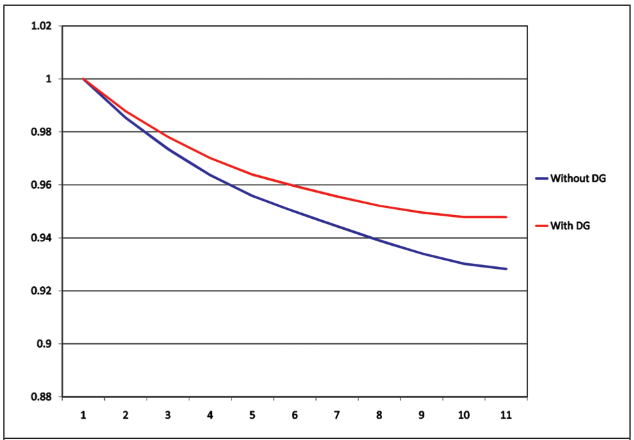

FIG. 4 VOLTAGE PROFILE OF 10 BUS NODE

The convergence speed of the proposed GA based solution methodology in finding the global optimum solution of the DG allocation and sizing problem, is shown in Figure 5.

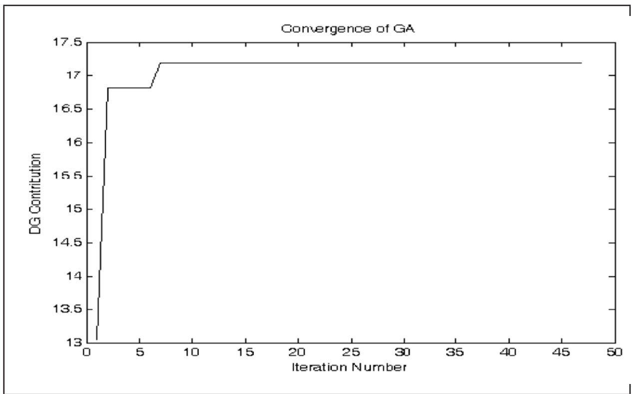

FIG. 5 CONVERGENCE CHARACTERISTICS OF GENETIC ALGORITHM

8.0 CONCLUSIONS

In this paper, the GA was tested on a 10 bus test system to find the optimum location and size of DG. The objective was to minimize real power losses, voltage sensitivity index, improvement in reliability indices and voltage profile. The objective function was subjected to operating constraints. The simulation results are shown before and after DG. In addition, the results indicate that GA has effectiveness to search optimum point and size of DGs on power system network.

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