IJARIIT INTERNATIONAL JOURNAL OF ADVANCE RESEARCH, IDEAS AND INNOVATIONS IN TECHNOLOGY

ISSN: 2454-132X

Impact factor: 4.295

(Volume3, Issue3)

Available online at www.ijariit.com

Impact of Distribution Feeder Reconfiguration for Loss Reduction on Bus Voltages -A Perspective

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Abstract: A huge power is dissipated in distribution systems as power losses. The loss reduction and bus voltage improvement are the critical parameters of effective distribution feeder power flow. There are several techniques followed for power loss reduction and voltage profile improvement in distribution systems. Specifically, Distribution Feeder Reconfiguration (DFR) method is employed for the proposed system. The most important criterion of Distribution Feeder Reconfiguration is loss reduction, voltage profile improvement and relieving of the power lines from overloading. The proposed method is tested on a 3-Feeder distribution network and IEEE 33-Bus system. Genetic Algorithm (GA) optimization approach is applied to get the optimal switching scheme for feeder reconfiguration. Simulation results from load flow analysis and GA methodology have shown that the implementation of this method leads to a significant enhancement in voltage profile and reduction in the real power loss. Finally, results of system loss reduction and voltage stability enhancement with brief overview of approached model are revealed in this paper.

Keywords: Distribution Systems, Feeder Reconfiguration, Bus Voltage Improvement, Optimization Approach, Loss Reduction and Genetic Algorithm.

I. INTRODUCTION

Distribution Feeder Reconfiguration is a vital component of distribution automation system. In general, the distribution networks are radially configured. DFR is performed to transfer the load from heavy loaded feeder to lightly loaded feeder, load balancing, and loss reduction. The operation of the power systems is being complicated because of increased power supply demand and bulk load requirements. The distribution system configuration needs to be changed from time to time to meet the load demand and to facilitate the expansion of feeders. A distribution engineer has to look into many constraints to achieve a suitable topology of the distribution system. To meet the load demand with reduced losses and acceptable voltage magnitudes at the buses and to have a proper loading of the power lines, the DFR will be adopted. The power from generating station is transmitted through the transmission lines to various distribution networks that the utility operates. The role of the distribution system is to deliver the power to the consumers to serve their demands. In the process of delivering power to the consumers through a vast network, a significant portion of the power that is transmitted from generating station is lost in the distribution process. The major sources of losses in the distribution system are the power lines which connect the substation to the loads. Virtually the power that is lost in the distribution system is due to copper losses. Since these losses are a function of the square of the current flow through the line, the losses in distribution lines are larger at high power levels than they are lesser at lower levels. Network reconfiguration, capacitor placement, and distributed generation are among different ways of decreasing losses. The reduction in losses in distribution system leads to improve system voltage. Thus, these two facts are interconnected. The distribution system possesses two types of switches i.e, normally open switches as tie-switch and normally close switches as a sectionalizing switch. The aim of the DFR is to reduce power losses in the distribution system thereby the voltage profile of the buses also can be improved. Analysis of the impact of DFR for loss reduction on bus voltages [1] has been presented in this paper.

A loss reduction method by performing switch exchange operations was proposed by Civanlar et al [2]. The switch exchange operation becomes very time consuming and it does not ensure near an optimum solution. Search techniques by applying two approximate power flow methods were presented by Baran and Wu [3]. Carlos *et al* [4] reported an efficient reconfiguration based on loss change estimation method as proposed in [2].

A search technique with load flow on a meshed power system proposed by Merlin and Back [5], opening the links with lowest flow and finally by applying branch and bound procedure. Shri Mohammad and Hong [6] used a robust heuristic method developed based on the idea presented in [5]. Goswami and Basu [7] further modified the method of ref. [6] by handling one loop at a time. Huddleston *et al* [8] developed a quadratic loss function in which multiple switching pairs are considered simultaneously with linear current balance equations as constraints. McDermott *et al* [9] proposed a nonlinear constructive method for reconfiguration problem of distribution networks. Lin and Chin [10] suggested an algorithm, which adopts a switching index to get a proper set of switching operation. Switching indices were derived using branch voltage drops and line constants.

Artificial Intelligence based techniques have been proposed by Kim, H. *et al* [11], Liu, C. C. et a*l* [12] and Chang, G. et al [13]. Lin, W. M. *et al* [14] proposed a method for distribution system planning based on evolutionary programming. Nara et al [15], J. Mendoza [16] implemented GA for obtaining loss minimum reconfiguration. Lin et al [17] used refined GA approach to solving the loss minimum reconfiguration of the distribution network. Different optimization techniques, both traditional and non-traditional are being practiced to solve reconfiguration problems [18], [19], [20], [21], [22]. This algorithm has been implemented on two widely used, 3-feeder and IEEE-33 bus test systems. With appropriate choice of crossover and mutation and random initial population. The final position of the switches and system loss obtained is same as obtained by earlier authors.

II. FEEDER RECONFIGURATION IN DISTRIBUTION SYSTEMS

The problem is to find the configuration of a distribution network which yields minimum loss and analyze the impact of such configuration on bus voltages in the network. The constraints imposed in DFR include reducing line losses, supplies all the loads connected in the initial configuration, maintains the radial topology of the network, to have acceptable voltage profile at all the nodes and current limits in all the branches.

The above problem can mathematically be expressed as:

Minimize $Z = [P_{loss}]$ (1)

Subject to

(i) Power flow balance expressed as

$F(x,d) = 0$ (2)

(ii) Limit on bus voltage magnitude expressed as

$V_{max} \geq V_i \geq V_{min}$ for $i = 1$ to N (3)

(iii) Limit on branch current magnitude expressed as

$I_j \leq I_{max}$ for $j = 1$ to M (4)

(iv) All the loads are served.

(v) Radial topology of the network is maintained

Where,

P_{loss} = active power loss in the network
Z = objective function value
x = Power flow variables (complex voltages at buses)
d = Demand (complex load) at different buses
V_{max} = 1.0 p.u, maximum voltage magnitude,.
V_{min} =minimum acceptable voltage magnitude
V_i = voltage magnitude at bus i
I_{max} = maximum branch current magnitude limit
I_j = current magnitude of branch j
N = number of buses in the network
M = number of branches in the network
P_{Vi} = penalty factor for violation of voltage limit of bus i
P_{Ij} = penalty factor for violation of current limit of branch j
P_c = penalty factor for having common switch, for non-radial topology or not supplying load.

Each solution in the search process satisfies the power flow equations (2). However, the constraints on bus voltages and branch currents expressed by equations (3) and (4) are imposed by the addition of appropriate penalty terms in objective function so as to decrease the fitness function. Thus the problem is reduced to,

$$\text{Min. } Z = [P_{loss}] + \sum_{i=1}^{N} P_{Vi}[V_i - V_{lmt}]^2 + \sum_{j=1}^{M} P_{Ij}[I_j - I_{lmt}]^2 \quad (5)$$

Where,

$V_{lmt} = V_i$ if $[V_{max} \geq V_i \geq V_{min}]$
$V_{lmt} = V_{min}$ if $[V_i < V_{min}]$
$V_{lmt} = V_{max}$ if $[V_i > V_{max}]$
$I_{lmt} = I_j$ if $[I_j \leq I_{max}]$
$I_{lmt} = I_{max}$ if $[I_j \geq I_{max}]$

The other constraints of supply to all the loads and maintenance of radial structure are enforced by non-acceptance of those solutions (chromosomes) which violate these constraints. This is achieved by further penalizing the fitness function and described in the section III.C *Fitness assignment*.

III. SOLUTION METHODOLOGY

The above problem is solved using GA. GA approach involves encoding of initial solution, fitness assignment, and selection of mating population, crossover and mutation. A particular configuration of the network is represented in form of a binary string. The GA search starts with a sufficient population of such bit strings corresponding to feasible solutions to find out bit string with maximum fitness value. The crossover and mutation probabilities are suitably selected.

A. Encoding of Solution Point

Representation of every legal search solution uniquely and searching the entire solution space are the two important criteria for encoding solution.

The initial, intermediate and final solutions in the population must be legal points. A solution consisting of all the busses and maintaining radial topology is called legal solution. Encoding of the chromosome is very important to solve the problem using GA. The solution procedure is explained below:

1. Identify the Normally open switches (shown dotted) which indicate the mesh (Fig.1.(a)).
2. Switches in each mesh are encoded with a binary number and form a chromosome.
3. Calculate the String length of the chromosome by the number of switches available in the mesh.
4. Each chromosome with different open switches information in binary form forms the encoded network configuration for the GA Methodology. The network is renumbered sequentially as per mesh number (Fig.1.(b)).

B. Initial Generation for GA

The initial population required to start the GA cycle is generated randomly. According to the encoding of the open tie/sectionalizing switches; a combination of ‘0’ and ‘1’ are generated for specified chromosome length. After initial population evaluation, its operators generate successive populations using the GA.

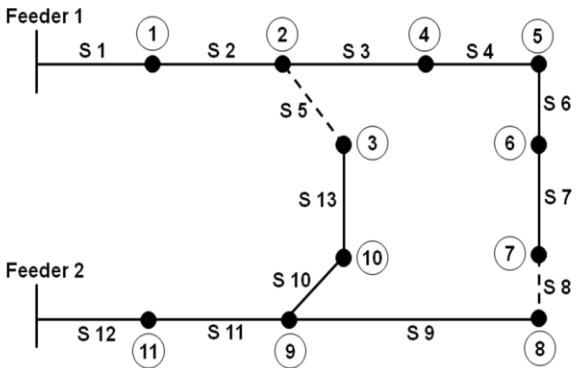

Fig. 1(a): Sample 2-feeder system

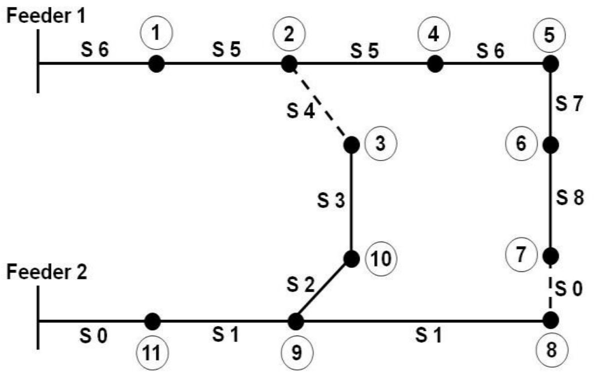

Fig. 1(b): Sample 2- feeder system after renumbering the branches.

C. Fitness Assignment

An appropriate fitness is assigned to a chromosome according to the objective function. Since the objective, in the present case, is to have minimum loss configuration, its reciprocal is taken as fitness function governed by the relation expressed by equation (6).

Fitness = $1/(1+Z)^2$ (6)

The fitness of the chromosome will be maximum if the objective function value is minimum thereby giving the minimum loss configuration network.

The above fitness governed by equation (6) is valid for feasible strings only. However, for infeasible strings generated for common switches, not maintaining radial topology and not supplying all the loads, the fitness is evaluated using equation (7). This relation uses a high-value penalty term, ‘P_c’, such that the infeasible solution arising due to above-mentioned reasons are regretted because of their low value of fitness.

Fitness = $1/(1+P_c)$ (7)

D. Selection of Mating Population

Roulette wheel selection is commonly used scheme in GA’s. Good solution points should have more chance to survive or to be reproduced in the next generation of the population. A solution point with larger fitness value has more slices and hence has a greater probability of being selected into the mating population. Some of the solutions may be selected several times and some may not be selected at al.

E. Crossover

Single point crossover is employed in this work. One pair of the chromosome will be considered at a time and a random number is generated between 1 and (L-1) of the chromosome, where, ‘L’ is the length the string. The two chromosomes will be swapped at the crossover point checking the crossover probability.

F. Mutation

The mutation prevents premature convergence to local optimum value. The mutation occurs with a small probability after cross over. It randomly jumps to new solution points that might be in the promising range of the search space. In mutation, all the bits in the chromosome are evaluated by generating a random number to check for the necessity of mutation. Some of the bits are changed in this process. A binary encoding is used here, and selected bit ‘1’ will be changed to ‘0’ and ‘0’ will be changed to ‘1’.

G. Decoding

The chromosome in the new generation will be decoded for checking the feasibility related to electrical constraints. The chromosome which is having highest fitness at the end of generation will be decoded and that gives the minimum loss reconfiguration of the distribution network.

IV.OVERVIEW OF 3-FEEDER AND IEEE-33 BUS SYSTEMS

A. 3 - Feeder Test System

This system consists of thirteen normally closed sectionalizing switches and three normally opened tie switches s15, s21 and s26 as shown Fig. 2 and can form three meshes. For encoding the above switches of all the three meshes in binary form, a bit length of 3, 3 and 4 are used for representing an operating condition of the switches of meshes 1,2 and 3 respectively.

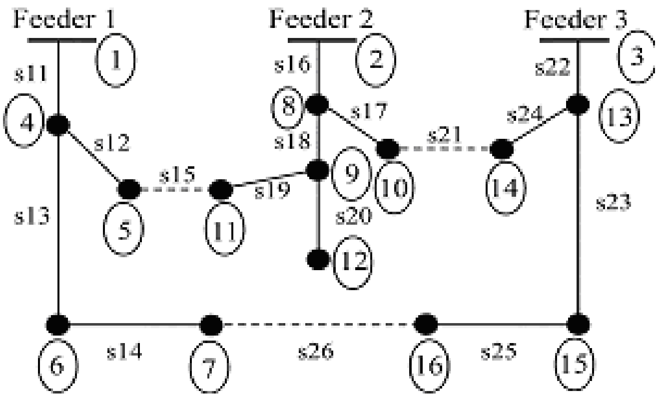

Fig. 2: 3-feeder system (initial configuration)

B. IEEE -33 bus test System

This system has 32 nodes, 32 sectionalizing switches and 5 tie switches as shown in Fig. 3. The tie switches (s33, s34, s35, s36 and s37 shown by dotted lines) are open in the initial configuration of the system. This network can form 5 meshes and these meshes have 10, 7, 7, 11 and 16 tie/sectionalizing switches respectively. Bit lengths of 4, 3, 3, 4 and 4 are used to encode these meshes respectively resulting in a bit length of 18 (4+3+3+4+4) to encode the entire network.

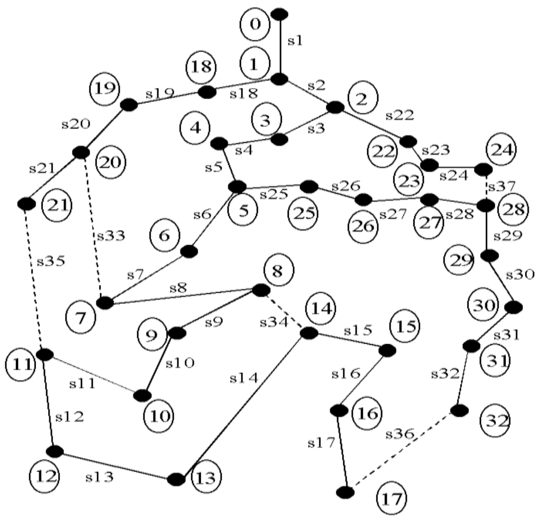

Fig. 3. IEEE 33-bus radial distribution system.

V. SIMULATION AND TEST RESULTS

To analyze the impact of DFR for loss reduction on bus voltages in distribution systems the GA methodology has been adopted. The variation in losses and alleviation of bus voltages during the process of reconfiguration has been studied and presented. The GA optimization technique is normally used for maximization problem with an appropriate fitness function which in current problem has been taken as reciprocal of the objective of minimum loss $(1/(1+Z)^2)$. When the majority of chromosomes have close values of objective functions which were observed in this case, discrimination of different fitness functions also become difficult. To overcome this problem, square of the fitness has been taken as actual fitness function.

The final solution by GA depends upon the proper choice of fitness, crossover and mutation probabilities. Various combinations of crossover and mutation probabilities were tested thoroughly for which the solution converges to a global minimum. A population size often was adopted. The initial population was randomly generated to start the solution. The crossover and mutation probabilities of 0.6 to 0.63 and 0.045 were found to be suitable for the problem studied. The analysis has been carried out on two widely used 3-feeder and IEEE - 33 bus test systems [2], [3].

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A. 3-Feeder System

With the GA encoding the chromosome is formed with a string length of 10 (3+3+4), which represents an operating configuration of the entire network. Starting with a random population, proposed method converged in forty-six generations. And starting with a known initial configuration, GA has converged in the seventh generation. In the final reconfigured system, switches s26, s17 and s19 are open and switches s15 and s21 are closed for known initial configuration. It is observed that this result is same as reported by earlier authors [2], [3] and [4]. The system loss reduced to 0.00466 p.u from initial loss of 0.00511 p.u. Loss reduction from 0.03391 p.u to 0.00466 p.u (Fig.:4 & 6) is noticed with the population generated randomly for the initial iteration of GA cycle. The voltage magnitudes at buses were improved from 0.8184 p.u to 0.97159 p.u during the process of loss reduction through DFR for minimum losses (Fig.:5 & 6). The impact of loss reduction on bus voltages is summarized in Table.1.

Table.1

Generation Number	Losses (p.u)	Minimum Bus Voltage (p.u)
0	0.03391	0.81840
1	0.01132	0.92582
2	0.00560	0.96946
19	0.00560	0.96946
27	0.00512	0.96946
30	0.00484	0.97149
33	0.00484	0.97149
34	0.00484	0.97149
35	0.00484	0.97149
36	0.00484	0.97149
38	0.00484	0.97149
42	0.00479	0.97159
43	0.00479	0.97159
44	0.00479	0.97159
46	0.00466	0.97159

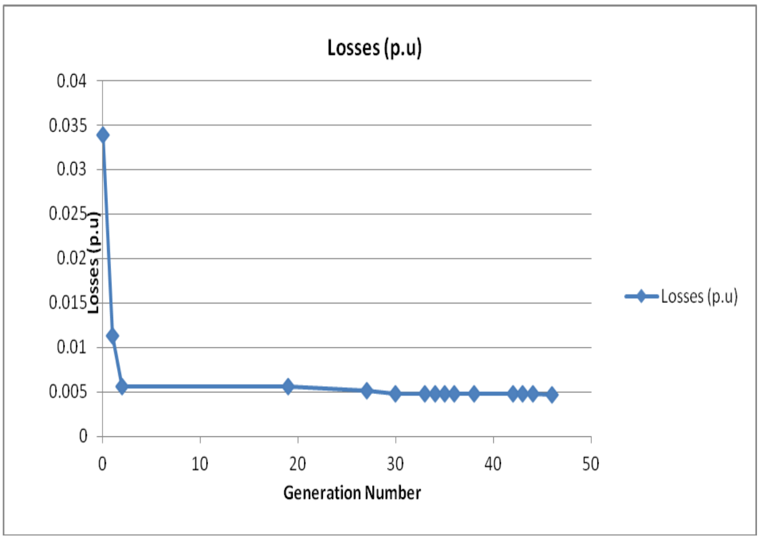

Fig.4: Loss reduction Vs Generation Number

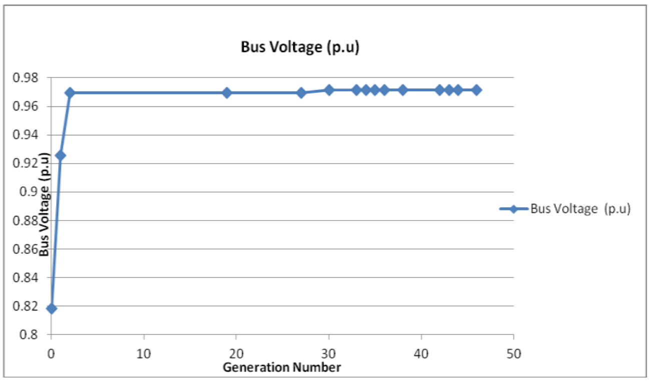

Fig. 5: Bus Voltage Vs Generation Number

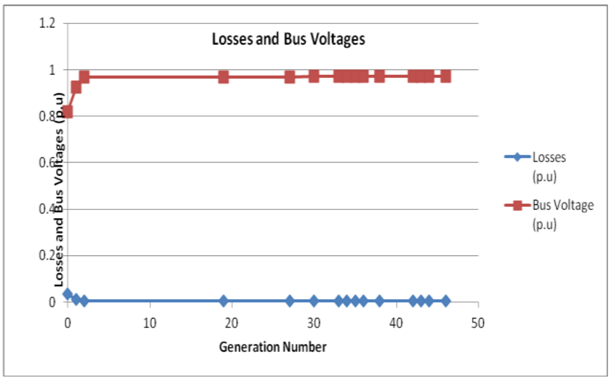

Fig. 6: Loss and Bus Voltage Vs Generation Number

B. IEEE-33 Bus Test System

With the GA encoding, the chromosome is formed with a string length of 18 (4+3+3+4+4), which represents an operating configuration of the entire network. Several trials were made with different initial population and the solution always converged within a maximum of 152 generations. The highest number of generations to arrive at an optimal solution is 152. The final configuration with open switches s7, s9, s14, s32 and s37 yield a system loss of 0.13954 p.u which is 31.10% lower than the original network configuration. The similar results were reported by earlier authors using conventional methods [3], [7], and [10] which require switch exchange and loop power/current flow solution. The proposed method yields solution retaining the radial structure of the system. It is observed from the results that the voltage magnitudes at the buses were improved from 0.67736 p.u to 0.93782 p.u (Fig.: 7 & 9) with the reduction of losses from 1.16275 p.u to 0.13954 p.u. (Fig.: 7 & 8) by using randomly generated initial population for GA cycle. The impact of loss reduction on bus voltages is summarized in Table.2.

Table.2

Generation Number	Losses (p.u)	Minimum Bus Voltage (p.u)
0	1.16275	0.67736
1	0.14643	0.93713
5	0.14275	0.93782
40	0.14275	0.93782
152	0.13954	0.93782

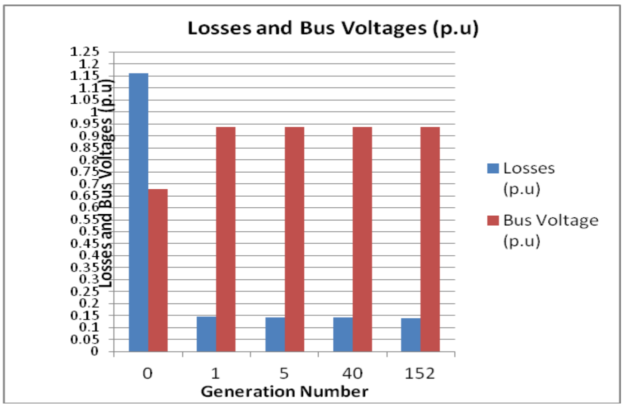

Fig. 7: Loss and Bus Voltage Vs Generation Number

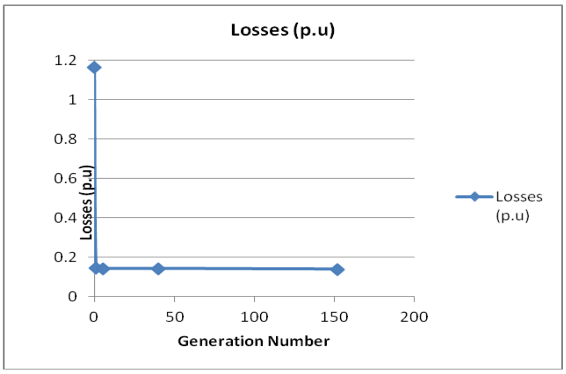

Fig.8: Loss reduction Vs Generation Number

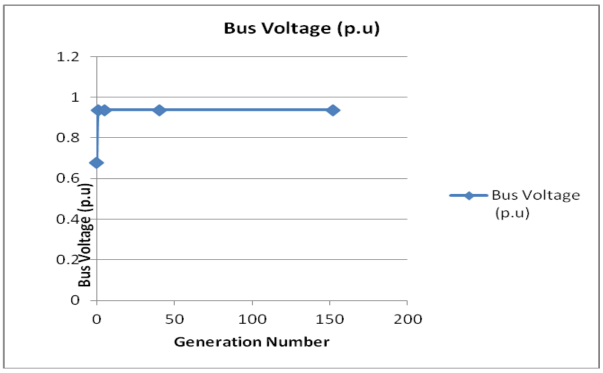

Fig. 9: Bus Voltage Vs Generation Number

CONCLUSIONS

After reconfiguration process, voltage regulation and efficiency of distribution systems are better since operating voltage is above 0.9 p.u and line losses also reduced considerably. The values of minimum voltage and real power loss reduction are presented. The power losses and voltage profiles were studied and simulation results on standard test systems were described in this paper. According to simulation results, network reconfiguration is the most effective way for the proposed system. From these results, total real power loss reduced by about 31.1% after network reconfiguration for IEEE-33 bus test system. Thus, it is clearly proved that when distribution system loss is reduced, all operating bus voltages also are alleviating and reaching within stability limits (>0.9 p.u). The power flow in this method can be avoided for each and every configuration for fitness evaluation process by training Artificial Neural Networks (ANN) to have the power flow data of all the feasible network configurations in future work. The GA optimization technique is proved to be an effective one for DFR. The proper selection of GA parameters and fitness assignment plays an important role in guiding the search to an optimal solution in Genetic Algorithm. This method yields a globally optimal solution. Genetic Algorithm guarantees the best solution out of the most of the methods available for loss minimum configuration problem which in turn improves the voltage magnitudes at the buses in the network. The loss minimum reconfiguration using Genetic Algorithm does not require any switch exchanges, loop power or loop current evaluation as in other methods for decision making. The radial topology of the distribution system is maintained throughout the search process. Test results of two test systems, 3-feeder, and IEEE-33 bus systems, are same as obtained by earlier authors with less computational effort.

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