Distribution Feeder Reconfiguration for minimum losses using Genetic Algorithms

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Abstract - *The binary encoding and global search capability of Genetic Algorithm (GA) is exploited to develop a technique to reconfigure distribution networks for minimum loss. A set of switches corresponding to an open switch of a mesh in the entire network is represented in binary form. Minimization of network loss is taken as objective function and square of its reciprocal as fitness function. The constraints are handled in an appropriate manner. It is demonstrated, on 3-feeder and 5-feeder 32-bus test systems, that the proposed method yields global solution. Choice of appropriate fitness function and other GA parameters are discussed.*

***Index Terms*— Computational methods, losses, network, optimization, power flow, topology.**

I. INTRODUCTION

The distribution networks are operated radially because of simpler protection and lower short circuit currents. Distribution losses vary for the changed configuration under same loading condition. Therefore, under normal operating conditions, distribution engineers periodically reconfigure distribution feeders by opening and closing of switches in order to increase the reliability and reduce line loss. The resulting feeders must remain radial and meet all the load requirements. There are numerous numbers of switches in the distribution system and the number of possible switching operations is tremendous.

The loss minimum distribution system reconfiguration is a complex combinatorial optimization problem which yields the best distribution network configuration with minimal losses by optimizing an appropriate objective function and at the same time, maintaining the constraints imposed upon the network. These constraints are voltage limits at nodes, radial topology of network and supply of power to all loads. Several methods have been proposed in the recent past for obtaining the loss minimum configuration. These methods can broadly be classified as loss change estimation, sequential switch opening, quadratic programming, voltage and loss indices and artificial intelligence methods.

Civanlar et al [1] proposed a method to achieve loss reduction by performing switch exchange operations. The switch exchange operation becomes very time consuming and it does not ensure near optimum solution. Baran and Wu [2] presented search techniques by applying two approximate power flow methods with varying degree of accuracy. The methods are computationally attractive.

Carlos *et al* [3] reported an efficient reconfiguration based on loss change estimation method as proposed in [1].

Merlin and Back [4] proposed a search technique with load flow on a meshed power system, opening the links with lowest flow and finally by applying branch and bound procedure. Shrimohammadi and Hong [5] used a robust heuristic method developed based on the idea presented in [4]. This method uses an optimal flow pattern and converges to the near-optimum solution and the final solution is independent of the initial status of the network switches. Goswami and Basu [6] further modified the method of ref. [5] by handling one loop at a time. This reduced the dimensionality of the problem. Huddleston *et al* [7] developed a quadratic loss function in which multiple switching pairs are considered simultaneously with linear current balance equations as constraints. This method has advantage of solving multiple switching options. McDermott *et al* [8] proposed a non-linear constructive method for reconfiguration problem of distribution networks. This algorithm starts with all operable switches open, and at each step, closes the switch that results in the least increase in the objective function. A simplified loss formula is used to screen candidate switches. Lin and Chin [9] 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. Afsari [10] developed a power based sequential switch opening method.

The AI based reconfiguration methods have become popular in view of automation of Distribution Networks. Artificial Neural Network (ANN) based feeder reconfiguration for loss reduction was proposed by Kim, H. *et al* [13]. Liu, C. C. et a*l* [14] discussed an expert system based operation scheme for loss reduction and a knowledge based distribution system analysis and reconfiguration method was proposed by Chang, G. et al [15]. Lin, W. M. *et al* [16] proposed a method for distribution system planning based on evolutionary programming. In this, cost and reliability of optimal distribution planning is considered.

Nara et al [11] implemented GA for obtaining loss minimum reconfiguration. Lin et al [12] used refined GA approach to solve the loss minimum reconfiguration of distribution network. Being similar to conventional GA, the method used initial population obtained and crossover and mutation schemes were refined by a competition mechanism.

Recently Genetic Algorithm (GA) has attracted attention towards feeder reconfiguration problem due to its inherent property of string coding and global optimization. The computational methods are generally at their most efficient when they take advantage of the physical properties of the system being solved. The distribution system feeder reconfiguration problem involves determination of position (closed/open) of switches in the system, which would cause minimum loss satisfying the constraints imposed. This switch position can easily be encoded in a form of binary string as desired by GA. Minimum loss configuration of a distribution network is a mixed-integer, non- linear, combinatorial problem.

A new formulation of feeder reconfiguration in the framework of GA is addressed in this paper. Minimization of losses of the network for any configuration is taken as objective function and the constraints on bus voltages and branch currents are handled using penalty function. The open tie/sectionalizing switch corresponding to a mesh is represented into binary form. A set of open/close switch positions (a particular network configuration) represented in binary form results in a bit string. A bit string causing minimum loss to the network is searched in GA.

This algorithm has been implemented on two widely used, 3-feeder and 5-feeder 32-bus, test systems. With appropriate choice of cross over and mutation and random initial population, the solution was obtained within seven and sixty generations respectively for two systems. The final position of the switches and system loss obtained is same as obtained by earlier authors.

II. Problem Statement

The problem is to find the configuration of a distribution network which yields minimum loss, satisfies the acceptable voltage profile at all the nodes and current limits in all the branches, supplies all the loads connected in the initial configuration and maintains the radial topology of the network.

The above problem can mathematically be expressed as:

$$\text{Minimize } Z = [\,P_{loss}] \tag{1}$$

Subject to

(i) Power flow balance expressed as

$$F(x,d) = 0 \tag{2}$$

(ii) Limit on bus voltage magnitude expressed as

$$V_{max} \geq V_i \geq V_{min} \quad \text{for } i = 1 \text{ to } N \tag{3}$$

(iii) Limit on branch current magnitude expressed as

$$I_j \le I_{max} \quad \text{for } j = 1 \text{ to } M \tag{4}$$

(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 addition of appropriate penalty terms in objective function so as to decrease the fitness function. Thus the problem is reduced to,

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

Where,

$V_{lmt} = V_i$ if $[\, V_{max} \ge V_i \ge V_{min}\,]$

$V_{lmt} = V_{min}$ if $[\, V_i < V_{min}\,]$

$V_{lmt} = V_{max}$ if $[\, V_i > V_{max}\,]$

$I_{lmt} = I_j$ if $[I_j \le I_{max}]$

$I_{lmt} = I_{max}$ if $[I_j \ge I_{max}]$

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.3 *Fitness assignment*.

III. Solution Methodology using GA

The above problem is solved using GA. This approach involves encoding of initial solution, fitness assignment, and selection of mating population, cross over 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 chromosome is very important to solve the problem using GA.

The solution procedure is explained with the help of a sample network shown in Fig. 1(a). The network has 13 branches. It is assumed that every branch has a switch. The normally open branches with tie switches are shown by dotted lines (s7 and s13). Closure of any tie switch would result in formation of a mesh. Thus this network can form two meshes corresponding to tie switches s13 and s7 called mesh 1 and mesh 2 respectively. Binary encoding is employed for the network considered. The positions of the switches in each mesh are encoded in a binary number and the resulting chromosome represents which switches are open in two meshes. The mesh 1 has seven branches/switches (s1, s2, s5, s13, s10, s11 & s12) and mesh 2 has nine branches/switches (s3, s4, s6, s7, s8, s9, s10, s13 & s5). This would require 3 and 4 binary bits respectively for their representation. Thus the length of the chromosome to represent the entire network would be seven (3+4) bits. The branches are renumbered sequentially mesh wise for convenience while maintaining same numbers for branches common to other meshes. The renumbered network is shown in Fig. 1 (b). The branches s2, s3 and s4 are common in both the meshes. Encoding of the network for two configurations of open switches s3 and s8 and s5 and s6 in meshes 1 and 2 respectively are shown in Fig. 2.

B. Population of Initial Generation

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

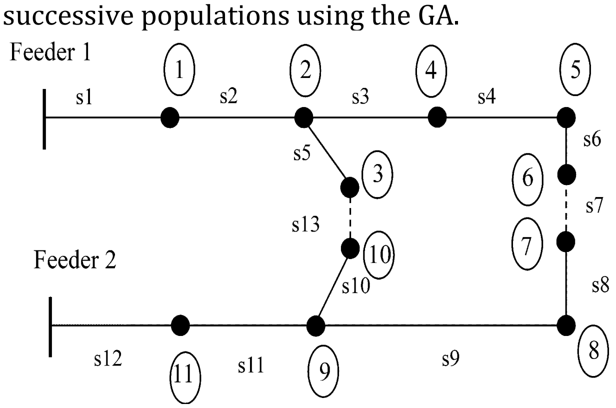

Fig. 1(a): Sample 2-feeder system

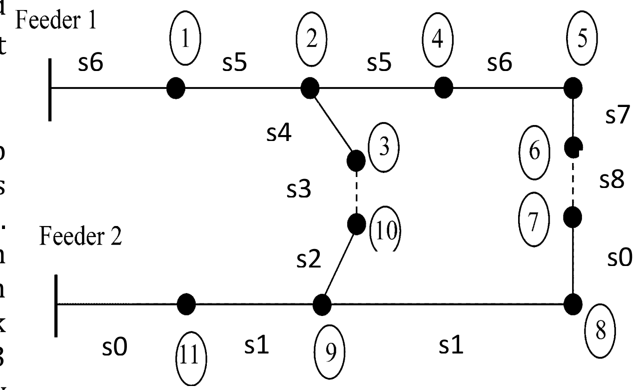

Fig. 1(b): Sample 2-feeder system after renumbering the branches.

C. Fitness Assignment

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

$$\text{Fitness} = 1/(1+Z) \tag{6}$$

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 population. A solution point with larger fitness value has more slices and hence has greater probability of being selected into the mating population. Some of the solution may be selected several times and some may not be selected at al.

E. Crossover

Single point cross over is employed in this work. One pair of 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

Mutation prevents premature convergence to local optimum value. 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 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'.

Configuration		Encoding						
3	8	0	1	1	1	0	0	0
5	6	1	0	1	0	1	1	0

Fig. 2. Encoding of sample network for two configurations

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. Implementation And case studies

The GA 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)). When 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 of ten was taken. The initial population was randomly generated to start the solution. The cross over and mutation probabilities of 0.6 and 0.045 were found to be suitable for the problem studied. Efficient forward sweep power flow method suitable for radial networks, as explained in [10], has been used to compute the desired quantities during the solution process. The performance of proposed GA based method has been tested on two widely used 3-feeder and 5-feeder test systems [1,2].

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A. 3-Feeder System

This system consists of thirteen normally closed sectionalizing switches and three normally opened tie switches s15, s21 and s26 as shown Fig. 3 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.

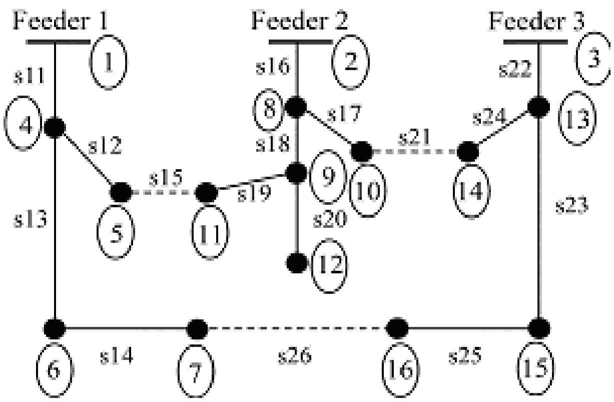

Fig. 3: 3-feeder system (initial configuration)

With this encoding the chromosome is formed with a string length of 10 (3+3+4), which represents an operating configuration of the entire network. Several run of proposed method converged within seven generations. In the final reconfigured system, switches s26, s17 and s19 are open and switches s15 and s21 are closed. It is observed that this result is same as reported by earlier authors [1, 2, 3]. The system loss reduced to 0.00466 pu from initial loss of 0.00511 pu.

B. 5-Feeder System

This system has 32 nodes, 32 sectionalizing switches and 5 tie switches as shown in Fig. 4. 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. Several trials were made with different initial population and the solution always converged within 60 generations. The highest number of generations to arrive at optimal solution is 59. The final configuration with open switches s7, s9,s14, s32 and s37 yield a system loss of 0.013921 pu which is 31.10% lower than the original (initial) network configuration. The similar results were reported by earlier authors using conventional methods [2, 6, 9, 10] which require switch exchange and loop power/current flow solution. The proposed method yields solution retaining the radial structure of the system.

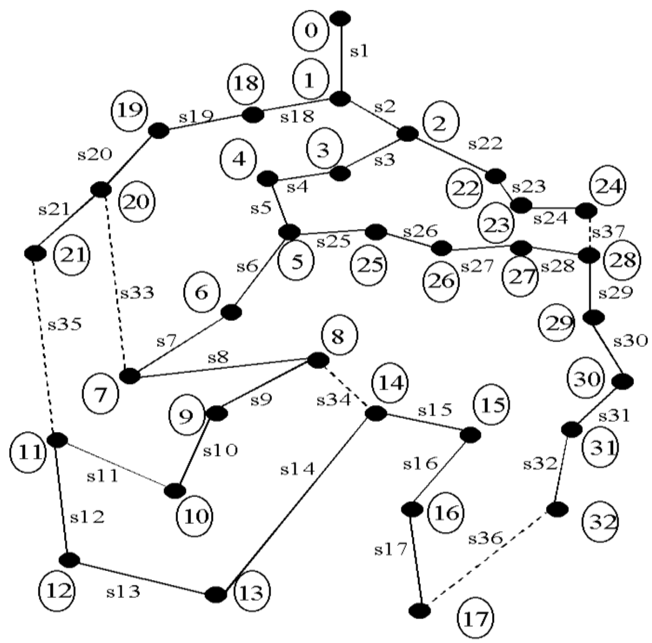

Fig. 4: 5-feeder system (initial configuration)

C. Observations

The genetic algorithm starts with initial population and improved solutions are obtained in subsequent generations using GA parameters, crossover and mutation. The present method uses randomly generated ten feasible solution points as initial population. The crossover and mutation probabilities of 0.6 and 0.045 respectively were selected after experimenting with several combinations. This choice plays significant role on number of generations in which the solution converges. Many combinations could not converge even in 100 generations. Similarly, a better combination may exist which may yield results in less number of generations than reported in this paper. Similar attempts had been made in ref. [12] through refined crossover and mutation. Even 50% of initial population, in this method, was generated using near optimal solution obtained by method reported in [5] and rest at random. Further reduction in computational time was achieved by preparing a tabu list of visited solutions to avoid repetition of solutions.

Thus, there are various ways by which solution time can be saved. Incorporation of such features in presently proposed method, which is plain implementation of GA with proper choice of crossover and mutation probabilities, would also reduce the number of generations. The basic aim of this research is to demonstrate that the GA based approach yield global solution to reconfiguration problem but the number of power flow solutions required is very high. Even if solution is obtained in a single generation, the number of power flow runs would be 10 for a population size of 10 (as used in this paper). Although, an efficient power flow technique suitable for radial networks has been used in this method, alternate methods which can further reduce the number of power flow solutions if cannot eliminate completely, would enhance the performance of the method.

V. Conclusions

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 global optimal solution. Genetic Algorithm guarantees a best solution out of the most of the methods available for loss minimum configuration problem. 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 5-feeder systems, are same as obtained by earlier authors with less computational effort.

VI. References

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