

Distribution System Network Reconfiguration for Loss Reduction using Genetic Algorithm

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Abstract - For the successful operation of any radial distribution system, the configuration of the feeder with statuses of switch must be determined. Minimizing loss during Normal condition and voltage drop during fault is important. This paper proposes a method based on Genetic Algorithm using pruffer number encoding/decoding to predict the Network configuration.

I INTRODUCTION

Distribution system feeder reconfiguration is defined as altering the topological structures of distribution feeders by changing the open/closed states of the sectionalizing and ties switches. The distribution reconfiguration belongs to a complex combinatorial optimization problem. Configuration alterations may be performed by changing the status of network switches (open/close), in such way that radiality is always re-established after the operations are completed. Now the topology of the distribution system changes because of the Network reconfiguration. However, due to the reasons such as easy to locate fault, isolation of faults and co-ordination of protective device, etc., power distribution systems are often required to operate in a radial fashion. Hence, it is important to maintain this radiality of the systems, even when the topology of the systems is undergoing changes during Network reconfiguration process. Moreover, because of the varying topology and the connected loads, the bus voltages and line currents do also change during the Network reconfiguration process. To maintain the safety and security of different power system components, it is important that the bus voltage and line current should not cross their respective operational limits. As the time taken by the Network reconfiguration depends on the number of switching operations, it follows from the above requirement that the number of switching operations should be kept as minimum as possible. Also, the software run-time required by the Network reconfiguration should be minimum for speedier solution. The distribution automation function of feeder reconfiguration has been addressed for different objectives such as voltage drop minimization and loss minimization. Based on these objectives, various researchers have identified different methods for changing the topological structure of the distribution system.

II PROBLEM FORMULATION

There are many criteria depending on the performance of the system for an operator to determine the switch statuses in the distribution system. In this paper, suppose that the operator hopes the MW loss is minimized after the occurrence of fault. The objective function and the constraints of the Network Reconfiguration problem are described below

A. Objective function:

1. Minimization of losses

$$\text{Minimize } f1(x) = \sum_{i=1}^{nl} \text{losses}$$

i.e.

$$\text{Minimize } f1(x) = \sum_{i=1}^{nl} k_i |I_i|^2 R_i$$

Where nl is the set of branches. Loss, is losses in branch i . I_i is the current in branch i . R_i is the resistance of branch i . k_i represents the topological status of the branches. $k_i=1$ if the branch i is closed, and $k_i=0$ if the branch i is open.

2. Minimization of Voltage Drop:

$$\text{Minimize } f2(x) = \sum_{i=1}^{nl} \text{Voltage drop}_i$$

Where Voltage drop = $V_{i+1} - V_i$,

B. Constraints:

1. Radiality in the Network should be maintained.
2. Bus Voltages should be within the acceptable limits.

$$V_{\min} < V_i < V_{\max}$$

V_{\min} is the minimum permissible bus voltage, V_i is the Voltage at i^{th} bus and V_{\max} is the maximum permissible bus voltage.

3. Line currents should be within acceptable limits.

$$i_{\min} < i_i < i_{\max}$$

As mentioned above, the Network reconfiguration problem is formulated as a multi-objective optimization problem. Hence the proposed method optimizes objective 1 and 2.

III. PROPOSED METHOD

A. Prufer Number Encoding/Decoding

The Genetic Algorithms (GAS) provides a useful tool for this purpose and GA has the capability of encoding the chromosomes with integers, e.g., Prufer number. Traditionally, the statuses of the switches were considered as genes (binary bits) in GAS. The bit with a value of “zero” (“one”) implies that the corresponding switch is open (close). After the genetic operations are applied, the structure of the distribution system may not be radial. An extra “mesh check” algorithm will be incorporated with GAS to discard the infeasible mesh (loop) structures.

This paper utilizes the “Prufer number” to encode the structure of a distribution system. The Prufer number ensures that the system structure is radial without an additional “mesh check” process. The concept of the Prufer number is a node or bus(vertex) encoding/decoding rather than a branch or switch(traditional edge) encoding/decoding. It was proved that there was an (N-2)-bit permutation to uniquely represent a radial structure.

IV. IMPLEMENTATION OF GA

GA is suitable for multi-objective optimization problems because it is a multi point search. Therefore, we utilize GA in order to effectively search for optimal solutions for the Network reconfiguration problem.

4.1. BASICS OPERATORS

String encoding

Before a GA can be applied to an optimisation problem, an encoding scheme that maps all possible solutions of the problem into symbol strings (chromosomes) must be introduced. The most natural coding method is to have a binary string with length equal to the number of switches in the network. Each switch state is represented by one bit with a value ‘1’ or ‘0’ corresponding to ‘closed’ or ‘open’, respectively.

Initial Population of the String

In this project, population of the strings is randomly generated such that number ‘1’s are equal to number of sectionalizing switches and number of ‘0’ switch is equal to the number of the tie switches. The length of the

string is equal to the total number available switches. All the strings are subjected in to Radiality checking by encoding the prufer number.

Fitness Evolution

Most optimization problems impose constraints on the solutions, so it is possible that the solution that a chromosome describes would not be feasible. An objective function can be modified to account for these constraints by penalising any solution that violates a constraint. In this method a penalty term, which depends on the constraint is subtracted from the calculated fitness value. This ‘penalty function method’ permits new constraint formulations to be added readily to a GA-based optimization method.

The GA objective function for the Network Configuration is

Objective function

$$f = WL * f_1 + WVD * f_2 + WS * f_3 \quad (4.1)$$

Where, f_1 - Total Real Power Loss.
 f_2 - Total Voltage Drop of all lines.
 f_3 - Number of switching Operations.
 WL - Weighting factor for Real Power Loss
 WVD - Weighting factor for Voltage Drop.
 WS - Weighting factor for Switching

operation.

In this Problem formulation in minimization of objective function. Therefore,

For Minimization,

$$\text{Fitness} = 1/(1+f) \quad \text{for } f=0 \\ = 1/f \quad \text{for } f \neq 0 \quad (4.2)$$

Typical weight values, used in the experiments reported here, an 10.0 for power losses, 5.0 for voltage Drop, 1.0 for switch operation. Varying the weights can lead to alternative solutions being produced, but does not seem to have much influence on the speed of convergence.

Penalty Functions

For dealing with inequality constraints in GA more efficiently, penalty functions are employed in this project. This function indicates that a violated inequality constraint will be punished and then augmented to the fitness functioning this project, the penalty function dealing with the V_i is as follows:

$$-PF^{N/NS} (V_i - V_i^{\min})^2 \quad (4.3)$$

Where PF is called the penalty factor in this method and N is the iteration number. Equation implies that the penalty weight ($PF^{N/NS}$) should be increased gradually and has less effect in the initial iterations.

Tournament Selection

In this project, tournament selection is used. The formula of choosing Chromosome is of the form:

$C_i = \min \{C_i, C_j\}$.

It means that two chromosomes are chosen randomly. Through comparing their fitness function value, the good candidate for the fitness function is chosen, and the chosen chromosome of the good candidate is copied to the next generation directly.

Single Point Cross Over, Uniform Mutation

In single-point crossover, one crossover position is selected uniformly at random and the variables are exchanged between the individuals about this crossover position, then two new offsprings are produced. The process is that some genes are changed from 1 to 0 or from 0 to 1.

Termination of GA

Because the GA is a stochastic search method, it is difficult to formally specify convergence criteria. As the fitness of a population may remain same for a number of generations before a superior individual is found, the application of conventional criteria terminate the GA after a pre specified number of generations and then test the quality of the best members of the population against the problem definition. If no acceptable solutions are found, the GA may be restarted

4.2. STEPS FOR PROPOSED ALGORITHM

The proposed algorithmic steps for solving Network reconfiguration can be summarized as follows.

Step 1: Read the bus data, line data, and switch data, etc.

Step 2: Estimate the population size, crossover rate, and mutation rate for the GA. The initial chromosomes encoded by the Prufer number are randomly selected. The length of each chromosome is the number of switches available in the network. Each bit in the chromosome indicates the status of the switch. ('0' means that switch is opened. '1' means that switch is closed.).

Step 3: This chromosomes are encoded into the prufer number. N is the number of buses, If the length of the prufer number is N-2, then the network corresponding to that coded chromosome is radial. If the length of the chromosome is less than or more than N-2, the network, corresponding to that coded chromosome is not radial These chromosomes are converted into the radial configuration and then added to the population for further process.

Step 4: Compute the load flow calculation for each chromosome using backward sweeping method. From this load flow calculation, the bus voltages, line current through all the lines, real and reactive power losses on the each line can be easily computed for each chromosome.

Step 5: If inequality constraints are violated, the penalty function is augmented to the fitness function (the negative objective for maximization).

Fitness = 1/objective function for minimization function.

Where,

Objective function = $W_1 \cdot \text{Total Losses} + W_2 \cdot \text{Total Voltage drop} + W_3 \cdot \text{No. Of Switching Operations}$.

Where,

W1-Weighting factor for Total real Power losses.

W2-Weighting factor for Total Voltage Drop.

W3- Weighting factor for No. Of Switching

Step 6: Tournament selection approach is used to reproduce new offspring.

Step 7: If all the new chromosomes are the same (convergent), then stop. Otherwise go to the next step.

Step 8: Perform crossover and mutation operations in GA.

Step 9: Go to Step 3.

V. LOADFLOW CALCULATION

Generally distribution networks are radial and the R / X ratio is very high. For this reason distribution networks are ill-conditioned and conventional Newton Raphson (NR) and fast decoupled load flow (FDLF) methods are inefficient in solving such networks. The proposed method uses 'backward sweeping method'. Convergence is likely for any type of practical radial distribution network with realistic R / X ratios. Loads have been represented as constant power. Thus the parameters such as voltage at each node, current flowing through line, real and reactive power injected at each node, real and reactive power loss on line for the distribution system are calculated easily.

5.1 BACKWARD / FORWARD SWEEP METHOD

5.1.1. NOMENCLATURE

N B = total number of nodes

(j) = branch number, $j = 1, 2, \dots, NB - 1$

PL(i) = real power load of i^{th} node

QL(i) = reactive power load of i^{th} node

|V(i)| = voltage magnitude of i^{th} node

R (j) = resistance of j^{th} branch

X (j) = reactance of j^{th} branch

I (j) = current flowing through branch j

P(i + 1) = total real power load fed through node i + 1

Q(i + 1) = total reactive power load fed through node i + 1

$\delta(i + 1)$ = voltage angle of node $i + 1$

$LP(j)$ = real power loss of branch j

$LQ(j)$ = reactive power loss of branch j

$N L$ = total number of laterals

$[L]$ = lateral number, $L = 1, 2, \dots, N L$

$SN(L)$ = source node of lateral L

$EB(L)$ = end node of lateral L

$LB(L)$ = node, just ahead of source node of lateral L

5.1.2 SOLUTION METHODOLOGY

The one line diagram of such a feeder comprising n nodes and $R - 1$ branches is shown in Fig. 5.1

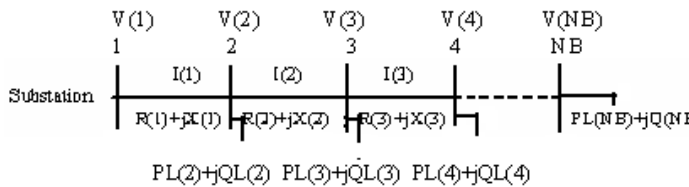


Fig. 5.1

From the fig 5.1 shown, following equations are written

$$I(i) = |V(i)| \angle \Phi(I) - |V(i+1)| \angle \Phi(i+1) \quad (5.1)$$

From eqn 5.1, we get $V(2)$,

$$|V(2)| = \left[\frac{\{(P(2)R(1)+Q(2)X(1) - 0.5|V(1)|^2)^2 - (R^2(1)+X^2(1))(P^2(2)+Q^2(2))\}^{1/2}}{(P(2)R(1)+Q(2)X(1)-0.5|V(1)|^2)^{1/2}} \right] \quad (5.2)$$

generalised form of the equation is

$$|V(i+1)| = \left[\frac{\{(P(i+1)R(i)+Q(i+1)X(i) - 0.5|V(i)|^2)^2 - (R^2(i)+X^2(i))(P^2(i+1)+Q^2(i+1))\}^{1/2}}{(P(i+1)R(i)+Q(i+1)X(i)-0.5|V(i)|^2)^{1/2}} \right] \quad (5.3)$$

Eqn. 5.3 is a recursive relation of voltage. Since the substation voltage magnitude $|V(1)|$ is known, it is possible to find out the voltage magnitudes of all other nodes.

$$P(i+1) = \sum_{j=i+1}^{nb} PL(j) + \sum_{j=i+1}^{Nb} LP(j) \quad \text{for } i = 1, 2, 3, \dots, nb-2$$

$$Q(i+1) = \sum_{j=i+1}^{nb-2} QL(j) + \sum_{j=i+1}^{Nb} LQ(j) \quad (5.4)$$

From eqn. 5.4, it is clear that total load fed through node 2 is the load of node 2 itself plus the load of all other nodes plus the losses of all branches except branch 1.

Real and Reactive power Losses on 'i' th branch

$$LP(i) = R(i) * (P^2(i+1) + Q^2(i+1)) / |V(i+1)|^2$$

$$LQ(i) = X(i) * (P^2(i+1) + Q^2(i+1)) / |V(i+1)|^2 \quad (5.5)$$

Eqn. 5.5 is a very good initial estimate for obtaining the load flow solution of the proposed method.

VI. SIMULATION RESULT FOR NETWORK RECONFIGURATION

6.1. SINGLE OBJECTIVE FUNCTION

Minimization of Real power loss

A IEEE 16-bus system used to show the applicability of the proposed methods. The system data is provided in appendix. The one line diagram for IEEE 16-bus for this system is provided in appendix. It can be found that there are 13 sectionalizing switches and 3 tie switches in the system. Hence, the Proposed Genetic algorithm requires 16 bits for a chromosome. The voltages of this IEEE 16-bus system are calculated by the load flow equations and are shown in table 1. The real power for original configuration loss is 510 KW and total voltage drop is 0.7501 KV for this original configuration.

Table 1 : Test Result : IEEE-16 bus system

Configuration	Real Power loss (KW)	Min_Voltage (V)	Switching operation	Voltage drop p.u
1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 (Initial)	510	0.9532	Open-14,15,16	0.0591
1 1 1 1 1 1 1 0 0 1 1 1 1 1 1 1 (Final)	460	0.9732	Open-7,8 Close-14,15	0.0579

After reconfiguration Process, the real power loss is 460 KW. There is 9.804% loss reduction. At 12th node, the minimum voltage occurs and is 0.9732pu. This voltage becomes higher than the voltage before reconfiguration. Hence, this method of reconfiguration improves voltage at

each node. After, the reconfiguration process, 7th and 8th sectionalizing switches are opened and 14th and 15th tie switches are closed. Network configuration before reconfiguration process is shown in Fig.6.1

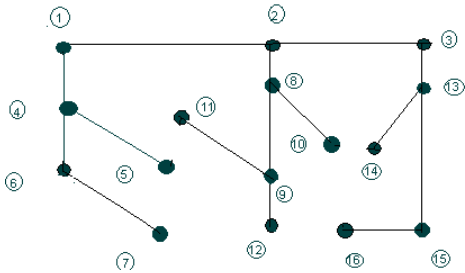


Fig.6.1

Network configuration after reconfiguration process is shown in Fig.6.2

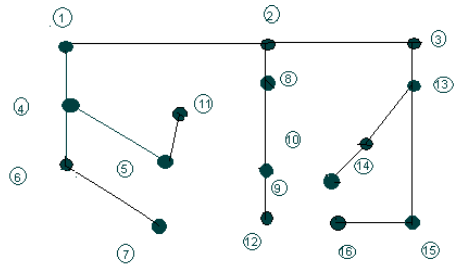


Fig.6.2

Genetic Parameters

The parameters used in the present method are,

Population Size = 20

Maximum number of Generation = 100

Probability of mutation = 0.01

Probability of crossover = 0.8

The convergence characteristic is shown in fig 6.3. From this characteristic, The objective function values are high indicating constraint violation. However, in the 38th generation the power loss sharply drops from 485KW to 460KW and maintain constant upto 100th generation. The Convergence time is 230.56 sec

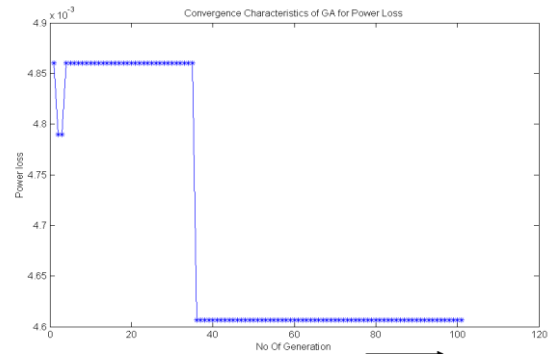


Fig. 6.3

Minimization Voltage Drop

Before reconfiguration process, total voltage drop is 0.0591p.u for this original configuration. The minimum voltage occurred at 12th node is 0.9532.

Table 2 : Test Result of IEEE-16 bus system

Configuration	Min_Voltage (V)	Voltage drop p.u	Switching operation
111111111111 11000 (Initial)	0.9532	0.0591	Open-14,15,16
11011001111 11111 (Final)	0.9687	0.0448	Open-3,6,7 Close-14,15,16

After reconfiguration Process, The new total voltage drop is 0.0591p.u. There is 24.19% voltage drop reduction .The minimum voltage occurred at 12th node is 0.9687. This voltage becomes higher than the voltage before reconfiguration. Hence, this reconfiguration improves voltage at each node. After, the reconfiguration process, 3th, 6th and 7th sectionalizing switches are opened and 14th, 15th and 16th tie switches are closed. Test Result for minimization of voltage drop is shown in table 2.

Network configuration after reconfiguration process is shown in fig 6.4

VII. CONCLUSION

The method based on the Genetic Algorithms is proposed for Multi objective Network reconfiguration problem in the distribution systems. The real power loss, voltage drop and number of switching operation after the occurrence of the fault are expected to be minimized. The Prufer number is used to encode the chromosome in Genetic Algorithms. The vertex encoding/decoding based on the Prufer number ensures that all generations from the evolution in Genetic Algorithms have radial structures for the distribution system.

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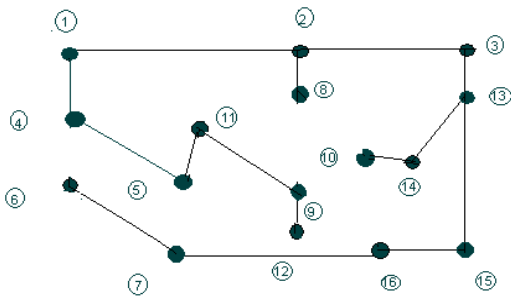


Fig 6.4

The convergence characteristic is shown in fig 6.5. From this convergence characteristic, The objective function values are high indicating constraint violation. However, in the 80th generation the voltage drop sharply drops from 0.0455p.u to 0.0448 and maintain constant upto 100th generation.

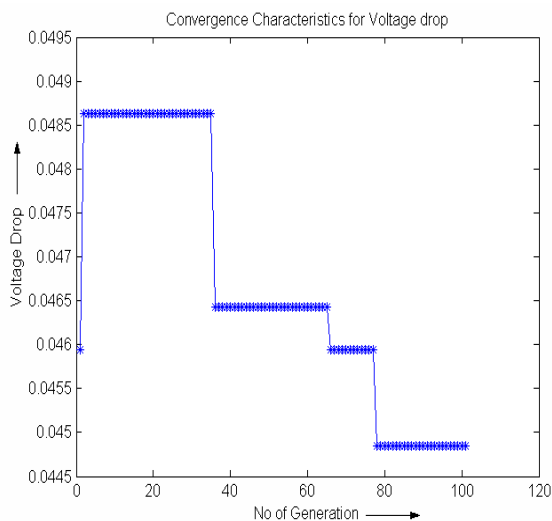


Fig 6.5