Distribution Network Reconfiguration for Loss Reduction

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Chintan Patel
G H Patel College of Engineering and Technology (GCET)

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Avani G. Patel
PG Student, Department of Electrical Engineering
G. H. Patel College of Engineering & Technology
Vallabh Vidyanagar, Gujarat, India
67avani@gmail.com

Chintan Patel
Asst. Prof., Department of Electrical Engineering
G. H. Patel College of Engineering & Technology
Vallabh Vidyanagar, Gujarat, India
chintanpatel@gcet.ac.in

Abstract— **This paper discusses the reduction of real power loss in the distribution system by reconfiguration of the distribution network. Reconfiguration is done by changing the status of the sectionalizing and tie switches. The optimal configuration with minimum real power loss is to be determined. First, the configuration is determined manually and to overcome its limitations, Genetic algorithm (GA) technique is used to determine the optimal configuration. To further reduce the losses, Distributed Generation (DG) is added to the system. This method is tested on two different cases of 16 bus distribution network. Test results are included in the paper. The results show that the reconfiguration is really useful in reducing active power loss and improving the voltage profile of the network.**

Keywords— Network reconfiguration, loss reduction, radial network, Load flow, GA, GD.

I. Introduction

The distribution system is a very important part of the power system as it connects the transmission system to the consumers. The distribution system is built as interconnected network, but operated in radial. One of the major issues in the distribution system is active power loss. So to reduce the active power losses of the distribution system, one of the methods is the reconfiguration of the network. The advantages of network reconfiguration are reduction in power loss, improved voltage profile, balanced system load and increased reliability.

Here, it is assumed that the network is made up of sectionalizing (normally closed) and ties (normally open) switches. The configuration of the network is altered by changing the status of these switches so that all the loads are supplied and the real power loss of the system is reduced. The status of these switches is changed in such a way that the radiality of the system is not violated.

The radially operated distribution networks have a high R/X ratio. Due to this, the distribution networks are ill-conditioned and normally used Newton-Raphson (NR) and Fast Decoupled Load Flow (FDLF) methods are not capable of solving them [1-4]. There will be difficulty in the convergence of the solution. This needs modified versions of conventional load flow methods.

In this work, reconfiguration is achieved by manually deciding the status of various switches which is very tedious and time consuming job. To overcome its limitations, artificial intelligence technique is used for reconfiguration. Here, Genetic Algorithm is used for the reconfiguration of the distribution network. The reconfiguration of a distribution network is typically performed by changing the status of switches. The status of each switch in distribution systems is naturally represented by a binary parameter 0 or 1 which makes GA suitable for network reconfiguration. Here, it is also discussed that to further reduce the losses, a DG is added to the system. DG is defined as electrical power resources that are directly connected to the distribution system [5]. The size of DG is selected depending upon the total load of the system and the losses in the system.

II. Problem Formulation

The network reconfiguration problem in a distribution system is to find the best configuration of radial network that provides minimum power loss while the operating constraints are to be satisfied. The main objective is to minimize the real power loss of the distribution system. The total power loss can be obtained from the load flow calculations.

In network reconfiguration, the loss reduction problem is formulated as:

$$Min\sum_{0}^{n-1} PLoss_n \tag{1}$$

This function is to be minimized subject to the following constraints:

1) Network radiality where each node has to be supplied from a single feeder.
2) Load satisfaction where each load node has to be supplied with its load active and reactive power requirements.
3) The power flow constraint formulation.

In addition, the optimal solution has to satisfy the following bounds:

- Node voltage magnitude bounds

$$V_{i\min} < V_i < V_{i\max} \quad (2)$$

where, $V_{i\min}$ and $V_{i\max}$ are the lower and upper limits of bus voltage magnitude respectively.

III. Load Flow Analysis

In this section, a simple and efficient method for solving radial distribution network is used [6-9]. This method includes simple algebraic equations of voltage and power loss. The equations will also not have trigonometric functions like in traditional load flow equations. This method is very efficient to compute. Convergence is always guaranteed for any type of radial distribution system using this method of load flow.

Consider the Fig. 1.

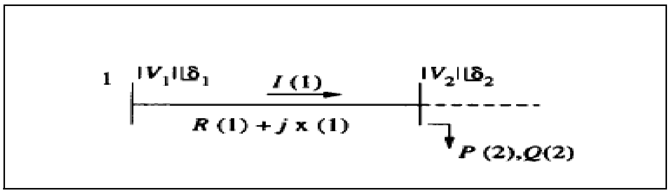

Fig. 1. Equivalent diagram of radial network

From the Fig.1, the following equations can be derived:

$$I(1) = \frac{|V(1)|\angle\delta(1) - |V(2)\angle\delta(2)}{R(1) + jX(1)} \quad (2)$$

$$P(2) - jQ(2) = V(2) * I(1) \quad (3)$$

where, I(n) is the current flowing in branch n

V(n) is the voltage on bus n

δ(n) is the load angle

R(n) is the resistance of branch n

X(n) is the reactance of branch n

By solving (2) and (3),

$$\begin{aligned}|V(2)| = \{[(P(2)*R(1) + Q(2)*X(1) - 0.5|V(1)|^2)^2 \\ -(R^2(1) + X^2(1))(P^2(2) + Q^2(2))]^{1/2} \\ -(P(2)*R(1) + Q(2)*X(1) - 0.5|V(1)|^2)\}^{1/2}\end{aligned} \quad (4)$$

where P(2) and Q(2) are total real and reactive power loads fed through node 2.

As expressed in (4), the real and reactive power losses can be calculated.

A flowchart for load flow analysis by MATLAB programming is shown in Fig. 2.

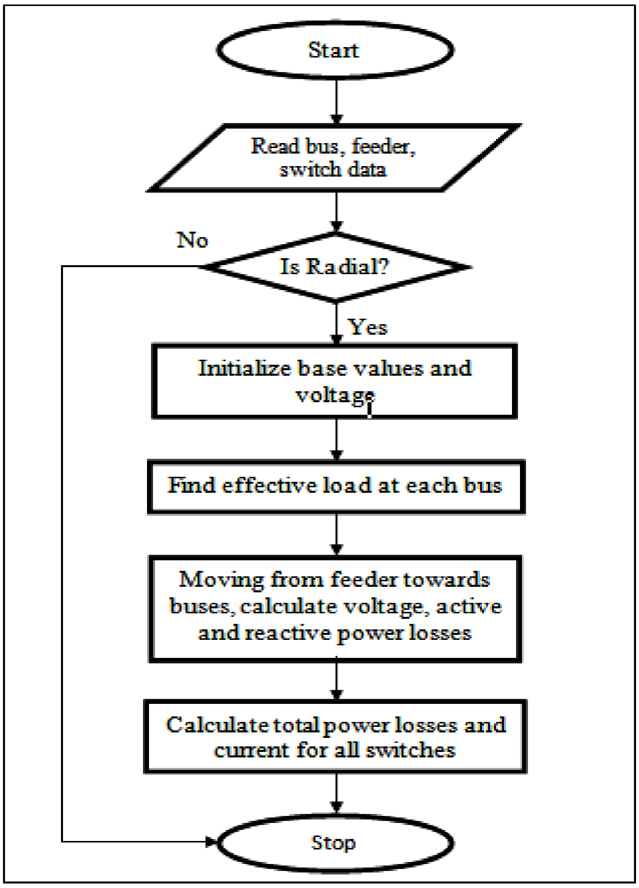

Fig. 2. Flowchart of load flow analysis.

$$LP(1) = \frac{R(1) * [P^2(2) + Q^2(2)]}{|V(2)|^2}$$

$$LQ(1) = \frac{X(1) * [P^2(2) + Q^2(2)]}{|V(2)|^2} \quad (5)$$

IV. Genetic Algorithm

GA is applied to find out the optimal configuration with minimum active power loss of the system [10-11]. The GA is a search technique based on the process of natural selection and evolution. The input of our system is in the form of binary, i.e. ‘0’ and ‘1’ which represents the chromosomes. The GA uses a number of populations as initial solution and a group of chromosomes is called a population.

A. Initial population and fitness function

A random set of populations is generated in binary form. In input, 0 represents an open switch and 1 represents a closed switch. After generating the initial population, the fitness is calculated using a fitness function.

The fitness function is given as:

$$\frac{1}{PLoss} \quad (6)$$

where, PLoss is the total real power loss of the system.

B. Genetic operators

Three operators in GA are applied to the chromosomes during each generation to obtain a better solution [12-13]. The operators are:

a) Reproduction

b) Crossover

c) Mutation

The reproduction operator, also known as selection operator is applied first to select the parent chromosomes. The parent chromosomes are selected according to the fitness of the population. The population having the best fitness is selected as the parent.

After reproduction, crossover operator is applied to the parent chromosomes. It is the process of selecting a random point in the parent chromosomes and swapping the genes either right or left of the point with each other.

After applying crossover, mutation operator is applied to the new generated offspring. Mutation is applied to maintain the diversity in the population. It is the process of changing one or two bits in the chromosome string from '1' to '0' or '0' to '1'.

The proposed GA steps are as follows:

1. Read the line data, bus data and feeder data of the test system.
2. Generate random no. of variables in the form of '0' and '1' according to the no. of switches in the system.
3. Check the radiality for all the random populations generated. Discard the ones which are not radial. And again go to step 2 and continue till the total no. of radial population is generated.
4. Apply load flow to the generated radial populations and calculate the fitness of each population.
5. Perform selection operation by selecting 2 best populations.
6. Then perform crossover operation on the 2 best populations selected.
7. Then apply mutation operation by changing two bits from 1 to 0 and 0 to 1. Then check for radiality. If the offspring does not obey radiality, replace one of the 0 to 1.
8. Select the best individual from the offsprings by calculating their fitness.
9. The best configuration is displayed and also the voltages and losses in that system are displayed.
10. Stop the program.

V. Test System And Results

The test system used here is IEEE 16 bus distribution system with 3 feeders. The network is shown in Fig. 3. The

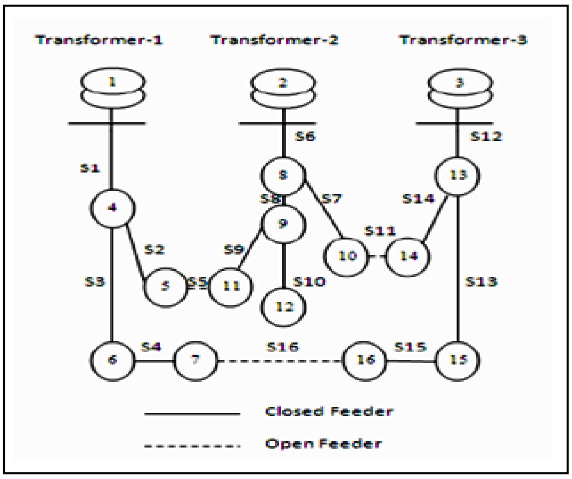

Fig. 3. IEEE 16 bus distribution system

data of the system are given in [1], also presented in Table III in Appendix.

In this system, there are 3 tie switches and 13 sectionalizing switches. The switches 5, 11 and 16 are the tie switches and rests of the switches are the sectionalizing switches. The total load of the system is 28.7 MW and 17.3 Mvar. The minimum and maximum voltage limits are set as 0.95 p.u. and 1.05 p.u respectively. A DG of 1 MW is added to the system. The placement of DG is decided according to the load on the buses. The performance of the system is tested by providing a DG at various buses one by one which are heavily loaded compared to others. Four different cases are considered as follows:

1) System before reconfiguration and without adding a DG
2) System after manual reconfiguration without adding a DG
3) System after reconfiguration using GA without adding a DG
4) System before reconfiguration by adding a DG

The results of the mentioned cases are provided in Table I.

TABLE I. COMPARISON OF 3 CASES

System Configuration and Parameters	Case No.		
	Case 1	*Case 2*	*Case 3*
Switches open in the system	5,11,16	7,5,16	7,9,16
Total real power loss (kW)	529.5593	506.2615	489.6304
Lowest Voltage (p.u.)	0.9611	0.9630	0.9642
Lowest voltage node	12	12	12

The voltage of the original system, i.e. the system before reconfiguration, on each bus is shown in Fig. 4. The real power loss in the branches connected to a respective bus before reconfiguration is shown in Fig. 5.

The Table I show that the losses are reduced from 529.5593 kW to 489.6304 kW after reconfiguration of the distribution network using GA.

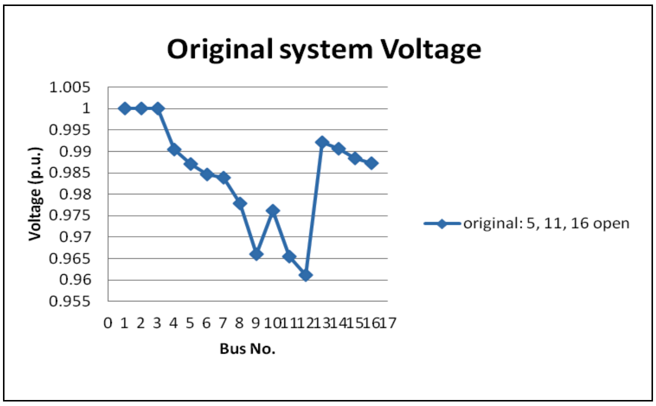

Fig. 4 Voltage at each bus of original system

In the original system, switches 5, 11 and 16 were open and in this paper, after reconfiguration using GA, switches 7, 9 and 16 are open. Also the voltage profile of the system is improved. The lowest voltage is identified on bus 12 and it is improved from 0.9611p.u. to 0.9642 p.u. after reconfiguration.

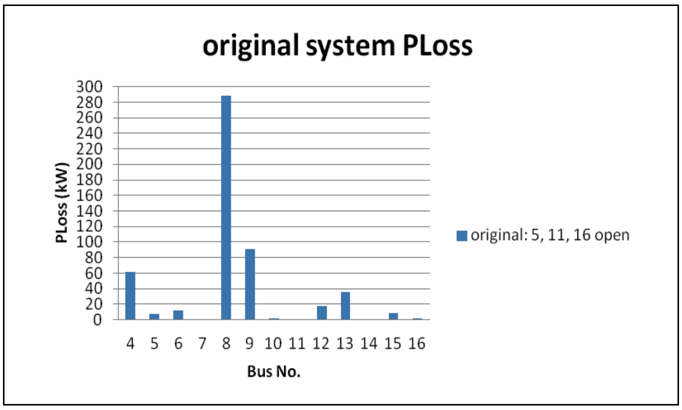

Fig. 5. Power Loss in a branch connected to respective bus of original system

The bus voltages considering 3 cases: i) original configuration, ii) configuration when switches 7, 8, 16 are open and iii) configuration when switches 7, 5, 16 are open are compared in Fig. 6. It is clearly seen that the voltage on the bus 12 is improved after reconfiguration of the network.

Table II shows the active power loss and voltage at end node when a DG of 1MW is added to the system. As stated above, the DG is placed on different buses and the losses are calculated. From the results and Fig. 7, it can be observed that the provision of DG on bus 12 results in minimum real power loss which is 465.6716 kW.

TABLE II. LOSSES AND VOLTAGE WITH DG

DG on Bus	P Loss (kW)	Q Loss (kvar)	Lowest V(p.u.)	Lowest V bus
5	496.2499	571.3505	0.9623	12
8	501.0683	581.2566	0.9621	12
9	471.3799	546.8550	0.9640	12
12	465.6716	539.0062	0.9647	12
16	498.2798	577.3079	0.9623	12

VI. CONCLUSION

It is concluded that after manual reconfiguration of the distribution network, the overall system losses have decreased by 4.3994% and the voltage at the end bus is also improved from 0.9611p.u. to 0.9630 p.u.. It will be very difficult to reconfigure the large distribution networks manually. It will take more time to obtain the optimal configuration of the distribution system. Also the configuration obtained may not be optimal as many other combinations cannot be considered.

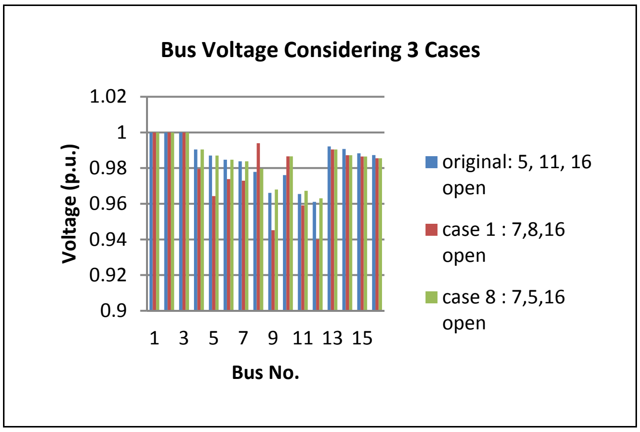

Fig. 6. Bus voltage comparing 3 cases

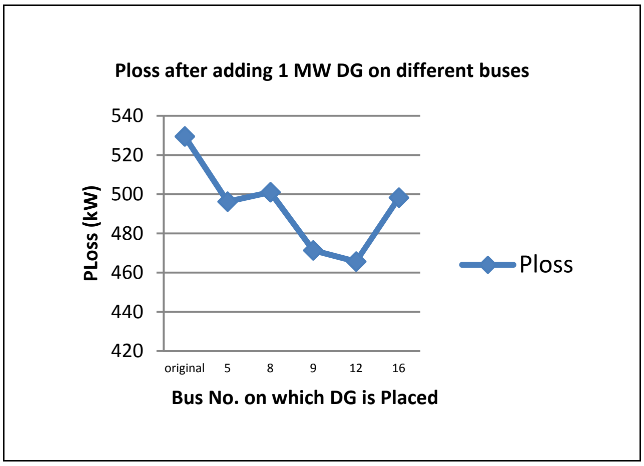

Fig. 7. Power loss after adding DG on original system

To overcome the difficulties, the artificial intelligence technique is used. The GA technique is well suited for this particular problem as GA works well with the binary inputs like the status of switches. By implementing GA, the configuration is achieved in which real power loss is reduced by 7.5 %, which is almost double than manual method. Also, voltage at end bus is improved from 0.9611 p.u. to 0.9642 p.u.

In future the cost comparison can be done for the system for pre- and post-reconfiguration.

APPENDIX

TABLE III. SYSTEM DATA
Base: 100Mva, 11kV

Bus to bus	Section resistance (p.u.)	Section reactance (p.u.)	End bus load(MW)	End bus load(Mvar)
1-4	0.075	0.10	2.0	1.6
4-5	0.080	0.11	3.0	1.5
4-6	0.090	0.18	2.0	0.8
6-7	0.040	0.04	1.5	1.2
2-8	0.110	0.11	4.0	2.7
8-9	0.080	0.11	5.0	3.0
8-10	0.110	0.11	1.0	0.9
9-11	0.110	0.11	0.6	0.1
9-12	0.080	0.11	4.5	2.0
3-13	0.110	0.11	1.0	0.9
13-14	0.090	0.12	1.0	0.7
13-15	0.080	0.11	1.0	0.9
15-16	0.040	0.04	2.1	1.0
5-11	0.040	0.04	-	-
10-14	0.040	0.04	-	-
7-16	0.090	0.04	-	-

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