Network Reconfiguration for Loss Reduction and Improved Voltage Profile in Distribution System with Distributed Generation using Genetic Algorithm

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Abstract

This paper presents a feeder reconfiguration problem to the distribution system with distributed generation. The main objective of this paper is to minimize the system power loss and improve bus voltage profile. The optimization problem is subjected to system constraints consisting of load-point voltage limits, radial configuration format, no load-point interruption and feeder capability limits. A method based on genetic algorithm to determine the minimum configuration is presented. A genetic algorithm is a search or optimization algorithm based on the mechanics of natural selection and natural genetics. The developed methodology is demonstrated by a 33-bus radial distribution system with distributed generation. The study results show that the optimal on/off patterns of the switches can be identified which give the minimum power loss while respecting all the constraints.

Keywords: Network reconfiguration, Loss reduction, Distributed generation, Genetic algorithm

1. Introduction

Distribution systems are normally configured radially for effective coordination of their protective devices [1]. Two types of switches are generally found in the system for both protection and configuration management. These are sectionalizing switches (normally closed switches) and tie switches (normally opened switches) [2]. By changing the statuses of the sectionalizing and tie switches, the configuration of distribution system is varied, and loads are transferred among the feeders while the radial configuration format of electrical supply is still maintained. This implementation is known as feeder reconfiguration. The advantages obtained from feeder reconfiguration are, for example, real power loss reduction, balancing system load, bus voltage profile improvement, increasing system security and reliability, and power quality improvement [3-4].

Over the last decade, distribution systems have seen a significant increase in small-scaled generators, which is known as distributed generation (DG). Distributed generation are grid-connected or stand-alone electric generation units located within the distribution system at or near the end user. Recent development in DG technologies such as wind, solar, fuel cells, hydrogen, and biomass has drawn an attention for utilities to accommodate DG units in their systems. As the penetration of distributed generation is expected to increase significantly in the near future, a paradigm shift in control, operation and planning of distribution networks may be necessary if this generation is to be integrated in a cost-effective manner [5]. Such a transition enables the system operator to maximize the use of the existing circuits by taking full advantage of generator dispatch, control of transformer taps, voltage regulators, reactive power management and system reconfiguration in an integrated manner.

Most of the algorithms in the literature for network reconfiguration are heuristic search techniques based on analytical. Distribution system reconfiguration for loss. Civanlar et al. [6] made use solely of heuristics to determine a distribution system configuration which would reduce line losses. Shirmohammadi et al. [7] described a technique for the reconfiguration of distribution networks to decrease their resistive line losses and included results pertaining to large scale system examples. Nara et al. and Zhu [8-9] have proposed network reconfiguration techniques for minimum loss using a genetic algorithm (GA).

This paper emphasizes the advantage of network reconfiguration to the distribution system in the presence of DG units for loss reduction and bus voltage improvement. The application of a genetic algorithm is applied to determine the optimal on/off patterns of the switches to minimize the system loss subject to system constraints. The effectiveness of the methodology is demonstrated by a practical sized distribution system consisting of 33 buses.

2. Problem Formulation

The objective of the optimal feeder reconfiguration problem is to minimize the total power loss as:

$$\text{Minimize } L = \sum_{t=1}^{Nl}\sum_{k=1}^{l}\left|I_k\right|^2 R_k \tag{1}$$

where L = total power loss
Nl = number of load levels
l = number of feeders
I_k = current flow in branch k
R_k = resistance of branch k

The objective function in (1) is subject to the following constraints.

1) Power flow equations:

$$P_i = \sum_{j=1}^{Nb} \left| Y_{ij} V_i V_j \right| \cos(\theta_{ij} + \delta_j - \delta_i) \quad (2)$$

$$Q_i = -\sum_{j=1}^{Nb} \left| Y_{ij} V_i V_j \right| \sin(\theta_{ij} + \delta_j - \delta_i) \quad (3)$$

where P_i, Q_i = active and reactive power at bus i
Nb = number of buses
Y_{ij} = element (i, j) in bus admittance matrix
V_i, V_j = voltage of bus i and bus j
θ_{ij} = angle of Y_{ij}
δ_i, δ_j = voltage angle of bus i and bus j

2) Bus voltage limits:

$$V^{\min} \le V_i \le V^{\max} \quad (4)$$

3) Feeder capability limits:

$$\left| I_k \right| \le I_k^{\max} \quad k \in \{1,2,3,\ldots l\} \quad (5)$$

4) Radial configuration format

5) No load-point interruption

where $V^{\min}$ = minimum voltage
$V^{\max}$ = maximum voltage
$I_k^{\max}$ = maximum current capability of branch k

3. Genetic Algorithm

The genetic algorithm is applied to solve the optimal or near optimal solution of the network configuration for the loss minimum problem by taking the following steps:

Step 1. Read the bus, line data for the distribution test system and data for genetic algorithm such as population size, max generation and penalty factor.

Step 2. Generate initial population. Each individual in the population is represented by a string for the status open switches and consider the network structures must be radial, no-load point interruption respectively.

Step 3. Calculate the fitness function by using Eq.(1) for each individual in the population.

Step 4. Check bus voltage limits using Eq.(4) and feeder current limits using Eq.(5) after reconfiguration.

Step 5. Sort populations and off springs, keep the best fitness from population.

Step 6. Bring population to the selection, crossover and mutation process.

Step 7. Check maximum generation by repeating step 3 through step 6 until maximum generation is reached.

Step 8. Report the optimal solution.

Step 9. End program.

A flowchart for feeder reconfiguration algorithm by MATLAB Programming is shown in Figure 1.

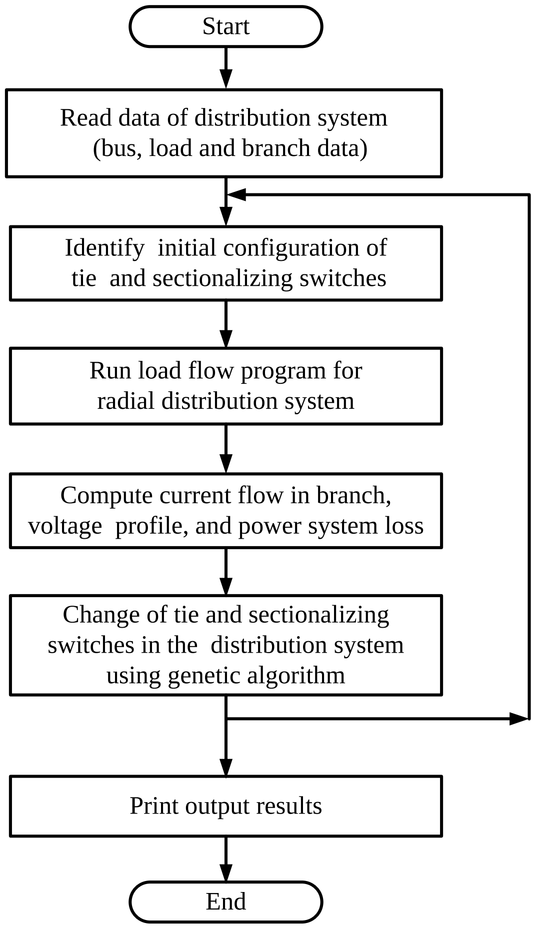

Fig.1. Flowchart of network reconfiguration

5. Case Study

The test system for the case study is radial distribution system with 33 buses, 5 tie-lines (looping branches), as shown in Figure 2. The load data are given in Table A1 and branch data in Table A2 [10].

The initial statuses of all the sectionalizing switches (switches No. 1-32) are closed while all the tie-switches (switch No.33-37) are open. The total loads for this test system are 3,715 kW and 2,300 kVAr. The current carrying capacity of branch No.1-9 is 400 A, and the other remaining branches including the tie lines are 200 A. The minimum and maximum voltages are set at 0.95 and 1.05 p.u., respectively. The maximum iteration for the genetic algorithm is 100. Four cases are examined as follows:

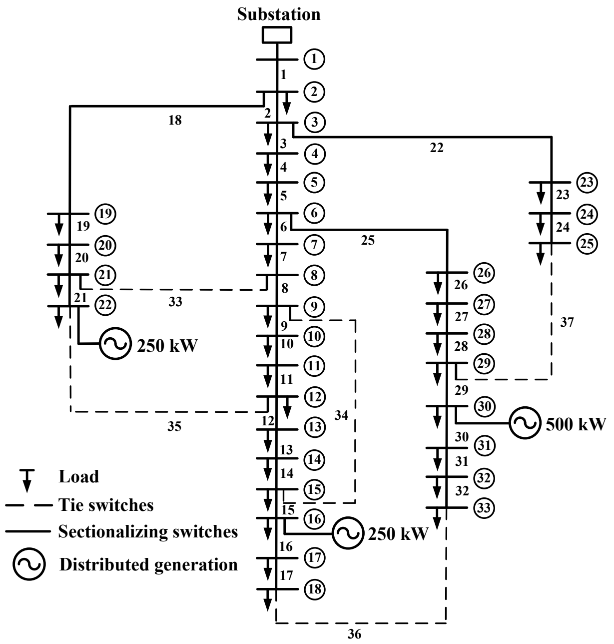

Fig. 2. Single-line diagram of 33-bus radial distribution system with distributed generation

Case 1: The system is without distributed generation and feeder reconfiguration

Case 2: The same as case 1 except that the feeders can be reconfigured by the available sectionalizing switched and the tie switches.

Case 3: The same as case 1 except that there are 3 small power producers who can provide only firm active power to the system by their DG units. The producers are located at buses 16, 22, and 30 with capacities of 250, 250 and 500 kW, respectively.

Case 4: The same as case 3 but with feeder reconfiguration.

The numerical results for the four cases are summarized in Table 1.

Table1.Results of cases study

	Case 1	Case 2	Case 3	Case 4
Sectionalizing switches to be open	-	11, 32, 27	-	9, 32, 28
Tie switches to be closed	-	35, 36, 37	-	35, 36, 37
Total power loss (kW)	202.70	146.50	127.60	91.70
Minimum voltage (p.u.)	0.913	0.938	0.937	0.953
Percentage of loss reduction	-	27.76	37.05	54.76

It is noticed a considerable decrease in the power loss values when the distributed generator is placed in the distribution system. It is confirmed from case 3 that the distributed generation helps to reduce the system loss from 202.70 kW to 127.60 kW, or 37.05% of those configurations without distributed generation. When comparing case 2 with case 3, the former sees a higher power loss. The minimum loss is observed in case 4, where there are changes in branch currents after the reconfiguration. Distributed generation, from the perspective of losses, impacted positively in the analyzed distribution network, achieving values of 54.76%.

This confirms that DG units can normally, although not necessarily, help to reduce the current flow in the feeders; and hence contributes to the power loss reduction, mainly because they are usually placed near the load being supplied. In case 4, where the feeders are reconfigured and the voltage constraint is imposed in the optimization process, no bus voltage is found violated. The bus voltage profile and current flows in branch for case 1 and case 4 are depicted in Figure 3 and 4.

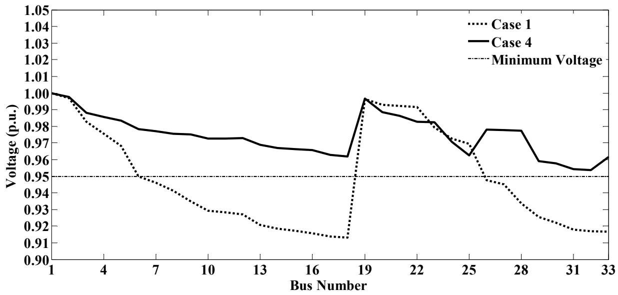

Fig.3. Bus voltage profile of case1 and case 4

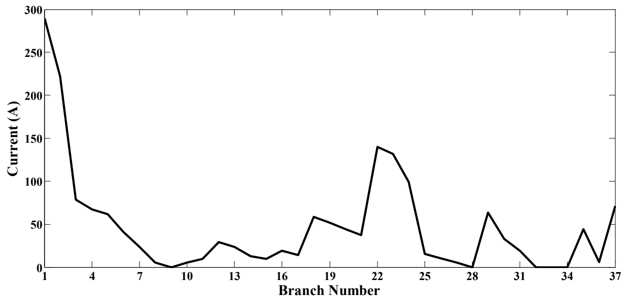

Fig.4. Current flow in branch of case 4

7. Conclusions

Genetic algorithm optimization technique has presented in this paper to find the most appropriate topology of the distribution system in the presence of distributed generation. A 33-bus distribution system with three distributed generation is used to demonstrate the effectiveness of the proposed technique. Although the distributed generation contributes to loss reduction, some bus voltages violate the minimum voltage constraint. Such a problem can be remedied by network reconfiguration. The results show that the optimal on/off patterns of the switches can be identified which give the minimum power loss while keeping bus voltage magnitudes within the acceptable limits.

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Appendix

TableA1. Load data for 33-bus distribution system

Bus No.	P_L (kW)	Q_L (kVAr)	Bus No.	P_L (kW)	Q_L (kVAr)
2	100	60	18	90	40
3	90	40	19	90	40
4	120	80	20	90	40
5	60	30	21	90	40
6	60	20	22	90	40
7	200	100	23	90	50
8	200	100	24	420	200
9	60	20	25	420	200
10	60	20	26	60	25
11	45	30	27	60	25
12	60	35	28	60	20
13	60	35	29	120	70
14	120	80	30	200	100
15	60	10	31	150	70
16	60	20	32	210	100
17	60	20	33	60	40

TableA2. System data for 33-bus distribution system

Branch Number	Sending end bus	Receiving end bus	R (Ω)	X (Ω)
1	1	2	0.0922	0.0470
2	2	3	0.4930	0.2512
3	3	4	0.3661	0.1864
4	4	5	0.3811	0.1941
5	5	6	0.8190	0.7070
6	6	7	0.1872	0.6188
7	7	8	0.7115	0.2351
8	8	9	1.0299	0.7400
9	9	10	1.0440	0.7400
10	10	11	0.1967	0.0651
11	11	12	0.3744	0.1298
12	12	13	1.4680	1.1549
13	13	14	0.5416	0.7129
14	14	15	0.5909	0.5260
15	15	16	0.7462	0.5449
16	16	17	1.2889	1.7210
17	17	18	0.7320	0.5739
18	2	19	0.1640	0.1565
19	19	20	1.5042	1.3555
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3084
23	23	24	0.8980	0.7091
24	24	25	0.8959	0.7071
25	6	26	0.2031	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.0589	0.9338
28	28	29	0.8043	0.7006
29	29	30	0.5074	0.2585
30	30	31	0.9745	0.9629
31	31	32	0.3105	0.3619
32	32	33	0.3411	0.5302
34	8	21	2.0000	2.0000
36	9	15	2.0000	2.0000
35	12	22	2.0000	2.0000
37	18	33	0.5000	0.5000
33	25	29	0.5000	0.5000

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