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Reconfiguration of Distribution Network Based on a Genetic Algorithm for Loss Reduction Considering Capacitor Placement

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***Abstract* - Reducing losses in Distribution networks, due to their considerable level, has been pursued by many researchers. Finding the optimal configuration of the network is known as one of the most effective and cost-effective approaches. This can be done by choosing the best states of the networks' switches. In this paper, a genetic algorithm is proposed for optimizing network configuration in presence of discrete variables. While most of available studies have used average value of the network demand, in this paper variable daily profile of the demand of the network is employed. The simulation results on the IEEE 33-bus system indicates that changing the state of the network switches can considerable lower the losses and improve voltage profile.**

***Keywords* - distribution network reconfiguration, radial distribution network, genetic algorithm, losses, capacitor.**

1. Introduction

Distribution networks transmit energy from distribution centers to the end-users. The distribution networks are typically radial grids with numerous branches. They have the largest contribution to the power system losses, owing to the larger currents flowing through the low-voltage cables compared to the high-voltage transmission lines. Hence, analysis and study of the ohmic losses in the distribution networks is of high importance.

Generally, the methods for loss reduction in distribution networks can be classified as follows,

- Capacitor placement
- Optimization of conductor size
- Network reconfiguration
- Network development
- Substation location
- Load management of distribution transformers
- Voltage correction

The ratio of benefit-to-the-cost for the aforementioned methods has been presented in Table I [1]. Clearly, the network reconfiguration and transformer load management have the highest ratios among all methods.

Table I. ratio of benefit-to-cost for different loss reduction methods

Loss reduction method	Benefit-to-cost ratio
Capacitor placement	2 to 8
Network expansion	0.6 to 8
Voltage correction	1.5 to 3
Transformer load management	1 to 15
Reconfiguration	Around 13

In this paper, capacitor placement in distribution network has been considered. Distribution network capacitors reduce the losses and improve voltage profile by compensating the reactive power. In this paper, placement of a 450-kVar capacitor bank is addressed.

In References [3] and [4], combination of genetic algorithm (GA) and neural networks has been used to solve reconfiguration problem in distribution networks. A feeder reconfiguration technique has been proposed in [5], [6] and [7], where a formulation has been developed to calculate changes in network losses for each switching based on some assumptions. This formulation allows easier, but approximate, computation of the loss changes for different switching, compared to the power flow routine.

Ant colony optimization has also been employed for reconfiguration of distribution networks [8], [9], and [10].

In most available studies, the average demand has been used in network reconfiguration problem. Hence the network is not operated in optimal condition under different demand levels. To tackle this shortcoming, in this paper a variable daily demand profile is employed. In this paper, three types of demand, including industrial, commercial and residential demand is considered. Moreover, the proposed reconfiguration method is applied on the IEEE 33-bus test system for evaluations and assessment over a 24-hour period.

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2. Problem Description

Reconfiguration of the distribution networks implies change in the network topology for performance improvement while the radial structure of the network is preserved. Such changes can be achieved by varying the states of the network switches. Distribution network reconfiguration not only reduces network losses, but also improves voltage profile and balances the loads. Generally, the distribution networks have a weak screening structure, but are operated radially due to protection issues, such as lowering short-circuit level, easy relay coordination and better protection. Hence, there are a number of normally open (NO) and normally closed (NC) switches in the network, which can be employed for the reconfiguration of the distribution network to achieve the lowest distribution losses. For instance, in case of a fault in the network, some of switches are open to clear the fault. In this circumstance, some of the NO switches must be closed to allow energy transmission to the non-faulted areas in such a way that the best network configuration, in terms of losses, is obtained.

3. Capacitor Banks in Distribution Networks

Capacitor banks serve different purpose in electric energy systems. Generally, the main benefits of the capacitor banks can be summarized as follows,

- Compensate the reactive power
- Enhancing transmission capacity
- Lowering network losses
- Power factor correction
- Steady-state voltage profile correction

While a capacitor bank can provide all the above-mentioned influences simultaneously, but the size and location of the capacitor bank depends on the main objective function, in form of one or several of the above-mentioned benefits [11].

The capacitors are effectively reduce transmission losses by compensating for the reactive power and hence lowering the current from the generators to the capacitor bank. Hence, capacitor banks are able to reduce transmission losses as well as the transmission lines loading. Accordingly, capacitor placement and network reconfiguration are suitable measures to reduce losses in the distribution networks.

4. Problem Formulation

In this paper, minimization of the losses serves as the objective function, as stated below,

$$Ploss = \sum_{b=1}^{N_r} {I_b}^2 * R_b \qquad (2)$$

where, R_b and I_b represent the resistance and current of feeder b, respectively and N_r is the number of feeders.

During network reconfiguration, the following three requirements must be always satisfied,

- The radial structure of the network must be preserved.
- The demand of all network consumers must be met.
- The bus voltages and load currents must be within their permissible limits.

1.1. Necessary condition to have a radial network

In a tree with A nodes and B branches, if the following holds,

$$A=B+1 \qquad (1)$$

hen, it can be concluded that the necessary condition for the absence of any mesh in the network is satisfied.

1.2. Sufficient condition to have a radial network

If one-by-one elimination of the first-order nodes (i.e. nodes with only one branch) of a three leads to the elimination of the whole tree, it can be concluded that the tree represents a radial network.

1.3. Non-islanding operation check

It is necessary to check if the all buses of the distribution network are interconnected. Examples can be drawn where a radial network is formed by a number of islanded sub-networks.

To check for the non-islanding operation of the distribution network, a routing algorithm, presented in the Appendix, is employed. The routing algorithm is based on the node-node connection matrix which, owing to the radial topology of the distribution networks, allows easy finding of the path between each end node and the slack node as well as the intermediate buses.

If all buses of the network are available in the matrix, then the network is non-islanded. The node-node connection matrix is defined as an $n \times n$ matrix, where n is number of network nodes. In this matrix, the entries of the row i and column j (a_{ij}) and row j and column i (a_{ji}) are unity if the buses i and j are directly connected through a feeder, and zero otherwise (i.e. if these two buses are not directly connected).

1.4. Loss calculation methodology

In this paper, network losses are determined using a backward-forward load flow program. This technique is simple with reasonable computational burden and allows easy analysis of the distribution networks.

1.5. Reconfiguration time

To decide upon the reconfiguration time point, 24 hours of the day are divided into several sub-intervals. The best time for the network reconfiguration is designated by the highest reduction in the network losses. If the benefit of a reconfiguration surpasses the associated costs, the time and new configuration are saved. This procedure is terminated when the cost of the reconfiguration is higher than its benefit.

In this study, the three types of load, including commercial, industrial and residential loads, are considered.

Each bus includes a different ratio of these three load types. However, the load/time curve of each load type is identical [12].

$$L_{k,j} = \sum_{i=1}^{3} L_{kmax} \times M_{k,i} \times C_{i,j} \qquad (3)$$

where, k is the bus number, i indicates load type, j shows the time, $C_{i,j}$ represent the portion of i-th load type at time j, $M_{k,i}$ denotes the ration of the i-th load type at bus k, and L_{kmax} is the peak load at bus k (120% of the main data).

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The parameters of the GA algorithm are presented in Table II.

Table II. Parameters of the GA algorithm

Parameter	Population size	Selection function	Elit count	Single point crossover	Uniform mutation
Value	50	Uniform random	2	0.8	0.03

5. Simulation Results

1.6. Simulation results without considering capacitor bank

The IEEE 33-bus test system is used to assess the proposed method. This system includes 33 buses and five meshes. The open switches in the initial configuration of the system include s33, s34, s35, s36, and s37. A variable system load has been considered in this study. The study horizon is one day, divided into 24 points (T0=[1 25]). The transmission zlosses of the initial configuration for one day are about 2305.051 kW. More detailed data are presented in Tables III and IV.

The cost of each MW has been assumed 0.6 $ while each network reconfiguration costs one $. Based on the obtained results, the first reconfiguration has occurred at the first hour and the switches s7, s 9, s14, s28, and s32 have been opened. The network losses due to this reconfiguration amount to 1530.39 kW. For this case, reconfiguration benefit is higher than the reconfiguration cost. Hence, the first reconfiguration is justified.

The second reconfiguration has occurred at hour 17 when the switches s7, s9, s14, s32, and s37 have been opened. The network losses after this reconfiguration are 1526.95 kW. The higher reconfiguration benefit compared to its cost, also justifies the second reconfiguration.

For the third reconfiguration at the hour 22, the switches s7, s9, s14, s28, and s32 have been opened. In this case, transmission losses are 1526.07. In contrast to the previous reconfigurations, the cost of the third reconfiguration is higher than the obtained benefits, indicating inefficiency of this change.

Table III. Ratio of each load type at each bus [12]

K	M1	M2	M3	K	M1	M2	M3
2	0.2	0.5	0.3	18	0.4	0.5	0.1
3	0.5	0.3	0.2	19	0.5	0.2	0.3
4	0.5	0.2	0.3	20	0.7	0.3	0
5	0.6	0.1	0.3	21	0.5	0.3	0.2
6	0.4	0.4	0.2	22	0.3	0	0.7
7	0.6	0	0.4	23	0.5	0.4	0.1
8	0.3	0.3	0.4	24	0.4	0.5	0.1
9	0.4	0.6	0	25	0.6	0.4	0
10	0.3	0	0.7	26	0.7	0.3	0
11	0.6	0.2	0.2	27	0.1	0	0.9
12	0.5	0.5	0	28	0.6	0.3	0.1
13	0.6	0.4	0	29	0.4	0.1	0.5
14	0.4	0.4	0.2	30	0.7	0.2	0.1
15	0.5	0.1	0.4	31	0.4	0.4	0.2
16	0.2	0.7	0.1	32	0.2	0.1	0.7
17	0.3	0.3	0.4	33	0.3	0.7	0

Table IV. Hourly load distribution [12]

J	C1	C2	C3	J	C1	C2	C3
1	0.1	0.1	0.3	13	0.6	0.7	0.5
2	0.1	0.1	0.3	14	0.7	0.6	0.6
3	0	0.1	0.4	15	0.8	0.5	0.8
4	0	0.1	0.2	16	1	0.6	0.8
5	0	0.4	0.2	17	1	0.7	0.7
6	0	0.3	0.3	18	0.8	0.8	0.7
7	0.1	0.4	0.3	19	0.6	0.9	0.8
8	0.2	0.4	0.4	20	0.7	1	0.9
9	0.7	0.3	0.8	21	0.6	1	1
10	0.8	0.3	1	22	0.2	0.6	0.8
11	0.8	0.5	0.9	23	0.1	0.5	0.5
12	0.7	0.6	0.9	24	0.1	0.2	0.4

Table V. Results of reconfiguration of the test system

Hour	Number of ti -switch	$\Delta ploss(MW)$	$Ct\Delta ploss(\$)$
1	s7 -s9 -s14 -s28 -s32	0.774	464.4
17	s7 –s9 –s14 –s32- s37	0.0034	2.04
22	s7 –s9 –s14 –s28 –s32	0.00088	0.53

Fig. 1 compared the voltage profile of the test system before any reconfiguration and after the second reconfiguration. It is seen that voltage magnitude of almost all buses has been improved. The lowest voltage magnitude for the initial reconfiguration was 0.977 pu at bus 17 while in the GA-improved system the lowest voltage has been enhanced to 0.984 pu at bus 31.

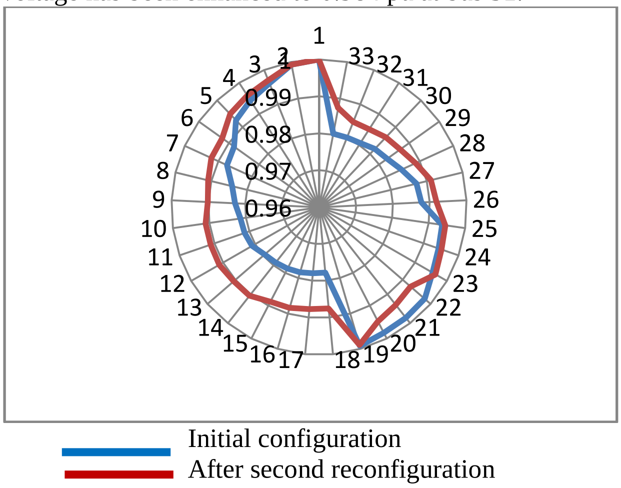

Fig. 1. Comparison of the voltage profile before any reconfiguration and after the second reconfiguration without any capacitor placement

1.7. Simulation results with capacitor bank

In this stage, a 450-MVar capacitor bank is connected to the system. The location of the capacitor bank is found using the GA algorithm in order to minimize the objective function.

Table VI. Results for system reconfiguration after the capacitor bank placement

Hour	Number of ti –switch	$\Delta ploss(MW)$	$Ct\Delta ploss(\$)$
5	s7 -s9 -s14 –s32 –s37	1.058	634.85

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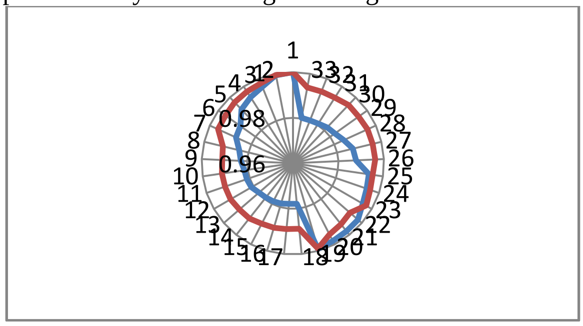
22	s7 –s9 –s14 –s28 –36	0.00179	1.074

According to the obtained results, two reconfigurations are cost-effective. The first one has happened at the hour five with the switches s7, s9, s14, s32, and s37 opened and the network losses of 1246.96 kW. The second reconfiguration has happened at the hour 22 and the switches s7, s9, s14, s28, and s36 have been opened. For this case, the transmission losses were 1227.16 kW. In both cases, bust 29 was selected as the best location for the capacitor bank. Fig. 2 shows the voltage profile before and after the capacitor bank placement at bus 29. Obviously, the voltage profile at almost all buses has been enhanced. The minimum voltage magnitude of 0.977 pu at bus 17 in the initial configuration has been improved to 0.988 pu at bus 17 after the capacitor placement by use of the genetic algorithm.



Initial configuration
After second reconfiguration

Fig.2. Comparison of the voltage profile before any reconfiguration and after the second reconfiguration with the capacitor placement

6. Conclusion

This paper proposed a distribution network reconfiguration methodology for reducing losses. Based on the simulation results, reconfiguration of the distribution network can considerably reduces transmission losses. The obtained results on the IEEE 33-bus test system showed that the when no capacitor bank was installed, the transmission losses were reduced b 33.8% via network reconfiguration while in case of installed capacitor bank the losses were lowered by 46.7%.

Besides, it was shown the network reconfiguration improves voltage profile. According to the simulation results, installing a capacitor bank at bus 29 yielded the highest voltage profile improvement.

Inclusion of distributed generation resources can also help releasing distribution network capacity, improving reliability, generating heat and power simultaneously, enhancing power quality and voltage profile and finally reducing transmission losses.

Appendix

Table I. IEEE 33-bus system data

Bus	Line	R (Ohms)	X (Ohms)	End bus real load (KW)	End bus reactive load (KVAr)
0-1	S1	0.0922	0.047	100	60
1-2	S2	0.493	0.2511	90	40
2-3	S3	0.366	0.1864	120	80
3-4	S4	0.3811	0.1941	60	30
4-5	S5	0.819	0.707	60	20
5-6	S6	0.1872	0.6188	200	100
6-7	S7	1.7114	1.2351	200	100
7-8	S8	1.03	0.74	60	20
8-9	S9	1.044	0.74	60	20
9-10	S10	0.1966	0.065	45	30
10-11	S11	0.3744	0.1238	60	35
11-12	S12	1.468	1.155	60	35
12-13	S13	0.5416	0.7129	120	80
13-14	S14	0.591	0.526	60	10
14-15	S15	0.7463	0.545	60	20
15-16	S16	1.289	1.721	60	20
16-17	S17	0.732	0.574	90	40
1-18	S18	0.164	0.1565	90	40
18-19	S19	1.5042	1.3554	90	40
19-20	S20	0.4095	0.4784	90	40
20-21	S21	0.7089	0.9373	90	40
2-22	S22	0.4512	0.3083	90	50
22-23	S23	0.898	0.7091	420	200
23-24	S24	0.896	0.7011	420	200
5-25	S25	0.203	0.1034	60	25
25-26	S26	0.2842	0.1447	60	25
26-27	S27	1.059	0.9337	60	20
27-28	S28	0.8042	0.7006	120	70
28-29	S29	0.5075	0.2585	200	600
29-30	S30	0.9744	0.963	150	70
30-31	S31	0.3105	0.3619	210	100
31-32	S32	0.341	0.5302	60	40
20-7	S33*	2	2		
8-14	S34*	2	2		
11-21	S35*	2	2		
17-32	S36*	0.5	0.5		
24-28	S37*	0.5	0.5		

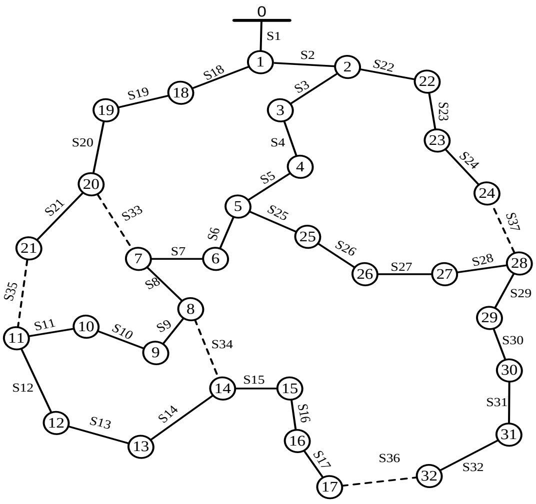


Fig. 1. IEEE 33-bus test system

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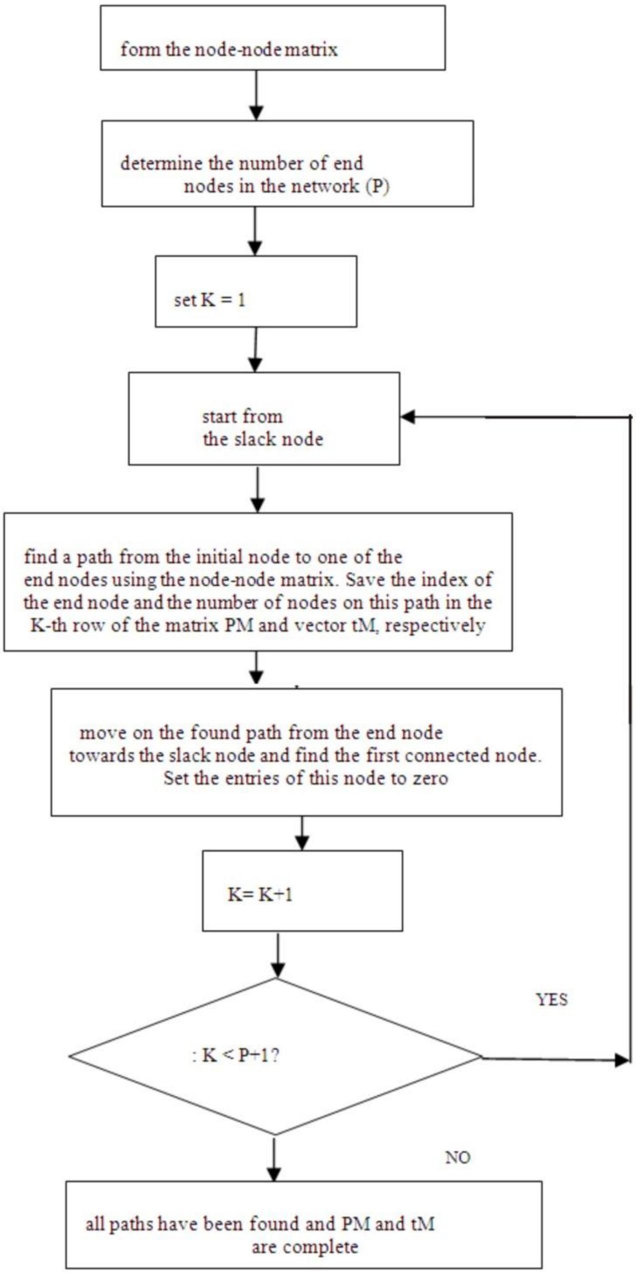

Fig. 2. The proposed routing algorithm

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