A Unique Distribution System Loss Minimization Scheme via Reconfiguration with Line Capability Limits

James A. Momoh and Yanchun Wang
Electrical Engineering Department
Howard University
Washington, DC 20059

D. Tom Rizy
Oakridge National Laboratory
Oakridge, TN 37831

Abstract

This paper describes an integrated scheme for distribution system loss minimization with consideration of line capability limits via reconfiguration. Line capability limits are incorporated into the single loop optimization process as constraints. The integrated scheme is tested by 38 - bus distribution system for different initial configurations, system losses are reduced significantly without any overload occurrence on feeder transformer network.

Introduction

Distribution system reconfiguration is a process of altering the topology structures of distribution feeders by changing open/closed status of the sectionalizing and tie switch. As operating conditions change, networks are reconfigured for two purposes: (1) to reduce the network real power losses and (2) to relieve overloads in the network, or to balance network load. Since the distribution systems are configured radially and there may be a lot of switches to be dealt with in reconfiguration process, heuristic approaches, mostly based on approximate power flow estimation methods, have been suggested to solve the reconfiguration problem.

The works by [1, 2, 3] develop multi loop optimization technique. In the multi loop optimization method, all network switches (Normally Open Switches) are first closed to form a meshed network. The switches are then opened successively to restore the radial configuration. Several approximations are used for the determination of the open/closed switch. In this approach, the open/closed switch scheme is determined for a meshed network. Therefore, the switch to be opened (for opening a loop) can be selected properly at the last solution step only where there is one loop in the network and the remaining portion is radial. In all other steps, there are a number of network loops, which do not correspond to the actual operating condition. Therefore, the feeder configuration obtained by the multi loop approach may not be the optimum or near optimum one. The single loop optimization [4, 5, 6] is proposed to overcome this shortcoming. In the single loop optimization process, an initial open switch list is needed and formed according to system normally open switches. System single loop is formed by closing one switch in the open switch list. The loss minimization procedure is to find a branch in the single loop so that the loss increase caused by opening the selected branch is lowest. This branch will be opened to form a new radial configuration. The open switch list will be refreshed by the new branch switch. This process is conducted consecutively for all switches. At each step, when the branch in the single loop is determined, the open switch list will be refreshed by the new branch switch. This process will be stopped until the switches in the open switch list are not changed. The network reconfiguration with loss minimization is determined by the finally open switch list. Figure 1 is used to explain single loop optimization. There are 10 lines (1-10), 2 Normally Open Switches (NOS) in the system. Two loops are formed by closing NOS 11 and 12. Loop 1 is formed by lines 2, 3, 5, 6, and NOS 11, while loop 2 is formed by lines 3, 4, 8, 9, 10, and NOS 12. The initial switches in switch list are NOS 11 and 12. The optimization process starts with closing NOS 11 in loop 1, then the process tries to open lines one by one in loop 1 to calculate system loss for each open line scheme. The line with the lowest loss will be opened to maintain radial configuration. Then similar process is applied to loop 2. The above process is the first cycle of the optimization. Since the open line scheme in loop 2 may change the open line scheme in loop 1, the process goes back to loop 1 to determine the open line scheme. Similarly, same process is applied to loop 2. This is the second cycle of the optimization. This process will be stopped when open line scheme are same for cycle j and cycle (j+1).

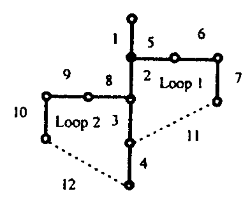

Figure 1. Single Loop Optimization

A key problem for single loop optimization is to define a criterion which is used to determine the open branch in the single loop to minimize system loss. With the

DISCLAIMER

assumption of constant current load, the single loop optimization becomes a very simple process, therefore, is a very fast process.

Since the optimization criteria are different, loss minimization and load balancing processes are often studied separately. Line capability is not considered in the optimization process of loss minimization and overloads may occur in some lines for operating conditions. On the other hand, in load balancing, an average load balance index is minimized. This average load balance index cannot reflect load condition in all lines, therefore, overload may still occur in some lines.

Recently, multiple objective optimization technique was used to solve distribution system reconfiguration problem [7, 8, 9]. This approach can handle loss minimization, load balancing, voltage deviation minimization, as well as reliability simultaneously. Also, the capability constraints can be taken into account. In order to get a globally optimum solution, two stage solution approach is introduced. The first stage is to yield a reasonably good solution for stage 2 using a power flow type solution approach. The branch exchange scheme is employed to find a better solution until stopping criteria are met. This optimization process may be time consuming.

This paper investigates an unique integrated scheme of distribution system loss minimization with consideration of line capability via reconfiguration using single loop optimization. By integrating the line capability constraints into the optimization process, the reconfiguration scheme will be loss minimized without line overloads.

The proposed scheme is tested on 38-bus distribution system for the different initial network configurations. The optimization results show that the network losses are reduced significantly without any overload occurrence on the feeder transform networks comparing with existing techniques.

Loss Minimization Criterion Model and Capability Constraint Model

Loss Minimization Criterion Model

In order to simplify the optimization process, a constant current load model is used. Supposing I_j is the current flow in the j^{th} branch prior to opening, the change in the losses in branch i is given by

$$\Delta P_{Lossi} = \left| I_i - I_j \right|^2 r_i - \left| I_i \right|^2 r_i \qquad (1)$$

where

ΔP_L is the change in loss

I_i is the current in line i

I_j is the current in line j

r_i is the resistance of line i

Eqn (1) can be rewritten as

$$\Delta P_{Lossi} = \left| I_j \right|^2 r_i - 2\,\mathrm{Re}(I_i I_j^*) r_i \qquad (2)$$

With single loop approach, the objective is to minimize the change in loss in loop l due to opening of branch j, i.e.,

$$\min\{\Delta P_L\} = \sum_{i=1}^{n} \{\left| I_j \right|^2 r_i - 2\,\mathrm{Re}(I_i I_j^*)\, r_i\} \qquad (3)$$

Line Capability Constraint Model

Assuming line capability limits are expressed by the maximum current capability, the line current should satisfy the constraint, i.e.,

$$\frac{P_i}{P_i^{Max}} < L_i^{Max} \qquad (4)$$

Where

P_i^{Max} is the current capability of line i

L_i^{Max} is the maximum load balance index of line i

Loss minimization is the minimize Eqn (3) subject to line constraints of Eqn (4).

Implementation

The algorithm of loss minimization is shown in Figure 1.

The program starts with initial condition input which includes net work data input and Normally Open Switch (NOS) data input. Then, the program forms the initial open switch list and conducts radial power flow calculation.

An iteration process is designed to find the final optimization solution. At each iteration, the switch in open switch list is closed one by one. When switch i is closed, weakly meshed power flow is calculated. Then the program searches branch j in the loop formed by closing switch i. Branch j is selected so that the network loss increase is lowest without violation in line capability limits. The open switch list is renewed by introducing branch j instead of switch i. Branch j is ranked at the last of the list. This iteration process is stopped when the switches in the list are not changed. Finally, the program output the results of open switch list and network loss.

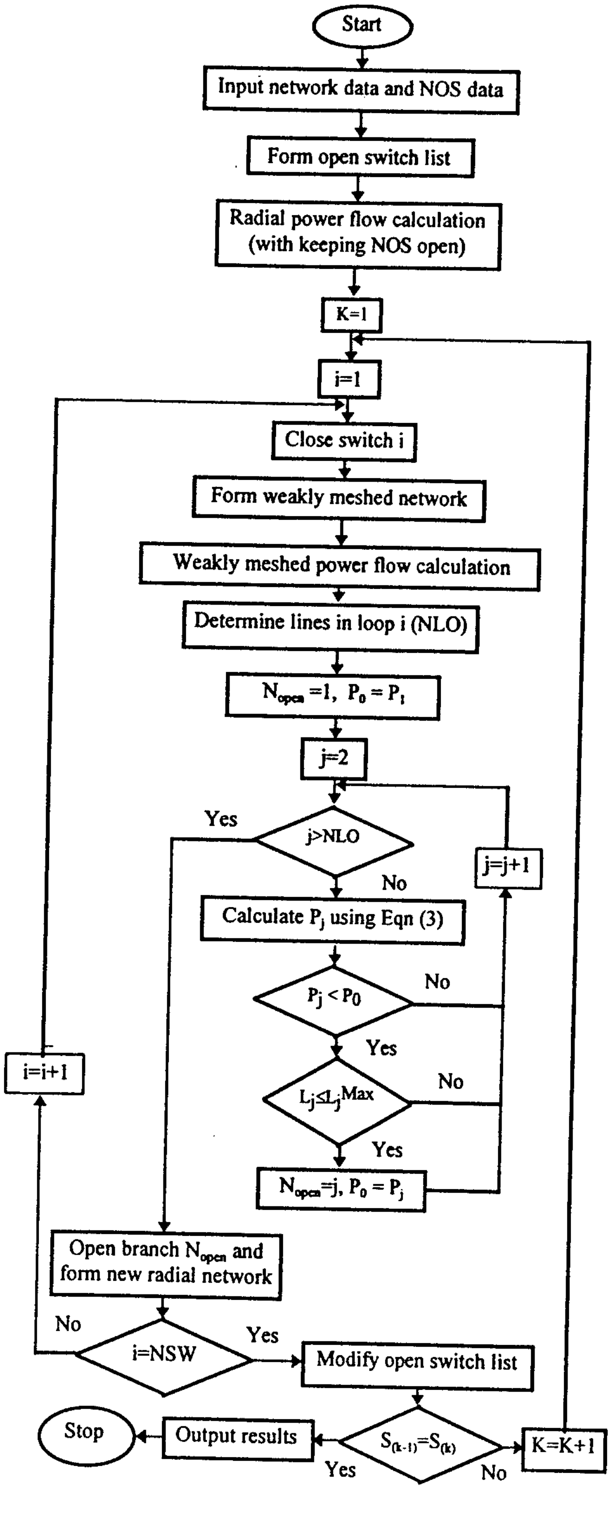

Figure 2. Algorithm of Network Loss Minimization

Validation Studies

The proposed scheme is tested by 38-bus distribution system. Figure 2 shows the system diagram. The system data can be found in [4].

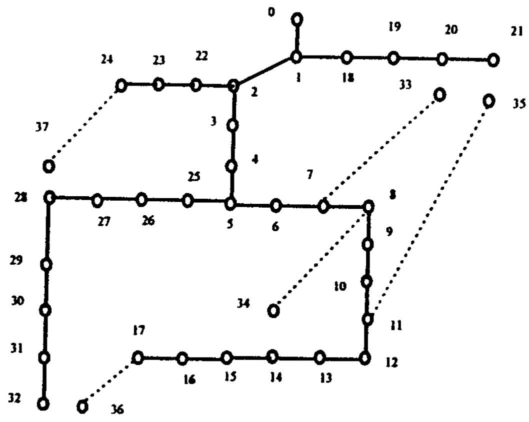

Figure 3. 38 - Bus Distribution System

Since initial configuration may be different for a distribution system, we designed three different initial configurations for program testing. Three Normally Open Switch (NOS) lists according to three initial configurations are given in Table 1.

Table 1. Three Cases for Program Test

Case	NOS 1	NOS 2	NOS 3	NOS 4	NOS 5
	from - to bus	from - to bus	from - to bus	from - to bus	from - to bus
1	7 - 33	8 - 34	11 - 35	17 - 36	24 - 37
2	3 - 4	11 - 12	11 - 35	17 - 36	24 - 37
3	2 - 3	9 - 10	20 - 21	29 - 30	22 - 23

Loss Minimization without Line Capability Limits

First, the scheme is tested without line capability limits for the selected three cases. The test results are summarized in Table 2 through Table 4. Table 2 shows the result of case 1. The network initial loss is 0.02027 (p.u.). The program starts with the first loop. NOS 8 - 20 is closed. After comparing the losses among line open schemes, it is found that system loss reaches minimum value when line 6 - 7 is opened in the first loop. System loss is reduced from 0.02027 to 0.01498. Similarly, the program continues to deal with other loops. After nine iterations, the network loss reaches minimum value, the open switches are changed to 23-24, 6-7, 12-13, 8-9, 30-31, the network loss is reduced to 0.0108389 (p.u.). The network loss is decreased by 47%. Table 3 shows the results of case 2. The network initial loss is 0.0360375 (p.u.), after nine iterations, the network loss reaches minimum value, the open switches are changed to 23-24, 6-7, 12-13, 8-9, 30-31, the network loss is reduced to 0.0108389 (p.u.). The network loss is decreased by 70%. Table 3-4 shows the results of case 3. The network initial loss is 0.058018 (p.u.), after 15 iterations, the network loss reaches minimum value, the open switches are changed to 8-9, 30-31, 23-24, 6-7, 12-13, the network loss is 0.0108389 (p.u.). The network loss is decreased by 81%. From the above results, we can see that the program gives the same optimization solution for the different initial conditions.

The final system configuration without line capability limits is shown in Figure 4.

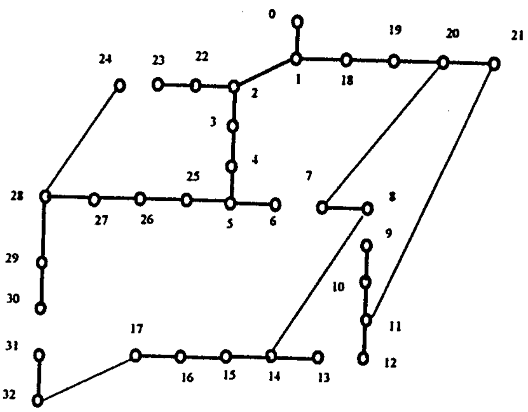

Figure 4. Reconfiguration without Line Capacity Limits

Loss minimization with Line Capability Limits

System line ratings are listed in Table 5. These line capability constraints are incorporated into single loop optimization procedure. Three different cases shown in Table 1 are used to test the scheme. The results are displayed in Table 6 and Table 7.

Table 6 shows the optimization progress for case 1. In the first iteration, if line capability is not considered, opening line 6-7 will cause lowest loss in network. While when considering line constraints, opening line 6-7 will cause overload in line 19-20. This open line scheme cannot be adopted. The available minimum loss without overload scheme is to open line 7-33 in the first iteration (the first loop). With this open line scheme, system loss is reduced from 0.02027 to 0.01877. Then the similar processes are applied to the other loops. After 15 iteration, network loss reaches a minimum value without overload in lines. The open switches are: 8-9, 12-113, 6-7, 17-36, and 23-24. Network loss is decreased by 36%. Table 7 shows the results of case 2. The result is similar to the case 1. The network loss is decreased by 64%. The final network configuration is the same as the case 1. For case 3, the similar result is obtained. The network loss is decreased by 78%. The final configuration is the same as the configurations of cases 1 and 2. Three different initial configurations converge to the same optimized solution. The final configuration is shown in Figure 5.

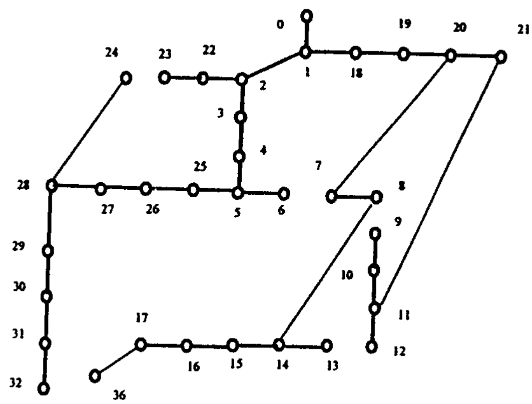

Figure 5. Reconfiguration with Line Capacity Limits

Table 2. Loss Minimization via Reconfiguration using Initial Configuration of Case 1 (without line limits)

Iteration Count	Branch Number		PLOSS (p.u.) (radial)	Open switches / branches				
	IN	OUT		1	2	3	4	5
0	-	-	0.02026789	7-33	8-34	11-35	17-36	24-37
1	6-7	7-33	0.01498043	8-34	11-35	17-36	24-37	6-7
2	12-13	8-34	0.01373004	11-35	17-36	24-37	6-7	12-13
3	8-9	11-35	0.01332715	17-36	24-37	6-7	12-13	8-9
4	30-31	17-36	0.01137770	24-37	6-7	12-13	8-9	30-31
5	23-24	24-37	0.01083887	6-7	12-13	8-9	30-31	23-24
6	6-7	6-7	0.01083887	12-13	8-9	30-31	23-24	6-7
7	12-13	12-13	0.01083887	8-9	30-31	23-24	6-7	12-13
8	8-9	8-9	0.01083887	30-31	23-24	6-7	12-13	8-9
9	30-31	30-31	0.01083887	23-24	6-7	12-13	8-9	30-31

Table 3. Loss Minimization via Reconfiguration using Initial Configuration of Case 2 (without line limits)

Iteration Count	Branch Number		PLOSS (p.u.) (radial)	Open switches / branches				
	IN	OUT		1	2	3	4	5
0	0	0	0.03603754	3-4	11-12	11-35	17-36	24-37
1	6-7	3-4	0.01440607	11-12	11-35	17-36	24-37	6-7
2	12-13	11-12	0.01373004	11-35	17-36	24-37	6-7	12-13
3	8-9	11-35	0.01332715	17-36	24-37	6-7	12-13	8-9
4	30-31	17-36	0.01083887	24-37	6-7	12-13	8-9	30-31
5	23-24	24-37	0.01083887	6-7	12-13	8-9	30-31	23-24
6	6-7	6-7	0.01083887	12-13	8-9	30-31	23-24	6-7
7	12-13	12-13	0.01083887	8-9	30-31	23-24	6-7	12-13
8	8-9	8-9	0.01083887	12-31	23-24	6-7	12-13	8-9
9	30-31	30-31	0.01083887	23-24	6-7	12-13	8-9	30-31

Table 4. Loss Minimization via Reconfiguration using Initial Configuration of Case 3 (without line limits)

Iteration Count	Branch Number		PLOSS (p.u.) (radial)	Open switches / branches				
	IN	OUT		1	2	3	4	5
0	0	0	0.05801805	2-3	9-10	20-21	29-30	22-23
1	6-7	2-3	0.01934802	9-10	20-21	29-30	22-23	6-7
2	12-13	9-10	0.01702889	20-21	29-30	22-23	6-7	12-13
3	8-9	20-21	0.01552281	29-30	22-23	6-7	12-13	8-9
4	28-29	29-30	0.01353083	22-23	6-7	12-13	8-9	28-29
5	23-24	22-23	0.01156790	6-7	12-13	8-9	28-29	23-24
6	6-7	6-7	0.01156790	12-13	8-9	28-29	23-24	6-7
7	12-13	12-13	0.01156790	8-9	28-29	23-24	6-7	12-13
8	8-9	8-9	0.01156790	28-29	23-24	6-7	12-13	8-9
9	30-31	30-31	0.01083887	23-24	6-7	12-13	8-9	30-31
10	23-24	23-24	0.01083887	6-7	12-13	8-9	30-31	23-24
11	6-7	6-7	0.01083887	12-13	8-9	30-31	23-24	6-7
12	12-13	12-13	0.01083887	8-9	30-31	23-24	6-7	12-13

Table 5. Line Capabilities

from - to bus	P^{Max} (MW)	from - to bus	P^{Max} (MW)	from - to bus	P^{Max} (MW)	from - to bus	P^{Max} (MW)	from - to bus	P^{Max} (MW)
0 - 1	7.950	8 - 9	2.430	16 - 17	1.481	24 - 25	3.241	7 - 33	5.000
1 - 2	5.545	9 - 10	2.430	17 - 18	2.430	25 - 26	3.241	8 - 34	5.000
2 - 3	5.545	10 - 11	2.430	18 - 19	2.430	26 - 27	3.241	11 - 35	5.000
3 - 4	5.545	11 - 12	2.430	19 - 20	0.950	27 - 28	3.241	17 - 36	5.000
4 - 5	5.545	12 - 13	2.430	20 - 21	0.950	28 - 29	1.279	24 - 37	5.000
5 - 6	3.241	13 - 14	2.430	21 - 22	1.279	29 - 30	0.950		
6 - 7	3.241	14 - 15	2.430	22 - 23	1.279	30 - 31	0.950		
7 - 8	2.430	15 - 16	1.481	23 - 24	0.950	31 - 32	0.950		

Table 6. Loss Minimization via Reconfiguration using Initial Configuration of Case 1 (with line limits)

Iteration Count	Branch Number		PLOSS (p.u.) (radial)	Open switches / branches				
	IN	OUT		1	2	3	4	5
0	-	-		7-33	8-34	11-35	17-36	24-37
1	7 - 33	7 - 33	0.02026789	8-34	11-35	17-36	24-37	7-33
2	12 - 13	8 - 34	0.01876874	11-35	17-36	24-37	7-33	12-13
3	6 - 7	11 - 35	0.01403961	17-36	24-37	7-33	12-13	6-7
4	17 - 36	17 - 36	0.01403961	24-37	7-33	12-13	6-7	17-36
5	23 - 24	24 - 37	0.01369355	7-33	12-13	6-7	17-36	23-24
6	8 - 9	7 - 33	0.01298909	12-13	6-7	17-36	23-24	8-9
7	12 - 13	12 - 13	0.01298909	6-7	17-36	23-24	8-9	12-13
8	6 - 7	6 - 7	0.01298909	17-36	23-24	8-9	12-13	6-7
9	17 - 36	17 - 36	0.01298909	23-24	8-9	12-13	6-7	17-36
10	23 - 24	23 - 24	0.01298909	8-9	12-13	6-7	17-36	23-24
11	8 - 9	7 - 33	0.01298909	12-13	6-7	17-36	23-24	8-9
12	12 - 13	12 - 13	0.01298909	6-7	17-36	23-24	8-9	12-13
13	6 - 7	6 - 7	0.01298909	17-36	23-24	8-9	12-13	6-7
14	17 - 36	17 - 36	0.01298909	23-24	8-9	12-13	6-7	17-36
15	23 - 24	23 - 24	0.01298909	8-9	12-13	6-7	17-36	23-24

Table 7. Loss Minimization via Reconfiguration using Initial Configuration of Case 2 (with line limits)

Iteration Count	Branch Number		PLOSS (p.u.) (radial)	Open switches / branches				
	IN	OUT		1	2	3	4	5
0	-	-	0.03603754	3-4	11-12	11-35	17-36	24-37
1	7-33	3-4	0.01955611	11-12	11-35	17-36	24-37	7-33
2	12-13	11-12	0.01847687	11-35	17-36	24-37	7-33	12-13
3	6-7	11-35	0.01403096	17-36	24-37	7-33	12-13	6-7
4	17-36	17-36	0.01403096	24-37	7-33	12-13	6-7	17-36
5	23-24	24-37	0.01369355	7-33	12-13	6-7	17-36	23-24
6	8-9	7-33	0.01298909	12-13	6-7	17-36	23-24	8-9
7	12-13	12-13	0.01298909	6-7	17-36	23-24	8-9	12-13
8	6-7	6-7	0.01298909	17-36	23-24	8-9	12-13	6-7
9	17-36	17-36	0.01298909	23-24	8-9	12-13	6-7	17-36
10	23-24	23-24	0.01298909	8-9	12-13	6-7	17-36	23-24
11	8-9	8-9	0.01298909	12-13	6-7	17-36	23-24	8-9
12	12-13	12-13	0.01298909	6-7	17-36	23-24	8-9	12-13
13	6-7	6-7	0.01298909	17-36	23-24	8-9	12-13	6-7
14	17-36	17-36	0.01298909	23-24	8-9	12-13	6-7	17-36
15	23-24	23-24	0.01298909	8-9	12-13	6-7	17-36	23-24

Conclusion

This paper presents a unique scheme for distribution system loss minimization via reconfiguration. Line capability limits are incorporated into the single loop optimization process. By testing the proposed scheme, we have following conclusions:

1. Single loop minimization process is a very efficient tool to solve distribution system reconfiguration problem. Different initial configurations converge to the same optimum solution. Network losses are reduced significantly. Without line capability limits, some lines may be overloaded for the optimum network configuration;
2. Line capability constraints can be easily incorporated in the optimization process. With line capability limits, network reconfiguration is a sub-optimum solution, system will be operated in a lower network loss fashion without overload in any line;
3. Different initial configurations converge to the same solution using single loop optimization method;
4. Based on the proposed scheme, distribution system operators can select the switching scheme for reconfiguration to minimize system loss without overloads. Also, since the single loop optimization is a very fast process, it can be used for both off line and on line distribution system reconfiguration.

Acknowledgment

The research is supported by the Department of Energy, US.

Reference

[1] S. Civanlar, J. J. Grainger, H. Yin, S. S. H. Lee, "Distribution Feeder Reconfiguration for Loss Reduction", IEEE Transaction on PWRD, Vol-3, July 1988, pp 1217 - 1223

[2] Mesut E. Baran, Felix. Wu, "Network Reconfiguration in Distribution Systems for loss reduction and load balance", IEEE Transaction on PWRD, Vol 4, No 2, April 1989, pp 1401 - 1407

[3] D. Shirmohammadi, H. H. Hong, "Reconfiguration of Electric Distribution Network for Resistive line losses reduction", IEEE Transaction on PWRD, Vol 4, No 2, April 1989, pp 1492 - 1498

[4] S. K. Goswami, S. K. Basu, " A New Algorithm for the Reconfiguration of Distribution Feeders for Loss Minimization", IEEE Transaction on PWRD, Vol 7, No 3, July 1992, pp 1484 - 1491

[5] Ji - Yuan Fan, Lan Zhang, Jonh D. McDonald, "Distribution Network Reconfiguration: Single Loop Optimization", IEEE Transaction on Power Systems, Vol. 11, No. 3, August 1996, pp 1643 - 1646

[6] G. J. Peponis, M. P. Papadopoulos, N. D. Hatziargyriou, "Optimal Operation of Distribution Networks", IEEE Transaction on Power Systems, Vol. 11, No. 1, February 1996, pp 59 - 67

[7] R. J. Sarfi, M. M. A. Salama, A Y. Chikhani, "Distribution System Reconfiguration for Loss Reduction: An Algorithm Based on Network Partitioning Theory", IEEE Transaction on Power Systems, Vol. 11, No. 1, February 1996, pp 504 - 510

[8] I. Roytelman, V. Melnik, S. S. H. Lee, R. L. Lugtu, "Multi-Objective Feeder Reconfiguration by Distribution Management System", IEEE Transaction on Power Systems, Vol. 11, No. 2, May 1996, pp 661 - 666

[9] Jin - Cheng Wang, Hsiao - Dong Chiang, Gray R. Darling, "An Efficient Algorithm for Real - Time Network Reconfiguration in Large Scale Unbalanced Distribution Systems", IEEE Transaction on Power Systems, Vol. 11, No. 1, February 1996, pp 511 - 517

M98003212

Report Number (14) ORNL--98003212
CONF-9701101--

Publ. Date (11) 199706
Sponsor Code (18) DOE, XF
UC Category (19) UC-900, DOE/ER

DOE