Network Reconfiguration for Loss Minimization in Power Distribution System Using Sensitivity Analysis

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***Abstract*-- This paper present the two stage method for reduce the power loss in power distribution system. The study involved the implementation of sensitivity analysis in order to minimum loss due to distribution system configuration. This method uses the loss sensitivity of transfer line with respect to the impedance of candidate branches in the stage I and branch exchange method in the stage II. In the stage I, the reconfiguration of power distribution system start with all candidate switches to be closed forming a meshed system, then the switches will be opened based on loss sensitivity analysis until the power distribution system forming a radial network structure and all load condition must have connectivity. In the stage II, implementation of branch exchange method is used to improve the solution found by the first stage. This method was implemented on 16-bus system and 33-bus system for demonstrating the effectiveness of proposed method.**

***Index Terms* -- radial distribution systems, minimization of losses, network reconfiguration, sensitivity analysis.**

I. INTRODUCTION

Currently, most of the electric energy produce by power generation is lost during transmission and distribution before arriving at the consumer [1, 2]. Power distribution network produces a large number of power loss. It is because the distribution network operates in low voltage level [1]. Low voltage level may increase the current flow through the radial feeder (cable) and because of that, it will produce a large amount of power loss [1, 3]. High power losses will cause voltage drop at the receiving end. Voltage drop must be reduced to keep the voltages at load point within a standard limit [4]. Power loss may also increase when distribution network using radial feeder with long distance or large load. Radial feeder with long distance have more resistance as reported by J. P. Tewari [5]. The resistance of the radial feeder is the cause of the real power loss occurrence [3]. Occurrence of power loss also causes the temperature of the radial feeder (cable) to rise. The temperature rise on the cable will reduce the life span of the cable [5, 6]. Power loss can also reduce the reliability of power distribution network.

The networks of distribution system are operated in a radial configuration, but their topology, especially in urban areas, is normally meshed to improve reliability of system [7]. Distribution network are generally built as interconnected network [1]. The number of normally close switches and number of normally open switches in distribution network allow the distribution network operate in a radial tree structure configuration [8]. Power distribution system are divided into subsystem radial feeder. Distribution network operate in radial configuration to simplify the protection [9, 10]. The connection in radial distribution can reduce the cost of operation with simplicity of their protection schemes and operating procedures, in addition to their lower short circuit currents [7].

Reconfiguration of a distribution system is a process, that alters the network distribution structure by changing the status (open/close) of the tie switches (normally open) and the sectionalizing switches (normally close) in the system [11]. After reconfiguration of distribution network process, the distribution network should operate at minimum cost and improve the system reliability [9]. To improve the reliability of radial distribution system, the values of all bus voltage magnitude in the system should be in their range [9, 12].

In this study, the reconfiguration process of radial distribution network are implemented based on real power sensitivities with respect to the impedances of the candidate branches in the first stage procedure [13, 14]. For the second stage procedure, branch exchange operation is used to improve the solution from the first stage procedure. In the second stage, the process is formed to simply to make exchanges among each of the switches and the corresponding top ranked neighbors, which were identified in the first stage [1, 14]. The solution algorithm will be tested on 16-Bus system and 33-bus system for demonstrating the effectiveness of proposed method.

II. SOLUTION METHODOLOGY

The objective of a distribution system reconfiguration is to minimize the power loss. It alters the network distribution structure by changing the status (open/close) of the tie switches (normally open) and the sectionalizing switches (normally close) in the system [7]. In determining the switch to be opened and closed, the system must also meet all the criteria needed to ensure the reliability of the distribution system [1].

Some of the criteria required in the reconfiguration is as follows:

$V_{min} \leq V_i \leq V_{max}$, i= 1,2,3,..No. of nodes (1)

$I_L \leq I_{Lmax}$, L=1,2,3,….No. of branches (2)

Load connectivity (3)

Radial network structure (4)

Where

P_L real power loss of the system

V_i bus voltage magnitude

I_L current magnitude of branch

I_{Lmax} maximum current carrying capacity of branch

V_{max} maximum bus voltage magnitude at the bus

V_{min} minimum bus voltage magnitude at the bus

Load connectivity means that all nodes in the network must be connected by some branches. Radial network structure means that distribution system network in radial connectivity.

In this method, there have two stages of reconfiguration process. In the first stage procedure, the reconfiguration of power distribution system start with all candidate switches to be close forming a meshed, and then, the switches will be open based on loss sensitivity analysis until the power distribution system forming a radial network structure and all load condition must have connectivity [1, 9]. Branch exchange method used in the second stage to improve the solution obtained from the first stage [1, 9, 14].

A. Stage I

The reconfiguration process start by performing a power flow with all switches are closed, and then, the sensitivities of each branches was evaluate and rank them in the ascending order. The branches which result has the smallest sensitivities values (top tanked) are opened. Only one switch is opened, whereas all the remaining switches are closed. The criteria of the network configuration is that all nodes in the network should be connected by some branches and values of all bus voltage magnitude should be in range. If the network does not satisfy the criteria, the switches are back to closed condition. Under this condition, the next ranked branch/switch is selected to be open and above mentioned criteria are check again. The candidate switch is opened after the criteria are satisfied. Furthermore, store the neighboring switch with switch that have been opened in the list, based on the smallest sensitivities values. The list that will be use in the second stage procedure. After one of the switches is opened, the sensitivities of remaining branches closed are evaluate again, and the above procedure is repeated until the connectivity of the distribution system in radial network [1, 9].

Because of the step by step selection of the switches to be opened, the first stage procedure may not guarantee optimum solution. Thus, there is possibility of the solution to improve using branch exchange method [1].

B. Stage II

A second stage procedure is to improve the solution found in the stage I. In the stage II, a branch exchange operation is performed to improve the solution obtained from stage I. An exchange operation is defined as the action to close an opened switch and at the same time, open another switch where the switch is switched to the neighboring switch has been closed, so that the connectivity of network still in radial network [1, 14].

The list has been prepared from the first stage consists of branch number. It based on the smallest sensitivities of the neighborhood of the opened switches. From the list, the switch are selected and an exchanged operation is performed. One by one, the opened branch in stage I is closed and the switch in the list is opened. For each configuration, all criteria must be satisfied. If the all criteria are satisfied, power flow is performed and the real power loss is determined and compared to the real power loss obtained in the previous configuration. If one of the configurations produce smaller real power loss in the system, then that switch is selected to be opened to replace the previously open switch [1, 9].

C. Evaluation of Sensitivities

The sensitivities of the branch is required to determine the switch that should be opened. The sensitivities of the branch are directly calculated from transfer line real power loss as follows [1]:

$$Sensitivity = \frac{\partial P_L}{\partial |z_{ij}|} = \frac{|V_i - V_j|^2}{|z_{ij}|^2} \cos(\theta_{ij}) \quad \ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Where:

V_i, V_j the node voltage at node i and node j

Z_{ij} the impedance of branch l between node i and node j

θ_{ij} the angle of impedance Z_{ij}

D. Algorithm

The algorithm for the proposed method is as follows.

Step :

1. All the switches in the system are closed
2. Perform power flow
3. Evaluate sensitivities of real power loss with respect to the branch impedances and rank them in the ascending order.
4. The top ranked switch are opened
5. Check the load connectivity. Make sure all nodes has been connected by some branches
6. If one of the node has no connectivity, close the opened switch and open next ranked switch and go to step 5
7. If the all nodes has connectivity, perform a power flow with this switch open
8. Check the solution. If the solution is not satisfied with the criteria required, close the opened switch and open the next ranked switch and go to step 5
9. If the solution satisfied with the criteria required, then store the switch number in the neighborhood of the opened switch with the minimum sensitivity, in the branch exchange list
10. If the system is not radial then go to step 2
11. Exchange the switch with the corresponding switch in the branch exchange list
12. Check the load connectivity. If one of the node no has connectivity then discard this branch exchange operation and go to step 18
13. If all nodes has been connected by some branches, perform a power flow
14. Check the solution. If the solution is not satisfied with the criteria required, then discard this branch exchange operation and go to step 18

15. If the solution satisfied with the criteria required, compare real power loss with that previous configuration
16. If the real power loss increase from previous then discard this branch exchange operation and go to step 18
17. If the real power loss decrease from previous, update the new network configuration
18. Remove the neighborhood switch of the switch opened in Stage I from the branch exchange list
19. If the list is empty, stop, otherwise go to step 10

The flow chart of the proposed method is shown in Figure 1.

III. Explanation of the Proposed Method

Consider the 16-bus distribution system are sample for explanation of the proposed method. The configuration of the system as shown in Figure 2. This sample distribution system consist of 3 feeders, 16 branches and 16 buses [14].

For the reconfiguration process, all the sectionalizing switches and tie switches are considered as candidate switches. All the tie switches are initially closed, formed a meshed system and then power flow was performed for this system. The sensitivities of all candidate branches was evaluated. The candidate branches/switches are ranked in the ascending order based on the sensitivity values.

Sensitivities of all candidate branches for the first iteration are shown in Table I. First iteration, the best ranked switch is s16. Branch s16 are opened and branch s4 are stored in the neighborhood switch list because s4 has better rank compared with the other adjacent branch s13. Power flow was performed with s16 opened. The criteria required for the system is the values of all bus voltage magnitudes not exceed the limits for a more reliable system. So, the bus voltage was checked to ensure the values of all bus voltage magnitudes remain within the limits. If the values of bus voltage magnitudes out of range, s16 are closed back and the next ranked switches is selected to be open. In this case, the value of bus voltage magnitude remain within the limits. So, the solution was satisfied with the criteria required, and then, the system are checked whether the system in radial network or not. For the first iteration, the system are not in radial network, the sensitivities of the remaining branches was evaluate again with s16 are opened. Once switch s16 are selected to be opened, all the switches in the same loops should be excluded from the list of switches. The opening of one of them will produce disconnected systems. Hence, rank the other branches in the ascending order based on sensitivities values.

Since, the second iteration, top ranked sensitivities now is s7. Sensitivities at this iteration are shown in Table II. Branch s7 are opened and branch s15 are stored in the neighborhood switch list. Power flow was performed with s7 opened. If the solution was satisfied with the criteria required, and then, the system are checked whether the system in radial network or not. For this iteration, the system still not in radial network, sensitivities of the remaining branches was evaluate for next iteration. At this iteration, once switch s16 and s7 are selected to be opened, all the switches in the same loops should be excluded from the list of switches. The opening of one of them will produce disconnected systems. Hence, rank the other branches in the ascending order based on sensitivities values.

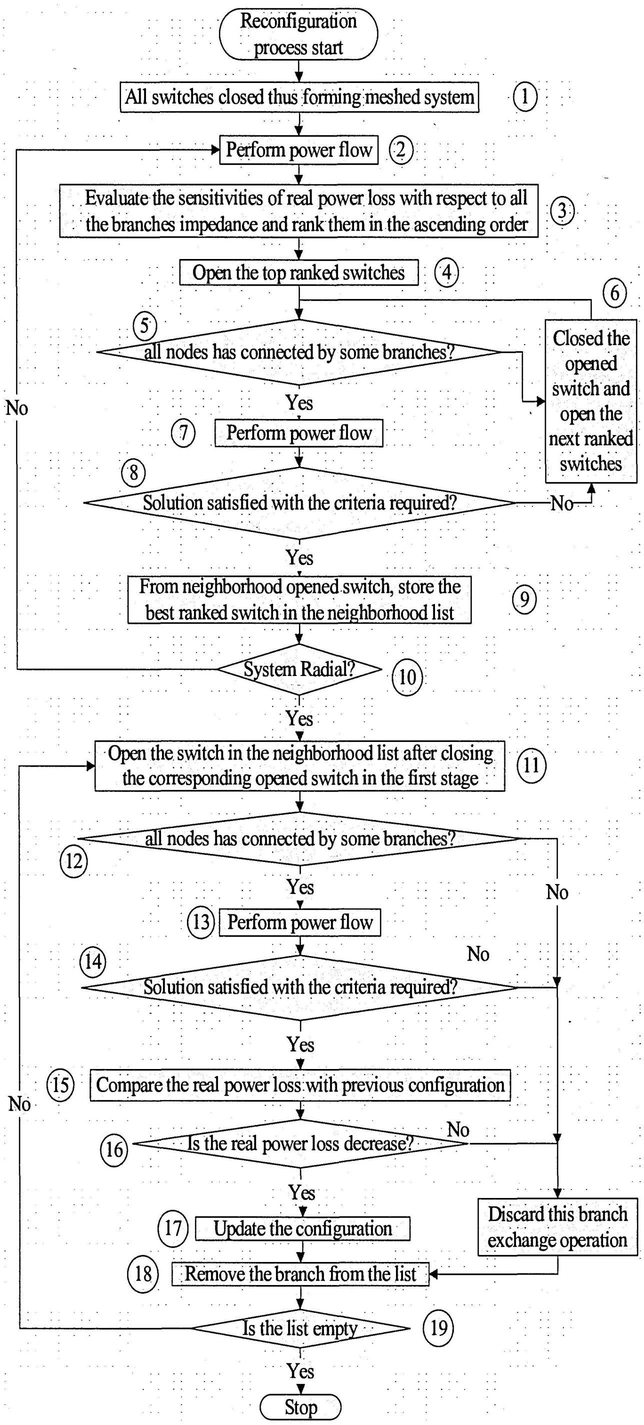

Figure 1: Flow chart of the proposed method

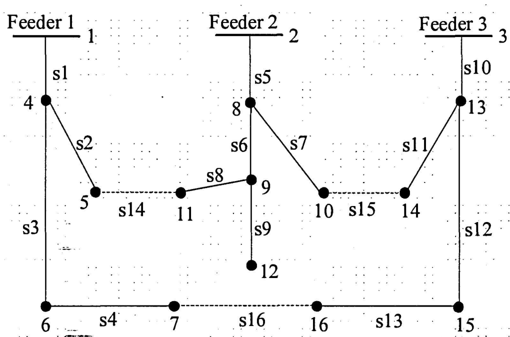

Figure 2: Configuration of 16-bus system

The sensitivities values of remaining candidate switches are shown in Table III. From Table III, it can be seen that, the top ranked switch is s8. Branch s14 are stored in the neighborhood switch list. Power flow was performed. At this iteration the system configuration in radial network. Procedure of the Stage I are completed. The opened switches at end of Stage I are s16, s7 and s8.

The stage II procedure involve branch exchange operations. The branch exchanged method are to compute the change of power losses by operating a pair of switches (close one and open another one at the same time). The pair of the switch are between s7 and s15, s8 and s14, s16 and s4.

Stage II procedure started with switch s16 are closed and s4 are opened. The others switches are remain open/close. Power flow are performed and the real power loss of this configuration are compared with previous configuration (with s16, s7 and s8 open). It can be seen that no reduction in the real power loss. So, the previous configuration is retained.

Next, switch s7 are closed and s15 are opened. The others switches are remain open/close. Power flow are performed and the real power loss of this configuration are compared with previous configuration (with s16, s7 and s8 open). It can be seen that no reduction in the real power loss. So, the previous configuration is retained.

Next, switch s8 are closed and s14 are opened. The others switches are remain open/close. Power flow are performed and the real power loss of this configuration are compared with previous configuration (with s16, s7 and s8 open). It can be seen that no reduction in the real power loss. So, the previous configuration is retained. Hence, the configuration at the end is opened switches is s16, s7 and s8.

TABLE I
SWITCHES AND SENSITIVITIES VALUES OF FIRST ITERATION OF FIRST PROCEDURE 16-BUS SYSTEM

Sensitivity	switch	Sensitivity	switch
8.66E-06	s16	0.000108608	s14
1.08E-05	s7	0.000146304	s12
4.31E-05	s4	0.000323202	s2
5.64E-05	s3	0.000382727	s6
6.42E-05	s11	0.001071719	s10
7.09E-05	s13	0.001691393	s1
1.01E-04	s8	0.002321581	s5
0.000107902	s15		

TABLE II
SWITCHES AND SENSITIVITIES VALUES OF SECOND ITERATION OF FIRST PROCEDURE 16-BUS SYSTEM

Sensitivity	Switch	Sensitivity	Switch
1.86E-05	s7	3.01E-04	s2
7.88E-05	s11	4.08E-04	s6
8.57E-05	s8	9.11E-04	s10
9.29E-05	s14	0.001889306	s1
1.30E-05	s15	0.00229813	s5

TABLE III
SWITCHES AND SENSITIVITIES VALUES OF THIRD ITERATION OF FIRST PROCEDURE 16-BUS SYSTEM

Sensitivity	Switch	Sensitivity	Switch
1.03E-04	s8	3.77E-04	s6
1.11E-04	s14	1.96E-03	s1
3.29E-04	s2	2.64E-03	s5

IV. RESULT AND DISCUSSION

The proposed method was implemented on 16-bus system and 33-bus system for demonstrating the effectiveness of proposed method.

A. 16-Bus System

The proposed method was tested on 16-bus distribution system. The 16-bus distribution system before reconfiguration as shown in Figure 3, which has three feeders, 16 buses and 16 branches (13 sectionalizing switches and 3 tie switches). The base value for the 33-bus system are V=12.66kV and S=10MVA. 3 tie switches (normally open) are between nodes 5 and 11, 10 and 14, 7 and 16 [14]. Power flow was performed at the initial configuration. Total real power loss for initial configuration are 0.3128MW.

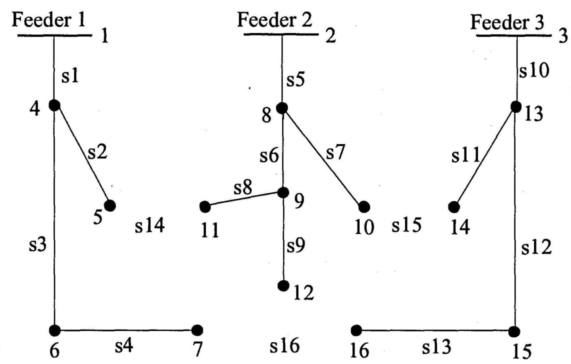

Figure 3: Initial configuration of 16-bus system

After the proposed method was implemented, the configuration of 16-bus system distribution at the first stage, it can be seen that the opened switches are s7, s8 and s16 and the neighborhood switch list are s15, s14 and s4. The configuration of 16-bus system at the first stage as shown in Figure 4. The total real power loss at the first stage are 0.2857MW.

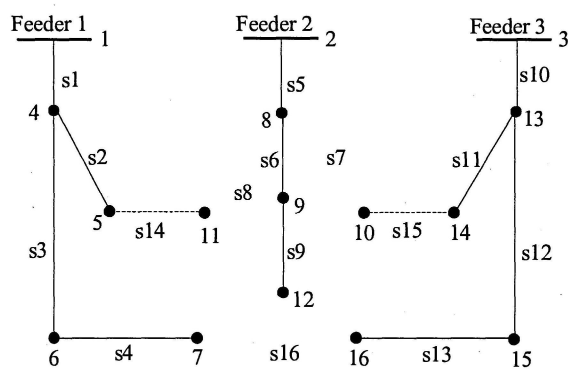

Figure 4: Final configuration of 16-bus system

The stage II procedure involve branch exchange operations. The branch exchanged method are to compute the change of power losses by operating a pair of switches (close one and open another one at the same time). The pair of the switch are between s7 and s15, s8 and s14, s16 and s4.

After branch exchanged method was implemented, it can be seen that, the opened switches are s7, s8 and s16. There are no has changed switch. It means that, there are no reduction in the real power loss after branch exchanged method was implemented. The switches opened from stage I are remain opened. The configuration at the end of second stage are same with the configuration the first stage as shown in Figure 4. The total real power loss at the first stage are 0.2857 MW. Hence, the configuration at the end is opened switches are s7, s8 and s16.

Table IV show the result for power loss minimization of 16-bus system. For initial configuration, the opened switches are s14, s15 and s16 (refer to Figure 3). After reconfiguration process in the first stage, the opened switches are s16, s7 and s8 (refer to Figure 4). The real power loss are reduced from 0.3128MW to 0.2857MW. At the second stage procedure, there are no reduction in the real power loss. So, the result of configuration at the first stage are the final configuration. The whole percentage reduction in the real power loss is 8.66%. Minimum voltage are also improve from 0.9811 pu to 0.9825 pu at bus 12.

TABLE IV
THE RESULT FOR POWER LOSS MINIMIZATION OF 16-BUS TEST SYSTEM

System Status	Open Switches	Real power loss (MW)	Minimum bus voltage magnitude
Initial configuration (Original)	s14, s15 and s16	0.3128	0.9811 pu (bus 12)
Final configuration (optimal)	s16, s7 and s8	0.2857	0.9825 pu (bus 12)
Loss reduction (%)		8.66	

B. 33-Bus System

The proposed method is also tested on 33-bus distribution system. This 33-bus test system consists of 1 source transformer and 32 load nodes and 37 branches (32 sectionalizing switches and 5 tie switches). The base value for the 33-bus system are V=12.66kV and S=10MVA. It is shown in Figure 5 [14]. 5 tie switches (normally open) are between nodes 8 and 21, 9 and 15, 12 and 22, 18 and 33, 25 and 29. Power flow was performed at the initial configuration. Total real power loss for initial configuration are 0.1720 MW.

After the proposed method was implemented, the configuration of 33-bus system distribution at the stage I, it can be seen that the opened switches are s7, s10, s14, s32 and s37 and the neighborhood switch list are s6, s9, s13, s36 and s28. The configuration of 33-bus system at the first stage as shown in Figure 6. The total real power loss at the first stage are 0.1123 MW.

The stage II procedure involve branch exchange operations. The branch exchanged method are to compute the change of power losses by operating a pair of switches (close one and open another one at the same time). The pair of the switch are between s7 and s6, s10 and s9, s14 and s13, s32 and s36, s37 and s28.

After branch exchanged method was implemented, it can be seen that the opened switches are s7, s9, s14, s32 and s37. It means that, the changed switch are from pair switch between s10 and s9 only. Otherwise, the switches opened from stage I are remain opened. The configuration of 33-bus system at the second stage as shown in Figure 7. The total real power loss at the second stage are 0.1115 MW. Hence, the configuration at the end is opened switches are s7, s9, s14, s32 and s37.

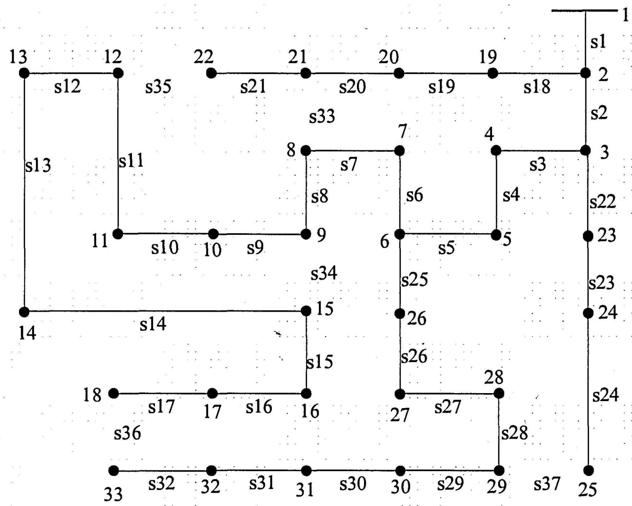

Figure 5: Initial configuration of 33-bus distribution system

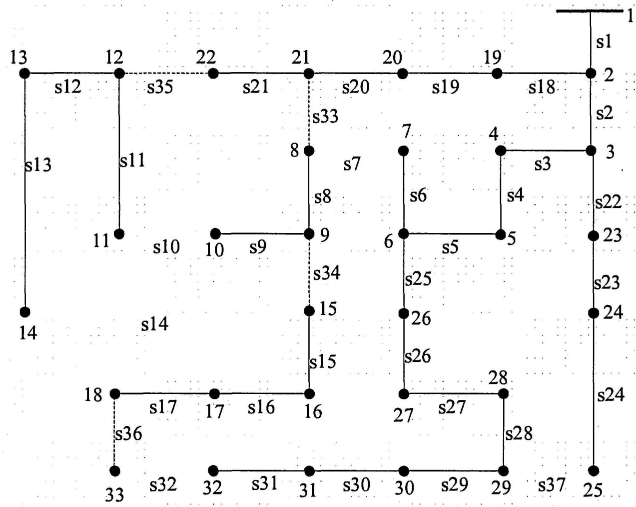

Figure 6: First stage configuration of 33-bus distribution system

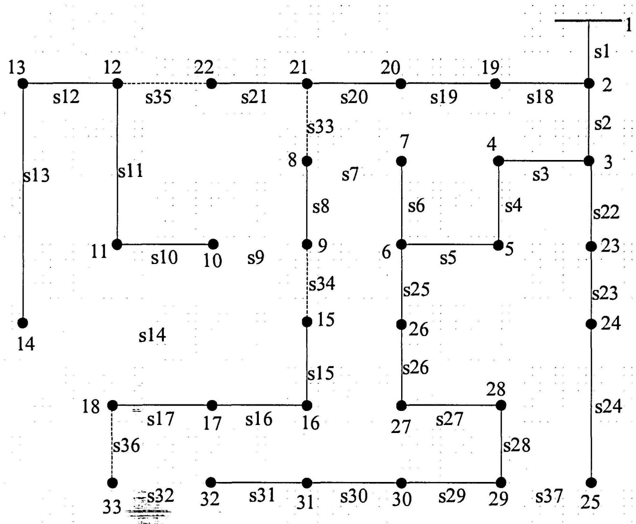

Figure 7: Second stage configuration of 33-bus distribution system

For the 33-bus system, it can be seen that the real power loss are reduced from 0.1720MW to 0.1123MW at the first stage procedure. At the second stage procedure, the real power loss are reduced from 0.1123MW to 0.1115MW. Table V show the result for power loss minimization of 33-bus system. For initial configuration, the opened switches are s33, s34, s35, s36 and s37 (refer to Figure 5). After reconfiguration process in the first stage, it can be seen that the opened switches are s7, s10, s14, s32 and s37 (refer to Figure 6). In the second stage, the real power loss are reduced when opened switches s10 was exchange with s9. So, the opened switches configuration is changed from previous configuration. The opened switches in the second stage are s7, s9, s14, s32 and s37 (refer to Figure 7). The whole percentage reduction in the real power loss are 35.17%. The smallest value of bus voltage magnitude for initial configuration are 0.9121 pu at bus 18. After the first stage proposed method are implemented, the smallest value of bus voltage magnitude are 0.9457 pu at bus number 33, and after the second stage proposed method are implemented, the smallest value of bus voltage magnitude are 0.9473 pu, it also at bus number 33.

TABLE V

THE RESULT FOR POWER LOSS MINIMIZATION OF 33-BUS TEST SYSTEM

System Status	Open Switches	Real power loss (MW)	Minimum bus voltage magnitude
Initial configuration (Original)	s33, s34, s35, s36 and s37	0.1720	0.9121 pu (bus 18)
First stage configuration	s7, s10, s14, s32 and s37	0.1123	0.9457 pu (bus 33)
Second stage configuration (optimal)	s7, s9, s14, s32 and s37	0.1115	0.9473 pu (bus 33)
Loss reduction (%)		35.17	

V. CONCLUSION

The two stage method, reconfiguration distribution network and branch exchange method has been presented in this paper. The purpose of this method is to reduce the real power losses subject to radial structure in which all loads must be served. Efficiency of this method is due to the use of sensitivity of the candidate branches at the first step. The next step is uses branch exchange method to improve the solution. The result shows that the real power loss are reduced as much as 8.66% for 16 bus system and 35.17% for 33-bus system. Voltage profile of the system are also improved. Since the proposed method are based on heuristics, this method may not guarantee a optimum solution. However, it provides a good suboptimal solution.

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REFERENCES

[1] M. Cheraghi and P. Ramezanpour, "An efficient-fast method for determining minimum loss configuration in radial distribution networks based on sensitivity analysis," in *Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 Ieee International*, 2012, pp. 46-51.

[2] T. M. Khalil and A. V. Gorpinich, "Reconfiguration for loss reduction of distribution systems using selective particle swarm optimization," *IEEE*, vol. 3, 2012.

[3] R. Prasad, *Fundamental of electrical engineering*, Eastern economy edition ed.: Prentice-Hall of india private limited, 2005.

[4] L.Ramesh, S.P.Chowdhury, S.Chowdhury, A.A.Natarajan, and C.T.Gaunt, "Minimization of Power Loss in Distribution Networks by Different Techniques," *International Journal of Electrical and Electronics Engineering*, 2009.

[5] J. P. Tewari, *Basic Electrical Engineering*: NEW AGE INTERNATIONAL(P) LIMITED, 2003.

[6] U. A. Bakshi and M. V. Bakshi, *Elements of Power Systems*, first edition ed.: Technical Publication Pune, 2008.

[7] A. Gonzalez, F. M. Echavarren, L. Rouco, and T. Gomez, "A Sensitivities Computation Method for Reconfiguration of Radial Networks," *Power Systems, IEEE Transactions on*, vol. 27, pp. 1294-1301, 2012.

[8] F. V. Gomes, S. Carneiro, J. L. R. Pereira, M. P. Vinagre, P. A. N. Garcia, and A. Leandro Ramos de, "A New Distribution System Reconfiguration Approach Using Optimum Power Flow and Sensitivity Analysis for Loss Reduction," *Power Systems, IEEE Transactions on*, vol. 21, pp. 1616-1623, 2006.

[9] G. Raju and P. R. Bijwe, "An Efficient Algorithm for Minimum Loss Reconfiguration of Distribution System Based on Sensitivity and Heuristics," *Power Systems, IEEE Transactions on*, vol. 23, pp. 1280-1287, 2008.

[10] N. Rugthaicharoencheep and S. Sirisumrannukul, "Feeder reconfiguration with dispatchable distributed generators in distribution system by tabu search," in *Universities Power Engineering Conference (UPEC), 2009 Proceedings of the 44th International*, 2009, pp. 1-5.

[11] R. S. Rao and S. V. L. Narasimham, "A New Heuristic Approach for Optimal Network Reconfiguration in Distribution Systems," *International Journal of Engineering and Applied Sciences*, vol. 5:1, 2009.

[12] A. A. Chowdhury and D. O. Koval, *Power distribution system reliabilty* Canada: John Wiley & Sons, Inc, Publication 2009.

[13] F. V. Gomes, S. Carneiro, Jr., J. L. R. Pereira, M. P. Vinagre, P. A. N. Garcia, E. J. Oliveira, and L. R. Araujo, "A new distribution system reconfiguration approach using optimal power flow technique and sensitivity analysis for loss reduction," in *Power Engineering Society General Meeting, 2005. IEEE*, 2005, pp. 897-901 Vol. 1.

[14] J. Zhu, *Optimization of Power System Operation*. Canada: John Wiley & Sons, Inc., Hoboken, New Jersey, 2009.