

A NEW FAST AND EFFICIENT RECONFIGURATION METHOD OF ELECTRICAL DISTRIBUTION NETWORKS FOR REDUCING LOSSES

A. AISSAOUI¹

H. SAYAH²

¹Electrical Engineering Department, Hassiba Benbouali University, Chlef, 02000, Algeria, aissaouidz@yahoo.fr

²Intelligent Control and Electrical Power Systems Laboratory, Djillali Liabes University, Sidi Bel Abbes, 22000, Algeria. Housayah@yahoo.fr

M. BRAHAMI

Intelligent Control and Electrical Power Systems Laboratory, Djillali Liabes University, Sidi Bel Abbes, 22000, Algeria. mbrahami@yahoo.com

Abstract: This paper proposes a new heuristic reconfiguration method for reduction of active losses in distribution networks. This method is based on the principle that active losses are minimal when these networks are meshed and a branch traversed by a minimal current can be cut without it leads to a significant increase in these minimal losses. It begins by evaluating a load flow calculation where all the tie switches installed in the network are closed, then open simultaneously a similar number of sectionalizing switches travelled by the minimum currents so as to obtain a radial configuration. This first operation leads to a first radial configuration with minimal losses. A second operation of refinement is applied to further reduce these losses. It consists to successively close the switches already opened during the first operation on the basis of the maximum voltage difference criterion, then open each time another switch on the basis of the minimal current criterion. This method is tested for two network examples. The results are compared with other results found in the literature.

Key words: Distribution Networks, Loss Minimization, Network Reconfiguration.

1. Introduction

The electrical distribution network is the largest part of an electric power system. Accordingly, the active losses are very important in this part of the system. Reducing these losses can be obtained by reconfiguration (changing the network topology) through the opening and closing of different interruption and sectioning devices installed in these networks. Two types of switches exist in a medium voltage electrical distribution network. There are sectionalizing switches (normally closed) to isolate the faulty part of the network and tie switches (normally open) for rescue the remaining charges. Because of the large number of switches installed,

the distribution networks reconfiguration is a combinatorial optimization problem very difficult to solve by traditional optimization techniques. Several heuristics and metaheuristics methods have been proposed in the literature to solve the problem of distribution networks reconfiguration for the reduction of active losses. In 1975, Merlin and Back [1] were the first they had introduced the distribution networks reconfiguration concept using a discrete branch and bound technique for determining a configuration with minimal active losses. Civanlar *et al.* [2] used a heuristic method to reduce losses in the distribution network based on the change estimation in losses during transfer of a charges group from a feeder to another. Baran and Wu [3] proposed a general formulation and solution methodology for distribution network reconfiguration by changing the state of sectioning switches for loss reduction and load balancing.

Shirmohammadi and Hong [4] described a heuristic method of distribution network reconfiguration for loss reduction based on the branch and bound method. However, many approximations have been made in their algorithm. Sarfi and Salama [5] presented a review on the distribution network reconfiguration for loss reduction. Boroza, *et al.* [6] described a heuristic method based on the optimality condition developed by Merlin and Back. Although the method proposed is very similar to that of Shirmohammadi and Hong, but the proposed method is faster. McDermott *et al.* [7] proposed a constructive heuristic that consists in opening all switches and then close them in an order that ensures any increase losses to form a radial configuration. Kashem *et al.* [8] have modified the solution methodology proposed by Baran and Wu [3].

In [9-10], different approaches based on the use of genetic algorithms have been used to obtain a configuration with minimum losses. Gomes *et al* [11] used a destructive heuristic method where all the switches are first closed and then opened successively on the basis of a minimal increase in losses. Permutations of branches are then applied in the vicinity of the open switches to improve the solution. In [12-14], solution strategies have been proposed for the distribution network reconfiguration using simulated annealing. Das [15] presented a fuzzy multi-objective approach based on heuristic rules.

Viswanadha Raju and Bijwe [16] presented an efficient method of reconfiguration for minimizing losses in two stages. It starts by calculating load flow where all the switches are closed. Switches traversed by minimum current, which cause minimal changes in losses, are opened successively. Then permutations of branches are explored in the vicinity of open switches to improve the solution. Srinivasa Rao and Narasimhan [17] proposed a new heuristic reconfiguration for loss minimization. It consists in closing the tie switches with maximum voltage difference and opening in their place those causes less active losses. Savier and Das [18] presented a multi-objective approach for the reconfiguration of distribution networks using heuristic rules to select the switches opening and closing sequences. In [19-20], modified Particle Swarm Optimization methods have been used to solve the distribution network reconfiguration problem. Bouharas and Labridis [21] propose an approach based on heuristic rules to study the charge variation influence on the optimal distribution networks reconfiguration for loss reduction. Lantharhong *et al.* [22] used the tabu search for radial distribution network reconfiguration for load balancing. Asuhaimi *et al.* [23] used a circular updating mechanism based on the principle of minimum current for the distribution network reconfiguration. A.V.Sudhakara Reddy [24] used a meta-heuristic dragon fly algorithm to solve the network reconfiguration problem with an objective of minimizing real power loss and improving the voltage profile in radial distribution system.

As has been seen, there are a wide variety of heuristic methods to solve the distribution networks reconfiguration problem in the literature. However, these methods do not lead to a global minimum. Accordingly, it seems to need to develop a simple, fast and efficient heuristic reconfiguration method. In this perspective, our work is to propose a new heuristic reconfiguration method for reduction of active losses in distribution networks that is closer to the global optimum. This proposed method is based on the use of two heuristic criteria. The first, inspired from reference [16], is based on the principle that the meshing of electrical networks

always leads to the minimum active losses and that the opening of a switch traversed by a minimum current produces a minimal increase in active losses. The second, inspired from reference [17], rested on the principle that the closing of a switch with maximum voltage difference causes more reduction in active losses and further improves the voltage profile. Details of the methodology are explained in Section 3.

Finally, this work is organized as follows. The distribution networks reconfiguration problem formulation for reduce of active losses is presented in section 2. The methodology of the problem solving is explained in Section 3. The results and discussions are exposed in section 4. Finally, conclusions are made in Section 5.

2. Formulation of the Distribution Network Reconfiguration Problem

The electrical distribution network reconfiguration process to reduce active losses can be considered as an optimization problem. Its mathematical formulation can be represented as follows:

Minimize

$$P_L = \sum_{k=1}^m R_k I_k^2 \quad (1)$$

Subject to constraints:

$$P_i = P_{Gi} - P_{Di} = V_i \sum_{i=1}^n Y_{ik} V_k \cos(\delta_k - \delta_i + \gamma_{ik}) \quad (2)$$

$$Q_i = Q_{Gi} - Q_{Di} = -V_i \sum_{i=1}^n Y_{ik} V_k \sin(\delta_k - \delta_i + \gamma_{ik})$$

$$V_{\min} \leq V_i \leq V_{\max} \quad \text{for } i = 1, \dots, n \quad (3)$$

$$I_k \leq I_{k,\max} \quad \text{for } k = 1, \dots, m \quad (4)$$

$$\text{Radial configuration} \quad (5)$$

$$\text{Connectivity of all loads} \quad (6)$$

where:

- n is the total number of nodes,
- m is the total number of branches,
- P_L are the total active losses in the network,
- R_k is the resistance of the branch k ,
- I_k is the current in the branch k ,
- P_i, Q_i are the active and reactive injections at node i ,
- V_i, δ_i are the amplitude and phase of the voltage at node i ,
- Y_{ik}, γ_{ik} are the amplitude and phase of the branch admittance between nodes i and k ,
- V_{\min}, V_{\max} are respectively the lower and upper

node voltage limits,

$I_{k,max}$ is the upper current limit in the branch k ,

Equation (1) is the objective function. Equation (2), equality constraints type, represents the load flow equations. Equations (3) and (4) represent respectively the inequality constraints type of voltage and current. Equation (5) indicates the radiality restriction in MV distribution network. Equation (6) represents the constraint of connectivity to the source of all charges.

3. Explanation of the method

In this proposed method, the fundamental mesh concept [20] is used to avoid configurations that do not respect the network constraints (5) and (6). A mesh is called fundamental if it has at least one branch does not belong to another fundamental mesh. The number of fundamental meshes n_f is computed from equation (7):

$$n_f = (m + b) - n + 1 \quad (7)$$

where b is the number of tie branches.

It is noted that each fundamental mesh is obtained by the closure of a tie switch, as shown in figure 1. In order to obtain any radial configuration, a single sectionalizing switch must be opened for each fundamental mesh.

The proposed method starts by a first load flow calculation where all the tie switches are closed to form a meshed network for which the active losses are the most minimal. The branch currents are then calculated for all branches. Based on the principle that the opening of a branch traversed by a minimum current leads to a minimal increase in active losses, we identify, for each fundamental mesh, a switch traversed by a minimal current as candidate for opening. These switches candidates for the opening must be chosen from among those that satisfy the constraints (5) and (6).

To get a first radial configuration with minimum active losses, we open all candidate switches to the opening simultaneously. Then, we evaluate the active losses after a second load flow calculation. Certainly, the first reconfiguration operation does not lead to a global minimum of active losses. For come closer to the global optimum, an operation of refinement that reuses the same principle of reconfiguration is individually applied for each switch already open.

In fact during this second reconfiguration operation, we first calculate the voltage differences across the switches already opened during the first operation. The switch which possesses a maximum voltage difference is the first closed, because the closure of the latter causes more active losses reduction and further improves the tension profile. Then, a new load flow calculation is evaluated to compute current in all branches of the mesh thus formed. Next, we open the switch with minimal

current in the mesh in question. It must be ensured that the opening of this switch must check the constraints (5) and (6), otherwise, it must be opened in its place another switch with minimum current. This process of closing / opening and load flow calculating is repeated for the rest of the open switches. It may be that, in an iteration, the closed switch is traversed by a minimum current. In this case, we must keep it open. A final load flow calculation is executed for calculate the minimum active losses. The configuration finally obtained is considered as a global optimum.

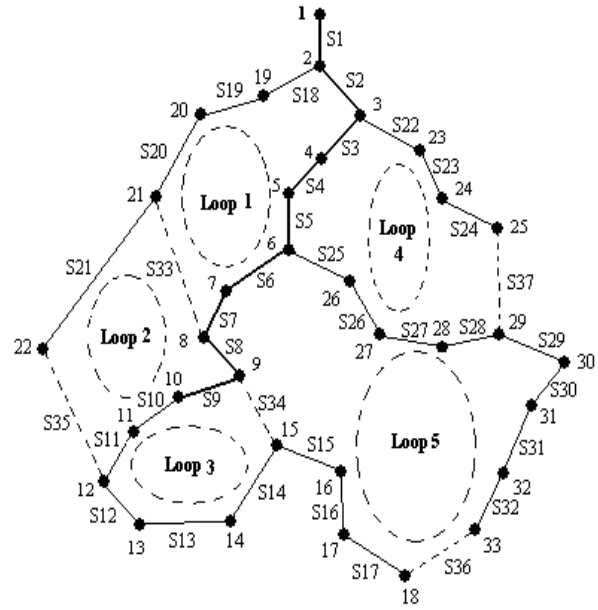


Figure 1. The 33 bus network and the associated meshes

The algorithm of the proposed method includes the following steps:

1. Introduce the necessary network data,
2. Close all tie switches and evaluate a load flow calculation,
3. For each fundamental mesh, determine a switch with minimum current candidate for opening among those which satisfy the constraints (5) and (6),
4. Open switches candidates for opening and execute a load flow calculation,
5. Calculate voltage differences across the open switches and classify them according to the criterion of maximum voltage difference,
6. Close the first switch with maximum voltage difference,
7. Evaluate a load flow calculation,
8. Open the switch with minimum current in the formed mesh which satisfies the constraints (5) and (6),
9. Check if all open switches are explored, if yes, go to item 11,

10. Otherwise, close the following switch with maximum voltage difference and go to item 7,
11. Stop.

The flowchart of the algorithm is presented in figure 2.

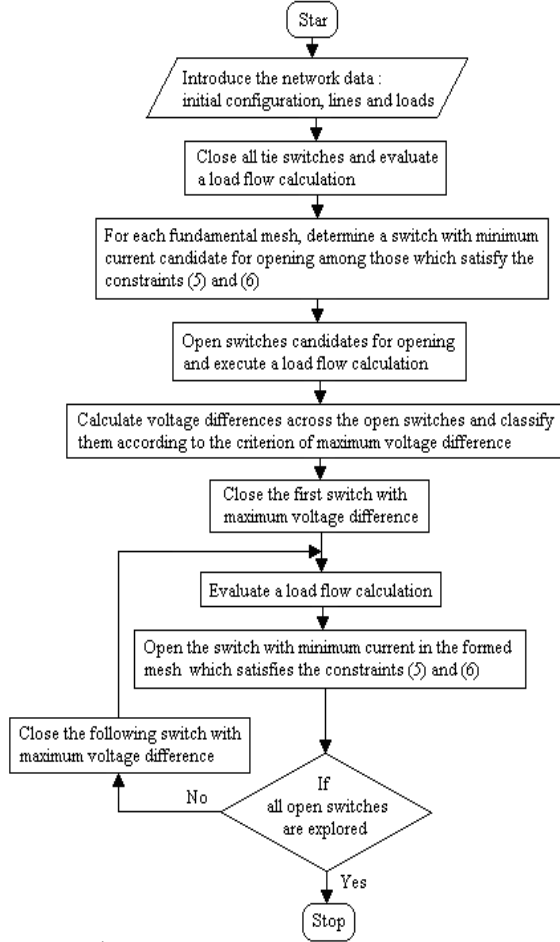


Figure 2. Flowchart of the proposed method

The forward and backward sweep algorithm [24-25], developed specifically for the calculation of load flow in radial distribution networks, is used to calculate currents in lines and voltages at nodes. The lines are modeled by series impedances in a distribution network. Voltage drops across closed switches are assumed to be zero.

4. Results and Discussions

To demonstrate the efficiency and rapidity of our proposed reconfiguration method, this latter is tested for two theoretical examples of distribution network often used in the literature. These are the 33-bus and 69-bus Systems. The 33-bus system is treated in more detail to fully explain the methodology.

A. The 33-bus system

The 33-bus, 12.66 kV system given in [3] is a radial distribution network. The total active and

reactive loads of the system are 3715 kW, 2300 kVAr respectively. Its initial configuration is shown in Figure 1. It is composed of 32 branches, in solid lines, each one is supposed equipped with a normally closed sectionalizing switch and 5 tie branches, in dashed lines, each one is equipped with a normally open switch. Lines from 1 to 9 have a maximum transmission capacity of 400 A. For the rest, it is 200 A.

In a first step, we close all the tie switches: S_{33} , S_{34} , S_{35} , S_{36} and S_{37} . Then, from a first load flow calculation, we calculate the branch currents. For each fundamental mesh, we determine a switch with minimum current candidate to the opening and which checks the constraints (5) and (6). The switches with minimum current: S_7 , S_{10} , S_{14} , S_{32} and S_{37} are then opened together and a second load flow calculation is evaluated to compute the voltage differences across all the opened switches. The switches open are at last ranked on the basis of the maximum voltage difference. The results of this first step are summarized in Table 1. The active losses calculated during the first step are found equal to 140.28 kW.

Table 1
Switches open during the first step for the 33-bus system

Mesh	Switch open	Voltage difference (pu)	Ranking
1	S_7	0.0164	3
2	S_{10}	0.0080	5
3	S_{14}	0.0110	4
4	S_{37}	0.0299	1
5	S_{32}	0.0270	2

To further reduce these active losses, we proceed to an operation of refinement which consists in successively close the switches open in the first step based on the maximum voltage difference and run every time a load flow calculation to find out if one switch with a minimum current can exist in the formed mesh.

In fact, the switch S_{37} having a maximum voltage difference is the first closed. A load flow calculation is then executed to calculate the branch currents of the formed mesh. No minimum current switch is measured in the loop other than the switch S_{37} . This will keep the switch S_{37} open during the first iteration. This refinement operation is repeated for the remaining open switches: S_{32} , S_7 , S_{14} and S_{10} successively. The same result was found with the switch S_{37} except the switch S_{10} which is guarded closed and replaced by the switch S_9 with over minimal current.

Finally, one last load flow calculation is evaluated to compute the active losses that are found

equal to 139.55 kW. Configurations obtained for this 33-bus system are presented in Table 2. We have found an optimal configuration identical to those found in [16] and [23].

Table 2
Results obtained for the 33-bus system

Configuration	Active losses (kW)	Switches open
Initial	202.68	S ₃₃ , S ₃₄ , S ₃₅ , S ₃₆ , S ₃₇
First step	140.28	S ₇ , S ₁₀ , S ₁₄ , S ₃₂ , S ₃₇
Second step	139.55	S ₇ , S ₉ , S ₁₄ , S ₃₂ , S ₃₇

B. The 69-bus system

The 69-bus, 12.66 kV system given in [13] is also a radial distribution network which has a total active and reactive loads of 1107.908 kW and 897.930 kVAR respectively. It is composed of 68 branches supposed all equipped with normally closed sectionalizing switches and 5 tie switches: S₆₉, S₇₀, S₇₁, S₇₂, S₇₃ normally open. Lines from 1 to 9 have a maximum transmission capacity of 400 A. Lines 46-49 and 52-64 have a maximum transmission capacity of 300 A. The remaining branches including the tie lines have a transmission capacity of 200A.

The results obtained for this second example network are summarized in Table 3. The optimal configuration obtained is identical to that found in [13] and better than that found in [16].

Table 3
Results obtained for the 69-bus system

Configuration	Active losses (kW)	Switches open
Initial	69.77	S ₆₉ , S ₇₀ , S ₇₁ , S ₇₂ , S ₇₃
First step	32.59	S ₁₃ , S ₂₀ , S ₅₈ , S ₆₁ , S ₆₉
Second step	30.09	S ₁₄ , S ₇₀ , S ₅₈ , S ₆₁ , S ₆₉

Table 4 presents a comparison, established between our proposed method and others presented in literature, in terms of number of load flow calculations required for each system to obtain the optimal configuration. In fact, our proposed method requires fewer load flow calculation for the two examples of networks. This allows us to qualify our proposed method as the faster.

Table 4
Comparison with other methods in terms of number of load flow calculations

Systems	Methods			
	[13]	[16]	[23]	Proposed
33-bus	-	16	9	8
69-bus	15	16	14	8

5. Conclusions

A new distribution networks reconfiguration method is presented in this work. The 33-bus system is used as a support to explain and test the proposed methodology. The 69-bus system is used as a second example to further confirm the effectiveness of the proposed method. The results showed that the optimal configuration obtained for each test network coincide perfectly with those found in the literature, but with a much reduced calculation load flow number. This allows us to qualify our method as the best in the current literature in terms of efficiency and rapidity. It can be used as a very effective tool in the area of reconfiguration and planning of electrical distribution networks.

References

- Merlin A., Back G.: *Search for Minimum-Loss Operational Spanning Tree Configuration for an Urban Power Distribution System*. In: *the Fifth Power System Conferenc. Cambridge, 1975*.
- Civanlar S., Grainger J., Yin H., Lee S. S. H.: *Distribution Feeder Reconfiguration for Loss Reduction*. In: *IEEE Transactions on Power Delivery*, Vol. 3, No. 3, 1988, p. 1217-1223.
- Baran M. E., Wu F. U.: *Network reconfiguration in distribution systems for loss reduction and load balancing*. In: *IEEE Transactions on Power Delivery*, Vol. 4, No. 2, 1989, p. 1401-1407.
- Shirmohammadi D., Hong H. W.: *Reconfiguration of Electric Distribution Networks for Resistive Line Losses Reduction*. In: *IEEE Transactions on Power Delivery*, Vol. 4, No. 2, 1989, p. 1492-1498.
- Sarfi R. J., Salama M. M. A., Chikhani A. Y.: *A survey of the state of the art in distribution system reconfiguration for system loss reduction*. In: *Electric Power Systems Research*, Vol. 31, 1994, p. 61-70.
- Borozan V., Rajicic D., Ackovski R.: *Minimum Loss Reconfiguration of Unbalanced Distribution Network*. In: *IEEE Transactions on Power Delivery*, Vol. 12, No. 1, 1997, p. 435-41.
- McDermott T. E., Drezga I., Broadwater R. P.: *A heuristic non-linear constructive method for distribution system reconfiguration*. In: *IEEE Transactions Power Systems*, Vol. 14, No. 2, 1998, p. 478-483.
- Kashem M. A., Jasmon G. B., Ganapathy V.: *A new approach of distribution system reconfiguration for loss minimization*. In: *Electrical power and Energy Systems*, Vol. 22, 2000, p. 269-276.
- Zhu J. Z.: *Optimal reconfiguration of electrical distribution network using the refined genetic algorithm*. In: *Electric Power Systems Research*, Vol. 62, 2002, p. 37-42.
- Hong Y. Y., Ho S. Y.: *Determination of network configuration considering multi-objective in distribution systems using genetic algorithms*. In: *IEEE Transactions Power Systems*, Vol. 20, No. 2, 2005, p. 1062-1069.
- Gomes F. V., Carneiro S., Pereira J. L. R., Vinagre M.

- P., Garcia P. A. N.: *A new distribution system reconfiguration approach using optimum power flow and sensitivity analysis for loss reduction*. In: IEEE Transactions Power Systems, Vol. 21, No. 4, 2006, p. 1616-1623.
12. Chiang H. D., Jean-Jameau R. M.: *Optimal network reconfiguration in distribution systems, Part 1: a new formulation and a solution methodology*. In: IEEE Transactions on Power Delivery, Vol. 5, No. 4, 1990, p. 1902-1909.
 13. Chiang H. D., Jean-Jameau R. M.: *Optimal network reconfiguration in distribution systems, Part 2: solution algorithms and numerical results*. In: IEEE Transactions on Power Delivery, Vol. 5, No. 3, 1990, p. 1568-1574.
 14. Jeon Y. J., Kim J. C., Kim J. O., Shin J. R., Lee K. Y.: *An efficient simulated annealing algorithm for network reconfiguration in large-scale distribution systems*. In: IEEE Transactions on Power Delivery, Vol. 17, No. 4, 2002, p. 1070-1078.
 15. Das D.: *A fuzzy multi-objective approach for network reconfiguration of distribution systems*. In: IEEE Transactions on Power Delivery, Vol. 21, No. 1, 2006, p. 202-209.
 16. Raju G. K. V, Bijwe P. R.: *Efficient reconfiguration of balanced and unbalanced distribution systems for loss minimization*. In: IET Generation, Transmission, Distribution, Vol. 2, No. 1, 2008, p. 7-22.
 17. Srinivasa Rao R., Narasimham S. V. L.: *A new heuristic approach for optimal network reconfiguration in distribution systems*. In: International journal of engineering and applied sciences, Vol. 5, No. 1, 2009, p. 15-21.
 18. Savier J.S., Das D.: *Multi-objective method for network reconfiguration*. In: IJE Transactions A: Basics, Vol. 22, No. 4, 2009, p. 333-350.
 19. Abdelaziz A. Y., Mohammed F. M., Mekhamer S. F., Badr M. A. L.: *Distribution Systems Reconfiguration using a modified particle swarm optimization algorithm*. In: Electric Power Systems Research, Vol. 79, No. 11, 2009, p. 1521-1530.
 20. Arya A., Kumar Y.: Dubey M., *Reconfiguration of electric distribution network using modified particle swarm optimization*. In: International Journal of Computer Applications, Vol. 34, No. 6, 2011, p. 54-62.
 21. Bouharas A. S., Labridis D. P.: *Influence of load alterations to optimal network configuration for loss reduction*. In: Electric Power Systems Research, Vol. 86, 2012, p. 17-27.
 22. Lantharhong T., Rugthaicharoencheep N.: *Network reconfiguration for load balancing in distribution system with distributed generation and capacitor placement*. In: World Academy of Science, Engineering and Technology, Vol. 64, 2012.
 23. Asuhaimi A., Khorasani A., Khairuddin A. B., Mortazavi M.: *Reconfiguration of radial distribution network through minimum-current-circular-updating-mechanism method*. In: IEEE Transactions on Power Systems, Vol. 27, No. 2, 2012, p. 968-974.
 24. A. V. Sudhakara Reddy, M. Damodar Reddy, *Optimization of distribution network reconfiguration using dragonfly algorithm*, In: jee Journal for Electrical Engineering, Vol 16, Edition 4, 2016.
 25. A.G. Esposito, E.R. Ramos, *Reliable Load Flow Technique for Radial Distribution Networks*, IEEE Transactions on Power Systems, Vol.14, No.3, August 1999, pp.1063-1069.