Reconfiguration of Actual Distribution Network with Optimum Power Flow for Loss Reduction

İlker Dursun and Feyzi Karaosmanoğlu
Bogazici Electricity Distribution Company, İstanbul, Turkey
Email: {idursun, feyzi.ka}@gmail.com, ilker.dursun@bedas.com.tr

Nurettin Umurkan
Yildiz Technical University, İstanbul, Turkey
Email: umurkan@yildiz.edu.tr

***Abstract*—This study presents loss-reduction on radial electrical distribution system by reconfiguration based on optimum power flow pattern. A real section of distribution network from Istanbul is modeled according to actual load and network data. A new configuration is sought heuristically in order to minimize the interference on the optimum flow pattern. Reconfiguration is performed by closing all switches and consecutively opening the suitable switches carrying the minimum current until the radial system is acquired. Existing configuration and the meshed configuration with all switches closed are analyzed according to load flow calculations. A new network configuration satisfying the voltage and current limitations of the system with reduced losses is proposed for the system.**

***Index Terms*—radial distribution networks, loss reduction, network modeling, optimum power flow, reconfiguration**

I. Introduction

Energy policies are major arguments of the international politics. The energy has a vital role for all countries and the main goal is reaching cost effective and sustainable energy sources. Since conventional energy sources are limited and energy saving is the most cost effective energy source, energy efficiency is regarded as a major topic for many countries [1]. Distribution system losses constitute a significant part in total electrical losses [2]. Network reconfiguration is one of the fundamental methods of loss reduction in distribution systems [3].

Electrical distribution systems aim a single direction power flow from the source to the load to minimize operation difficulty and costs. However, designing the system as a mesh offers the possibility to achieve alternative network configurations in order to maintain the continuity of supply under failiures. As a result the conventional distribution systems are constructed as a weak mesh with closed rings [4] but operated radially.

Radial operation constraint makes it compulsory to open the distribution feeders connected to multiple sources or to a single source with a ring configuration from a suitable switching location. Meshed networks offer many alternative configuration options and it is possible to reconfigure the network by interchanging the switching locations. Different configurations alternate the existing feeder lengths, voltage and current rates, loading levels and amount of losses. Accurate selection of switching locations would reduce losses, increase the lifetime of equipment and improve system reliability by balancing the system loading [5].

Distribution system configurations are usually chosen during planning of the system according to normal operation conditions and average loading levels. Nevertheless the load flows are not constant and they variate with different factors including changing demand, failiures, maintainence operations or additonal loads and sources connecting to the network [5], [6]. In a very fast growing city such as Istanbul, the electricity demand increase and network growth rate is also high. As a result it is not quite probable for the initial network configuration to maintain the optimum system loading for a long time under such conditions.

Locations of tie switches in a network providing minimum loss configuration can be determined by optimum distribution system reconfiguration methods. Most of the optimum reconfiguration methods are based on heuristics. Consequtively opening switches from meshed network [7] and branch exchange [8], [9] methods are used in many different reconfiguration studies. Recently probabilistic methods including genetic algorithms [10], [11], particle swarm optimization [12], ant colony optimization [13] and artifical bee colony [14] are also applied to optimum reconfiguration algorithms. Studies evaluating the use of heuristic methods on distribution system reconfiguration are also presented in recent years [15]-[17].

The objective function of reconfiguration optimization is defined as minimization of the resistive losses in most of the previous studies. However the optimization function can be defined as maximization of reliability [18], balancing feeder lengths and loadings [19], minimization of voltage drop or overloads [20], [21] and integration of distributed generation [22].

This study purposes to determine a new network configuration on the chosen network section from Istanbul, to reduce the system losses by evaluating the

Manuscript received February 15, 2015; revised June 1, 2015.

doi: 10.18178/ijeee.4.1.56-60

fitness of present configuration and simulating alternative switching operations. As a result, the chosen network section is modelled and a reconfiguration algorithm is generated on Matlab, based on opening switches consecutively according to optimum flow pattern [7].

II. Mathematical Background

A. Load Flow Calculation

The load flow analyses are performed by calculating the admittance matrix of the network and using Newton-Rhapson method. P and Q values of each bus regarding to voltage magnitude and angles and the new voltage and current values of the network elements are calculated iteratively.

P(i) is active power of bus i calculated by

$$P(i) = V(i)V(k)[G(i,k)cos(\theta i - \theta k) + B(i,k)cos(\theta i - \theta k)] \quad (1)$$

Q(i) is reactive power of bus i calculated by

$$Q(i) = V(i)V(k)[G(i,k)cos(\theta i - \theta k) + B(i,k)cos(\theta i - \theta k)] \quad (2)$$

where, i and k are the number of the buses at the head and end of branches respectively. $V(i)$ is voltage at bus i, θ_i and θ_k are voltage angles at bus i and k; $G(i,k)$ and $B(i,k)$ are conductance and susceptance from bus i to bus k.

The objective function of this reconfiguration algorithm shown in (3) is minimization of the total resistive power losses of the network as mentioned earlier.

$$Minimize\ f = \{sum\ [Real(S(i,k) - S(k,i)]\} \quad (3)$$

where, $S(i,k)$ is apparent power flow bus i to bus k.

The apparent powers flowing through branches are evaluated with the bus voltages and branch currents obtained from load flow calculations.

Apparent power flow bus I to bus k given by

$$S(i,k) = V(i)\, I(i,k) * \quad (4)$$

where, $I(i,k)$ is current flow from bus I to bus k.

The constraints defined for this reconfiguration method are the current carrying limits of the lines, the voltage boundaries of the network and the ratings of the equipment.

$$|I(i,k)| \leq Imax(i,k) \quad (5)$$

$$Vmin(i) \leq V(i) \leq Vmax(i) \quad (6)$$

where, $I_{max}(i,k)$ is the current carrying capacity of branch from bus i to bus k, $V_{min}(i)$ and $V_{max}(i)$ are the minimum and maximum allowed voltages at bus i respectively.

Another constraint of the reconfiguration method used in this study is, maintaining the radial operation of the system. In order to satisfy this, all the loads at the network has to be supplied by a single source and none of the loads should be left unfed. The details about how to achieve radiality will be explained in the methodology section.

B. Methodology

The reconfiguration method utilized in this study to reduce resistive losses of the distribution system starts with analyzing the load flow of the meshed system by closing all the switches in the network. According to the Kirchoff's laws, current favors to flow through the path with minimum losses. Whereas the system is operated as a meshed network, the resistive losses would be minimum and opening a line carrying high amount of current would force the current to flow through paths with higher losses. With the acceptance of opening the minimum current carrying switch would interfere the optimum flow least, the increase in losses by opening the switches would be minimized. This switch opening step is repeated until the network is radial in order to achieve a low loss configuration.

The method uses a meshed network with all switches closed in the begining of the reconfiguration process, thus the resulting configuration would be independent of the initial state of the network. However all the switch selections of network reconfiguration methods have impact on selection of other switches, due to their influence on the load flows. Therefore the sequential switching method used in this study would not guarantee a global optimum solution to the minimum loss network reconfiguration problem.

Ensuring radiality is one of the main constraints and challenges of distribution system reconfiguration. In order to achieve radial configuration there has to be only one electrical path from any given point of the network to another. In graph theory a connected graph without any loops is defined as a tree [23]. A graph can be a tree if the number of edges, e is one less than the number of vertices, v.

The edges and vertices can be defined as graphical equivalents of nodes and branches of a network. As a result, the number of connected lines, n_{line} has to be one less than the number of nodes in a network to have a radial configuration. The number of edges e given by

$$e = v - 1 \quad (7)$$

n_{line} is number of lines given by

$$nline = nnode - 1 \quad (8)$$

where v, n_{node} are numbers of vertices and nodes respectively

The number of tie switches need to be opened can be calculated according to (7). During switching, radially of the network is checked by comparing the number of open switches with the number of tie switches.

n_{Tsw} is number of tie switches that has to be opened, represented by

$$nTsw = nbranch - nbus - 1 \quad (9)$$

where n_{branch} and n_{bus} represent the number of branches and buses in the network respectively.

In order to keep all the loads supplied by the source, only one switch can be opened on the same feeder. Only operable switches are evaluated during reconfiguration. When a switch is chosen as tie switch, rest of the switches on the same feeder are defined as non operable switches, and added to a backlist. Thus the next switch is certainly chosen from other feeders. When entire tie switches are chosen, none of the remaining switches will be operable and radial network will be obtained. Flowchart of the optimization algorithm can be seen in Fig. 1.

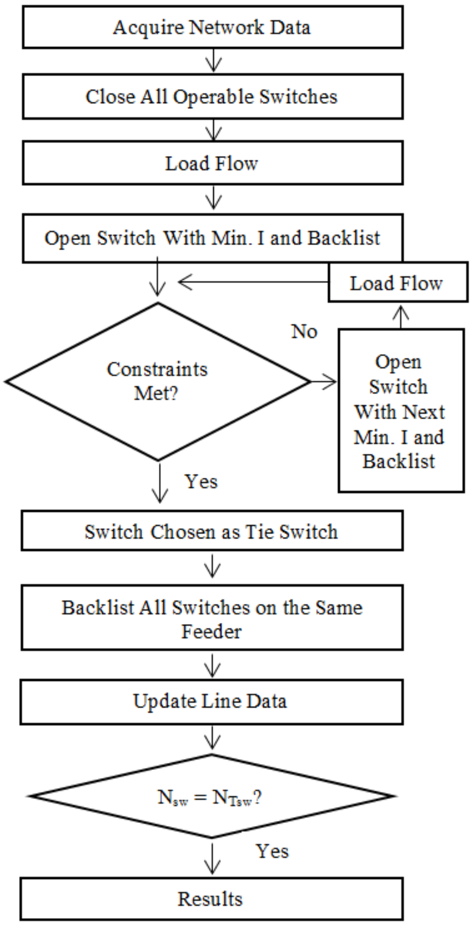

Figure 1. Reconfiguration algorithm.

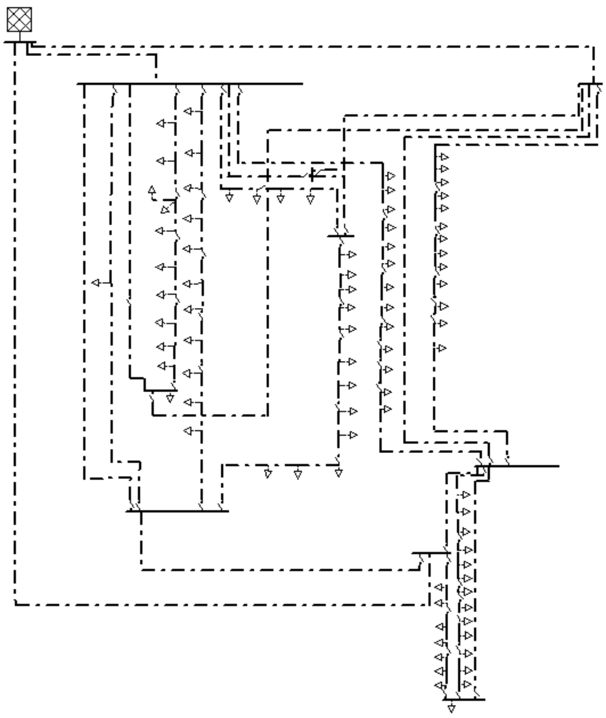

Figure 2. Single line diagram of the network.

III. System Description

The network used in this study is a section from 34.5kV distribution system of Istanbul. The network consists of 95 buses, 107 branches and 58 switches connected with 7.2km of 150mm^2 three core, 38.5km of 240mm^2 three core and 15km of 240mm^2 single core, armored copper cables with XLPE insulation. Total length of the network is 60.7km with 86 distribution transformers connected to the network.

Distribution transformers are modeled as medium voltage loads with 97.6MVA apparent power in total. The power factor is taken as 0.85, at the reactive power penalty limit to be conservative. The minor unbalances between phases are neglected for calculation simplicity.

The single line diagram of the modelled network is shown with loads, switches cables and the modelled source in Fig. 2.

IV. Results and Discussions

The resulting power losses from actual configuration, meshed network, and the configuration achieved by the reconfiguration algorithm are analyzed in this section.

The meshed configuration of the network with all switches closed has total resistive loss of 94kW. The actual configuration of the network is with switches s1, s8, s10, s19, s28, s29, s36, s38, s39, s40, s49, s54 and s58 open and the resistive losses are calculated as 169kW.

The configuration achieved by the reconfiguration algorithm has switches s3, s7, s10, s18, s20, s30, s35, s38, s39, s40, s48, s51 and s55 open resulting total resistive losses of 124kW. The mentioned configurations, open switches and resistive losses are shown in Table I.

TABLE I. Resistive Losses of Configurations

Configuration	Open Switches	Resistive Losses (kW)
Meshed Network	-	94
Actual	s1, s8, s10, s19, s28, s29, s36, s38, s39, s40, s49, s54, s58	169
New	s3, s7, s10, s18, s20, s30, s35, s38, s39, s40, s48, s51, s55	124

During the reconfiguration algorithm resistive losses in the network from different switching steps are shown in Fig. 3. First 9 switches do not have an observable effect on the resistive losses of the network. The losses start increasing after opening 10th switch and a rapid increase occurs at last switch.

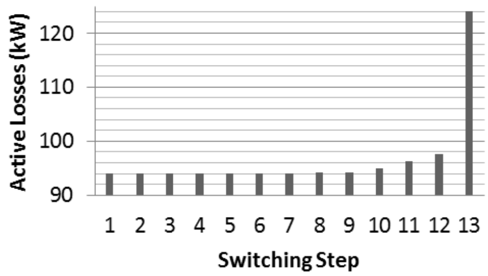

Figure 3. Resistive losses of switching steps.

V. CONCLUSIONS

The network section used in this study has been analyzed for the existing state of the network, the meshed network and the configuration achieved methodologically to reduce the resistive losses of the system. The network has 13 tie switches and by interchanging 7 of the open switch locations, resistive losses of the system is reduced 26.6% for the resulting network configuration.

The implementation of a recommended network configuration can be restricted due to the availability of switching equipment and ease of operation. However providing practicable outputs and implementing best possible switching scenario have high importance. The algorithm used in this study is capable of suggesting applicable switching maneuvers by grouping equipment according to their properties and operation restrictions. As a result, possible improvements without investment can be carried out directly and cost benefit analysis can be performed for additional switching equipment required.

A. Future Work

The reconfiguration method used in this study is aimed to be improved by addition of a next step to the algorithm for reducing the disadvantages of consecutive switching. A method for finding lower loss configurations is being investigated.

REFERENCES

[1] *Directive 2012/27/EU of the European Parliament and of the Council on Energy Efficiency*, Oct. 2012.

[2] S. Sehgal, A. Swarnkar, N. Gupta, and K. R. Niazi, “Reconfiguration of distribution network for loss reduction at different load schemes,” in *Proc. IEEE Students’ Conference on Electrical, Electronics and Computer Science SCEECS*, Mar. 2012, pp. 1-4.

[3] H. L. Willis, H. Tram, M. V. Engel, and L. Farley, “Optimization applications to power distribution,” *IEEE Computer Applications in Power*, vol. 8, no. 4, pp. 12-17, Oct. 1995.

[4] T. E. McDermott, I. Drezga, and R. P. Broadwater, “A heuristic nonlinear constructive method for distribution system reconfiguration,” *IEEE Trans. Power Syst.*, vol. 14, no. 2, pp. 478-483, May 1999.

[5] H. R. Esmaeilian, R. Fadaeinedjad, and S. M. Attari, “Distribution network reconfiguration to reduce losses and enhance reliability using binary gravitational search algorithm,” in *Proc. 22nd International Conference on Electricity Distribution*, 2013.

[6] P. Zhang, L. Wenyuan, and W. Shouxiang, “Reliability-Oriented distribution network reconfiguration considering uncertainties of data by interval analysis,” *International Journal of Electrical Power and Energy Systems,* vol. 34, no. 1, pp. 138-144, Jan. 2012.

[7] D. Shirmohammadi and H. W. Hong, “Reconfiguration of electric distribution for resistive line loss reduction,” *IEEE Trans. Power Del.*, vol. 4, no. 2, pp. 1492-1498, Apr. 1989.

[8] S. Civanlar, J. J. Grainger, H. Yin, and S. S. H. Lee, “Distribution feeder reconfiguration for loss reduction,” *IEEE Trans. Power Del.*, vol. 3, no. 3, pp. 1217-1223, Jul. 1988.

[9] S. K. Goswami and S. K. Basu, “A new algorithm for the reconfiguration of distribution feeders for loss minimization,” *IEEE Trans. Power Del.*, vol. 7, no. 3, pp. 1484-1491, Jul. 1992.

[10] S. K. Prasad, R. Ranjan, N. C. Sahoo, and A. Chaturvedi, “Optimal reconfiguration of radial distribution systems using a fuzzy mutated genetic algorithm,” *IEEE Trans. Power Del.*, vol. 20, no. 2, pp. 1211-1213, Apr. 2005.

[11] A. Mazza, G. Chicco, and A. Russo, “Optimal multi-objective distribution system reconfiguration with multi criteria decision making-based solution ranking and enhanced genetic operators,” *International Journal of Electrical Power and Energy Systems*, vol. 54, pp. 255-267, Jan. 2014.

[12] T. M. Khalil and A. V. Gorpinich, “Reconfiguration for loss reduction of distribution systems using selective particle swarm optimization,” *International Journal of Multidisciplinary Sciences and Engineering*, vol. 3, no. 6, Apr. 2012.

[13] L. C. Daniel, I. H. Khan, and S. Ravichandran, “Distribution network reconfiguration for loss reduction using ant colony system algorithm,” in *Proc. IEEE INDICON*, Dec. 11-13, 2005, pp. 619-622.

[14] H. Nasiraghdam and S. Jadid, “Optimal hybrid PV/WT/FC sizing and distribution system reconfiguration using multi-objective artificial bee colony (MOABC) algorithm,” *Solar Energy*, vol. 86, no. 10, pp. 3057-3071, 2012.

[15] Y. Hu, N. Hua, C. Wang, J. Gong, and X. Li, “Research on distribution network reconfiguration,” in *Proc. International Conference on Computer Mechatronics, Control and Electronic Engineering*, Oct. 2010, pp. 176-180.

[16] A. S. Deese, “Comparative study of accuracy and computation time for optimal network reconfiguration techniques via simulation,” *International Journal of Electrical Power and Energy Systems*, vol. 63, pp. 394-400, Dec. 2014.

[17] A. K. Ferdavani, *et al.*, “A review on reconfiguration of radial electrical distribution network through heuristic methods,” presented at IEEE 4th International Conference on Modeling, Simulation and Applied Optimization (ICMSAO), 2011

[18] K. F. Abdollah and T. Niknam, “Multi-Objective stochastic distribution feeder reconfiguration from the reliability point of view,” *Energy*, vol. 64, pp. 342-354, Jan. 2014.

[19] P. K. Ravibabu, K. Venkatesh, and C. S. Kumar, “Implementation of genetic algorithm for optimal network reconfiguration in distribution systems for load balancing,” in *Proc. IEEE Region 8 International Conference on Computational Technologies in Electrical and Electronics Engineering*, Jul. 2008, pp. 124-128.

[20] M. H. Hemmatpour and M. Mohammadian, “Novel approach for optimum reconfiguration and SVC planning considering variable load pattern based on voltage security margin,” *International Journal on Technical and Physical Problems of Engineering*, vol. 2, no. 11, Nov. 2011.

[21] M. M. Aman, G. B. Jasmon, A. H. A. Bakar, and H. Mokhlis, “Optimum network reconfiguration based on maximization of system loadability using continuation power flow theorem,” *International Journal of Electrical Power and Energy Systems*, vol. 54, pp. 123-133, Jan. 2014.

[22] V. Rashtchi and S. Pashai, “Network reconfiguration in distribution power system with distributed generators for power loss minimization,” in *Proc. International Conference on Advances in Computer and Electrical Engineering ICACEE*, Nov. 2012.

[23] N. Christofides, *Graph Theory an Algorithmic Approach*, 1st ed., New York: Academic Press, 1975, pp. 122-135.

İlker Dursun received the B.Sc. degree in 2003 and M.Sc. degree in 2006 from Sakarya University, TURKEY. Now, he is currently studying for his PhD degree at Yildiz Technical University. Also, he has been working at Bogazici Electricity Distribution Company for more than 8 years at different departments and duties. Now he is working as R&D Manager. His main interests are power systems, smart grid applications, distributed generation, switching optimization, balanced-unbalanced load flow analysis, technical/non-technical loss analysis.

Feyzi Karaosmanoglu received the B.Sc. degree in 2009 from Middle East Technical University, Turkey, and the M.Sc. degree in 2012 from Rheinisch-Westfälische Technische Hochschule, Aachen, Germany. Since 2013 he is working at Bogazici Electricity Distribution Company in R&D department. His main interests are power system analyses, integration of renewables and storage systems and loss reduction in distribution systems.

Nurettin Umurkan was born in Tokat, Turkey, in 1964. He received the degree in electrical engineering, the M.S. degree and the Ph.D. degree in electrical engineering from Yildiz Technical University (YTU), in 1988, 1991 and 1995, respectively. Since 1990 he has worked as an academician at YTU. He is a Professor of electrical engineering at YTU. He has directed 23 M.S. and 4 Ph.D. theses. He is the author and coauthor of more than 50 scientific papers and technical reports on magnetic shielding, power systems, electromagnetic fields of HV power line and grounding. His areas of interest are magnetic shielding, grounding and smart grid in power systems.