Indian Journal of Science and Technology, Vol 9(48), DOI: 10.17485/ijst/2016/v9i48/74786, December 2016
ISSN (Print) : 0974-6846
ISSN (Online) : 0974-5645

MV/LV Distribution Networks Modelling Based on Malaysian Power Network Context

Meysam Shamshiri, Chin Kim Gan and Rosli Bin Omar

Universiti Teknikal Malaysia Melaka (UTeM), Hang Tuah Jaya, 76100 Durian Tunggal, Melaka, Malaysia; meysamshamshiri@yahoo.com, ckgan@utem.edu.my, rosliomar@utem.edu.my

Abstract

In strategic planning of distribution network, the distribution planner need to evaluate the functionality of the networks on different case studies and various network conditions in order to establish an economic and reliable network. The fractal-based network model generation and Particle Swarm Optimization methods are used in this paper in order to model a distribution network considering the specified features of Malaysian electricity supply application handbook. The proposed method is able to optimize the settlement of consumers and substations based on the distribution planner desires. In the proposed approach 10000 network models have been generated for both urban and rural areas in order to find the adequate numbers of required substations. The results of the case study illustrated that the desired number of substations with acceptable range of violations are obtained from the proposed approach. The distribution network models are designed with settlement of LV consumers and optimum feeder routing from LV consumers connected to distribution transformers. Moreover, the optimum distribution transformers placement and size with optimum MV feeder routing connected to MV substation are modelled. It is concluded from the statistical analysis that proposed method could be utilized to generate the similar realistic network models for strategic assessment of distribution network planning.

Keywords: Distribution Network Modelling, Fractal Network Model Generation, Minimum Spanning Tree, Particle Swarm Optimization

1. Introduction

One of the main challenges of distribution network planners is to develop optimal network design strategies[1]. Due to the lack of information of LV network and non-adequate data logging, it is not logical to rely on real data for large strategic design of distribution networks. Therefore, distribution network modelling is essential that involves modelling of a wide range of cable sizes and types, substations locations, and transformers types and sizes. Recently, several researchers have proposed the methodologies to model the distribution networks. The optimal feeder routing problem using the dynamic programming techniques and Geographical Information Systems (GIS) facilities have been performed by researchers in order to reduce total investment cost[2]. The line losses and reliability have been taken into the account with related constraints such as voltage drop and thermal capacity issues. The optimum planning of large distribution network based on losses characteristics matrix for optimum substation location and graph theory was proposed by researchers[3]. Moreover, it optimizes feeder routing in real size of distribution network by using Genetic Algorithm (GA) method[3]. The optimal planning of radial distribution networks using simulated annealing techniques has been used in order to address the minimum capital cost by applying the steepest descent approach[4]. There are several method for distribution network modelling and planning which have been analysed under normal condition and emergency planning[5]. An attempt to reduce the cost of feeders by selecting the optimal conductor type and size of feeders segment was presented by researchers that performed a new computer algorithm and heuristic optimization technique[6].

This paper aims to generate the large scale of distribution network models with thousands of nodes with similar statistical features and different configurations in order to investigate the reliability of the proposed method. The fractal-based network generation has been utilized in this paper to generate the economic

* Author for correspondence

model of LV distribution network. The fractal model generation is more adequate to represent the LV networks with low load densities as compared with geometric models[7]. Accordingly, the proposed method generates large sets of weakly meshed networks. Basically, LV networks have radial structure, as further adjustments have carried out to transform network to radial ones. The fractal network generation[1] has been utilized in this paper in order to model the Malaysian LV network as general test case. The Malaysian utility service (TNB) guide book[8] specification was considered to generate similar LV network compared to exciting Malaysian LV distribution network. Power flow engine is vital issue in distribution network planning due to the vast size of the network. This paper has used OpenDSS engine as power flow solution in distribution network planning in order to obtain the network parameters such as voltages, current of feeders and losses of the network during optimization procedures. This paper has performed the PSO algorithm to find the optimal placement and sizing of distribution substations and used modified Minimum Spanning Tree (MST) algorithm for optimal feeder routing from LV distribution transformers to MV substations.

2. Methodology

In order to design the distribution network model for Malaysian context the following methodologies have been performed. The fractal LV network generation model is performed to generate the costumer's position and LV connections with respective coordinates for LV distribution networks. The candidate substations placement have been obtained from the T-point LV lines connections. The PSO algorithm has been used in order to find the optimum placement and sizing of distribution substations (11/0.4)[9]. Subsequently, the MST method has been performed for MV feeder rooting that can connect the main intake substation into the distribution substations.

2.1 Fractal LV Network Model Generation

The algorithm of fractal LV network model generation is given in[10]. The consumer point generation algorithm employs based on fractal dimension of consumers' settlement by statistically adjustment of consumers' distance in order to find the similar realistic consumer positions[10]. The expected network length l with this law $1 \propto n^{\alpha}$ is founded for consumer connection with desire value of distances D:

$$D = 1/1 - \alpha \tag{1}$$

The fractal geometry is control by value of D as an economic model which has both repulsiveness and attractiveness with following representation:

$$k = \begin{cases} <1 & \text{if} \quad t_1 < l < t_2 : \text{Attracive} \\ >1 & \text{if} \quad t_2 < l < t_1 : \text{repulsive} \end{cases} \tag{2}$$

$$k(l) = \frac{1}{t_1 + t_2}\left(\frac{t_1.t_2}{l} + 1\right) \tag{3}$$

where, k is a function of typical separation l between existing points. The variable k is built into the consumer settlement model using transformation equations that can be written as follows:

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\theta.x & -\sin\theta.y \\ \sin\theta.x & \cos\theta.y \end{bmatrix} \begin{bmatrix} k & 0 \\ 0 & k \end{bmatrix} + \begin{bmatrix} x_c \\ y_c \end{bmatrix} \tag{4}$$

where, x' and y' are the coordinates of final settlement of a new point, x and y are the coordinates of random point settlement, x_c and y_c are the coordinates of centre of the primitive network. The new costumer point settlement by applying affine transportation is shown in[10].

Once the consumer points are generated, there are connected with straight lines, thereby giving origin to a certain number of T-points. The number of connections can then be accordingly identified using the concept of Branching ate (BR); that is, the ratio of the number of (T-pints) to the total number of consumer nodes of the generated networks. The BR is depend on how the next consumer will be connected the existing network in a dynamic process. The detail explanation of the algorithm can be obtained from[10].

2.2 Particle Swarm Optimization

The swarm intelligent algorithm is one of the evolutionary computation methods that have been introduced to solve the optimization problems and since then, their ability has been demonstrated[11]. In this method, the movement towards the optimal position is obtained from the best information of each particle which is included in the initial population (Best Personal Position) and the optimal position that is found by the neighbours' positions (Best Global Position). Researchers applied PSO algorithm successfully in complex non-linear engineering problems principally in distribution system planning, control systems, multi-objective optimization problems with multiple constraints, shape optimization and etc[12]. Since the capacitor installation in distribution system has the non-linear and discrete equations, therefore, this paper utilized PSO algorithm as one of the accurate methods to solve the substation placement and sizing problem. The procedures of this algorithm have been described in reference[13]. Figure 1 illustrates the particle movement bases on PSO algorithm.

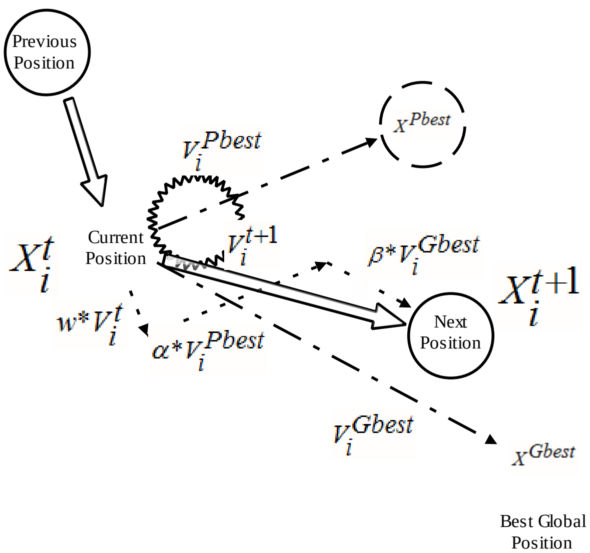

Figure 1. Principle of the PSO particle movement.

The PSO algorithm has been performed as an optimization engine to find the desired load profile as platform of minimization of an objective function for consumers who are willing to participate in DR programs. The load profile represents the power consumption of aggregate groups of consumers who accepted the DR program's conditions and accepted to follow the pattern. The objective function of load pattern has been discussed in next Section.

2.3 Methodology for Identification of Optimum Number of Distribution Substations Placement and Sizing and MV Feeder Routing

In order to identify the optimum numbers of substations in LV Malaysian distribution network model, a methodology has been performed to obtain the coordinates of residential consumers, the candidate substation placement and LV feeder paths[13]. Figure 2 described a method to apply fractal LV network model generation in order to design the optimum MV feeder rout and optimum substations placement and sizing. The PSO algorithm seeks to find the optimum placement and size of the substations based on the obtained results of candidate substation placement (T-points) and LV feeder paths. Therefore, the following objective function has been introduced that needs to be minimized:

$$Min;\ Z = CL + CC + PF \tag{5}$$

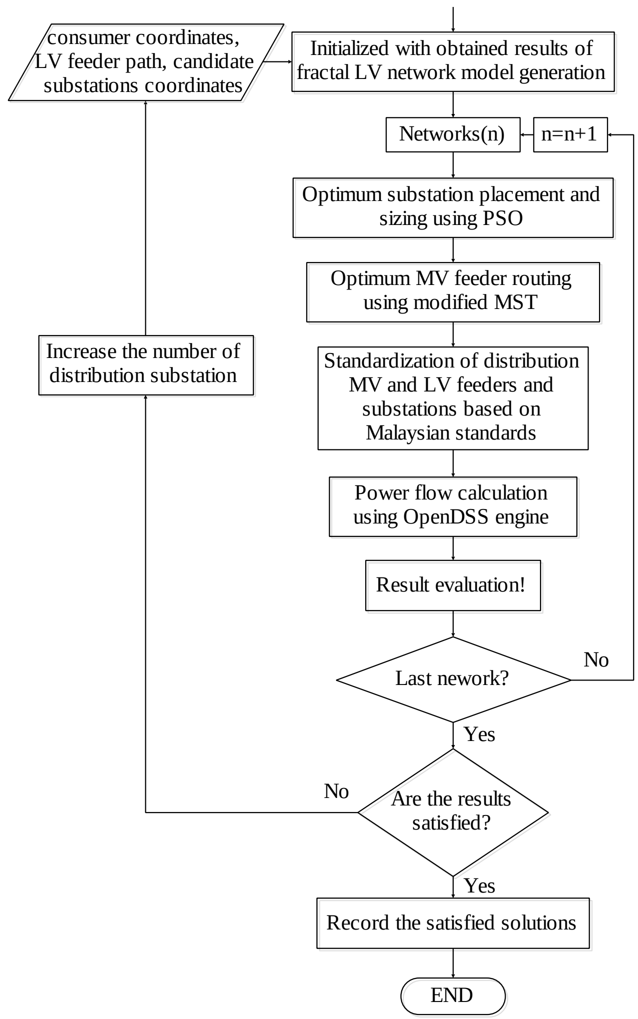

Figure 2. The proposed flowchart of optimum substation placement and sizing and feeder routing for distribution networks.

where, Z represents the objective function of optimum placement and sizing of the substations, CL is the total losses cost for a study year, CC represents the annuitized capital cost [*$/year*], and PF is the penalty factor which would be realized by the optimization constraints.

$$CL = C_L . \sum_{i=1}^{nlb} P_{Loss}^{i} .8760 \tag{6}$$

where, C_L *[$/kWh]* represents the cost of real power losses (C_L*=168 $/kW/year]*)[14], P_{Loss}^{i} [*kWh*] is the real power losses at consumer *i* and *nlb* indicates the number of consumers.

The investment cost of substation should be annuitized in order to be accumulated with other network costs[1]. Thus, to annuitize the investment cost of distribution network, the following economic consideration should be performed.

$$VC_S = \sum_{j=1}^{ns} C_{var}(j) . \left(\sum_{i=1}^{nlb} d_{lb}(j,i) \right) \tag{7}$$

$$FC_S = \sum_{j=1}^{ns} C_{fix}(j) \tag{8}$$

$$C_s = VC_s + FC_s \tag{9}$$

where, VC_s stands for the total substation variable cost, $C_{var}(j)$ represents the cost of substation *j* per MVA, $d_{lb}(j,i)$ is the consumer demand *I* which connected to substation *j*. FC_s represents the total fixed cost of substations and $C_{fix}(j)$ is the fixed cost of substation *j*. The variable cost of substation included the cost of operation and maintenance, and the fixed cost consists of installation and other related fix cost of substation such as land and equipment prices and etc.

$$IC = \sum_{j=1}^{ns} C_S^j * C_l \tag{10}$$

$$CC = IC * \frac{d(1+d)^T}{(1+d)^T - 1} \tag{11}$$

where, IC stand for Investment Cost [*$*], C_S is the total substation installation and operation costs [*$*], C_l is the total cost of the lines [*$*], *d* is the discount rate and *T* is the number of operation years.

In distribution system planning, the geographical distribution of loads density and allocation of the feasible candidate substations are the major information that should be considered. In order to optimal distribution substation allocation and feeder routing, the following constraints must be satisfied. Firstly, all of the consumers in the network should be supplied. Secondly, the voltage drops at the receiving bus should not violate the limit. Thirdly, the maximum load capacity of all substations should be considered. Lastly, the total cost of new constructed substation should be minimized. As mentioned previously, the problem constraints could be included in objective function as *PF* which can be written as follows:

$$PF = \sum_{i=1}^{nv} (\beta \times Violation_i) \tag{12}$$

where, *nv* is the number of violations and β is the fine rate that might be adjusted by type of the violations. One of the constraints of distribution network planning is acceptable voltage drop at receiving bus (V_i) that should be within the predefined range by related standards[8].

$$0.95 \le V_i \le 1.05 \tag{13}$$

The other constraints of distribution network planning are the longest distance of each consumer from the distribution substation which are obtained by substation radius based on standard. To consider this constraint the following condition must be considered:

$$D_j^i \le R_{max}^j \tag{14}$$

where, D_j^i stands for distance between substation *j* to consumer *I* and R_{max}^j is the maximum acceptable radius of substation *j* that can supply the consumers.

Subsequently, once LV network with adequate substation placements and sizes have been designed, the proposed optimum MV feeder routing algorithm will be performed for MV feeders' connections using obtained results of LV network. The MST is modified to perform for the MV feeder connections. MST theory is assigned as one of the important part of mathematic sciences which has been introduced in 19s century. A graph is a collection of ordered pairs of branches and nodes that can be written as $G \equiv (V, E)$. Where, V is node and E is branch. In fact, a graph is a diagrammatic model of a system. In general, a graph represents a binary relation between system components. A single graph can have many different spanning trees assigned by weight. MST is the graph with the minimum weight on branches. The MST algorithm has been implemented as feeder routing solution in distribution networks[3]. There are lots of algorithm to solve the MST problems which are Kruskal's algorithm, Prim's algorithm, Dijkstra's algorithm and etc. This paper uses the prim's algorithm to solve the optimum feeder routing for MV networks. However, prim's algorithm cannot carry out the desired optimal routing thus the modified prim's algorithm needs to be performed. This is because exists some technical issues. First issue is that the network should be radial design and there should not exists any ring network. The second issue is that the branches should not pass through each other. Therefore, because of the two mentioned issues the new modified MST method is proposed. Figure 3 shows the modification algorithm of prim's algorithm in MST in order to find the optimum MV feeder routing in distribution network.

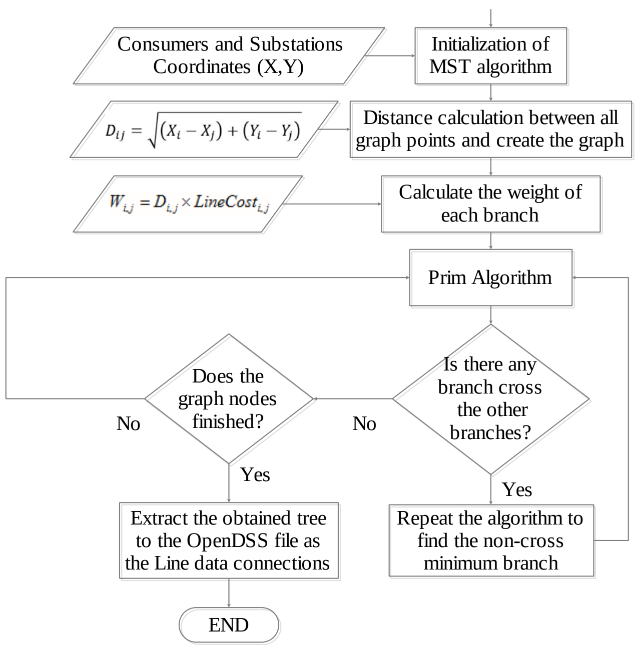

Figure 3. The flowchart of modified MST algorithm in order to solve the optimum MV feeder routing in distribution network.

Once the MV feeder routing algorithm has been performed, the next step of network model designing is the standardization of the conductors and substation types and sizes. The LV and MV feeders as well as transformers sizes should be standardized based on Malaysian standards that have been defined in their related standards[8,15]. Next, Power flow calculation is performed in order to demonstrate the design conditions in terms of bus voltages and thermal capacity of the lines. The results of each network are evaluated till desired results are obtained.

3. Case Study

Two type of distribution networks, urban and rural are generated in this paper. There are 100 networks are evaluated in each iteration thus there will a total of 10000 iterations of each types. It has been performed to find the probability of the network generation model in terms of violated voltage. The maximum/minimum voltages of all the sending-end and receiving-end busses are checked to indicate the network operation within the statutory LV limits defined by Malaysian standards to be -6% to +10%[8]. Increasing the number of substation per iteration and monitoring the minimum voltages has been applied to find the satisfactory range of required substations. The increment number of substations is set to approximately 10% of heuristically estimated optimum number of substations[1]. Figure 4 illustrates the percentage of violated voltages for 100 generated networks model with 15MVA/km^2.

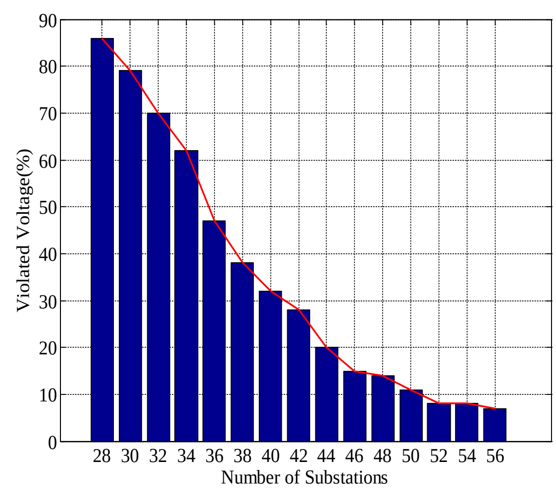

Figure 4. Percentage of violated cases for 15 MVA/km^2 of 100 networks.

By increasing the number of substation the percentage of violated cases has been reduced and based on the predefined 10% violation adjustment, the range of substation numbers is found to be 52 urban networks. The probability of minimum voltage distribution is shown in Figure. 5. It depicts around 90% of the generated network models with 52 substations for urban are satisfied in terms of minimum voltage violation.

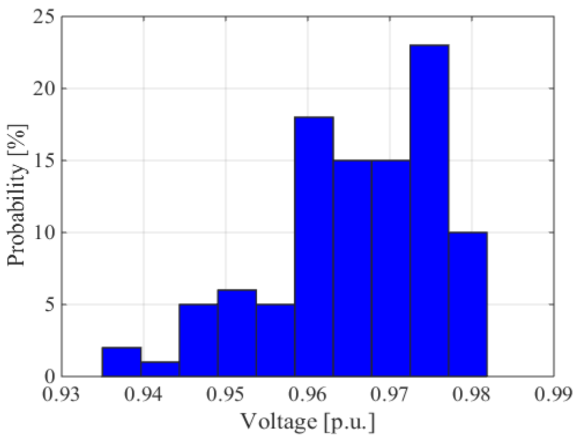

Figure 5. Probability of Distribution of minimum voltages for the case 15MVA/km² with 52 substations100 networks.

Figure 6 illustrates one of non-violated networks model that has been selected to demonstrate as valid generated network model. This network consists of 2000 urban residential consumers in the area of 1km². The mean box plot of power losses for different substations number is demonstrated in Figure 7. It shows that 52 substations has lesser mean value of power losses compared to the others numbers of substations. Moreover, Figure 8 indicates the histogram plot of total power losses with 52 numbers of substations that evidence above 90% of the networks with 52 substations has satisfactory power losses. The maximum peak snapshot power flow calculation shows the minimum voltage of 0.95607p.u and maximum voltage of 1.05703p.u with total power losses of 377.9kW of the chosen LV urban residential network with 52 substations. The same procedure can be performed on rural networks in order to generate the distribution network model of rural area. Therefore, Figure 9 and 10 shows the samples of the generated networks for both urban and rural areas with different load densities.

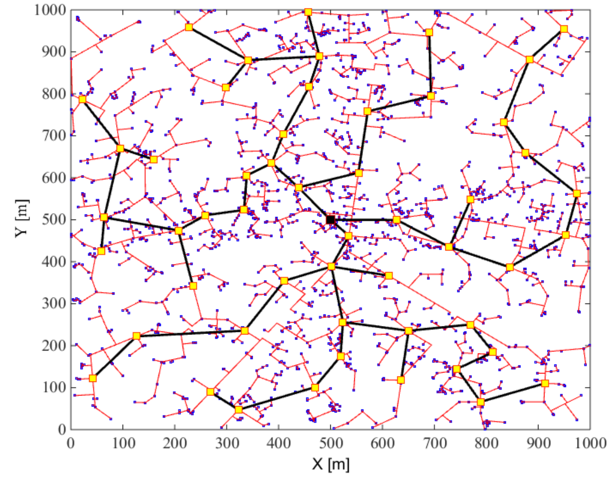

Figure 6. Urban distribution network model (Malaysia context) designed by 2000 consumers and 52 distribution substations in the area of 1km² and load density 15MVA/km².

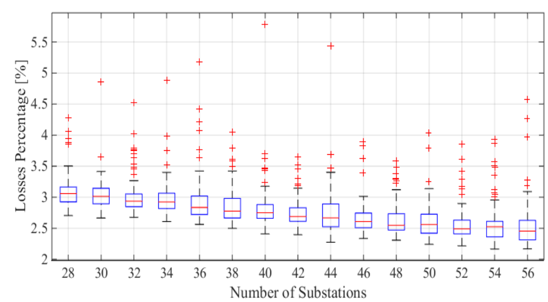

Figure 7. Power losses for the case 15MVA/km² with 52 substations100 networks.

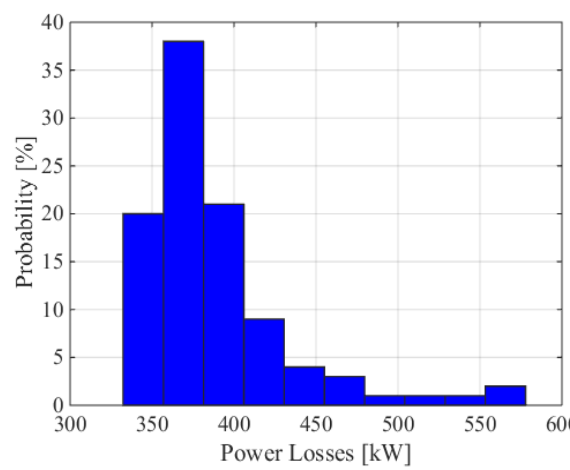

Figure 8. Probability of distribution of power losses for the case 15MVA/km² with 52 substations100 networks.

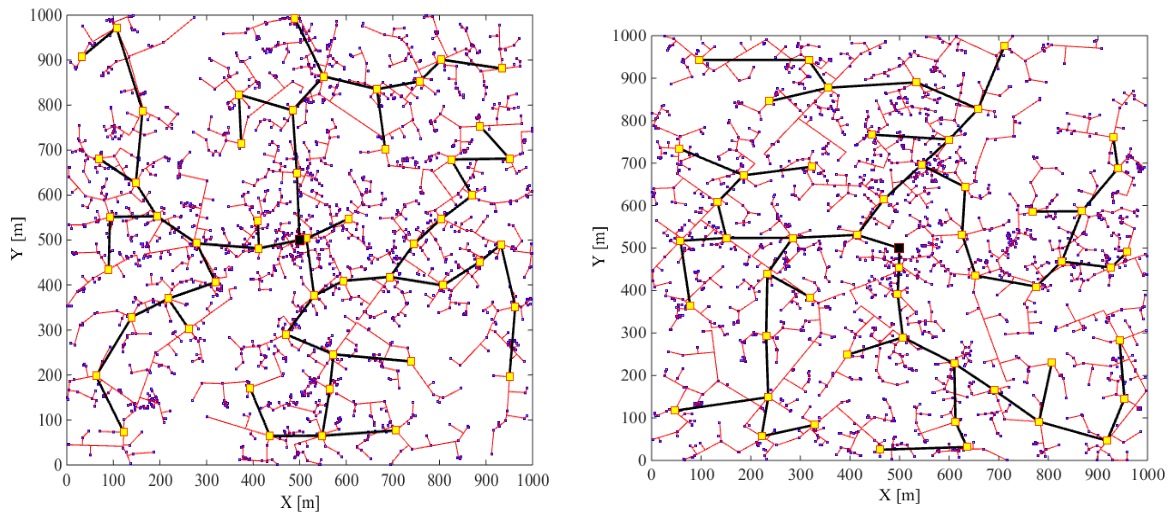

Figure 9. Urban distribution network model (Malaysia context) with 15MVA/ km^2.

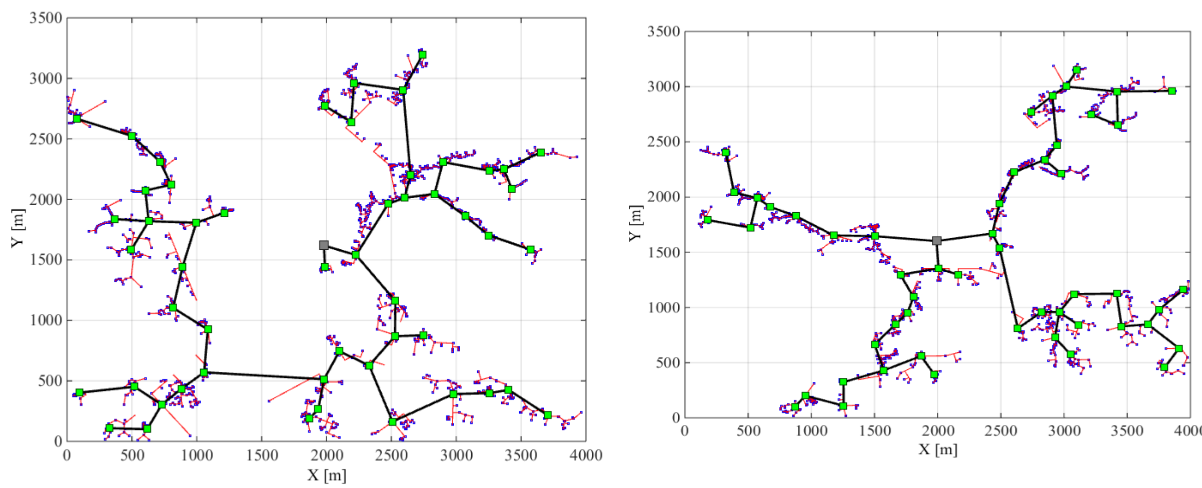

Figure 10. Rural distribution network model (Malaysia context) with 0.5MVA/ km^2.

4. Conclusion

This paper proposed a methodology to generate the LV/MV distribution network model based on Malaysian context. The model could be utilized for large scale applications of strategic assessments with thousands of LV nodes with MV/LV feeder connections and optimum distribution substation sitting and sizing. The fractal-based network model generation was performed to generate the large number of consumers' settlement with LV feeder connections and candidate substation coordinates. The optimum placement and sizing of distribution substation was achieved by executing the PSO algorithm on the obtained information of LV network generation. The modified MST algorithm was used to find the optimum MV feeder routing to connect the primary substation to distribution substations with minimum length and optimized cost. The case study shows two types of rural and urban networks that were designed based on the proposed method. The result of the case study indicates that generated network models are similar to realistic network. Furthermore, the generated models can be applied in strategic planning of distribution network.

5. Acknowledgement

The authors would like to thank the Universiti Teknikal Malaysia Melaka for funding the research work under research grant No. FRGS/1/2015/TK04/FKE/02/F00255 and UTeMZamalah Scheme UTeM 29.02/600-1/9/5.

6. References

1. Gan CK, Mancarella P, Pudjianto D, Strbac G. Statistical Appraisal of Economic Design Strategies of LV Distribution Networks, Electric Power Systems Research, 2011; 81(7):1363-72.
2. Boulaxis N, Papadopoulos M. Optimal Feeder Routing in Distribution System Planning using Dynamic Programming Technique and GIS Facilities, IEEE Transactions on Power Delivery. 2002; 17(1):242-47. Accessed January 20, 2014. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=974213.
3. Najafi S, Hosseinian SH, Abedi M, Vahidnia A, Abachezadeh S. A Framework for Optimal Planning in Large Distribution Networks, IEEE Transactions on Power Systems. 2009; 24(2):1019-28.
4. Nahman JM, Peric DM. Optimal Planning of Radial Distribution Networks by Simulated Annealing Technique, IEEE Transactions on Power Systems. 2008; 23(2):790-95.
5. Khator SK, Leung LC. Power Distribution Planning: A Review of Models and Issues, IEEE Transactions on Power Systems. 1997; 12(3):1151-59.
6. Islam SJ, Ghani MRA. Economical Optimization of Conductor Selection in Planning Radial Distribution Networks, Transmission and Distribution Conference, 1999 IEEE. 1999; 2:858-63.
7. Grenard S. Optimal Investment in Distribution Systems Operating in a Competitive Environment, PQDT - UK and Ireland, 2005.
8. Tenaga National Berhad Malaysia. Electricity Supply Applicaion Handbook, TNB; 2010, p. 132.
9. Hasan IJ, Shamshiri M, Gan CK, Ruddin M, Ghani A, Omar R Bin. Optimum Feeder Routing and Distribution Substation Placement and Sizing Using PSO and MST, Indian Journal of Science and Technology (IJST). 2014.
10. Gan CK. Strategies for Design of Future Distribution Networks, Imperial College London, UK, 2011, p. 244. Accessed September 25, 2014. http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.537192.
11. Kennedy James. Particle Swarm Optimization. Encyclopedia of Machine Learning. Springer US; 2010. p. 760-66.
12. Taher SA, Karimian A, Hasani M. A New Method for Optimal Location and Sizing of Capacitors in Distorted Distribution Networks using PSO Algorithm, Simulation Modelling Practice and Theory. 2011; 19(2):662-72.
13. Shamshiri M, Gan CK, Jusoff K, et. al. Using Particle Swarm Optimization Algorithm in the Distribution System Planning, Australian Journal of Basic and Applied Sciences (AJBAS). 2013; 7(3):85-92.
14. Eajal A, El-Hawary M. Optimal Capacitor Placement and Sizing in Distorted Radial Distribution Systems Part III: Numerical Results. In: 4th International Conference on Harmonics and Quality of Power (ICHQP), IEEE, 2010, p. 1-8. Data accessed: November 9, 2014. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=5625474.
15. Tie CH, Gan CK. Impact of Grid-Connected Residential PV Systems on the Malaysia Low Voltage Distribution Network. In: IEEE 7th International Power Engineering and Optimization Conference (PEOCO2013), 2013; p. 670-75.