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A New Approach of DNR by using Multi-Population Evolutionary Programming (MPEP) for Losses Minimization

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Abstract: Electric power distribution loss and reliability are major concerns in power system as the demand for electrical energy by customers keeps increasing day by day. One of the suggested methods to minimize these problems is by doing reconfiguration process to the existing distribution network. A reconfiguration is performed by opening or closing the sectionalizing switches to maintain the feeder in radial network. This study presents a method of Distribution Network Reconfiguration (DNR) by using Multi Population Evolutionary Programming (MPEP). The main objectives of this study are to minimize the power losses and improve the voltage profile. The performance of the Multi-Population Evolutionary Programming (MPEP) method has been investigated and the impact to the distribution network has been analyzed. The proposed algorithm has been tested on IEEE 16, 33 and 69 buses of radial distribution systems network accordingly. The real results have been compared with the conventional initial network and an optimization technique which is conventional Evolutionary Programming (EP). The results of this study are hoped able to help electrical engineers in solving the losses problem in the distribution network while increasing the efficiency of the real distribution system significantly.

Key words: Distribution Network Reconfiguration (DNR), Multi Population Evolutionary Programming (MPEP), Evolutionary Programming (EP), power loss reduction, voltage profile improvement, system

INTRODUCTION

There are three main processes in an electric power system which are to generate, transmit and distribute electrical supply to customers (Blume, 2007). Distribution network commonly have 33, 22 and 11 kV of voltage levels interconnected to the transmission part of a power system. The distribution power system supplies 415 and 240 V of voltage levels to consumer level. As the number of consumers keeps increasing day by day, the demand of electric energy also increases and as a result, the distribution lines are heavily loaded, plus the losses along the transmission lines. In developed countries such as Malaysia, the power losses should not more than 10%. Based on the 2008 and 2012 reports from Electricity Supply Industry in Malaysia (PEC., 2014) the demand of grid systems in Peninsular Malaysia has increased from 13, 620 MW in 2007 to 15, 826 MW in 2012 while the yearly electricity demand showed increase from 2008 with 99.548-108,473 GWh in 2012 in Peninsular Malaysia. Hence, it is crucial to improve the reliability and efficiency of the distribution system network. During a feeder reconfiguration, two objectives are considered by the operating system operator which are to minimize power losses and to improve the voltage profile based on the distribution systems. In order to ensure reliability and secure the system economically, the increasing demand in power system is a challenging job to power system engineers. This is due to the heavy loaded network that would increase the load current drawn from the source and at the same time, it leads to huge voltage drop and system losses. Each feeder in a distribution system has different mixture of commercial, residential and industrial type loads and the daily load variations of these load types are dissimilar. This means that the ratio of power loss in all lines in the network is not constant. In order to give the best performance to the radial distribution structure and enhance the network efficiency, reconfiguration of the distribution network is needed. By changing theposition of the switches in the existing network, different power loss is gained.

Several methods have been proposed to solve the problems for feeder reconfiguration such as Ant Colony System (ACS) (Daniel *et al*., 2005), Rank Evolutionary Particle Swarm Optimization (REPSO) (Sulaima *et al*., 2014), Evolutionary Particle Swarm Optimization (EPSO) (Sulaima *et al*., 2015), multi-objective evolutionary programming method (Hsu and Tsai, 2005) and network

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partitioning theory (Sarfi *et al*., 1996), all with the objectives to solve 16,33 and 69 kV distribution network reconfiguration problems and analyze the application of these methods to distribution network reconfiguration. Loss reduction is an important element in minimizing the energy loss in a large power distribution system as stated by Ravibabu *et al*. (2010). The researchers proposed a method for energy loss reduction by developing a heuristic rules to lead the efficiency process, to make the energy loss minimization method effective.

There are many optimization methods which can be applied to solve the 11, 33 and 69 kV distribution network reconfiguration system. The previous related work had presented some optimization methods in solving distribution network reconfiguration to minimize power losses and voltage profile improvement. Comparison showed that evolutionary programming is better compared to other algorithms. Therefore, in the study, evolutionary programming had been chosen for modification for better reduction in power losses and to improve voltage profile. However, to date, there is no efficient method to apply for distribution network reconfiguration. In this study, optimizing methods of Multi-Population Evolutionary Programming (MPEP) had been tested, to find the best optimization based on the results to reduce power losses and to improve voltage profile in the distribution system.

MATERIALS AND METHODS

Formula formulation and constraints: Multi-Population Evolutionary Programming (MPEP) was used in this project to determine the best configuration that can give the maximum reduction of power loss and improve the voltage profile. The newton raphson method had been chosen for power flow analysis to find power and line losses value. The initial power loss value (before reconfiguration) was set as base case study. Multi-Population Evolutionary Programming (MPEP) had been used with IEEE 16, 33 and 69 bus system tests to determine the optimal reconfiguration of the system which will indirectly reduce the loss. However, the network used in this project is limited to radial distribution network which means when switching is performed, the network needs to be maintained in radial form.

Mathematical formulation: The objective of the feeder reconfiguration is to minimize the total power loss. Therefore, to reduce loss in network reconfiguration, the following equation had been formulated:

$$f_c = \sum_{i=1}^{n} \text{Loss ii} \in NL \quad (1)$$

$$f_c = \sum_{i=1}^{n} |I_i|^2 k_i R_i \; i \in NL \quad (2)$$

Where:

f_c = The loss function
I_i = The current in branch i
R_i = The resistance of branch
NL = The total number of branch and
K_i = The variable that represents the topological status of the branch (0 = open, 1 = close)

From Eq. 1, the total power loss can be reduced by sending a large amount of current, I_i from the main source through a branch in the network to achieve the target demand at the end of the feeder. Therefore, through network reconfiguration, power losses can be minimized by changing the close and open switching in the network accordingly. Nevertheless, several constraints must be satisfied during the network reconfiguration.

Radial network constraint: Distribution network should compose the radial structure, considering operational point of view.

Node voltage constraint: Voltage magnitude at each node must lie within their permissible ranges to maintain power quality. The standard minimum voltage used is 0.95 and the maximum voltage is 1.05 (1±5%):

$$V_{min} \le V_{bus} \le V_{max} \quad (3)$$

The voltage for each bus should operate within the acceptable limit which is in between 1.05 and 0.95 (±0.05).

Feeder capability limits:

$$|I_k| \le I_k^{max} \in \{1, 2, 2, \ldots,\} \quad (4)$$

where, I_k^{max} = maximum current capability of branch k.

Load flow and line losses: In this study, the Newton Raphson load flow method had been used where load flow studies were needed in scheduling, economic planning, control of the existing system and planning its future expansion. The Newton-Raphson load flow equation is as follows:

$$P_i = \sum_{j=1}^{n} |Y_i||V_j||Y_{ij}|\cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (5)$$

$$Q_i = -\sum_{j=1}^{n} |Y_i||V_j||Y_{ij}|\sin\left(\theta_{ij}-\delta_i+\delta_j\right) \quad (6)$$

Where:

V_j, V_i = The Voltage magnitude of bus i and j, respectively

δ_i, δ_j = The voltage angle of bus i and j, respectively

Y_{ij}, θ_{ij} = The magnitude and angle of Y_{ij} element in the bus admittance matrix, respectively

The equations for the difference in real Power (ΔP_i) and reactive Power (ΔQ_i) are:

$$\Delta P_i = P_i^{sp} - P_i \quad (7)$$

$$\Delta Q_i = Q_i^{sp} - Q_i \quad (8)$$

P_i^{sp} and Q_i^{sp} are the specified real and reactive power at bus i, respectively. The rectangular Newton-Raphson power flow is expressed as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial V} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial V} \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix} \quad (9)$$

Power loss: Power loss is estimated as follows:

$$P_{loss} = \sum_{i=1}^{n}\sum_{i=1}^{n} A_{ij}\left(P_iP_j+Q_iQ_j\right)+B_{ij}\left(Q_iP_j-P_iQ_j\right) \quad (10)$$

$$A_{ij} = \frac{R_{ij}\cos\left(\delta_i-\delta_j\right)}{V_iV_j} \quad (11)$$

$$B_{ij} = \frac{R_{ij}\cos\left(\delta_i-\delta_j\right)}{V_iV_j} \quad (12)$$

Where:

P_i = Real power at bus i, respectively

P_j = Real power at bus j, respectively

Q_i = Reactive power at bus i, respectively

Q_j = Reactive power at bus j, respectively

R_j = Line resistance between i and j

V_i, V_j = Voltage magnitude of bus i and j, respectively

δ_i, δ_j = Voltage angle of bus i and j, respectively

The voltage profile formulation: During normal conditions of the power system operation, 0.95 and 1.05 pu are acceptable range of voltage magnitude. Voltage profile is calculated as follows:

$$P_{prof} = \sum_{i=1}^{N}\left(V_i-V_i^{ref}\right)^2 \quad (13)$$

Where:

V_i^{ref} = 0.95 if $v_i \leq 0.95$ i: load bus

V_i^{ref} = 0.95 if $v_i \geq 1.05$ i: load bus

V_i^{ref} = V_i^{set} i: generation bus

Allele's migration or multi-population: The Evolutionary Programming (EP) technique is preferable to solve any of the power system matters. Modifying EP is by adding some other techniques will make it become more powerful and efficient. As to optimize the system, multi population or migration can be integrated. Allele's migration technique can be applied to select the best location and size by giving the maximum value of minimum voltage. Generally, Allele's migration is a method to generate a new population by modifying a mutation value (Chen *et al*., 1999). The migration models can be expressed as in Eq. 14 as:

$$Z_1(t+1) = \left((1-m)*Z_1(t)\right)+\left(m*Z_2(t)\right) \quad (14)$$

$$m = \text{rand}(1, 1)*1 \quad (15)$$

Evolutionary Programming (EP): EP is effective for searching optimal solution to a complex problem. There are several steps for developing EP which are:

Step 1; Random generation of initial population: The process for the optimal solution is done by determining a population of candidate solution over a number of generations randomly.

Step 2; Fitness computation: The strength of each candidate solution is determined based on its fitness function which is evaluated based on the constraint in the objective function of the optimization process.

Step 3; Mutation: Others will combine through a process of mutation to breed a new population.

Step 4; Combination: Combination process will occur after the mutation which combines the parent and offspring.

Step 5; Tournament selection: Tournament selection is by choosing the survival of the next generation.

Step 6; Transcription of next generation: The new population is evaluated and the process is repeated.

Multi-population evolutionary programming implementation: Multi-population evolutionary programming search method is proposed in this study for determining the optimal solution to the network reconfiguration problem. The programming functions to write and use the entire data network. In this study, MPEP programming had been tested with MATLAB for result analysis. The switch position of the network had been optimized by determining the basis of its fitness function. Tie switches are symbolized by labeling them as 1, 2 or 3. Evolutionary Programming (EP) was pioneered by Lawrence J. Fogel at 1960. In EP, mutation is done according to the Gaussian or any other mathematical formulation.

The MPEP is an effective method for searching optimal solution to a complex problem. MPEP is applied by several steps which are:

Step 1; Population initialization: The MPEP must be provided by individuals at the start in which user can specify a range of values as the initial population. If the user does not specify an initial population, the algorithm will create one using the creation function.

Step 2; Fitness evaluation: In this step, each chromosome in the initial population is evaluated using the fitness function which is the driving force behind MPEP, to choose the best value.

Step 3; New population: A new population is created by using the selection, crossover and mutation operators.

Step 4; Migration: The migration operation between the populations may be carried out according to the setting of migration parameters which includes directions of migration, fraction values and interval values.

Step 5; Replacement: The new generated population is used to further run the algorithm.

Step 6; Termination: The iteration will be stopped if the stopping criterion is satisfied. In this algorithm, a maximum generation of 100 and tolerance of 1e-6 are used as stopping criteria (Fig. 1).

Test system: In this study, test system which consisted of 16, 33 and 69 buses radial distribution system had been used as shown in Fig. 2-4 congruently. Two cases had been executed in determining their reliability of having MPEP in the test system to achieve the best configuration.

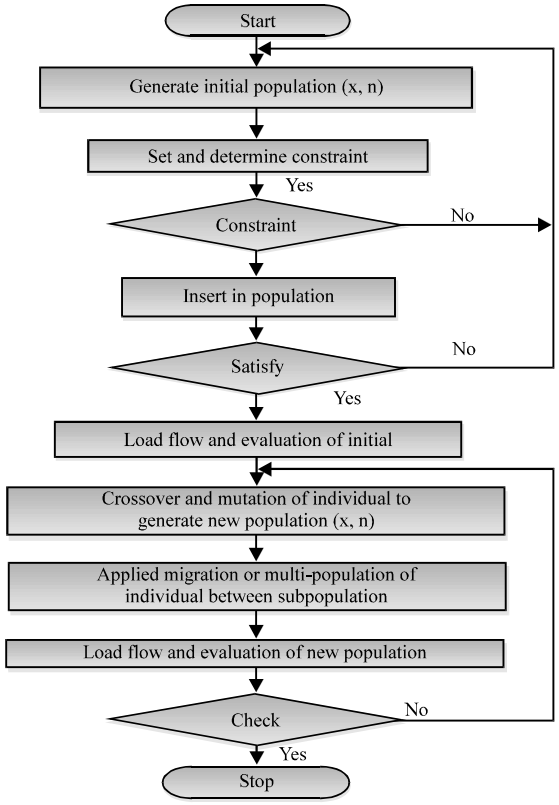

Fig. 1: Flowchart of MPEP algorithm implementation

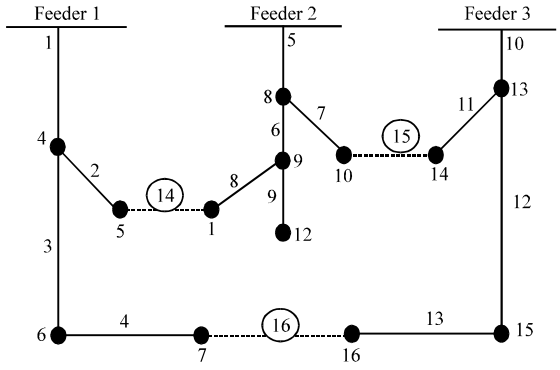

Fig. 2: Initial configuration of the 16-bus radial distribution system

Case 1: In this case, the system followed the original network distribution of 16, 33 and 69 buses without any alteration. All the tie switches in the network remained as they were.

Case 2: In this case, the system was a modified network reconfiguration using MPEP method. Analysis of the

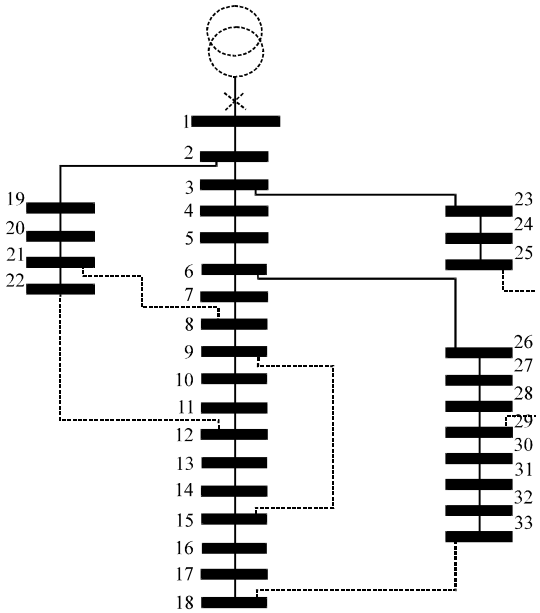

Fig. 3: Initial configuration of the 33-bus radial distribution system

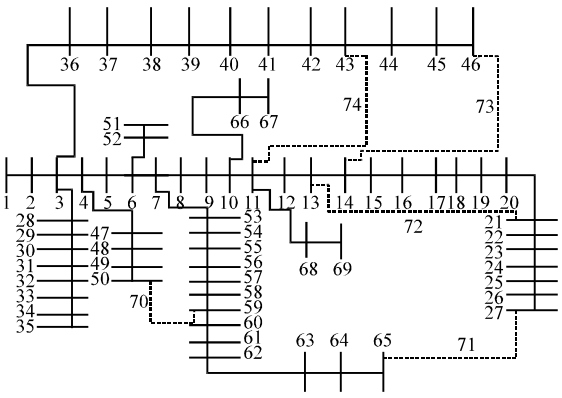

Fig. 4: Initial configuration of the 69-bus radial distribution system

reconfiguration was done by using MPEP methods. Tie switches and sectionalizing switches were considered as the main control variables. The optimal power losses depended on the flexibility of the switches. The programming was run randomly, for approximately 1000 times by using MATLAB software by which the minimum power losses with selection of the voltage profile of each bus. The results catered three and five opened switches, total power losses and voltage profile value. Two important parts, part A and part B were evaluated where the analyses of the results were mainly focused on the power loss reduction and voltage profile improvement.

RESULTS AND DISCUSSION

Power loss reduction: Table 1-3 show the results for overall performance of the 3 types of buses accordingly. In finding, the optimal solution for the total power losses, important parameters should be considered for opening the switches, reducing power losses and estimating power loss percentage for each case.

It was observed that when the MPEP techniques were applied to the system, the value of total power losses decreased. The proposed algorithm was tested on radial 16 bus distribution test system. The radial and non-radial constraints had been sustained by three switches to be opened when the EP and MPEP techniques were applied to the system. In EP technique, the selected switches to be opened were switches 16, 8 and 7 while in the MPEP, the open switches were 8, 11 and 4, respectively. The value of minimum power losses between initial and EP decreased (0.4661 MW) but for MPEP technique, the value for power losses between initial and EP increased to 0.5185 MW. In terms of loss reduction, the radial switch for the EP had a more significant reduction compared to the MPEP technique because the number of open switches was not radial compared to EP technique.

From 3 types of buses tested, MPEP had proven to be the best technique to reduce power losses for 33 buses and above of the feeder reconfiguration system. For bus 33, EP technique had managed to reduce power loss from 0.2027-0.1197 MW which was about 0.083MW, while MPEP technique had successfully reduced the power loss from 0.2027-0.1172 MW which was a total reduction of 0.0855 MW. For 69 buses, EP technique was able to reduce loss from initial 0.22544-0.16814 MW. Later on, the total power loss was further reduced to 0.0573 MW. MPEP had successfully reduced the power loss more than EP with a total reduction of 0.17284 MW.

Significant changes in power loss were due to the Allele's migration technique, since, the presence of initial load process and migration mutation are capable of reducing power loss. Therefore, the result agreed with the previous researcher Tan *et al.* (2012) that multi-population method is more efficient in power loss reduction compared to analytical method. Therefore, in this study, the objective to reduce power losses had been achieved.

Sectionalizing switches were the contributors in getting the optimal value of power losses for each case. Figure 5 shows that the original switches opened from original network were at buses 14, 15 and 16. After reconfiguration, the MPEP algorithm opened the sectionalizing switches at buses 8, 11 and 4. As seen in Fig. 6, the original switches opened from original network were at buses 33, 34, 35, 36 and 37. After reconfiguration,

Table 1: Comparison of losses of 16-bus

	16-bus		
Items	Initial	EP	MPEP
Switch to be open	14,15,16	16,8,7	8,11,4
Total power loss (MW)	0.5114	0.4661	0.5185
Loss reduction (MW)	0	0.0453	-0.0071
Loss reduction (%)	0	8.86	-1.39

Table 2: Comparison of losses of 33-bus

	33-bus		
Items	Initial	EP	MPEP
Switch to be open	33,34,35,36,37	14,7,31,10,37	7,10,32,14,37
Total power loss (MW)	0.2027	0.1197	0.1172
Loss reduction (MW)	0	0.083	0.0855
Loss reduction (%)	0	40.95	42.18

Table 3: Comparison of losses of 69-bus

	69-bus		
Items	Initial	EP	MPEP
Switch to be open	69,70,71,72,73	17,55,43,24,9	26,10,18,12,54
Total power loss (MW)	0.22544	0.0573	0.0526
Loss reduction (MW)	0	0.16814	0.17284
Loss reduction (%)	0	74.58	76.67

the MPEP algorithm opened the sectionalizing switches at buses 7, 10, 32, 14 and 37. In Fig. 7, the original switches opened from original network were at buses 69, 70, 71, 72 and 73. After reconfiguration, the MPEP algorithm opened the sectionalizing switches at buses 26, 10, 18, 12 and 54.

Voltage profile improvement: Network reconfiguration was performed by opening the sectionalizing switches and closing the tie switch of the network. Normally, open tie-switch is closed to transfer the voltage from one feeder to another feeder while an appropriate sectionalizing switch is opened to reduce the active power loss. This action will balance the voltage among the feeders and finally improve the overall voltage profile of the system. The limit for voltage was set between 0.95 and 1.05 pu which had been coded in the MATLAB program. Only the voltage which fell within the limit had been accepted for the next process.

The impact on the voltage profile of 16-bus system operation using EP and MPEP method is depicted as in Fig. 8. The result showed that the voltage profile had been improved for buses 7-10, followed by buses 12, 15 and 16. However, the voltage profile looked almost similar for bus 1 until 3 and bus 13. The rest of the bus only showed that EP was higher than MPEP. Therefore, the implementation of reconfiguration technique had given a better voltage profile compared to without reconfiguration. Musirin and Rahman (2003) and Sulaima *et al.* (2013, 2016) and Napis *et al.* (2015) stated that when power loss is reduced, voltage profile will improve. However, for the 16-bus, using MPEP technique was found able to improve the voltage profile but the

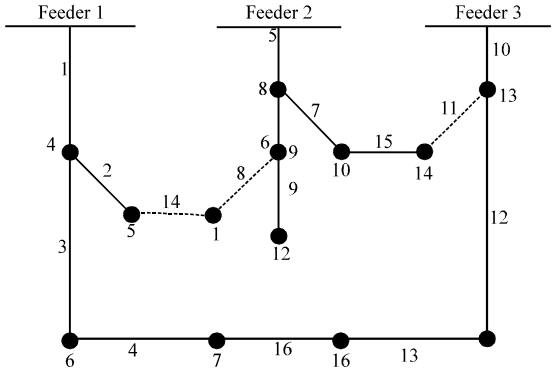

Fig. 5: 16-bus after MPEP reconfiguration

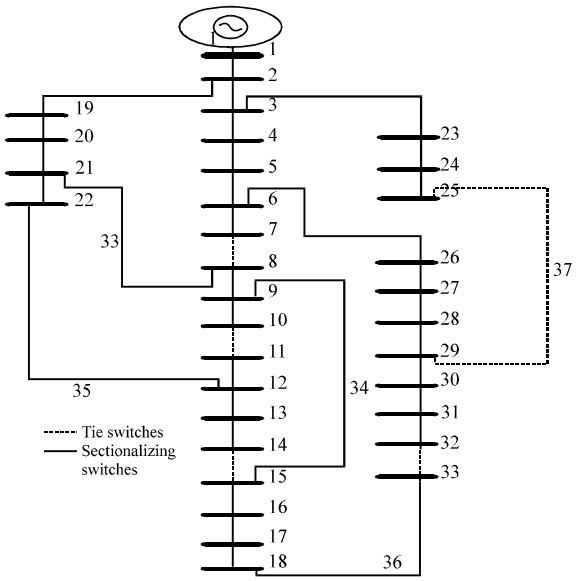

Fig. 6: The 33-bus after MPEP reconfiguration

power losses could not be reduced. Thus, the result of 16-bus was not similar to that of previous researcher and hence, the objective was not achieved for the 16-bus only. The voltage profile for several nodes after reconfiguration with EP and MPEP method showed some significant improvements compared to the initial configuration as shown in Fig. 9. However, the result obtained clearly showed that MPEP method had improved the voltage profile more compared to EP method. Through the MPEP method, the system showed improvement at both nodes 8 and 9 which had increased to 0.9990 pu while other buses only showed slight improvement.

Meanwhile, the voltage profile for several nodes after reconfiguration through EP and MPEP method showed some significant improvements compared to the initial configuration as shown in Fig. 10. However, the result

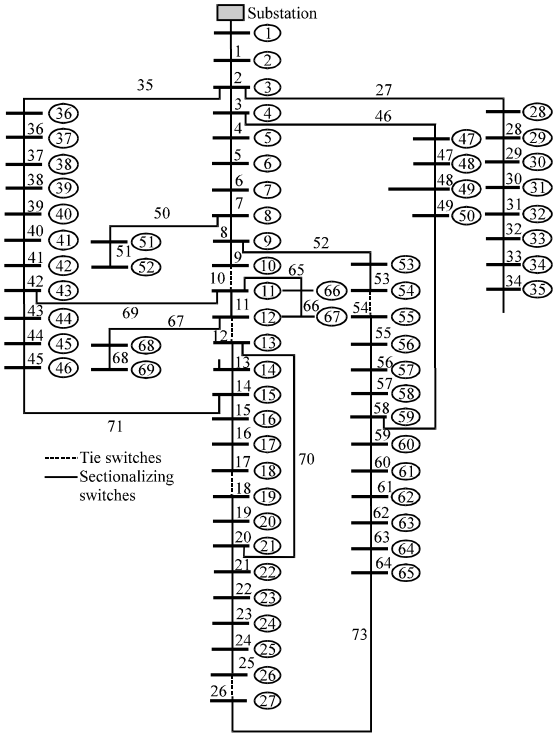

Fig. 7: The 69-bus after MPEP reconfiguration

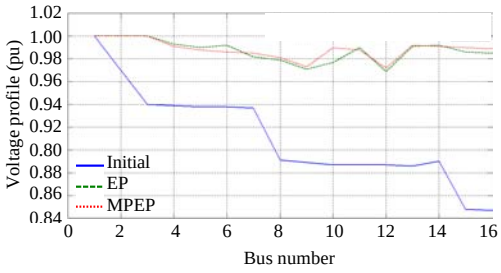

Fig. 8: Improvement comparison between 16-bus voltage profile to initial, EP and MPEP reconfiguration; Bus number vs. voltage profile (pu)

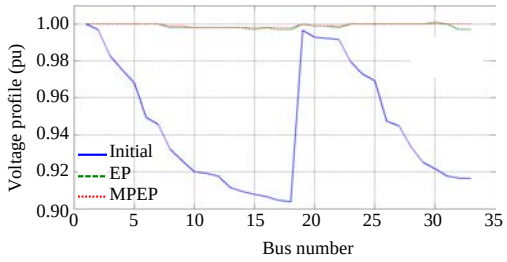

Fig. 9: Improvement comparison between 33-bus voltage profile to initial, EP and MPEP reconfiguration; Bus number vs. voltage profile (pu)

obtained also, clearly showed that the MPEP method improved the voltage profile more. Through the MPEP

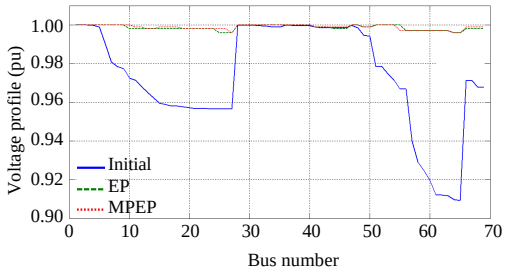

Fig. 10: Improvement comparison between 69-bus voltage profile to initial, EP and MPEP reconfiguration; Bus number vs. voltage profile (pu)

method, the system showed improvement at nodes 10 until 18. The value increased up to 0.9990 pu while other buses only showed slight improvement. Next, the improvement of the voltage profile for the 33 and 69-bus was due to power loss reduction using MPEP technique. This agrees with the previous research by Tan *et al.* (2012) that when power loss is reduced, voltage profile will improve. Therefore, the objective to improve the voltage profile is achieved.

CONCLUSION

MPEP has been successfully tested in the original IEEE 16, 33 and 69-bus distribution network system and it indeed offers better performance in terms of power loss reduction and voltage profile improvement but only effective for IEEE 33 and 69-bus. Performance evaluation has been done by comparing two optimization methods which are initial network and EP. Through MPEP method, power loss can significantly be reduced which improves the voltage profile value. MPEP algorithm has been proven able to yield an optimal value and is can be concluded that the implementation of MPEP can greatly enhance 33, 69 and larger bus power distribution feeder reconfiguration system.

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