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APPLICATION OF FUZZY MULTI-OBJECTIVE METHOD FOR DISTRIBUTION NETWORK RECONFIGURATION WITH INTEGRATION OF DISTRIBUTED GENERATION

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ABSTRACT

This paper proposes an application of fuzzy multi-objective method for distribution network reconfiguration with integration of distributed generation (DG). The method transforms the multi-objectives of the configuration optimization problem into a single objective problem using theory of fuzzy set. In fuzzy set, each objective of optimization is associated with a membership function. The function represents the level of satisfaction of the objective. There are four objectives which are formed in fuzzy membership function including minimum power loss, maximum branch current loading, maximum bus voltage magnitude and load balancing the entire feeders of electric power distribution network while a radial structure must be maintained. In this work, the fuzzy multi-objective method has been applied in optimization of an IEEE 77-bus distribution network configuration with integration of DG. The results show that efficiency of the network is improved significantly.

Keywords: *Fuzzy Multi-Objective; Optimization; Distribution Network; Distributed Generation.*

1. INTRODUCTION

Electric power distribution network have sectionalizing switches which remain normally closed and tie switches which remain normally open. These switches are operated in order to configure the networks. Reconfiguration of electric power distribution network is built through operation of the switches. In recent years, multi-objective optimization for network reconfiguration problem has been implemented. The multi-objectives in distribution network optimization are considered for minimizing power loss, improving voltage profile, and balancing the load among the feeders while a radial structure of the network in which all loads must be energized.

The motivation of this study is based on that the need for renewable energy sources with respect to energy reserve and environmental issues make the new power plant technologies such as micro hydro, solar photovoltaics, wind farms, fuel cells and other resources more and more popular. The technologies with the capacity of less than 10 MW powered by renewable energy sources which are connected to distribution systems is called distributed generation (DG) [1]. The size and number of DG integrated to distribution network is increased rapidly. There are many advantages of DG integration in distribution network, i.e. reducing power losses, improving voltage profiles and load factors and thus deferring or eliminating system upgrades [2-7]. Increasing in levels of DG will need to change planning and design of distribution networks to harness approaches that use information and communication technology to actively manage the network [8-9].

In the literature has been much studied and conducted studies to minimize the loss of active power through the reconfiguration of power distribution networks. Network distribution optimization with network reconfiguration proved

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most effective and efficient. These research efforts can be broadly classified into two categories: conventional approaches [3, 10-15] and artificial intelligence-based approaches (AI) [4-7, 16-28]. The conventional approach includes classical optimization algorithms and heuristics. The first attempt at reconfiguring a distribution network with a loss reduction goal was proposed by Merlin and Back [10]. They have used conventional techniques that consider a branch and are bound to determine the minimum loss configuration. After that, many conventional methods aimed at reducing the loss of active power distribution network. In reference [11] it has proposed a reduction of energy loss using critical switch operations, while at 12-13 it has considered the application aspect of the optimal distribution network configuration. An optimization method for determining network configuration has been studied in [14]. In [15] it has proposed a network reconfiguration technique using a voltage index a decision to determine the switching operation. For most conventional approaches, this technique does not guarantee global optimization.

The current method of optimization is the use of artificial intelligence (AI). A distribution network optimization effort based on the AI method has been submitted in [16]. They have used two algorithms to optimize distribution network configuration for restoration and load balancing services. In their study, a combination of heuristic rules and fuzzy logic in goal optimization for robust efficiency and strong performance were used. The use of a genetic algorithm (GA) for reconfiguration of distribution network techniques to minimize power loss has been proposed at [17], while at [18] GA has proposed matrix theory based on matrix theory and graph theory. The application of the fuzzy multi-purpose method for optimum distribution network configuration has been presented by Das [24], and Syahputra et al. [26]. In this method, there are several objectives that include active dead power, load balancing between feeders, bus voltage irregularities, and current branch offenses for simultaneous modeling and resuming. Criteria for choosing membership functions for each purpose are not given in their work. Also, the weight of each goal is not considered.

In our research, the problem distribution formulation is subject to electrical and operational constraints. The objectives of this research are: minimization of active power loss, minimization of node voltage deviation, minimization of branch offset, and load balancing among various feeders. The above objectives are converted into fuzzy circuits by using different types of fuzzy membership functions. This is a very influential factor in this study. The radial of the distribution network must remain after reconfiguration where all loads must be energized simultaneously. The main advantage of this research is to propose a new network reconfiguration method based on a fuzzy multi-purpose algorithm with DG where all goals can be weighted simultaneously. Weight all goals depend on optimization priority. The objective functional weights are an important issue in multi-objective optimization [27-28]. The goal of minimizing active power loss is paramount in our work. Therefore, the proposed method can be used as another useful alternative for optimizing distribution network configuration with DG integration.

2. FUZZY MULTI-OBJECTIVE METHOD

2.1 Problem Formulation

Optimization of distribution network configuration is a very important function of distribution system to reduce power loss, improve bus voltage profile, load balancing, and to improve system security. Loads can be transferred from the feeder to the feeder by changing the state of the sectionalizing switch to tie switch. In this work, network reconfiguration to minimize active power loss can be formulated as follows:

$$\min P_{loss} = \sum_{i=1}^{N_k} R_i \frac{P_i^2 + Q_i^2}{V_i^2} \qquad (1)$$

where P_{loss} is real power loss; P_i and Q_i are the real and reactive powers flowing out the bus, respectively; n_b is the branch number, and R_i and V_i are the resistance and magnitude of voltage at bus i, respectively. The optimization also took into consideration the subject to the following: magnitude of voltage constraint, magnitude of current constraint, power source limit constraint, and radial network constraint.

The proposed algorithm alters the multi-purpose reconfiguration problem into a single objective optimization problem using fuzzy set theory. In the fuzzy domain, each destination is associated with a membership function. Membership function indicates the level of satisfaction of the goal. The function of fuzzy membership has an important role in optimization. The fuzzy membership function has not considered the weighting factor for each goal. The four objectives built into the fuzzy membership function include: reduction of active power reduction, maximum bus voltage deviation, maximum branch current load index, and load balancing between feeders.

2.2 Membership Function of Fuzzy Objective for Real Power Loss

The most important goal of network distribution configuration optimization is to reduce the active power. Therefore, the first task to build a fuzzy membership function is how to reduce the loss of active power from the distribution system. The total active power ratio lost after and before reconfiguration can be defined as

$$\alpha_i = \frac{P_{loss,i}}{P_{loss,B}}, \quad for\ \ i = 1,2,3,..., N_k \qquad (2)$$

where, N_k is the total of switches in the loop including sectionalyzing-switch and tie- switch when i-th tie-switch is closed; $P_{loss,i}$ is the total real power loss of the network when i-th branch in the loop is opened; and $P_{loss,B}$ is the total real power loss before network optimization. It can be seen that if α_i is high, real power loss reduction is low and a lower membership value is applied. If α_i is low, the active power loss reduction is high and a higher membership value is applied. In this study, membership function of the fuzzy multi-objective is assigned to be trapezoidal fuzzy as shown in Fig. 1. It is assumed that α_{min} = 0.5, α_{max} = 1.0, and the factor of weight for the membership function is 0.3.

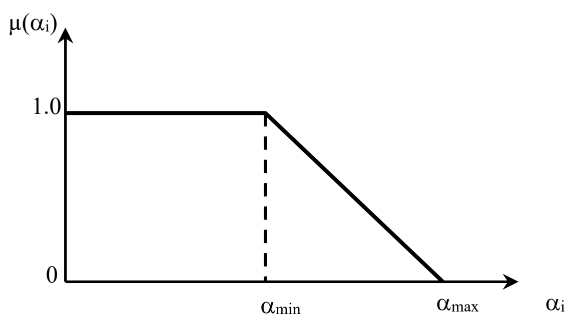

Fig. 1. Fuzzy membership function for power loss

The value membership function of $\mu(\alpha_i)$ can be expressed as

$$\mu(\alpha_i) = \begin{cases} \dfrac{(\alpha_{\max} - \alpha_i)}{(\alpha_{\max} - \alpha_{\min})}, & for\ \ \alpha_{\min} < \alpha_i < \alpha_{\max} \\ 1, & for\ \ \alpha_i \le \alpha_{\min} \\ 0, & for\ \ \alpha_i \le \alpha_{\max} \end{cases} \qquad (3)$$

2.3 Membership Function of Fuzzy Objective for Bus Voltage

The aim of building the membership function fuzzy objective for bus voltage is that the deviation of bus voltage should be less. The maximization factor of bus voltage deviation may be defined as follow,

$$\beta_i = \max|V_{i,j} - V_s|, \quad for\ \ i = 1,2,3,..., N_k\ \ and\ \ j = 1,2,3,..., N_B. \qquad (4)$$

where, N_B is number of bus of distribution system; V_s is substation voltage, in p.u; and $V_{i,j}$ is voltage of node corresponding to the opening of the i-th switch in the loop, in p.u. The membership function of the objective is also assigned to be trapezoidal fuzzy as shown in Fig. 2. It has been assumed that α_{min} = 0.05, α_{max} = 0.1, and the weight factor for the fuzzy membership function is 0.225.

In fuzzy domain of this study, if the maximum voltage deviation is less, a higher membership value is applied. If deviation is more, a lower membership value is applied. Fig. 2 shows the fuzzy membership function for maximum of deviation of node voltage. As can be seen in Fig. 2, the fuzzy membership value of $\mu(\beta_i)$ can be defined as

$$\mu(\beta_i) = \begin{cases} \dfrac{(\beta_{\max} - \beta_i)}{(\beta_{\max} - \beta_{\min})}, & for\ \ \beta_{\min} < \beta_i < \beta_{\max} \\ 1, & for\ \ \beta_i \le \beta_{\min} \\ 0, & for\ \ \beta_i \le \beta_{\max} \end{cases} \qquad (5)$$

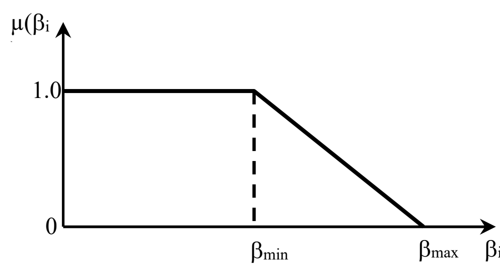

Fig. 2. Fuzzy membership function for voltage deviation.

2.4 Membership Function of Fuzzy Objective for Branch Current Loading

The aim for building membership function of fuzzy objective for branch current loading is to

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minimize the branch current constraint violation. The index of branch current loading could be writen as

$$\textit{Branch current loading index} = \frac{|I_{i,m}|}{I_{c,m}}, \quad (6)$$
$$for \;\; i = 1,2,3,...,N_k, \;\; and \;\; m = 1,2,3,...,N_B - 1.$$

where, $|I_{i,m}|$ is magnitude of electric current in branch-m when the i-th switch in the loop is opened; $I_{c,m}$ is line capacity of switch-m.

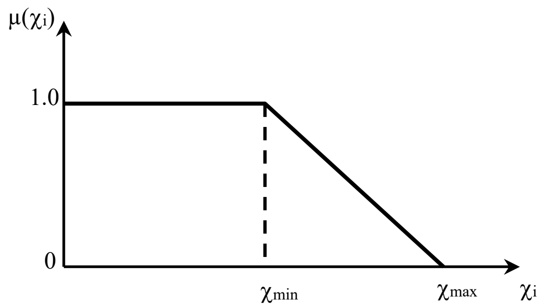

Fig. 3. Fuzzy membership function for current loading index

The maximization factor for index of branch current loading may be writen as

$$\chi_i = \max\left[\frac{I_{i,m}}{I_{c,m}}\right], \quad (7)$$
$$for \;\; i = 1,2,3,...,N_k, \;\; and \;\; m = 1,2,3,...,N_B - 1.$$

The trapezoidal form of fuzzy membership function of this objective is shown in Fig. 3. When the branch current index exceeds unity, a lower membership value is applied. If the branch current index is less than or equal to unity, the maximum membership value is assigned. It has been assumed that α_{min} = 1.0, α_{max} = 1.15, and the weight factor for the fuzzy membership function is 0.2. By the Fig. 3, the fuzzy membership value of $\mu(\chi_i)$ can be defined as

$$\mu(\chi_i) = \begin{cases} \dfrac{(\chi_{\max} - \chi_i)}{(\chi_{\max} - \chi_{\min})}, & for \;\; \chi_{\min} < \chi_i < \chi_{\max} \\ 1, & for \;\; \chi_i \le \chi_{\min} \\ 0, & for \;\; \chi_i \le \chi_{\max} \end{cases} \quad (8)$$

2.5 Membership Function of Fuzzy Objective for Load Balancing of Feeder

Load balancing is one of the main goals of reconfiguration of distribution networks. In the reconfiguration of the distribution network, each buffer must remain in a balanced state in any configuration. The load balancing index (LBI) represents the loading rate between feeders. This index measures how many branches can be loaded without exceeding the rated capacity of the branch. An effort to increase the widely loaded feeding margin is to divert some of its cargo to a lightweight distribution feeder.

The load balancing index objective may be expressed as

$$LBI_{i,j} = \frac{(IFF_{i,\max} - IF_{i,j})}{IFF_{i,\max}}, \quad (9)$$
$$for \;\; i = 1,2,3,...,N_k, \;\; and \;\; j = 1,2,3,...,N_F.$$

where, $IF_{i,j}$ is current of feeder corresponding to the opening of the i-th switch in the loop; $IFF_{i,max}$ is the maximum of all the electric currents corresponding to the opening of the i-th switch in the loop while $IFF_{i,max} = \max(IF_{i,j})$, for j = 1, 2, 3, …, N_F.

The factor of maximization of load balancing index may be writen as

$$\delta_i = \max(LBI_{i,j}), \quad (10)$$
$$for \;\; i = 1,2,3,...,N_k, \;\; and \;\; j = 1,2,3,...,N_F.$$

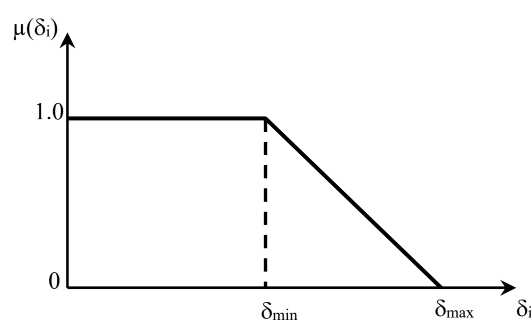

Fig. 4. Fuzzy membership function for the load balancing index

Fig. 4 shows the fuzzy membership function for index of load balancing. From Fig. 4, the fuzzy membership value of $\mu(\delta_i)$ can be expressed as

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$$\mu(\delta_i) = \begin{cases} \dfrac{(\delta_{\max} - \delta_i)}{(\delta_{\max} - \delta_{\min})}, & for\ \delta_{\min} < \delta_i < \delta_{\max} \\ 1, & for\ \delta_i \le \delta_{\min} \\ 0, & for\ \delta_i \le \delta_{\max} \end{cases} \quad (11)$$

In this study, it has been assumed that α_{min} = 0.10, α_{max} = 0.50, and the weight factor for the fuzzy membership function is 0.275.

3. METHODOLOGY

In this research, optimization of power distribution network configuration by maintaining radial structure. The fuzzy multi-objective method for distribution network optimization has been expanded by adding weighting factors to each objective function. The addition of this weight is an extension of the method that has been done by the researcher presented in reference [11]. It provides an important weighting factor in multi-objective optimization, but has not been used in the reconfiguration of distribution networks. The weighting of the objective function is to lose power by 0.35, for the purpose function of the bus voltage of 0.325, for the current branch loading index of 0.3, and for the load balancing at 0.375. The proposed extended fuzzy multi-purpose algorithm for optimizing the distribution network configuration in this study is shown in Figure 5.

In this study, the boundary constraints are defined as: DG which is integrated only from wind and solar power plants.

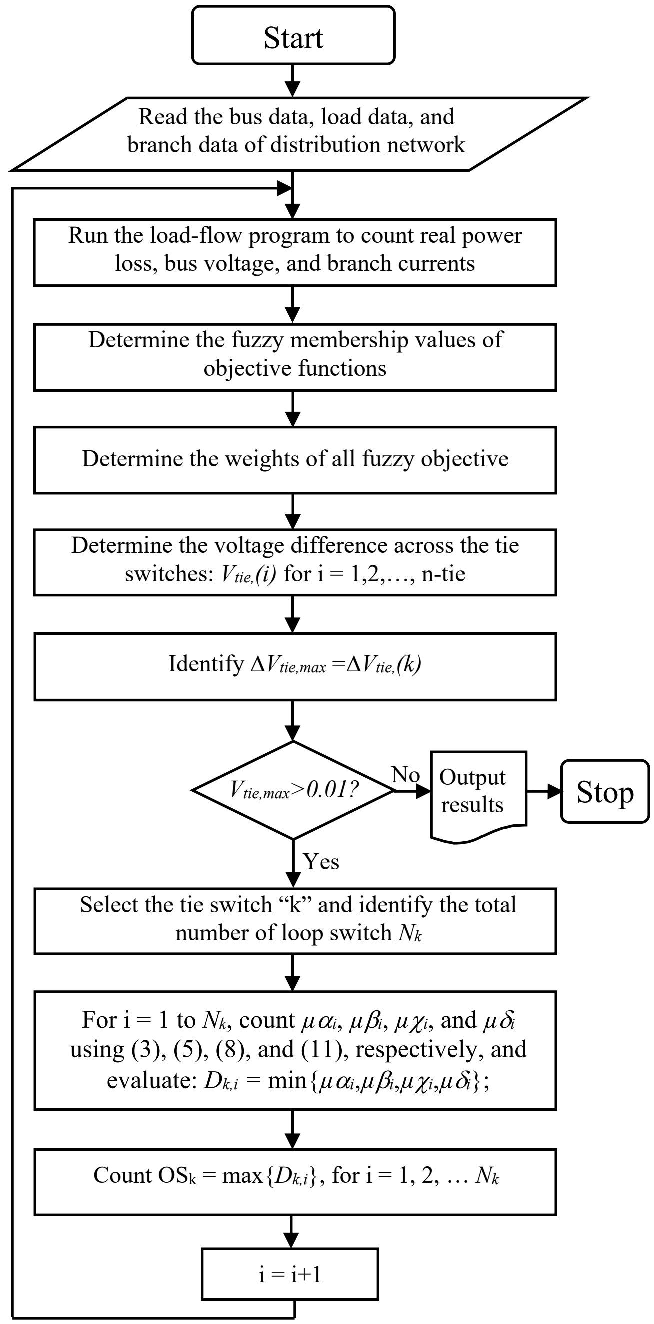

Fig. 5. Fuzzy Multi-Objective Method For Network Configuration Optimization

4. RESULTS AND DISCUSSION

In this research, optimization of power distribution network configuration using multi-objective fuzzy method. The distribution network is modelled that DG comes from an integrated renewable energy source. There are two types of DGs that are modelled to connect solar photovoltaic

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distribution networks and wind farms. DG operation is considered stable. Therefore, DG from solar photovoltaics is modelled only as active power injected, whereas DG from wind farms is modelled as either active or reactive power, both injection P_i and Q_i.

In this study, a radial distribution network of 20 kV has been examined. This system has one substation, two feeders, and 77 buses as shown in Figure.6. The switch from the distribution system consists of 114 encoding switches and 10 tie switches. The switch ties of this system are open under normal conditions. Figure 1 shows the initial configuration of power distribution network without DG integration. Load and branch data from the IEEE 77-bus distribution network can be found at [12].

In order to analyze the impact of DG, some DGs on each bus 5, 7, 14, 22, 28, 34, 36, 41, 46, 54, 59, 68, 70 and 74 are installed, as shown in TABLE I. The DG model consists of both solar photovoltaic and wind farms. DG solar photovoltaics with unit power factor and wind farms with a power factor of 0.8-0.9 (lagging) are assumed.

Table I Dg Location And Capacity On Ieee 77-Bus Distribution System

Bus Number	DG Capacity (kW)	Power Factor
5	140	0.8
7	110	0.9
14	110	0.9
22	100	1
28	140	0.9
34	75	0.8
36	110	0.9
41	140	0.8
46	100	0.9
54	220	0.9
59	110	1
68	220	0.9
70	75	0.8
74	130	0.9

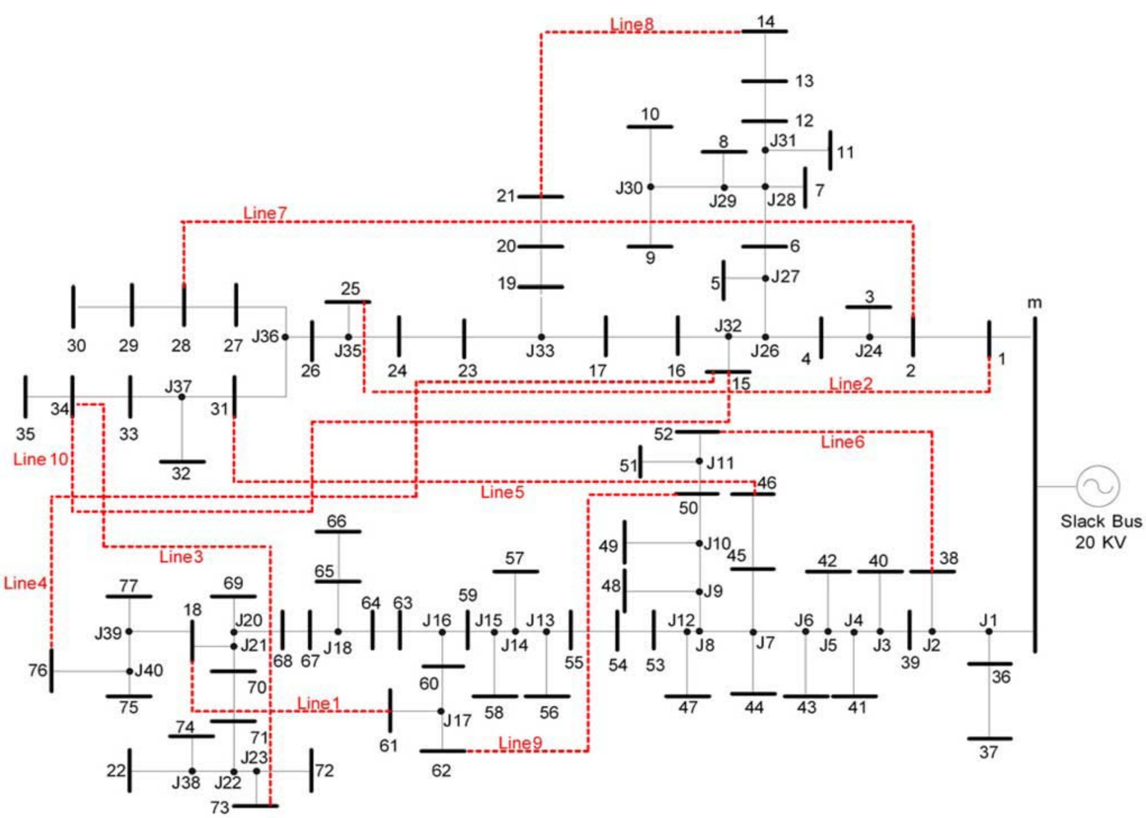

Fig.6. IEEE 77-Bus Distribution Network

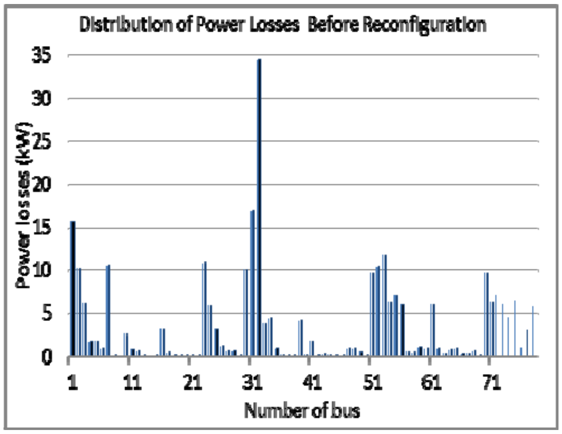

Fig. 7. Distribution Of Power Loss Before Optimization For IEEE 77-Bus Test System

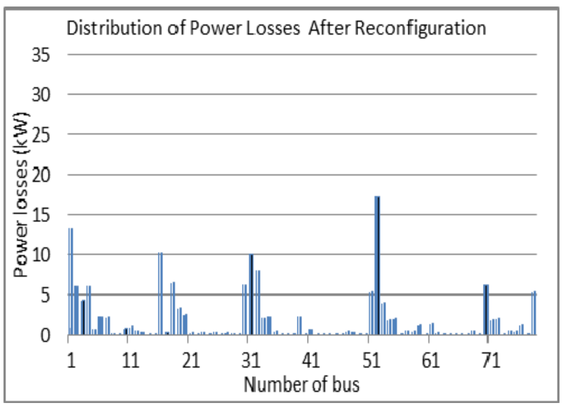

Fig. 8. Distribution Of Power Loss After Optimization For IEEE 77-Bus Test System

In this research, the IEEE distribution system of 77 buses has been checked, as shown in Figure.6. The research conducted is the distribution network optimization. Optimization is done to improve distribution network performance. The ultimate goal is to improve the efficiency of the distribution network. For the base case, prior to the optimization of the network configuration, the total active tissue loss under study was 228.95 kW. The dispersed active power loss of each distribution network bus for the base case is shown in Figure 7. Under these circumstances, the minimum voltage is 0.914 p.u which occurs on bus 76.

From the case study results in this study, it can be seen from the 77 bus system that integrates DG has the effect of reducing active power loss to the feeder on this particular case. This result can be seen by running the power flow program in Matlab software. Load flow simulation results show that the total loss of active power of the system with DG integration is 178.87 kW, or in other words the distribution network efficiency is 94.73%, as shown in TABLE II. For the evaluation of the voltage profile it produces a minimum voltage of 0.931 p.u on bus 76.

Furthermore, the distribution network configuration is optimized. The optimization method used is fuzzy based method. After experimenting with the extended fuzzy multifunctional technique for reconfiguration purposes, the total active power loss was 162.07 kW, or in other words, the efficiency of the research network was 96.05%, as shown in TABLE II. The loss of scattered power from each distribution network bus with DER integration after reconfiguration is shown in Figure 8. From our research results shown in Figures 7 and 8, it was observed that losses in almost every bus were reduced, except at 4, 6, 16, 17, 18, 19, 20, and 53, where losses increase due to shifting the load to this feeder. The minimum voltage is 0.949 p.u magnitude occurring on bus 76.

TABLE II The Simulation Results Of IEEE 77-Bus Distribution Network

Test Case	Parameters of Analysis				
	Active Power Loss (kW)	Efficiency of Distri-bution Network (%)	Minimum Voltage (p.u.)	Tie Switches to be Closed	Sectiona-lizing Switches to be Open
Distribution network without DG before reconfigura-tion	228.95	93.25	0.914 (V_{76})	NA	NA
Distribution network with DG before reconfigura-tion	178.87	94.63	0.931 (V_{76})	NA	NA
Distribution network with DG after reconfigura-tion	162.07	96.05	0.949 (V_{76})	Line3, Line4, Line6, and Line7	J9, J16, J21, and J33

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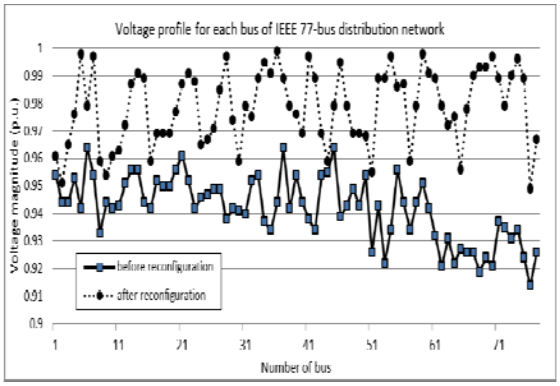

Fig. 9. Voltage Profile For Each Bus Of IEEE 77-Bus Test System

Analysis of the next simulation result is on the distribution network voltage profile. Based on the research results, the voltage profile for each bus from the IEEE 77-bus power distribution network has been shown in Figure 9. As can be seen in Figure 9 and TABLE II that the minimum voltage value before optimization is 0.914 pu that occurs on bus 76, while the minimum magnitude of voltage after optimization is 0.949 pu which also occurs on the same bus. Furthermore, data observed the influence of installation of DG in the distribution network. The impact of DG deployment in some locations of the model of IEEE 77-bus bus test system is an increase in the voltage of the bus. The maximum voltage after optimization is 0.999 p.u in magnitude occurring on bus 36, as shown in Figure 9.

From the test results of network distribution network of radial model f IEEE 77-bus which DG has the effect of loss reduction and increase of voltage quantity at feeder, and structure of optimum network topology in base case is different from DG integration. Based on the radial distribution system of 77 IEEE buses with DG integration, the fuzzy multi-objective method proposed in this paper has significant loss reduction to improve the performance of electrical distribution systems by considering DG integration. Optimization method proved able to increase distribution network efficiency significantly.

5. CONCLUSION

In this study, an efficient, fuzzy multi-objective method for optimizing distribution network configurations with DG integration to improve performance has been proposed. The advantages of this method have been demonstrated by the IEEE 77-bus distribution network test system. The advantages of the proposed method are the ability to reduce the loss of active power and increase the voltage quantity of each distribution network bus to improve network performance. The simulation results show that for the IEEE 77-bus test system, 1.38% improvement in distribution network efficiency is achieved by this method. The fuzzy multi-objective method proposed in this paper has significant loss reduction to improve the performance of electrical distribution systems by considering DG integration.

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