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Reconfiguration of Distribution Network for Minimizing Losses and Improving Voltage Stability Index Using Binary Firefly Algorithm

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Abstract: Voltage stability and losses are important parameters to measure the power quality in distribution networks. Voltage stability represents the voltage condition on each bus while losses describes the effectiveness of distribution systems. Losses in distribution network depend on the length of line and loading in the system. There are some methods to minimize losses namely network reconfiguration, distributed generator and capacitor installation, etc. The simplest method to minimize losses is network reconfiguration. This study proposes to optimize network configuration using binary firefly algorithm. The propose of this optimization method is to minimizes losses and improve voltage stability indices. Voltage stability level on a bus is measured by using Voltage Stability Index (VSI). Network reconfiguration is used for simulation by opening and closing switches on IEEE 33 bus radial distribution network. Simulation results show that before reconfiguration, the losses is 202,69 kW with the highest VSI of 0,988 and the lowest VSI of 0,683. After reconfiguration, the optimal losses is 139,96 kW with the highest VSI of 0,988 and the lowest VSI of 0,770.

Key words: Osses, VSI, reconfiguration, binary firefly algorithm, voltage

INTRODUCTION

Distribution network is an important part of a power systems, because its location is close to the load. So it is necessary to maintain power b quality in good condition. Power quality reduction occurs due to power factor decrement, voltage drop and losses in distribution network (Sadat, 2002). Losses in the distribution network depend on the line length and system loading (Chen and Yang, 2009). There are several ways to minimize losses namely network reconfiguration, Distributed Generator and capacitor installation. Distribution networks are normally configured radially and have two types of switches. One is normally closed switch (sectionalizing switch) which connect line sections and the other one is normally open switch (tie switch) which connect two feeders or loop type laterals. Network reconfiguration is one way to minimize losses by opening and closing the switches of a distribution network (Kashem and Ganapathy, 2002).

Reconfiguration methods can be classified into heuristics and Artificial Intelligence (AI). Several approaches of reconfiguration methods based on heuristics have already been described in (Civlnar *et al*., 1988; Baran and Wu, 1989). On the other hand, Artificial Intelligence (AI) with reconfiguration methods have been described by Jin *et al*. (2004) and Shariatkhah *et al*. (2012). VSI is used to determine the level of voltage stability of the overall system (Fergany, 2014).

The propose of this reconfiguration method is to improve VSI with minimum losses. This study proposes algorithm to optimize the reconfiguration of a distribution network using binary firefly algorithm. Network reconfiguration is performed by opening and closing switches on IEEE 33 bus radial distribution network.

MATERIALS AND METHODS

The IEEE 33 bus distribution network has 32 sectionalizing switches (normally closed) and 5 branch tie switches (normally open) (Ding and Loparo, 2012). The single line diagram of the system is shown in Fig. 1.

Modelling of load flow: One load flow method that has been developed for radial distribution network is ZBR method. The load flow equations are obtained from the impedances of radial distribution line in form of a matrix. ZBR method has Bus Injection to Branch Current (BIBC) matrix and Branch Current to Branch Voltage (BCBV) matrix. BIBC matrix and BCBV matrix are used to calculate the voltage drop in the distribution network. An example of load flow calculation steps in a radial distribution system is shown as.

Figure 2 shows a simple radial distribution system. The equations of current flowing in the system are shown in Eq. 1-5.

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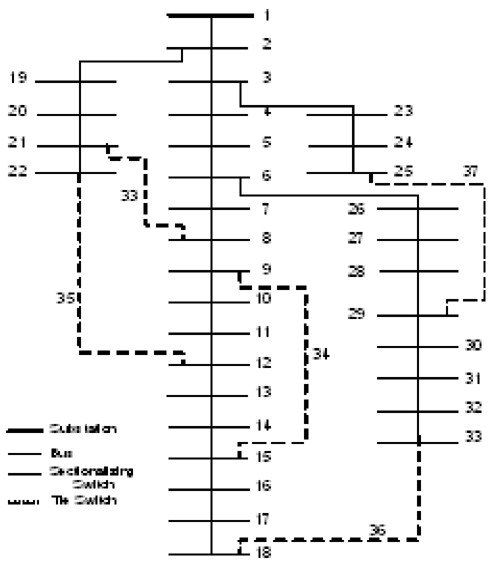

Fig. 1: IEEE 33 bus radial distribution network

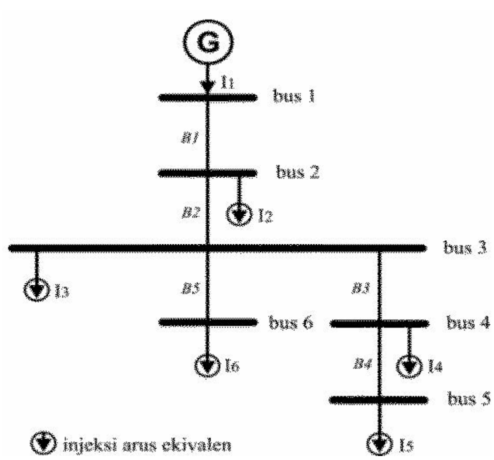

Fig. 2: Single line diagram 6 bus

$$B_5 = I_6 \quad (1)$$

$$B_4 = I_5 \quad (2)$$

$$B_3 = I_4 + I_5 \quad (3)$$

$$B_2 = I_3 + I_4 + I_5 + I_6 \quad (4)$$

$$B_1 = I_2 + I_3 + I_4 + I_5 + I_6 \quad (5)$$

Current injection equations are shown using a BIBC matrix, namely:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 11111 \\ 01111 \\ 00110 \\ 00010 \\ 00001 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (6)$$

$$[B] = [BIBC][1]$$

The voltage drop calculations are:

$$V_2 = V_1 - B_1.Z_{12} \quad (7)$$

$$V_3 = V_1 - B_1.Z_{12} - B_2.Z_{23} \quad (8)$$

$$V_5 = V_1 - B_1.Z_{12} - B_2.Z_{23} + B_3.Z_{34} \quad (9)$$

$$V_5 = V_1 - B_1.Z_{12} - B_2.Z_{23} + B_3.Z_{34} - B_4.Z_{45} \quad (10)$$

$$V_6 = V_1 - B_1.Z_{12} - B_2.Z_{23} + B_5.Z_{36} \quad (11)$$

Then:

$$V_1 - V_2 = B_1.Z_{12} \quad (12)$$

$$V_1 - V_3 = B_1.Z_{12} + B_2.Z_{23} \quad (13)$$

$$V_1 - V_4 = B_1.Z_{12} + B_2.Z_{23} + B_3.Z_{34} \quad (14)$$

$$V_1 - V_5 = B_1.Z_{12} + B_2.Z_{23} + B_3.Z_{34} + B_4.Z_{45} \quad (15)$$

$$V_1 - V_6 = B_1.Z_{12} + B_2.Z_{23} + B_5.Z_{36} \quad (16)$$

The previous equations can be express using BCBV matrix are:

$$\begin{bmatrix} V_1 - V_2 \\ V_1 - V_3 \\ V_1 - V_4 \\ V_1 - V_5 \\ V_1 - V_6 \end{bmatrix} = \begin{bmatrix} Z_{12}\ 0\ 0\ 0\ 0 \\ Z_{12}\ Z_{23}\ 0\ 0\ 0 \\ Z_{12}\ Z_{23}\ Z_{34}\ 0 \\ Z_{12}\ Z_{23} Z_{34}\ Z_{45}\ 0 \\ Z_{12}\ Z_{23}\ 0\ 0 Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (17)$$

$$[\Delta V] = [BCBV][B]$$

Modelling of network reconfiguration: In normal conditions, network reconfiguration is done for two reasons, namely:

- Reducing losses in the system
- Balancing load to prevent excessive loading on the network

Table 1: Group for combination on-off Switches

Loops	Switch open
1	2, 3, 4, 5, 6, 7, 18, 19, 20, 33
2	12, 13, 14, 34
3	8, 9, 10, 11, 21, 35
4	15, 16, 17, 29, 30, 31, 32, 36
5	22, 23, 24, 25, 26, 27, 28, 37

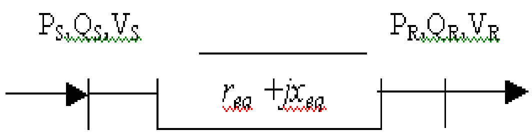

Fig. 3: Equivalent system of two bus

IEEE 33 bus distribution network is normally configured radially. The configuration of IEEE 33 bus distribution network will have a loop configuration if one of the tie switches is closed. To keep the network configuration remains radial, it is require to open one of sectionalizing switches. Number of tie switches closed should be equal to the number of sectionalizing switch opened.

All possible switches closed with sectionalizing switches opened are grouped into 5 groups. Combinations of switches are grouped as shown in Table 1.

Modelling of Voltage Stability Index (VSI): Voltage stability is defined as the ability of a distribution network to maintain the voltage of all buses at the normal condition after a disturbance occurs (Kundur, 1994). Voltage Stability Index (VSI) is used to determine the voltage stability of a bus in the distribution network (Fergan, 2014). The equivalent system of two-bus for multi-bus systems is shown in Fig. 3.

Active Power (PR) and Reactive Power (QR) of a load on the two bus system require active power (PS) and reactive power (QS) generation so that the equivalent impedance of the system is . The r_{eq}+jx_{eq} load flow equations in the two bus systems are:

$$P_S = P_L + P_R \quad (18)$$

$$Q_S = P_L + Q_R \quad (19)$$

Losses equations in the line of two bus system are:

$$P_L = r_{eq}\left(\frac{P_S^2 + Q_S^2}{V_S^2}\right) \quad (20)$$

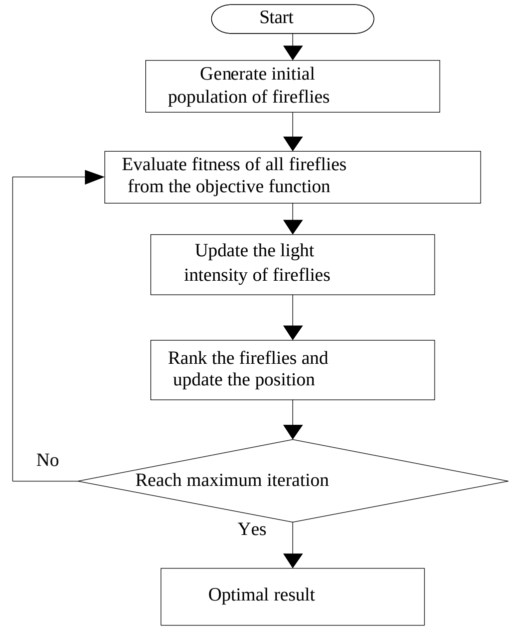

Fig. 4: Flowchart for BFA

$$Q_L = x_{eq}\left(\frac{P_S^2 + Q_S^2}{V_S^2}\right) \quad (21)$$

VSI is calculated as follows:

$$VSI(j) = |V_i|^4 - 4|P_j X_{ij} - Q_j R_{ij}|^2 - 4|P_j R_{ij} - Q_j X_{ij}|.|V_i|^2 \quad (22)$$

The value of VSI is between $1 \geq VSI(j) \geq 0$. Thus, the level of voltage stability of the system can be measured using the calculated VSI so that appropriate action can be taken if the value of VSI is close to zero.

Modelling of binary firefly algorithm: Firefly algorithm is a metaheuristic algorithm inspired by the behavior of firefly attracting other fireflies (Eslami, 2014). In firefy algorithm, there are two important parameters: the variation of light intensity and attractiveness function. However firefly's attractiveness is proportional to light intensity seen by adjacent firefly. So, we can now define the attractiveness (β) of a firefly by:

$$\beta(r) = \beta_0 * e(-\gamma r^m), \quad (m \geq 1) \quad (23)$$

The distance between the fireflies i and j at location x, x_i and x_j can be determined from the point/position where the firefly are spread randomly. The distance between any two fireflies can be formulated as follow:

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (24)$$

The movement of firefly i moving towards firefly which has the brightest light can be described by following Eq. 25:

$$x_i b = x_i + \beta_0 e(-\gamma r^2_{ij})(x_i - x_j) + r(\text{rand} - \frac{1}{2}) \quad (25)$$

A binary firefly algorithm (BFA) was lately developed by Sayadi *et al*. (2010). It is a discrete version of Firefly Algorithm (FA) which gives the output in binary number with either '1' or '0'. When firefly i attracts by firefly j, its position, xi will vary from binary number to real number. Therefore, sigmoid function S(xi) as shown in Eq. 26 is employed to limit the continuous output between zero and one Eq. 27:

$$S(x_i) = \frac{1}{1 + \exp(-x_i)} \quad (26)$$

$$x_i = \begin{Bmatrix} 1, & \text{if } S(x_i) > r \\ 0, & - \end{Bmatrix} \quad (27)$$

Based on the concepts above, the flow of BFA can be explained as depicted in Fig. 4:

Application of binary Firefly algorithm: Switch combination becomes the input of the binary firefly algorithm. There are 5 switches which is open in one combination. For example switch 2, 12, 8, 36, 22, then input binary firefly algorithm are 1, 1, 1, 0, 1. This indicates that the only tie switch '36' is open. The number of combinations switches depends on the number of fireflies in the spread. Firefly (x_i) in the implementation binary firefly algorithm for network reconfiguration is means the combination switch. Switch combination are used to minimize losses. The objective function to minimize losses according to Eq. 28:

$$\text{MinF} = \min(P_{loss} + \lambda_v \times S_{CV}) \quad (28)$$

Where Ploss is losses and and λ_v is voltage limits. Steps of the proposed method is shown in the flow diagram in Fig. 5. The step begins by modeling the IEEE 33 bus distribution network. Then check the voltage and losses in the system by running the load flow.

The next step is implementation of binary firefly algorithm. Then check whether the minimum losses is obtain or has a maximum iteration. Then calculate the value of VSI using Eq. 22. The final step is showing the simulation results.

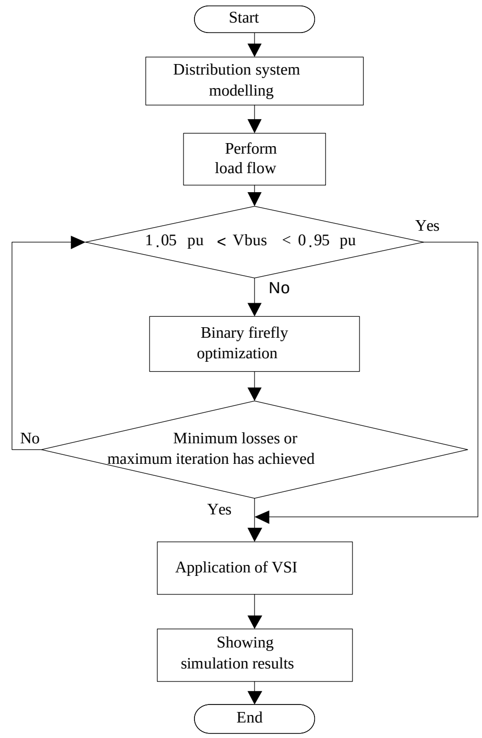

Fig. 5: Flowchart diagram of proposed method

RESULTS AND DISCUSSION

Network reconfiguration using binary firefly algorithm is used for simulation in MATLAB 2014a. The simulation is performed by opening and closing the switches on the IEEE-33 bus radial distribution network. In normal condition, the number of open switches are 33, 34, 35, 36, 37. Before reconfiguration, IEEE 33 bus distribution network has losses 202,69 kW with the highest VSI of 0,988 and lowest VSI of 0,683. Minimum voltage is registered as 0,913 p.u. at the 18th bus.

After optimal reconfiguration by closing the number of switches 33, 34, 35, 36, 37 and opening switches number 7, 14, 9, 32, 37, the minimum losses is 139.53 kW with the highest VSI of 0,988 and the lowest VSI of 0.759. The minimum voltage is registered as 0.937 pu at the 32nd bus. After reconfiguration, the value of loss reduction is 31, 16%. The result of performance BFA method in IEEE 33 bus is shown in Table 2.

The comparison of losses before and after reconfiguration is shown in Table 3. The green colors in the table show the open switches. Figure 6 explains that bus voltages in the system after reconfiguration are greater than before reconfiguration. This shows that reconfiguration can reduce voltage drop.

Table 2: Performance BFA in IEEE 33 bus

Parapeters	Switch off 0 0 0 0 0	Losses (kW)	Loss reduction (%)	V min (pu)
Before (V18)	33 34 35 36 37	202,69	-	0,913
After (V32)	7 14 9 32 37	139,53	31,16	0,937

Table 3: The results of losses comparison

Losses from bus	To bus	Before kW	Before kVAR	After kW	After kVAR
1	2	12.24	6.240	11.87	6.050
2	3	51.79	26.38	26.82	13.66
3	4	19.90	10.13	1.120	0.570
4	5	18.70	9.520	0.740	0.380
5	6	38.25	33.02	1.220	1.050
6	7	1.910	6.330	0.060	0.200
7	8	4.860	1.600	0.000	0.000
8	9	4.180	3.000	1.240	0.890
9	10	3.560	2.520	0.000	0.000
10	11	0.550	0.180	0.010	0.010
11	12	0.880	0.290	0.030	0.010
12	13	2.670	2.100	0.450	0.360
13	14	0.730	0.960	0.080	0.100
14	15	0.360	0.320	0.000	0.000
15	16	0.280	0.210	0.450	0.330
16	17	0.250	0.340	0.480	0.650
17	18	0.050	0.040	0.150	0.120
2	19	0.160	0.150	2.260	2.160
19	20	0.830	0.750	18.06	16.27
20	21	0.100	0.120	4.230	4.940
21	22	0.040	0.060	1.180	1.560
3	23	3.180	2.170	3.210	2.200
23	24	5.140	4.060	5.100	3.830
24	25	1.290	1.010	1.290	1.080
6	26	2.600	1.320	0.050	0.030
26	27	3.330	1.690	2.800	1.420
27	28	11.30	9.960	9.630	8.520
28	29	7.830	6.820	6.600	5.800
29	30	3.900	1.980	3.220	1.640
30	31	1.590	1.570	1.090	1.070
31	32	0.210	0.250	0.120	0.140
32	33	0.010	0.020	0.000	0.000
21	8	0.000	0.000	5.620	5.620
9	15	0.000	0.000	1.740	1.740
22	12	0.000	0.000	2.150	2.150
18	33	0.000	0.000	0.020	0.020
25	29	0.000	0.000	0.000	0.000
Total		202.69	135.14	139.53	102.37

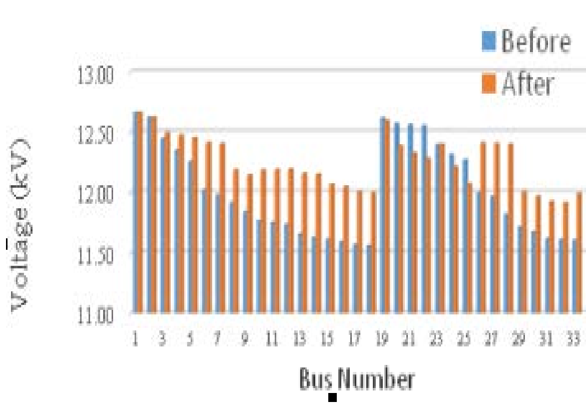

Fig. 6: Voltage magnitude before and after reconfiguration

Table 4: The result comparison of reconfiguration method

Method	Losses (kW)	Loss reduction (%)	Final configuration
Baran and Wu (1989)	147,99	26,99	(11, 28, 31, 33, 34)
Kashem *et al.* (2000)	143,21	29,34	(6, 9, 14, 32, 37)
BFA	139,53	31,16	(7, 9, 14, 32, 37)

Table 5 Simulation results of the case

Case	Switch off	Losses (kW)	VSI_{max}	VSI_{min}
Case 1A		202,69	0,988	0,683
Case 1B	33 34 35 36 37	975,81	0,974	0,406
Case 2A		139,53	0,988	0,759
Case 2B	7 14 9 32 37	623,32	0,976	0,560

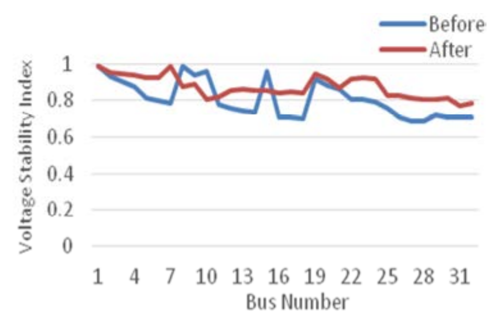

Fig. 7: VSI comparison before and after reconfiguration

Figure 7 explains that VSI profile in the system after reconfiguration is greater than before reconfiguration. This shows that reconfiguration can improve VSI. The results are summarized and compared to methods presented by Baran and Wu (1989) and Kashem *et al.* (2000). Table 4 represents the effectiveness of proposed method which could have achieved the optimal configuration compared to other methods. The power loss of final configuration obtained by BFA method is 139.53 kW which is less than other method. The simulations are also performed for 4 other cases. Cases that have been performed are as follows:

- Case 1A: Normal load and before reconfiguration
- Case 1B: The load changes twice (2x) of the normal load and before reconfiguration
- Case 2A: Normal load and after reconfiguration
- Case 2B: The load changes twice (2x) of the normal load and after reconfiguration

Table 5 shows the simulation results for each case. According to Table 5, the load changes on the system will increase the losses. Table 5 also explains that the load changes will also increase the value of Voltage Stability Index (VSI). The system is unstable if the VSI has a value close to zero. The losses change also affect the value of VSI. If total losses increase, the value of VSI will decrease.

CONCLUSION

In this study, binary firefly algorithm is used to optimize network reconfiguration. The proposed optimization method is to minimizes losses and improve voltage stability indices. Simulation results show the number of switch combination are 7, 14, 9, 32, 37. After reconfiguration, network losses decrease to 139,53 kW, with the highest VSI of 0,988 and the lowest VSI of 0,759. It can be concluded that optimal network reconfiguration minimizes losses and improves voltage stability index.

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