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Distribution Network Reconfiguration Using Binary Particle Swarm Optimization to Minimize Losses and Decrease Voltage Stability Index

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ABSTRACT

Power losses and voltage drop are existing problems in radial distribution networks. This power losses and voltage drop affect the voltage stability level. Reconfiguring the network is a form of approach to improve the quality of electrical power. The network reconfiguration aims to minimize power losses and voltage drop as well as decreasing the Voltage Stability Index (VSI). In this research, network reconfiguration uses binary particle swarm optimization algorithm and Bus Injection to Branch Current-Branch Current to Bus Voltage (BIBC-BCBV) method to analyze the radial system power flow. This scheme was tested on the 33-bus IEEE radial distribution system 12.66 kV. The simulation results show that before reconfiguration, the active power loss is 202.7126 kW and the VSI is 0.20012. After reconfiguration, the active power loss and VSI decreased to 139.5697 kW and 0.14662, respectively. It has decreased the power loss for 31.3136% significantly while the VSI value is closer to zero.

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1. INTRODUCTION

The distribution of electrical power from the substation to load requires distribution lines. There are several problems with the distribution system, such as losses and voltage drop. Losses and voltage drop are affected by the main parameters of the resistance and reactance current in feeders [1]. Therefore, network reconfiguration method in the distribution system is applied to overcome the problems.

The reconfiguration of the distribution network is one of the available approaches to reduce losses in the distribution network and improve the reliability of the distribution system. Reconfiguration is processed by altering the topological structure of distribution networks through the open and close status of the sectionalizers and tie switches in the distribution system [2].

In general, the reconfiguration of a distribution network can be classified into two groups, those are heuristic and artificial intelligence (AI). Reconfiguration of the distribution network by using a heuristic approach proposed a heuristic switch exchange algorithm to reduce losses and presented a simple formula to estimate changes in power losses from a feeder to another [3]. In other research, another formula was introduced as a calculation for the load balancing index [4]. The heuristic method was also developed [5] considering all switches closed and the switch opened to form a radial network.

Several AI-based approaches using various types of meta-heuristics and evolutionary algorithm have been proposed for the optimization of the distribution network reconfiguration. Those approaches cover reconfiguration of distribution network using Genetic Algorithm, Binary Genetic Algorithm, and Particle Swarm Optimization to reduce power losses [6-8]. The implementation of several AI methods previously mentioned was also developed in Distributed Generation (DG) [9, 10]. The implementation of several AI methods has increased the power quality and Load Balancing Index (LBI) based on PSO and BPSO methods [11, 12]. However, only a few papers have discussed VSI.

In this study, the distribution network reconfiguration is implemented to minimize losses and improve system stability in the distribution networks based on BPSO algorithm to solve discrete function in optimization problems. The discrete function is the selection of any combination provided by the switches from the distribution network. In this research, the power flow in the radial distribution system could be calculated with Bus Injection to Branch Current-Branch Current to Bus Voltage (BIBC-BCBV) method. The level of voltage stability for the distribution system is determined by the Voltage Stability Index (VSI). The appropriate reconfiguration could be decided after considering the index value. It depends on the closeness to the unity, the closer the feasible candidates to the unity the better the results. The next section of this paper is organized as follows: Section 2 describes the methodology of the proposed method. The simulation results of the voltage profile, minimal losses, switches selection, and voltage stability index are presented and supported by analysis in section 3. Finally, in section 4, the conclusions are obtained from the results and the analysis.

2. DESCRIPTION OF THE PROPOSED METHOD

2.1. Distribution Network Reconfiguration Problem Formulation

This paper has two objectives those are losses minimization and stability improvement of the system. Minimal losses are able to increase the system economical value. Moreover, it could be obtained by reconfiguring the system. The Voltage Stability Index (VSI) is an important parameter to the system stability. The first objective function is to minimize the total loss by following (1) and (2) [13]. The symbol of *Ploss* and *Qloss* are the total active and reactive power loss, respectively. *BB(jj)* is the branch current. The symbol *R(jj)* and *X(jj)* are the resistance and the inductance.

$$Ploss = \left|BB(jj)^2\right|R(jj) \tag{1}$$

$$Qloss = \left|BB(jj)^2\right|X(jj) \tag{2}$$

The second objective function is VSI. VSI is used to determine the stability of the distribution system. The distribution system models are converted into two buses system [14]. Figure 1 shows an equivalent of the two buses system while VSI equation is shown in (5). Voltage stability level of the total interconnected system could be measured by using the proposed VSI. In this model, the system is declared to be stable if the value of the index is closer to zero [15]. P_{i+1} and Q_{i+1} are the total active and reactive power from the total load. V_{i+1} is voltage receiving. In addition to that, r_i and x_i are equivalent circuit model. Those are obtained by calculating the total active and reactive power loss in (3) and (4). The symbol of P_1 and Q_1 are the total active and reactive power generation. And V_i is voltage sending.

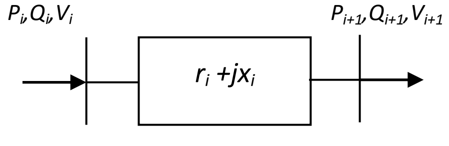

Figure 1. The equivalent of two buses system

$$P_l = r_i \frac{(P_{i+1}^2 + Q_{i+1}^2)}{V_{i+1}^2} \tag{3}$$

$$Q_l = x_i \frac{(P_{i+1}^2 + Q_{i+1}^2)}{V_{i+1}^2} \tag{4}$$

The value of VSI must be less than 1

$$(L_i) = \frac{4\sqrt{(P_{i+1}^2+Q_{i+1}^2).(r_i^2+x_i^2)}}{V_i} \leq 1 \quad (5)$$

2.2. Bus Injection to Branch Current–Branch Current to Bus Voltage (BIBC-BCBV) Method

Power flow in a distribution system is different from the power flow in a transmission system because a distribution system has a radial network [16]. One of the methods to calculate power flow in the radial distribution system is Bus Injection to Branch Current-Branch Current to Bus Voltage (BIBC-BCBV). Figure 2 shows a simple example of the radial distribution network. The symbols of B1 until B5 are branches current from line 1 until line 5. I_1 to I_6 are the current injection from bus 1 until bus 6.

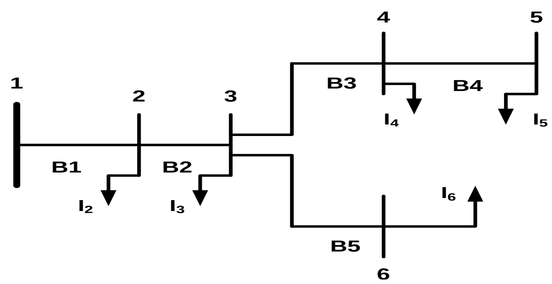

Figure 2. Example of a radial distribution network

From Figure 2, the current injection presented in the BIBC matrix as shown as in (6).

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \quad (6)$$

$$[B] = [BIBC][I] \quad (7)$$

BCBV matrix is obtained from the voltage drop in (8).

$$\begin{bmatrix} V_1 - V_2 \\ V_1 - V_3 \\ V_1 - V_4 \\ V_1 - V_5 \\ V_1 - V_6 \end{bmatrix} = \begin{bmatrix} Z_{12} & 0 & 0 & 0 & 0 \\ Z_{12} & Z_{23} & 0 & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & 0 & 0 \\ Z_{12} & Z_{23} & Z_{34} & Z_{45} & 0 \\ Z_{12} & Z_{23} & 0 & 0 & Z_{36} \end{bmatrix} \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} \quad (8)$$

$$[\Delta V] = [BCBV][B] \quad (9)$$

If (7) and (9) substituted into the mentioned equation, subsequently the equation ΔV transformed into (10) and (11).

$$[\Delta V] = [BCBV][BIBC][I] \quad (10)$$

$$[\Delta V] = [DLF][I] \quad (11)$$

Completion of power flow computation could be obtained by iteration of (12) and (13).

$$I_i^{(k)} = \left(\frac{Pi+jQi}{Vi^{(k)}}\right)^* \quad (12)$$

$$[\Delta V^k]=[DLF][I^k] \quad (13)$$

As shown in (14) is used to update the new voltage for the next iterative steps

$$[V^{k+1}]=[V_1]-[\Delta V^k] \tag{14}$$

2.3. The Particle Swarm Optimization

The standard form of PSO algorithm could be written as in (15), and (16) [17,18]. The symbol of v_i and x_i are the velocity and the position of particles, successively. In this case, c_1 and c_2 are positive constants; φ_1 and φ_2 are two random variables occurred between 0 and 1; p_i is a combination of switches obtained from the best position of the particle; p_g is a combination of switches obtained from the best position of all existing populations; w is the inertia weight which states the effect of the previous velocity vector of the new vector.

$$v_i(t+1)=w.v_i(t)+c_1\varphi_1(p_i-x_i(t))+c_2\varphi_2(p_g-x_i(t)) \tag{15}$$

$$x_i(t+1)=x_i(t)+v_i(t+1) \tag{16}$$

The standard procedure for applying the PSO algorithm is as follows:

a. Initialization of velocity, position, and parameters of the PSO
b. Update the particle velocity based on (15)
c. Update the particle position using (16)
d. Evaluation of the fitness function to update the value of p_i and p_g
e. Compare each candidate of p_g in the value of the fitness function in order to get the best value of p_g.
f. If the value of p_g is not the best value, then return to step 2
g. Repeat the iterations until it reached the limit to get a p_g with the smallest fitness function or the best value [17].

2.4. Binary Particle Swarm Optimization

The switches combination in this problem is the positive integers. Accordingly, the PSO algorithm requires next steps to convert the calculated results of the velocity and the position into positive integers such as in (17) and (18) [19]. The symbol of v_{ij} and x_{ij} refers to the velocity and the position of the particle. While r_{ij} is a random number.

$$v_{ij}(t)=sig\left(v_{ij}(t)\right)=\frac{1}{1+e^{-v_{ij}(t)}} \tag{17}$$

$$x_{ij}(t+1)=\begin{cases}1 \ if \ r_{ij}<sig\ (v_{ij}(t+1))\\ 0 \qquad\qquad otherwise\end{cases} \tag{18}$$

The modification procedure for applying the BPSO algorithm, in this case, is as follows:

a. Initialization of the velocity, the position, and the parameters of PSO
b. Update the particle velocity based on (15), then the result of (15) is used by (17)
c. Update the particle position using (18).
d. Evaluation of the fitness function to update p_i and p_g
e. Compare each candidate of p_g by the value of the fitness function in order to get the best value p_g.
f. If the result of p_g is not the best available value and return to step 2
g. Repeat the iterations until it achieved the limit to get the value of p_g with the smallest fitness function or the best value [17]. The fitness function or the best from (1) and (5) are the losses and the VSI.

2.6. Genetic Algorithm (GA)

The conventional GA is used to get minimal losses [7]. The standard procedure for applying GA, in this case, is similar to conventional GA. However, the VSI calculation is added in this paper.

3. EXPERIMENTAL RESULTS

The proposed reconfiguration method has been tested on the 33 buses system at 12.66 kV. This system consists of five tie-switches which are set to normally open and 32 sectionalizer switches that normally closed. Figure 3 is a schematic diagram of the test system. The original system is simulated in MATLAB by using the BIBC-BCBV method. Initially, the first opened switches of this system are switch-33(s33), (s34), (s35), (s36), (s37). The initial power loss of this system is 202.6845 kW, while the minimum voltage is 0.9131 pu, and the voltage stability condition of this system is at 0.20688. The minimum voltage occurs at bus 33 because the furthest load is located on this bus. This result shows that the further the load is, the lower the voltage due to the increased losses.

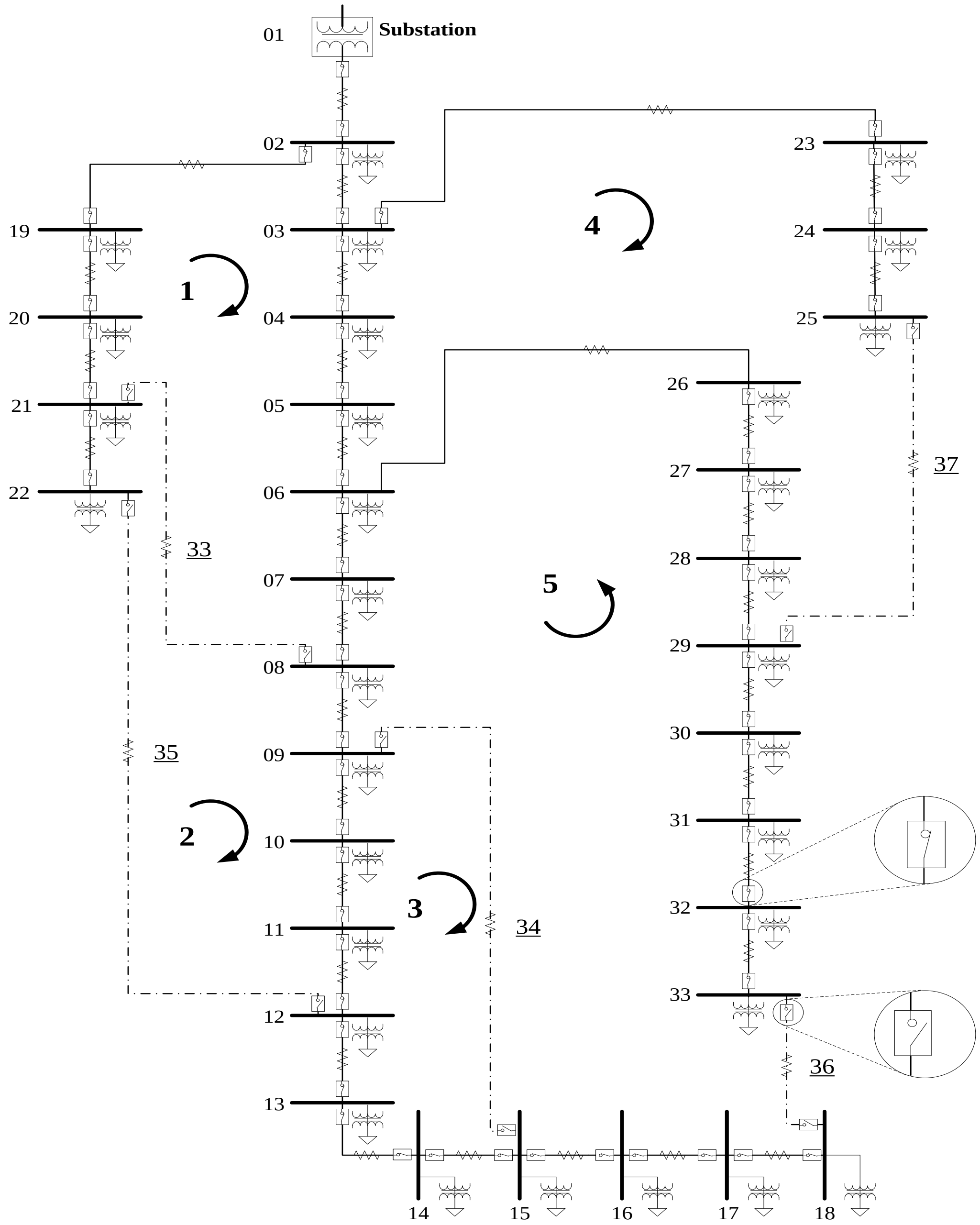

Figure 3. Schematic system 33 buses

The proposed reconfiguration method is BPSO. The parameters used in the simulation network are 20 populations, 5 dimensions, and 100 number of iterations. Figure 4 is the schematic diagram of the reconfiguration system using BPSO. After reconfiguration, the simulation results are obtained in Figure 5. The active and the reactive power losses calculated by using BIBC-BCBV method are 139.2168 kW and 102,0619 kVAR. The minimum voltage is 0.9378 pu which is occurred on bus 32. The percentage of power loss reduction is 31.3136%. After the reconfiguration is processed, the voltage becomes better and the power loss compared to the initial condition is decreased. Figure 5 shows that there are 7 buses which the voltages are below 0.95 pu, as the minimum standard. Those buses are bus 17 to bus 18 and bus 29 to bus 33. This condition indicates that most buses before the reconfiguration processed were already in under-voltage condition and it has been fixed by reconfiguring the network. The quality of the electricity service to the consumers is increased with the average voltage obtained in the simulation is 0.9652 pu. The corresponding value of VSI for new configuration is 0.14999. Thus, the total voltage stability level of the 33-bus system in the condition after reconfiguration is closer to zero than the initial VSI value. The final VSI value in Table 1 indicates better system stability.

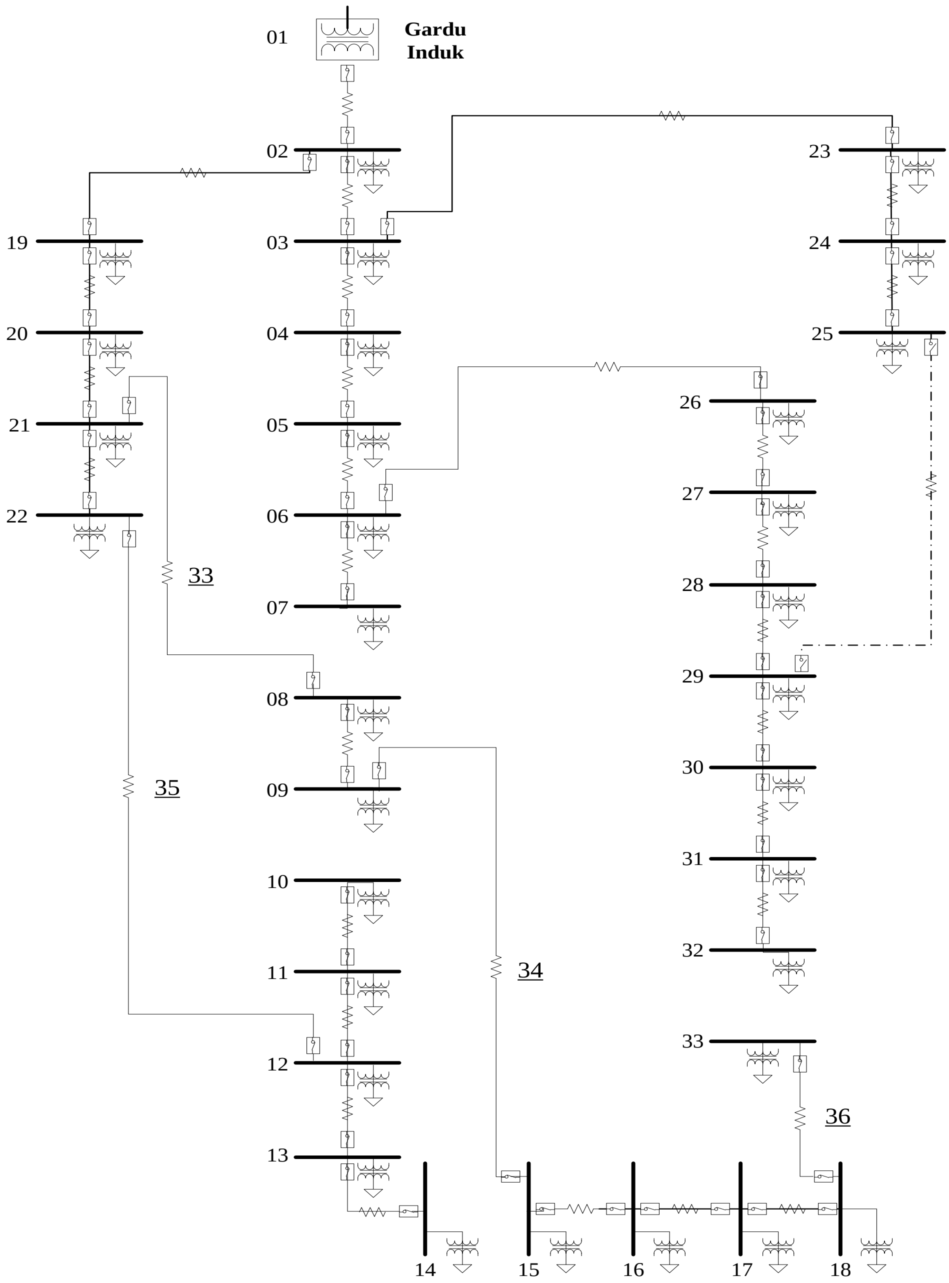

Figure 4. Schematic diagram of the reconfiguration system using BPSO

Table 1. Schematic System 33 Buses before Reconfiguration and after Reconfiguration with BPSO

Scenario		
Before reconfiguration	Switch open	33, 34, 35, 36, 37
	P_{loss} (kW)	202,6845
	Minimum voltage (pu)	0,9131
	L-index	0,20688
After reconfiguration	Switch open	7, 9, 14, 32, 37
	P_{loss} (kW)	139,2168
	Minimum voltage (pu)	0,9378
	Loss reduction (%)	31,3136
	L-index	0,14999

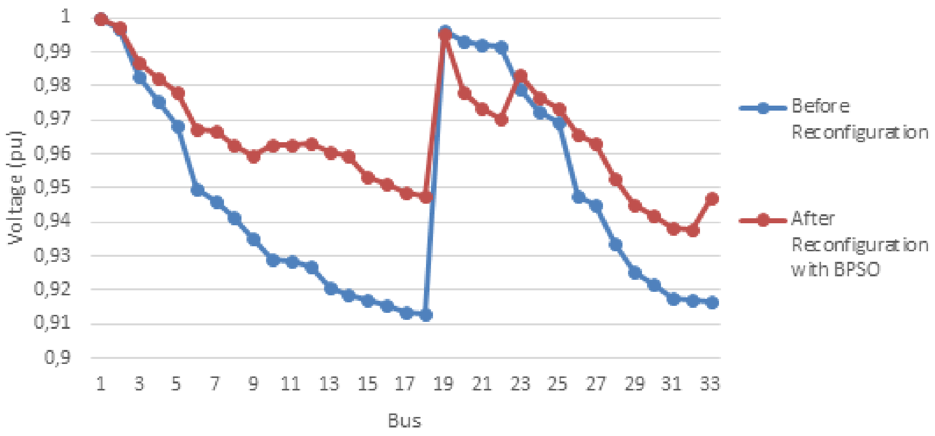

Figure 5. Voltage on each bus before and after the reconfiguration with BPSO

To compare the performance of BPSO, all scenarios are simulated with GA and the results are provided in Table 2. Reconfiguring a network using GA gives 146.4 kW of active power. The percentage of that power loss reduction is 27.7695%. The minimum voltage on bus 33 is 0.937 pu. Figure 6 shows there are 6 buses below 0.95 pu. Those buses are bus 18, and bus 29 to bus 33. The average produced voltage of a network reconfiguration with GA is 0.96657 pu. The results of VSI value is 0.1531. In Table 2, it is confirmed that the performance of BPSO is better than GA in the terms of quality of the solutions in all scenarios. The power losses from BPSO and GA are 139.2168 kW and 146.4 kW, respectively. The value of VSI simulation results of BPSO and GA are 0.14999 and 0.1531.

Table 2. Comparison Schematic System 33 buses after the Reconfiguration with BPSO and after the Reconfiguration with GA

Method	Item	After reconfiguration
BPSO	Switch open	7, 9, 14, 32, 37
	P_{loss} (kW)	139,2168
	Minimum voltage (pu)	0,9378
	Loss reduction (%)	31,3136
	L-index	0,14999
GA	Switch open	9, 28, 33, 34, 36
	P_{loss} (kW)	146,4
	Minimum voltage (pu)	0,9370
	Loss reduction (%)	27,7695
	L-index	0,1531

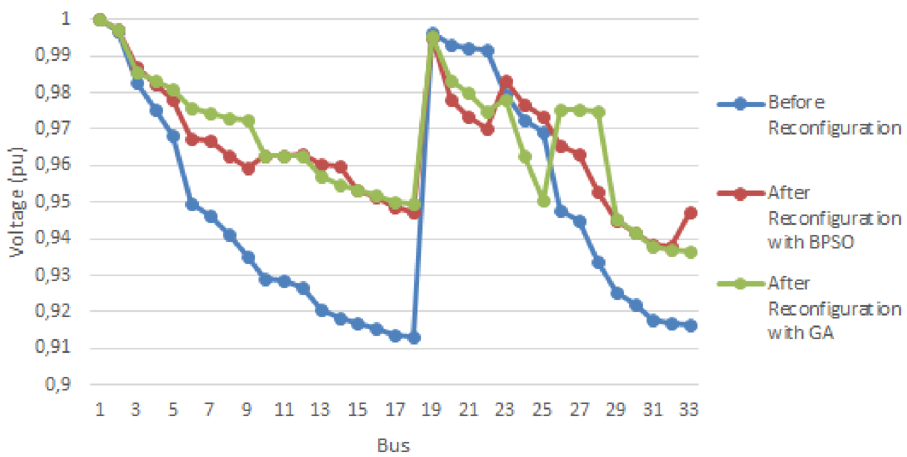

Figure. 6 The voltage profile each bus obtained from the calculation based on BPSO and GA

4. CONCLUSION

The reconfiguration process is successfully conducted by using BPSO, which provides lower power losses and better VSI. The VSI value is closer to zero. The optimal reconfiguration is obtained when the opening switches are (s7), (s9), (s14), (s32), (s37). The simulation results from BPSO give a better minimal loss and VSI value than GA.

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