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Improvement of voltage profile for large scale power system using soft computing approach

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ABSTRACT

In modern power system operation, control, and planning, reactive power as part of power system component is very important in order to supply electrical load such as an electric motor. However, the reactive current that flows from the generator to load demand can cause voltage drop and active power loss. Hence, it is essential to install a compensating device such as a shunt capacitor close to the load bus to improve the voltage profile and decrease the total power loss of transmission line system. This paper presents the application of a genetic algorithm (GA), particle swarm optimization (PSO), and artificial bee colony (ABC)) to obtain the optimal size of the shunt capacitor where those capacitors are located on the critical bus. The effectiveness of the proposed technique is examined by utilizing Java-Madura-Bali (JAMALI) 500 kV power system grid as the test system. From the simulation results, the PSO and ABC algorithms are providing satisfactory results in obtaining the capacitor size and can reduce the total power loss of around 15.873 MW. Moreover, a different result is showed by the GA approach where the power loss in the JAMALI 500kV power grid can be compressed only up to 15.54 MW or 11.38% from the power system operation without a shunt capacitor. The three soft computing techniques could also maintain the voltage profile within 1.05 p.u and 0.95 p.u.

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1. INTRODUCTION

In electric power systems, transmission lines play a key role to distribute electrical energy from power plants to consumers. Electrical energy distributed by transmission lines consists of active and reactive powers. In fact, the place of electric power plants is spatially isolated from the consumer. This causes an enormous challenge in electricity transportation over a long distance which could affect the level of performance and security of the system. Reactive power is not only generated by the impedance of a large power system network but also produced by electrical devices such as motor, transformer and other power electronic components. Hence, this power may have a great impact on the system performance. Reactive power consumed by all electrical loads is supplied by generation units when there are no sources of reactive power on electrical load from the transmission line system. The current flowing in the transmission lines increases due to reactive power on electrical load increases which initiates large reactive current flowing in the transmission lines. A large amount of reactive currents flowing in the transmission line causes decreasing in the power factor, increasing network loss and voltage drop. Therefore, the desired voltage profile on the consumer side becomes inappropriate. To overcome this problem, the shunt capacitor is an important device to install in the transmission line as reactive power compensation [1]. An appropriate planning methodology should be conducted for merging shunt capacitors as reactive power compensation into a power system network in order to get its benefit. The installation of these compensating devices at non-appropriate areas with incorrect sizing leads to negative consequences such as an increase in power loss and voltage instability. There were classical approaches for solving reactive power problems such as mixed-integer programing, non-linear programing, linear programing and quadratic programing [2-4]. Nevertheless, these approaches have some issues in solving the objective functions that were trapped in local minima. To tackle the inherent limitations of these solution methods, some simplification has been used to all these practices. Divergence and local minimum could emerge due the simplification of the problems. Additionally, the conventional method is consuming computation burden time for finding the solution.

Nowadays, many new soft computing methods have been used for solving optimization problems and widely employed to handle various problems in engineering fields. Smart computation can be divided into three categories: first categories is biologically inspired approaches such as grey wolf optimization, fruit fly algorithm and social spider algorithm. Second categories is physically inspired such as simulated annealing algorithm, and lastly social inspired such as imperialist competitive algorithm, and tabu search algorithm [5]. There are a number of researches that utilizing soft computing based on biological inspired approaches to solve optimization problems such as genetic algorithm (GA) to determine the optimal generator output [6], ant colony optimization (ACO) for reactive power management [7], differential evolution (DE) algorithm to solve non-convex and high non-linear problems [8, 9], particle swarm optimization (PSO) for reactive power dispatch [10], biogeography based optimization (BBO) for optimal VAR control [11], harmony search algorithm (HSA) for reactive dispatch [12], hybrid tabu search algorithm (TS) and simulated annealing algorithm (SA) for optimal reactive power problem [13], teaching learning based optimization algorithm (TLBO) for reactive power planning [14], group search optimization (GSO) for power and emission dispatch [15], honey bee mating optimization (HBMO) for power loss minimization [16], gravitational search algorithm (GSA) to determine the optimal FACTS for reactive power planning [17], artificial bee colony algorithm (ABC) for reactive power flow [18], cuckoo optimization algorithm (COA) [19] and artificial immune system (AIS) [20] for distribution network reconfiguration problem.

Moreover, the application of soft computing in optimizing the size of the shunt capacitor has been investigated by many researches as reactive power compensation as reported in [21]. In [21] the bacterial foraging algorithm is used to locate as well as sizing the capacity of the capacitor in the radial distribution system. The application of fuzzy logic for placement of the capacitor in the radial distribution system is reported in [22]. Moreover, the application of a whale optimization algorithm for the siting of capacitors in the radial distribution network is reported in [23]. In this paper, three computing methods i.e GA, PSO and ABC are employed to find the optimal size of the shunt capacitor as reactive power compensation. The GA, PSO, and ABC are used in this study because they have been popular in academia and industry because of its ability to effectively solve highly non-linear problems. Some benefits of GA are defined as follow: a) it has the aptitude to elude being trapped in local optimal due to GA search parallel from a population of points unlike traditional and other optimization methods, which search from a single point and affect the methods to trapped on local optima, b) it uses probabilistic preference rules rather than deterministic ones, c) the potential solution parameters are encoded to chromosome rather than the parameters themselves, d) the fitness score obtained from objective functions is utilized without other derivative or auxiliary information. Meanwhile, the GA has drawbacks due to it has many parameters that should be set appropriately and has expensive computational cost. Furthermore, the PSO method has attracted much attention from researcher communities due to it has few parameters to adjust, it can be simple to implement, it can converge fast, it doesn't need a crossover and mutate, it has higher probability and efficiency in finding global optima, and it has short computational time. Those are the advantages of PSO compared to GA. While the usage of ABC due to ABC has the same effectiveness (finding the true global optimal solution) as the PSO. Both PSO and ABC are having significantly better computational efficiency (fewer function evaluations) than GA.

2. RESEARCH METHOD

The objective function is to minimize the active power loss (P_{loss}) of the transmission line. Reactive power compensation is obtained by installing the shunt capacitor on Java-Madura-Bali (JAMALI) 500 kV power system grid to reduce the losses of P_{loss}. The active power loss (P_{loss}) can be calculated using (1).

$$P_{loss} = \sum_{k=1}^{Nl} g_k [(t_k V_i)^2 + V_j^{\,2} - 2t_k V_i V_j \cos\theta_{ij}] \quad (1)$$

In (1), N_l is the number of transmission lines, g_k is conductance of branch k between i and j, t_k is the tap ratio of transformer k, V_i is the voltage magnitude at bus i, and θ_{ij} is the difference of voltage angle between buses i and j, respectively. By obtaining the minimum objective function, the determination of the size of the shunt capacitor as reactive power compensation is essential. Furthermore, the equality constraint in optimal power flow can be described in (2) and (3).

$$P_{g_i} - P_{d_i} - V_i \sum_{j=1}^{N_{bus}} V_j (G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij}) = 0 \text{ , for } i=1,\ldots, N_{pv}+N_{pq} \quad (2)$$

$$Q_{g_i} - Q_{d_i} + Q_{c_i} - V_i \sum_{j=1}^{N_{bus}} V_j (G_{ij} \sin\theta_{ij} + B_{ij} \cos\theta_{ij}) = 0 \text{ , for } i=1,\ldots, N_{pq} \quad (3)$$

where N_{pv} and N_{pq} are the number of generators and load buses, respectively. While the inequality constraint of power flow can be calculated using (4), (5), (6) and (7).

$$P_{g,slack}^{\min} \le P_{gen,slack} \le P_{g,slack}^{\max} \quad (4)$$

$$V_{L_i}^{\min} \le V_{L_i} \le V_{L_i}^{\max} \text{ , for i=1,..., Npq} \quad (5)$$

$$Q_{g_i}^{\min} \le Q_{g_i} \le Q_{g_i}^{\max} \text{ , for } i=1,\ldots,N_{gen} \quad (6)$$

$$S_{line} \le S_{line}^{\max} \text{ , for } i=1,\ldots, N_{line} \quad (7)$$

The inequality constraint as the control variable can be described in (8), (9), and (10):

$$V_{gen_i}^{\min} \le V_{gen_i} \le V_{gen_i}^{\max} \text{ , for } i=1,\ldots, N_{pv} \quad (8)$$

$$t_{k_i}^{\min} \le t_{k_i} \le t_{k_i}^{\max} \text{ , for } i=1,\ldots, N_{tf} \quad (9)$$

$$Q_{c_i}^{\min} \le Q_{c_i} \le Q_{c_i}^{\max} \text{ , for } i=1,\ldots, N_{comp} \quad (10)$$

where N_{tf} and N_{comp} are the number of tap transformer and reactive compensating devices, respectively.

3. THE PROPOSED ALGORITHM

3.1. Genetic algorithm (GA)

The genetic algorithm (GA) is a soft computing method inspired by the theory of gen in biological sciences [6] where introduced by John Holland in 1970. Chromosome variation will affect the reproduction rate and level of ability of the organism to survive. The control parameters of GA consist of population size, crossover, and mutation. Basically, there are four conditions that affect the evaluation process of GA:

- Organism's ability to reproduce.
- The existence of populations of organisms that can perform reproduction.
- The diversity of organisms within a population.
- Different inability to survive.

Stronger individuals would have the level of survival and reproduction rates are higher when compared to an individual who is not strong. At a certain time (generation), the overall population will contain more fit organ-isms. Processing steps of Genetic Algorithm are defined as follow:

- Encoding problem solution into a set of chromosome structures
- GA initialized to a population with a few *N* chromosomes
- Each chromosome will be encoded into an individual with a specific fitness value.

- Selecting individuals with the best fitness value. The method used is different, for example by using the method roulette wheel.
- To generate a new population, it is necessary to use the genetic
  a. Cross Over: generate new offspring by replacing some of the information from the parent chromosomes that are crossed by.
  b. Mutation: create new individuals by modifying one or more genes in the chromosome.

3.2. Particle swarm optimization

The second optimization approach employed in this paper is particle swarm optimization (PSO) proposed by Kennedy and Eberhart in 1995 [10] where this algorithm mimics the behavior of bird flocking. This algorithm is a population-based search approach where each individual in a population is presented as a particle. Each particle in a swarm flies around in a multi-dimensional search space by memorizing its own experience and the experience of neighboring particles [10]. Furthermore, the flowchart of PSO is depicted in Figure 1.

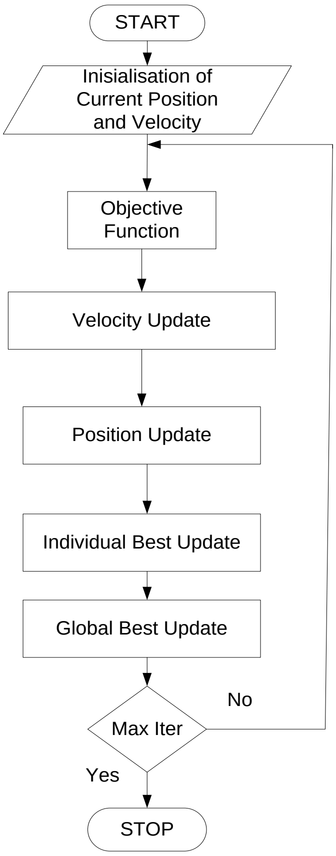

Figure 1. Flowchart of PSO

The velocity of a particle to move can be evaluated using information from: (i) the present velocity, (ii) the distance between the starting position with the best position that has been found. Based on the concept of PSO, the mathematical representation of particle velocity and particle position can be expressed using (11) and (12),

$$v_i^{k+1} = v_i + c_1 r_1 (P_{best_i} - x_i^k) + c_2 r_2 (G_{best} - x_i^k) \quad (11)$$

$$x_i^{k+1} = x_i + v_i^{k+1} \quad (12)$$

in (11) and (12), *w* is inertia weight, *c* is the speed constant, the *rand* is a uniform random value in the range [0, 1], P_{best} is the best position of the *i-th* particle and G_{best} is the best position of all P_{best}.

3.3. Artificial bee colony

The third optimization method utilized in this study is an artificial bee colony algorithm introduced by Karaboga [18] where this algorithm mimics the behavior of bees in searching for the food. In the ABC algorithm, the colonies of artificial bees are classified into three categories of bees i.e the employed bees, the onlooker bees, and the scout bees. The employed bees seek the new food source that never prior to being visited, while the onlooker bees that are waiting in the dance area are to make decisions in the preference of food sources site. The third bees are the scout bees that are doing random searching for the food sources. Noted that only one employed bee exists for each food source. Thus, it could be emphasized that the number of food sources around the nest equals the set of employed bees in the colony. When the employed bees run out of their food sources, then, they become the scout bees [18]. The location of a food source denotes a potential solution to the optimization issue. The number of food sources called the nectar corresponds to the quality (fitness) of the associated solution. Furthermore, the main steps of ABC are described below:

- Initialize the location for food source.
- Devolve the employed bees onto their food sources and specify the number of their nectars. A new food source of each employed bee is described as (13). The new solution is compared to the solution x_{ij} after the result in v_ij and the employed bee exploits the better source.

$$v_{ij} = x_{ij} + \varphi_{ij}(x_{ij} - x_{kj}) \tag{13}$$

- Devolve the onlooker bees towards the food sources and specify the number of their nectars. In this step, the probability is employed by an onlooker bee to pick a food source and yields a new source in the location of the chosen food source. While for the employed bee, the preferred food source is defined to be exploited by (14).

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i} \tag{14}$$

- Determine the food source to be forsaken and allocate its employed bee as a scout for finding the new food sources based on a random search by (15).

$$x_i^j = x_{\min}^j + rand[0,1](x_{\max}^j - x_{\min}^j) \tag{15}$$

- Memorize the best food source found so far.
- Go steps 2-until the termination criteria are satisfied.

4. NUMERICAL RESULTS

In this paper, the test system is Java-Madura-Bali (JAMALI) 500kV power grid as depicted in Figure 2. The data of the JAMALI 500kV power grid is taken from [24]. Simulation is conducted by using a MATLAB software environment. Furthermore, the appropriate control parameter plays key role in the computation techniques and is very sensitive problem of finding a good solution for the soft computing technique. The parameters of soft computing approaches used for the simulations are defined as follow:

GA parameters:

N_{Gen}=Dimension of problem; Crossover probability = 0.8; Population siz = 50;
Mutation probability = 0.05; Maximum generations = 150

PSO parameters:

$N_{Variabel}$ = Dimension of problem; Social parameter (C2) = 0.9; Weight (w)= 0.9;
Cognitive parameter (C1) =1.5; Population size = 50; Maximum iterations = 150;

ABC parameters:

Dimension (D) = Dimension of problem; FoodNumber = NP/2; limit = FoodNumber*D;
colony size (NP) = 50; Maximum cycles = 150;

The dimension search space (Dim) of each algorithm depends on the number of compensating devices corresponding to the number of bus systems that have voltage value (p.u) lower than voltage reference standard around -5% of its nominal value.

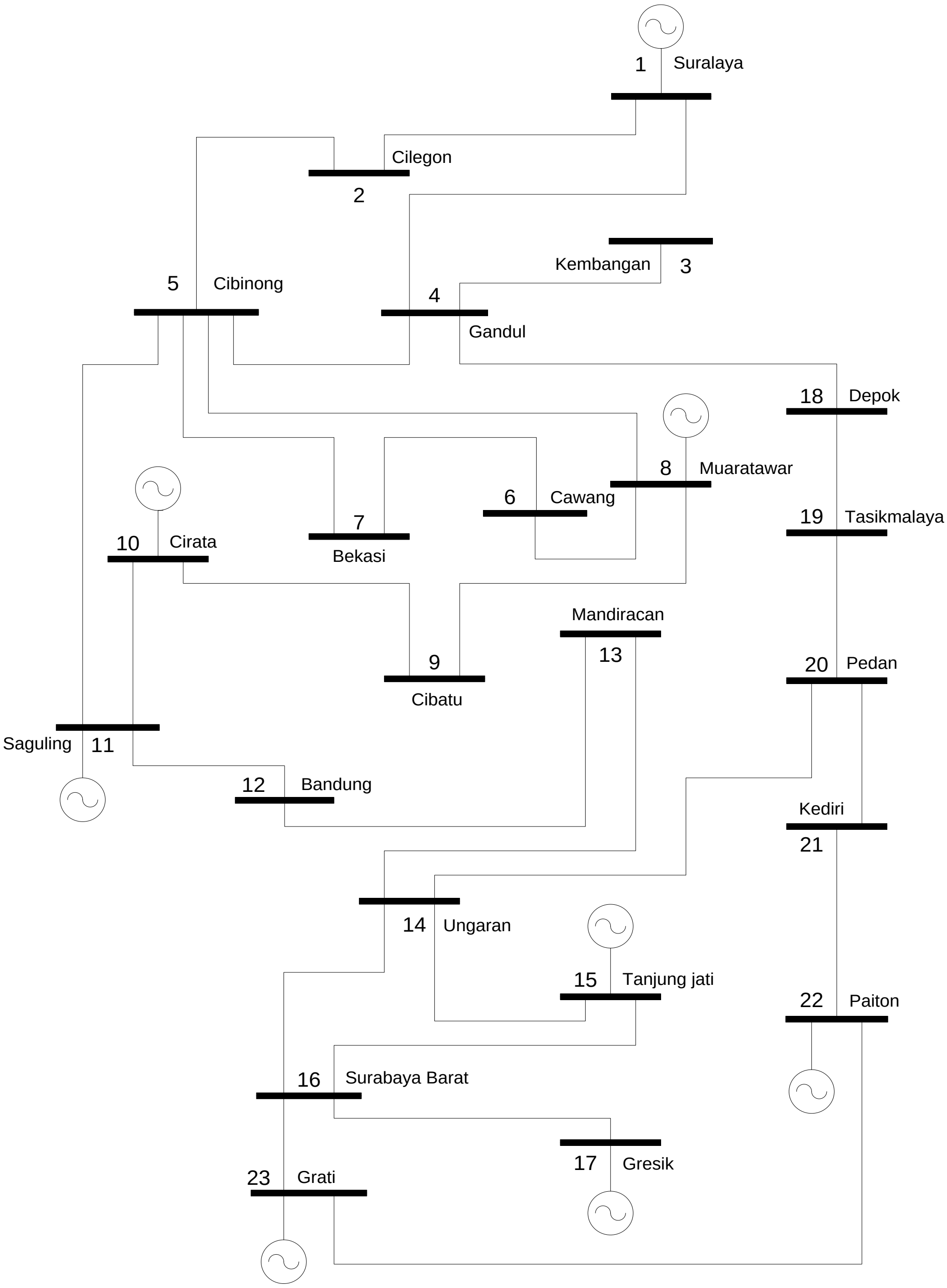

Figure 2. Single line diagram of JAMALI 500 kV transmission system [25]

The evaluation of fitness for each population of the GA, PSO, and ABC algorithms is frequently conducted in one iteration. The convergence characteristic of three soft computing techniques is compared to the number of fitness evaluations due to the fitness evaluation is consuming the optimization process time. The convergence behavior of all soft computing approaches is depicted in Figure 3. Figure 3 illustrates that all soft computing approaches obtained satisfactory performances to reach their convergence values for the chosen parameters. The convergence characteristics of GA are faster than ABC but may not investigate deeply for potential candidates as found by ABC. While PSO towards convergence value quickly and explores a good potential solution rather than other soft computing methods. Table 1 shows the comparison of total loss before and after the installing of capacitors from each of these methods. The results obtained are that the GA method can reduce the transmission line losses 11.38%. A better result is obtained by using PSO and ABC algorithm with a percentage decrease of 11.63%. While Table 2 depicts the capacity of capacitors installed on each of the critical buses. The comparison of the voltage level on each result is depicted in Figure 4. It is found that after the system is compensated, the voltage drops decrease in order to obtain better performance of voltage.

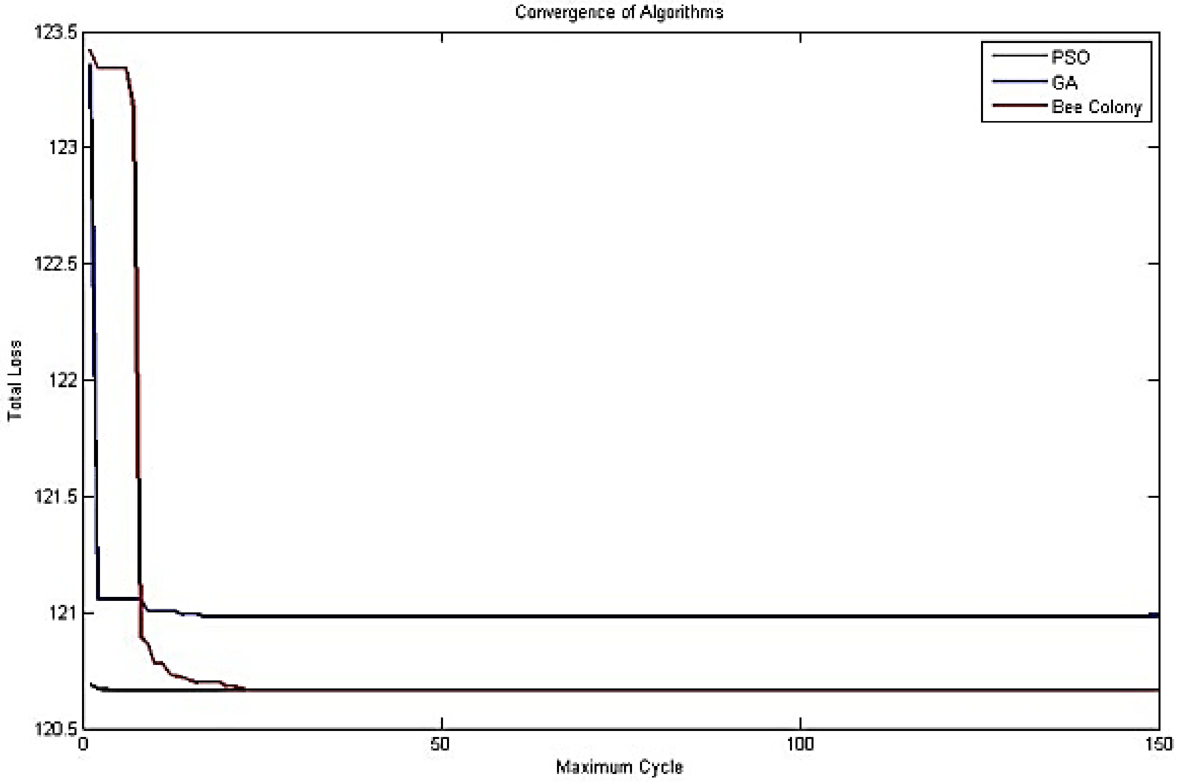

Figure 3. Convergence characteristics of algorithms

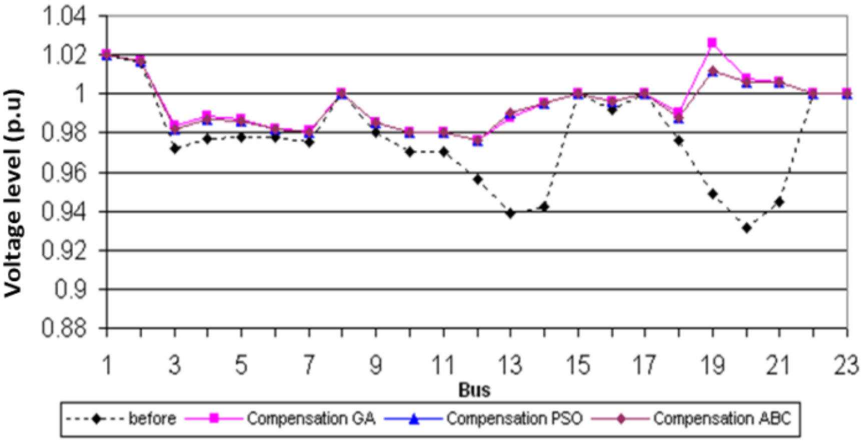

Figure 4. Comparison of voltages level

Table 1. Comparison of total active power loss

		Before	GA	PSO	ABC
Total Loss	(MW)	136.539	120.999	120.666	120.666
The difference of total loss	(MW)	-	15.54	15.873	15.873
	%	-	11.38	11.63	11.63

Table 2. Optimization of shunt capacitor's size

Unit	Bus	Compensation GA (MVAR)	Compensation PSO (MVAR)	Compensation ABC (MVAR)
1	13	370.451	400	400
2	14	376.878	400	400
3	19	399.272	248.244	248.245
4	20	386.468	400	400
5	21	369.731	400	400
Total	1902.8	1848.244	1848.245	

5. CONCLUSION

In this paper, the use of three different soft computing techniques to overcome the reactive power compensation issue in the transmission system has been investigated. From the simulation result, it is shown that the GA method to reach convergence on the 20th iteration, PSO on the 3rd iteration and ABC on the 23rd iteration. The ABC dan PSO algorithms can reduce the total active power loss by 15.873 MW, from 136.539 MW to 120.666 MW. These results obtained are better than the GA approach where it only can reduce by 15.54 MW, from 136.539 MW to 120.999 MW. From all the simulation results, the PSO algorithm is very superior rather than the other methods in the viewpoint of the selected set of parameters to tackle the reactive power compensation issue in the transmission system.

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