Chapter 26
Artificial Bee Colony Algorithm for Optimal Power Flow on Transient Stability of Java-Bali 500 KV

Irrine Budi Sulistiawati and M. Ibrahim Ashari

Abstract Power flow optimization is a growing issue today. The system does not grow or develop, in contrast to the electricity power demand from consumers. Therefore, smart efforts have to be done to overcome this increasing electricity power demand. Power flow optimization is one of the efforts that can be done to optimize the current system. The use of Artificial Bee Colony algorithm can give an optimal result without being disturbed by mathematical problems that need much computation time. From the simulation result on Java-Bali 500 kV System, an optimal result has been achieved, in which this method can reduce system power losses from active power losses of 297.607 MVA and reactive power losses of 2926.825 MVAR to become 71.292 MVA and 530.241 MVAR, respectively.

Keywords Artificial bee colony · Optimal power flow · Transient stability

26.1 Introduction

Electricity power system cannot be separated from the effort to optimize its operation, which means that the control variable has to be arranged to produce a system operation that is safe and cheap. To gain this desired system operation process, Optimal Power Flow (OPF), a method that uses mathematical calculation to gain a cheap fuel cost result, is often used as the prescribed limit. According to [1–5], Non Linear Programming and Linear Programming are widely used to solve several problems in the optimal power flow.

Like another conventional method, this method is considered a classic method due to its limitation in solving mathematic equations that represent dynamic system characteristics; that is, an optimization problem in a transient condition.

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If we observe the operation condition in field, system operations of electricity power all this time are operated at a condition far from their safety limit. Systems operate at a maximum operating condition, because the increasing electricity energy demand is not followed by the addition of new power plants for the reasons of cost efficiency; thus, the systems are always fully operational. This condition certainly makes the system operation prone to collapse if there is a small interference or change in the system. Based on this condition, a preventive action has to be done for planning and operating electricity power system. This is accomplished by performing system optimization while observing the system transient condition.

However, transient stability analysis cannot be separated from the use of mathematic equations with their non-linear patterns that need time and accuracy to get the results. This is the challenge because those are differential equations that describe dynamic behavior of the system [1–5].

Past research [6, 7] involved sensitivity in rescheduling to obtain solution in power plant cost, while other research with discretization scheme [8] converted differential equations to algebra equations as inequality constraints produce low accuracy solution.

In some advanced research [9, 10], since the system being used was increasingly big and the variables were increasingly complex, the calculation convergence would be a problem by itself. The use of a method with transformation technique [11] can change an infinite-dimensional problem of Transient Stability Control Optimal Power Flow (TSCOPF) to become a finite-dimensional programming problem. Yet, like the other classical optimization methods, this method has a weakness, that is, it experiences convergence at local optima, thus transient stability limit is not included in the constraints of optimization problem. A solution to address those problems is to use Artificial Intelligence to solve the transient stability calculation problem [1–3]. The use of AI eases the burden to solve the Transient Stability Control Optimal Power Flow (TSCOPF) problem and can find global optimum or good solution without being restricted by the model employed. Several applications that use AI like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Differential Evolution (DE) can give satisfied results in TSCOPF problem.

Research in this paper tries to propose a solution for the Transient Stability Control Optimal Power Flow (TSCOPF) problem using a modern heuristic optimization technique—i.e., Artificial Bee Colony Algorithm (ABC), which is an algorithm that simulates the behavior of honey bee—for solving the problem of electricity power system optimization.

26.2 Methodology

26.2.1 Transient Stability Control Optimal Power Flow Formula

Transient Stability Control Optimal Power Flow (TSCOPF) problems basically are formulated from system fuel cost, that is expressed as a quadratic equation function:

$$f_i = a_i + b_i P_{Gi} + c_i P_{Gi}^2 \tag{26.1}$$

where a_i, b_i, are c_i are the cost coefficients from each power plant unit.

By incorporating various constraints, like fuel losses due to valve opening process at turbine and generator effect due to valve point effect, the objective function becomes non linear, non convex with several minima. So, the equation becomes:

$$\begin{aligned} F = & \sum_{i=1}^{N} \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2\right) + K_p \left(P_{G1} - P_{G1}^{\lim}\right)^2 \\ & + K_v \sum_{i=1}^{NL} \left(V_i - V_i^{\lim}\right)^2 + K_q \sum_{i=1}^{N} \left(Q_{Gi} - Q_{Gi}^{\lim}\right)^2 \\ & + K_s \sum_{i=1}^{nl} abs\left(S_i - S_i^{\lim}\right)^2 + K_l \sum_{j=1}^{NL} \left(L_j - L_j^{\lim}\right)^2 \end{aligned} \tag{26.2}$$

where K_p, K_v, K_q, K_s, and K_l are penalty factors, NL is the number of load buses, nl is the number of transmissions and x^{lim} is the margin limit. Incorporating valve point loading effect to power plant cost curve, the equation becomes [1]

$$f_i = a_i + b_i P_{Gi} + c_i P_{Gi}^2 + \left|d_i \sin(e_i(P_{Gi}^{\lim} - P_{Gi}))\right| \tag{26.3}$$

Combining the objective function and the constraints, the complete equation becomes:

$$\begin{aligned} F = & \sum_{i=1}^{N} \left(a_i + b_i P_{Gi} + c_i P_{Gi}^2 + \left|d_i \sin\left(e_i\left(P_{Gi}^{\lim} - P_{Gi}\right)\right)\right|\right) + K_p (P_{G1} - P_{G1}^{\lim})^2 + K_v \sum_{i=1}^{NL} \left(V_i - V_i^{\lim}\right)^2 \\ & + K_q \sum_{i=1}^{N} \left(Q_{Gi} - Q_{Gi}^{\lim}\right)^2 + K_s \sum_{i=1}^{nl} abs\left(S_i - S_i^{\lim}\right)^2 + K_l \sum_{j=1}^{NL} \left(L_j - L_j^{\lim}\right)^2 \end{aligned} \tag{26.4}$$

where a_i, b_i, c_i, and e_i are cost coefficient from each power plant unit, K_p, K_v, K_q, K_s, and K_l are penalty factors, NL represents the number of load buses, nl and $x^{\lim}$ are respectively the number of transmissions and the margin limit. So, the non linear equations of power flow are:

$$\begin{aligned} P_{Gi} - P_{Di} - V_i \sum_{j=1}^{N} V_j \left(G_{ij} \cos \alpha_{ij} + B_{ij} \sin \alpha_{ij} \right) = 0 \\ Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N} V_j \left(G_{ij} \sin \alpha_{ij} - B_{ij} \cos \alpha_{ij} \right) = 0 \end{aligned} \tag{26.5}$$

where N is the total number of buses, P_{Gi} and Q_{Gi} are active and reactive power of ith power plant bus, P_{Di} and Q_{Di} are active power for ith load bus, Vi is the magnitude of voltage bus, α_{ij} is the voltage angle difference between ith bus and jth bus, G_{ij} and B_{ij} are the transfer conductance and susceptance between ith bus and jth bus.

26.2.2 Transient Stability

In transient condition, the power system generator is described with equation:

$$\begin{aligned} M_i \frac{d^2 \delta_i}{dt^2} = P_{mi} - P_{ei} \\ \dot{\delta}_i = \omega_i \end{aligned} \tag{26.6}$$

where $\dot{\delta}_i$ and ω_i are rotor angle and velocity angle of ith generator, P_{mi} and P_{ei} are mechanic power input and electricity power output from ith generator, and Mi is inertia moment from ith generator.

Center of inertia (COI) of the electricity power system can be represented by linear combination of every generator's rotor angles such as follows:

$$\delta_{COI} = \frac{1}{M_T} \sum_{i=1}^{N_G} M_i \delta_i \tag{26.7}$$

where $M_T = \sum_{i=1}^{N_G} M_i$ is the center of inertia. Rotor angle and velocity in COI frame are shown by Eqs. (26.8) and (26.9).

$$\theta_i = \delta_i - \delta_{COI} \tag{26.8}$$

$$\dot{\theta}_i = \tilde{\omega}_i \tag{26.9}$$

Therefore, the equations in COI frame become:

$$M_i\dot{\tilde{\omega}}_i = P_{mi} - P_{ei} - \frac{M_i}{M_T}P_{COI} \equiv PAC_i \tag{26.10}$$

$$P_{COI} = \sum_{i=1}^{N_G}(P_{mi} - P_{ei}) \tag{26.11}$$

where PAC$_i$ is accelerating power from ith generator.

Transient Energy Function (TEF) from the model of electricity power system above is defined as follows:

$$TEF = KE + PE \tag{26.12}$$

$$KE = \frac{1}{2}\sum_{i=1}^{N_G} M_i\tilde{\omega}_i^2 \tag{26.13}$$

$$PE = -\sum_{i=1}^{N_G}\int_{\theta_i^{SEP}}^{\theta_i} PAC_i^P d\theta_i \tag{26.14}$$

where KE is kinetic energy, PE is potential energy, θ_i^{SEP} is rotor angle of the post-fault system at the stable equilibrium point, and PAC_i^P is accelerating power of the post-fault system.

26.2.3 Artificial Bee Colony Algorithm (ABC)

Artificial Bee Colony is an algorithm that adopts the behavior of bee colony in search of food. When bees are searching for food, they divide their duty in three groups, which are labor, onlooker, and scout bees. The food searching process is started with bees gathering in a hall called dance area, where they make a decision to determine food sources that they have known before. The decision maker are bees group called onlooker bees. Meanwhile, labor bees are bees group that will visit those food sources. Bees that have to find food sources randomly are called scout bees.

Based on [12], to solve the problem, the control variable can be expressed as

$$u^T = \left[P_{g2}, \ldots P_{gN2}, V_{g1}, \ldots V_{gN2}\right] \tag{26.15}$$

This equation does not consider slack bus. To measure the quality of the artificial bee colony algorithm, the calculation of fitness Fi can be expressed as:

$$F_i = 1/(fi + K_v F_{vi} + K_q F_{qi} + K_{ps} F_{ps}) \tag{26.16}$$

where f_i is the generating fuel cost, while F_{vi} and F_{qi} are the sums of normalized PQ bus voltage and reactive power from output generator i, respectively.

26.3 Implementation

To see the effectiveness of the proposed method, a test was performed at Java Bali 500 kV system, as shown in Fig. 26.1. The electricity system of Java Bali 500 kV consists of 8 generators and 25 buses that are interconnected together. Some power plants are water power plant, but most of them are steam power plant. Their specifications can be seen in Table 26.1.

The generators are Suralaya, Muaratawar, Cirata, Saguling, Tanjungjati, Gresik, Paiton, and Grati. Among these eight plants, power plants Saguling and Cirata are water power plants, while others are steam power plants. In this study, Suralaya power plant acted as a slack generator.

The load data were obtained from PT PLN (Persero). The kV base is 500 kV, MVA base is 1000 MVA, and the system frequency is 50 Hz. Generator data used are shown in Table 26.1.

Simulation was run on the system for as many as 50 cycles to achieve the best result. From the test that had been performed, that number of cycles could give us the desired result. The number of bees in the colony that was employed is 50.

26.4 Result and Analysis

From the performed simulation, the initial result was obtained, and it can be seen in Table 26.2. In the table, losses at every bus can be seen. The total losses of the system are 297.607 MVA for active power and 2926.825 MVAR for reactive power.

The next step is to perform load flow optimization using the method that had been proposed, which is the artificial bee colony algorithm. From the performed simulation, the obtained results are as follows (Table 26.3):

To further determine the effectivity of the proposed method, calculation simulation was performed as many as 125 times to validate its reliability and accuracy. Figure 26.2 depicts the results for as many as 125 iteration. Figure 26.2 shows the total losses of the system. It can be seen that the proposed method gives the same losses values at various iteration and this means that statistically the proposed method can prove its reliability.

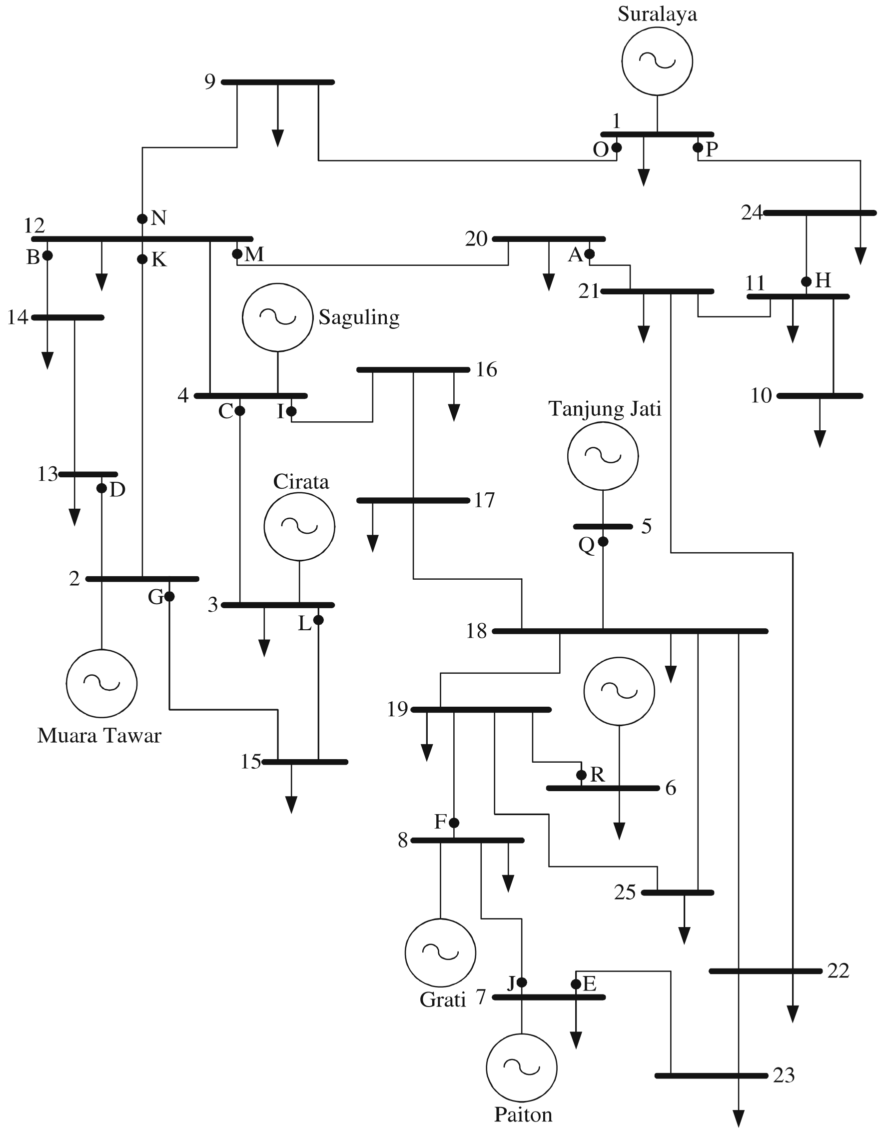

Fig. 26.1 Java Bali 500 kV system

Table 26.1 Generator data

Generator Number	Generator Name	Xd' (pu)	H	Generator Number	Generator Name	Xd' (pu)	H
1	Suralaya	0.297	5.19	5	Tanjung Jati	0.258	3.2
2	Muaratawar	0.297	1.82	6	Gresik	0.297	2.54
3	Cirata	0.274	2.86	7	Paiton	0.297	4.42
4	Saguling	0.302	1.64	8	Grati	0.297	3.5

Table 26.2 Initial condition

No bus	Voltage	Losses		No bus	Voltage	Losses	
		P	Q			P	Q
10	0.980	0.003	0.033	15	1.000	5.075	49.663
11	0.970	0.510	5.705	16	0.963	0.818	27.875
12	0.948	0.053	11.623	17	0.970	0.228	2.193
13	0.911	1.928	4.987	18	0.960	0.080	0.772
14	0.907	2.086	5.975	19	0.875	0.342	24.145

Table 26.3 Final condition

No bus	Voltage	Losses		No bus	Voltage	Losses	
		P	Q			P	Q
10	0.980	0.003	0.033	15	1.000	5.075	49.663
11	0.980	0.51	5.705	16	0.971	3.223	27.875
12	0.973	1.928	4.987	17	0.970	0.228	2.193
13	0.970	1.928	4.987	18	0.974	0.08	0.772
14	0.977	2.086	5.975	19	0.950	0.343	24.145

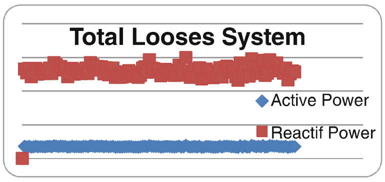

Fig. 26.2 Total looses system

26.5 Conclusion

From evaluating the proposed method, it can be concluded that the proposed ant bee colony algorithm can give satisfied results for reducing losses, particularly for optimizing the system's power flow. The proposed method can statistically be proven to be capable, reliable, and accurate.

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