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Economic Dispatch using Novel Bat Algorithm Constrained by Voltage Stability

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***Abstract*—Economic Dispatch (ED) of thermal power plant has a role in maintaining economic power system. The main purpose of ED is to set the control variables of power system so that the generators can generate maximum power according to load demand based on each generator characteristic with lower production cost. In this paper, the economic dispatch will be done in thermal power system using Novel Bat Algorithm (NBA) constrained by voltage stability. NBA is a recent optimization method that is developed build upon bat behavior. The result showed that the NBA can optimize the thermal power system by showing lower price of production cost. The NBA can reduce 9.23% of the production cost. Not only is the production cost smaller but also the power loss obtained by NBA. Voltage stability is also maintained in this research by showing better improvement of critical point with average 0.920 per unit. The proposed method is applied in real system of SULSELBAR 150 kV power system.**

Keywords—economic dispatch, thermal power system, NBA, voltage stability, SULSELBAR 150 kV power system

I. INTRODUCTION

Electricity is the main requirement of every community. Along with the times, the need for electrical energy is multiplying. Thus, the purpose of a power system is to provide the electricity needed by the customers. In order to meet this electricity demand, a way is needed to be able to provide electrical energy with a minimum operating system cost and each plant is expected to produce maximum electricity. The economical operation of a power plant or economic dispatch is one of the modern ways to regulate the operation of a power system. The main economical scheduling objective of is to regulate the variable power control system so that the generator can produce maximum electrical power in accordance with the demand based on the character of each generator and with low production costs.

Over the past few years, more and more optimization method and algorithms have been used in the ED of thermal plants in power systems. Based on the abstraction of the nature, metaheuristic algorithms have been advanced [1]. Recently, metaheuristic algorithm has been developed to solve ED problems such as Particle Swarm Optimization (PSO) [2], Biogeography-based Optimization (BBO) [3], Artificial Bee Colony algorithm (ABC) [4], Krill Herd algorithm (KHA) [5], Cultural Algorithm (CA) [6], Charged System Search (CSS) [7] and Bat Algorithm (BA) [8]. Not only metaheuristic algorithms but also another algorithm such as Tabu Search algorithm [9], Teaching Learning-based Optimization (TLBO) [10] are used to solve optimization economic power generation problems. Both BA and NBA have been applied for ED problem in [8, 11]. But in this paper, NBA has been used for ED problem in the real system and constrained by voltage stability. The NBA itself is the development of the BA. In the implementation of the NBA algorithm, it is adjusted to the ability of bats to catch their prey which is considered very unique because bats have a reliable ability in echolocation. In this study, the application of the NBA method shows optimal results in the economical scheduling of thermal plants in the electric power system. The NBA optimization method is applied to the SULSELBAR 150 kV power system.

Nowadays large integrated power systems are being operated under heavily stressed conditions which imposes threat to voltage stability. Voltage collapse occurs when a considerable part of the system attains a very low voltage profile or collapses [12]. The Continuation Power Flow (CPF) method is used to assess how far the system is from voltage instability.

II. ECONOMIC DISPATCH PROBLEM

The matematical expression of ED problem that commonly used is shown as the he power generation cost function, which is as an objective function as given in the following equation (1).

$$F(P_i) = a_i + b_i P_i + c_i P_i^2 \quad (1)$$

With:

$F(P_i)$ = input-output cost function of power generation i (IDR/hour)

a_i, b_i, c_i = cost coefficient of power generation i

P_i = output power generation i (MW)

i = index of dispatch able unit

The constrains that must be met in the calculation are limitation of power equilibrium as shown in (2) and (3) and power generation limits of each generator as shown in (4).

$$\sum_{i=1}^{N} P_i = P_D + P_{Loss} \quad (2)$$

With:

$$P_{Loss} = P_i^T B P_i \quad (3)$$

Where:

P_{Loss} = transmission lost (MW)

P_i^T = power generation output i transposable

P_i = power generation output i (MW)

B = coefficient transmission losses

P_D = power demand load (MW)

N = number of power generation units

$$P_{i,min} \leq P_i \leq P_{i,max} \quad (4)$$

Where:

$P_{i,min}$ = lower limit power generation unit i (MW)

$P_{i,max}$ = upper limit power generation unit i (MW)

III. Novel Bat Algorithm

Xin-She Yang as in [13] was the first to introduce a new metaheuristic inspired by bat algorithm. The ability of bats to catch their prey is very unique and different from other animals. Bats have a reliable ability in echolocation. Echolocation is the ability to determine a location by using echo or waves. The ability of echolocation is used in detecting prey, avoiding obstacles and locating their roosting crevices in the dark.

This bat releases a very strong sound pulse level and listens to echoes that bounce back from the surrounding objects [13]. Pulse levels can vary and correlate with strategies to hunt down a bunch of bats. The following is a representation of the bat's ability in the bat algorithm:

1) The ability of bats in echolocation can be developed in variations to BA. For example, rules or rules of ability to determine distance and bats can be used to determine differences in prey and obstructions.

2) Bats fly randomly at velocity (Vi) at position (Xi), with frequency (f) fixed, wavelength (λ) and loudness (A). Bats have the ability to alter the wavelength of the pulse beam and the level of pulse emission (r) ϵ [0,1] which can be used to determine the nearest prey.

3) While loudness can vary regardless of that, it is assumed that loudness can be changed from maximum to a minimum constant number [13].

The description above can be mathematical formulated detail as in [1], (5-8).

$$rand\ (0,1) < A_i \ \&\&\ f\ (x_i) < f(x)) \quad (5)$$

$$f(x) = f(x_i) \quad (6)$$

$$A_i^{t+1} = vA_i^t \quad (7)$$

$$r_i^{t+1} = r_i^0(1 - e^{-\varphi t}) \quad (8)$$

Various types of bats are involved in habitat search. Bats can regulate their echolocation performance in diverse habitats where the bats adapt, so that it can encourage bats to forage in some habitats. In addition, in similar habitat different bat species can also feed food. In the original BA, the Doppler Effect and the hunting prey idea are not considered. In NBA, the Doppler Effect has been deliberated. Thus, the NBA consists of several ideal rules, namely;

1) Bats can move freely in dissimilar habitats.

2) Doppler Effect in echoes can be offset by all bats. Bats can familiarize and change their compensation level based on the proximity of the prey [1].

B. Habitats Selection

Stochastic decisions are models of habitat selection. The choice threshold is represented as P ϵ [0, 1] and the uniform random number is represented as R [0, 1]. If P is greater than R, bats will decide on mechanical behavior to find food in restricted habitats; if not, the quantum behavior will be selected by the bats for finding the food in large habitats [11].

C. Quantum Behavior of Bats

Quantum behavior means foraging in a large habitat. The bats will feed from another bat when they find food in the habitat. The virtual bats with quantum behavior can be mathematically expressed as in [1, 11], (9).

$$x_{ij}^{t+1} = \begin{cases} g_j^t + 0 * \left|mean_j^t - x_{ij}^t\right| * ln\frac{1}{u_{ij}}, if\ rand_j(0,1) < 0.5, \\ g_j^t - 0 * \left|mean_j^t - x_{ij}^t\right| * ln\frac{1}{u_{ij}}, if\ rand_j(0,1) < 0.5, \end{cases} \quad (9)$$

Where:

x_{ij}^{t+1} = individual's position

g_j^t = global best position

u_{ij} = a number uniformly distributed in the interval (0, 1)

D. Mechanical Behavior of Bats

Bats cannot outreach the sound speed that is 340 m/s. In the NBA, the Doppler Effect is compensated by the bats. This compensation rate (CR) differs through different bats. To evade the probability of division by zero, the ε value is reflected as the lowest constant in the computer. The CR ϵ [0, 1] and the inertia w ϵ [0, 1] [10]. If the Doppler Effect is compensated fully by the bats, the CR given is 1. If the Doppler Effect is not compensated by the bats at all then CR is given 0. These descriptions can be mathematically formulated as follows [1, 11], (10-12).

$$f_{ij} = \frac{(c + v_{i,j}^t)}{c + v_{g,j}^t} * f_{i,j} * \left(1 + C_i * \frac{(g_j^t - x_{i,j}^t)}{|g_j^t - x_{i,j}^t| + \varepsilon}\right) \quad (10)$$

$$v_{i,j}^{t+1} = w * v_{i,j}^t + (g_j^t - x_{i,j}^t) * f_{i,j} \quad (11)$$

$$x_{i,j}^{t+1} = x_{i,j}^t + v_{i,j}^t \quad (12)$$

E. Local Search

The bats will increase their quietness and rate of pulse emission when they approach their prey. When the loudness of a bat is high, it will be difficult to catch their prey. The noise in the nearby environment must be taken into consideration as well. The expressions for the new position of the bat in the local search is shown in (13)-(15), where rand n (0, σ^2) is a Gaussian distribution with mean 0 and σ^2

as standard deviation. The bats mean loudness at time step t is A_{mean}^{t} [1, 11], (13-15).

$$If\ (rand\ (0,1) > r_i\ ) \quad (13)$$

$$x_{i,j}^{t+1} = g_j^{t} * (1 + rand\ n\ (0, \sigma^2)) \quad (14)$$

$$\sigma^2 = |A_i^t \text{-} A_{mean}^t| + \varepsilon \quad (15)$$

IV. Continuation Power Flow

Analyzing steady state voltage stability by tracing the load flow solution based on the loading scenario is known as the method of continuity of power flow. This method uses tangents, predictors, and corrector systems. The initial condition is known by using Newton Raphson technique with modification of adding columns and rows. To analyze the location of the critical point and determine the maximum limit that can be borne so that the P-V curve is used [14].

By using Newton Raphson technique and adding load parameters, the basic conditions are known. This modification is stated on the load and the bus generator as a lambda function. So that the general form of the equation can be written as follows [14], (16-19).

$$\Delta P_i = P_{Gi}(\lambda) \text{-} P_{Li}(\lambda) \text{-} P_{Ti} = 0 \quad (16)$$

$$\Delta Q_i = Q_{Gi}(\lambda) \text{-} Q_{Li}(\lambda) \text{-} Q_{Ti} = 0 \quad (17)$$

$$P_{Ti} = \sum_{j=1}^{n} V_i V_j |Y_{ij}| cos(\delta_i \text{-} \delta_j \text{-} \gamma_{ij}) \quad (18)$$

$$Q_{Ti} = \sum_{j=1}^{n} V_i V_j |Y_{ij}| cos(\delta_i \text{-} \delta_j \text{-} \gamma_{ij}) \quad (19)$$

P_{Gi}, P_{Li} and P_{Ti} respectively each shows generation, load and injection power. Lambda value varies from zero until reach the critical condition $0 \le \lambda \le \lambda_{critical}$. Condition of load changes can be known by modifying P_{Li}, (20), (21).

$$P_{Li} = P_{Li0}[1 + \lambda K_{Li}] \quad (20)$$

$$Q_{Li} = Q_{Li0}[1 + \lambda K_{Li}] \quad (21)$$

In addition, the active generation power can be modified as shown below. K_{Li} is the rate of load change at bus i and K_{Gi} is the rate of change in generation, (22).

$$P_{Gi} = P_{Gi0}[1 + \lambda K_{Gi}] \quad (22)$$

E. Prediction Step

The next step corresponds to the estimation of the next solution using prediction step. Equations for each bus by adding loading parameters λ is written below;

$$F(\delta, V, \lambda) = 0 \qquad 0 \le \lambda \le \lambda_{critical} \quad (23)$$

Where δ represents the vector from the voltage angle bus and V represent vectors of magnitude bus voltage. The basic conditions (δ_0, V_0, λ_0) are known from Conventional power flow and solution paths are still searching for. In the initial conditions is determined by λ = 0, prediction the next can be made by taking a step size as the direction of moving the path that will form curve. This direction is called vector tangent. Tangent vector is obtained by decreasing both sides of the equation power flow.

$$dF(\delta, V, \lambda) = F_\delta d\delta + F_v dV + F_\lambda d\lambda = 0 \quad (24)$$

Eq. (25) is obtained by factorizing (24) by matrices.

$$[F_\delta F_v F_\lambda] \begin{bmatrix} d\delta \\ dV \\ d\lambda \end{bmatrix} = 0 \quad (25)$$

On the left side is a derivative matrix multiplied by the derivative vector. Thus, it can be seen that on the left side of the part of the Jacobian matrix this power flow is added by one column (Fλ). During the vector tangent search, there is a problem in determining a Jacobian matrix of n×n size. Thus, a set of equations is needed to complete it which aims to specify the value of the parameter sought [14], (26), (27).

$$t = \begin{bmatrix} d\delta \\ dV \\ d\lambda \end{bmatrix}, t_k = \pm 1 \quad (26)$$

So that the following equation is obtained.

$$\begin{bmatrix} F_\delta F_v F_\lambda \\ e_k \end{bmatrix} [t] = \begin{bmatrix} 0 \\ t_k \end{bmatrix}, t_k = \pm 1 \quad (27)$$

Where this e_k is a vector line dimension with all elements are zero except k^th^ which is worth one.

F. Corrector Step

After the predictor step is done, the next step is the corrector. The corrector step is used to ascertain whether the value of the predictor is correcting in actual conditions. At this time, a series of equations are added to the equation to specify the value of all variables as well as predictors. This is intended to specialize voltage magnitude values, bus voltage angles, and load parameters λ. So, the value of Jacobian can be expressed in (28).

$$\begin{bmatrix} F(x) \\ x_{k\text{-}\eta} \end{bmatrix} = [0] \quad (28)$$

Where, value $x_k = \eta$, η is the approximation value for k^{th} of element x.

After that there is one more step, whether the goal of the predictor and corrector to know the critical point has been exceeded or not. This is quite easy if considering that the critical point is a condition where the load reaches the maximum and starts to decrease. Because of this, the vector tangent component of that indicates the value of lambda will be zero at the critical point ($d\lambda = 0$). After that the lambda value will decrease below the critical point area [15].

V. Results and Discussion

In the case 150 kV SULSELRABAR power system that consists of 7 thermal power generation, 28 buses and 34 lines. Data of bus, line, limitation of generation and cost function is taken from [16]. This data has been applied in [16] and the result is compared with the proposed method. This data is a peak load data on March 11th 2015 at 7 p.m. During peak load times, the conditions of electricity accumulate to a large extent and almost always affect the overall decrease in electrical voltage. The use of electronic devices when the voltage is down will force the devices to work longer and heavier. That is one of the causes that make the electricity use during peak load times is bigger and the thermal power plant will be operated under heavy conditions. The single line diagram of the power system is shown in Fig. 1.

NBA parameters used in the simulation are population size = 30, maximum iterations = 1000, dimension = 20, frequency of upgrading the loudness and pulse emission rate = 10, the maximal and minimal CR for Doppler Effect in echoes respectively = 0.9 and 0.1, the upper and lower pulse rate respectively = 1 and 0, the maximal and minimal frequency respectively = 1.5 and 0 and the maximum and minimum loudness respectively = 2 and 1.

The results of NBA simulation that are compared with the MIPSO simulation indicated in Table I. Economical optimization solutions that are visible by the method of NBA with the total cost IDR.299, 900,000 per hour compared with the MIPSO simulation with total cost IDR.324, 842,000 per hour. The cost that can be reduced by NBA method is IDR.24, 942,000. Not only is the total cost obtained by NBA smaller but also the power loss. The power loss that is obtained by NBA method is 17.45 MW and power loss obtained by MIPSO method is 28.30 MW.

TABLE I. RESULT COMPARISON

Bus	MIPSO [16]	NBA
6 (MW)	44.67	38.12
8 (MW)	34.42	38.73
13 (MW)	2	2
18 (MW)	5	6.62
20 (MW)	222.1	222.35
26 (MW)	219.5	219.5
28 (MW)	1.25	1.25
Ploss (MW)	28.30	17.45
Cost (IDR/h)	324,840,000	299,900,000

Besides showing a better result in economical optimization, the voltage stability is also constrained. Using the generation dispatch that is obtained by NBA applied in CPF method, the voltage stability is also better than using the MIPSO generation dispatch. The results indicated in Table II showed that there is a better improvement of critical point with average 0.92 per unit of the NBA method.

TABLE II. CRITICAL POINT COMPARISON

Bus	MIPSO (pu)	NBA (pu)
2	0.968	0.970
3	0.916	0.919
4	0.85	0.90
5	0.92	0.98
7	0.917	0.920
9	0.964	0.970
10	0.940	0.950
11	0.925	0.930
12	0.967	0.970
14	0.920	0.930
15	0.97	0.95
16	0.954	0.958
17	0.928	0.936
19	0.88	0.90
21	0.92	0.94
22	0.77	0.78
24	0.76	0.78
25	0.87	0.88
Average	0.901	0.920

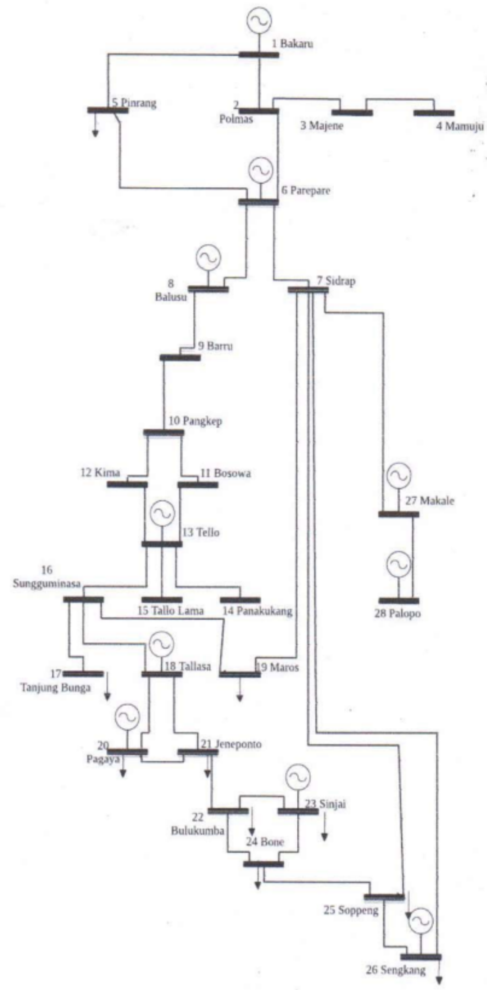

Fig. 1. Single Line Diagram of Studied System

VI. Conclusion

In this paper, the NBA for an ED problem is proposed. For the case of the studied system with a 7-thermal generator, NBA demonstrates to be the best in giving cheapest production cost and smaller power loss which is IDR.299, 900,000 per hour compared with MIPSO method which is IDR.324, 842,000 per hour. The NBA method can reduce 9.23% of production cost. The CPF method that is used to assess the voltage instability using the dispatch generation of NBA showed the system is far from the voltage instability by giving better critical point with average 0.920 per unit when compared using the dispatch generation of MIPSO.

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