OPERATIONAL COST REDUCTION OF GAS-THERMAL POWER PLANT BASED ON BAT ALGORITHM

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Abstract
An optimised operation of a thermal power plant is required to optimise fuel consumption cost. It is still high and becomes a problem of economic dispatch in the operation of the plant. Load scheduling and generator capacity are needed to get optimal plant operation, especially energy usage. This paper presented a thermal power plant operation analysis to obtain optimum operational energy costs using the Bat Algorithm (BA). The actual data of 6 thermal power plants to serve the peak loads in 2018 is used for the calculation. The problem solution is simulated and calculated using maximum (95%) capacity and the BA method. The Simulation is done by using MATLAB software. The generator unit and generator load characteristics are collected to obtain objective functions and constraint functions. BA completes this function to get the lowest energy. The BA method will be compared with the calculation of real-time energy generation without BA to analyse its accuracy. The total operational cost of the actual power plant without BA is $ 1,988,410. BA simulation gave the total energy cost is $1,653,374. So, the generated energy savings is 16.85%, or 335,036 MW reduction.

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INTRODUCTION

In general, energy needs have become human needs in the world. Energy has covered all aspects of everyday human life [1]. Likewise, in Indonesia, as a developing country, the government project to increase domestic electricity generation capacity by 35,000 megawatts is s fact that the people's need in Indonesia for electricity will continue to grow. Aan excellent electric power operating system is required to fulfil this [2].

Fuel consumption of the thermal power plants operation is significant because almost 60% of required total operating costs come from fuel oil. For this reason, therefore, analysis of Economic Load Dispatch (ELD) is essential. The purpose of this ELD analysis is to regulate the output power distribution to multiple operated generator units [3, 4, 5]. The reached result is the cost reduction of thermal power

plant operation. A good power plant operation system is determined by various things, a good heat-rate value [6]. Heat-rate compares the amount of fuel as an input and the amount of megawatt production as output from a power plant. The heat-rate value talks about the fuel consumption needed to produce energy so that the quality of electricity produced is affordable and efficient [7].

Each generator has its characteristics and its varied capacity. Gas and steam are used to operate this thermal power plant. A maximum generator capacity and good operational scheduling are needed by adjusting each unit's load at the most efficient point. The heat-rate value can be adjusted to meet the demand for energy [8]. From this problem, it is necessary to analyse the generator operations in the thermal power plant systems in terms of

fuel, especially from the gas usage, so that an optimal operating schedule is obtained [9]. Therefore, the objective function of a thermal power plant is determined. The constraint function, which is a function in the cost optimisation and optimisation process, is implemented in the ELD problem to determine the optimal scheduling of power plant operations.

ELD problem solving can be done by various methods [10]. The deterministic approach is based on mathematical engineering, while the in-deterministic approach is heuristic using probability [11]. There are several methods used to solve the ELD problem [12] [13], namely the Lagrange Multiplier [14], Merit Order method [15]. In contrast, the ELD problem's in-deterministic solution is based on a heuristic approach such as using PSO [16], Genetic Algorithm, Ant Colony Optimization and Bat Algorithm [17].

The BA is one of the newest swarm intelligence-based algorithms that simulate bats' intelligent hunting behaviour found in nature [18]. BA is a flexible optimisation method inspired by their bat-like behavior that uses sonar called echolocation to detect prey, avoid obstacles, and locate perch in the dark [19].

A BA method has been widely used in various research, which has a non-linear high level, such as wind speed forecasting. Accurate speed forecasting is essential to the dispatch and management of wind power systems to improve wind power plants' operation reliability. BA has been used in obtaining a satisfactory predictive value in Power Load Prediction [20], Forecasting Model [21], and Power System Stabilizer in Gen- Excitation [22].

This paper will use the BA method because it's one of the meta-heuristic algorithms used to solve thermal power plants' cost optimisation problems. These calculations will be done using the MATLAB application and then compared with the real operation cost of a power plant. This research goal is to analyse deterministic and in-deterministic methods to obtain optimum thermal power plants' optimum costs.

In several other algorithms, an analysis has been carried out in previous research. BA as an in-deterministic method will be applied for ELD optimisation [23]. The comparison of normal operation and BA will be presented. To arrange the amount of hourly costs per unit operating is used by real-time operation at its maximum of 95% capacity output [24].

The BA is based on bat echolocation characteristics [25]. The Echolocation of Micro bats is simulated on a computer program with three parameters: position, velocity, and bats frequency. The two methods compared were carried out with equality and inequality limits to calculate economic load dispatch [26]. The limitation of equality reflects the balance between the total generated power, with 95% capacity by the system's total required load power. The inequality limit reflects the minimum generator operation that must be fulfilled to reach the optimum total cost [27].

METHOD
Economic Load Dispatch (ELD)

BA's main parameters in reducing a thermal power plant's operational costs are ELD and generator operating time. So, some ELD problems must be solved. This research is conducted concerning ELD, where BA determines the amount of power that must be supplied from each generator unit to fulfil certain loads by dividing the load into the generating units that exist in the system optimally to minimise fuel consumption. So, to get this value is determined the function of the constraints and the objective function.

The final goal in resolving problems of ELD is an optimisation in terms of fuel costs of operation. Or it is called that the main objective of economic load dispatch is keeping the total fuel cost at a minimum level while meeting the total demand power. Principally, total generated power at the thermal power plants meets the needed demand power by consumers.

To define an ELD cost equation function from a generator operation in this study is a second-order polynomial equation as a quadratic function. These parameters can be expressed in (1), as follows:

$$F_i (P_i) = (a_i + b_i P_i + c_i P_i^2) \times fp \qquad (1)$$

Where:
F_i = Input Fuel Usage (Litre/Hour)
P = Electricity generated output Power (MW)
a, b, c = constants
fp = fuel pricing ($/k cal)
The characteristics of (1) are not linear. The minimum value can be presented in the following derivative:

$$\text{Min} \sum F_i (P_i) = \text{Min} \sum (a_i + b_i P_i + c_i P_i^2)$$

Total generated power by i-generator is calculated as follows:

$$\sum P_i = P_d + P_{loss} \qquad (2)$$

The amount of thermal power plant is used to analyse. P_d represents total demand power by consumer and P_{loss} is total transmission line losses, respectively. Transmission losses

coefficients are ignored so that, $P_{Loss} = 0$. Load Demand can be calculated by:

$P_d = \sum (P_i) - P_{Loss}$

$P_d = \sum (P_i)$ (3)

$P_{imin} < P_i < P_{i\,max}$

Pi is the generator unit's output power, where the system installed several generator units in a thermal power plant. Some available power plants will be a combined generator unit that operates made by the real-time and BA method. This method is based on the cost of fuel per hour per unit operating at its maximum generated power output. The operation is arranged by the generation start unit's priority order, the cheapest to the most expensive unit. After that, a combination priority plant can be arranged with a predetermined list to supply the required load.

These output power requirements are forecast-ed beforehand for successive operating every day. Consequently, generator units in the systems must be scheduled on an hourly basis i.e., a week ahead forecast-ed. The system's ON or OFF operation status of the Power system is scheduled together with generator units' power outputs to accomplish the forecast-ed demand for some time. With the variations in each day load curve, there is a requirement to generate enough power to meet customer load needs.

Structured steps are needed to schedule a generator to supply the required load as follows [9]:
1. Making a list of the order and capacity based on the number of the average production cost of each unit generator of (1) to (4) and compile it.
2. An operation combination of unit generators is arranged based on a list of cost priority orders to supply usage loads.
3. Analysing and calculating the ELD of any combination of the generator unit at the level of the load with the value of the maximum and minimum power limit and paying attention to the obstacles to supply the load.
4. The calculation of each generator's production costs is based on the minimum distribution cost for each active generator unit produced previously.
5. Repetition of the process from step 2 to 4 carried to the latter stages.

The Value of average fuel cost $X < (X+1) < (X+2) < (X + m)$. The priority operation (1, 2, ..., n) of the ON generator is based on the generator's cheaper operation cost. The priority cost is cheaper. The power plant with an average fuel cost is \$ X is cheaper than the power plant with an average fuel cost of \$X+1. The first power plant (\$X) is the cheapest operating cost as the priority. So, the last priority (end priority) operated generator is the most expensive operator cost, as shown in Table 1.

Table 1. Operation Cost Priority

No.	Power Plant	Average Fuel Cost ($/MWh)	Priority
1	G(n-1)	X	1
2	G(n-0)	X +1	2
3	G(n-5)	X +2	3
..	G(n-x).	….	..
n-2	G(n-x+1)	X + (m-2)	
n-1	G(n-4)	X + (m-1)	n -1
N	G(n-2)	X + (m)	N

Bat Algorithm (BA) Method

Bats are in the world as mammalian animals that they are fascinating animals because bats are the only mammal's animal with 2wings and have advanced capability of accredited echolocation. They have unique characteristics that can fly at high speed without an accident and random distance [9].

The principle of a bat working the echolocation of a bat is to emit a thunderous sound pulse and sensitive listen for the echo that bounces back from the surrounding objects. So, the BA is a metaheuristic algorithm for global optimisation. It was inspired by small bats' echolocation behaviour, with varying pulse rates of emission and loudness.

BA Method is a new bionic intelligent optimisation algorithm to simulate the foraging behavior and the bats' echolocation principle. Most bats use echolocation to a certain degree; among all the species, small bats are a famous example as small bats use echolocation extensively while large bats do not. BA is used more and more attention because of its simple, fewer parameters, strong robustness, and the advantage of easy implementation. Firstly, BA was proposed to solve the problem with the continuous real search space. The BA method is used in this research to optimise the operation fuel cost of a thermal power plant. This operated algorithm is based on the echolocation characteristics of small bats.

It can be idealised assumed as follows, to simplify the characteristics of the used BA method:
1. In a certain sense, the distance is not usually. Bats use echolocation ability. All bats can also find the difference between food ingredients/ prey animals and the surrounding situation in a great miraculous way.
2. Bats fly freely at high speed and are stable (v_i) and at various positions (x_i) with a fixed frequency (f_{min}), varying the wavelength (λ)

and loudness (A0) to find their prey. They can automatically adjust wavelength or frequency pulse emits a soft voice and adjust the pulse emission levels $\beta \in [0,1]$ depending on their intended targets' closeness.

3. The level of loudness can be done in many diverse ways. But it is assumed that the loudness's value varies from large or positive (A0) to a constant value of minimum (A_{min}).

By using a principle of the BA, the generator optimisation analysis stages are done based on the input-output curve of the used generator obtained from (1)-(3). The generated output power by the 6 (six) generators and operation costs are calculated and analysed by (1) until (4) stages.

After that, the based-on priority scheduled generator is done to determine which plants are on and off. The operated parallel generator will serve the existing needed load. In managing the scheduling of generator units using dynamic programs [18]:

$$F_n (X) = Min \{G_n(Y) + F_{n-1} (X-Y)\} \quad (4)$$

Where $F_n (X)$ is minimum fuel cost for generator units (n) to loads X MW ($/h), $G_n(Y)$ is Fuel costs for units (n) to loads Y MW in $/hour, $F_{n-1} (X-Y)$ is minimum fuel cost for other generator units for (n-1) to loads (X-Y) MW ($/h) and n is value from 2, 3, 4, …., n. Equation (4) is a limited condition by:

$$Y_{nmin} < Y < Y_{nmax}$$
$$X_{n-1min} < (X-Y) < X_{n-1max}$$

After that, the generator unit that will operate is scheduled to serve the required load. Optimisation of power plant costs is done by determining rules for varied positions (x_i) and stable speeds (v_i) in the search dimension. The used generators of power plants are operated based on priority operation cost.

The foraging space of bats is the d dimension. At the time (t-1), the i-th bat's location and flight velocity are x_i^{t+1} and $v_i^{t+1,}$ respectively, and X* is the current global optimal location. The researched new solution (x_i^t) is calculated by using of the BA. The achieved solution (x_i^t) is the bat position to-(i) with the iteration to-(t) and the speed (v_i^t) is the bat velocity to-(i) with the iteration to-(t), can be presented as follows [12]:

$$f_i = f_{max}+ (f_{max} - f_{min}) \ \beta \quad (5)$$

$$v_i^{t+1} = v_i^t + (x_i^t \ X^*) f_i$$
$$x\_i^{(t+1)} = x_i^t + v_i^t \quad (6)$$

where the Constants $\beta \in [0,1]$ is a random vector taken from a uniform distribution. Here (x^*) is the best global solution obtained after comparing all solutions between all bats (n) [17]. At first, each bat is spread randomly with frequencies taken from the uniform distribution [f_{min}, f_{max}]. The calculated result will be compared with the real-time of the total operation cost.

In the position search section, after the obtained solution is defined by comparing among the best solutions at (t), then the new gotten solution for each bat that is generated locally using a random way is defined as follows:

$$x_i^{t+1} = x^* + \in A^t \quad (7)$$

Where $\varepsilon \in [-1,1]$ is a random number, while (A^t) is the average loudness of all the bats at this time step (t) [18]. So, the update of velocity (v_i) and position (x_i) of the bat is affected by loudness (A_i) and the rate (r_i) of pulse emission at each iteration. After the obtained solution result in a better process, a new location or new solution value will be chosen (rand < A_i & f (x_i) < f(x^*)) [10]. Increased pulse emission (r_i),

$$r_i^{t+1} = r_i^t [1- e^{(-\gamma t)}] \quad (8)$$

And decreased the loudness (Ai),

$$A_i^{t+1} = \alpha A_i^t \quad (9)$$

where, the loudness level (γ) and pulse emission rate (α) are constants. Besides that, any value is between 0 and 1 or $0 < \alpha < 1$ and $\gamma > 0$. The Calculation step by step is done to get the minimum result. With the calculation steps, the best solution is found the result with a minimum operating cost of a thermal power plant and obtained by the restrictions provided in the power plant operation.

Economic Load Dispatch (ELD) Modelling

One of the most considerable topics in modern powers plant systems is Economic Load Dispatch (ELD). The ELD problem is solved; many methods were developed and used at different power plant systems [15]. Economic Load Dispatch of a power system is essential in controlling and planning that power system. The main goal of ELD is distributed total demand power among the committed thermal generator units with minimum production cost by satisfying a set of equality and inequality constraints. So, ELD plays a huge role in operated power plants. For this reason, a lot of researchers studied this issue. Several optimisation techniques developed and applied to the ELD problem [11].

This research is calculated by supported using real-time data of the power plant. This data are actual data of thermal power plants from the East Java Region. In this region are six power Plants which are connected in parallel with the 150kV system [12]. The calculation is based on

the power plant's condition operation in the peak load condition of 2018.

The ELD calculation results are used for the main parameters to simulate thermal power plant fuels' operating costs, whose energy sources use fossil fuels [22]. The collection of field data taken from Power System in East Java, which are available generator capacity, is greater than the electrical load demand. Proper scheduling generators and ELD - analysis are supportive for the acquisition of optimal fuel costs.

In Power Generation allowed for a maximum operating within a limited time, or about 2 hours of operation at 100% power load. However, if any part of the generator unit does not operate optimally, the maximum load can be reduced by up to 90% operating load power [6]. Based on safe operating conditions, can be determined the plant's capacity to produce power with minimum and maximum limits. The continuous loading of the analysis in this paper has a maximum limit of 95% of the maximum load.

Table 2. Operated Power Plant Capacity

Power Plant	Pmin-max (MW)	Pmax Operated 95% (MW)
G1	100 300	285
G2	80 160	152
G3	160 350	333
G4	10 32	30
G5	310 560	532
G6	408 650	618
Total		**1,950**

The data of six units of the power generator are 95% generated operated power from PLN each can be found in Table 2. The power plant G1 can generate an output power from 100MW as minimum load until 300 MW (maximum load), but it will be generated only 95% of capacity for operation (285MW). Based on the basic principle, the power plant's total output power meets the demand load requirements. The total maximum operated thermal power is 1950 kW of 2052 kW.

The optimisation performance is supported by carrying out the analysis and the simulation experiments on six cost functions.

Power Plant Modeling

In determining the input characteristics, Power Output did with polynomial regression of order 2 of the matrix. The Gauss-Siedel method is used to make iteration. To create a modeling system in the generation consisting of 6 units of power plants must be known to the fuel consumption required to produce specific output power. Fuel consumption with hate rate value derived from field data in units (kcal/kWh). For example, this hate rate and generated Energy of power plant G1 will be calculated for each generated energy (100MW to 300MW). The result can be shown in Table 3. To get the energy of 243,500.00 kcal/hour is need 2,435 hate rates.

Gas flow from the power plant unit is used to get the cost of the power plant. The results from the multiplication of the gas price ($/mm BTU) with the gas flow (mm BTU/h) or coal price ($/Ton) with Coal flow (Ton/h) will get the cost of generated power ($/h). The price was $ 9.00/mm BTU (gas) and $ 100.89/Ton (Coal). Conversion value for gas is 3.97×10^{-6} mm BTU/ kcal and 1.43×10^{-6} Ton/ kcal for coal.

This calculation is used data of power plant G1 as the third priority. The exchange rate is $ to Rp.15,158.23. Gas Flow is a multiplication of energy with fuel conversion. The result of the production costs can be seen in Table 4. Based on the data in Table 3 and Table 4, the settlement matrix can be made to get the value of the constants a, b and c as follows a = 2,234.551, b = 67.169 and c = - 0.013. Gauss-Seidel iteration method with as much as 5874 times obtained quadratic function. An input-output characteristic equation power plant unit (PLTGU_1) is presented as (1):

$$Fi (Pi) = (2,234.551 + 67.169\ Pi + 0.013\ Pi^2)$$

This formula as cost function is relevant for only Power plant G1. For the other Power plant has self-cost function.

Table 3. Power plant G1 Hate rate.

No.	Power Plant G1	Heat Rate (kCal/kWH)	Energy (kCal/h)
1	100	2,435.00	243,500.00
2	122	2,361.00	288,042.00
3	144	2,286.00	329,184.00
4	167	2,212.00	369,404.00
5	189	2,138.00	404,082.00
6	211	2,083.00	439,513.00
7	233	2,058.00	479,514.00
8	256	2,032.00	520,192.00
9	278	2,007.00	557,946.00
10	300	1,983.00	594,900.00
Average	200	**2,159.50**	**422,627.73**
	Total		**4,226,277.30**

Table 4. Cost calculation of Power plant G1

P-Plant G1	Gas Flow (Mmbtu/h)	Cost ($)	Cost (Rp)
100	966.29	8,697	131,831,126.00
122	1,144.99	10,305	156,205,560.00
144	1,310.57	11,795	178,791,323.00
167	1,463.05	13,167	199,588,414.00
189	1,602.43	14,422	218,611,993.00
211	1,745.40	15,709	238,120,635.00
233	1,905.32	17,148	259,933,328.00
256	2,060.70	18,546	281,124,534.00
278	2,212.21	19,910	301,800,359.00
300	2,361.21	21,251	322,127,546.00
Average		15,095	228,812,433.20
Total			**2,288,124,332.00**

By the same calculation process method is also applied for five other generating units and the calculation results are shown in Table 5. In this table will be also presented the results calculated heat rate and cost function equation.

Table 5. Heat Rate and Cost Functions

Power Plant	Heart Rate (kCal/kWH)	Cost Function ($/H)
G1	2,435 / 1,983	$2,234.551 + 67.169 P - 0.013 P^2$
G2	3,558 / 3,183	$0.020155 + 140.484 P - 0.167 P^2$
G3	3,183 / 2,848	$6,213.32 + 65.609 P + 0.054 P^2$
G4	3,542 / 3,399	$0.0036 + 128.823 P - 0.232 P^2$
G5	2,456 / 2,280	$-514.075 + 40.802 P - 0.0124 P^2$
G6	2,604 / 2,371	$5,063.18 + 23.418 P + 0.0045 P^2$

The thermal power plant's performance is measured based on a value called heat rate, with the unit commonly used is kCal/kWh. The parameter represents the input energy value (kCal) than the energy produced in (kWh). The real-time power plant is operated to serve demand can be shown in Figure 1. The figure presents a Load increase with increasing numbers of output power generation system. The peak load of this thermal power plant at this figure shown that peak load occurs at 18:00.

RESULTS AND DISCUSSION
Real Power Plant Operating

A daily load curve or load profile is a chart illustrating the variation in demand / electrical load over a day (24 hours) in a power plant system. The researcher had used this information to plan how much power they will need to generate at any given time to serve demand.
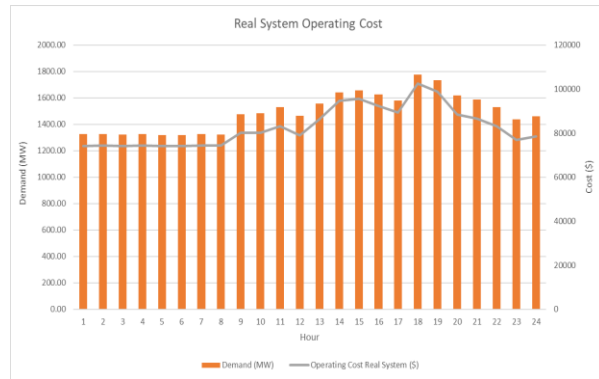

Figure 1. Real Operating Cost and Demand curve

Figure 1 shows the real system operating cost of the power plant and Demand load. These demand load data and the used power plant based on real data on October 17, 2018. The obtained real data of the power plant can be used to make the figure.

Based on the real data calculation of operated Generator scheduling, the total cost is $1,988,410. The operated Power plant consists of 6 generators that work a full day (24 hours). Each generator has needed an average fuel cost, which will determine the priority position. Average Fuel Cost and Priority are shown in Table 6.

Table 6. Average Fuel Cost Data and priorities

No.	Power Plant	Average Fuel Cost ($/MWh)	Priority
1	G5	34.07	1
2	G6	35.42	2
3	G1	75.47	3
4	G3	104.44	4
5	G2	119.46	5
6	G4	123.40	6

The first priority G5 is the cheapest operated generator to serve the demand load. The most expensive power plant G4, is operated as the last alternative to service need demand. All Generators are operated to service loads during peak loads in October 2018, except power plant PLTG-4, the power plant with the smallest output power not operated at peak load.

This power plant is the most expensive operating cost and as a standby unit generator. The peak load occurs from 18:00 to 22:00, and all generator generates the maximum power is 1,774 MW at 18.00. The Peak Load curve is presented in Figure 2.
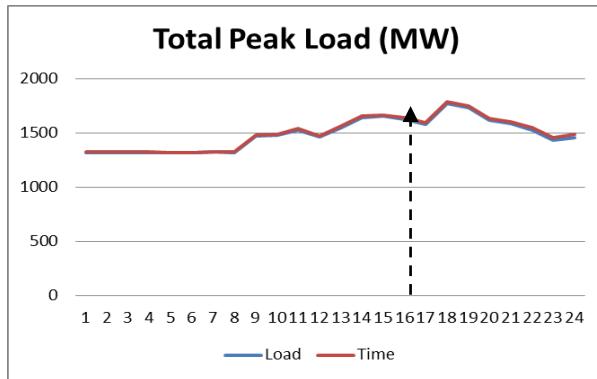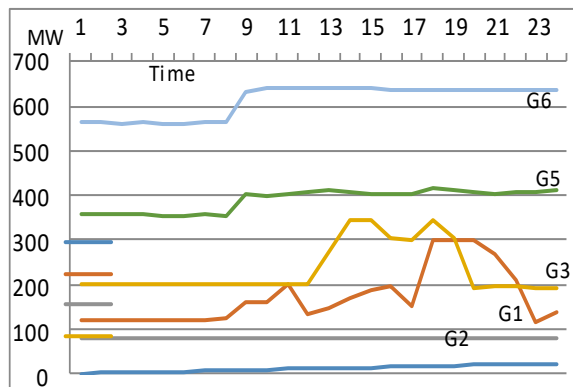
Figure 2. Total Peak Load for 6 Generators

Figure 3. Operated each Generator for Peak Load

All six generator will be operated, but G_4 is a standby unit Generator to generate power to serve and support the peak load as real-time data. G_1, G_2, G_3, G_5 and G_6 will be operated. The real Operation of the 6 Generator at peak load on October 17, 2018, is illustrated in Figure 3. The figure shows the operated generator of a thermal power plant in Peak Load time.

Bat Algorithm Method Results

To optimise the power plant is done by using the BA method and supported by ELD simulation. In simulating ELD with the BA method, it is compiled by the algorithm of (5)-(9). This algorithm is simulated using MATLAB R2018a application software which can be seen in Figure 4. The algorithm is assumed parameters for 24 hours, 100 bats with frequency 0-100, 6 Generators, minimum- and maximum capacity [7].

Figure 4. Data of BA with MATLAB [7]

The BA Method supported parameters consists of:
o The number of bats search variables is recommended between 20 and 100 (100 bats) as total bats [19].
o A total Iteration to achieve stable results with 1000 recommended iteration [5].
o A total Dimension is the number of used Generators of power plant (six units).
o A Total Load is a daily operating time of 24 Hours.
o Lb is Lower Bound Limit power plant (P_{min}) and Ub is Upper Bound Limit Power (P_{max})
o The minimum and maximum frequency are used to calculate the bat's velocity by calculating random vectors, then set the frequency (fmin = 0; fmax = 100) [18].
○ The Value of Pulse Emission Rate (α) with range 0 < α <1 and Loudness Level (γ) with range γ> 0. By simplifying the constants, a value (α = 0.9; γ = 0.9) is used [18].

The calculated result of the generated thermal power cost Function is shown in Table 7. Each power plant has ELD with its constant that it will be calculated. For example, ELD formula of PLTGU_1 is 2,234.551+ 67.169 P - 0.013 P2.

Table 7. Generated Power cost Function

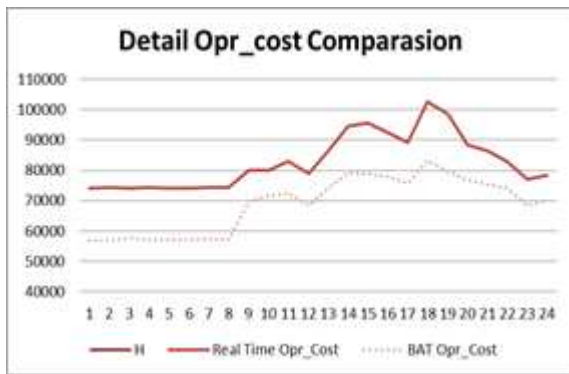| Power Plant	Fcost ($/h)
G1	$2,234.551 + 67.169 P - 0.013 P^2$ = 5,874,000,000
G2	$0.020155 + 140.484 P - 0.167 P^2$ = 25,374,000,000
G3	$6,213.32 + 65.609 P + 0.054 P^2$ = 16,353,000,000
G4	$0.0036 + 128.823 P - 0.232 P^2$ = 4,416,000,000
G5	$-514.075 + 40.802 P - 0.0124 P^2$ = 43,331,000,000
G6	$5,063.18 + 23.418 P + 0.0045 P^2$ = 92,889,000,000

Figure 5. Operating Cost Comparison Curve

By using BA Method calculated cost function of power plant can be seen in Table 7. In this table there are six generators with six cost function equations.

The operation cost for every hour can be known and simulated. Figure 5 presented the comparison of real-time operation cost and with BA calculated detail operating cost. Based on Figure 5, it appears that the real load curve significantly increases costs at 9.00 and 18.00 because the start-up of the power plant must be carried out to meet the generated total power.

In the curve in Figure 5, it can be seen that there has been an increase in operational costs at 9.00 and 18.00, while at 12.00 and 17.00 there has been a slight decrease in costs. This is because at 12.00 and 17.00 it is likely a break time for technician workers so that some electrical equipment is not used and power consumption decreases. At 17.00-22.00, the lights have been turned on. This is the peak load time. It is seen that the trend in operation costs follows the load curve profile.

Table 8 presents six units of generated power for each Generator (G1, …, G6 in MW) and total generated power. The total fuel consumption cost ($/h) for daily operation (24 hours) as an operation by BA method calculated cost could be shown in Table 9. To get the efficiency value, the thermal power plant must usually attend to its fuel consumption at peak load as a priority scale.

The calculated results of the used generator using BA, the total cost, is $1,653,374, shown in Table 9. Thus, the real-time generator operation cost is more expensive than using BA calculated operation cost.

The curve shape of the BA shows the trend of similarity in operating costs to the real system. This is because the selection of loads generated using a dynamic program using BA is then randomly optimised.

Table 8. BA Result of operated Power Plant

H	Calculated Result with BAT Method (MW)						
	G-1	G-2	G-3	G-4	G-5	G-6	Total
1	118.9	0.00	0,00	0,00	558.1	648.0	1,325.0
2	122.1	0.00	0,00	0,00	556.1	647.0	1,325.2
3	144.9	0.00	0,00	0,00	548.9	627.8	1,321.6
4	126.0	0.00	0,00	0,00	554.1	644.0	1,324.1
5	131.1	0.00	0,00	0,00	537.0	649.0	1,317.1
6	135.0	0.00	0,00	0,00	543.2	640.0	1,318.2
7	136.0	0.00	0,00	0,00	549.2	640.3	1,325.5
8	133.9	0.00	0,00	0,00	546.1	642.1	1,322.0
9	153.2	0.00	164.9	0,00	544.9	611.1	1,325.1
10	135.0	0.00	205,1	0,00	525.9	615.2	1,474.0
11	160.9	0.00	180.5	0.00	546.2	642.2	1,481.8
12	108.1	0.00	175.6	0.00	547.3	634.0	1,530.0
13	214.1	0.00	163.6	0.00	542.2	636.1	1,465.0
14	299.0	0.00	160.0	0.00	560.0	623.1	1,325.0
15	285.4	0.00	160.0	0.00	560.0	649.9	1,556.30
16	250.9	0.00	173.7	0.00	555.9	644.3	1624.8
17	227.9	0.00	171.3	0.00	558.0	623.0	1580.2
18	280.1	0.00	203.3	0.00	551.0	639.2	1775.6
19	299.0	0.00	160.3	0.00	551.9	604.3	1731.5
20	248.1	0.00	160.0	0.00	560.1	649.9	1618.1
21	207.2	0.00	173.4	0.00	560.1	647.1	1587.8
22	208.1	0.00	180.7	0.00	517.2	625.1	1531.1
23	133.2	0.00	171.9	0.00	485.2	647.3	1437.6
24	153.2	0.00	174.2	0.00	525.3	609.9	1462.6

Table 9. Operational Cost with BA Method

H	Operational Cost with BAT Calculation ($)						
	G-1	G-2	G-3	G-4	G-5	G-6	Total
1	100.34	0.00	62,13	0,00	183.94	221.28	56.770.
2	102.39	0.00	62,13	0,00	183.42	220.97	56.891.
3	116.95	0.00	62,13	0,00	181.47	215.37	57.592.
4	104.94	0.00	62,13	0,00	182.87	220.12	57.006.
5	108.16	0.00	62,13	0,00	178.22	221.55	57.006.
6	110.64	0.00	62,13	0,00	179.90	218.92	57.159.
7	111.30	0.00	62,13	0,00	181.54	219.01	57.399.
8	109.95	0.00	62,13	0,00	180.70	219.55	57.233.
9	122.17	0.00	184,97	0,00	180.38	210.54	69.807.
10	110.64	0.00	219,41	0,00	175.15	211.73	71.693.
11	127.07	0.00	198,15	0,00	180.72	219.58	72.552.
12	93.41	0.00	193,95	0,00	181.02	217.18	68.557.
13	160.22	0.00	183,89	0,00	179.63	217.79	74.153.
14	211.57	0.00	180,93	0,00	184.45	214.03	79.099.
15	203.47	0.00	180,93	0,00	184.46	221.82	79.068.
16	182.70	0.00	192,41	0,00	183.37	220.19	77.867.
17	168.68	0.00	190,38	0,00	183.91	213.98	75.695.
18	200.31	12.53	217,83	0,00	182.02	218.71	83.140.
19	211.53	14.10	181,15	0,00	182.29	208.57	79.763.
20	181.00	0.00	180,93	0,00	184.49	221.83	76.825.
21	155.91	0.00	192,10	0,00	184.50	221.02	75.353.
22	156.52	0.00	198,34	0,00	172.70	214.61	74.217.
23	109.49	0.00	190,90	0,00	163.65	221.06	68.510.
24	122.22	0.00	192,82	0,00	174.96	210.19	70.019.
Total Operational Cost with BAT ($)							1,653,374
Real Operational Cost ($)			1,988,410.03			Dev.	335,016
Efficiency (%)							16.85

The cost-efficiency that is resulted in a BA is 16.85% or $335,036 from the actual or real cost. A comparison between real operations cost and BA simulation results and deviation (%) every hour and deviation value can be presented in Table 10. The table will describe the deviation in % per hour and compare real-time operation cost and BA calculated operation cost of the thermal power plant hourly. The minimum deviation is

10.53% at 10.00 am, and the maximum deviation occurred at 01.00 am with a value of 23.48% as the biggest. The highest thermal power plant operation costs occur significantly from 1:00 pm to 6:00 pm as load peak time. The thermal power plant's operation cost (PLTU) fell again from 10.00 pm to 01.00 am, as shown in Table 10.

Table 10 is presented the by BA Method calculated operational cost every hour for 6 Generator units. To turn on a Generator in PLTGU needs 6-8 hours starting time and required operation cost.

Table 10. Comparison cost and deviation

H	Real-Time Opr. Cost	BA Opr. Cost	Dev. (%)
1	74,192.51	56,770.21	**23.48**
2	74,248.11	56,891.21	23.38
3	74,212.78	57,592.44	22.40
4	74,247.84	57,005.83	23.22
5	74,024.73	57,006.07	22.99
6	74,022.42	57,158.95	22.78
7	74,247.01	57,399.18	22.69
8	74,374.64	57,233.44	23.05
9	79,997.69	69,806.87	12.74
10	80,130.14	71,692.94	**10.53**
11	83,064.02	72,552.09	12.66
12	78,855.61	68,556.64	13.06
13	86,397.04	74,153.08	14.17
14	94,531.74	79,098.79	16.33
15	95,669.01	79,067.68	17.35
16	92,381.32	77,867.02	15.71
17	89,275.04	75,694.84	15.21
18	**102,559.00**	**83,140.08**	**18.93**
19	98,731.25	79,763.00	19.21
20	88,312.79	76,824.83	13.01
21	86,484.23	75,352.80	12.87
22	83,009.27	74,217.40	10.59
23	76,992.82	68,509.59	11.02
24	78,448.98	70,018.85	10.75
Total	**1,988,410**	**1,653,374**	**16.85**
Efficiency			**16.85**

The BA method can produce a more efficient or smaller operation cost than real-time operated cost. Bat's unique character can occur because the BA manages to create a loading combination of more efficient thermal power plants. The efficiency value obtained from this BA research reached 16.85%.

CONCLUSION

This paper presents the operational cost reduction of thermal power plant based on the BA Method. Optimisation of the loading arrangements in thermal power plants units of 150 kV systems in East Java province is very suitable for the ELD based on the BA method. The operation cost result of the BA method has to be compared with the real-time operation of the Thermal Power plant. Based on the calculation with a loading capacity factor of 95%

of the generated power, it is found that the total operational cost at peak load for one day is $ 1,988,410, while the calculation using the BA method shows the total operating cost at $ 1,653,374. Thus, the BA method user can reduce a thermal power plant's operating costs by $ 335,036 or a savings of 16.85%.

REFERENCES

[1] I. F. Hanafi and I. R. Dalimi, "Economic Load Dispatch Optimation of Thermal Power Plant Based on Merit Order and Bat Algorithm," *2019 IEEE International Conference on Innovative Research and Development (ICIRD)*, Jakarta, Indonesia, 2019, pp. 1-5, DOI: 10.1109/ICIRD47319.2019.9074734

[2] U. G. Knight, *Power Systems Engine and Mathematics*, 1st Ed. International Series of Monographs in Electrical Engineering, Pergamon, UK, 1972

[3] X. Wang, and K. Yang, "Economic load dispatch of renewable energy-based power systems with high penetration of large-scale hydropower station based on multi-agent glowworm swarm optimisation," *Energy Strategy Reviews*, vol. 26, Nov. 2019, DOI: 10.1016/j.esr.2019.100425

[4] M.B. Shareh, et al., "An improved bat optimisation algorithm to solve the tasks scheduling problem in open shop," *Neural Computing and Application,* 2020, DOI: 10.1007/s00521-020-05055-7

[5] M. Saka et al., "Analysis of Economic Load Dispatch with a lot of constraints using Vortex Search Algorithm", *Advances in Science Technology and Engineering Systems Journal*, vol. 2, no. 6, pp. 151-156. December 2017, DOI: 1025046/aj020619

[6] I. F. Hanafi, "Optimisation of Economic Load Dispatch for Thermal Power Plant based on Merit Order and Bat algorithm", *Thesis*, Faculty of Engineering, Universitas Indonesia, 2019

[7] M. Suman, et. all, "Solution of Economic Load Dispatch problem in Power System using Lambda Iteration and Back Propagation Neural Network Methods," *International Journal on Electrical Engineering and Informatics*, vol. 8, no. 2, pp. 347-355, June 2016, DOI: 10.15676 /ijeei.2016.8.2.8]

[8] A. Arabkoohsar and M. Sadi, "Thermodynamics, economic and environmental analyses of a hybrid waste–solar thermal power plant," *J. Therm. Anal. Calorim.,* April 2020, DOI: 10.1007/s10973-020-09573-3

[9] L. A. Wulandhari, S. Komsiyah, and W. Wicaksono, "Bat Algorithm Implementation on Economic Dispatch Optimization Problem," *Procedia Computer Science*, vol. 135, 275-282, 2018, DOI: 10.1016/j.procs.2018.08.175

[10] J. N. Kuk et al., "An empirical analysis of constraint handling on evolutionary multi-objective algorithms for the Environmental/Economic Load Dispatch," *Experte Systems with Applications,* vol. 165, 2021, DOI: 10.1016/j.eswa.2020.113774

[11] T. Niknam, R. Azizipanah-Abarghooee, M. Zare and B. Bahmani-Firouzi, "Reserve Constrained Dynamic Environmental /Economic Dispatch: A New Multi-Objective Self-Adaptive Learning Bat Algorithm," in *IEEE Systems Journal*, vol. 7, no. 4, pp. 763-776, Dec. 2013, DOI: 10.1109/JSYST.2012.2225732.

[12] NN, "Electricity Supply Business Plan (RUPTL) 2019-2028", *PT. PLN (Persero)*, Jakarta, Indonesia, 2019

[13] A. Rudolf and R. Bayrleithner, "A genetic algorithm for solving the unit commitment problem of a hydro-thermal power system," in *IEEE Transactions on Power Systems*, vol. 14, no. 4, pp. 1460-1468, Nov. 1999, DOI: 10.1109/59.801929

[14] R. N. Priyanto, R. S. Wibowo and O. Penangsang, "Perkiraan Biaya Operasi dengan Mempertimbangkan Kondisi Kontingensi di Sistem Jawa Bali 500 KV," *Jurnal Teknik ITS, vol.* 2., no. 1, pp. B1-B6, 213, DOI: 10.12962/j23373539.v2i1.2214

[15] T. O. Ting, M. V. C. Rao and C. K. Loo, "A novel approach for unit commitment problem via an effective hybrid particle swarm optimisation," in *IEEE Transactions on Power Systems*, vol. 21, no. 1, pp. 411-418, Feb. 2006, DOI: 10.1109/TPWRS.2005.860907

[16] S. Virmani, E. C. Adrian, K. Imhof and S. Mukherjee, "Implementation of a Lagrangian Relaxation Based Unit Commitment Problem," in *IEEE Power Engineering Review*, vol. 9, no. 11, pp. 34-34, Nov. 1989, DOI: 10.1109/MPER.1989.4310370

[17] X. Xia and A. M. Elaiw, "Optimal dynamic economic dispatch of generation: A review," *Electrical. Power System Research,*" vol. 80, no. 8, pp. 975–986, August 2010, DOI: 10.1016/j.epsr.2009.12.012

[18] N. Talbi, "Design of Fuzzy Controller rule base using Bat Algorithm", *Energy Procedia*, vol. 162, pp. 241-250, April 2019, DOI: 10.1016/j.egypro.2019.04.026

[19] C. Qi, Q. Zhang, X. Tian, K. Zhang and W. Tang, "Power load prediction method based on kernel extreme learning machine with t-distribution variation bat algorithm", *IOP Conf.: Materials Sci. and Eng.*, vol. 631, no. 4, 2019

[20] Y. Zhang and L. Chen, "A Hybrid Forecasting Model Based on Modified Bat Algorithm and ELM: A Case Study for Wind Speed Forecasting", *IOP Conf. Series: Earth and Env. Sci.*, vol.153, no. 2, 2018

[21] D. Rahmalia et al., "Goal programming on optimal pairings selection from flight schedule using Bat Algorithm" *Journal of Physics: Conf. Series*, vol. 1490, 2020

[22] M. R. Djalal and Herman HR, "*BAT Algorithm Implementation to Optimally Design the Stabilizer Power System on The SUPPA Generator*," *SINERGI*, vol. 23 no. 3, pp. 233-238, 2019, DOI: 10.22441/sinergi.2019.3.007

[23] K. Syah et al., "Analisa Perbandingan Economic Dispatch Pembangkit menggunakan Metode Lagrange dan CFPSO", *Journal EECCIS*, vol. 6, no. 1, pp. 91-96, June 2012.

[24] X. S. Yang, "A New Metaheuristic Bat-Inspired Algorithm," In: González JR, Pelta D.A., Cruz C., Terrazas G., Krasnogor N. (eds) *Nature Inspired Cooperative Strategies for Optimization (NICSO 2010). Studies in Computational Intelligence*, vol. 284, 2010, Springer, Berlin, Heidelberg, DOI: 10.1007/978-3-642-12538-6_6

[25] V. Julianto, "Penerapan Hybrid Bat Algortihm (BA) dengan Differential Evolution (DE) untuk mengoptimasi Model Multiobjektif," *Jurnal Sains and Informatika*, vol. 2, no. 2, pp. 130-135, Nov. 2016

[26] Z. G. Hassan, M. Ezzat and A. Y. Abdelaziz, "Solving unit commitment and economic load dispatch problems using modern optimisation algorithms," Int. Journal of Eng., Sci. and Tech., vol. 9, no. 4, pp. 10-19, 2017

[27] M. Fan, Z. Zhang and C. Wang, *Mathematical Models and Algorithms for Power System Optimization*, 1st Ed. ScienceDirect, Academic Press, UK, 2019