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Mr. M. Febriansyah
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Congratulation! We are pleased to inform you that your article entitled

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

was reviewed by the reviewer and got a positive opinion. The paper has been ACCEPTED for publication at *SINERGI* and to be published on June 30, 2021 (Vol. 25 No. 2). Attached herewith the final version of the article, Similarity Check with Turnitin and *the Copyright Transfer Agreement*. Please send ***the Copyright Transfer Agreement*** as soon as possible via this email.

Again, thank you for working with *SINERGI*. I believe that our collaboration will help to accelerate the global knowledge creation and sharing one step further. *SINERGI* looks forward to your confirmation. Please do not hesitate to contact me if you have any further questions.

Sincerely,

Prof. Dr. Andi Adriansyah,

Friday, February 26, 2021
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OPERATIONAL COST REDUCTION OF GAS-THERMAL POWER PLANT BASED ON BAT ALGORITHM

Agus Sofwan[1*], M.Febriansyah[1], Sugeng[2] (10pt Bold)
[1]Department of Electrical, Institute Sains dan Teknologi Nasional (ISTN)
Jl. M.Kahfi II, Jagakarsa, Jakarta 12640, Indonesia asofwan@istn.ac.id
[2]Electrical Dep. Universitas Islam '45 UNISMA, Bekasi, Indonesia
*Corresponding Author Email: asofwan8@gmail.com

Abstract -- *An optimized operation of thermal power plant is required to optimize fuel consumption cost. In fact, it is still high and becomes a problem of economic dispatch in the operation of plant. Load scheduling and generator capacity are needed to get optimal plant operation especially in terms of energy usage. In this paper presented on the analysis of thermal power plant operation in order to obtain optimum operational energy costs by using 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 by using maximum (95%) capacity and BA method. The Simulation is done by using Mathlab software. Heat rate characteristics of generator unit and generator load are collected to obtain objective functions and constraint functions. This function is completed by BA to get the lowest energy. To analyze its accuracy, the BA method will be compared with the calculation of real time energy generation without BA. The total operational cost of 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.*

Keywords: Optimization, Economic Dispatch, Thermal Power Plant, Operational Cost, Real Time.

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INTRODUCTION

In general, the 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 needs in Indonesia for electricity will continue to increase. To fulfill this, a good electric power operating system is required [2].

Fuel consumption of the thermal power plants operation is very important because almost 60% of required total operating costs come from fuel oil. For this reason, therefore, analysis on Economic Load Dispatch (ELD) is very necessary. The purpose of this ELD analysis is to regulated 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 a variety of things, one of which is a good heat-rate value [6]. Heat-rate is a comparison value between the amount of fuel as 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 own characteristics and own varied capacity. Gas and steam are used to operate this thermal power plant. To meet the demand for energy, a maximum generator capacity and good operational scheduling is needed by adjusting the load on each unit at the most efficient point, so that the heat-rate value can be adjusted [8]. From this problem, it is necessary to analyze 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 thermal power plant is determined and the constraint function which is a function in the cost optimization and optimization process is implemented in the ELD problem, so that optimal scheduling of power plant operations can be determined.

The ELD problem Solving can be done by various methods [10]. The deterministic approach is based on mathematical engineering while the un-deterministic approach is heuristic using probability [11]. The used methods to solve of the ELD problem [12] [13], namely the Lagrange Multiplier [14], Merit Order method [15] while the un-deterministic solution of EDL problem is based on 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 simulates the intelligent hunting behavior of bats found in nature [18]. BA is an flexible optimization method inspired by their bat-like behavior that uses sonar called echolocation to detect prey, avoid obstacles, and locate perch in the dark [19]. BA method has been widely used in a variety of 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 for the improvement in operation reliability of wind power plants. BA has been used in obtaining a satisfactory predictive value [20][21].

In this paper will use the BA method, because it's one of the metaheuristic algorithms that are used to solve cost optimization problems in thermal power plant. The proses of these calculations will be done by using the MATLAB application and then is compared with real operation cost of power plant. This research goal is specialized to the analysis of deterministic and un-deterministic methods to obtain optimum costs in thermal Power plant. In several other algorithms an analysis has been carried out in previous research. BA as an un-deterministic method will be applied for ELD optimization [22]. The comparison of normal operation and BA will be presented. To arrange amount of hourly costs per unit operating is used by real time operation at its maximum of 95% capacity output [23],

The BA is based on bat echolocation characteristics [24]. The Echolocation of Micro bats are simulated on a computer program with 3 parameters that are position, velocity and frequency of bats. The two methods compared were carried out with the limits of equality and inequality to calculate economic load dispatch [25]. Limitation of equality reflects the balance between the total generated Power with 95% Capacity by the total required load power on the system. The inequality limit reflects the min- and maximum generator operation that must be fulfilled so that the optimum total cost is reached [26].

Methods

A. Economic Load Dispatch

The main parameters of BA in reducing the operational costs of a thermal power plant are ELD and generator operating time. So, there are some ELD problems that must be solved. This research 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 on the generating units that exist in the system optimally with the aim of minimizing fuel consumption. So to get this value, is determined the function of the constraints and the objective function.

The final goal in the resolution of problems of ELD is an optimization 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 as minimum level while meet the total demand power. Principally, total generated power at the thermal power plants meet the needed demand power by consumers.

Basically defined cost function of ELD as a quadratic function as 1-equation. The special form of the generator function cost equation is the form of second order polynomial equation and can be stated in the following equation [22]:

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

Where :

Fi = Input Fuel Usage (Liter / Hour)

P = Electricity generated output Power (MW)

a, b, c = constants

fp = fuel pricing ($/kcal)

The Characteristics of this equation is not linier. The minimum value can be presented in the following derivate equation:

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

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

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

The amount of thermal power plant is used to analyze. 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:

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

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

$$P_{imin} < Pi < Pi_{\ max}$$

Pi is the amount of output power generated by a generator unit, where in the system installed several generator units in thermal Power plant. From a number of power plants that are available will be combined generator unit that operates made by the method of 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 in accordance with the priority order of generation start unit the cheapest to the most expensive unit. After that, it can be arranged combination priority power plant with a list of predetermined sequence to supply the required load.

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

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

To supply the required load, structured steps are needed to schedule the generator as follows [9]:

1. Make a list of the order and capacity based on the number of average production cost of each unit generator of equation 1 to 4 and compile it.
2. An operation combination of unit generators is arranged that based on a list cost priority orders to supply usage loads.
3. Analyzing and calculating on the EDL of any combination of the generator unit at the level of the load with the value of the maximum and minimum power limit and pay attention to the obstacles to be able to supply the load.
4. The calculation of production costs for each Generator is carried out, which 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 ON generator is based on the cheaper operation cost of Generator. The first priority cost is cheaper. The power plant with an average fuel cost in $ X is cheaper than the power plant with an average fuel cost in $X+1. The first Power plant ($X) is the cheapest operating cost as the first priority. So, the last priority (end priority) operated Generator is the most expensive operator cost. The average fuel cost and priority will be shown in table 1.

B. **BA Method**

It's known, that Bats are in the world as mammalian animals that they are fascinating animals, because bats are the only mammals animal with two wings and have advanced capability of accreted echolocation. They have unique own characteristic, that they can fly with high speed without accident and random distance [9].

The principle of bat working the echolocation of a bat is to emit a very loud sound pulse and sensitive listen for the echo that bounces back from the surrounding their objects. So, the BA is a meta heuristic algorithm for global optimization. It was inspired by the echolocation behavior of small bats, with varying pulse rates of emission and loudness.

BA Method is a new bionic intelligent optimization algorithm to simulate the foraging behavior and the echolocation principle of the bats. Most bats uses echolocation to a certain degree; among all the species, small bats are a famous example as small bats use echolocation extensively while the large bats do not. BA is used more and more attention because of its simple, less 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 optimize the operation fuel cost of thermal power plant. This operated algorithm is based on the echolocation characteristics of small bats.

For simplify the characteristics of used BA method, it can be idealized assumed as follows:

1. In a certain sense the distance is not usually, bats use echolocation ability. All bats are also able to find the difference between food ingredients / prey animals and the surrounding situation in a miraculous great way.
2. Bats fly freely at high speed and are stable (vi) and at various positions (xi) with a fixed frequency (fmin), 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 level of the pulse emission levels β € [0,1] depends on the closeness of their intended targets.
3. The level of loudness can be done in many diverse ways. But is assumed that the value of the loudness varies from large or positive (A0) to a constant value of minimum (A_{min}).

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

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

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,….until n.

The above equation is limited condition:

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

After that, the generator unit that will operate is scheduled to serve the required load. Optimization of power plant costs is done by determining rules for varied positions (xi) and stable speeds (vi) 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 time (t-1) the location and the flight velocity of the i-th bat 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]:

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

$$v_i^{\ t+1} = v_i^{\ t} + (x_i^{\ t} \ \ x_*) \ f_i$$

$$x\_i^{(t+1)} = x_i^{\ t} + v_i^{\ t} \qquad (6)$$

Where the Constanta β € [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 compare with the real time of total operation cost.

In the position search section, after the obtained solution is defined by the 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:

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

Where ε ∈ [-1,1] is a random numbers, 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 the pulse emission (r_i),

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

And decreased the loudness (Ai),

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

Where, the loudness level (γ) and pulse emission rate (α) are constants. Besides that, any value is between 0 and 1 or 0 < α <1 and γ> 0. The Calculation step by step is done to get the minimum result. So, with the calculation steps, that the best solution is found the result with a minimum operation costs of thermal power plant and of course obtained in accordance with the restrictions provided in the power plant operation.

MODELING

A. ELD Modelling

In modern powers plant systems, one of the most considerable topics is economic load dispatch (ELD). The ELD problem is solved; a lot of methods were developed and used at different power plant systems [15]. Economic load dispatch of a power system is very important in terms of control and planning of that power system. Main goal of ELD is distributed total demand power among the committed thermal generator units with minimum production cost by satisfying set of equality and inequality constraints. So, ELD plays very big role for operated power plants. For this reason, a lot of researcher studied this issue. A number of optimization techniques developed and applied to ELD problem [11].

This research in this paper is calculated by supported using a real time data of power plant. This data's are actual data of thermal power plants from East Java Region. In this region are 6 Power Plants which are connected in parallel with the 150kV system [12]. The calculation is based on condition operation of the power plant in peak load condition of 2018.

The EDL calculation results are used for the main parameters to simulate the operating costs of thermal power plant fuels whose energy sources use fossil fuels [22]. 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 EDL- analysis are very 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 it can be determined the capacity of the plant to produce power with minimum and maximum limits. For continuous loading of the analysis in this paper have a max 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		1950

The data's of 6 (six) unit 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 principally, the total output power of power plant meets to serve the demand load requirements. The total maximum operated thermal Power is 1950 kW of 2052kW. The optimization performance is supported by carrying out the analysis and the simulation experiments on six cost functions.

B. Power Plant Modeling

In determining the input characteristics Power Output done with polynomial regression equation of order 2 of the matrix equation. 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 a 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 energy of 243.502.000 kCal/hour is need 2435 hate rate.

Table 3: Power plant G1 Hate rate.

No.	Power Plant G1	Heat Rate kCal/kWH	Energy (kCal/h)
1	100	2435	243.502.000
2	122	2361	288.531.530
3	144	2286	330.258.741
4	167	2212	368.683.333
5	189	2138	403.805.407
6	211	2083	439.833.815
7	233	2058	480.132.333
8	256	2032	519.288.037
9	278	2007	557.469.136
10	300	1983	595.008.000
Avarage	200	2159.5	392.169.731
	Total		3.921.697.310

Gas flow from the Power plant unit is used to get the cost of Power plant. The results from the multiplication of the gas price ($/mmBTU) with gas flow (mmBTU/h) or coal price ($/Ton) with Coal flow (Ton/h) will get the cost of generated power ($/h). The price at that time was $ 9.00/mmBTU (gas) and $ 100.89/Ton (Coal). Conversion value for gas is 3.97 x 10^{-6} mmBTU/kcal and 1.43 x 10^{-6} Ton/ kcal for coal.
In this calculation is used data of Power Pant G1 as the third Priority. Exchange rate is $ to Rp.15,158.23,-. Gas Flow is a multiplication of energy with fuel conversi. The calculation result of the production costs can be seen in table 4.

Table 4: Cost calculation of Power plant G1.

Power Plant G1	Gas Flow Mmbtu/h	Cost ($)	Cost (Rp)
100	966.29	8,697	131.825.674
122	1144.99	10,305	156.203.549
144	1310.57	11,795	178.793.526
167	1463.05	13,167	199.595.605
189	1602.43	14,422	218.609.786
211	1745.40	15,709	238.114.632
233	1905.32	17,148	259.931.206
256	2060.70	18,546	281.129.090
278	2212.21	19,910	301.799.348
300	2361.21	21,251	322.121.916
Average		2159.5	228.812.431
	Total		**1,144,062**

Based on the data in table 3 and table 4 above, it can be made to the settlement matrix to get the value of the constants a, b and c as follows a=2234.551, 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 equation 1:

$$Fi\ (Pi) = (2.234{,}551 + 67{,}169\ Pi + 0{,}013\ Pi^2)$$

This equation as cost function is relevant for only Power plant G1. For the other Power plant has self cost function. By the same calculation proses method is also applied for five (5) other generating units and the calculation results are shown in Table 4. In this Table 4 will be also presented the results calculated heat rate and cost function equation.

Table 5: Heat Rate and Cost Functions

1	2 HR	3 Fcost ($/h)
G1	2435 1983	$2234.551 + 67.169\ P - 0.013\ P^2$
G2	3558 3183	$0.020155 + 140.484\ P - 0.167\ P^2$
G3	3183 2848	$6213.32 + 65.609\ P + 0.054\ P^2$
G4	3542 3399	$0.0036 + 128.823\ P - 0.232\ P^2$
G5	2456 2280	$-514.075 + 40.802\ P - 0.0124\ P^2$
G6	2604 2371	$5063.18 + 23.418\ P + 0.0045\ P^2$

1 = Power Plant, 2= Heat Rate (kcal/kwh), 3= Cost Function.

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

RESULTS AND ANALYSIS

Real Power Plant Operating

In a power plant system, a daily load curve or load profile is a chart illustrating the variation in demand / electrical load over a day (24 hours). Researcher had used this information to plan how much power they will need to generate at any given time to serve demand. Figure 1 shows the real system operating cost of power plant and Demand load. These demand load data and the used power plant based on real data on October 17, 2018. On the obtained real data of Power plant can be used to make Figure 1.

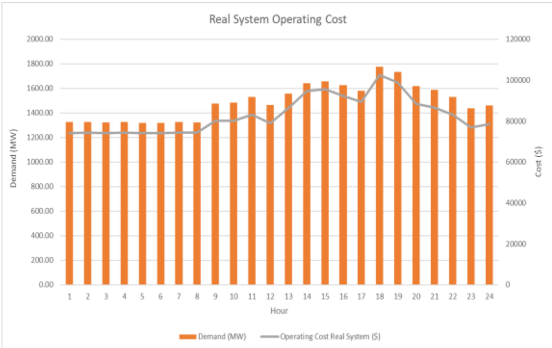

Figure 1.Real Operating Cost and Demand curve

Based on the real data calculation of operated Generator scheduling is obtained that the total cost is $1.988.410. The operated Power plant consists of 6 generators that they work full day (24 hours). Each Generator has needed average fuel cost, which will determine the priority position. Average Fuel Cost is shown in table 6.

Table 6. Average Fuel Cost Data and priorities

No	Power Plant	Average Fuel Cost ($/MWh)	To 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 a last alternative to service need demand. The real Operation of 6 Generator at peak load on October, 17, 2018 is illustrated in figure 3. All Generators are operated to service loads during peak loads in October 2018, except Power plant PLTG-4 that is the power plant with the smallest output power not operated at peak load. This power plant is the most expensive operating cost and as standby unit generator. The peak load occurs from 18:00 to 22:00 and the maximum power is generated by all generator is 1,774 MW at 18.00. The Peak Load curve is presented in Figure 2.

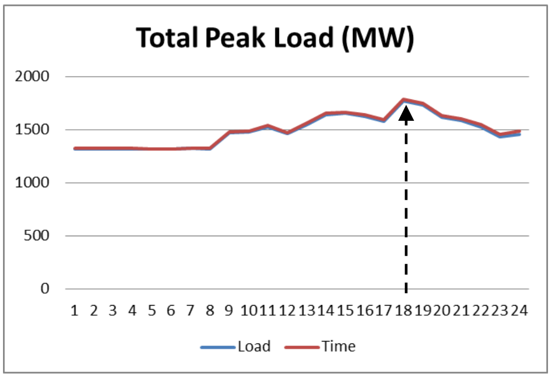

Figure 2: Total Peak Load for 6 Generators.

To serve and to support the peak load as real time data, will be operated all generator (6 Generators), but G_4 is as standby unit Generator. G_1, G_2, G_3, G_5 and G_6 will operated to generate power. Figure 3 illustrate the operated each Generators of thermal Power plant in Peak Load time.

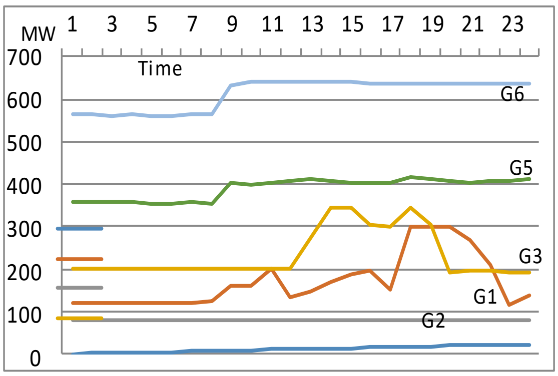

Figure 3: Operated each Generator for Peak Load

a. Bat Algorithm Method

To optimize the power plant is done by using BA method and supported by ELD simulation. In simulating ELD with the BA method, it is compiled by the algorithm of equation 5-13. This algorithm equation 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].

```
clc;
Total_Load = 24;
Total_Bat = 100;
Total_Iteration = 1000;
Total_Dimension = 6;
Lb = [100 80 160 10 310 408];
Ub = [300 160 350 32 560 650];

min_Frekuensi = 0;
max_Frekuensi = 100;

Pulse_Emission_Rate = 0.9; % (0,1)
Loudness_Level = 0.9;%>0
```

Figure 4. Data of BA with Matlab [7]

The BA Method supported parameters consists of:

- The number of bats search variables is recommended between 20 and 100 (100 bats) as total bat. [19].
- Total Iteration to achieve stable results with 1000 recommended iteration [5].
- Total Dimensions is number of used Generators of power plant (6 units).
- Total Load is daily operating time for 24 Hours.
- Lb is Lower Bound Limit Power Plant (P_{min}) and Ub is Upper Bound Limit Power (P_{max})
- By the minimum and maximum Frequency are used to calculate the velocity of the bat 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 generated thermal power cost Function is shown in table 8 below. To simulate the result is done and is presented. Each power plant has ELD with own constant equation that it will be calculated. For example, ELD equation of PLTGU_1 is 2234.551+ 67.169 P - 0.013 P2.

Table 8: Generated power cost Function

1	Fcost ($/h)
G1	2234.551 + 67.169 P - 0.013 P^2 = 5.874.000.000
G2	0.020155 + 140.484 P - 0.167 P^2 = 25.374.000000
G3	6213.32 + 65.609 P + 0.054 P^2 = 15.353.000.000
G4	0.0036 + 128.823 P - 0.232 P^2 = 4.415.000.000
G5	-514.075 + 40.802 P - 0.0124 P^2 = 4.331.000.000
G6	5063.18 + 23.418 P + 0.0045 P^2 = 92.889.000.000

By using BA calculated cost Function of Power plant can be seen in Table 8. In table 9 will presented generated power for each Generator (6 units in MW), total generated power. The total fuel consumption cost ($/h) for daily operation (24 hours) as operation by BA method calculated cost can be shown in table 10. To get the efficiency value, usually, the thermal Power Plant must attend to its fuel consumption at peak load as priority scale.

The operation cost for every hour can be known and simulated. The calculated results of used generator using BA, the total cost is $1,653,374 that is shown in table 10. Thus, the real time generator operation cost is more expensive than by using BA calculated operation cost. Figure 4 presented the Comparison of real time operation cost and with BA calculated detail operating cost. In table 10 is presented the by BA Method calculated operational cost every hours for 6 Generator units. To turn on a Generator in PLTGU needs 6-8 hours starting time and of course, required operation cost.

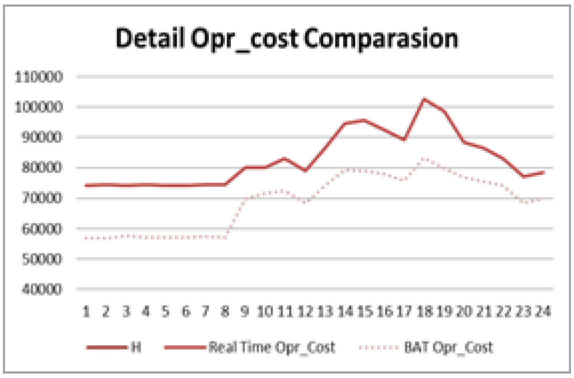

Figure 4: Operating Cost Comparison Curve

Table 9: 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 P
1	118,9	0,0	0,0	0,0	558,1	648,0	1324,95
2	122,1	0,0	0,0	0,0	556,1	647,0	1325,13
3	144,9	0,0	0,0	0,0	548,9	627,8	1321,59
4	126,0	0,0	0,0	0,0	554,1	644,0	1324,16
5	131,1	0,0	0,0	0,0	537,0	649,0	1317,06
6	135,0	0,0	0,0	0,0	543,2	640,0	1318,08
7	136,0	0,0	0,0	0,0	549,2	640,3	1325,47
8	133,9	0,0	0,0	0,0	546,1	642,1	1322,1
9	153,2	0,0	164,9	0,0	544,9	611,1	1474,05
10	135,0	0,0	205,1	0,0	525,9	615,2	1481,2
11	160,9	0,0	180,5	0,0	546,2	642,2	1529,79
12	108,1	0,0	175,6	0,0	547,3	634,0	1464,87
13	214,1	0,0	163,6	0,0	542,2	636,1	1555,95
14	299,0	0,0	160,0	0,0	560,0	623,1	1642,12
15	285,4	0,0	160,0	0,0	560,0	649,9	1655,25
16	250,9	0,0	173,7	0,0	555,9	644,3	1624,86
17	227,9	0,0	171,3	0,0	558,0	623,0	1580,13
18	280,1	101,5	203,3	0,0	551,0	639,2	1775,06
19	299,0	116,5	160,3	0,0	551,9	604,3	1731,87
20	248,1	0,0	160,0	0,0	560,1	649,9	1.618,09
21	207,2	0,0	173,4	0,0	560,1	647,1	1587,75
22	208,1	0,0	180,7	0,0	517,2	625,1	1531,15
23	133,2	0,0	171,9	0,0	485,2	647,3	1437,60
24	153,2	0,0	174,2	0,0	525,3	609,9	1462,57

Table 10: Operational Cost with BA Method

H	Operational Cost with BAT Calculation ($)						BAT
	G-1	G2	G3	G4	G5	G6	T_cost
1	100,34	0,00	62,13	0,0	183,94	221,28	56.770
2	102,39	0,00	62,13	0,0	183,42	220,97	56.891
3	116,95	0,00	62,13	0,0	181,47	215,37	57.592
4	104,94	0,00	62,13	0,0	182,87	220,12	57.006
5	108,16	0,00	62,13	0,0	178,22	221,55	57.006
6	110,64	0,00	62,13	0,0	179,90	218,92	57.159
7	111,30	0,00	62,13	0,0	181,54	219,01	57.399
8	109,95	0,00	62,13	0,0	180,70	219,55	57.233
9	122,17	0,00	184,97	0,0	180,38	210,54	69.807
10	110,64	0,00	219,41	0,0	175,15	211,73	71.693
11	127,07	0,00	198,15	0,0	180,72	219,58	72.552
12	93,41	0,00	193,95	0,0	181,02	217,18	68.557
13	160,22	0,00	183,89	0,0	179,63	217,79	74.153
14	211,57	0,00	180,93	0,0	184,45	214,03	79.099
15	203,47	0,00	180,93	0,0	184,46	221,82	79.068
16	182,70	0,00	192,41	0,0	183,37	220,19	77.867
17	168,68	0,00	190,38	0,0	183,91	213,98	75.695
18	200,31	12,53	217,83	0,0	182,02	218,71	83.140
19	211,53	14,10	181,15	0,0	182,29	208,57	79.763
20	181,00	0,00	180,93	0,0	184,49	221,83	76.825
21	155,91	0,00	192,10	0,0	184,50	221,02	75.353
22	156,52	0,00	198,34	0,0	172,70	214,61	74.217
23	109,49	0,00	190,90	0,0	163,65	221,06	68.510
24	122,22	0,00	192,82	0,0	174,96	210,19	70.019
	Total Operational Cost With BAT ($)						**1.653.374**
	Real Operational Cost ($			1.988.410,03		Dev.($)	335.036
Eficiency (%)							16,85

Based on Figure 4 above it appears that the real load curve significantly increases costs at 9.00 and 18.00 o'clock because the start-up of the power plant must be carried out to meet the generated total power. In the above curve there is an increase in costs at 9.00 o'clock and 18.00 o'clock, while at 12.00 o'clock and 17.00 decreases slightly due to the possibility of rest time for technician workers so some electrical equipment is not used. 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.

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 optimized. The cost efficiency results with a BA of 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. This Table 10 will describe the Deviation in % per hour and comparison between real time operation cost and by BA calculated operation cost of thermal power plant hourly. The minimum deviation is 10.53% at 10.00 am and the maximum deviation occurred at 01.00 with a value of 23.48% as the biggest.

Table 10: Comparison cost and Deviation

H	**Real Time**	**BA**	Dev.(%)
	Opr_Cost	Opr_Cost	
1	74192,51	56770,21	23,48
2	74248,11	56891,21	23,38
3	74212,78	57592,44	22,40
4	74247,84	57005,83	23,22
5	74024,73	57006,07	22,99
6	74022,42	57158,95	22,78
7	74247,01	57399,18	22,69
8	74374,64	57233,44	23,05
9	79997,69	69806,87	12,74
10	80130,14	71692,94	10,53
11	83064,02	72552,09	12,66
12	78855,61	68556,64	13,06
13	86397,04	74153,08	14,17
14	94531,74	79098,79	16,33
15	95669,01	79067,68	17,35
16	92381,32	77867,02	15,71
17	89275,04	75694,84	15,21
18	102559	83140,08	18,93
19	98731,25	79763,00	19,21
20	88312,79	76824,83	13,01
21	86484,23	75352,80	12,87
22	83009,27	74217,40	10,59
23	76992,82	68509,59	11,02
24	78448,98	70018,85	10,75
Tot	1988409,99	1653374	16,85
	Efficiency		**16,85**

The biggest thermal power plant operation costs occur significantly start from 1:00 pm to 10:00 pm (load peak time). The operation cost of thermal power plant decreases again above 22.00 until 01.00 pm. The BA method can produce a more efficient or smaller operation costs than real time operated cost. As Bat unique character, so that it can occur because of the BA manages to create a loading combination of more efficient thermal power plants**.**

CONCLUSION

This paper presents operational cost reduction of thermal Power Plant based on BA Method. Optimization of the loading arrangements in thermal power plants units of 150 kV systems in the province of East Java are very suitable to be applied to the ELD is based on the BA method. The operation cost result of the BA method has to be compared with the cost of real-time operation of 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 million, while the calculation using the BA method shows the total operating cost at $ 1,653,374. Thus, the using of the BA method can reduce the operating costs of thermal power plant by $ 335,036 or a savings of 16.85%.

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TABLE OF CORRECTION

Article ID		OPERATIONAL COST REDUCTION OF GAS-THERMAL POWER PLANT BASED ON BAT ALGORITHM
Authors		Agus Sofwan1*, M.Febriansyah1, Sugeng2

Article ID		**OPERATIONAL COST REDUCTION OF GAS-THERMAL POWER PLANT BASED ON BAT ALGORITHM**
	Reviewer A: This paper is very useful to implement and has a major contribution to energy efficiency. This paper explains the accuracy of the problem, summarizes the context of relevant research, and explains the research findings, this article is quite new, deep enough, and interesting. The method used has been described precisely and is quite detailed. BA parameters are well explained, the results are well presented. The conclusion has answered the hypothesis. A little correction from me: 1. Bat Algorithm (BA) or BAT Algorithm? It's better to be consistent. 2. BA method in scheduling has been widely used, please explain the advantages of this study compared to previous papers. (Besides differences before and after using BA) 3. Please explain the parameters of BA in reducing the operational costs of a gas-thermal power plant 4. Picture 3, Please adjust the image size 5. Some grammar and format of writing please improve. =========================== Reviewer C: Reviewer notes on the manuscript "OPERATIONAL COST REDUCE OF GAS-THERMAL POWER PLANT BASED ON BAT ALGORITHM" In general, there is quite nothing new proposed and emphasized in the manuscript. The economic load dispatch using bat algorithm has been discussed in many studies. It is suggested that the authors may try to explore the advantages and disadvantages of the previous related/similar studies of other researchers, and furthermore explain what to be proposed as an improvement to previous studies or contribution in the knowledge field. The authors may try to focus more on the optimization methods, improvement of previous methods, the fields of application, etc.	Makalah ini sangat bermanfaat untuk diimplementasikan dan memiliki kontribusi yang besar terhadap efisiensi energi. Makalah ini menjelaskan keakuratan masalah, merangkum konteks penelitian yang relevan, dan menjelaskan temuan penelitiannya, artikel ini cukup baru, cukup dalam, dan menarik. Metode yang digunakan telah dijelaskan dengan tepat dan cukup rinci. Parameter BA dijelaskan dengan baik, hasilnya disajikan dengan baik. Kesimpulan tersebut telah menjawab hipotesis. Sedikit koreksi dari saya: 1. Algoritma Bat (BA) atau BAT Algorithm? Lebih baik konsisten. 2. Metode BA dalam penjadwalan sudah banyak digunakan, mohon jelaskan keunggulan penelitian ini dibandingkan makalah sebelumnya. (Selain perbedaan sebelum dan sesudah menggunakan BA) 3. Jelaskan parameter BA dalam mengurangi biaya operasional pembangkit listrik tenaga gas-termal 4. Gambar 3, Harap sesuaikan ukuran gambar 5. Beberapa tata bahasa dan format penulisan harap ditingkatkan. Secara umum, tidak ada hal baru yang diusulkan dan ditekankan dalam naskah. Pengiriman beban ekonomis menggunakan algoritma kelelawar telah dibahas dalam banyak penelitian. Disarankan agar penulis mencoba menggali kelebihan dan kekurangan penelitian sebelumnya yang terkait / serupa dari peneliti lain, dan selanjutnya menjelaskan apa saja yang akan diusulkan sbagai perbaikan dari penelitian atau kontribusi sebelumnya di bidang pengetahuan. Penulis dapat mencoba untuk lebih fokus pada metode optimasi, perbaikan metode sebelumnya, bidang aplikasi, dll.

	The literature review on the Introduction part is not enough to support the problem considered in the paper. The use of English also needs much improvement. Hope the following notes useful for improvement. Why not “Operational Cost Reduction of Gas-Thermal Power Plant based on Bat Algorithm”? “…it is still high and become …” è”….becomes…” Reformulate the sentence: “As Electrical Engineers, has researched to analyses the scheduling for operations and maximized capacity with the real load demand and a minimum operational energy cost.” Correct the usage of English. There must be at least Subject and Verb in a sentence. Pay attention to the “Subject-Verb Agreement”. Be careful in translating noun phrase from Indonesian into English: “…the algorithm method bat…”, “Results Optimization …”, “…equation theory…”, “…data loading plant..” Some incomplete sentences are found in the manuscript. ======================== Use the correct term: “The dates …” Distinguish between “analyse/analyze” as a verb and “analysis” as a noun. Pay attention not to use ‘Then’ at the beginning of a sentence. “The purpose of this ELD research in the generated power is to set the output power distribution to multiple units are operated generator” è ‘double-verb’ case, please	Tinjauan pustaka pada bagian Pendahuluan tidak cukup untuk mendukung masalah yang dipertimbangkan dalam makalah. Penggunaan bahasa Inggris juga perlu banyak perbaikan. Semoga catatan berikut bermanfaat untuk perbaikan. Mengapa tidak “Pengurangan Biaya Operasional Pembangkit Listrik Tenaga Panas Gas Berbasis Algoritma Bat”? “… Masih tinggi dan menjadi…” è ”…. Menjadi…” Merumuskan ulang kalimat: "Sebagai Insinyur Listrik, telah meneliti untuk menganalisis penjadwalan operasi dan memaksimalkan kapasitas dengan permintaan beban nyata dan biaya energi operasional minimum." Perbaiki penggunaan bahasa Inggris. Harus ada setidaknya Subjek dan Kata Kerja dalam sebuah kalimat. Perhatikan "Perjanjian Subjek-Kata Kerja". Berhati-hatilah dalam menerjemahkan frasa kata benda dari bahasa Indonesia ke bahasa Inggris: “… metode algoritme bat…”, “Optimasi Hasil…”, “… teori persamaan…”, “… pabrik pemuatan data ..” Beberapa kalimat yang tidak lengkap ditemukan di dalam naskah. Gunakan istilah yang benar: "Tanggal ..." Bedakan antara "menganalisis / menganalisis" sebagai kata kerja dan "analisis" sebagai kata benda. Perhatikan untuk tidak menggunakan 'Then' di awal kalimat.

	correct/reformulate! The numbering order of references in text is based on the order of their appearances in the text. “Based on the above discussion and analysis results can be obtained several conclusions as follow” èthis sentence needs to be corrected grammatically.	“Tujuan dari penelitian ELD ini pada daya yang dibangkitkan adalah untuk mengatur distribusi daya keluaran ke beberapa unit yang dioperasikan generator” è kasus 'double-verb', mohon dikoreksi / reformulasi! Urutan penomoran referensi dalam teks didasarkan pada urutan kemunculannya dalam teks. “Berdasarkan pembahasan dan hasil analisis di atas dapat diperoleh beberapa kesimpulan sebagai berikut” è Kalimat ini perlu dikoreksi secara gramatikal.

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

Agus Sofwan[1*], M. Febriansyah[1], Sugeng[2]
[1]Department of Electrical Engineering, Institute Sains dan Teknologi Nasional (ISTN), Indonesia
[2]Electrical Dep. Universitas Islam '45 UNISMA, Indonesia

Abstract
An optimized operation of thermal power plant is required to optimize fuel consumption cost. In fact, it is still high and becomes a problem of economic dispatch in the operation of plant. Load scheduling and generator capacity are needed to get optimal plant operation especially in terms of energy usage. In this paper presented on the analysis of thermal power plant operation in order to obtain optimum operational energy costs by using 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 by using maximum (95%) capacity and BA method. The Simulation is done by using MATLAB software. Heat rate characteristics of generator unit and generator load are collected to obtain objective functions and constraint functions. This function is completed by BA to get the lowest energy. To analyze its accuracy, the BA method will be compared with the calculation of real time energy generation without BA. The total operational cost of 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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Keywords:
Economic Dispatch;
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Corresponding Author:
Agus Sofwan
Department of Electrical, Institute Sains dan Teknologi Nasional (ISTN), Indonesia
Email:
asofwan@istn.ac.id

INTRODUCTION

In general, the 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 need in Indonesia for electricity will continue to increase. To fulfill this, a good electric power operating system is required [2].

Fuel consumption of the thermal power plants operation is very important because almost 60% of required total operating costs come from fuel oil. For this reason, therefore, analysis on Economic Load Dispatch (ELD) is very necessary. The purpose of this ELD analysis is to regulated 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 a variety of things, one of which is a good heat-rate value [6]. Heat-rate is a comparison value between the amount of fuel as 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 own characteristics and own varied capacity. Gas and steam are used to operate this thermal power plant. To meet the demand for energy, a maximum generator capacity and good operational scheduling is needed by adjusting the load on each unit at the most efficient point, so that the heat-rate value can be adjusted [8].

From this problem, it is necessary to analyze 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 thermal power plant is determined and the constraint function which is a function in the cost optimization and optimization process is implemented in the ELD problem, so that optimal scheduling of power plant operations can be determined.

The 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]. The used methods to solve of the ELD problem [12] [13], namely the Lagrange Multiplier [14], Merit Order method [15] while the in-deterministic solution of ELD problem is based on heuristic approach such as using PSO [16], Genetic Algorithm, Ant Colony Optimization and Bat Algorithm [17].

The BA is one of the newest swarm's intelligence-based algorithms that simulates the intelligent hunting behavior of bats found in nature [18]. BA is a flexible optimization method inspired by their bat-like behavior that uses sonar called echolocation to detect prey, avoid obstacles, and locate perch in the dark [19]. BA method has been widely used in a variety of 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 for the improvement in operation reliability of wind power plants. 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].

In this paper will use the BA method, because it's one of the meta-heuristic algorithms that are used to solve cost optimization problems in thermal power plant. The process of these calculations will be done by using the MATLAB application and then is compared with real operation cost of power plant. This research goal is specialized to the analysis of deterministic and in-deterministic methods to obtain optimum costs in thermal Power plant. In several other algorithms an analysis has been carried out in previous research. BA as an in-deterministic method will be applied for ELD optimization [23]. The comparison of normal operation and BA will be presented. To arrange 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 are simulated on a computer program with 3 parameters that are position, velocity and frequency of bats. The two methods compared were carried out with the limits of equality and inequality to calculate economic load dispatch [26]. Limitation of equality reflects the balance between the total generated Power with 95% Capacity by the total required load power on the system. The inequality limit reflects the min- and maximum generator operation that must be fulfilled so that the optimum total cost is reached [27].

METHOD

Economic Load Dispatch

The main parameters of BA in reducing the operational costs of a thermal power plant are ELD and generator operating time. So, there are some ELD problems that must be solved. This research 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 on the generating units that exist in the system optimally with the aim of minimizing fuel consumption. So to get this value, is determined the function of the constraints and the objective function.

The final goal in the resolution of problems of ELD is an optimization 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 as minimum level while meet the total demand power. Principally, total generated power at the thermal power plants meets the needed demand power by consumers. Basically, to define an ELD cost equation function from a generator operation in this study is a form of second order polynomial equation as a quadratic function. These parameters can be expressed in equation 1 as follows:

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

Where:
Fi = Input Fuel Usage (Litre/Hour)
P = Electricity generated output Power (MW)
a, b, c = constants
fp = fuel pricing ($/k cal)
The characteristics of (1) is 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:

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

The amount of thermal power plant is used to analyze. 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:

$$P_d = \sum (P_i) - P_{Loss}$$
$$P_d = \sum (P_i) \qquad (3)$$
$$P_{imin} < Pi < Pi_{max}$$

Pi is the amount of output power generated by a generator unit, where in the system installed several generator units in thermal Power plant. From a number of power plants that are available will be combined generator unit that operates made by the method of 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 in accordance with the priority order of generation start unit the cheapest to the most expensive unit. After that, it can be arranged combination priority plant with a list of predetermined sequence 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 the 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 the power outputs of generator units in order to accomplish the forecast-ed demand for some time. With the variations in each day load curve, there is a requirement of generating enough power to meet the need of costumer load.

To supply required load, structured steps are needed to schedule generator as follows [9]:

1. Make a list of the order and capacity based on the number of average production cost of each unit generator of (1) to (4) and compile it.
2. An operation combination of unit generators is arranged that based on a list cost priority orders to supply usage loads.
3. Analyzing and calculating on 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 pay attention to the obstacles to be able to supply the load.
4. The calculation of production costs for each Generator is carried out, which 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 ON generator is based on the cheaper operation cost of Generator. The first priority cost is cheaper. The power plant with an average fuel cost in $ X is cheaper than the power plant with an average fuel cost in $X+1. The first Power plant ($X) is the cheapest operating cost as the first priority. So, the last priority (end priority) operated Generator is the most expensive operator cost. This can be 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 Method

It's known, that 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 own characteristic, that they can fly with high speed without accident and random distance [9].

The principle of bat working the echolocation of a bat is to emit a very loud sound pulse and sensitive listen for the echo that bounces back from the surrounding their objects. So, the BA is a meta heuristic algorithm for global optimization. It was inspired by the echolocation behavior of small bats, with varying pulse rates of emission and loudness.

BA Method is a new bionic intelligent optimization algorithm to simulate the foraging behavior and the echolocation principle of the bats. 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 the large bats do not. BA is used more and more attention because of its simple, less 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 optimize the operation fuel cost of thermal power plant. This operated algorithm is based on the echolocation characteristics of small bats.

For simplify the characteristics of used BA method, it can be idealized assumed as follows:

1. In a certain sense the distance is not usually, bats use echolocation ability. All bats are also able to find the difference between food

ingredients/ prey animals and the surrounding situation in a miraculous great way.

2. Bats fly freely at high speed and are stable (vi) and at various positions (xi) 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 level of the pulse emission levels β € [0,1] depends on the closeness of their intended targets.
3. The level of loudness can be done in many diverse ways. But is assumed that the value of the loudness varies from large or positive (A0) to a constant value of minimum (A_{min}).

By the using a principle of the BA, the generator optimization 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 analyzed 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]:

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

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,….until n. Equation (4) is 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. Optimization of power plant costs is done by determining rules for varied positions (xi) and stable speeds (vi) 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 time (t-1) the location and the flight velocity of the i-th bat 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 β € [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 total operation cost.

In the position search section, after the obtained solution is defined by the 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 ε ∈ [-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 the 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 < α < 1 and γ > 0. The Calculation step by step is done to get the minimum result. So, with the calculation steps, that the best solution is found the result with a minimum operation costs of thermal power plant and of course obtained in accordance with the restrictions provided in the power plant operation.

Economic Load Dispatch (ELD) Modelling

In modern powers plant systems, one of the most considerable topics is Economic Load Dispatch (ELD). The ELD problem is solved; a lot of methods were developed and used at different power plant systems [15]. Economic load dispatch of a power system is very important in terms of control and planning of that power system. Main goal of ELD is distributed total demand power among the committed thermal generator units with minimum production cost by satisfying set of equality and inequality constraints. So, ELD plays very big role for operated power plants. For this reason, a lot of researcher studied this issue. A number of optimization techniques developed and applied to ELD problem [11].

This research is calculated by supported using a real time data of power plant. This data are actual data of thermal power plants from East Java Region. In this region are 6 Power Plants which are connected in parallel with the 150kV system [12]. The calculation is based on condition operation of the power plant in peak load condition of 2018.

The ELD calculation results are used for the main parameters to simulate the operating costs of thermal power plant fuels whose energy sources use fossil fuels [22]. 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 it can be determined the capacity of the plant to produce power with minimum and maximum limits. For continuous loading of the analysis in this paper have a max 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 unit 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 principally, the total output power of power plant meets to serve the demand load requirements. The total maximum operated thermal Power is 1950 kW of 2052 kW. The optimization 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 done 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 a specific output power. Fuel consumption with hate rate value derived from field data in units (k cal / 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 energy of 243,500.00 k cal/hour is need 2,435 hate rate.

Table 3. Power plant G1 Hate rate.

No.	Power Plant G1	Heat Rate (kCal/kWH)	Energy (kCal/h)
1	100	2,435	243,500.00
2	122	2,361	288,042.00
3	144	2,286	329,184.00
4	167	2,212	369,404.00
5	189	2,138	404,082.00
6	211	2,083	439,513.00
7	233	2,058	479,514.00
8	256	2,032	520,192.00
9	278	2,007	557,946.00
10	300	1,983	594,900.00
Average	200	**2,159.5**	**422,627.73**
	Total		**4,226,277.30**

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

In this calculation is used data of Power Plant G1 as the third Priority. 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.

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
122	1,144.99	10,305	156,205,560
144	1,310.57	11,795	178,791,323
167	1,463.05	13,167	199,588,414
189	1,602.43	14,422	218,611,993
211	1,745.40	15,709	238,120,635

P-Plant G1	Gas Flow (Mmbtu/h)	Cost ($)	Cost (Rp)
233	1,905.32	17,148	259,933,328
256	2,060.70	18,546	281,124,534
278	2,212.21	19,910	301,800,359
300	2,361.21	21,251	322,127,546
Average		15,095	228,812,433.20
	Total		**2,288,124,332.00**

Based on the data in Table 3 and Table 4, it can be made to the settlement matrix 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. By the same calculation process method is also applied for five (5) 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 k Cal /kWh. The parameter represents the value of the input energy (k Cal) than the energy produced in (kWh). The Real Time power plant is operated to serve Demand can be shown at Figure 1. This Figure presents a Load increase with increasing numbers of output power generation system. Peak load of this thermal power plant at this Figure 1 shown that peak load occurs at 18:00.

RESULTS AND DISCUSSION

Real Power Plant Operating

In a power plant system, a daily load curve or load profile is a chart illustrating the variation in demand / electrical load over a day (24 hours). Researcher had used this information to plan how much power they will need to generate at any given time to serve demand. Figure 1 shows the real system operating cost of power plant and Demand load. These demand load data and the used power plant based on real data on October 17, 2018. On the obtained real data of Power plant can be used to make Figure 1.

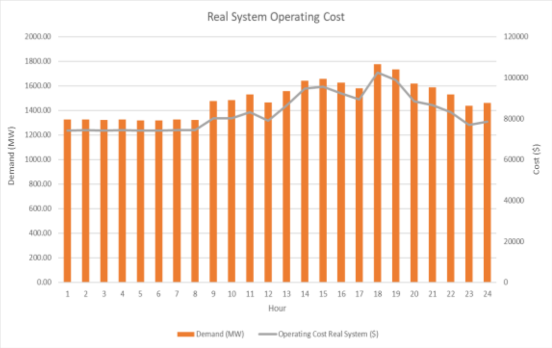

Figure 1. Real Operating Cost and Demand curve

Based on the real data calculation of operated Generator scheduling is obtained that the total cost is $1,988,410. The operated Power plant consists of 6 generators that they work full day (24 hours). Each Generator has needed 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)	To 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 a last alternative to service need demand. All Generators are operated to service loads during peak loads in October 2018, except Power plant PLTG-4 that is the power plant with the smallest output power not operated at peak load.

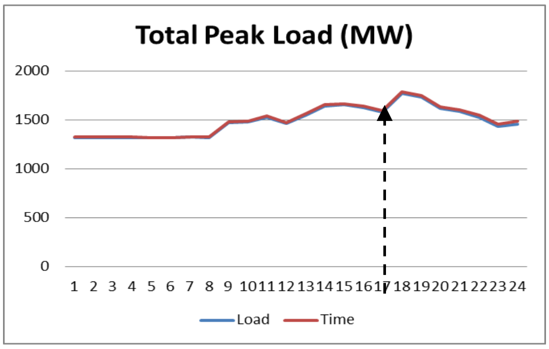

Figure 2. Total Peak Load for 6 Generators.

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

To serve and to support the peak load as real time data, will be operated all generator (6 Generators), but G_4 is as standby unit Generator. G_1, G_2, G_3, G_5 and G_6 will be operated to generate power. The real Operation of 6 Generator at peak load on October, 17, 2018 is illustrated in Figure 3. This figure illustrate the operated each Generators of thermal Power plant in Peak Load time.

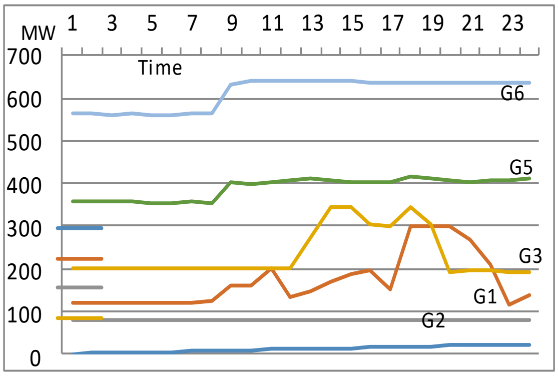

Figure 3. Operated each Generator for Peak Load

Bat Algorithm Method Results

To optimize the power plant is done by using BA method and supported by ELD simulation. In simulating ELD with the BA method, it is compiled by the algorithm of (5)-(13). 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].

```
clc;
Total_Load = 24;
Total_Bat = 100;
Total_Iteration = 1000;
Total_Dimension = 6;
Lb = [100 80 160 10 310 408];
Ub = [300 160 350 32 560 650];

min_Frekuensi = 0;
max_Frekuensi = 100;

Pulse_Emission_Rate = 0.9; % (0,1)
Loudness_Level = 0.9;%>0
```

Figure 4. Data of BA with MATLAB [7]

The BA Method supported parameters consists of:

- The number of bats search variables is recommended between 20 and 100 (100 bats) as total bats [19].
- Total Iteration to achieve stable results with 1000 recommended iteration [5].
- Total Dimensions is number of used Generators of power plant (6 units).
- Total Load is daily operating time for 24 Hours.
- Lb is Lower Bound Limit Power Plant (P_{min}) and Ub is Upper Bound Limit Power (P_{max})
- By the minimum and maximum Frequency are used to calculate the velocity of the bat 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 generated thermal power cost Function is shown in Table 7. To simulate the result is done and is presented. Each power plant has ELD with own 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

Power Plant	Fcost ($/h)
G6	$5,063.18 + 23.418\ P + 0.0045\ P^2$ = 92,889,000,000

By using BA Method calculated cost Function of Power plant can be seen in Table 7 above. In This table 7 there are 6 generators with 6 cost function equations.

The operation cost for every hour can be known and simulated. Figure 4 presented the Comparison of real time operation cost and with BA calculated detail operating cost. Based on Figure 4, it appears that the real load curve significantly increases costs at 9.00 and 18.00 o'clock because the start-up of the power plant must be carried out to meet the generated total power.

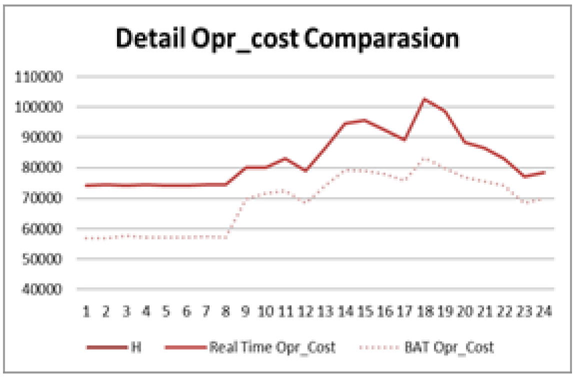

Figure 4. Operating Cost Comparison Curve

In the curve in Figure 4, 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.

In Table 8 will presented 6 units generated power for each Generator (G1…..G6 in MW) and total generated power.

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

The total fuel consumption cost ($/h) for daily operation (24 hours) as operation by BA method calculated cost can be shown in Table 10. To get the efficiency value, usually, the thermal Power Plant must attend to its fuel consumption at peak load as priority scale.

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

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 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 optimized. The cost efficiency results with a BA of 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. This Table will describe the Deviation in % per hour and comparison between real time operation cost and by BA calculated operation cost of 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 biggest thermal power plant operation costs occur significantly start from 1:00 pm to 18:00 pm as load peak time. But, The operation cost of thermal power plant (PLTU) fell again from 22.00 pm to 01.00 am in the morning as shown in table 10 below.

In 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 of course, 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 costs than real time operated cost. As Bat unique character, so that it can occur because of 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 operational cost reduction of thermal Power Plant based on BA Method. Optimization of the loading arrangements in thermal power plants units of 150 kV systems in the province of East Java are very suitable to be applied to the ELD is based on the BA method. The operation cost result of the BA method has to be compared with the cost of real-time operation of 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 using of the BA method can reduce the operating costs of thermal power plant by $ 335,036 or a savings of 16.85%.

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