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# Optimization of Thermal Power Plant Operations Using Genetic Algorithms

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## A B S T R A C T

Accurate scheduling of capacity and operating time for electricity generation is intended to be able to determine the start and end periods of electricity generation operations and produce power output that can meet load requirements. In this research, the goal is to know the existence of power plants when to start operating and when to stop operations, and minimize operational costs by dividing the value of the power generated at each power plant. Genetic algorithms are applied to thermal power plant data patterns to design a scheduling plan. The process involves combining the six power-generating units to be tested into three samples. It was found that the total power load and total cost for Sample 1 was 78,109 MW and IDR 200,285,266.26, Sample 2 was 74,497 MW and IDR 149,774,156.41, and Sample 3 was 78,681 MW and IDR 156,297,893, respectively. 08. This shows that the cost of sample 1 compared to sample 2 decreased by 25.22%, then in sample 2 when compared to sample 3 it increased by 4.17%. The data also shows that a higher number of generations results in lower costs. Therefore, genetic algorithms produce better solutions from one generation to the next.

## INTRODUCTION

Accurate capacity and time scheduling for electricity generation require selecting power plants [1] with an economic advantage. Moreover, the planning and scheduling process involves determining the combination of available power plant units, setting the power generated by each unit, and minimizing total operating costs while adhering to system and unit constraints [2] [3]. The process also involves solving power plant scheduling problems using discrete variables such as power plants on/off status and continuous ones such as power output per hour [4] [5].

A short-term power system operation plan is a schedule that covers a time horizon of up to 168 hours and is normally applied to short-term power plants units [6] [7]. It is usually constrained by a maximum and a minimum load limit determined by estimating the medium-term load. It is important to note that short-term planning provides a more detailed breakdown of time [8].

Genetic algorithms can solve power plants problems with non-convex curves [9]. It usually operates based on an evolutionary theory using probability instead of deterministic methods [10]. Genetic algorithm normally determines solutions from generated populations, thereby providingferent multiple options to solve a particular problem [11] [12].

Several studies have been conducted to solve short-term scheduling problems using genetic algorithms as observed in the application of ant colony optimization [13] and one other example that is more relevant is Economic Generation in Diesel Power Units where the use of the genetic algorithm method in this study is based on the presence of several weaknesses when using conventional methods. If viewed from the objectives to be achieved, the previous research mentioned above with this research has the same goal, namely to minimize the total cost of generation. However, there are several differentiating points, one of which is the object of its application, whereas in the previous research, it was applied to Power Plants. Diesel, while in this study it was applied to Thermal Power Plants, the arrangement of the steps of the genetic algorithm method also has slight differences depending on the object of its application. The genetic algorithm method was chosen for this study because it can minimize costs to meet certain constraints and provide optimal power output scheduling of all hydro and thermal units studied during the given power load period and available water sources [14]. This study applied a genetic algorithm with fitness scaling to combine coal-fired and gas-fired power plants. The purpose was to solve complex problems considered difficult for conventional methods. Moreover, the fitness scaling was included to provide optimal solutions by maintaining the best chromosomes.

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## METHOD

### *Problem Solving Stages*

The following are the steps for solving the problem of generation costs and accurate operation scheduling using the genetic algorithm method. First, to ensure efficient electricity generation, developing precise capacity and time allocation schedules is essential. It involves carefully selecting power plants that offer economic advantages during operation. Then, the genetic algorithm method was applied to this research problem by systematically demonstrating the acquisition and subsequent processing/analysis of the research data to determine the optimal solution.

### *Thermal Power Plants Scheduling*

There are limits to the power balance in each power plant,nown as the equality and inequality constraints [15]. The equality constraints require that the total power generated fulfills the total power demand, as expressed in the following Equation (1):

$$\sum_{i=1}^{n} P_i^t = Pdt \qquad (1)$$

Where, $P_i^t$ is the output power from power plants *i* at time *t* and Pdt is the load power at time *t*.

The inequality constraints require that the output power generated by a unit be greater than or equal to the minimum allowable power and less than or equal to the maximum allowable power. This is expressed in the following Equation (2):

$$P_{min} \leq P \leq P_{max} \qquad (2)$$

The main objective of these characteristics is to determine the cost equation in the form of a second-order polynomial.

$$F_i\,(P_i) = a_iP_{i2} + b_iP_i + c_i \qquad (3)$$

Where, $F_i\,(P_i)$ represents the input fuel for thermal power plants (liters/hour), Pi is the output power of a thermal power plant (MW), while ai, bi, and ci are the input-output constants of thermal power plants.

Therefore, the total generation cost can be solved using Equation (4) as follows:

$$FT = \sum_{i=1}^{n}[Fi(P_i^t)] \qquad (4)$$

Where, FT is the total production cost of all power plants, $Fi(P_i^t)$ is the cost of each power plant per unit time t, and $P_i^t$ is the output power of each power plant at time t.

A set of equations to represent the objective function based on the existing constraints can be summarized as follows:

$$\frac{dFi}{dPi} = \lambda \qquad (5)$$

i = 1, ..., n

The identification of the inequality constraints showed that the required conditions are stated as follows:

$dF_i/dP_i = \lambda$ for $P_{imin}<P_i<P_{imax}$;
$dF_i/dP_i \leq \lambda$ for $P_i = P_{max}$;
$dF_i/dP_i \geq \lambda$ for $P_i = P_{min}$.

### *Genetic Algorithm*

A Borland C++ program listing can be created using a genetic algorithm. The scheduling flowchart is presented in the Figure 1:

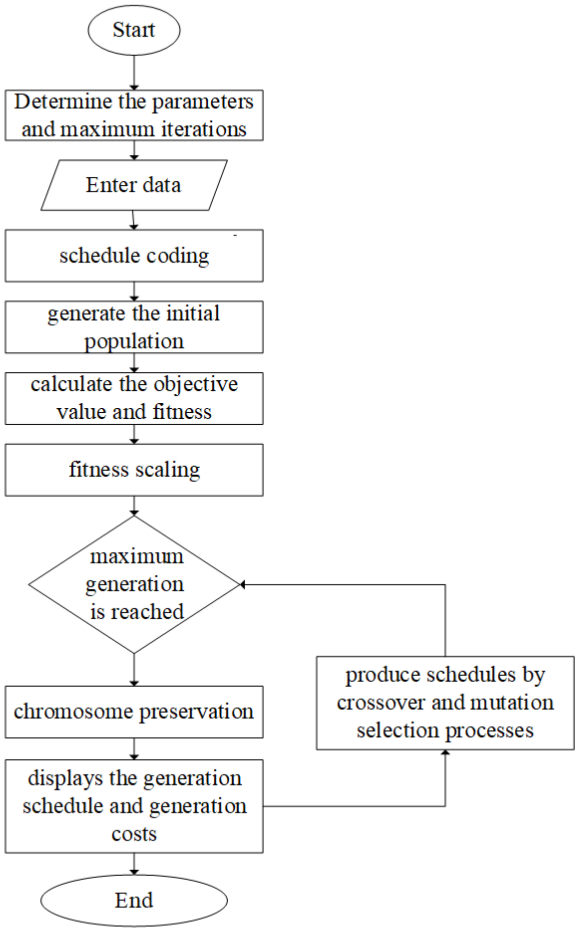


Figure 1. Flowchart of genetic algorithm solving

In order to optimize the process, specific parameters must be established, and the maximum number of iterations must be determined. These parameters include the number of chromosomes in a given population, the probability of crossover ($P_c$), the probability of mutation ($P_m$), the probability of preserving chromosomes, and the termination criterion (maximum iterations) [16]. Once these parameters have been established, input the relevant data, such as the nomenclature of power plant units, the lower limit ($P_{min}$), and the upper limit ($P_{max}$) of power generation for each unit, along with the coefficients a, b, and c. After that, create the initial population by constructing a binary string consisting of n bits, each produced randomly. Then, compute the goal value and fitness. The fitness function is a metric for maximizing profit or minimizing cost [17][18]. To formulate the mapping from the objective function (in the case of minimization) to the fitness function, follow the formulation provided by [19]:

$$f(x) = \begin{cases} C_{max} - g(x) \; if \;\; g(x) < C_{max} \\ \quad 0 \; if \; g(x) = \; C_{max} \end{cases} \qquad (6)$$

Where *f(x)* is the fitness function and *g(x)* is the objective function to be minimized. Notably, *g(x)* is the largest value of *f(x)* obtained in the current population.

The genetic algorithm requires the convergence of a population towards the desired solution, thereby making the difference in fitness values between chromosomes from generation to generation very small [20]. This slight difference hinders the best chromosomes from being superior or prioritized in selection. So, after the fitness function is obtained, the fitness scaling is applied to each schedule's fitness values to make them the most superior [21].

This study applied exponential scaling, and this method could reproduce chromosomes with low fitness values and increase the superiority of the best ones. Therefore, the exponential scaling equation is as follows:

$$\text{Fitness(i)} = (\text{fitness(i)} + 1)^2 \quad (7)$$

After the scaling completed, the data are reproduced by the generation schedule in the reproduction steps. The first is selection steps. The method is a roulette wheel that calculates the total fitness value using the formula $\sum F = F_1 + F_2 + F_3 + F_4$. Then the probability and cumulative value of each generation schedule are calculated using the following Equation:

$$Pi = \frac{fi}{\sum ifi}, \quad i = 1, ..., n \quad (8)$$

After that, random numbers are generated for selection (rs) between 0-1 within the population size. Furthermore, select the π-th schedule as the parent.

To reproduce the parent, the genes are crossed over. The technique used for crossover is the one-point crossover. First, the number of schedules to be crossed is determined. A random number ($r_c$) is then generated to identify the schedule that will undergo crossover. If the value of $r_c$ is less than $p_c$, the π-th schedule is selected as the parent. Next, a single point is randomly selected to perform the crossover.

After reproduction, the gene are mutated by determining the mutation probability ($p_m$) first. Moreover, the gene to undergo mutation was determined by generating mutation random numbers ($r_m$) for each gene such that those with $r_m < p_m$ were mutated.

## RESULTS AND DISCUSSION

This study applied genetic algorithm method to produce the short-term scheduling plan for thermal power plants to determine the power output to fulfill load demand at a minimum cost. This was achieved using three samples, including Loads 1, 2, and 3. The results obtained were used to determine the on/off combinations of power plants according to load requirements.

### *Input Data*

The input data used were the parameters of power plant units as indicated in Table 1. It was observed that the 24-hour load data and genetic parameters used [22] were the optimal population size (popsize) of 20, the crossover probability (Pc) ranged from 0.6 to 0.9, and the mutation probability ranged from one divided by the number of genes. The $P_m$ was 0.00009, Pc was 0.85, the study time was 24, and the number of units was 6. Moreover, it was assumed that the cost per kWh is Rp 1,190, and the simulation was conducted on loads 1 to 3 using Borland C++ software, with each having its demand.

### *Generated Power*

Table 1. Power plants parameter data.

| Power Plant | Pmin (MW) | Pmax (MW) | Coefficient a | Coefficient b | Coefficient c |
|---|---|---|---|---|---|
| SPP RBG | 150 | 560 | 0.00292 | 0.00185 | 0.03596 |
| SPP TJ 1 & 2 | 365 | 1322 | 0.00130 | 0.00138 | 0.03178 |
| SPP TJ 3 & 4 | 365 | 1322 | 0.00097 | 0.00137 | 0.03443 |
| SGPP TBK LRK | 169 | 675 | 0.00372 | 0.00390 | 0.07171 |
| SPP ADIPALA | 154 | 615 | 0.000716 | 0.001733 | 0.02812 |
| SPP CILACAP | 154 | 614 | 0.30009 | 0.00159 | 0.02812 |

Figures 2, 3, and 4 show the simulation results of the scheduling for six thermal power units and demand load for 24 hours in the form of power generated (economic dispatch).

Figure 2 shows the scheduling graph for the six thermal power units and demand load for 24 hours on Monday, May 21, 2018. It was discovered that the total load was 78109 MW and the total cost was Rp 200,285,266.26. The highest load was recorded to be 3903 MW at 6:00 pm WIB and supplied by five power plants, including SPP Rembang, Tanjung Jati 1 & 2, Tanjung Jati 3 & 4, Adipala, as well as SGPP Tambak Lorok. Meanwhile, the lowest load was 2635 MW at 7:00 am WIB and supplied by six power plants, including SPP Rembang, Tanjung Jati 1 & 2, Tanjung Jati 3 & 4, Adipala, Cilacap, as well as SGPP Tambak Lorok.

Figure 3 shows the scheduling graph for the six thermal power units and demand load for 24 hours on Monday, May 22, 2019. The total load was 74497 MW, and the total cost was Rp 149,774,156.41. The highest load was found to be 3846 MW at 7:00 pm WIB and supplied by five power plants, including SPP Rembang, Tanjung Jati 1 & 2, Tanjung Jati 3 & 4, Adipala, as well as SGPP Tambak Lorok. Meanwhile, the lowest load was recorded to be 2534 MW at 7:00 a.m. and supplied by the six power plants listed in Table 1.

Figure 4 shows the scheduling graph for the six thermal power units and demand load for 24 hours on Monday, May 21, 2019. The total load was found to be 78681 MW, and the total cost was Rp 156,297,893.08. The highest load was recorded as 3928 MW at 6:00 p.m. and supplied by the six power plants listed in the table. Meanwhile, the lowest load was 2696 MW at 7:00 a.m. and supplied by five power plants, including SPP Rembang, Tanjung Jati 1 & 2, Tanjung Jati 3 & 4, and Cilacap, as well as SGPP Tambak Lorok.


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### *Generation Cost*

The generation cost was determined using Equation (3) to minimize the total cost in Equation (1) based on the assumption that the cost per kWh is Rp 1,190.

The minimum cost for load 1 with the highest load at 6:00 pm WIB was found to be Rp 6,710,476.971 while the lowest load at 7:00 am WIB had Rp 11,470,683.165.

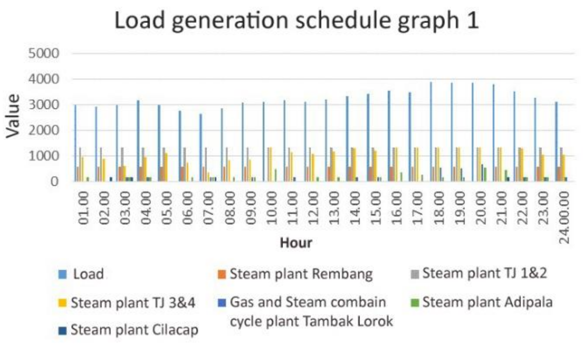


Figure 2. Generation scheduling graph for load 1.

The minimum cost for the highest load recorded at 19:00 WIB for load 2 was Rp 6,465,125.457, while the lowest load at 07:00 WIB was Rp 3,842,537.387. The values for the highest load at 19:00 WIB for load 3 was Rp 6,595,207.125, while the lowest load at 07:00 WIB had IDR 4,290,802.177.

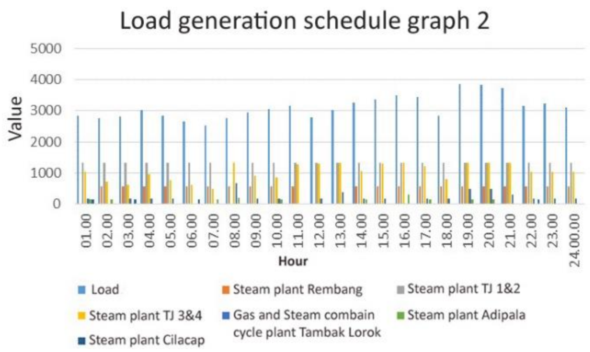


Figure 3. Generation scheduling graph for load 2.

### *Generation Operation*

The problems associated with the scheduling of the power generation system were solved using binary individual modeling [23]. The scheduling period for each unit can be in on or off condition and the generation schedule was found in the 25th generation [24]. Moreover, the graph shows that SPP Tanjung Jati 1 & 2 and Tanjung Jati 3 & 4 operated for 24 hours, SPP Rembang for 22 hours, SGPP Tambak Lorok for 11 hours, SPP Adipala for 19 hours, and SPP Cilacap for 4 hours. It was also discovered from the graph that SPP Rembang operated for 22 hours, SPP Tanjung Jati 1 & 2 for 23 hours, SPP Tanjung Jati 3 & 4 for 24 hours, SGPP Tambak Lorok for 19 hours, SPP Adipala for 10 hours, and SPP Cilacap for 4 hours.

The genetic algorithm produced a solution that converges to the best value. It was discovered that the power generation cost decreased compared to the values obtained in previous generations as the number of generations increased. This was associated with the ability of genetic algorithm to reproduce schedules through selection, crossover, and mutation. Therefore, the schedule obtained in one iteration improved those produced by previous iterations.

The schedules with low or high fitness values were eliminated and replaced by those with the best fitness value (minimal power generation cost) in the selection stage and later applied as the parent in the crossover stage. The best parent was crossed in the crossover stage to produce the best offspring. The mutation stage also ensured that the schedule was not damaged or changed to become less optimal during the crossover stage. Therefore, genetic algorithms produce a better solution from generation to generation.

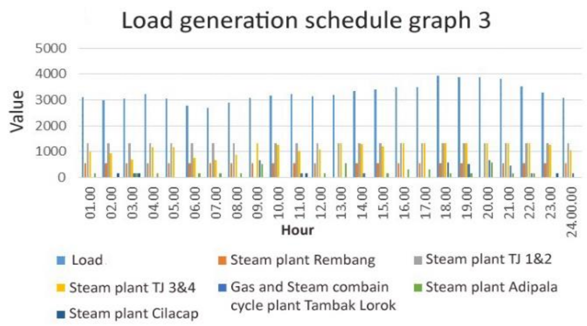


Figure 4. Generation scheduling graph for load

## CONCLUSIONS

Applying the genetic algorithm method to plan the schedule for the combination of 6 thermal power plant units produced an optimal solution per the predetermined constraints. It provided an efficient and effective scheduling result to determine the period to start and end the operation of power plants. Also, it produces the power output that can fulfill the load demand. Moreover, the genetic algorithm maintained and manipulated a set of solutions and applied the strongest survival strategy in the search for better solutions using its reproductive processes of schedules with selection, crossover, and mutation stages. It was discovered that a higher number of generations produced the lowest cost. Therefore, genetic algorithm produced better solutions from one generation to the next.

## CONFLICT OF INTEREST STATEMENT

One of the authors of this article, Syafii, is a member of editorial team of this journal. This relationship could potentially create a conflict of interest. However, several steps have been taken to ensure the review and publication process's integrity, transparency, and fairness.

1. The author was not involved in any stage of the article's editorial decision-making process.
2. The article was subjected to the same rigorous peer-review process as any other submissions, handled independently by another editorial board member.
3. Syafii has no access to the review reports or any other privileged information regarding his manuscript's submission.

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