

Economic dispatch and operating cost optimization for thermal power in 500 KV system using genetic algorithm (GA)

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Abstract. Electricity system is divided into three main parts, namely power plants, electricity distribution or transmission, and distribution of electricity. Power generation is the biggest cost component in a power system. The analysis to minimize generational costs is called Economic Dispatch. The meaning of Economic Dispatch is the division of loading on existing generating units in the system optimally and economically at a certain load price. With the implementation of Economic Dispatch it will get a minimum cost of generation of electricity production. Then the need for optimization that is by using a heuristic approach with Genetic Algorithm (GA). With this approach will be obtained an economical operating costs. Genetic algorithms are able to find the optimal power generation value. The case studies in this research are available on thermal generation in the Java-Bali 500 kV system. The research stations are Suralaya, Muara Tawar, Tanjung Jati, Gresik, Paiton and Muara Karang plants. Software used is Matlab R2017a. In this research we use the data of heatrate equation function and equation of operating cost at thermal generator then made arrangement to output (power) from generator to reduce operating cost of generation. Genetic Algorithm is very simple because it involves only crossover and string mutations so this research uses the algorithm to find the solution of the problem. With genetic algorithm, the result of operating cost where the biggest cost is 3.172.653.871 Rp / h and the smallest cost is 2.336.431.759 Rp / h.

1. Introduction

Power generation is the largest cost component in an electric power system [1]. The plant also needs to obtain optimal operation in meeting the load requirements [2]. The analysis to minimize generational costs is called Economic Dispatch. The meaning of Economic Dispatch is the division of loading on existing generating units in the system optimally and economically at a certain load price. With the implementation of Economic Dispatch, it will get a minimum cost of generation of electricity production [3].

The solution of the problem Economic Dispatch can use both deterministic and indeterministic methods. Examples of Deterministic solutions in the problem Economic Dispatch, for example, using the Lagrange method [3], while indeterministic solution problem Economic Dispatch based on a heuristic approach can use Genetic Algorithm (GA).

In the last decade, conventional optimization techniques such as the lambda iterative method (Lagrange Multiplier), linear programming and quadratic programming have been successfully used to



overcome the problem of optimization of generating systems such as commitment units [4]. Due to the complexity and non-monotonicity of the optimization problems, many alternatives are introduced aside from the genetic algorithm [5]. However, GA is easier to apply because the optimization process at this operating cost is a quadratic equation with a certain constraint and for the constraint is already available in the GA feature in MATLAB.

2. Literature Review

2.1. Power System

Generally speaking, power systems are divided into three main parts, namely power generation, power distribution or transmission, and power distribution [6]. The electric power station is usually located away from the load centers where electrical energy is used. The power plant is where the first electric energy is generated, where there is a turbine as a prime mover and a generator that generates electricity.

2.2. Power Plants

The power plant is the first place where electrical energy is generated or generated. There are several types of power plants that are usually divided into two major parts, namely hydropower plant (PLTA) and thermal power plant (PLTU, PLTG, PLTGU, PLTD, PLTP) [6]. Electrical power systems comprising hydro-generating groups and thermic generators require load-sharing paths between the two generating groups to achieve optimum operating conditions or in the sense of minimum fuel cost [7].

The process of generating electricity in thermal power plants requires a small amount of fuel. Fuel costs and losses in the network are factors that must be pressed to become as small as possible. Operational costs are generally the largest cost of power systems. Broadly speaking, the operating costs of a power system consist of:

1. The cost of purchasing electricity
2. Employee costs
3. Fuel costs and material operations
4. Other expenses.

Of the four costs above, generally the cost of fuel is the largest cost. For PLN, fuel costs are approximately 60% of overall operating costs [8].

2.3. Thermal Plants

In electric systems, there are many thermal generators. Some are fueled by steam, coal, or gas. In principle, the most expensive thermally generating unit should have a minimum kWh production and should be cultivated for the PLTA to be used up [7].

There are several characteristics of the thermal generating unit:

2.3.1. Input-output characteristic. The input-output characteristics of the plant illustrate the relationship between the fuel input (R_p / h) and the output of power generated by the generator (MW). By knowing the difference in characteristics among all existing generators, optimization of the operation of the plant can be done.

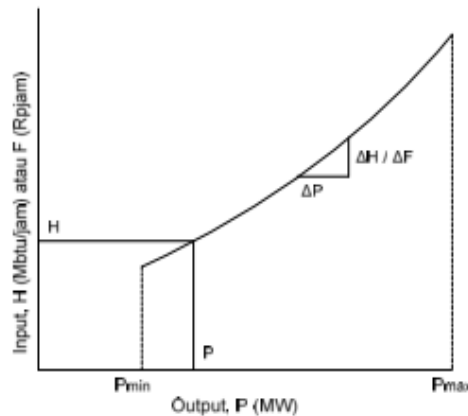


Figure 1. Input-Output Unit Thermal Characteristic Curve.

The input of the generator is indicated on the vertical axis of heat energy required in Mbtu / h (Million of BTU per hour) form because it uses the British Unit Temperature Unit (when using SI to MJ / h or Kcal / H) or total cost per hour /hour). The output of the generator is shown on the horizontal axis of electrical power, which has critical operating limits of the maximum and minimum power of the generator [9].

The widely used input-output characteristics of the generating unit are quadratic functions as follows:

$$F = aP_i^2 + bP_i + c_i \quad (1)$$

Where:

a, b, and c = input-output characteristic coefficients

i = the generating index to i (i = 1,2,3, N).

F = the cost of thermal generation of thermal fuel (Rp / hour).

P = thermal generator output (MW).

2.3.2. Characteristics of Cost Increase or Heat of Thermal Generating. Another characteristic that needs to be known of a thermal generating unit is the characteristic of the thermal rise rate which can also be said to be a cost increment characteristic. This characteristic is a slope of the input and output characteristics. If the input-output equation of the generating unit is expressed in approximation by using the quadratic equation, then the cost increment characteristic will have a straight-line form [9].

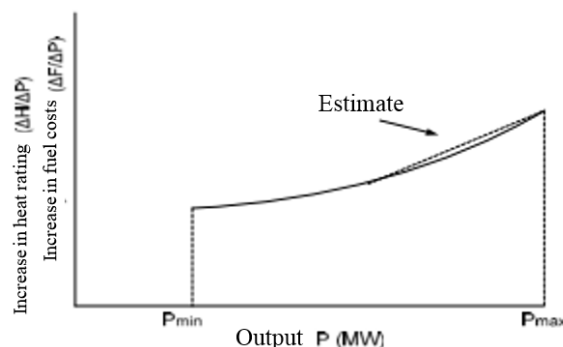


Figure 2. Characteristic Curve of Increase Cost or Heat of Thermal Unit.

2.3.3. Characteristic of Efficiency to Output. Characteristics of the heatrate is also one of the characteristics that need to be known. At this characteristic, the input is the sum of heat per kilowatt-hour (Btu / kWh) and the output is electric power in MW.

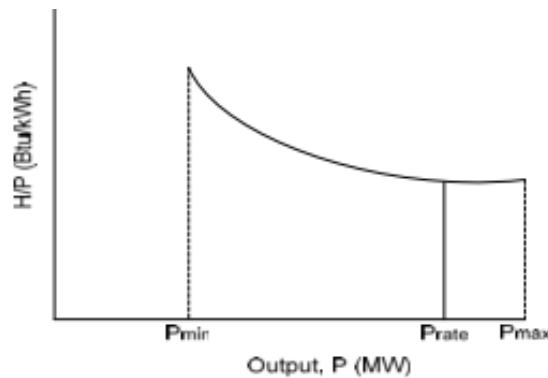


Figure 3. The curve of the efficiency characteristics of the output.

2.4. Economic Dispatch (ED)

Economic dispatch or economic scheduling is an attempt to determine the amount of power that must be supplied from each generator unit to meet a certain load by dividing the load into the generating units present in the system [10]. Optimal load sharing will minimize the cost of generating operations [11].

The economical operation of a power plant must meet certain limits or constraints. Two constraints used in this study are equality and inequality of constraints. Constraint equality is the equilibrium power constraint, which requires that the total power generated by the plants should equal the total load requirement. Whereas constraint inequality requires that the output power of each unit be greater than or equal to the minimum power allowed and less than or equal to the maximum power allowed [12].

The constraint description is described as follows [18] :

- Equality konstrain

$$\sum P_g = P_D + P_L \quad (2)$$

Where :

P_g = Power generated by the generating unit.

P_D = Power load on the system.

P_L = Power losses on transmission.

In this case, power losses can be ignored because the author is more focused on searching for power generated by power plants. So as not to be disturbed by the transmission parameters that are affected by various things. Power raised will affect the number of fuel costs incurred. Power on the plant must be able to meet the load requirements of the system as in equation 2.

- Inequality konstrain

$$P_{G \min} \leq P_G \leq P_{G \max} \quad (3)$$

Where :

$P_{G \min}$ = Minimum power generated by the generating unit.

$P_{G \max}$ = Maximum power generated by the generating unit.

E. Genetic Algorithm (GA)

The Genetic Algorithm is a heuristic search approach applicable to various optimization issues. This flexibility makes them attractive to use on many issues in practice optimization. Evolution is the basis of the Genetic Algorithm [13]. Inspired by Darwin's theory of evolution and the laws of nature from survival, Genetic Algorithm (GA) is a global search procedure to gradually improve solutions in populating populations using operations that mimic natural evolution such as reproduction, crossover, and mutation [14]. The terms in the genetic algorithm are described in Table 1 [15].

Table 1. The term in the genetic algorithm.

Genetic Algorithm	Explanation
Chromosome (string, individual)	Solution (encoding)
Genes (bits)	Part of the solution
Locus	The position of the gene
Alleles	The values of the genes
Phenotype	Solutions that are decoded
Genotype	The encoded solution

GA has certain stages to search for solutions that are as follows:

1) Population initialization

population initialization in Genetic Algorithm is done by selecting a string randomly [16]. The initial population is generated by forming a binary string of 10 bits or 3 bits. Each bit of this binary string is generated randomly [17]. At the beginning of the evolutionary process, the initial population is randomly generated within the minimum and maximum loads [18].

2) Chromosome Encoding

There are several kinds of coding techniques that can be done in genetic algorithms, including binary encoding, permutation encoding, value encoding and tree or tree coding [19].

a	
Chromosome 1	101010101100110011100
Chromosome 2	111111000000011111100

b	
Chromosome A	1.3532, 6.566, 2.9234, 4.3241
Chromosome B	P,Q,R,S,T,U,V
Chromosome C	Up, Down, Front, Back

c	
Chromosome 1	1 5 3 2 6 4 7 9 8
Chromosome 2	8 5 6 7 2 3 1 4 9

Figure 4. a) binary encoding, b) encoding values, c) encoding permutations.

The encoding procedure itself can be seen as follows [20]:

a. Real number encoding

$$X = rb + (ra - rb)g \quad (4)$$

b. Discrete decimal encoding

$$X = rb + (ra - rb)(g_1 \times 10^{-1} + g_2 \times 10^{-2} + \dots + g_N \times 10^{-N}) \quad (5)$$

c. Binary encoding

$$X = rb + (ra - rb)(g_1 \times 2^{-1} + g_2 \times 2^{-2} + \dots + g_N \times 2^{-N}) \quad (6)$$

3) Fitness

In general, this fitness function is divided into two purposes, namely the function to find the maximization (maximum value) and to find the minimization value (minimum value). For the general formula as follows [20]:

- Maximize Problems

$$\text{fitness function} = \text{purpose function} \quad (7)$$

- Minimization Problems

$$\text{Fitness function} = \frac{1}{(\text{purpose function} + \text{Small number})}$$

4) Crossover

Crossover is a genetic operator that operates on two chromosomes at a time and produces offspring by combining both chromosome features [15].

5) Mutation

Mutations are background operators that generate spontaneous random changes across multiple chromosomes. A simple way to achieve mutations is to change one or more genes [15].

6) Selection Process

Selection is the selection process of prospective mothers. The selection process is a chromosomal selection technique that will be eliminated from a good parent in the next evolutionary process. The change of each individual from one generation is determined by the fitness value. The goal is to produce the best offspring of a population to be processed through recombination and mutation. Then the selection is done by using three techniques, namely roulette wheel selection (fitness-based selection), rank selection and tournament selection [21].

3. Research Methods

In this research flow is optimized with Genetic Algorithm. In the algorithm there are certain stages to get the optimal value. For more details note the picture 5 as follows :

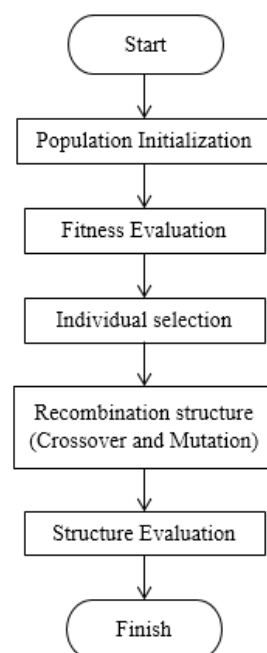


Figure 5. flow chart of the genetic algorithm.

4. Research Result

In this research, we use heatrate equation data on thermal plants and adjusted to output from the plants to reduce operating cost of generation. Optimization is done using the genetic algorithm. The method will be applied with Matlab R2017a software. In the initial step before the process in Matlab, there is an operational cost equation for each plant as shown in Table 2.

Table 2. Equation of Operating Cost of Termal Generating Unit

No.	Units	Equation of Operating Cost (Rp/h)
1	Suralaya	$F_1 = -0,1301 P_1^2 + 458605P_1 + 0,00002$
2	Muara Tawar	$F_2 = -0,2353 P_2^2 + 402084P_2 - 0,000003$
3	Tanjung Jati	$F_3 = -0,1128 P_3^2 + 428951P_3 - 0,00003$
4	Gresik	$F_4 = -0,0167 P_4^2 + 135060P_4 + 0,00000004$
5	Paiton	$F_5 = -0,0252 P_5^2 + 77501P_5 + 0,0000004$
6	Muara Karang	$F_6 = -0,0459 P_6^2 + 371144P_6 - 0,000001$

Then there is the limit of Net Capability that is the power that can be issued by each generator. The raised power must not exceed that limit. For the upper and lower limits of generation can be seen in table 3.

Table 3. Power generation limits on the thermal plants

No.	Units	Power Generation (MW)
1	Suralaya	$1900,8 \leq P \leq 3801,6$
2	Muara Tawar	$971,5 \leq P \leq 1943$
3	Tanjung Jati	$1321,9 \leq P \leq 2643,8$
4	Gresik	$265,5 \leq P \leq 531$
5	Paiton	$677,5 \leq P \leq 1355$
6	Muara Karang	$699 \leq P \leq 1398$

With the constraints then the next step is to process the algorithm. Power is made into chromosomes and follows constraints. Then evaluated by using fitness value that is operational cost equation. As for the fitness results on his chromosome is as follows :

Table 4. The fitness value of each chromosome.

No.	Chromosome	Fitness value
1	Chromosome 1	1,20698E-09
2	Chromosome 2	1,12686E-09
3	Chromosome 3	1,15897E-09
4	Chromosome 4	1,30892E-09
5	Chromosome 5	1,12922E-09
6	Chromosome 6	1,31158E-09
Total Fitness		7,24253E-09

The greatest fitness value is on chromosome 6 which is a form of the 6th generation in the existing population. In the chromosome contains a combination of power values that are still binary (0 and 1). So the value that has a great chance for life (has the best value) is chromosome 6. After going through the process of the genetic algorithm it will get new power value and have better fitness. The optimized value of genetic algorithm in the form of "X" is the output power of each generating unit so as to produce optimal operating cost. The value of "X" is the result of the latest chromosome decode after going through the above processes. The number of iterations used 200 times. The next step is to repeat the

above program to meet the load demand in the system. The optimization result of the genetic algorithm can be seen in table 5.

Table 5. Optimization results with Genetic algorithm.

Time	Demand (MW)	Power Plant (MW)					
		Suralaya	Muara tawar	Tanjung jati	Gresik	Paiton	Muara karang
0:00	8544	1900,8	971,5	2387,7	531	1355	1398
3:00	6732	1961,9	1062,9	1395,8	473,3	1139,1	699
6:00	7146	1900,81	971,58	1325,13	362,54	1354,97	1230,97
9:00	8527	1900,8	971,5	2370,7	531	1355	1398
12:00	8348	1900,8	971,5	2191,7	531	1355	1398
15:00	9005	1900,8	1176,4	2643,8	531	1355	1398
18:00	8726	1900,8	971,5	2569,7	531	1355	1398
21:00	8290	1900,8	971,5	2133,7	531	1355	1398

The power is then fed into the operating cost equation. Then the result of operating cost optimization resulted as follows :

Table 6. Results of operating cost optimization with GA.

Time	Total Cost (Rp/h)
0:00	2.980.661.415
3:00	2.336.431.759
6:00	2.440.628.631
9:00	2.973.378.373
12:00	2.896.688.264
15:00	3.172.653.871
18:00	3.058.628.724
21:00	2.871.837.405

Table 6 shows the results of operating costs where the largest costs occurred at 15.00 and 18.00 and the smallest cost occurred at 3.00. With a genetic algorithm obtained optimal results so that the output generation can serve the needs of the load on the system. Then the power generated is in accordance with the ability of the generator.

5. Conclusion

Referring to the findings and discussions in the previous chapter, there are several conclusions that can be taken. The conclusions are as follows:

- Optimization of operating costs can be minimized by finding power and dividing the load optimally on existing plants in the system.
- Iteration algorithm is done as much as 200 times and raises chromosomes a number of 10x6 bits and the number is in accordance with the number of generators used as research. Then the chromosome decoded results correspond to the power generation limits.

- c. The results of operating costs that have been optimized by the genetic algorithm have the largest cost that occurred at 15.00 and the smallest cost occurred at 3:00. At 15.00, the operating cost is 3,172,653,871 Rp / hour and at 3.00 for 2,336,431,759 Rp / hour.

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