Coordination Hydrothermal Interconnection Java-Bali Using Simulated Annealing

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Abstract. Hydrothermal power plant coordination aims to minimize the total cost of operating system that is represented by fuel costand constraints during optimization. To perform the optimization, there are several methods that can be used. Simulated Annealing (SA) is a method that can be used to solve the optimization problems. This method was inspired by annealing or cooling process in the manufacture of materials composed of crystals. The basic principle of hydrothermal power plant coordination includes the use of hydro power plants to support basic load while thermal power plants were used to support the remaining load. This study used two hydro power plant units and six thermal power plant units with 25 buses by calculating transmission losses and considering power limits in each power plant unit aided by MATLAB software during the process. Hydrothermal power plant coordination using simulated annealing plants showed that a total cost of generation for 24 hours is $ 13,288,508.01.

Keywords : Coordination hydrothermal, Simulated Annealing, Transmission losses

1. Introduction

Nowadays, scheduling of hydro and thermal power plants in the most economical way is the most important thing of modern power systems to meet the needs of energy market [1]. The main goal of hydrothermal power plants optimization is to minimize the total cost of operating system that is represented by cost of fuel, hydro power plant constraints and optimization of thermal power plants during the time of optimization [2]. Scheduling of hydrothermal power plants have a basic concept, that is to maximize hydro power plants and minimize thermal power plant production, thus ensuring reliability and power supply economically.

Over the last few years, there are several methods used by researchers to solve the optimization problem, such as interactive fuzzy satisfying method, improved genetic algorithm (IGA), modified NSGA-II, differential evolution, simulated annealing (SA), particle swarm optimization technique, improved quantum-behaved particle swarm optimization, differential evolution with adaptive Cauchy mutation, bacterial foraging algorithm, mixed integer programming, and so on [3]. SA algorithm was introduced by Metropolis in 1953 which is analogized on annealing (cooling) process applied in the manufacture of materials composed of crystals. Metropolis used several variables in scheduling the refrigerant to control the search process. Simulated annealing algorithm in performing economic dispatch approach requires some parameters in order to produce solutions in the scheduling of power plant units [4] [5].

In this study, the results of optimization using simulated annealing optimization is expected to give an optimal result in the coordination of the Java-Bali 500 kV hydrothermal power plant. The result of this study is expected to be a reference for certain parties in performing the operation of electrical power generation, in order to obtain an optimal level of power generation economics.

2. Hydrothermal Coordination

Optimized scheduling of hydrothermal power plants involve the setting of hydro and thermal power plants to meet the load demand and constraints of the power generation system. These problems can be solved by knowing the discharge of hydroand thermal power plants to minimize the total cost of fuel as well as to overcome the existing constraints [6]. Hydrothermal power plant scheduling, from economic perspective, is the most important thing in modern power system to increase competition in power market [1].

2.1. Objective Function

$$F_T = \sum_{i=1}^{T}\sum_{j=1}^{N} F_j\big(P_S(j,t)\big) \tag{1}$$

Where:

F_T : Total production cost function
P_S (j,t) : Power of thermal generator of unit j in period t
F_j (Ps (j,t)) : Production cost for P_S (j,t)
N : Thermal power plant unit number
T : Period time number

Function of electrical production cost is explained as follows:

$$F_j\big(P_S(j,t)\big) = a_j + b_j P_S(j,t) + c_j P_s^2(j,t) \tag{2}$$

Where a_j, b_j, c_j are coefficients of cost of thermal power plant unit.

2.2 Hydraulic Model

Input-output characteristics of hydro-electric power plant units can be formulated using the flow of water and output power such as the modelling by Glimn-Kirchmayer:

$$q_j(t) = K\psi(h_j(t))\phi(P_{Hj}(t)) \tag{3}$$

Where:

q_j (t) : Discharge of reservoir j inperiod t
K : Comparison value
h_j (t) : Head effectiveness of j in period t
P_{Hj} (t) : Power of hydro generator of unit j in period t
$\psi\phi$: Independent function, can be found using:

$$K\psi\left(h_j(t)\right) = a_0 + a_1 h_j(t) + a_2 h_j^2(t) \tag{4}$$

$$\phi\left(P_{Hj}(t)\right) = b_0 + b_1 P_{Hj}(t) + b_2 P_{Hj}^2(t) \tag{5}$$

where a_0,a_1,a_2,b_0,b_1,b_2 are hydro coefficient models.

2.3 Constraint

The coordination of hydrothermal plants have constraints as follows:

- Load Balance

$$\sum_{i=1}^{M} P_H(i,t) + \sum_{j=1}^{N} P_S(j,t) = P_D(t) - P_L(t) = 0 \tag{6}$$

- Power plant capacity

$$P_S(j)^{min} \leq P_S(j,t) \leq P_S(j)^{max} \tag{7}$$
$$P_H(i)^{min} \leq P_H(i,t) \leq P_H(i)^{max} \tag{8}$$

3. Simulated Annealing

Simulated Annealing (SA) uses the concept of local search or neighborhood search at each iteration of SA to perform the optimal layout search with minimum cost. SA algorithm can be used to find the optimal value of the problem of combination of unit commitment optimization. The linkage of physics regarding the simulated annealing method with optimization, which can be translated into atomic energy, is analogized as objective cost function and final ground state and is stated as a minimum result of cost function. Besides, the determination of the temperature becomes the main parameters in the optimization process [8][9]. Simulated annealing approach used for global optimization aims to discover the approximate global solution. Simulated annealing is a development of Monte Carlo method in his research on states and frozen states in a system. The resulting solution in simulated annealing is obtained from initialization parameters that are randomly generated. The solution is solved by selecting one position and moving it to another location. If the new solution is better than the previous one, the solution is stored. Where as if it is not, it can be stored with probability setting by reducing the parameters of temperature, commonly known as Boltzmann probability that is expressed as $e^{-(s_n - s_b/T)}$, where s_n is the current value and sb is the previous value, T is temperature parameter whose initialization value is 100. Subsequently, the temperature parameter is reduced in the next iteration, thus possibility reduction is acceptable. The iteration process is complete when the criteria is achieved and a solution is found [10]. If depicted in the flowchart would like Figure 1.

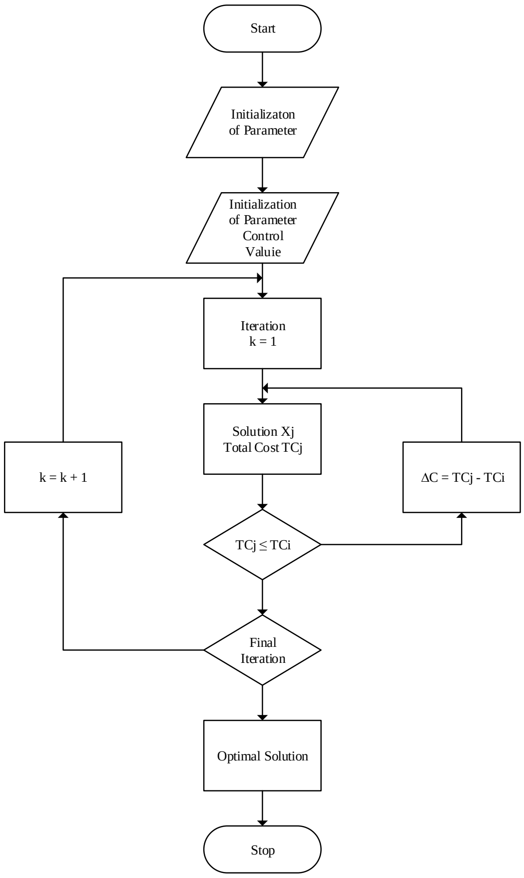

Figure 1. Flow chart Simulated Annealing

4. Simulation Results

Characteristics of hydro power plants in this study can be seen in the table below:

Table 1. Comparison of Input and Output Characteristics

No	Hydro power plant	Comparison of Input and output characteristics (m^3/hour)
1	Saguling	Q = 72077.5 + 335.68 P
2	Cirata	Q = 234703.20 + 563.83 P

While the thermal power plants have the following characteristics:

Table 2. Generation Cost Characteristic

Power plant	Generation cost characteristic ($/h)
Suralaya	$275.17 + 34.21P – 0.00149P^2$
Muaratawar	$624.93 + 178.86P – 0.0512P^2$
TanjungJati	$348.55 + 27.25P – 0.00188P^2$
Gresik	$538.37 + 52.83P – 0.00026P^2$
Paiton	$-212.50 + 151.78P – 0.00835P^2$
Grati	$-119.39 + 45.64P – 0.00606P^2$

In Java-Bali 500 kV interconnection system, there are 25 buses with transmission losses as follows:

$$B = \begin{bmatrix} 0.0157 & 0.0089 & -0.0093 & -0.0202 & -0.0241 & -0.0104 \\ 0.0089 & 0.0319 & -0.0106 & -0.0422 & -0.0481 & -0.0093 \\ -0.0093 & -0.0106 & 0.0342 & 0.0155 & 0.0178 & 0.0089 \\ -0.0202 & -0.0422 & 0.0155 & 0.1253 & 0.1037 & 0.0145 \\ -0.0241 & -0.0481 & 0.0178 & 0.1037 & 0.1544 & 0.0257 \\ -0.0104 & -0.00930 & 0.0089 & 0.0145 & 0.0257 & 0.0268 \end{bmatrix}$$

$$B0 = [0.00021 \quad 0.00039 \quad -0.000099 \quad -0.0008 \quad -0.0009 \quad -0.000039]$$

$$\boldsymbol{B00 = 0.0000032896}$$

After the characteristics of each plant were known, the calculation using simulated annealing could be performed with the aid of MATLAB software, so the results of hydrothermal plant optimization can be seen in the following table:

Table 3. Results of Hydrothermal Coordination

Time	PD	MW							
		Saguling	Cirata	Suralaya	MuaraTawar	TanjungJati	Gresik	Paiton	Grati
01.00	7783.32	105.97	0	1600	750	2630.24	900	1400	150
02.00	7368.35	105.97	0	1600	750	2630.24	900	1400	150
03.00	7229.87	105.97	0	1600	750	2630.24	900	1400	150
04.00	7068.49	118.44	0	1874	750	2700	900	1400	150
05.00	8075.23	118.44	0	1874	750	2700	900	1400	150
06.00	8309.28	118.44	0	1874	750	2700	900	1400	150
07.00	8063.53	135.17	83.67	2957.45	750	2700	900	1400	150
08.00	9009.28	135.17	83.67	2957.45	750	2700	900	1400	150
09.00	9953.89	135.17	83.67	2957.45	750	2700	900	1400	150
10.00	10193.6	255.91	62.67	3400	779.43	2700	1220.56	1726.05	152.33
11.00	10556.99	255.91	62.67	3400	779.43	2700	1220.56	1726.05	152.33
12.00	9844.09	255.91	62.67	3400	779.43	2700	1220.56	1726.05	152.33
13.00	10439.09	250.987	76	3400	1018.44	2700	1144.77	2006.67	151.02
14.00	10798.41	250.987	76	3400	1018.44	2700	1144.77	2006.67	151.02
15.00	10681.73	250.987	76	3400	1018.44	2700	1144.77	2006.67	151.02
16.00	10482.43	242.123	102	3400	1005.81	2700	1215.59	1768.69	224.21
17.00	10118.5	242.123	102	3400	1005.81	2700	1215.59	1768.69	224.21
18.00	11083.13	242.123	102	3400	1005.81	2700	1215.59	1768.69	224.21
19.00	11014.04	301.19	155.67	3400	1070.29	2700	1217.13	1904.04	251.98
20.00	11002.32	301.19	155.67	3400	1070.29	2700	1217.13	1904.04	251.98
21.00	10669.44	301.19	155.67	3400	1070.29	2700	1217.13	1904.04	251.98
22.00	9824.48	93.1733	63	3400	836.91	2700	902.854	1569.16	157.84
23.00	9644.4	93.1733	63	3400	836.91	2700	902.854	1569.16	157.84
24.00	9481.54	93.1733	63	3400	836.91	2700	902.854	1569.16	157.84

Coordination results of hydro thermal plants used simulated annealing on 9 September 2013 for 24 hours by taking into account the transmission losses, resulting in a total generation cost of $ 13,288,508.01 of 2 hydro power plant units and 6 thermal power plant units. In 2 early periods or at 1:00 to 6:00,Cirata hydro power plant unit was not operated because its water debit, if the plant was operated, would have produced output power below the minimum generation limit of Cirata unit. The most expensive operating costs occurred in the period of 7 or at 19.00 - 21.00 because this time was the peak load of the day, so all power plants were operated, with hydro power plant producing 301.19 MW of power for Saguling unit and 155.67 MW for Cirata unit. For thermal power plants in Suralaya and Tanjung Jati unit, the maximum power produced was 3400 MW and 2700 MW, while for the other units it was 1070.29 MW for Muara Tawar power plant unit, 1217.13 MW for Gresik power plant unit, 1904.04 MW for Paiton power plant unit and 157.84 for Grati power plant unit.

5. Conclusion

Concerning the load distribution of hydro and thermal power plants where hydro power plants were used to support basic load while thermal power plants were used to support the remaining load that could not be supported by hydro power plants, the optimization result using simulated annealing showed that the total operating cost obtained was $ 13,288,508.01.

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