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Influence Types of Startup on Hydrothermal Scheduling

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Abstract

The energy costs of a power plant consist of startup cost and cost of power usage. In contrast to the existing literature, this study introduces at startup cost based on the duration of thermal power plant downtime. The approach of startup cost function in this research is done by using startup type. Startup of a steam power plant depends on its condition. Generally, there are three types of startup the power plant when the turbine temperature is still very high, i.e. hot start, very hot start and very-very hot start. This paper uses multistage optimization to solve the problem of hydrothermal scheduling with including the startup type cost in the objective function. The simulation results showed operating cost savings when the objective function for optimization also consider the cost based on startup type i.e. when compared with the optimization result which the objective function does not take the cost of startup type.

***Keywords**: Optimization, operating cost, startup types*

1. Introduction

The schedule of hydrothermal in the electric power system has been discussed by using the optimal costs. Some journals showed that the formulations of energy costs as the objective function were also discussed without involving the startup costs [1], [2], [5]-[6]. In other journals were also discussed the optimization that involves the startup costs [4], [7]-[8]. But from those papers reviews of startup does not yet involve any kind type of a startup. Various types of the startup in that statement are a cold start, warm start, and hot start. Various types of the startup are based on the start time. That depends on downtime of the power plant from grid [9].

Modern optimization methods such as particle swarm optimization for minimization costs [10], as well as to maximize profit [11] has also been explored in scheduling the hydrothermal system. The particle swarm or genetic algorithms are used in addition to optimization in the economic dispatch [12]-[13], or environmental/economic dispatch [14], they have also been used in other topics, such as to control of power plants to handle the load change [15], as well as for optimization of load shedding in the electrical distribution system [16]. In addition, the evaluation of the power system with multi-objective functions for mixing various types of long-term electricity generation was done by using the modern optimization methods, i.e. the dynamic programming [17]. It has been used to purpose the evaluations of the electricity market [18]. In this paper will be used the multistage optimization algorithms with using the modern optimization method through evolutionary algorithms and classical method with the interior point in determining, the scheduling of hydrothermal with involving startup type costs.

The startup period can be viewed under two conditions. In the first condition, the startup type is reviewed by looking at the turbine temperature [19]-[20]. That is a cold start, warm start, and hot start. The hot start is when the temperature turbine still very hot. In this paper proposed for the hot startup type is seen using steam readiness to rotate the turbine, i.e. when steam is not available it is called hot start, when steam is available but not yet fulfilled the pressure to rotate turbine called very hot start, and high very hot start when steam fulfills for turning the turbine but the generator is off the grid.

Startup for steam power plants, they have taken the time to reach the Carnot cycle. So, the type of startup can also be said that it depends on the time. While superheated steam is

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used to moving turbine generator. So, the start-up costs of the steam power plant can be said depending on the time of startup to meet loads [7]-[8].

In paper [1], it is shown that multistage optimization that can combine the modern optimizations such as maximization water use in a dam and with the classical method for minimization cost to obtain optimal results of a scheduling in an operating electrical system. But those paper does not involve startup type costs as an objective optimization function. In this paper, we will modify the multistage algorithm by adding the scheduling stage by considering the cost of different startup types.

With considering startup time, so in this paper will be simulated the optimization costs to the effects of startup type. That is, the optimization result will be compared to using an objective function with different types of startup and with no startup cost. On optimization at no startup cost will be done the final cost calculation by adding startup costs. While on the optimization with start-up costs will be done by considering the cost of various types of a startup as an objective function.

Scheduling hydrothermal with startup type costs will be done by using a modification of multistage optimization algorithm from reference [1]. And optimization without startup type costs will use the de-commitment unit interior point solver [2], then after the result was obtained then the startup type cost will be added to the final energy cost calculation. Optimization of this scheduling will be done during 24 hours in the short term operating plan.

2. Problem Formulations

Scheduling hydrothermal power plants to obtain minimal energy costs, it can be grouped into energy costs at thermal power plants and hydropower generation costs. Energy costs of hydropower plants are usually very cheap so that hydropower plants to serve more loads are constrained on the availability of water to be converted into electricity. Whereas costs of energy of hydropower are the retribution costs of water. Where the hydropower is lower costs, they were always able to first priority on the maximum capacity. For example, if the water supply has been limited, water use will be maximized [1].

Other costs of steam thermal power plants are the startup costs. In this paper, the startup of steam thermal power plants has been grouped into five types, i.e. cold start, warm start, and hot start, very hot start and very-very hot start. In this paper, the review is within 24 hours of operation so startup is reviewed only on 3 types. That is hot start, very hot start and very-very hot start.

This three condition of hot startup criteria then describes as follows. In the very-very hot start, the superheated steam has a lot of steam because the burner is still already on, metal temperature casing turbine is near metal temperature the full load and power plant ready to connect to the grid. In this paper, the very- very hot start is assumed after disconnect less than 1 hour. The very hot start is assumed after disconnect greater than 1 hour and less than 2 hours. While the hot start is assumed after disconnect great than 2 hours but less than 24 hour. Hydro power plant and gas turbines don't use the types of startup because they can directly start.

2.1 Formulations of Reservoir Management

Simulation for optimization of the energy costs in the hydrothermal system, the first stage is done with maximize using of water. Maximizing the use of water can use the following constraints and functions, as shown reference [1]. Equations (1) through (7) are taken from reference (1). The first constraint,

$$v_j = v_{j-1} + \left(q_{in.j} - q_{res.j} - q_{out.j}\right).\Delta t \quad (1)$$

Where,

$$q_{out,j} = \frac{P_j}{K.\varepsilon} \quad (2)$$

The second constraints are,

$$v_{min} \leq v_j \leq v_{max} \quad (3)$$

For water management will use the volume of water at the hour at $j = 25$ that is equal to or smaller than the volume of water reservoirs at $j = 1$, namely.

$$v_{j=25} \geq v_{j=1} \tag{4}$$

Where $v_{j=25}$ is calculated as an optimization constraint condition, whereas $v_{j=1}$ is a constant defined based on previous optimized results or defined as initiation. So the objective function of the problem is expressed by in Equation (5).

$$max \; \sum_{j=1}^{24} f_a\left(q_{out,j}\right) \tag{5}$$

With,

$$f_a\left(q_{out,j}\right) = \sum weight\ values \ \times q_{out,j} \tag{6}$$

While weighting value for the energy cost can be expressed by Equation (7).

$$\frac{Energy\ cost\ values\ reviewed\ every\ hour\ for\ 24\ hours}{The\ value\ of\ minimum\ energy\ costs\ at\ a\ given\ period} \tag{7}$$

2.2. Formulations of Power Plant Startup Costs

Startup costs depend on duration a power plant has not connected to the grid or downtime duration. The downtime duration for short time scheduling hydrothermal is grouped into 4 conditions. That is the current condition $\left(u_{x,0}\right)$, the condition of one hour earlier $\left(u_{x,-1}\right)$, the condition of two hours earlier $\left(u_{x,-2}\right)$, and the condition of three hours earlier $\left(u_{x,-3}\right)$. So the startup costs can be expressed as follows.

$$S'_{u_{x,j}} = f\left(\left(u_{x,-3}, u_{x,-2}, u_{x,-1}, u_{x,0}\right), S_{u_{x,j}}\right) \tag{8}$$

Two important conditions to identify those startup costs are the current conditions and the previous conditions. Namely, when $u_{x,0} = 1$ and $u_{x,-1} = 0$ then there will be startup costs. Then startup types expressed at the time $j = -2$ and $j = -3$. Detail conditions of the startup type can be described as follows.

$$\left[\text{If } f(0{,}0{,}0{,}1), \text{then } S'_{u_{x,j}} = \text{hot start cost}\right], \left[\text{If } f(1{,}0{,}0{,}1), \text{then } S'_{u_{x,j}} = \text{very hot start cost}\right],$$
$$\left[\text{If } f(1{,}1{,}0{,}1), \text{then } S'_{u_{x,j}} = \text{very very hot start cost}\right], \left[\text{If } f(\ 0{,}1{,}0{,}1), \text{then } S'_{u_{x,j}} = \right.$$
$$\left.\text{very very hot start cost}\right].$$

Other conditions that need to be considered is the condition of no startup costs. That is, when $u_{x,0} = 0$. This condition is called power plant disconnected from the grid. Furthermore, without the cost of startup is when $u_{x,-1} = 1$ and $u_{x,0} = 1$. That is the condition of the power plant is still connected to the grid.

2.3. Formulations of Hydrothermal Costs

The objective function of energy costs optimization is:

$$min \sum_{j=1}^{24} \sum_{x=1}^{N} f_x\left(P_{x,j}\right) \tag{9}$$

With N is total number of power plant, and $f_x\left(P_{G_{x,j}}\right)$ is:

$$f_x\left(P_{G_{x,j}}\right) = u_{x,j} \times \left(S'_{u_{x,j}} + \alpha + \beta . P_{G_{x,j}} + \gamma . {P_{G_{x,j}}}^2\right) \tag{10}$$

With α, β, γ are the parameters cost which depends on the type of power plant, as shown in reference [21]. Symbols subscript x is a power plant that is cost at the time j. Then $\left(S'_{u_{x,j}}\right)$ are startup type cost for each power plant.

2.4. Formulation of Power Plant and Grid Constraints

Furthermore, to optimize the use of power on the grid will require the formulation of constraints such as power constraints, voltage, and phase angle. The constraints on the electrical system refer to the paper written by Zimmerman [2]. The constraint consists of constraint Equations and inequality constraints. The equation constraint consists of the active power equation and the reactive power equation on each bus of the electrical system being reviewed. The inequality constraints consist of maximum and minimum voltage constraints, maximum and minimum phase margin constraints, active and maximum reactive power limits, as well as minimum and maximum reactive power on power plants.

3. Algorithm Optimization

Modification of the multistage algorithm from reference [1] will be done with the following steps.

1. Optimization begins by maximizing the use of water in hydropower plants. Maximizing the hydroelectric performed to determine the amount of the power plant that will support the grid, and determines the amount of power generated by each unit. Maximizing done for every hour in 24 hours of operation. In this first stage will get a number of power plants and the power to be supplied to the grid for every hour of operation.
2. Then, the selection of the thermal power plant will be connected to the grid. Selection is done by using economic dispatch without computing grid constraints. I.e. by using evolutionary algorithms contained in the solver spreadsheet to minimizing the cost of power generation by determining the power plants that will commit operation for every hour. Included in this calculation are various types of startup costs. To ensure that stages of the optimal power flow (algorithms stage 3) can be done very well, at this stage of economic dispatch, the estimated load is set to increase by approximately 2%.
3. Next step, there will be optimization of power flow. Simulation of optimal power flow will use an interior point method. Optimization of power flow, it will generate optimal of power from each power plants that will be committed for connected to the grid at each hour of operation.
4. With simulation results of optimal power flow, and then inserted into the spreadsheet that is to calculate the overall energy costs including startup costs. Flowchart of the optimization algorithm as shown in Figure 1.

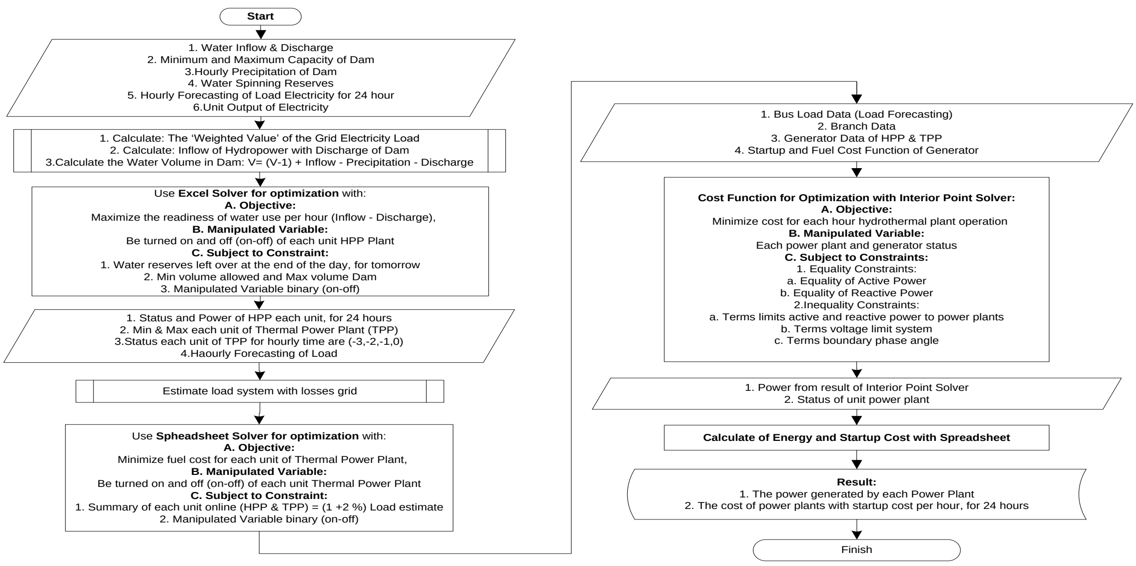

Figure 1. Flowchart of the minimization cost with modified of multi-stage algorithms [1]

As a comparison calculation, optimal power flow calculation will be done using the de-commitment units interior point solver to obtain the thermal power plants to be connected to the grid at every hour of operation. After that, the same with a step 4 on multistage optimization, the results of the optimization of the power then inserted into the spreadsheet that is to calculate the total energy cost including the startup cost.

4. Simulation and Results

Simulation algorithms for scheduling hydrothermal system have been described in the section above. The data in the following tables will be used to support the simulation. The Table 1 and Table 2, an electrical system data, that are taken from reference [1].

Table 1. Data on the Power Plant Electrical Systems

bus	Unit	mBase	Pmax	Pmin	bus	Unit	mBase	Pmax	Pmin
24	CPP1	10000	650	260	48	HPP7	10000	110	70
25	CPP2	10000	650	260	49	HPP8	10000	110	70
26	CPP3	10000	650	260	40	CPP9	10000	330	132
27	CPP4	10000	650	260	41	CPP10	10000	330	132
28	CPP5	10000	350	140	32	CCGT1	10000	600	240
29	CPP6	10000	350	140	33	CCGT2	10000	600	240
30	CPP7	10000	350	140	34	CCGT3	10000	600	240
31	CPP8	10000	350	140	35	CPP11	10000	630	252
42	HPP1	10000	175	70	36	CPP12	10000	630	252
43	HPP2	10000	175	70	37	CPP13	10000	630	252
44	HPP3	10000	175	70	38	CPP14	10000	630	252
45	HPP4	10000	175	70	39	CPP15	10000	630	252
46	HPP5	10000	110	70	50	GT1	10000	220	88
47	HPP6	10000	110	70	51	GT2	10000	220	88

Table 2. Data Branching Between Buses

f_{bus}	t_{bus}	r	x	B	f_{bus}	t_{bus}	r	x	B
1	2	0.000626496	0.00700877	0	24	1	0.00001	0.0001	0
1	4	0.013133324	0.06257632	0.00599	25	1	0.00001	0.0001	0
2	5	0.146925792	0.00353057	0	26	1	0.00001	0.0001	0
3	4	0.001513179	0.01692831	0	27	1	0.00001	0.0001	0
4	5	0.001246422	0.01197501	0	28	8	0.00001	0.0001	0
4	18	0.000694176	0.0066693	0	29	8	0.00001	0.0001	0
5	7	0.00444188	0.0426754	0	30	8	0.00001	0.0001	0
5	8	0.0062116	0.059678	0	31	8	0.00001	0.0001	0
5	11	0.00411138	0.04599504	0.00442	32	17	0.00001	0.0001	0
6	7	0.001973648	0.01896184	0	33	17	0.00001	0.0001	0
6	8	0.0056256	0.054048	0	34	17	0.00001	0.0001	0
8	9	0.002822059	0.02711295	0	35	22	0.00001	0.0001	0
9	10	0.00273996	0.02632419	0	36	22	0.00001	0.0001	0
10	11	0.001474728	0.01416846	0	37	22	0.00001	0.0001	0
11	12	0.0019578	0.0219024	0	38	22	0.00001	0.0001	0
12	13	0.00699098	0.0671659	0.00643	39	22	0.00001	0.0001	0
13	14	0.013478	0.12949	0.01239	40	15	0.00001	0.0001	0
14	15	0.01353392	0.15140736	0.00364	41	15	0.00001	0.0001	0
14	16	0.01579856	0.1517848	0.00363	42	10	0.00001	0.0001	0
14	20	0.00903612	0.0868146	0	43	10	0.00001	0.0001	0
15	16	0.037539629	0.3606623	0.00863	44	10	0.00001	0.0001	0
16	17	0.00139468	0.0133994	0	45	10	0.00001	0.0001	0
16	23	0.003986382	0.04459666	0	46	11	0.00001	0.0001	0
18	19	0.014056	0.157248	0.01511	47	11	0.00001	0.0001	0
19	20	0.015311	0.171288	0.01646	48	11	0.00001	0.0001	0
20	21	0.010291	0.115128	0.01107	49	11	0.00001	0.0001	0
21	22	0.010291	0.115128	0.01107	50	23	0.00001	0.0001	0
22	23	0.004435823	0.04962466	0.00477	51	23	0.00001	0.0001	0

The line that forms the grid is described as a connection from f_{bus} to t_{bus} with specific of resistance (r), reactance (x), and Susceptance (B). Branch data between the buses on a grid shown in Table 2.

Power plants that are ready to supply the grid have the characteristics of a quadratic function to the generated power, see reference [21]. The cost function parameters consist of constants (α, β, γ). The type startup costs of the power plant in this paper are divided into 3 types: a hot start, very hot start, and very-very hot start. Furthermore, the quadratic function parameters (α, β, γ) of the cost function and type of the hot startup costs as shown in Table 3.

Table 3. Cost Function Parameters Data of Power Plants

		Energy Cost Parameters			Startup cost Parameters					Energy Cost Parameters			Startup cost Parameters		
Bus	Name	α	β	γ	Hot	V. hot	V. V.Hot	Bus	Name	α	β	Γ	V. hot	V.Hot	V.V. hot
24	CPP1	10.513	0.1905	-0.0001319	323.7	129.5	64.7	36	CPP12	14.810	0.2768	-0.0000330	467.2	186.9	93.4
25	CPP2	10.428	0.1889	-0.0001342	318.5	127.4	63.7	37	CPP13	18.009	0.3366	-0.0000401	467.7	187.1	93.5
26	CPP3	10.413	0.1887	-0.0001340	318.0	127.2	63.6	38	CPP14	21.207	0.3964	-0.0000472	468.9	187.6	93.8
27	CPP4	10.454	0.1894	-0.0001360	318.2	127.3	63.6	39	CPP15	24.406	0.4562	-0.0000543	469.7	187.9	93.9
28	CPP5	5.939	0.1998	-0.0001380	209.1	83.6	41.8	50	GT1	11.532	0.6173	-0.0016087	23.3	23.3	23.3
29	CPP6	5.959	0.2005	-0.0001365	209.5	83.8	41.9	51	GT2	12.051	0.6451	-0.0016812	23.2	23.2	23.2
30	CPP7	5.944	0.2000	-0.0001381	209.3	83.7	41.9	42	HPP1	0.142	0.0236	-0.0000315	5	5	5
31	CPP8	5.901	0.1986	-0.0001409	206.9	82.8	41.4	43	HPP2	0.142	0.0467	-0.0000623	5	5	5
40	CPP9	6.482	0.2070	-0.0002770	183.0	73.2	36.6	44	HPP3	0.142	0.0699	-0.0000932	5	5	5
41	CPP10	6.482	0.2070	-0.0002770	183.0	73.2	36.6	45	HPP4	0.142	0.0930	-0.0001240	5	5	5
32	CCGT1	24.139	0.3835	-0.0002248	516.2	206.5	103.2	46	HPP5	0.142	0.0236	-0.0000321	5	5	5
33	CCGT2	24.227	0.3849	-0.0002224	519.0	207.6	103.8	47	HPP6	0.142	0.0467	-0.0000623	5	5	5
34	CCGT3	24.319	0.3864	-0.0002211	521.6	208.6	104.3	48	HPP7	0.142	0.0699	-0.0000932	5	5	5
35	CPP11	11.611	0.2170	-0.0000258	468.1	187.2	93.6	49	HPP8	0.142	0.0930	-0.0001240	5	5	5

Grid load data for daily loads viewed during 24 hours operation. The change of load during the 24 hours is shown in Table 4.

Table 4. Hourly Load Data Grid (MW)

Times	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
bus_*i*	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd	Pd
1	353	354	354	355	356	354	355	358	359	358	359	361	361	362	368	369	453	459	460	456	402	361	357	353
2	245	245	245	246	246	246	245	245	245	247	247	247	247	248	248	249	300	423	423	423	308	300	245	245
3	265	265	265	265	265	265	265	265	265	265	265	265	265	265	265	260	360	562	671	675	560	560	265	265
4	121	171	221	221	221	221	221	221	221	221	221	221	221	221	221	244	344	544	678	778	544	544	221	221
5	392	392	393	397	397	397	392	391	391	391	394	395	396	397	398	399	599	668	696	798	695	645	392	392
6	423	422	462	436	456	462	461	460	463	664	667	471	472	472	471	470	659	662	663	665	660	652	423	423
7	541	541	541	546	550	550	552	531	535	535	535	542	543	544	546	532	442	545	555	556	642	647	541	541
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	402	402	402	422	423	426	423	405	405	406	412	412	413	415	417	423	323	729	729	729	823	523	402	402
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	490	490	490	494	494	499	499	472	472	485	487	492	492	491	492	453	401	598	753	753	595	582	490	490
13	482	482	481	489	493	492	396	392	492	491	496	392	392	398	499	389	242	697	782	782	591	492	482	482
14	128	128	128	143	165	166	168	161	293	294	294	164	294	294	162	129	226	429	532	632	429	322	128	128
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	279	279	279	293	303	368	369	362	362	368	368	342	379	382	281	362	422	662	662	662	623	562	279	279
17	310	310	310	345	346	348	350	332	333	334	335	330	332	337	338	312	314	410	442	445	431	423	310	310
18	310	310	310	314	318	321	312	314	310	310	310	310	310	310	314	321	410	441	442	442	442	350	311	310
19	262	262	262	267	274	278	251	252	253	252	253	255	252	251	252	252	220	277	287	288	286	277	262	262
20	262	262	262	265	268	262	263	243	256	257	246	243	243	243	243	224	424	489	492	492	490	424	262	262
21	278	278	278	282	283	284	258	258	258	258	258	272	282	283	283	258	220	458	459	459	358	358	278	278
22	169	169	169	175	176	179	169	169	269	269	269	168	168	168	172	178	439	839	839	839	539	539	169	169
23	99	99	99	102	103	105	98	98	99	102	105	152	102	104	104	120	130	122	124	125	125	126	99	99

Table 3 and Table 4 are dummy data, which are processed to support the service load description in the simulation to be performed. This simulation assumes that the grid served by coal power plants (CPP), gas turbine (GT), combined cycle gas turbine (CCGT), and hydropower plant (HPP).

Furthermore, the first stage is simulated to optimization for maximizing the use of water from the reservoirs. Overview of hydropower plants HPP arranged in a cascade of two dams. The upper dam consists of 4 units with an individual capacity are 170 MW with a nominal discharge of each unit are 58 m^3/s. On the lower dam, there are four units of the power plant with the power for each unit is 110 MW by water discharge per unit at about 100 m^3/s.

The upper dam constraint data at the upper side cascade, i.e.: The maximum water dam volume is 430 x 10^6 m^3. The minimum daily reserve value is 20x10^6 m^3. The minimum water limit that can be used is 15x10^6 m^3. Evaporation values are changed for 24 hours with the following variations are 1080 to 5760 m^3/h.

The bottom dam constraint data at the bottom side cascade, i.e.: The maximum dam volume is 80x10^6 m^3. The minimum water reserve for the next day is 10 x10^6 m^3. The minimum water limit that can be used is 5x10^6 m^3.

This simulation is done to maximize water use for the dry season, i.e. when the water supply is limited. Namely, with input for the upper dam about 60 m^3/s. The lower dam gets input from the upper dam and additional inputs from tributaries about 3 m^3/s. Maximizing the use of water is done by calculating the load data grid for a duration of 24 hours. This data is used to perform a weighted value for the use of water in a hydroelectric power plant. Optimization is based on the weighted value of the service load from the hydrothermal systems. The optimization results are shown in Table 5.

Table 5. Results of Optimization to Maximize the Use of Water (Cascade Dams)

	A) UPPER DAM											B) LOWER DAM									
time	Gen. status				Power Generation (MW)				Volume of water (m^3)			Gen. status				Power Gen.(MW)				Volume of water (m^3)		wighted
j	G 1	G 2	G 3	G 4	HPP 1	HPP 2	HPP 3	HPP 4	discharge	Precip.	Reservoir	G 5	G 6	G 7	G 8	HPP 5	HPP 6	HPP 7	HPP 8	Discharge	Reservoir	Load
1	0	0	0	0	-	-	-	-	0	1080	20000000	0	0	0	0	-	-	-	-	0	15000000	1
2	0	0	0	0	-	-	-	-	0	1080	20214920	0	0	0	0	-	-	-	-	0	15031680	1
3	0	0	0	0	-	-	-	-	0	1080	20429840	0	0	0	0	-	-	-	-	0	15063360	1
4	0	0	0	0	-	-	-	-	0	1080	20644760	0	0	0	0	-	-	-	-	0	15095040	1
5	0	0	0	0	-	-	-	-	0	1080	20859680	0	0	0	0	-	-	-	-	0	15126720	1
6	0	0	0	0	-	-	-	-	0	2160	21074600	0	0	0	0	-	-	-	-	0	15158400	1
7	0	0	0	0	-	-	-	-	0	2880	21288440	0	0	0	0	-	-	-	-	0	15189360	1
8	0	0	0	0	-	-	-	-	0	3240	21501560	0	0	0	0	-	-	-	-	0	15219960	1
9	0	0	0	0	-	-	-	-	0	3600	21714320	0	0	0	0	-	-	-	-	0	15249840	1
10	0	0	0	0	-	-	-	-	0	4320	21926720	0	0	0	0	-	-	-	-	0	15279360	1.5
11	0	0	0	0	-	-	-	-	0	4680	22138400	0	0	0	0	-	-	-	-	0	15308520	1.5
12	0	0	0	0	-	-	-	-	0	5400	22349720	0	0	0	0	-	-	-	-	0	15336960	1
13	0	0	0	0	-	-	-	-	0	5760	22560320	0	0	0	0	-	-	-	-	0	15365040	1
14	0	0	0	0	-	-	-	-	0	5760	22770560	0	0	0	0	-	-	-	-	0	15393120	1
15	0	0	0	0	-	-	-	-	0	5760	22980800	0	0	0	0	-	-	-	-	0	15421200	1
16	0	0	0	0	-	-	-	-	0	5400	23191040	0	0	0	0	-	-	-	-	0	15449640	1
17	0	1	1	1	-	170	92	140	494938	4680	23401640	0	0	0	0	-	-	-	-	0	15478080	1.5
18	1	1	1	1	170	170	170	170	837209	3960	23118022	0	1	1	1	-	77	109	110	972582	16001818	4
19	1	1	1	1	170	170	170	170	837209	2160	22492852	1	1	1	1	110	110	110	110	1445730	15897046	8
20	1	1	1	1	170	170	170	170	837209	1800	21869483	1	1	1	1	110	110	110	110	1445730	15319124	8
21	1	1	1	1	170	170	170	170	837209	1440	21246474	0	1	1	1	-	84	84	98	874010	14741203	3.5
22	1	1	1	1	170	170	170	170	837209	1440	20623824	1	1	1	0	110	110	109	-	1081012	14735003	2.5
23	0	0	0	0	-	-	-	-	0	1080	20001175	0	0	0	0	-	-	-	-	0	14521800	1
24	0	0	1	1	-	-	170	170	418605	1080	20216095	0	0	0	0	-	-	-	-	0	14552400	1

Finally, the optimization results have been obtained that all units can be connected to the network on the hour from 19.00 to 20.00. It was consistent with the fulfillment of peak load for the grid. Power generated by each unit, shown in Table 5. The minimize costs is done by selecting the power plants and the power must be supplied to the grid at every hour of operation.

4.4. Minimize the Energy Costs

Minimize costs will be performed by the economic dispatch. It will be used to select power plants that will be connected to the grid at certain time duration. Type of startup cost for thermal power plants will be done with the assumption that cost is comparable with the energy costs of a minimum power generated then multiplied by a constant. Constants will depend on the startup type whose value is as follows.

1. The very-very hot start will be multiplied by one.
2. The very hot start will be multiplied by two.
3. The hot start will be multiplied by three.

Table 6. Minimize Startup and Fuel Cost of Thermal Power Plant with Multistage Algorithms

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CPP1	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP2	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP3	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP4	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP5	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	0
CPP6	0	0	0	0	350	350	0	0	350	350	350	0	350	350	350	0	350	350	350	350	350	0	0	0
CPP7	0	0	0	0	0	0	0	0	0	0	350	0	0	0	0	0	350	350	350	350	350	0	0	0
CPP8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	350	350	350	350	0	0	0
CPP9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	330	330	330	0	0	0	0
CPP10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	330	330	0	0	0	0
CCGT 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	0	0
CCGT 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	0	0
CCGT 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	0	0
CPP11	630	630	630	630	630	630	630	630	630	630	630	630	630	630	560	630	630	630	630	630	630	630	630	630
CPP12	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630
CPP13	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630	630
CPP14	609	630	630	630	585	630	630	476	630	630	618	630	611	630	592	491	490	630	499	630	453	520	630	540
CPP15	378	408	498	605	378	419	594	630	477	484	378	581	378	381	378	630	508	402	517	477	470	538	463	558
GT1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	220	0	0	0	0
GT2	0	0	0	0	0	0	0	0	0	220	0	0	0	0	0	0	0	0	220	220	0	0	0	0
HPP1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	170	170	170	170	0	0
HPP2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	170	170	170	170	170	0	0
HPP3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92	170	170	170	170	170	0	170
HPP4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	170	170	170	170	170	0	170
HPP5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	110	0	110	0	0
HPP6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	110	110	84	110	0	0
HPP7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109	110	110	84	109	0	0
HPP8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	110	110	98	0	0	0

Notes for the implementation of the economic dispatch optimization using a spreadsheet solver are as follows. If the cases with a large grid and due to limitations of optimization ability on the spreadsheet solver, then at the stage of selection of thermal power plants that will enter the grid for 24 hours taking into account the type of startup can be done by dividing into 3 groups of optimization sequences or larger. So each group consists of 8 hours or less, depending on the spreadsheet solver. And, the three hours of optimization results on the previous day can be used as an initiation of economic dispatch.

Economic dispatch results then are given by the input to determine the optimization of power flow. Power flow optimization will get power every hour from every power plant serving the grid. The result of each step of the optimization is shown the Table 6.

In this comparison, the first step is to take the maximum water use outcome. Then, power flow optimization is performed using interior-point solver with the decommitment unit (DC-IPS) for every hour of operation for 24 hours. The results optimum power flow were as shown in Table 7

Table 7. Minimize Fuels Cost of Power with Unit De-commitment Interior Point Solver (DC-IPS)

Time	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
CPP1	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP2	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP3	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP4	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650	650
CPP5	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
CPP6	350	350	350	0	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
CPP7	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
CPP8	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350	350
CPP9	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
CPP10	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330	330
CCGT 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	600	0	0
CCGT 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	0	0	0	0
CCGT 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	600	600	600	0	0	0
CPP11	378	0	0	378	0	505	0	0	0	382	425	0	0	0	0	0	428	378	630	630	630	378	0	0
CPP12	378	630	630	378	630	630	580	630	630	630	630	567	630	467	607	630	630	630	630	630	630	630	630	544
CPP13	407	583	453	563	419	0	378	430	563	0	0	378	446	630	378	445	378	630	630	630	630	604	417	378
CPP14	0	0	0	0	0	0	0	0	0	407	378	0	0	0	0	0	0	514	378	630	0	0	0	0
CPP15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	417	477	422	378	0	0
GT1	0	0	220	220	220	220	220	220	220	220	220	220	220	220	220	0	220	220	220	220	220	220	0	0
GT2	0	0	0	220	220	220	220	0	220	220	220	220	220	220	220	220	220	220	220	220	220	220	220	0
HPP1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	170	170	170	170	0	0
HPP2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	170	170	170	170	170	170	0	0
HPP3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	92	170	170	170	170	170	0	170
HPP4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	170	170	170	170	170	0	170
HPP5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	110	0	110	0	0
HPP6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	77	110	110	84	110	0	0
HPP7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	109	110	110	84	109	0	0
HPP8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	110	110	110	98	0	0	0

After the optimal data obtained from the optimization of power flow on Table 6 and Table 7 above, then calculated energy cost by entering the power data to the spreadsheet. The spreadsheet in their calculations includes the cost of each type of startup. The energy cost calculation by considering the cost of each type of startup is in Table 8.

Table 8. Cost of Power Generation at Every Hour on Daily Operation Plan

Time duration hour	Total Load MW	Simulations Result			
		Multistage Optimizations		DC-IPS Optimizations	
		(MW)	(Million Rupiah)	(MW)	(Million Rupiah)
1	5811	5827	1749.679	5823	1877.513
2	5861	5878	1718.771	5873	1646.415
3	5951	5968	1738.432	5963	1774.878
4	6057	6075	1761.521	6069	1948.222
O5	6137	6153	2008.273	6149	1786.021
6	6223	6239	1817.918	6235	1856.516
7	6047	6064	1759.304	6058	1818.242
8	5929	5946	1733.539	5940	1746.747
9	6281	6297	1914.096	6293	1775.473
10	6507	6524	1832.019	6519	2815.545
11	6521	6536	2112.253	6533	1882.436
12	6034	6051	1756.425	6045	1909.004
13	6164	6179	1846.823	6176	1750.039
14	6185	6201	1809.579	6197	1754.599
15	6074	6089	1785.45	6085	1730.485
16	5944	5961	1736.788	5955	1616.588
17	6928	6940	2170.65	6938	2390.525
18	10014	10028	5117.97	10028	5192.299
19	10689	10705	3429.054	10705	3799.703
20	10999	11017	3417.705	11017	3394.392
21	9543	9559	3046.49	9558	2837.153
22	8687	8706	2790.554	8699	2419.165
23	5916	5933	1730.771	5927	1610.564
24	5911	5928	1646.105	5922	1594.313
	Total	166806	52430.17	166707	52926.83

5. Analysis and Result

5.1. Scheduling of Maximization Water Usage

Scheduling of hydro power plants (HPPs), is done by maximizing water use. In the simulation to maximize the use of water, it has been found that in the dry season the water discharge to less than nominal input, then the water will be optimal when used to meet peak load demand. It is also suitable for the fulfillment of the power capacity when peak loads. In this simulation, peak load is from 18.00 to 21.00. Optimization results have been shown in Table 5 above. Table 5 shows hydropower plant based on maximization of reservoir water use, the power plant is prepared to enter the grid during peak load hours. If the water is still sufficient to be used i.e. at the value of a considerable weight value then the HPPs unit is also possible to be prepared.

Maximizing the use of water in the dry season turned out to be useful for the fulfillment of the overall grid system. From the simulations, it has been found that the fulfillment of the peak load by HPPs, make the grid system capable of meeting the needs of the load for 24 hours. This is shown in Table 6 and Table 7 above.

5.2. Scheduling Economic Dispatch of Thermal Power Plants

Optimizing the use of primary energy in hydrothermal systems, especially at the minimization of thermal power generation costs, consists of two stages of optimization. The first is a thermal power plant scheduling that is prepared for connection to the grid with consideration to minimum energy costs as well as minimum startup costs based on startup type. The result of this scheduling is a generator prepared to support the electrical system in every hour of the operation plan.

In the step of maximizing the use of water for hydroelectricity, the result is the status of the generator at every hour on the daily operating plan. In the economic dispatch step during the daily operation plan, the result is a thermal power plant that does not serve the load on every hour of daily operation plan. Scheduling at the economic dispatch stage is the status of a thermal power plant at each hour of the daily operating plan. At this stage, the power of any planned thermal power plant unit has not been optimized. The economic dispatch result status seen in Table 6 is a thermal power generating power whose value is equal to zero (0). This indicates that the power plant is removed from the grid of the electrical system.

Because at this stage optimization is done by using economic dispatch then the next consideration is to determine the actual power needs in each power plant that supplies the grid system. Thus, the next calculation can be done with optimal power flow, i.e. by finding the minimum value of energy cost in each hour of operation plan for each plant that has been selected.

5.3. Optimization Energy Costs

Optimal power flow is the optimization of electric power that is easy to do when using the objective function in the form of deterministic function. That is, in equation (10) with the previous two steps we have obtained the value of each binary variable ($u_{x,j}$), so that the optimal calculation of power flow with deterministic function can be done with conventional algorithm.

In the previous two steps have been known the status of each power plant at every hour of the daily operating plan. From this step, in equation (10) has been known every value of binary variables, so the cost function equation has become a quadratic deterministic equation. The quadratic deterministic equation can then be optimized by optimizing the power flow. A fast and accurate way to optimize power flow with a deterministic objective function form and a single variable of its methods is with an interior point. This power flow optimization is done hourly from daily operating plans. The result is an optimum power rating every hour on each power plant that is planned to support the electrical system on a daily basis.

Optimization results of optimum power flow calculation with interior point method is in Table 6. Table 6 shows the optimal power value of multistage algorithm. The power value in Table 6 is the optimal power value generated by the multistage algorithm taking into account the startup type cost of each power plant.

Then as a comparison of the multistage algorithm will use the de-commitment algorithm of interior point solver unit to determine optimal power from the thermal power plant. The power generated at DC-IPS is shown in Table 7. When compared to Table 6 and Table 7 that is the thermal power plants, it is seen that the decommissioning unit to serve the load demand both types of optimization do so on different generating units. In the interior point method more CCP 5 to CCP 10 and CCGT are often removed from the grid. While the DC-IPS method turns out CCP 5 to CCP 10 is more used to serve the grid.

Thermal power plants in tables 6 and 7 in the scheduling have different results. That is, Table 6 has shown that the tendency the power plants to always serve the load if the power plant has been connected to the grid system. It is intended to avoid the startup costs with greater costs if the power plant to be colder. The result to be different when the optimization without the startup costs, as shown in Table 7. Table 7 that is in CCP 14, since it does not consider the startup cost type in its objective function it becomes activated at the 10th and 11th hour to replace CCP 13. Differences in the selection of status and power in both methods resulted in different optimization of generating costs.

Based on the power generated, the use of interior point algorithm without the startup type costs included in the objective function, the result was a bit more efficient. It has been shown in Table 8 in column 3 and 5. However, Table 8 in column 4 and column 6 has also been found that the calculation of the cost turns out to be a bit cheaper when the startup type costs included in the objective function.

6. Conclusion

In the hydrothermal system, during the dry season due to the limited water, maximize the use of water has become a priority to fulfill the peak load. The simulation results with modification of multistage algorithms for a minimization costs by engaging the startup type has been shown more effective results when compared with optimization without involving the startup type. But for power flow calculation, the results of the simulation with startup type showed relatively little more spendthrift. Thus the use of startup types on energy cost optimization for hydrothermal systems is better when included in the optimization algorithm.

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Nomenclature

v_j	Water volume of reservoir at time j
$q_{in,j}$	Water inflows from the rivers into the reservoir at time j
$q_{out,j}$	Water outflows from reservoir to generate the power at time j
$q_{res,j}$	Water evaporation from reservoir to ambient at time j
Δt	Time interval calculation
P_j	Electric power generated at time j
K	Multiplied number of energy conversion
ε	Performance parameter of the hydropower plant
$S_{u_{x,j}}$	Startup condition (hot, warm, cool)
$S'_{u_{x,j}}$	Startup costs at unit-*x*, at the time j
$u_{x,j}$	Binary condition for unit-*x* at a time j
$S'_{u_{x,j}}$	Startup costs with account of the startup type for unit-*x*, at a time j
P_{Di}	Active power of the load on bus i
P_{Li}	Active power flow through the line from bus i to k
P_{Gi}	Active power generated by the power plant on bus i
$\theta_{ik} = \theta_i - \theta_k$	Phase angle difference between bus i to k
G_{ik}	Conductance cable from bus i to k
B_{ik}	Susceptance from bus i to k
V_i^{min}	Minimum voltage of bus i
V_i	Voltage variable of bus i
V_i^{max}	Maximum voltage of bus i
P_{Gi}^{min}	Minimum active power on bus i
P_{Gi}^{max}	Maximum of active power on bus i
Q_{Gi}^{min}	Minimum of reactive power on bus i
Q_{Gi}	Reactive power on bus i
Q_{Gi}^{max}	Maximum of reactive power on bus i,
α, β, γ	Parameters of unit cost variable there are depending on the type of power plant

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