Particle Swarm Optimization Method To Reduce of Operational Energy for Thermal Power Plant

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Abstract. An Optimal operation of thermal power plant requires an efficient generator minimum energy. In fact required energy is still too high and become a problem of economic dispatch in the operation of the power plant. Scheduling is needed to get optimal power plant operation especially in terms of energy usage, but still notice the optimization of electricity. As Electrical Engineers in this research, has researched to purpose the scheduling arrangements for operations at PTCL with the requested load demand and a minimum operational energy. The optimum solution of this problem is using PSO method. Operational of this method used Mathlab software. Heat rate characteristics of the generating unit and generator load are collected to obtain objective functions and constraint functions. This function is completed by PSO to get the lowest energy. To analyse its accuracy, the PSO method will be compared with the manual calculation of real generation without PSO. The total actual energy without PSO is 26.226,4886 MWh. Then PSO simulation gave the total energy is 25.624,4762 MWh. So the generation energy savings is 602,0125MWh or 2.295% reduction. The results of this research provide an economical calculation using the PSO method.

Keywords: Energy, particle swarm optimization, economic dispatch, thermal power plant, operational schedule.

1. Introduction

The need for electrical energy has become a major requirement for humans. Electric energy has covered all aspects of everyday human life. Likewise in Indonesia, as a developing country, the government's project to increase domestic electricity generation capacity of 35,000 megawatts is the fact that the needs of the people in Indonesia for electricity will continue to increase [1]. To fulfil this, a good electric power system is needed. A good electric power system is determined by a variety of things, one of which is a good heat-rate value. Heat-rate is a comparison value between the amount of fuel (input) and the amount of megawatt (output) production from a power plant. The value of heat-rate talks about the consumption of fuel needed to produce a number of electrical energy [3]. Increasing the amount of electrical energy needs must be balanced with a good value of heat-rate, so that the quality of electricity produced is affordable and efficient. Each generating unit has its own characteristics. So that for power plants that use gas and steam. To fulfil the electricity needs there is a need for good operational scheduling by setting the load on each unit at the most efficient point, so that the heat-rate value is reached [4]. From that problem, it is necessary to analyse the generation of operations in the gas and steam power plant systems in terms of fuel, especially from the gas usage, so that an optimal operating schedule is obtained. Therefore, the objective function is determined and the constraint function which is a function in the optimization and optimization process is implemented in the economic dispatch [2], so that optimal schedule of operations can be determined. The results of these calculations will use the MATLAB application and use the particle swarm optimization method [5][6].

2. Particle Swarm Optimization Method

The method used in this study is particle swarm optimization (PSO) [7]. Before using PSO, there are some calculations that must be done. Research conducted concerning economic dispatch where PSO 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, it determined the function of the constraints and the objective function [8][9].

PSO calculates the above functions based on consideration of several factors, which are the characteristics of the generator load, the amount of fuel needed, the availability of generating units, and generator capacity. Then from the above values are obtained coefficients in determining the two functions. After determining and calculating the constraint and objective functions, the next step is to use the PSO algorithm. Objective function is setting the value of several variables in a function or equation so that the output of the function approaches the expected value. In the problem of optimization of electricity generation, the objective function is based on generator load characteristics, the amount of fuel needed and the availability of generating units to obtain the expected output, which is the generation efficiency. Mathematically, the formula can be written so that the objective function is obtained:

$$fT = \sum_{i=1}^{N} F_i(P_i) \qquad (1)$$

with the input-output function of the generator i so:

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \qquad (2)$$

The above equation can also be called the heat rate equation because the function has not been multiplied by the fuel cost. If the heat rate equation is multiplied by the fuel cost (C), then the equation will be obtained:

$$F_i(P_i) = C(a_i P_i^2 + b_i P_i + c_i) \qquad (3)$$

where:

C= Fuel Cost (Rp/Mbtu), $F_i(P_i)$ = input- output cost function of generator *i* (Rp/jam), $a_i b_i c_i$=Cost coefficient of generator *i*, P_i = Generator output *i* (MW), *N*= the number of gen unit and *i* = Index of dispatch able units

Normally, in a power system the amount of power generated is sufficient to meet the demand for a load plus the transmission losses. Because the transmission line is between generator and load, P-loss can occur anywhere before the generated power reaches the load (Pd). In this study to facilitate the settlement process, transmission losses will be ignored. So that we get the equation of constraints on the problem of efficient load operation planning:

$$\sum_{i=1}^{N} P_i = P_D \qquad (4)$$

where:

P_D= Power demand (MW), P_i= Output power of generator i (MW), N= Number of generating units, i= index of generator.

All generating units have several limitations in generating power regardless of type. In existing power systems, thermal units are important role. Thermal units can cause maximum and minimum barriers to generating power so that there are always various operations for the generating unit. The generator produces more minimum power which can cause the rotor to overspeed at maximum power. This can cause stability problems for synchronous generators. So it must be considered in all steps of problem solving:

$$P_{\mathrm{min}\,i} \leq P_i \leq P_{\mathrm{max}\,i} \qquad (5)$$

where $P_{\mathrm{min}\,i}$ and $P_{\mathrm{max}\,i}$ are minimum output power and maximum output power of generator *i*.

This research used PSO method, PSO toolbox for matlab. The steps in using PSO are as follows: The first step is Simplify objective functions and constraint functions by manipulating equations 1 and 4 so that they are obtained:

$$\sum_{i=1}^{N} F_i(P_i) + 100 * abs\left(\sum_{i=1}^{N} P_i - P_D\right) \qquad (6)$$

Provide input data in the PSO script in the form of generator load characteristics, amount of fuel needed, availability of generating units, and generator capacity. Giving the total value of system power needed. Processing the calculation results to the PSOt toolbox by typing [OUT]= pso_Trelea_vectorized('f7',n,1,ran,0,Pdef); Running the PSO program. Individuals from the population are randomly initialized according to the limits of each unit. Different particle speeds also randomly produce speeds in maximum and minimum values of speed. Individuals from this population must be viable solutions that meet the constraints of practical operations. Every solution in PSO must meet equality constraints. So equality constraints are examined. If any combination does not meet the constraint, it is determined according to the power balance equation. The evaluation function of each individual, calculated in the population using the evaluation function as in equation 2. Each Pbest value is compared with the other Pbest values in the population. The best evaluation values among Pbests are denoted as Gbest. Members of the velocity V of each individual are modified according to the update velocity equation in the equation 5. The position of each individual is modified according to the position update equation so that the following equation is obtained:

$$P_i^k = P_i + V_i^k \qquad (7)$$

If the evaluation value of each individual is better than the previous Pbest, the current value is set to become Pbest. If the best pbest is better than Gbest, the value is set to be gbest. After the results reach convergence, the PSO will stop and the info will appear "*Solution likely, GBest hasn"t changed by at least for 1e-10 for 5000 epochs*.". After the results reach convergence, the PSO will stop and the info will appear.

3. Research Data

The research site is divided into 3 plants and operates as a gas power plant, steam power plant and gas and steam power plant. Generating unit data can be seen in Table 1 below:

TABLE 1. Generating Units Data

Plant	Block	Unit	System	Fuel	Capacity
Jababeka	1	GTG#3	Combined Cycle (Gas and Steam Power Plant)	Gas Pertamina	36 MW
		GTG#4			36 MW
		GTG#6			36 MW
		STG#1		Steam	62 MW
	2	GTG#1	Combined Cycle (Gas and Steam Power Plant)	Gas Pertamina	36 MW
		GTG#2			36 MW
		GTG#5			36 MW
		STG#2		Steam	62 MW
	3	GTG#7	Simpled Cycle	Gas PGN	125 MW
		GTG#8	Combined Cycle (Gas and Steam Power Plant)		125 MW
		GTG#9			125 MW
		STG#3		Steam	125 MW
MM2100	4	GTG#10	Simple Cycle	Gas Pertamina	125 MW
Babelan		STG#1	Steam Power Plant	Batu Bara	138 MW
		STG#2	Steam Power Plant	Batu Bara	138 MW
Total Capacity					**1,24 GW**

All of these units provide a service burden to 2 types of consumers, namely industrial estates and PLN. Where there is a Daily Operation Plan from PLN every week that must be met. Three generator places are Jababeka, MM2100 and Babelan plants. The research object was PLTG and PLTGU (Jababeka and MM2100). In the constraint function, generated power is equal to demand. In the data load profile (table 2), load demand is a MW station. The data load profile is on April 10, 2018.

TABLE 2. *Load Profile* Tuesday 10 April 2018

Time	Export to PLN MWATT	IE Total MWATT	Station MWATT	Station + Line BBL MWATT	PLN Dispatch MWATT
0:00	167.56	401.91	330.16	580.20	180
1:00	167.78	403.79	331.67	582.98	180
2:00	170.54	411.14	345.23	595.12	180
3:00	173.47	395.64	328.46	579.21	180
4:00	175.36	390.55	329.44	579.21	180
5:00	178.31	360.53	316.25	551.61	180
6:00	189.43	379.34	338.89	583.88	180
7:00	181.64	387.42	332.72	581.57	180
8:00	232.32	467.83	466.46	714.92	180
9:00	263.94	513.43	544.64	791.80	260
10:00	314.53	508.43	591.47	839.87	300

Time	Export to PLN MWATT	IE Total MWATT	Station MWATT	Station + Line BBL MWATT	PLN Dispatch MWATT
11:00	291.34	516.87	579.64	824.54	300
12:00	312.00	443.78	532.08	773.34	300
13:00	285.47	490.64	551.61	791.71	300
14:00	298.13	520.72	596.56	834.48	300
15:00	271.80	506.70	556.35	794.41	300
16:00	252.42	483.54	510.35	750.58	250
17:00	220.74	469.22	465.47	705.90	250
18:00	273.40	432.35	471.58	720.15	250
19:00	260.75	424.02	470.94	699.09	300
20:00	217.52	417.57	427.76	648.71	250
21:00	187.08	440.01	428.73	641.33	180
22:00	194.00	436.53	432.52	643.27	180
23:00	172.48	433.56	431.73	619.16	180

The following is the generator characteristics data for block 1 and block 2 frame # 6 as shown in Table 3.

TABLE 3. Total *Heat Rate* Block 1 & 2 Unit Frame #6

Load GTG	Load STG	Total Load (3GTG+STG)	Fuel (MMSCFD)	Fuel (MMBTU/Hr)	Heat-rate (BTU/kWH)
0	0	0	0	0	0
1	1.7	4.7	8.5	354.1667	78167.2
2	3.5	9.5	9.2	383.3333	42100.9
3	5.2	14.2	9.8	408.3333	30078.9
4	7	19	10.5	437.5	24067.8
5	8.7	23.7	11.2	466.6667	20461.2
6	10.4	28.4	11.8	491.6667	18056.8
7	12.2	33.2	12.5	520.8333	16339.3
8	13.9	37.9	13.1	545.8333	15051.2
9	15.7	42.7	13.8	575	14049.4
10	16.8	45.8	14.2	591.6667	13496.6
11	19.1	52.1	15.1	629.1667	12592.2
12	20.9	56.9	15.8	658.3333	12045.7
13	22.6	61.6	16.4	683.3333	11583.3
14	24.4	66.4	17.1	712.5	11187
15	26.1	71.1	17.7	737.5	10843.5
16	27.8	75.8	18.4	766.6667	10542.9
17	29.6	80.6	19.1	795.8333	10277.8
18	31.3	85.3	19.7	820.8333	10042
19	33.1	90.1	20.4	850	9831.1
20	34.8	94.8	21	875	9641.3
21	36.5	99.5	21.7	904.1667	9469.5
22	38.3	104.3	22.3	929.1667	9313.4
23	40	109	23	958.3333	9170.9
24	41.8	113.8	23.7	987.5	9040.2
25	43.5	118.5	24.3	1012.5	8920
26	45.2	123.2	25	1041.667	8809
27	47	128	25.6	1066.667	8706.2
28	48.7	132.7	26.3	1095.833	8610.8
29	50.5	137.5	27	1125	8522
30	52.2	142.2	27.6	1150	8439.1
31	53.9	146.9	28.3	1179.167	8361.5
32	55.7	151.7	28.9	1204.167	8288.8
33	57.4	156.4	29.6	1233.333	8220.5
34	59.2	161.2	30.2	1258.333	8156.2
35	60.9	165.9	30.9	1287.5	8095.6

It is known that the higher the load of GTG, the higher the heat-rate owned. With a load of 165.9 MW from GTG it produces 60.9 MW of STG so the value of the heat-rate is 8095.6. From the table above the graph is obtained for incremental heat block 1 and block 2 of unit frame # 6 as shown in Figure 1a. 7 and 10 incremental Heat GTG graphs where the higher the GTG load, the higher the fuel used as shown in Figure 1.b. and 1.c for Block 3.

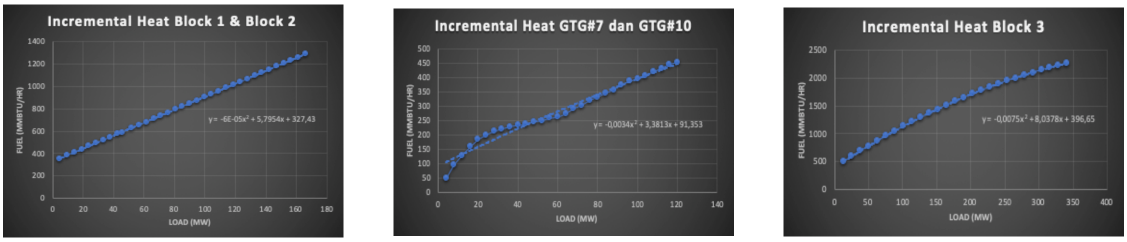


FIGURE 1.a. *Incremental Heat* Block 1 and 2 Frame#6 **1.b.** GTG#7 and GTG#10, **1.c** Incremental Heat Block 3

Following Table 4 is the incremental heat data for GTG # 7 and GTG # 10 which uses a simple cycle system:

TABLE 4. *Incremental Heat* GTG#7 and GTG#10

Load (MW)	Fuel (MMSCFD)	Fuel (MMBTU/Hr)	Load (MW)	Fuel (MMSCFD)	Fuel (MMBTU/Hr)
0	0	0	**64**	6.6	275
4	1.2	50	**68**	7	291.6667
8	2.3	95.83333	**72**	7.3	304.1667
12	3.1	129.1667	**76**	7.7	320.8333
16	3.8	158.3333	**80**	8	333.3333
20	4.4	183.3333	**84**	8.3	345.8333
24	4.8	200	**88**	8.6	358.3333
28	5.1	212.5	**92**	9	375
32	5.3	220.8333	**96**	9.3	387.5
36	5.5	229.1667	**100**	9.5	395.8333
40	5.6	233.3333	**104**	9.8	408.3333
44	5.7	237.5	**108**	10.1	420.8333
48	5.9	245.8333	**112**	10.4	433.3333
52	6	250	**116**	10.7	445.8333
56	6.2	258.3333	**120**	10.9	454.1667
60	6.3	262.5			

Like unit frame # 6, unit frame # 9 prioritizes combined cycle systems, but the difference is that unit frame # 6 uses 3 GTG units and 1 STG unit while unit # 9 uses only 2 GTG units and 1 STG unit. The following are data from the heat rate characteristics of block 3 as shown in Table 5.

TABLE 5. Total Heat Rate Block 3 Unit Frame#9

Load GTG	Load STG	Total Load (3GTG+STG)	Fuel (MMSCFD)	Fuel (MMBTU/Hr)	Heat-rate (BTU/kWH)
0	0	0	0	0	0
4	4.6	12.6	11.9	495.8333	40982.2
8	9.3	25.3	14.3	595.8333	24537.1
12	13.9	37.9	16.6	691.6667	18989.4
16	18,6	50.6	18.8	783.3333	16166.1
20	23.2	63.2	21	875	14432.4
24	27.8	75.8	23.1	962.5	13243.7
28	32.5	88.5	25.2	1050	12366.3
32	37.1	101.1	27.2	1133.333	11683.5
36	41.8	113.8	29.1	1212.5	11130.4
40	46.4	126.4	31	1291.667	10668.1

Load GTG	Load STG	Total Load (3GTG+STG)	Fuel (MMSCFD)	Fuel (MMBTU/Hr)	Heat-rate (BTU/kWH)
44	51	139	32.9	1370.833	10271.9
48	55.7	151.7	34.6	1441.667	9925.5
52	60.3	164.3	36.4	1516.667	9616.6
56	65	177	38	1583.333	9338
60	69.6	189.6	39.6	1650	9083.3
64	74.2	202.2	41.2	1716.667	8848.1
68	78.9	214.9	42.7	1779.167	8628.8
72	83.5	227.5	44.1	1837.5	8423
76	88.2	240.2	45.5	1895.833	8228.4
80	92.8	252.8	46.8	1950	8043.3
84	97.4	265.4	48	2000	7866.5
88	102.1	278.1	49.2	2050	7696.7
92	106.7	290.7	50.4	2100	7533.1
96	111.4	303.4	51.5	2145.833	7374.8
100	116	316	52.5	2187.5	7221.3
104	120	328.6	53.5	2229.167	7072
108	125.3	341.3	54.4	2266.667	6926.4

From table 5 it can also be seen that the higher the load of GTG, the better the heat-rate obtained. This shows the efficiency of the unit occurs when the load is high where with a load of 108 MW per GTG frame 9, the value of the heat-rate is 6926.4. From the table above, the incremental Heat GTG Frame 9 graph is obtained.in Figure 1.c. From the graph above, the incremental heat characteristics for block 1, block 2, block 3, GTG # 7 and GTG # 10 are obtained. Generator unit is based on data in table.1. At the research site, 2 gas sources are used to meet supply needs, namely gas from Pertamina and PGN, where both have different prices per MMBTU. Then the fuel cost for each gas source is: Pertamina (7.21 $/MMBTU) and PGN : 9.12 $/MMBTU. The price will be multiplied by the function characteristics of the generator unit fuel. So based on Equation 3.2, the input-output function is obtained as follows:

GTG Frame#6: $C = 7.21\ \$/\text{MMBTU},\ F_i(P_i) = -0.460719x^2 + 89.07234x + 592.50338$

Block 1 and Block 2: $C = 7.21\ \$/\text{MMBTU},\ F_i(P_i) = -0.0004326x^2 + 41.784834x + 2360.7703$

GTG Frame#9: $C = 9.12\ \$/\text{MMBTU},\ F_i(P_i) = -0.095608x^2 + 73.48459x + 1900.4199$

GTG#7: $C = 9.12\ \$/\text{MMBTU},\ F_i(P_i) = -0.031008x^2 + 30.837456x + 833.13936$

Block 3: $C = 9.12\ \$/\text{MMBTU},\ F_i(P_i) = -0.0684x^2 + 73.304736x + 3617.448$

GTG#10: $C = 7.21\ \$/\text{MMBTU},\ F_i(P_i) = -0.024514x^2 + 24.379173x + 658.65513$

From the input-output function above, the input-output function data of each GTG unit is obtained. In addition to determining the input-output function, the data needed is to determine the minimum and maximum power output of the generator.

4. Actual Required Energy

Before doing a simulation using PSO, energy calculations for generation are first carried out based on the load profile in table 4.2. The calculation carried out is the actual generation of the day. So that the actual calculation data is obtained on Tuesday April 10 2018 as shown in table 6.:

TABLE 6. Actual Generating on Tuesday 10 April 2018

Time	Load (MW)	Daya Pembangkit (MW)					Cost	Energi
		Block 1	Block 2	Block 3	GTG#7	GTG#10	($)	(MMBTU)
00.00	330,18	31,18	31.79	267,21	0,00	0,00	22,623	2770,73
01.00	331,69	30.96	32,19	268,54	0,00	0,00	23,684	2900,76
02.00	345,26	31,41	31,77	282,08	0,00	0,00	24,575	3009,90
03.00	328,48	31,08	31.77	265.63	0,00	0,00	23,400	2865,99
04.00	329,46	30.75	31,69	267,02	0,00	0,00	23.484	2876,20
05.00	316,28	31,31	31.74	253,23	0,00	0,00	22,695	2779,64

Time	Load (MW)	Daya Pembangkit (MW)					Cost ($)	Energi (MMBTU)
		Block 1	Block 2	Block 3	GTG#7	GTG#10		
06.00	338,92	31,30	39,41	268,21	0,00	0,00	23,962	2934,81
07.00	332,74	31,01	34.85	266.88	0,00	0,00	23,629	2894,00
08.00	466,48	51,40	86,32	328.76	0,00	0,00	32,597	3992,28
09.00	544.68	95,36	122.95	326,37	0,00	0,00	37,097	4543,49
10.00	591,49	119,70	147,04	324.75	0,00	0,00	39,464	4833,34
11.00	579.66	118,41	137.76	323,49	0,00	0,00	38,446	4708,66
12.00	532,11	104,84	112,45	314.82	0,00	0,00	35,805	4385,23
13.00	551.63	113,22	116.65	321.76	0,00	0,00	37,216	4557,99
14.00	596,60	132,01	144,58	320,01	0,00	0,00	39,231	4804,89
15.00	556,38	91,36	144,54	320,48	0,00	0,00	36,818	4509,34
16.00	510,39	93,51	95.75	321,13	0,00	0,00	34,074	4173,20
17.00	465,51	46,96	95.79	322,76	0,00	0,00	31,414	3847,46
18.00	471,62	48,73	98,05	324.84	0,00	0,00	31,687	3880,93
19.00	470.97	47,07	98,17	325.73	0,00	0,00	31,739	3887,21
20.00	427.77	49,19	49,45	329,13	0,00	0,00	29,162	3571,61
21.00	428.75	49,34	49,36	330,05	0,00	0,00	29,228	3579,74
22.00	432,56	50,08	49.62	332,86	0,00	0,00	29,431	3604,57
23.00	431.75	50,23	49.81	331.71	0,00	0,00	29,379	3598,22
			Total				**USD 730,850**	**89510,20**

From table 6, the energy calculation result is 89510.20 MMBTU or is the generation cost on the day of April, 2018 is U$ 730,850.8. The first PSO Simulation (PMIN = 0) is a simulation of generation using PSO with consideration of unit standby. This simulation aims to see the main priority of optimal generation when load demand changes every hour. The first step to simulate using PSO is to enter the input-output cost function in the Matlab script. The following is the input-output function data based on previous calculations.

TABLE 7. Input-Output Function Simulation ((PMIN = 0)

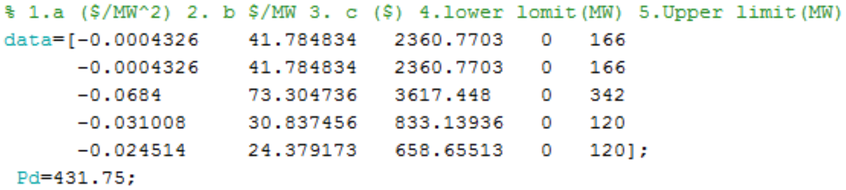
No.	Unit	a_i	b_i	c_i	P_{min}	P_{max}
1	Block 1	-0.0004326	41.784834	2360.7703	0	166
2	Block 2	-0.0004326	41.784834	2360.7703	0	166
3	Block 3	-0.0684	73.304736	3617.448	0	342
4	GTG#7	-0.031008	30.837456	833.13936	0	120
5	GTG#10	-0.024514	24.379173	658.65513	0	120

After all data is entered the next step is to run PSO. So that the PSO will operate until it is stable (convergence). From the use of PSO in matlab, the optimization results are as follows as shown in Table 8. From table 8, the generation energy is obtained on Tuesday 10 April 2018 amounting to 89510 MMBTU, or is the total generation cost of U $ D 590,910.2. Based on this, there was an energy savings of 17,139.07 MMBTU. Next is the actual comparison and simulation using energy PSO every hour. After input-output function data is entered, the next step is to enter data load demand (Pd).

Table 8. Result of PSO Simulation where Pmin = 0

Time	Load (MW)	Daya Pembangkit (MW)					Cost ($)	Energi (MMBTU)
		Block 1	Block 2	Block 3	GTG#7	GTG#10		
00.00	330.18	90.18	0	0	120	120	19,422	2378,68
01.00	331.69	91.68	0	0	120	120	19,485	2386,39
02.00	345.26	105.25	0	0	120	120	20,051	2455,69
03.00	328.48	88.48	0	0	120	120	19,351	2369,99
04.00	329.46	52.02	37.43	0	120	120	19,394	2375,21
05.00	316.28	76.27	0	0	120	120	18,842	2307,67
06.00	338.92	98.92	0	0	120	120	19,786	2423,32
07.00	332.74	92.73	0	0	120	120	19,529	2391,75

Time	Load (MW)	Daya Pembangkit (MW)					Cost ($)	Energi (MMBTU)
		Block 1	Block 2	Block 3	GTG#7	GTG#10		
08.00	466.48	165.99	40.04	0	120	120	24,272	2972,73
09.00	544.68	166	138.67	0	120	120	28,368	3474,34
10.00	591.49	166	165.99	19.49	120	120	30,909	3785,51
11.00	579.66	0	0	339.66	120	120	32,665	4000,58
12.00	532.11	166	126.1	0	120	120	27,844	3410,19
13.00	551.63	165.99	145.63	0	120	120	28,658	3509,81
14.00	596.06	145.99	0	342	120	120	33,337	4082,93
15.00	556.38	0	0	316.38	120	120	32,003	3919,51
16.00	510.39	165.99	104.39	0	120	120	26,939	3299,31
17.00	465.51	165.99	59.51	0	120	120	25,067	3070,02
18.00	471.62	166	65.61	0	120	120	25,322	3101,25
19.00	470.97	116.95	114.01	0	120	120	25,297	3098,20
20.00	427.77	166	92.84	0	120	120	23,491	2877,05
21.00	428.75	166	96.87	0	120	120	23,532	2882,06
22.00	432.56	166	26.56	0	120	120	23,691	2901,55
23.00	431.75	166	25.75	0	120	120	23,657	2897,40
Total							**USD 590,910.2**	**72371,13**



```
% 1.a ($/MW^2) 2. b $/MW 3. c ($) 4.lower lomit(MW) 5.Upper limit(MW)
data=[-0.0004326    41.784834   2360.7703   0   166
      -0.0004326    41.784834   2360.7703   0   166
      -0.0684       73.304736   3617.448    0   342
      -0.031008     30.837456   833.13936   0   120
      -0.024514     24.379173   658.65513   0   120];
 Pd=431.75;
```

FIGURE 3. Script Matlab for PSO

In the experiment, results were obtained which prioritized simple cycle units. While the combined cycle unit must start and stop within a period of time that is not far away. Even though starting a Steam Turbine Generator (STG) takes at least 10 hours. So that the next experiment using PSO with Pmin is the minimum value of power needed to run a combined cycle unit. So that, the actual optimized implementation the can be done by using PSO method. As in the next experiment, calculations will be used by PSO with the input and output values, where there is a minimum load is not 0. So that obtained generated energy savings of 17,139.07 MMBTU. By conducting of experiments, energy use data can be recorded which then converts the value in the form of energy to find out the value of electricity energy savings using the PSO method compared without using PSO as shown in Table 9 as follows:

TABLE 9. Efficiency Energy Using PSO Simulation

Condition	Energy (MMBTU)	Energy (MWh) (1 BTU = 293 kWh)	Energy Efficiency (MWh)	(%)
Actual (without PSO)	89.510,20	26.226,4886	0	0
Research(with PSO)	72.371,13	21.204,7411	5.021,7475	19,148

5. Conclusions

The chosen PSO method is the second experiment, because considering the minimum power in a combined cycle unit so that simulation can be applied where a combined cycle generator is scheduled with a minimum load and the unit start up, stop and load settings are carried out by a simple cycle unit. Particle Swarm Optimization succeeded in determining the optimal operating schedule with the lowest amount of fuel based on hourly load demand with a savings percentage of 19.148% per day where generated energy using the second experiment using PSO was worth 5,021.7475 MWh.

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