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Penulis	:	Adelhard B. Rehiara, Elias K. Bawan, Bibiana R. Wihyawari
Abstrak	:	Optimization of fossil-fuel power plants plays an important role in increasing efficiency of the plants. Economic dispatching of well combined power plants in unit commitment may place those plants in maximum efficiency. Lagrange multiplier, a method in economic dispatch, was utilized for rescheduling the demand of peak load in power system of PT. PLN branch Manokwari. The power system of the electrical company includes nine units and the other rental units of diesel power plant. Based on the investigation in the time of peak load for a week operation, diesel power plant units in the company system had not worked in optimal operation while handling the peak load. This condition has increased the operation cost of the generating system. By rescheduling the power plants using Langrange method, the company can save operation cost about USD 9548 per week of operation in peak load time. On the other hand, by recommitting efficient power plants for handling the peak load using simple unit commitment, the company can save cost about USD 11869 per week. This condition can also save fuel and reduce emission of carbondioxide.
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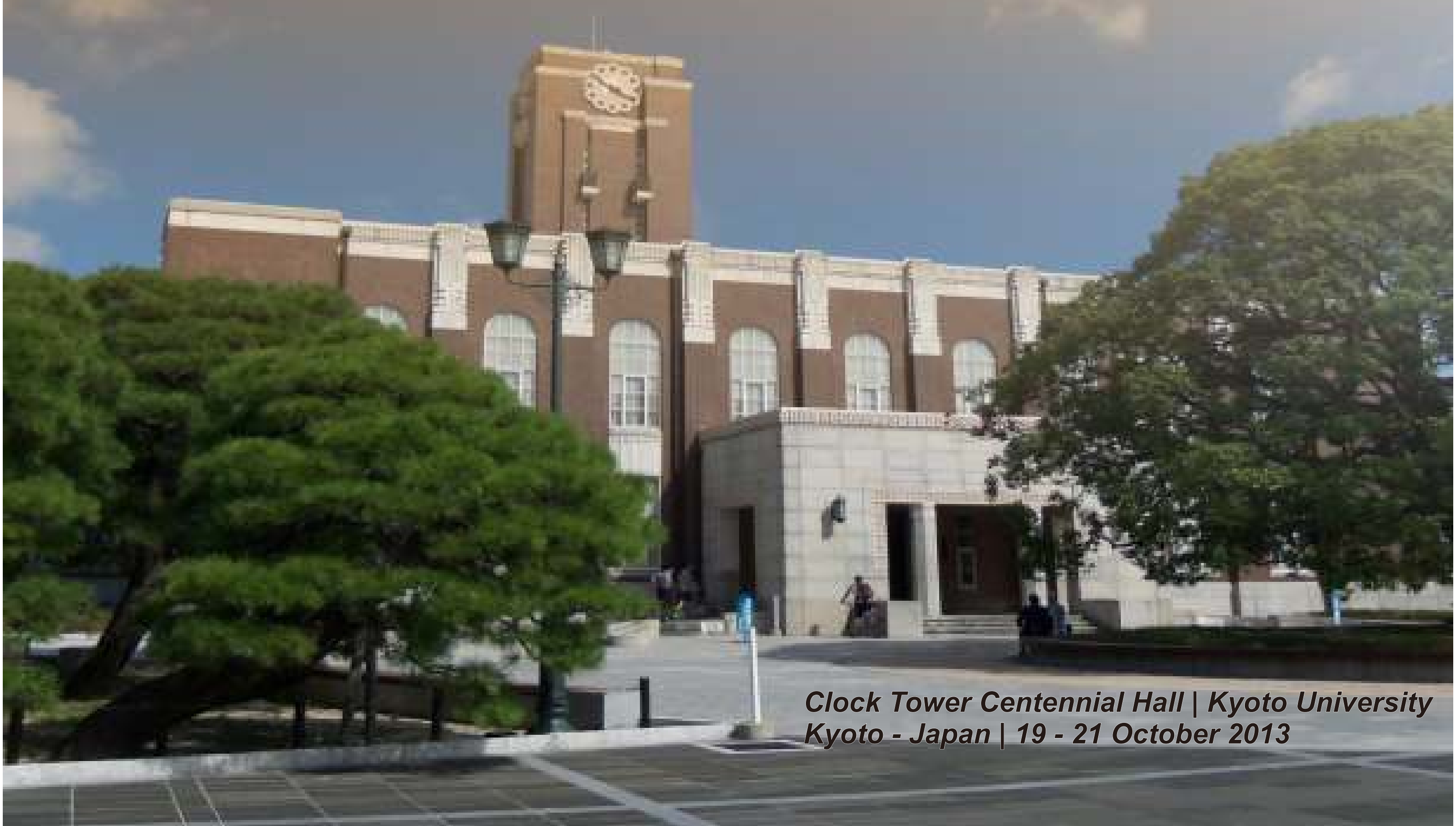

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Optimal Scheduling of Fossil-Fuel Power Plant in Anticipating Peak Load Demand: A Case Study in PT. PLN Manokwari

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Abstract

Optimization of fossil-fuel power plants plays an important role in increasing efficiency of the plants. Economic dispatching of well combined power plants in unit commitment may place those plants in maximum efficiency. Lagrange multiplier, a method in economic dispatch, was utilized for rescheduling the demand of peak load in power system of PT. PLN branch Manokwari. The power system of the electrical company includes nine units and the other rental units of diesel power plant. Based on the investigation in the time of peak load for a week operation, diesel power plant units in the company system had not worked in optimal operation while handling the peak load. This condition has increased the operation cost of the generating system. By rescheduling the power plants using Langrange method, the company can save operation cost about USD 9548 per week of operation in peak load time. On the other hand, by recommitting efficient power plants for handling the peak load using simple unit commitment, the company can save cost about USD 11869 per week. This condition can also save fuel and reduce emission of carbondioxide.

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Keywords : Economic dispatch; Lagrange multiplier; diesel power plant; optimize; peak load.

1. Introduction

Fossil-fuel power plant is a type of power plant that burns fossil fuels i.e. coal, natural gas or petroleum oil to produce electrical energy. Diesel power plant is a type of fossil-fuel power plant that converts diesel fuel to be electrical energy. The conversion process in diesel power plants may not over 80% of its efficiency and it will deliver some pollutants as the effect of the process [1]. Optimization of fossil-fuel power plant including diesel power plant will be a challenge in minimizing operation cost and reducing pollutants.

In optimizing a power plant, unit commitment can be applied to have optimal solution in power plant operation. The unit commitment is the process to take optimal solution of machine operation and this process is scheduling on and off the machine in best time. Many constraints can be applied to unit commitment in order to have maximum optimization.

Normally, the usage of electricity will increase before until mid-night because most of people will be at home at the time and those will need electricity, at least for lighting. This condition is called peak load and in this moment, power plant units installed to the power system should work maximum to fulfill the high demand load. The demand load can be in between afternoon and the mid-night where the usage of electrical energy is significantly increasing. According to the standard of PLN, peak load time can start from 18.00 – 22.00 pm of local time [2]. The peak load time depends on the load characteristic and also on the local environmental; therefore the peak load time can happen faster or later from the standardization time.

The oldest method in economic dispatching is Lagrange method and its basic formulation had been used in some previous research [1][3-10]. After unit commitment is applied to schedule machines, economic dispatch should be used to determine how the machines should be occupied to fulfill demand load. As an electrical company of Indonesian government in the area of Manokwari, which is the capital city of West Papua Province - Indonesia, PT. PLN Manokwari has done unit commitment in scheduling its power plant units. This paper will investigate the effectivity of scheduling operation especially in anticipating peak load demand of diesel power plant units in power system of the company.

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Nomenclature

i	number of unit
a,b	the coefficient of the cost input of the i-th generator
c	equivalent to fuel consumption of the generating unit operation without power output
n	total number of units in the system
F_i	fuel cost function of the units
P_i	generation of unit i
P_R	total system load
$Pmin,_i$	lower limit of the unit i
$Pmax,_i$	upper limit of the unit i
L	Lagrange function
λ	the Lagrange multiplier.

2. Economic Dispatch

Economic dispatch (ED) is the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognize any operational limits of generation and transmission facilities [10]. The economic dispatch (ED) problem is how to minimize a total generation cost of power system for a given demand load with satisfying various constraints including power balance constraint and generation power limits of each unit. While the load has been variated, the output of generators has to balance the load variation. The fundamental of the ED problem is the set of input-output characteristic of the power generating unit and the ED problem can be expressed as [1][3-12]:

Minimize

$$F_T = \sum_{i=1}^{n} F_i P_i \tag{1}$$

$$F_i(P_i) = (a_i P_i^2 + b_i P_i + c) \tag{2}$$

Subject to :

$$\sum_{i=1}^{n} P_i = P_R \tag{3}$$

$$P\min_i \leq P_i \leq P\max_i \tag{4}$$

The fundamental components in ED are planning for future dispatch and dispatching the power system today. Generally target function of ED can be investigated by Lagrange multiplier method, first or second order gradient method, and lambda iteration, but these methods may encounter some difficulties for complex generation cost functions [5]. Lagrange formulation can be rewritten as [1][11-13]:

$$L = F_T + \lambda\phi = \sum_{i=1}^{n} F_i P_i + \lambda(P_R - \sum_{i=1}^{n} P_i) \tag{5}$$

The function of output generating power is assumed that optimal condition is reached if gradient operation equals to zero. In other word, the first derivative of the Lagrange function L with respect to each of the independent variables has to be set equal to zero as follows.

$$\nabla L = \nabla F_T + \nabla\lambda\phi = 0 \tag{6}$$

$$\frac{\partial L}{\partial P_i} = \frac{\partial F_T}{\partial P_i} + \lambda\left(\frac{\partial P_R}{\partial P_i} - \frac{\partial P_i}{\partial P_i}\right) = 0 \quad (7)$$

By solving 7th equation, we get :

$$\frac{\partial F_i}{\partial P_i} + \lambda(0-1) = 0 \Rightarrow \frac{\partial F_i}{\partial P_i} = \lambda \quad (8)$$

Eq. 8 shows that optimum condition can be reached if the incremental of each power generation connected to the system is equal. This condition should respect to the constraint defined in eq. 4.

3. Unit Commitment

Unit Commitment optimization enables utilities to minimize power generation costs. Unit commitment (UC) is different from ED. ED consists of fitting a given set of power plants into a certain electric demand, while UC appoints to the set of plants from which dispatching can choose. The problem of UC involves finding the least-cost dispatch of available power plants that should be considered to supply the demand load. In dispatching decisions, there is no time to rapidly activate a power plant because the inertia of most plants will not allow this. UC ,therefore, prepares a set of plants and stipulates in which time period they have to be on-line and ready for dispatching [14].

The most talked-about techniques for the solution of the unit commitment problem are Priority-list schemes, Dynamic programming and Lagrange relation [10]. Priority-list scheme is a very simple method in unit commitment based on listing priority in which power plants are logically ranked. Normally, the plants are ranked according to full load cost, and then there will be some bias of the rank since not all of plants will be operated at full load. Dynamic programming is a strategy to build optimal problem formulated in some stages that have corelated each other. There is no standard formulation in dynamic programming and it has many advantages over the enumeration scheme, the chief advantage becomes a reduction in the dimensionality of the problem. The dynamic-programming method of solution of the unit commitment problem has many disadvantages for large power systems with many generating units. It is due to the necessity of forcing the dynamic-programming solution to search over a small number of commitment states to reduce the number of combinations that must be tested in each time period. In the Lagrange relaxation technique, these disadvantages disappear.

Some considerations that should be taken into account while doing the unit commitment including power constraint are minimizing objective function, minimum up and down operation time, and spanning reserve margin [13]. Simple UC can be applied when every generator has fulfilled the point of 1 to 3 and complex UC will be effective by taking into account the point of 4 and 5 as follows:

1. Minimum and maximum generation level which is power constraint of the generator. This level is preferred to be maximum level because producing over this level causes significant pollution.
2. Startup fuel consumption coefficient which is the coefficient of a generator while it starts with no load.
3. Linnear fuel consumption formula which is the fuel cost function.
4. Minimum up times and down times which is the minimum number of hours a generator must be on or off once turned on or off.
5. Maximum ramp up and ramp down rate which is the maximum amount that a generator can increase or decrease production in an hour.

4. Result and Discussion

4.1. Power plant units

Maximum electrical energy produce of PT PLN Manokwari machines is 7610 kW by operating nine diesel power plant units. The power plant units of are operated in the same location and directly connected to the grid system [1]. This condition makes an amenity to investigate the system since there is no loss in power transmission between each power plant. The specification of each machine is provided in table 1.

Table 1. Machine specifications

No of machine	Type of machine	Serie	Output power, kW	
			maximum	Minimum
1	DEUTZ	BV8M 628	950	180
2	DEUTZ	BV8M 628	1100	180
3	MAN	6L 26/32 H	900	150
4	MAN	6L 26/32 H	900	150
5	DAIHATSU	6DL - 28	1000	180
6	MITSUBISHI	S12 R -PTA	800	150
7	MITSUBISHI	S12 H -PTA	600	120
8	MITSUBISHI	S16 R -PTA	900	150
9	KOMATSU	SAA 6D 170-P800	460	75

. The fuel cost function of each power plant had been defined in previous research [1] as provided in table 2. The functions are contrained to minimum and maximum output of power plant.

Table 2. Fuel cost functions

Unit i	Fuel cost function F_i	Power constrain, kW
1	$-1.42e^{-4}P_1^2+0.343P_1-1.994$	$180 \leq P_1 \leq 950$
2	$1.17e^{-4}P_2^2+0.200P_2+15.800$	$180 \leq P_2 \leq 1100$
3	$0.001P_3^2-1.178P_3+554.8$	$150 \leq P_3 \leq 900$
4	$2.38e^{-4}P_4^2-4.90e^{-2}P_4+118$	$150 \leq P_4 \leq 900$
5	$1.23e^{-4}P_5^2+0.261P_5+0.860$	$180 \leq P_5 \leq 1000$
6	$0.001P_6^2+0.2P_6+1.006$	$150 \leq P_6 \leq 800$
7	$0.001P_7^2-0.62P_7+187$	$120 \leq P_7 \leq 600$
8	$4.64e^{-4}P_8^2-0.447P_8+285$	$150 \leq P_8 \leq 900$
9	$0.002P_9^2-1.014P_9+144.8$	$75 \leq P_9 \leq 460$

As the case study, data from 27 May to 2 June 2013 had been used and it was noted from 1st to 7th day. Although peak load can start from 18.00 to 22.00 pm at local time, the calculation was taken ± 1 hour of the peak load time. There are two scheme of case study in discussing the data i.e. economic dispatch first case study and unit commitment in second case study.

4.2. Economic dispatch case

The procedure of optimizing in a power system was done by applying unit commitment and it was followed by applying economic dispatch. In this case, unit commitment was applied by the company and the job here to apply Lagrange optimizer to the system by following the chosen unit commitment. Data and solution of 1st day are provided in table 3.

On the first day operation, machine 5 and 8 were not operated along peak load time and total operation cost was USD 9872. As mentioned in previous research [1], machine 1 will be the most economic unit and machine 6 is the least economic unit; therefore to decrease the operation cost, unit 1 should be operated in its maximum while unit 6 should be operated in its minimum and its output will be increased after all of the units have been operated in maximum. This scheme was done in Lagrange solution and it cost only USD 7908 to produce same amount output. As shown in table 3 that the most saving cost was done by reducing power output of unit 6 and the cost was down from USD 3233 to USD 397. It is also shown that the cost of the other units was increased as the risk of handling load from unit 6

Table 3. Data and Lagrange solution of 1st day

No of machine	Real operation in local time, kW 17.00	18.00	19.00	20.00	21.00	22.00	23.00	Cost, USD	Lagrange solution for local time, kW 17.00	18.00	19.00	20.00	21.00	22.00	23.00	Cost, USD
1	810	810	900	900	890	890	900	1326	950	950	950	950	950	950	950	1374
2	800	790	810	820	810	820	820	1780	941	689	1100	1100	1100	986	651	2169
3	820	730	810	810	820	700	710	1706	799	770	869	760	900	804	765	1814
4	810	730	810	790	830	740	780	1584	900	862	900	900	900	900	843	1832
6	500	360	750	750	750	640	-	3233	150	150	180	150	250	150	-	397
7	-	-	510	310	-	-	-	222	-	-	590	481	-	-	-	290
9	-	-	-	300	-	-	-	21	-	-	-	339	-	-	-	31
Total	3740	3420	4590	4680	4100	3790	3210	9872	3740	3420	4590	4680	4100	3790	3210	7908

On second to seventh day operation (see appendix A), total prize was the lowest cost while unit 6 was not operated as shown on fifth day operation. The second lowest prize was also shown on third day operation which operated unit 6 for only two hours. The Lagrange solution for both days operation could only save USD 298 and USD 557 compared with the other days that could save more than USD 1000.

While the output of power plants follows the Lagrange schemes, the saving cost for a week operation is USD 9548. The saving cost is the difference of real operation and Lagrange solution about USD 1964, 3065, 557, 1216, 298, 1054 and 1393 from 1st to 7th day operation respectively. The cost may reach USD 38190 to 42282 for whole month works and saving cost means saving money for the company. The other importance of saving cost is saving fuel for sustainability of the power plant operation, and then the effect of saving fuel may cause reduction in carbon dioxide emission.

4.3. Unit commitment case

In the previous case study, it is simply known that the operation of power plants in the company may not be optimized. In second case study, a simple unit commitment will be used to combine a group of power plants, and a very low cost of the combination will be the candidate to be selected to solve the demand load. The combination and solution on the 1st day is provided in table 4 and the other days are in Appendix B.

Table 4. Unit commitment solution of 1st day

No of machine	Unit commitment solution, kW 17:00	18:00	19:00	20:00	21:00	22:00	23:00	Operation cost, USD 17:00	18:00	19:00	20:00	21:00	22:00	23:00	Total
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	1100	1100	1100	1100	1100	1100	1100	377.1	377.1	377.1	377.1	377.1	377.1	377.1	2639.9
3	0	0	784	900	794	0	0	0.0	0.0	245.9	304.6	249.9	0.0	0.0	800.4
7	461	248	505	488	0	494	0	113.7	94.8	128.9	122.5	0.0	124.9	0.0	584.8
8	900	900	900	900	900	900	900	257.9	257.9	257.9	257.9	257.9	257.9	257.9	1805.0
9	329	222	351	342	356	346	260	27.7	18.2	35.3	32.1	37.3	33.3	16.4	200.2
Total	3740	3420	4590	4680	4100	3790	3210	972.7	944.3	1241.5	1290.5	1118.5	989.5	847.7	7404.7

Priority list of machine for minimal operation will be unit 5, 1, 2, 6, 4, 7, 8, 9 and 3, while for maximum operation it can be unit 1, 9, 8, 7, 4, 3, 2, 5 and 6. The maximum sequence means that a machine should work until it reaches its maximum rate before the other machine starts to charge the load. On the other hand, minimum sequence means that the machine starts to supply the load at its minimum rate before the other unit starts to work. Since PT. PLN may have other consideration for hour's works, maintenance, etc, the company has to operate machines out of the list, but in principle the company should obey the maximum sequence to get the maximum optimal works.

Using the method of priority list in unit commitment, the units that commit to work tend to be homogenous for all days. It also shows that most of plants will work at their maximum limit while the other two units will work in range. Overall, the designed unit commitment schemes show best optimization and they will save cost about USD 7404.7, 8654.7, 6850.9, 9459.1, 6784.5, 6933.8, and 7330.4 from first to seventh day operation respectively. The saving cost will reach USD 11869 per week or USD 47478 per month operation in peak load time. The result may not always be true since the company may have other consideration according to the work hours, maintenance, etc.

5. Conclusion

The result of investigating the scheduling in PT. PLN Manokwari shows that the effort done to anticipate peak load demand may not be effective to reduce operation cost. This evidence can be seen from the difference between real operation cost and the refine cost scheme with economic dispatch and unit commitment method. The result of rescheduling with this method has decreased operation cost at least USD 38190 per month by following the real unit commitment and USD 47478 by applying the designed unit commitment. The system in the company will be effective and efficient by rescheduling the machine to handle the peak load.

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Appendix A. Data and Lagrange Solution

Real operation and Lagrange solution for optimizing the operation is provided in following table. The table is used to show data from second to seventh day of peak load operation while the first day is shown in table 3.

No of	Real operation in local time, kW							Cost,	Lagrange solution for local time, kW							Cost,
machine	17.00	18.00	19.00	20.00	21.00	22.00	23.00	USD	17.00	18.00	19.00	20.00	21.00	22.00	23.00	USD
								2nd Day								
1	870	860	930	900	900	870	960	1344	950	950	950	950	950	950	950	1374
2	780	790	860	830	830	810	750	1773	950	1100	1100	1100	1100	1100	1100	2574
3	760	810	880	880	720	700	840	1795	800	794	900	843	765	688	900	1840
4	790	790	800	830	800	720	830	1607	900	900	900	900	900	900	900	1867
6	550	780	800	800	750	700	800	4926	150	150	231	154	150	150	330	546
7	-	-	510	500	350	400	-	449	-	-	600	564	486	409	-	553
9	-	220	320	150	-	300	-	102	-	356	419	380	-	303	-	178
Total	3750	4250	5100	4890	4350	4500	4180	11997	3750	4250	5100	4890	4350	4500	4180	8932
								3rd Day								
1	860	910	920	900	880	890	870	1339	950	950	950	950	950	950	950	1374
2	740	750	740	740	740	740	740	1597	240	602	851	667	607	780	344	1241
3	-	-	780	830	800	850	820	1300	-	-	789	767	760	780	729	1196
4	540	820	840	850	790	830	810	1596	641	819	900	851	822	900	692	1641
6	-	-	500	-	-	250	-	465	-	-	150	-	-	150	-	107
7	-	400	-	-	-	-	-	99	-	480	-	-	-	-	-	120
8	450	820	760	780	780	-	260	1255	758	849	900	866	851	-	784	1414
Total	2590	3700	4540	4100	3990	3560	3500	7651	2590	3700	4540	4100	3990	3560	3500	7094
								4th Day								
1	890	890	950	910	880	880	900	1346	950	765	950	950	950	950	410	1275
2	800	800	900	900	900	900	780	1905	628	1100	1100	1100	1100	1100	1100	2450
3	-	870	850	870	820	820	-	1372	-	652	900	900	780	780	-	1310
4	760	830	860	870	850	850	730	1673	832	900	900	900	900	900	900	1843
6	-	-	800	670	630	630		2433	-	-	251	150	150	150	-	275
7	500	500	500	370	400	400		674	484	373	600	600	501	501	-	821
8	800	800	840	800	810	810		1361	856	900	900	900	900	900	-	1531
9			330	340	340	340		122	-	-	429	230	349	349	-	164
Total	3750	4690	6030	5730	5630	5630	2410	10884	3750	4690	6030	5730	5630	5630	2410	9668

No of	Real operation in local time, kW							Cost,	Lagrange solution for local time, kW							Cost,
machine	17.00	18.00	19.00	20.00	21.00	22.00	23.00	USD	17.00	18.00	19.00	20.00	21.00	22.00	23.00	USD
								5th Day								
1	900	940	920	890	890	900	900	1349	950	950	950	950	950	950	950	1374
2	740	880	860	860	560	600	620	1585	624	602	869	473	425	543	581	1230
3	800	820	830	640	810	810	810	1760	762	759	791	744	739	753	757	1656
4	800	810	-	-	820	810	830	1179	830	819	-	-	732	790	809	1150
7	-	-	-	250	220	-	-	194	-	-	-	465	460	-	-	228
8	780	530	-	810	810	750	780	1277	855	849	-	817	805	835	844	1407
Total	4020	3980	2610	3450	4110	3870	3940	7344	4020	3980	2610	3450	4110	3870	3940	7046
								6th Day								
1	920	920	920	920	920	910	910	1356	950	950	950	950	950	950	950	1374
2	-	-	850	820	840	750	870	1304	-	-	1100	1100	1100	629	664	1519
3	820	820	810	800	810	800	810	1797	687	748	840	855	610	763	767	1686
4	-	730	800	790	790	770	640	1302	-	772	900	900	900	832	849	1513
6	-	-	750	740	450	-	-	1704	-	-	151	166	150	-	-	169
8	-	-	800	800	800	800	-	895	-	-	900	900	900	856	-	1015
9	200	-	290	-	-	-	-	41	303	-	379	-	-	-	-	69
Total	1940	2470	5220	4870	4610	4030	3230	8399	1940	2470	5220	4870	4610	4030	3230	7345
								7th Day								
1	890	840	880	930	910	910	900	1342	950	180	950	950	950	950	950	1233
2	-	620	720	870	860	860	330	1325	-	511	1100	1100	1100	731	453	1634
3	-	490	770	850	830	820	830	1527	-	749	630	900	900	775	742	1526
4	-	390	780	850	830	820	830	1329	-	900	900	900	900	882	746	1541
6	-	-	750	800	800	-	-	2316	-	-	150	310	230	-	-	313
7	-	-	300	550	550	-	-	388	-	-	351	600	600	-	-	443
8	-	-	780	810	800	810	-	895	-	-	900	900	900	882	-	1025
9	220	-	-	-	-	-	-	19	160	-	-	-	-	-	-	34
Total	1110	2340	4980	5660	5580	4220	2890	9140	1110	2340	4980	5660	5580	4220	2890	7748

Appendix B. Unit Commitment Solution

Unit commitment solution for optimizing the plants operation is provided in following table. The table is used to show data from second to seventh day of peak load operation while the first day is shown in table 4.

No of	Unit commitment solution, kW							Operation cost, USD							Total
machine	17:00	18:00	19:00	20:00	21:00	22:00	23:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	
2nd Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	1100	1100	1100	1100	1100	1100	1100	377.1	377.1	377.1	377.1	377.1	377.1	377.1	2639.9
3	-	894	900	900	900	900	847	-	300.9	304.6	304.6	304.6	304.6	274.6	1793.9
4	-	-	900	-	-	-	-	-	-	266.8	-	-	-	-	266.8
7	468	-	-	600	268	368	-	115.8	-	-	175.0	92.7	94.2	-	477.7
8	900	900	900	900	900	900	900	257.9	257.9	257.9	257.9	257.9	257.9	257.9	1805.0
9	332	406	350	440	232	282	383	28.7	62.8	34.9	85.8	17.2	17.9	49.6	297.0
Total	3750	4250	5100	4890	4350	4500	4180	975.8	1195.0	1437.6	1396.8	1245.8	1248.1	1155.6	8654.7
3rd Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	-	1100	1100	1100	1100	1100	1100	-	377.1	377.1	377.1	377.1	377.1	377.1	2262.7
3	-	-	764	794	-	-	-	-	-	238.5	249.9	-	-	-	488.4
7	473	434	485	0	600	341	301	117.3	106.4	121.5	-	175.0	91.9	91.0	703.1
8	833	900	900	900	900	900	900	233.8	257.9	257.9	257.9	257.9	257.9	257.9	1781.0
9	335	316	341	356	440	269	249	29.5	24.0	31.6	37.3	85.8	16.8	16.3	241.3
Total	2590	3700	4540	4100	3990	3560	3500	577.0	961.7	1223.0	1118.5	1092.2	940.0	938.6	6850.9
4th Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	1100	1100	1100	1100	1100	1100	1093	377.1	377.1	377.1	377.1	377.1	377.1	373.7	2636.5
3	-	824	900	900	900	900	-	-	263.1	304.6	304.6	304.6	304.6	-	1481.5
4	-	-	900	900	900	900	-	-	-	266.8	266.8	266.8	266.8	-	1067.0
6	-	-	251	-	-	-	-	-	-	114.2	-	-	-	-	114.2
7	468	545	600	600	600	600	-	115.8	146.1	175.0	175.0	175.0	175.0	-	961.9
8	900	900	900	900	900	900	-	257.9	257.9	257.9	257.9	257.9	257.9	-	1547.2
9	332	371	429	380	280	280	367	28.7	43.9	77.9	48.3	17.7	17.7	42.2	276.3
Total	3750	4690	6030	5730	5630	5630	2410	975.8	1284.5	1769.8	1626.0	1595.4	1595.4	612.3	9459.1

No of machine	Unit commitment solution, kW							Operation cost, USD							Total
	17:00	18:00	19:00	20:00	21:00	22:00	23:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	
5th Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	1100	1100	-	1100	1100	1100	1100	377.1	377.1	-	377.1	377.1	377.1	377.1	2262.7
3	741	-	-	-	801	-	-	230.9	-	-	-	252.7	-	-	483.6
7	-	600	478	268	-	548	294	-	175.0	119.2	92.7	-	147.4	91.1	625.4
8	900	900	844	900	900	900	900	257.9	257.9	237.7	257.9	257.9	257.9	257.9	1784.9
9	329	430	338	232	359	372	246	27.8	78.6	30.4	17.2	38.7	44.5	16.4	253.5
Total	4020	3980	2610	3450	4110	3870	3490	1090.0	1084.9	583.6	941.2	1122.7	1023.2	938.9	6784.5
6th Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	-	-	1100	1100	1100	1100	1100	-	-	377.1	377.1	377.1	377.1	377.1	1885.6
3	-	-	541	900	792	747	-	-	-	210.2	304.6	249.1	232.9	-	996.9
4	-	-	900	-	-	-	-	-	-	266.8	-	-	-	-	266.8
7	-	-	600	600	513	-	-	-	-	175.0	175.0	132.1	-	-	482.1
8	689	794	900	900	900	900	900	196.6	222.0	257.9	257.9	257.9	257.9	257.9	1707.9
9	301	326	229	420	355	333	280	20.9	26.8	17.4	71.7	36.9	28.8	17.7	220.2
Total	1940	2070	5220	4870	4610	4030	3230	413.8	445.1	1500.8	1382.7	1249.4	1093.1	849.0	6933.8
7th Day															
1	950	950	950	950	950	950	950	196.4	196.4	196.4	196.4	196.4	196.4	196.4	1374.5
2	-	1100	1100	1100	1100	1100	-	-	377.1	377.1	377.1	377.1	377.1	-	1885.6
3	-	-	900	900	900	874	-	-	-	304.6	304.6	304.6	289.1	-	1202.9
4	-	-	900	900	900	-	-	-	-	266.8	266.8	266.8	-	-	800.3
7	-	-	-	600	600	-	600	-	-	-	175.0	175.0	-	175.0	525.0
8	-	-	900	900	900	900	900	0.0	-	257.9	257.9	257.9	257.9	257.9	1289.3
9	160	290	230	310	230	396	440	33.8	18.9	17.4	22.7	17.4	56.9	85.8	252.8
Total	1110	2340	4980	5660	5580	4220	2890	230.1	592.4	1420.1	1600.4	1595.1	1177.3	715.1	7330.4

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