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POWER PLANT PERFORMANCE ANALYSIS ON VARIATIONS OF GENERATOR LOADING AT OMBILIN COAL FIRED STEAM POWER PLANT UNIT 1 (2X100 MW)

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Abstract— Steam Power Plants are classified as thermal plants that convert chemical energy in fuel into electrical energy. In an effort to increase the effectiveness of the work of the plant, there needs to be proper planning for its operations, this is important because it directly affects the operational costs incurred by the plant. This journal aims to determine the effect of changes in load or variations in generator loading on power plant performance, both efficiency, heat rate and production costs of electricity generation and to identify the magnitude of the decline in the thermal performance of the generator, as well as determine the causes and parts of the plant whose performance level decreases compared to optimal conditions. The method used to calculate the efficiency and heat rate is the "Direct Method", namely by directly comparing the input energy with the electrical output produced. The data used in this study is the "Power Plant Performance Test" data. The results of this study get the most optimal conditions when loading 93.39 MW Net with efficiency 34.693%, heat rate 2475,445 kcal/kWh and electricity production costs 413,297 Rp/kWh. The conclusion of this study is that plant performance is getting better at high loads.
Keywords: Thermal efficiency, Heat Rate, Electricity Production Cost, and Steam Power Plant

1. Introduction

Coal-fired Steam power plant is a thermal power plant that uses steam from the combustion of demineralized water in the combustion chamber (furnace) to turn a turbine and then convert the mechanical energy of the turbine into electrical energy in a generator. In terms of the water-steam cycle, the steam power plant is a closed system that uses the principle of the Rankine cycle. Rankine cycle is a thermodynamic cycle that converts heat into work [1]. Heat is supplied externally to an open flow, which usually uses water as the moving fluid. The fluid in the Rankine cycle follows a closed flow and is used constantly. Various types of fluids can be used in this cycle, but demin water was chosen because of its various physical and chemical characteristics such as non-toxic, available in large quantities, and cheap. Although technically the raw material for coal-fired power plant operates in a closed and constant cycle, in terms of utilizing heat energy to change the demin water phase into steam, there are many losses, because external combustion uses an open system which means that the heat from the combustion in the furnace will be discharged into the atmosphere. in the form of flue gas [2][3].

Performance analysis or efficiency management of thermal generators is guided by the Integrated Procedure Manual, which uses thermal efficiency and heat rate as a reference for the good and bad of the power plant system [11]. Power plant performance management aims to control plant operational activities in order to meet operating criteria and efficiency criteria in producing electricity. Generating efficiency is a measure of the generator's ability to convert the energy produced during primary fuel combustion into secondary energy in the form of electricity . Heat rate is the amount of energy required by a thermal generator to produce one kWh of electricity [14][15]. These two items are the main keys to analyze the performance of the power plant. Performance analysis is implemented by comparing the results of the performance test and commissioning test of the generator, the output of this analysis will

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lead to the determination of specific fuel consumption (SFC) and electricity production costs per kWh [4].

Specific fuel consumption (SFC) is the ratio of the total fuel consumption to the electricity generated in a power generation industry, usually used as a way to find out how efficient a power plant is and to predict the calorific value of the fuel used for combustion. The calorific value of coal as the main fuel in the operation of coal-fired plant affects the efficiency, heat rate and SFC of the generator. The higher the calorific value in coal with loading approaching full-load, the value of heat rate, SFC decreases and thermal efficiency increases [8][9]. While the cost of electricity production, although SFC decreases as the calorific value used increases, it does not make the cost of electricity production decrease, this is because coal prices are getting more expensive with higher calories from coal [5]. Changes in generator loading also affect the efficiency of generator performance, where research conducted by Naryono is to analyze the efficiency of gas turbines on operating loads where the analysis is carried out when the load is 90 MW, 100 MW, 110 MW, 125 MW and 136 MW, the results from this study shows that efficiency increases with every increase in load [6].

In previous studies there has been no research on the effect of generator loading on coal-fired plant performance, both efficiency, heat rate, SFC and electricity production costs. Therefore, in this article, we will present "*Powerplant Performance Analysis on Variation of Generator Loading at Ombilin Coal-fired Steam Power Plant Unit 1 (2x100 MW)*". This article aims to determine the effect of changes in load or variations in generator loading on power plant performance, both efficiency, heat rate and production costs of electricity generation and to identify the magnitude of the decline in the thermal performance of the generator, as well as determine the causes and parts of the plant whose performance level decreases compared to optimal conditions. The hope that this article can be considered in optimizing the operation of steam power plants and as a reference for the economical operation of the system.

2. Method

Steam power plant is a power plant that converts the chemical energy of the fuel into electrical energy at the generator output. Ideally, as long as there is a change in form from one type of energy to another, the amount of initial energy with the amount of final energy will be the same [10]. However, in coal-fired plant during the process of changing the form of energy, heat loss will occur. Heat loss in coal-fired plant mostly occurs in the condenser and flue gas boiler. The larger the losses, the lower the efficiency and in the end the heat rate, the cost of producing electrical energy per kWh will be higher.

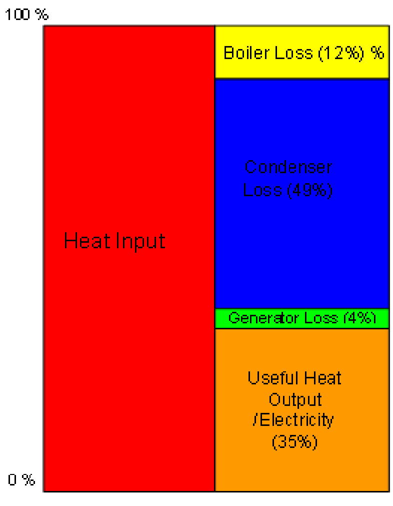

Figure 1. Correlation of Input, Output and Losses to Efficiency

The research location is at PT PLN (Persero) UPK Ombilin Unit 1, which is located in Talawi

District, Sawahlunto City. Ombilin coal-fired steam power plant is a power plant at the mouth of the Sawahlunto coal mine which has been operating since 1996 with equipment made by GEC ALSTHOM France. The data collection method that the author uses is field observations, interviews with several coal-fired plant parties including the operations, engineering, chemical operations, and power generation departments and taking data logsheets, performance tests that have been provided by the Ombilin Coal-fired Steam Power Plant. The method used to calculate the efficiency and heat rate is the "Direct Method", namely by directly comparing the input energy with the electrical output produced.

2.1 Data Collection

Data collected from the results of the power plant performance test. Performance test is a process to test the limits of resilience and stability of a system including application modules and infrastructure, as well as testing how the system/application can work again after a downtime under different load conditions [13]. The performance test of the Ombilin coal-fired steam power plant was carried out on five different loads, namely 60, 70, 75, 90 and 100 MW. With each loading, 4 data samples were taken. To review this research, data is needed that will support the research results. The data needed in this study are the amount of fuel, fuel calories, self-consumption load, generator output power and coal prices.

The fuel used in this research is bituminous coal. With calories based on the chemical laboratory test of ombilin 6300 kcal/kg or 26376.84 kJ/kg. Based on the Decree of the Minister of Energy and Mineral Resources No. 139.K/HK.02/MEM.B/2021 the selling price of coal for the supply of electricity for the public interest is US$70 per tonne or Rp. 1,050,567 per tonne at the dollar exchange rate of Rp. 15,008.10 [7]. This is to ensure that electricity prices can still be reached by the community while still considering the economics of coal exploitation.

Table 1. Performance Test Data of Ombilin Coal-fired Steam Power Plant on September 2022

Time	Gross Output Power (MW)	Nett Output Power (MW)	Auxiliarry Power Consumption (MW)	Coal Calories (HHV)		Coal Flow Rate (BB)		Coal Price	
				kcal/kg	kJ/kg	t/h	kg/h	USD/ton	Rp/ton
09.15	60	54.24	5.76	6300	26376.84	26.2	26200	70	1050567
09.30	60	54.26	5.74	6300	26376.84	26.24	26240	70	1050567
09.45	60	54.24	5.76	6300	26376.84	26.33	26330	70	1050567
10.00	60	54.25	5.75	6300	26376.84	26.33	26330	70	1050567
11.15	70	64.01	5.99	6300	26376.84	28.14	28140	70	1050567
11.30	70	64.02	5.98	6300	26376.84	28.75	28750	70	1050567
11.45	70	64	6	6300	26376.84	28.75	28750	70	1050567
12.00	70	64.01	5.99	6300	26376.84	28.77	28770	70	1050567
13.15	75	68.86	6.14	6300	26376.84	29.98	29980	70	1050567
13.30	75	68.86	6.14	6300	26376.84	29.99	29990	70	1050567
13.45	75	68.85	6.15	6300	26376.84	29.99	29990	70	1050567
14.00	75	68.88	6.12	6300	26376.84	30.01	30010	70	1050567
16.15	90	83.59	6.41	6300	26376.84	34.74	34740	70	1050567
16.30	90	83.61	6.39	6300	26376.84	34.73	34730	70	1050567
16.45	90	83.61	6.39	6300	26376.84	34.73	34730	70	1050567
17.00	90	83.59	6.41	6300	26376.84	34.75	34750	70	1050567
18.15	100	93.39	6.61	6300	26376.84	36.74	36740	70	1050567
18.30	100	93.39	6.61	6300	26376.84	36.79	36790	70	1050567
18.45	100	93.38	6.62	6300	26376.84	36.8	36800	70	1050567
19.00	100	93.39	6.61	6300	26376.84	36.8	36800	70	1050567

Source : Ombilin Performance Test Data, September 2022

2.2 Data Calculation and Analysis

Some important parameters in analyzing the performance of a coal-fired steam power plant are as follows:

Thermal Efficiency is a dimensionless measure that shows the performance of thermal equipment such as combustion engines (boilers), steam power plants and so on. The incoming heat is the energy obtained from the energy source [8]. The desired output can be either heat or work, or it may be both. Thermal efficiency is formulated by:

$$\eta_{PLTU} = \frac{P_{out(netto)}}{P_{in}} * 100\% = \frac{P_{out(bruto)-UAT}}{BB*HHV} * 100\% \quad (1)$$

Where :

P_{out} is the electrical energy of the generator output / Generator load (*MWh*)
UAT is electricity consumption of the power plant (*MWh*)
BB is fuel consumption (*kg*)
HHV is the calorific value of the fuel (*kcal/kg*)

Heat Rate is one of the power plant performance index that shows how much energy is needed to produce electrical energy [4]. The heat rate calculation in this study uses a net heat rate or the so-called Net Plant Heat Rate (NPHR) which is formulated by:

$$NPHR = \frac{BB*HHV}{P_{out(netto)}} \quad (2)$$

Where :

$NPHR$ is net plant heat rate (*kcal/kwh*)

Specific Fuel Consumption (SFC) is the ratio of the total fuel consumption to the electric power generated in a power generation industry [4], usually used as a way to find out how efficient a power plant is and to predict the calorific value of the fuel used for combustion.

$$SFC = \frac{BB}{P_{out\,(netto)}} \quad (3)$$

Where :

SFC is specific fuel consumption (*kg/kWh*)

Electricity Production Cost is the cost required to generate per kWh of electricity. The cost of electricity production is formulated as follows:

$$Electricity\ Production\ Cost = SFC\ x\ Fuel\ Price \quad (4)$$

2.3 Step Calculation

Step Calculation begins by collecting data from the performance test in the form of data on fuel consumption, generator load, auxiliarry power consumption and coal calories. Then proceed with calculating the thermal efficiency, heat rate, SFC and electricity production costs. The results of the calculation of generator load variations are analyzed and then displayed in graphical form.

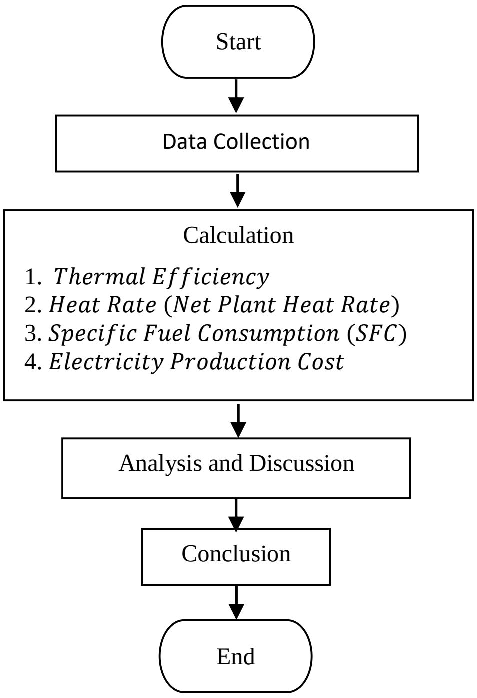

Figure 2. Step Calculation

3. Result and Discussion

Based on the ombilin performance test data in September, a generator performance analysis was calculated which included thermal efficiency, heat rate, SFC and plant production costs, which aims to obtain the performance of the generator at various loading variations. As shown in the table below:

Table 2. Calculation Results Data of Ombilin Coal-fired Steam Power Plant Performance Analysis

Time	Gross Output Power (*MW*)	Nett Output Power (*MW*)	NPHR (kcal/kwh)	Efficiency (%)	SFC Gross (kg/kwh)	SFC Netto (kg/kwh)	Electricity Production Cost (Rp/kwh)
09.15	60	54.24	3043.14	28.26	0.44	0.48	507.46
09.30	60	54.26	3046.66	28.22	0.44	0.48	508.05
09.45	60	54.24	3058.24	28.12	0.44	0.49	509.98
10.00	60	54.25	3057.68	28.12	0.44	0.49	509.89
11.15	70	64.01	2769.60	31.05	0.40	0.44	461.85
11.30	70	64.02	2829.19	30.39	0.41	0.45	471.79
11.45	70	64.00	2830.08	30.38	0.41	0.45	471.93
12.00	70	64.01	2831.60	30.37	0.41	0.45	472.19
13.15	75	68.86	2742.87	31.35	0.40	0.44	457.39
13.30	75	68.86	2743.78	31.34	0.40	0.44	457.54
13.45	75	68.85	2744.18	31.33	0.40	0.44	457.61

14.00	75	68.88	2744.82	31.33	0.40	0.44	457.72
16.15	90	83.59	2618.28	32.84	0.39	0.42	436.62
16.30	90	83.61	2616.90	32.86	0.39	0.42	436.39
16.45	90	83.61	2616.90	32.86	0.39	0.42	436.39
17.00	90	83.59	2619.03	32.83	0.39	0.42	436.74
18.15	100	93.39	2478.45	34.69	0.37	0.39	413.30
18.30	100	93.39	2481.82	34.65	0.37	0.39	413.86
18.45	100	93.38	2482.76	34.63	0.37	0.39	414.02
19.00	100	93.39	2482.49	34.64	0.37	0.39	413.97

From the calculation data, the generator performance analysis has been carried out. Then the effect of the difference in generator load on the performance of the generator can be depicted in a graph as follows:

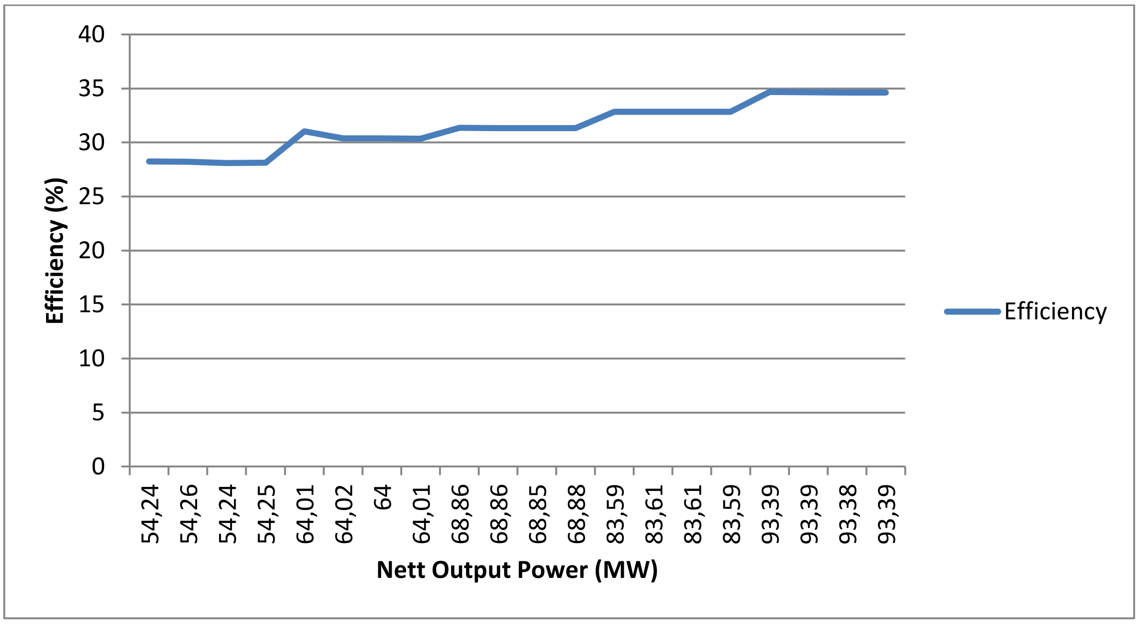

Figure 3. Relationship of Efficiency and Nett Output Power

According to figure 3 regarding the effect of generator load on efficiency, it shows the comparison of the lowest efficiency value of 28.116% and the highest efficiency of 34.693%. The results of the calculations can be seen in table 2 where at 09.45 the power plant has an efficiency of 28.116%. This is due to the low output power generated by the generator, with fuel used of 26330 kg/h, so that the heat generated is 192917,382 kJ/s. the low fuel used causes the steam produced to be not optimal so that the efficiency is low. In addition, the use of a superheater steam system is not effective enough to increase the efficiency of the generator. To increase efficiency, this plant should use a steam reheater system. A reheater system will make it much more effective. Because the generator will use 3 turbines. The first is a high pressure turbine (HP Turbine), an intermediate turbine and a low pressure turbine (LP Turbine), where this system utilizes steam that has been used to drive a high pressure turbine which then flows into a medium pressure turbine. This system will result in higher efficiency.

While the highest efficiency value is at 18.15 WIB with an efficiency value of 34.693%. This happens because at 18.15 the output power generated by the generator is large while the fuel user is 36790 kg/h. Circumstances like this will provide the effectiveness of the generator function. Because the higher the efficiency value, the better the performance of the resulting generator. Efficiency will affect at performance and losses of power plants, seen from the performance side, it means that the losses of steam power plants at high loads are smaller. This is because the absorption of heat in the economizer, superheater and combustion chamber is more optimal at high load points. while at a low load the heat is wasted is greater or the heat absorption is low so that the thermal efficiency is reduced.

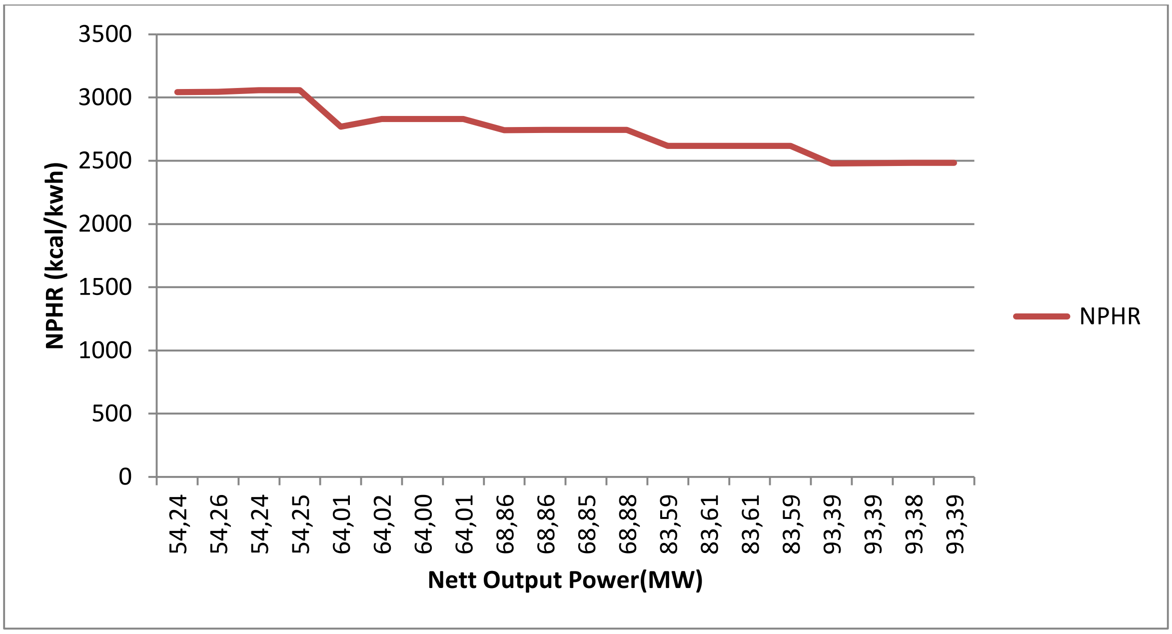

Figure 4. Relationship of NPHR with Nett Output Power

From figure 4, it can be seen that the NPHR of the generator is at its highest point at 09.45 WIB with 3058.24 kcal/kwh at 54.24 MW and the lowest at 18.15 WIB with 2478.45 kcal/kwh at 93.39 MW. That means to produce 1 kWh of electrical power, less heat is required at higher loads. This means that for the operation of the thermal power plant, it is better to operate at a high output power than at a low point. This is due to maximum heat utilization at a larger generator output. The flow of spray desuperheater is also very influential, because at low loads it is more difficult to regulate the temp of the superheater output steam, so spray desuperheater is needed for temperature regulation. Meanwhile, at high loads, all the heat will be used to rotate the turbine and the flow of the spray desperheater can be optimized.

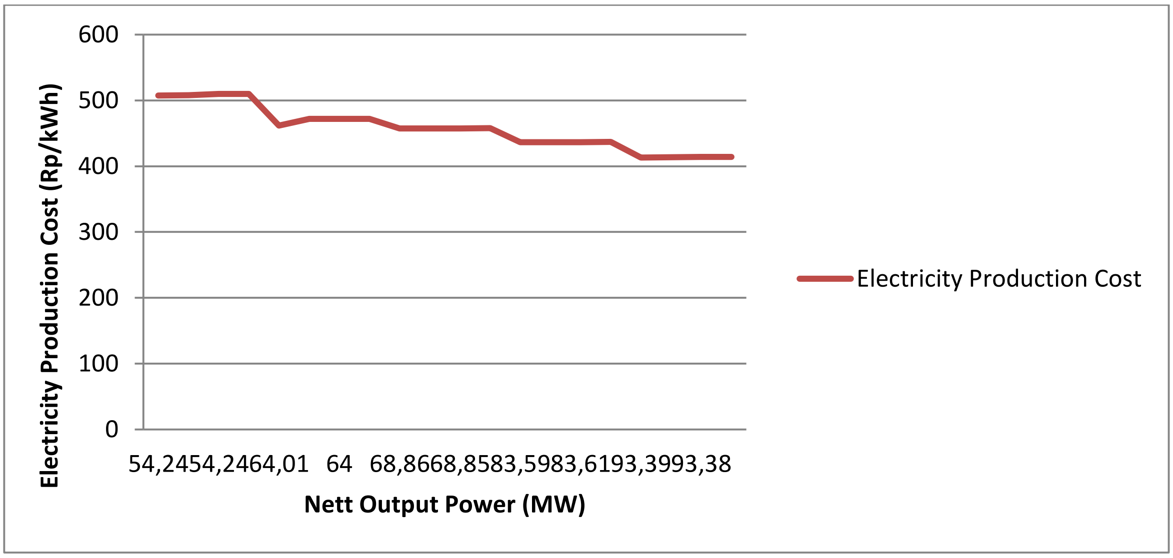

Figure 5. Relationship of Electricity Production Costs with Nett Output Power

From figure 5 it can be seen that the production cost of electricity generation is at its highest point at 09.45 WIB with 509.98 Rp/kwh at 54.24 MW and the lowest at 18.15 WIB with 413.2 Rp/kwh at 93.39 MW load. That means to produce 1 kWh of electrical power, less heat is required at higher loads. This identifies that the cost of electricity production will be lower when the generator load is high while on the other hand the cost of electricity production will be large if the generator load is getting smaller. For economical operation, these data are very decisive, where the thermal generator should be operated in full-load position because in terms of performance, both efficiency, heat rate and electricity production costs per kWh are more optimal than plants operated under full load.

4. Conclusion

Based on the research above, it can be concluded that changes in load or variations in generator loading affect the performance of power plants, both efficiency, heat rate and production costs of power plants. It is found that the characteristics of the generator's performance are that the greater the load generated, the better the performance of the generator. This means that the power plant is better operated at its maximum load. The characteristic of heat rate is that the greater the load, the smaller the heat rate of the generator. This means that heat energy from fuel will be utilized more optimally at the maximum load of the generator. There is an identification of a decrease in the thermal performance of the generator when it is not operated at its maximum load. This can be caused by the less than optimal performance of the spray desuperheater at low loads, as well as the construction of the turbine and superheater which should use a reheater, so that the heat from the boiler can be utilized as much as possible. The cost of electricity production is also lower when the generator load is higher, whereas when compared to fuel consumption, of course it is inversely proportional, this explains that the heat from the fuel is used more so that the heat loss at high load is smaller than in high load generating conditions. From the study that has been carried out on steam power plant ombilin unit 1, there are several suggestions that the author would like to convey, namely the need to check and modify coal-fired plant equipment to get higher efficiency values and lower heat rates.

References

[1] Alsthom, Gec. Steam Turbin. PT.PLN (Persero) Pembangkitan Ombilin. 1995.

[2] Education and Training Center. Coal-fired Plant Efficiency Optimization. Suralaya : PT PLN (Persero).2013.

[3] Education and Training Center. Efficiency and Heat Rate. Suralaya : PT PLN (Persero).2013.

[4] Tsou, Heat Rate Improvement Reference Manual. Palo Alto: EPRI. 1998.

[5] M Iqbal Syahputra. Analysis of the Effect of the Calorific Value of Coal on Fuel Consumption and Electricity Production Costs. Jakarta : State Polytechnic of Jakarta. 2020.

[6] Naryono. Gas Turbine Efficiency Analysis of Muara Tawar Power Plant Operation Load Block 1. Jakarta : Muhammadiyah University of Jakarta. 2013.

[7] Keputusan Menteri ESDM Nomor 139.K/HK.02/MEM.B/2021. Jakarta : Kementrian ESDM. 2021.

[8] Anang Nungki Ristyanto. Simulation of Calculation of Efficiency of Steam Power Generation System Rembang. Semarang : University of Diponogoro. 2011.

[9] Bambang Sugiantoro. Energy Analysis Method Calculation of Direct Indirect (Heat Rate) Coal Fuel and Its Effect on Steam System Performance. Purwokerto : STT Wiworotomo. 2008

[10] Ir. H. Suyamto. Comparison of Efficiency Calculations Between Conventional Steam Power Plants and Nuclear Power Plants. Yogyakarta : College of Nuclear Technology. 2009.

[11] Alamsyah, Dinda. Caring for Efficiency by Lowering NPHR. KITSBS Choir : Pointer. 2016.

[12] Indra D Permana. Comparative Study of the Power Capacity Efficiency of Hydrodynamic

Magnetic Power Generation Against Coal-fired Plant 100 MW Cilegon. Surabaya : Sepuluh Nopember Institute of Technology. 2010.

[13] Alifiyah, Intan. Efficiency Analysis of the Boiler Combustion System at Coal-fired Plant Unit III PT PJB UP Gresik with the Statistical Process Control Method. Surabaya : epuluh Nopember Institute of Technology. 2010.

[14] Havianto, Jonny. Power Plant Efficiency Surgery, Heat Rate Test!. http://jonny-havianto.blogspot.co.id/2013/01/bedah-inefisiensi-pembangkit-listrik.html. 2013.

[15] Agus Hendroyono Sahid. Heat Rate Analysis With Load Variations at the New Paiton Steam Power Plant Unit 9. Semarang : Semarang State Polytechnic. 2014