Turbine Blade Modification to Obtain Required NPHR Value with Low-Quality Coal Energy Source at Gorontalo Power Plant

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Abstract. Nowadays, the Indonesian government is actively building coal-fired power plants and one of the new power plant projects is in Gorontalo. The reliability of the PLTU Gorontalo was designed to have a Net Plant Heat Rate of 3068 kcal/kWh which can be reached using coal fuel quality above 4200 kcal/kg. Unfortunately, this type of coal is rarely available in the local market, local coal only reaches fuel quality of 3600 kcal/kg – 4200 kcal/kg, which means the plant reliability of 3068 kcal/kWh could not be obtained. To reach the required NPHR by using local coal that is available in the market, the turbine design needs to modify and the auxiliary power needs to adjust accordingly. The individual blade design was modified and the number of blade assembly also added to increase efficiency to 1.75 ~ 2.2%. The auxiliary power was reduced to 45.25 kW from its initial value. These modifications reach better NPHR value even though low-quality coal is used as a source of energy.

Keywords: NPHR · power plant · turbine blade · efficiency

1 Introduction

A power plant is an assembly of equipment that produce and deliver electrical or mechanical energy usually working on the Rankine cycle's principle [1]. Unrenewable energy from fossil fuel still dominate the role as an energy resource even though it causes severe environmental problems and triggers climate change [2]. Massive usage of coal is considered harmful to the environment, therefore regulation to reduce the usage of fossil fuels has become stricter than before [3]. There are difficulties in replacing those fossil fuels with renewable energy because renewable energy still requires a high technological level and instability of the power generation [4] and the utilities of Combined cycle power plants (CCPPs) which produce low air pollutants still require high production costs. [5]. Therefore, scientists all around the world keep on trying to find out the best solution using the power plant management approach [6].

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Currently, the Indonesian government is actively building a coal-fired power plant under the Presidential Regulation No. 71 of 2006 which assigned PT Perusahaan Listrik Negara to accelerate the development of a coal-fired electric power plant. In this provision, there is a plan for the construction of a steam power plant (PLTU) which includes 10 Power Plants in Java and 25 Power plants outside Java and Bali. Where Indonesia still highly rely on coal as the energy source for its power plant units, since 2018, several power plants have switched to lower-quality coal for cost reduction [7]. The Indonesian coal market is dominated by low-quality coal, which it makes difficult to fulfil the power plant's design requirement that needs high-quality coal. The use of coal that has different calories than the specifications requirement will affect plant performance parameters such as heat rate, boiler and turbine efficiency and also different pollution results [8]. To solve this problem most power plants use a coal blending system to obtain coal caloric value to reach better boiler efficiency [9, 10]. This blending system method was adopted because it complies with the emission regulation and prevents fluctuation price of the coal, but this still affected the boiler and its auxiliary equipment [11].

A high-efficiency factor is essential to run a power plant determined by the boiler efficiency [12]. A boiler is the main component of a coal-fired power plant to produce steam to run the turbine and consumes around 616 million tons of coal annually [13]. Another essential component is the turbine blades which are exposed to high temperatures and could improve the turbine efficiency [14]. These blades could improve turbine efficiency by increasing the gas-dynamic efficiency. Rusanov et al discovered that creating blade profiles individually for each flow part and the use of longer blades to align the flow of gas-dynamic characteristics by the channel height is the most appropriate approach in the high-power condensing steam turbine's last stages [15].

The performance of a power plant is measured based on the Net Plant Heat Rate (NPHR) value as reliability and efficiency indicators, high NPHR value represents low generation performance because a high value will produce smaller electrical energy [16]. Another factor that affected the NPHR value is the auxiliary power, which is the power consumed by the electrical equipment used for the electricity production process at the power plant. The ideal value of auxiliary power in a power plant is less than 11% of the power generated, where the increase in power added value causes the decrease of power supplied to the network [17]. Low NPHR represent a better value because the fuel consumed by the system getting better and ideal [18].

One of the new power plant projects is in Gorontalo. The reliability of the PLTU Gorontalo power plant during the operation was designed for 3068 kcal/kWh in 100% load of NPHR (Net Plant Heat rate) using coal fuel quality above 4200 kcal/kg. Available coal in the market only reaches fuel quality 3600 kcal/kg – 4200 kcal/kg, which means the plant reliability of 3068 kcal/kWh could not be obtained. Using high-quality coal is not an option because it will increase the production cost significantly and create supply difficulties, therefore another method to reach the required NPRH by using coal that is available in the market is to modify the turbine blade and adjust the auxiliary power accordingly.

2 Method

This research was conducted by doing observation and literature research simulation to find the best design solution for the Gorontalo power plant modification to accommodate the use of low-quality coal without decreasing the power plant efficiency.

3 Result

Based on research by Rusanov et al the blade profile was modified and the amount of the blade was added to increase steam flow (Fig. 2). Using the new scheme USES that uses impulse and reaction solution, the blade shape was modified to have a slightly bloated shape and pointed tip compared to the original scheme (Fig. 1).

For optimum result, the turbine structure improved by adding more blade structures from 19 to 36 units (Fig. 2).

Another effort in decreasing the NPHR value is by adjusting the auxiliary power consumption (Fig. 3). The auxiliary power was adjusted to adapt to the effect of low fuel quality coal (Table. 1).

After modification, the power plant unit runs for a performance test (Table.2) [19].

Fig. 1. Original scheme (left) and Modified scheme (right) of the turbine blade

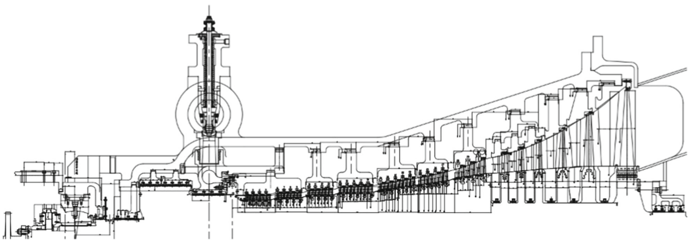

Fig. 2. Optimum structure improvement

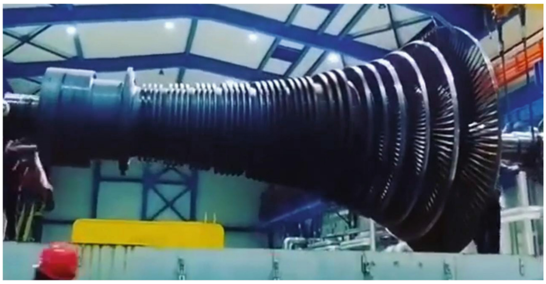

Fig. 3. Installation of the 36 blades structure

Table 1. The Auxiliary Power Consumption Adjustment

Prior	Adjustment
1. Fans (PA, FD, IO, EHE, etc.) / 1795 kW / 1 for every set	1. Fans (PA, FD, IO, EHE, etc.) / 1280 kW / 1 for every set
2. Crusher and Feeder / 11 kW / 1	2. Crusher and Feeder / 91.6 kW / 1
3. Condensate Pump / 110 kW / 1	3. Condensate Pump / 164 kW / 1
4. Boiler Feed Pumps / 1530 kW / 1	4. Boiler Feed Pumps / 1350 kW / 1
5. Circulating Water Pumps / 800 / 1 for every unit	5. Circulating Water Pumps / 1106 / 1 for every unit
6. Closed Cooling Water Pump / 110 kW / 1	6. Closed Cooling Water Pump / 93.2 kW / 1
7. Sea Water Booster Pump (if required) / 60 kW / 1	7. Sea Water Booster Pump (if required) / 115.2 kW / 1
8. Coal Handling System / 250 kW / 1	8. Coal Handling System / 216.68 kW / 1
9. Ash Handling System / 65 kW / 1	9. Ash Handling System / 285.75 kW / 1
10. Chemical Injection System / 15 kW / 1	10. Chemical Injection System / 3.2 kW / 1
12. Gland Steam Exhaust Blower / 10 kW / 1	11. Gland Steam Exhaust Blower / 2.56 kW / 1
13. Main Oil Tank Vapour Extractor / 10 kW / 1	12. Main Oil Tank Vapour Extractor Extractor / 0.48 kW / 1
14. Vacuum Pump 100 KW / 60 kW / 1	13. Vacuum Pump 100 KW / 28.68 kW / 1
15. Electrostatic Precepitator / 240 kW / 1	14. Electrostatic Precepitator / 340.4 kW / 1
16. Others / 1734 kW / 1	15. Generator Loss / 910 kW / 1
	16. Generator Transformer Loss / 360 kW / 1
	17. Auxiliary Transformer Loss / 100 kW / 1
	18. Others / 307 kW / 1
Total (1 unit) / 6800 kW	Total (1 unit) / 6754.75 kW

Table 2. Performance Test Result

Test Result	Unit	20-Nov-21 MCR1	20-Nov-21 MCR2	22-Nov-21 TMCR	23-Nov-21 VWO	24-Nov-21 50% MCR
Feed Water Flow	Ton/h	204.34	206.60	217.61	228.05	114.13
Feed Water Temperature	C	233.82	234.19	235.86	238.80	208.03
Main Steam Flow	Ton/h	208.34	210.95	217.61	228.05	114.13
Main Steam Pressure	MPa	8.69	8.66	8.63	7.92	6.84
Main Steam Temperature	C	534.25	531.67	532.45	531.06	533.93
Main Steam Enthalpy	kcal/kg	3476.30	3470.20	3477.50	3476.50	3494.70
Generator Output	KW	57688.64	58200.00	60725.00	62914.00	31483.00
Net Power	KW	51794.05	52414.40	54734.00	57488.00	26273.00
Gross Plant Heat Rate	KJ/KWh	8983.08	8990.62	8816.58	8849.89	9421.02
Steam Turbine Energy Input	KJ/h	127062195.92	140609740.70	90626696.56	127235714.67	59741362.04
Steam Turbine Heat Rate	KJ/KWh	2453.22	2682.65	1655.77	2213.26	2273.87
Aux Power	KW	5894.68	5785.68	5991.09	5426.09	5210.09
Boiler Efficiency	%	82.17	82.02	82.28	82.23	80.31
NPHR	kcal/kwh	2937.76	2936.30	2868.17	2841.67	3391.43

4 Discussion

The new blade was designed to reduce pressure loss caused by rough steam flow, the new conical blade design ensures smoother steam flow and prevents pressure loss. Each blade in the turbine is modified in order to increase turbine efficiency.

The modification of blade design further optimized by adding the number of turbine stages from 19 to 36. Design optimization by adding the number of turbine stages maximizes the energy from the steam pressure flow and reduces energy loss. This modification increases the efficiency of the reaction stage from 1.3% ~ 1.8% to 1.75 ~ 2.2% because more blades capture the pressure.

The auxiliary power was adjusted to adapt to the effect of low fuel quality coal. The auxiliary power is decreased to obtain a greater power output supply and gained the efficiency required for the new NPHR following the low fuel quality from coal as the energy source. Auxiliary power is managed to reduce by 45.25 kW from 6,800 kW to 6,754.75 kW (Table.2).

Performance test results on 20 Nov 2021 (MCR-1 and 2), 22 Nov 2021 (TMCR) and 23 Nov 2021 (VWO) show that the NPHR requirement of 3009 kcal/kWh has been reached even though low-quality coal of 3600–4200 kcal is used.

5 Summary

Based on the results of the performance test, the NPHR value has increased from 3068 kcal/kWh to 3009 kcal/kWh. This result validated that the modification of the turbine blades to accommodate the effect of the usage of low-quality coal is successful. Therefore any available coal fuel 3600 kcal/kg – 4200 kcal/kg can be used to replace the previously above 4200 kcal/kg required and the power plant can still meet the reliability NPHR required and can be operated smoothly.

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