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Analysis of the Effect of Blade Washing Compressor on Compressor Efficiency and Thermal Efficiency of Gas Turbine at PLTG XXX

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ABSTRACT

The most important parts of a gas power system are the compressor and gas turbine. Compressor performance will naturally decrease due to high ambient temperatures and dirt in the incoming air and make the compressor inefficient. To restore compressor efficiency, it is recommended to clean the compressor using the compressor blade washing method. The purpose of this study was to determine the compressor blade washing procedure used in the PLTG system and determine the parameters tested and analyses their effect on the thermal efficiency of the PLTG. This study was conducted on a PLTG unit operating at a load of 120 MW or 50% of the installed capacity, with research stages including data collection, calculation of the gas turbine heat rate, calculation of the thermal efficiency of the PLTG cycle and calculation of compressor efficiency. From the implementation of the compressor blade washing carried out, there was an increase in compressor efficiency of 2.62% and after the compressor blade washing caused a decrease in the heat rate of 853 kJ / kWh, so that there was an increase in the thermal efficiency of the PLTG of 1.74%.
Keywords: *PLTG, heat rate, compressor blade washing*

ABSTRAK

Bagian terpenting dari sistem tenaga gas adalah kompresor dan turbin gas. Kinerja kompresor secara alami akan menurun karena suhu lingkungan yang tinggi serta kotoran di udara yang masuk dan membuat kompresor tidak efisien. Untuk mengembalikan efisiensi kompresor, disarankan untuk melakukan pembersihan kompresor menggunakan metode pencucian sudu kompresor. Tujuan dari penelitian ini adalah untuk menentukan prosedur pencucian sudu kompresor yang digunakan dalam sistem PLTG dan menentukan parameter yang diuji serta menganalisis pengaruhnya terhadap efisiensi termal PLTG. Penelitian ini dilakukan pada unit PLTG yang beroperasi pada beban 120 MW atau 50% dari kapasitas terpasang, dengan tahapan penelitian meliputi pengumpulan data, perhitungan laju kalor gas turbin, perhitungan efisiensi termal siklus PLTG dan perhitungan efisiensi kompresor. Dari implementasi pencuci sudu kompresor yang dilakukan, terdapat peningkatan efisiensi kompresor sebesar 2,62 % dan setelah pencuci sudu kompresor menyebabkan penurunan laju kalor sebesar 853 kJ/kWh, sehingga terdapat peningkatan efisiensi termal PLTG sebesar 1,74 %.
Kata Kunci: PLTG, laju kalor, pencucian sudu kompresor

1. Introduction

1.1 Background

In addition to the combustion chamber, the most important components of the gas power system are the compressor and gas turbine [1]. Over time, compressor performance will naturally decrease due to high ambient temperatures and impurities in the incoming air [2]. These impurities stick to the compressor blades which if left unchecked will affect the pressure and temperature of the air, which in turn inhibits the compression process, swallows dirty materials, and makes the compressor inefficient, which in turn reduces the thermal effectiveness of the gas turbine. Several researchers have also conducted studies to predict the accumulation of dirt on the blades [3,4,5,6]. The decrease in gas turbine performance due to compressor fouling can be detected through a decrease in output power, as well as an increase in heat rate and fuel consumption [7]. Compressor blade washing helps remove dirt deposits and restore performance [8,9]. There are many ways to clean dirt that sticks to the compressor blades both when on and off [10,11]. Regarding the effectiveness of washing the axial compressor of the online combustion turbine using various levels of water purity and commercial washing detergents [12,13]. Maintaining and improving the efficiency of each washing session can be done by washing the compressor blades. User performance and environmental factors should be considered when determining the washing schedule. In addition, compressor washing can stop corrosion, which means the blades are more durable and spillage of dirt does not cause many corroded products [14]. Therefore, the purpose of this study is to determine the compressor blade washing procedure used in the PLTG system and to determine the parameters tested and analysed their effects on the thermal efficiency of the PLTG.

1.2 PLTGU Cycle

The gas Brayton cycle and the steam Rankine cycle, which together form the grid power source, are the two main components of the combined cycle power plant. Combustion of relatively hot gas results when the gas turbine is operating. Energy losses will occur with the direct release of these exhaust gases into the atmosphere [15].

1.3 Compressor Efficiency Calculation

To find the compressor efficiency calculation is as follows:

$$\eta c = \frac{T1C+273{,}15}{T2C-T1C}\, x\left(\frac{pcs+p\alpha}{p\alpha}\right)\frac{k-1}{k}\quad 1)\, x\, 100 \tag{1}$$

Description:
ηc = Compressor Efficiency (%)
TIC = Compressor input air temperature (°C)
T2C = Compressor output air temperature (°C)
PCS = Compressor outlet air pressure (kg/cm²)
Pa = Compressor outlet air pressure, kg/cm²
K = Specific heat ratio (K=1,4 constant)

1.4 Heat Rate Calculation

To find the heat rate calculation is as follows:

$$HR_{GTm} = \frac{WF_{GTm} \text{ x LHV}}{kW_{GTm}} \tag{2}$$

Description:
HR_{GTM} = Measured gas turbine heat rate (kJ/kWh)
WF_{GTM} = Fuel flow rate (kg/h)
LHV = Fuel heating value / Lower Heating Value (kJ/kg)
kW_{GTM} = Rated gas turbine generator output power (kW)

1.5 Thermal Efficiency of PLTGU Cycle

To find the thermal efficiency of PLTGU Cycle calculation is as follows:

$$\eta_{GT} = \frac{3600}{HR_{GT}} X\ 100\ \% \tag{3}$$

Description:
η_{GT} = Thermal efficiency of PLTGU gas turbine cycle (%)
HR_{GT} = Heat rate gas turbine correction (kj/kWh)

2. Methodology

In this study using quantitative methods where this method has the aim of collecting data and knowing the results of the value of compressor efficiency, thermal gas turbine, and heat rate value of 120 MW load.

2.1 Data Collection Technique

For the objectives in this study to be achieved properly, accurate data is needed as a basis for research. The author uses the following collection techniques:
- Direct Observation

- Indirect Observation
- Interview
- Literature Study

2.2 Research Design

To make it easier to conduct research, the authors make a problem-solving framework as follows:

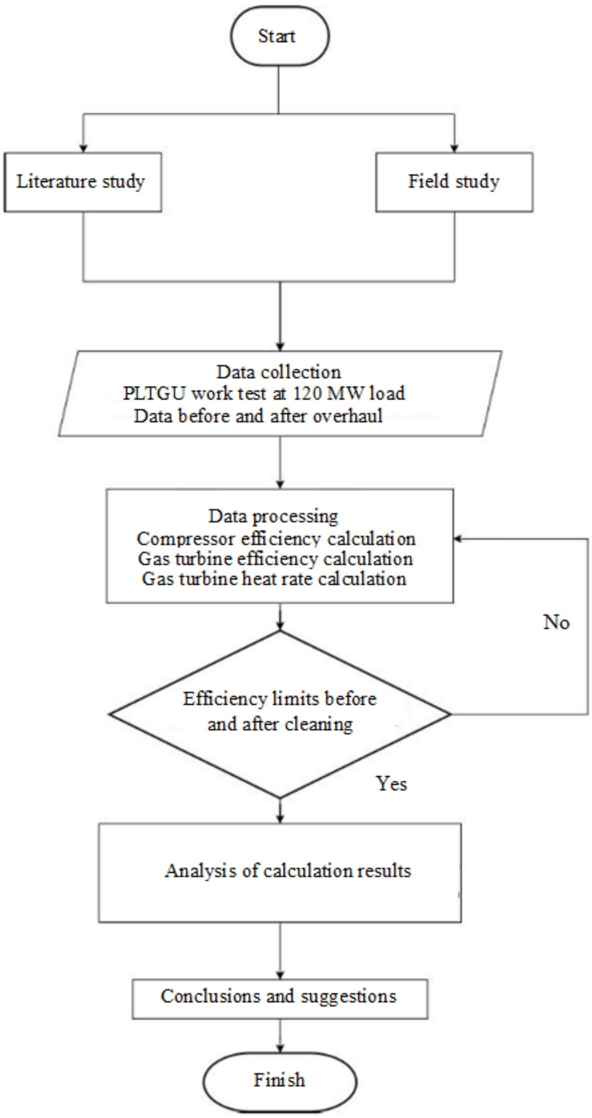

Figure 1. Flowchart

3. RESULTS AND DISCUSSION

The data collected include performance test data and data before and after overhaul at 120 MW load.

Table 1 Compressor Data Before Overhaul

No	Parameter	Symbols	Units	Value
1	Compressor inlet air temperature	T_1C	ºC	28.00
2	Compressor outlet air temperature	T_2C	ºC	386.21
3	Pressure air outlet compressor	PCS	kg/cm^2	10.59
4	Ambient air pressure	Pa	kg/cm^2	1.0856
5	Specific heat ratios	K	-	1.4

Table 2 Gas Turbine Before Overhaul

No	Parameter	Symbols	Units	Value
1	Gas turbine generator output	KW_{GTM}	kW	120457
2	Fuel flow rate,	Wf_{GTm}	kg/h	34.747
3	Inlet air temperature,	T_1	ºC	29.45
4	Ambient air pressure	P_1	mbar	1004.96
5	Relative humidity	RH	%	74.7
6	Fuel calorific value	LHV	kJ/kg	45.772
7	Fuel characteristics	C/H	-	3.1546
8	Generator frequency	F_{GT}	Hz	50
9	Power factor generator	PF_{GT}	%	99.84

Table 3 Compressor Data After Overhaul

No	Parameter	Symbols	Units	Value
1	Compressor inlet air temperature	T_1C	ºC	29.40
2	Compressor outlet air temperature	T_2C	ºC	388.50
3	Pressure air outlet compressor	PCS	kg/cm^2	10.64
4	Ambient air pressure	Pa	kg/cm^2	1.0496
5	Specific heat ratios	K	-	1.4

Table 4 Gas Turbine After Overhaul

No	Parameter	Symbols	Units	Value
1	Gas turbine generator output	KW_{GTM}	kW	120690
2	Fuel flow rate,	Wf_{GTm}	kg/h	33.785
3	Inlet air temperature,	T_1	ºC	28.00
4	Ambient air pressure	P_1	mbar	1008.56
5	Relative humidity	RH	%	80.8
6	Fuel calorific value	LHV	kJ/kg	44.119
7	Fuel characteristics	C/H	-	3.1453
8	Generator frequency	F_{GT}	Hz	50
9	Power factor generator	PF_{GT}	%	99.84

From the data, it can be summarized through the graph below

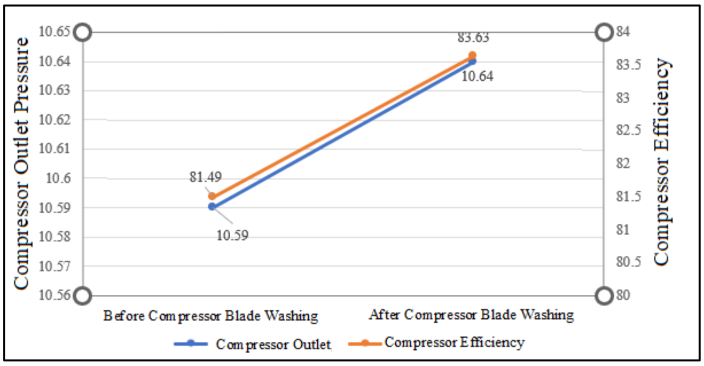

Figure 2. Compressor Outlet Pressure to Compressor Efficiency Ratio

After performing blade washing, the outlet air pressure of the compressor increased by 0.05 kg/cm^2, from 10.59 kg/cm^2 to 10.64 kg/cm^2. This small increase in pressure value, although seemingly minor, has a considerable impact on the overall performance of the compressor system.

In addition to the increase in air pressure, compressor efficiency also increased significantly after the blade washing process [. Before cleaning, the compressor efficiency was recorded at 81.49%, while after cleaning, the efficiency increased to 83.63%. This 2.62% increase in efficiency reflects a clear improvement in the way the compressor converts input energy into compression work.

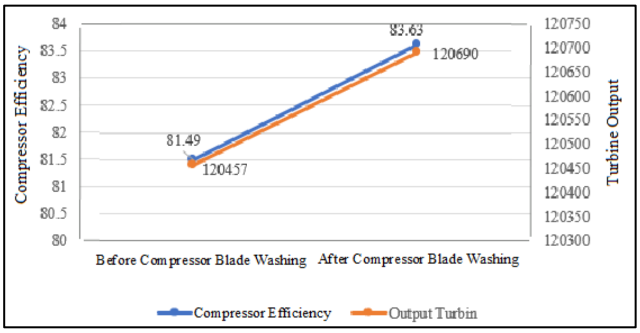

Figure 3. Compressor Efficiency Ratio to Turbine Output

Before the efficiency improvement, the gas turbine output was recorded at 120457 kW. However, after the compressor efficiency improvement, the gas turbine output increased to 120690 kW. This increase represents a 0.15% increase in output even though the fuel intake remained relatively the same.

The increase in compressor efficiency which reached 2.62% had a positive impact on the output of the gas turbine, increasing the output power from 120457 kW to 120690 kW.

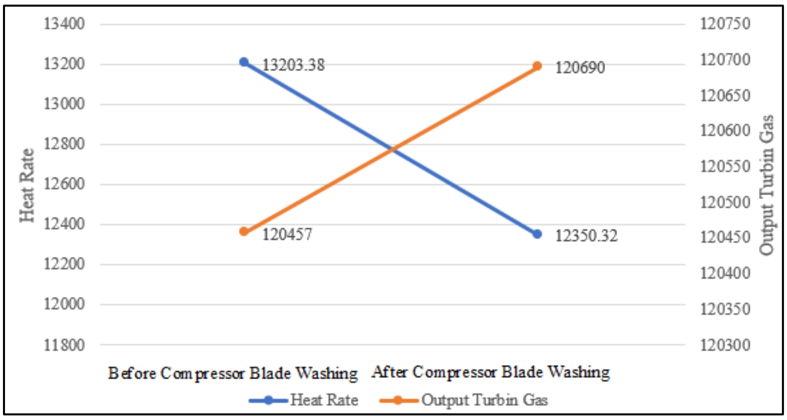

Figure 4. Comparison of Heat Rate with Gas Turbine Output

The measured heat rate decreased by 853 kJ/kWh, from an initial value of 13203 kJ/kWh to 12350 kJ/kWh after cleaning. This decrease in heat rate is a result of the increase in operational efficiency that occurred because of the compressor blade washing.

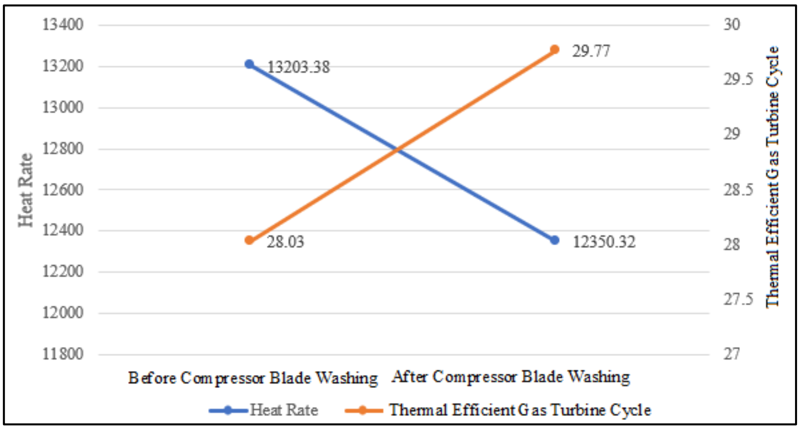

Figure 5. Comparison of Heat Rate and Thermal Efficiency of PLTG cycles

This decrease in heat rate is directly related to the increase in the thermal efficiency of the PLTG cycle which was recorded to increase by 1.74%, from 28.03% to 29.77%. This increase in thermal efficiency occurs because although the amount of heat energy required to produce power decreased, the turbine power output increased [5].

T-S & P-V Diagram Calculation

Table 5 P-V & T-S before Overhaul

No	Parameter	Symbols	Units	Value
1	Compressor inlet air temperature	T1	ºC	28.00
2	Compressor outlet air temperature	T2	ºC	386.21
3	Turbine outlet temperature	T4	ºC	560
4	Compressor inlet air pressure	P1	bar	1.0132
5	Compressor outlet air pressure	P2	bar	10.59

Table 6 P-V & T-S after Overhaul

No	Parameter	Symbols	Units	Value
1	Compressor inlet air temperature	T1	ºC	29.40
2	Compressor outlet air temperature	T2	ºC	388.50
3	Turbine outlet temperature	T4	ºC	562
4	Compressor inlet air pressure	P1	bar	1.0132
5	Compressor outlet air pressure	P2	bar	10.64

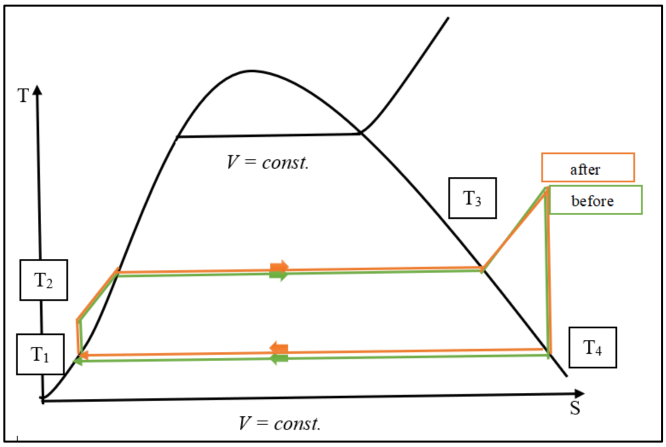

Figure 6. T-S Diagram Before and After Overhaul

Table 7 Ideal T-S Diagram Before and After Overhaul

before	after
T1: 28.00 ºC	T1: 29.40 ºC
T2: 386.21 ºC	T2: 388.50 ºC
T3: 1216.094 ºC	T3: 1215.219 ºC
T4: 560 ºC	T4: 562 ºC

Figure 7. P-V Diagram Before and After Overhaul

Table 8 Ideal P-V Diagram Before and After Overhaul

before	after
h_1: 301.955 kJ/kg	h_1: 302.775 kJ/kg
h_2: 669.808 kJ/kg	h_2: 672.247 kJ/kg
h_3: 1622.956 kJ/kg	h_3: 1621.861 kJ/kg
h_4: 858.517 kJ/kg	h_4: 860.727 kJ/kg

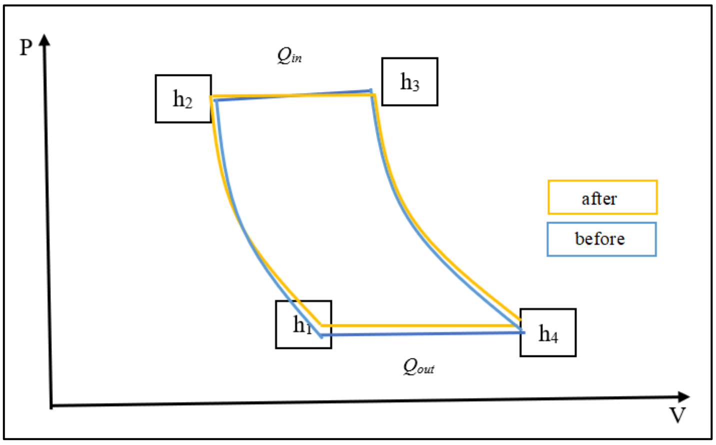

Figure 8. P-V Diagram Before and After Overhaul

3. Conclusions

The compressor blade washing process showed a significant increase in compressor efficiency. After the compressor blade washing was carried out, the air pressure exiting the compressor increased from 10.59 kg/cm² to 10.64 kg/cm², or by 0.05 kg/cm². This increase, although seemingly small, contributed greatly to the improvement in compressor efficiency by 2.62%, from 81.49% to 83.63%. This shows that compressor blade washing is effective in removing dirt that accumulates on the compressor blade, so that the air flow is smoother and the compressor operating load is reduced. The increase in thermal efficiency of the PLTG cycle is 1.74%.

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