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Analysis of Brayton Cycle Efficiency at 100 MW Load Before and After Overhaul of Unit 1 Block 1 at PLTGU PT. PLN Nusantara Power Up Gresik

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KEYWORDS	ABSTRACT
PLTG, efficiency	Electricity is one of the most important needs in everyday life due to technological advances. So various efforts are needed to increase electricity production, one way is to build a power plant that can produce productive electricity so that this happens, one way to determine electricity productivity is the value of cycle efficiency. If the value of the cycle efficiency is higher in a generator, then the PLTG performance will be maximized. And if the cycle efficiency value gets smaller, it can be said that the PLTG's performance is not good. Therefore, to maintain PLTG performance, it is necessary to carry out an overhaul to maintain optimal PLTG performance. In this study using cycle efficiency to determine the increase in efficiency before and after overhaul at a load of 100 MW and the causes, after analyzing the efficiency of the brayton cycle increased from 41% to 42%, the cause was a decrease in turbine efficiency from 74 to 91% and compressor efficiency from 73 to 82% after overhaul the increase affected fuel consumption so that the requirement of kcal/kwh decreased to 3196.4 kcal/ Kwh

Introduction

Electricity is one of the most important needs in everyday life because technological advances are growing rapidly and the use of electricity in Indonesia is increasing both for household and industrial needs all require electricity so that these activities can run (Annur, 2017). Electrical energy consumption, every year continues to increase, especially with the development of electric vehicles in Indonesia to reduce the use of fossil energy, it is recorded that the number of electric energy customers as of September 2021 reached 81.07 million customers, while in 2022 there are 83.43 million customers with ever-increasing needs (Fathoni, 2016).

Various efforts are needed to increase electricity production, one way is to build power plants that can produce large amounts of electricity and also needed resources or fuel to produce electricity (Firmansyah, 2017). In Indonesia itself has abundant resource reserves, but if the use of resources is not controlled properly, it will quickly consume

these resources because some of these resources cannot be renewed, therefore we must make the most of one way to utilize them is to maintain the efficiency of the plant, the higher the efficiency of the plant, the lower the fuel needed but not reduce production the electricity (Girsang & Ruman, 2016).

At PT PLN Nusantara Power UP Gresik, it strives to increase electricity production, by adopting a combination of cycles.Brayton with the Rankine cycle, or called the combined cycle (Ilham et al., 2020). The purpose of using a combined cycle is to reuse exhaust gas heat energy from gas turbines that still have relatively high heat energy, because the exhaust temperature reaches 500 °C.

One way to find out the performance of the plant is through the value of cycle efficiency. If the cycle efficiency value is higher in a plant, the performance of the PLTG will be maximized (Gultom, 2020). And if the cycle efficiency value is getting smaller, it can be said that the performance of the PLTG is not good. Therefore, to maintain the performance of the PLTG, it is necessary to carry out an overhaul to maintain the performance of the PLTG to remain optimal (Maulana, 2019).

This study will use cycle efficiency to determine the reliability of PLTG. The comparison that will be done is to compare the efficiency of the cycle before and after the overhaul. The PLTG that will be observed is in GT unit 1 block 1 PT. PLN Nusantara Power UP Gresik (Moran et al., 2010). By analyzing the unit, you will be able to find out whether after   overhaul can increase the efficiency value of the cycle.

Research Methods

This research was conducted by qualitative methods. Then it is based on field case studies on the Gresik PLTGU system and reinforced by several theories and scientific journals.

Where the qualitative method uses calculations from existing data and parameters at the Rembang PLTU then uses formulas related to turbine efficiency. In data processing using EES applications.

Steam and Gas Power Plant

Steam Gas Power Plant is a thermal plant that combines the working principle of Gas Power Plant and Steam Power Plant so it is referred to as combine cycle power. The goal of the process is to increase thermal efficiency sufficiently high up to 50% (KRISDIANTO, 2022). This is because Gas Power Plants have a low thermal efficiency of 30% and steam power plants with a thermal efficiency of 35%. So that to meet the increasing electricity demand¸ a power plant with a combined cycle (combine cycle) is needed that has better thermal efficiency. Electrical energy generated by PLTGU Unit (Puspawan et al., 2023).

Gresik generation averages 500 MW per block. The number of power plants at PLTGU UP Gresik is 3 blocks, where each block has 3.
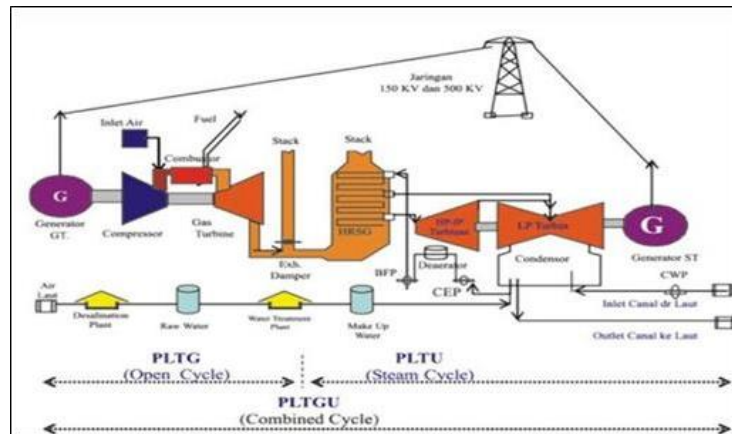
Figure 1 PLTGU Cycle
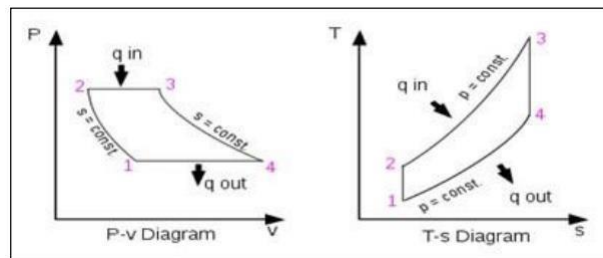
Brayton cycle

Figure 2 Brayton Cycle P-V and T-s diagrams

The processes that occur from the diagram above are as follows:

1. State 1 to 2 Isentropic Compression Process occurs when atmospheric air enters a gas turbine system through the inlet side of the compressor. In a compressor, the air is compressed to a certain pressure, thereby narrowing the volume of the chamber. This process does not cause a change in entropy, so it is called isentropic. This process is shown by the 2nd line of the curve above (Mulud, 2016).

2. State 2 to 3 Isobaric Combustion Process. Where compressed air enters the combustion chamber. At this stage, fuel is flowed into the combustion chamber, and followed by the fuel combustion process. The heat energy produced from the combustion process is absorbed by the air (q in), so that the air temperature increases and the volume of air temperature, and the volume of air increases. This process does not increase air pressure, because the air produced from the combustion process freely expands to the side of the turbine. Due to the fixed pressure of this process, it is referred to as isobaric (Setiawidayat & Rofii, 2020).

3. State 3 to 4 The process of Isentropic Expansion occurs when high-pressure air that has absorbed the heat of combustion, expands through the turbine. The turbine blades, which function as small nozzles, convert the thermal energy of the air into kinetic energy. Some of that energy is converted o to drive the compressor. In a turbine gas generation system, some of the other energy is converted to drive an electric generator (Hendri & Syammary, 2020).

4. State 4 to 1 occurs isentropic expansion, which is the discharge of air into the environment if this cycle is open and the air in this state has the potential for thermal energy that can be used to run HRSG. When this cycle is open heat energy (Qout) is absorbed by free air, to return to state 1 to 2 (Prastyo & Dhamayanthie, 2022).

Brayton *cycle efficiency calculation*

- Calculate fuel mass

$$\dot{m}_{bb} = \text{fuel gas flow x } \rho bb \tag{1}$$

-Calculate fuel pressure

$$\rho_{Bb} = SG \times \rho_{air} \tag{2}$$

-Calculate *Air Fuel Ratio*

$$w\text{turbine}_{Net} = (wT - w_C) \tag{3}$$

$$= (\text{mfuel}_{gas} + \dot{m}_{air})(h3 - h4) - \dot{m}_{air}(h2-h1)$$

$$= [1 + (\tfrac{A}{F})] \dot{m}_{bb}(h3-h4) - (\tfrac{A}{F}) \dot{m}_{bb}(h2-h1)$$

-Calculate air mass

$$\dot{m}_{air} = A/F \times \dot{m}_{Bb} \tag{4}$$

-Determine the working value of the compressor

$$\dot{w}_{Compressor} = \dot{m}_{air} \times (h2 - h1) \tag{5}$$

-Determine the working of the combustion chamber

$$Qin = Ff \times HHV \times \eta \text{ Combustion chamber} \tag{6}$$

-Determining the working of the turbine

$$\dot{w}_{turbine} = (\dot{m}_{air} + \dot{m}_{Bb}) \times (h3-h4) \tag{7}$$

-Calculation looking for compressor efficiency

$$\eta\text{compressor} = \frac{h2'-h1}{h2-h1} \times 100\% \tag{8}$$

- Calculation determines Combustion Chamber Efficiency

$$\eta\text{space burn} = \frac{h3-h2}{h3-h2'} \times 100\% \tag{9}$$

- Calculation determines Turbine Efficiency

$$\eta\text{turbine} = \frac{h3-h4}{h3-h4'} \times 100\% \tag{10}$$

-Brayton *cycle efficiency calculation*

$$\eta\text{cycle} = \frac{\dot{w}_{turbine} - w\text{compressor}}{\text{combustion chamber}} \tag{11}$$

-Calculates BWR

$$Bwr = \frac{\dot{w}_{compressor}}{\dot{w}_{turbine}} \tag{12}$$

-Calculate *Heat Rate*

$$Heat\ Rate = \frac{Wruang_{burn}}{Wturbin - W_{compressor}} \tag{13}$$

Results and Discussions

Based on the operating data of PLTGU UP Gresik before and after *overhaul,* the results of gas turbine efficiency calculations are presented in the following table:

Table 1 Result Parameter Data

No	Parameters	Unit	*Commissioning*		Before		After	
			Ideal	Current	Ideal	Current	Ideal	Current
1	A/F		41	31,8	38,2	28,4	38,9	29,3
2	$\dot{m}_{bb}$	kg/s	6,211	6,211	6,138	6,138	6,104	6,104
3	$\dot{m}_{air}$	kg/s	254,6	197,5	234,4	174,3	237,4	178,8
4	SFC	kg/kWh	0,19		0,22		0,21	
5	$\dot{w}_{compressor}$	kJ/s	97919,1	67169,7	91251,9	57222,69	89286	57448,4
6	$\dot{w}_{combustion\ chamber}$	kJ/s	371360,5	389641,7	330543	355422,5	335047,6	356433,7
7	$\dot{w}_{turbine}$	kJ/s	211465,5	180630,5	191227,7	157215,6	189519,1	157612,1
8	η Compressor %		88		84		85	
9	η Combustion Chamber	%	95		93		94	
10	η Turbine	%	92		91,2		91,3	
11	η Cycle	%	30,6	29	30,2	28	29	28,1
12	BWR		0,46	0,37	0,477	0,363	0,471	0,364
13	*Heat Rate*	Kcal/kWh	2811,9	2952,8	2854	3056,3	2842,8	3049,6

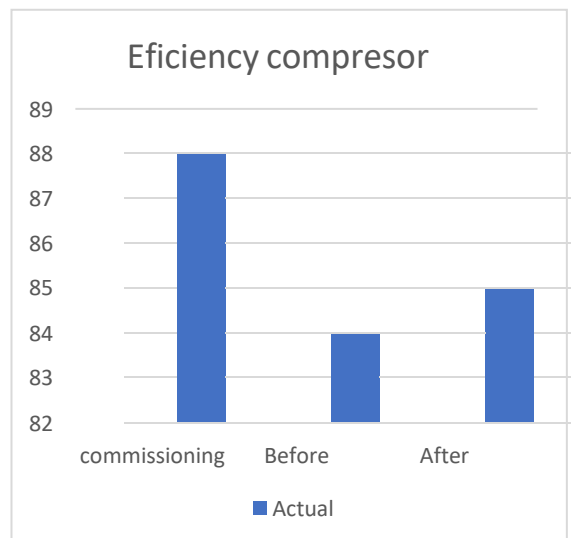**Compressor Efficiency Comparison Before, and After *Overhaul***

Figure 3 Compressor Efficiency Comparison Chart

In the analysis on the results of the commissioning compressor efficiency value of 88%, before overhaul 84% and after overhaul compressor efficiency 85% so that it can be concluded that compressor efficiency has increased by 1% but this increase cannot reach the maximum value such as commissioning value, the cause of the increase in efficiency can be known after overhaul the increase in compressor inlet temperature before overhaul 306.2 K and after overhaul to 304 K, compressor outlet temperature before overhaul 683.5 K decreased after overhaul to 669.2 K and for compressor outlet pressure before overhaul 1224 kPa and after overhaul decreased to 1195 kPa (Wijaya, 2015).

This is due to turbine inspection because the turbine is one shaft with the compressor, the performance of the compressor also increases following is the

inspection turbine carried out Inspection and repair of the turbine mainhole, Inspection and repair of turbine casings, Inspection and repair of flame tubes and combustor gaskets, Inspection and repair of exhaust, Inspection and cleaning of upper and lower ring blades 1,2,3,4 and Inspection and cleaning of vane and seal housing.

With the ideal enthalpy of the compressor before and after overhaul, the internal energy or actual enthalpy of the compressor increases so that the efficiency after overhaul increases from 84% to 85% for more details can be seen in the calculation **Comparison of Combustion Chamber Efficiency Before, and After *Overhaul***
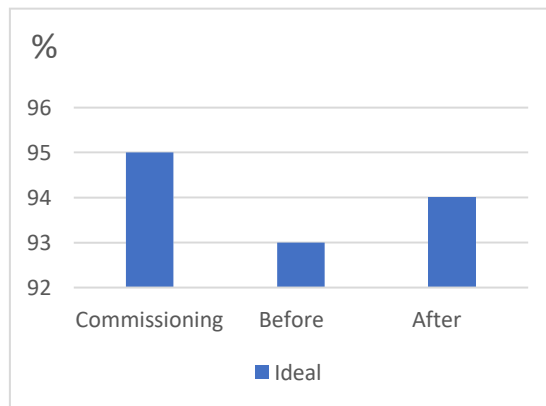

Figure 4 Combustion Chamber Efficiency Comparison Graph

Analyzed on the results of *the commssioning* value of 95% combustion chamber efficiency, before *overhaul* the efficiency was 93% and after *overhaul* 94% increased by 1%, this was due to the overhaul cleaning of the combustion chamber intake so that the fuel flow rate was greater

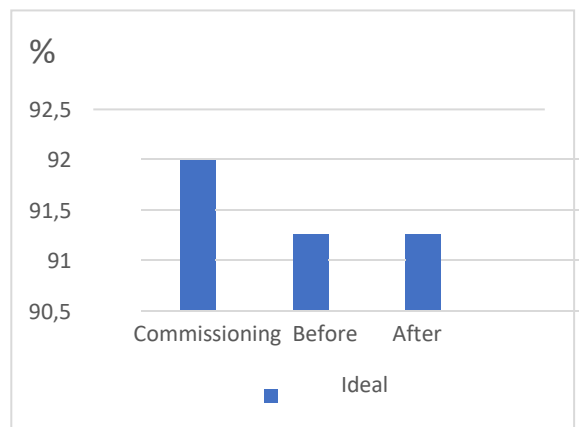**Comparison of Turbine Efficiency Before, and After *Overhaul***

Figure 5 Combustion Chamber Efficiency Comparison Graph

In the analysis of the commissioning value of 92% turbine efficiency, before overhaul the turbine efficiency value of 91.2% and after overhaul the turbine efficiency value of 91.3% which increased by 0.01% and the value was almost the same as the commissioning value, the cause of the increase in efficiency can be known after overhaul by looking at the change in turbine inlet temperature before overhaul 1478 K and after overhaul decreased by 1458 K, the temperature of the turbine oulet before overhaul 722.4 K decreased to 717.7 K after overhaul.

This is because the following inspection turbines are inspection turbines carried out Inspection and repair of turbine mainholes, Inspection and repair of turbine casings, Inspection and repair of flame tubes and combustor gaskets, Inspection and repair of

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exhaust, Inspection and cleaning of upper and lower ring blades 1,2,3,4 and Inspection and cleaning vane and Seal Housin

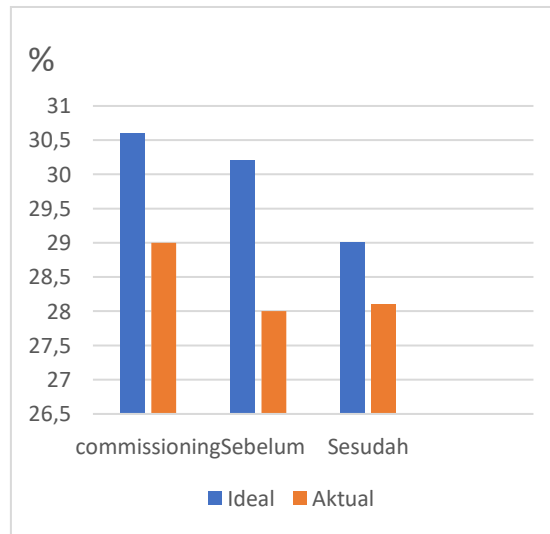**Cycle Comparison Brayton Before, and After Overhaul**

Figure 6 Cycle Efficiency Graph

The ideal commissioning cycle efficiency result is 30% and the actual 29% decrease is 1%

Cycle efficiency before overhaul ideal 30.2% and actual 28% decreased 2.2% and cycle efficiency after overhaul ideal 29% and actual 28.1% decreased 0.9%

After overhaul, the ideal cycle decreased by 1.2% and actually increased by 0.1%, this was due to the increase in compressor efficiency and the increase in combustion chamber work, so that it affected the cycle efficiency value.

Conclusion

From the results of calculations and analysis of braython cycle efficiency before and after the overhaul of PLTGU unit 1 block 1 PT. PLN Nusantara Power UP Gresik in chapter IV can be concluded as follows:

The ideal brayton cycle efficiency has increased from 27.6% to 29% and actually increased from 28% to 28.1%.

The ratio of compressor efficiency before and after overhaul increased from 84% to 85%. The ratio of combustion chamber efficiency before and after overhaul increased from 93% to 94%. Turbine efficiency ratio increased after overhaul 91.2% to 91.3%

The factor causing the value of the rising cycle efficiency is a decrease in the actual work of the compressor accompanied by an increase in the actual work of the combustion chamber and turbine work

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