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Analysis of the Effect of Inlet Compressor Temperature on the Thermal Efficiency of Gas Turbine Capacity 146 MW

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ABSTRACT

The PLTGU Grati block 3 comprises two gas turbines, namely unit 3.1 and unit 3.2, both boasting a Net Capacity of 145 MW each. However, within PLTG unit 3.2 Grati, a concerning issue surfaces regarding divergent thermal efficiency values attributed to fluctuations in the inlet compressor temperature. Notably, the thermal efficiency of PLTG unit 3.2 Grati peaks when the compressor's inlet temperature registers at a lower range. This prompts a meticulous exploration to discern the impact of the compressor's inlet temperature on the thermal efficiency of PLTG unit 3.2. Consequently, a comprehensive calculation regimen ensues, targeting parameters that directly influence thermal efficiency values for analytical insights. Within this study framework, meticulous computations were undertaken across three distinct compressor inlet temperature settings, specifically at 296.69 K, 299.49 K, and 304.11 K. These calculations yielded corresponding gas turbine thermal efficiency values of 32.17%, 31.84%, and 31.79%, sequentially. The findings starkly illustrate a discernible trend: as the compressor's inlet temperature escalates, the thermal efficiency value of the gas turbine proportionally diminishes. This observation underscores the imperative for further research endeavors and innovative interventions, such as integrating a cooling system into the gas turbine's inlet air filter mechanism, to sustain an optimal low compressor inlet temperature. Such initiatives are pivotal for ensuring the consistent and efficient operation of PLTG unit 3.2 Grati amidst variable operational conditions.

Keywords: *Temperature, PLTG, Efficiency*

ABSTRAK

PLTGU Grati blok 3 merupakan pembangkit listrik yang memiliki dua buah gas turbine, yakni unit 3.1 dan unit 3.2, yang masing-masing memiliki Daya Maksimum Netto (DMN) sebesar 145 MW. Namun, terdapat permasalahan yang muncul pada PLTG unit 3.2 Grati terkait perbedaan nilai efisiensi termal yang disebabkan oleh variasi temperatur masuk kompresor. Dalam konteks ini, efisiensi termal PLTG unit 3.2 Grati mencapai puncaknya ketika temperatur masuk kompresor berada pada kisaran yang rendah. Oleh karena itu, untuk menganalisis dampak temperatur masuk kompresor terhadap nilai efisiensi termal PLTG unit 3.2, dilakukan proses perhitungan terhadap parameter-parameter yang mempengaruhi nilai efisiensi termal sebagai bagian dari analisis mendalam. Dalam penelitian ini, hasil perhitungan pada tiga titik data temperatur masuk kompresor, yaitu pada 296,69 K, 299,49 K, dan 304,11 K, menghasilkan nilai efisiensi termal berturut-turut sebesar 32,17%, 31,84%, dan 31,79%. Dari hasil perhitungan tersebut, terlihat bahwa semakin tinggi temperatur masuk kompresor, maka nilai efisiensi termal PLTG unit 3.2 cenderung menurun secara signifikan. Hal ini menegaskan perlunya penelitian lebih lanjut serta inovasi dalam bentuk, misalnya, penambahan sistem pendingin pada filter udara masuk kompresor gas turbine, guna menjaga agar temperatur masuk kompresor tetap rendah dan optimal dalam menjaga efisiensi operasional PLTG unit 3.2 Grati.

Kata Kunci: *Temperatur, PLTG, Efisiensi*

1. INTRODUCTION

Electricity is a secondary energy that plays an important role in the life of modern society. The use of electricity is widespread in various aspects of daily life, including in households, communications, lighting and industry. One important source of electricity is the Gas and Steam Power Plant (PLTGU), which combines Gas Turbine (GT) and Steam Turbine (ST) technology to produce electricity (Indra Yogaswara, Supari, 2020). In Indonesia, PLTGU Grati is one of the gas and steam power plants owned by PT. Indonesia Power (IP). PLTGU Grati has a total Net Capable Power (DMN) of 1376 MW which is divided into 3 blocks, with the DMN of each block being different, namely block 1 of 456 MW, block 2 of 465 MW, and block 3 of 455 MW (Grati, 2021).

PLTGU Grati block 3, the focus of this research, is equipped with two GTs, namely unit 3.1 and unit 3.2, each of which has a DMN of 145 MW. The fuel combustion process in the PLTG Grati block 3 combustor uses natural gas, with the standard fuel composition attached in attachment 4. The hot gas produced from combustion is used to rotate the gas turbine, which is then coupled to the generator shaft to produce electricity (Grati, 2021) . The problem that is the focus of this research is changes in compressor inlet temperature values, which cause variations in the thermal efficiency values of PLTG unit 3.2 Grati. The thermal efficiency of PLTG unit 3.2 Grati was recorded as high when the compressor inlet temperature was in the low range, in accordance with the data documented in the Performance Management System (PMS), as depicted in Figure 1. Similar research was previously carried out in block 1 unit 2 of PLTGU Muara Karang by PT. Java Bali Generation (PJB). This study shows that the efficiency of PLTG (GT type: General Electric MS 9001 E) is influenced by the compressor inlet temperature (Putri et al., 2020). The results of the research are that the lowest thermal efficiency at the compressor inlet temperature of 35.23 °C (10.30) is 31.17% and the highest thermal efficiency is at the compressor inlet temperature of 30.91 °C (19.30) at 32.88%. However, there has been no research that specifically analyzes this problem in PLTG unit 3.2 Grati.

Based on this background, this research aims to conduct an analysis of "The Effect of Compressor Inlet Temperature on the Thermal Efficiency of PLTG Unit 3.2 Grati". Compressor inlet temperature analysis was carried out using data recorded on July 29 2020, at three different times, namely 06:45, 12:20, and 18:30. This data was chosen because at that time the GT 3.2 was in normal operating conditions with the same load in load limit operating mode.

2. RESEARCH METHODS

2.1. Direct Observation Method

Conducting field studies, collecting operational data of the Gas Turbine (GT) through log sheet records of operational parameters in Table 1 and the Central Control Room (CCR) Planned Maintenance System (PMS) of Block 3 at Grati Combined Cycle Power Plant (PLTGU Grati). In Figure 1, several data collection points for gas turbine operation are depicted, including various sensors for temperature, pressure, flow, and more

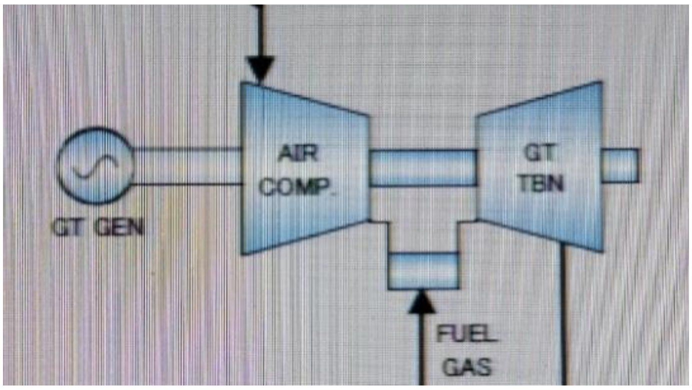

Figure 1. Data Collection Points for Gas Turbine Operation

Table 1. Log Sheet Record of GT Operational Parameters

No	Parameter	Simbol	Satuan	Temperatur Masuk Kompresor Gas Turbine	Temperatur Masuk Kompresor Gas Turbine	Temperatur Masuk Kompresor Gas Turbine
				296,69K	299,49K	304,11K
1	GT 3.2 Compressor Inlet Temperature	T1	degC	23,54	26,34	30,69
2	GT 3.2 Compressor Inlet Pressure	P1	Mbar	992,53	992,95	994,91
3	GT 3.2 Compressor Outlet Air Temperature	T2	degC	341,82	348,88	357,54
4	GT 3.2 Compressor Outlet Air Pressure	P2	Bar	11,11	11,19	11,14
5	GT 3.2 Exhaust Gas Duct Temp (ave)	T4	degC	555,58	556,86	566,89
6	GT 3.2 Exhaust Gas Duct Press	P4	Mbar	19,35	19,54	18,7
7	Black Active Power (Gross MW)	P	MW	146	146	146
8	Gas Volumetric Colorfic value of fuel		MJ/Nm^3	35,31	35,51	35,31
9	Fuel Gas Metering-flowrate energy		GJ/h	1701,45	1718,32	1719,37
10	Volume Bahan Bakar	Vbb	Nm^3/h	48186,07	48663,75	48693,66
11	Gas Lower Heating Value	LHV	kJ/kg	45269,23	45269,23	45269,23
12	Density Of Fuel Gas		kg/Nm^3	0,78	0,78	0,78

2.2. Indirect Observation Method

The literature review conducted is based on the gas turbine AE94.2 manual book and research journals on enhancing gas turbine efficiency.

2.3. Research Stage Design

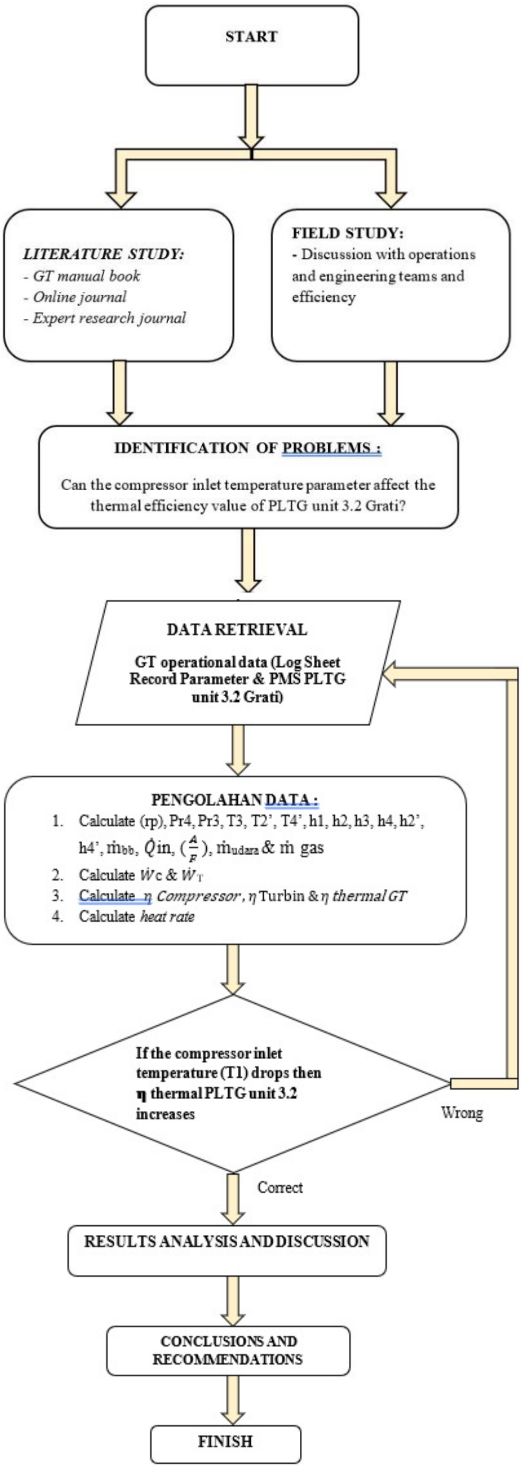

Figure 2. Research Methodology Flowchart

2.4 Calculation Method or Data Processing

To perform a comprehensive analysis of the gas turbine cycle, various calculations are conducted. Firstly, the compression ratio (rp) is determined using equation (5), followed by the calculation of the relative pressure of the gas exiting the turbine (Pr4) using equation (7), along with

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the relative pressure of the gas entering the turbine (Pr3) and the gas inlet temperature to the turbine (T3). Additionally, the ideal temperatures of air exiting the compressor (T2') and gas exiting the turbine (T4') are computed using equations (8) and (9) respectively. Enthalpy calculations are carried out utilizing interpolation method based on ideal-gas properties of air table, encompassing enthalpies at various stages including entering the compressor (h1), exiting the compressor (h2), entering the turbine (h3), exiting the turbine (h4), ideal enthalpy exiting the compressor (h2'), and ideal enthalpy exiting the turbine (h4'). Further calculations involve determining the mass flow rate of fuel ($\dot{m}$bb) using equation (17), heat input ($\dot{Q}in$) using equation (18), air-fuel ratio (A/F) using equation (12), mass flow rate of air ($\dot{m}$air) using equation (13), gas flow rate ($\dot{m}$Gas) using equation (14), compressor efficiency (ηCompressor) using equation (15), compressor power ($\dot{W}$c) using equation (16), turbine efficiency (ηTurbin) using equation (21), and turbine power ($\dot{W}$T) using equation (20). The thermal efficiency of PLTG unit 3.2 (calculated output power) is determined via equation (22) and also through the input-output method (measured output power) using equation (23/24). Finally, the heat rate is calculated using equation (25).

3. RESULT AND DISCUSSION

3.1. Comparison of Fuel Mass Flow Rate

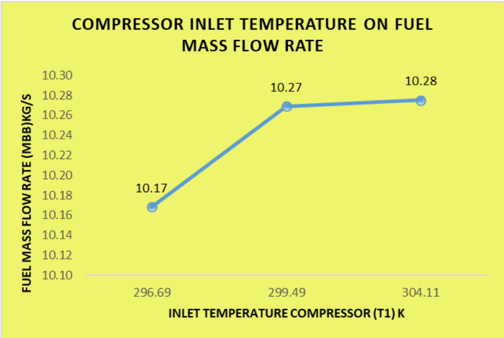

Figure 3. Comparison of Fuel Mass Flow Rate

The research results in Figure 3 show the highest fuel mass flow rate value at the compressor inlet temperature of 304.11 K, namely 10.28 kg/s, and the lowest at 296.69 K, namely 10.17 kg/s.

3.2. Compariosn Of Heat Input

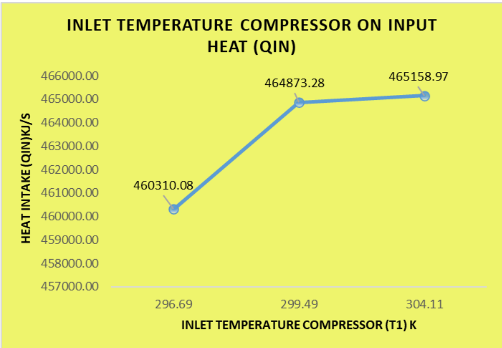

Figure 4. Comparison of Heat Input

The research results in Figure 4 show that the highest heat input value was obtained at the compressor inlet temperature of 304.11 K, amounting to 465,158.97 kJ/s, while the lowest was 296.69 K, amounting to 460,310.08 kJ/s.

3.3. Comparison of Combustion Chamber Efficiency

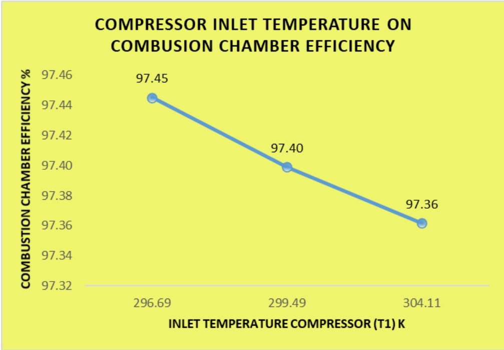

Figure 5. Comparison of Combustion Chamber Efficiency

The research results in Figure 5 show that the highest combustion chamber efficiency value was achieved at the compressor inlet temperature of 296.69 K, namely 97.45% and the lowest was 304.11 K, namely 97.36%.

3.4. Comparison of Air-Fuel Ratio

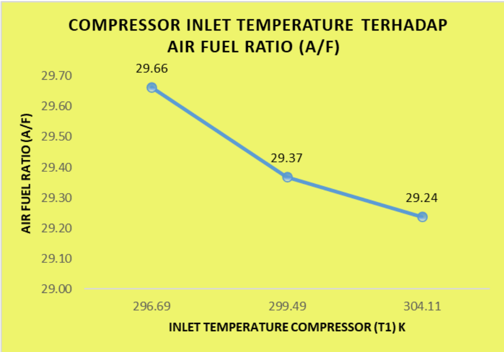

Figure 6. Comparison of Air-Fuel Rasio

The research results in Figure 6 show that the highest air-fuel ratio value was obtained at the compressor inlet temperature of 296.69 K, namely 29.66, while the lowest was 304.11 K, namely 29.24.

3.5. Comparison of Air Mass Flow Rate

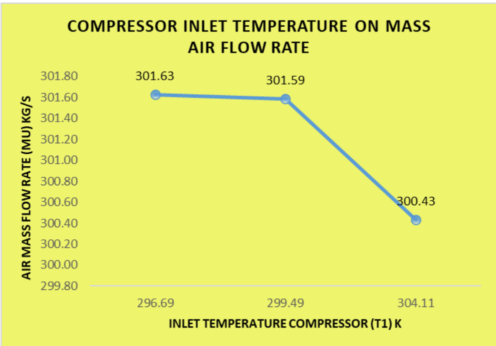

Figure 7. Comparison of Air Mass Flow Rate

The research results in Figure 7 show that the highest air mass flow rate value was obtained at the compressor inlet temperature of 296.69 K, 301.63 kg/s, while the lowest was 304.11 K, 300.43 kg/s.

3.6. Comparison of Compressor Efficiency

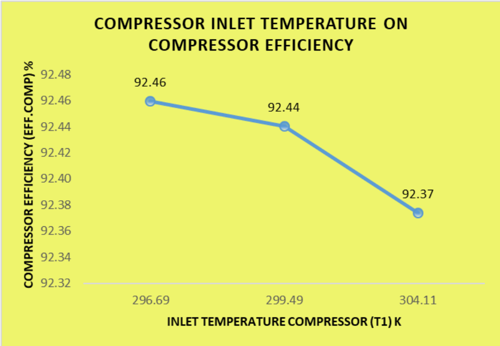

Figure 8. Comparison of Compressor Efficiency

The comparison of compressor efficiency in PLTG Unit 3.2 indicated that the higher the inlet compressor temperature, the lower the compressor efficiency. The compressor efficiency equation is affected by several factors, including the enthalpy entering the compressor, the enthalpy leaving the compressor, and the ideal enthalpy leaving the compressor. The research results show in Figure 8 that the highest compressor efficiency value occurs at the compressor inlet temperature of 296.69 K, namely 92.46% and the lowest at a temperature of 304.11 K, namely 92.37%.

3.7. Comparison of Turbine Efficiency

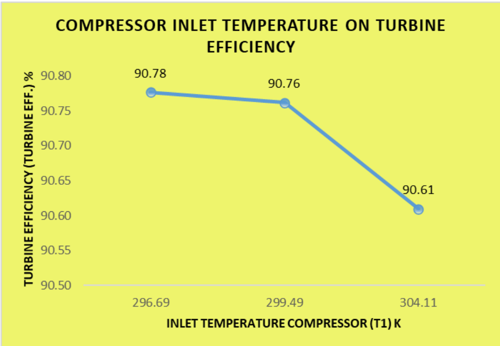

Figure 9. Comparison of Turbine Efficiency

The comparison of turbine efficiency in GTPP Unit 3.2 showed that the higher the inlet compressor temperature, the lower the turbine efficiency. The turbine efficiency is determined by the values of enthalpy entering the turbine, enthalpy leaving the turbine, and the ideal enthalpy leaving the turbine. The research results in Figure 9 show that the highest turbine efficiency value occurs at the compressor inlet temperature of 296.69 K, which is 90.78% and the lowest is 304.11 K, which is 90.61%.

3.8. Comparison of Thermal Efficiency of PLTG

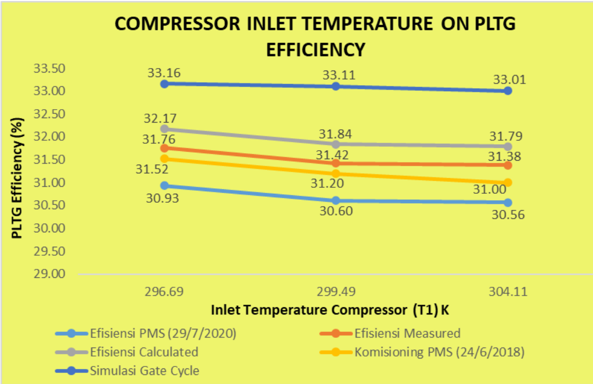

Figure 10. Comparison graph of thermal efficiency of PLTG

Table 2. Comparison of Thermal Efficiency for PLTG Unit 3.2

Name	23.54	26.34	30.96	^{o}c
Inlet Temperature Kompresor (T1)	296.69	299.49	304.11	K
Efisiensi PMS (29/7/2020)	30.93	30.60	30.56	%
Efisiensi Measured	31.76	31.42	31.38	%
Efisiensi Calculated	32.17	31.84	31.79	%
Komisioning PMS (24/6/2018)	31.52	31.20	31.00	%
Simulasi Gate Cycle	33.16	33.11	33.01	%

Figure 10 shows the results of all methods used to calculate thermal efficiency, it is evident that there is an effect of the inlet compressor temperature on the thermal efficiency of PLTG Unit 3.2. Specifically, as the inlet compressor temperature increases, the thermal efficiency of PLTG Unit 3.2 decreases. This effect is attributed to a decrease in compressor efficiency, contributing to the overall thermal efficiency reduction. The decrease in compressor efficiency is due to the increasing workload of the compressor when the inlet compressor temperature rises. The heavier workload on the compressor results from changes in the density of the incoming air. Lower air density reduces the mass flow rate of air. As the mass flow rate of air decreases, the mass flow rate of fuel increases, along with the heat input, due to the constant generator output setting. These factors lead to the low thermal efficiency of PLTG Unit 3.2. To address this issue, the addition of a cooling system to the GT compressor's inlet air filter is necessary. The purpose of this cooling system is to maintain a low inlet compressor temperature, around 296.69 K, which can result in improved thermal efficiency for PLTG Unit 3.2

3.9. Comparison of Heat Rate

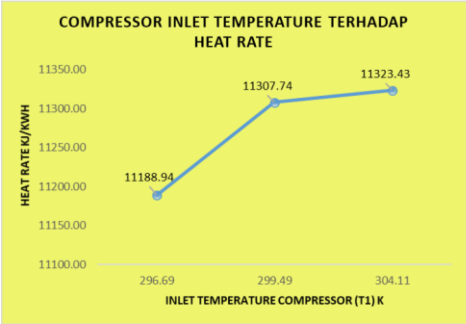

Figure 11. Comparison of Heat Rate

The research results in Figure 11 show that the highest heat rate value was obtained at the compressor inlet temperature of 304.11 K, amounting to 11,323.43 kJ/kWh, while the lowest was 296.69 K, amounting to 11,188.94 kJ/kWh.

3.10. Analysis of the Influence of Inlet Compressor Temperature on the Thermal Efficiency of PLTG Unit 3.2 Grati

Table 3. Inlet Compressor Temperature Data on Efficiency

Increase in temperature K	Increase in temperature C	Air mass flow rate (mu) kg/s	Compressor Efficiency (Eff. Comp)%	Thermal Efficiency of PLTG (Eff. PLTG)%
299.15	26	301.60	92.43	31.85
301.15	28	301.30	92.41	31.73

From the analysis data of the inlet compressor temperature's effect on the thermal efficiency of PLTG Unit 3.2 Grati, it was found that an increase of 2°C (275.15 K) in the inlet compressor temperature resulted in a decrease of 0.29 kg/s in the air mass flow rate and a decrease of 0.02% in compressor efficiency, leading to a decrease of 0.12% in the thermal efficiency of the PLTG.

4. CONCLUSION

Based on the analysis of the research above, the following conclusions can be drawn:

1) When the inlet compressor temperature increased by 2°C (275.15 K), it caused a decrease of 0.29 kg/s in the air mass flow rate and a decrease of 0.02% in compressor efficiency, resulting in a 0.12% decrease in the thermal efficiency of the PLTG.
2) The inlet compressor temperature affects the fuel mass flow rate,heat input,heat rate,air-fuel ratio, air mass flow rate,efficiency of the compressor, combustion chamber, and turbine.
3) The inlet compressor temperature affects the thermal efficiency value of Gas turbine capacity 146 MW. Specifically, as the inlet compressor temperature increases, the thermal efficiency of PLTG Unit 3.2 Grati decreases. This effect is evident when the inlet compressor temperature increases, specifically at 296.69 K, 299.49 K, and 304.11 K, resulting in a decrease in the thermal efficiency value of PLTG Unit 3.2 Grati to 32.17%, 31.84%, and 31.79%.

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REFERENCES

[1] Y. I. Putri, P. Studi, S. Teknik, F. Teknologi, dan D. A. N. Bisnis, "Analisis Pengaruh Temperatur Masuk Kompresor Terhadap Efisiensi PLTG Pada Blok 1 Unit 2 PLTGU Muara Karang Analysis Of Compressor Inlet Temperature Effect On The Efficiency In Gas Power Plant In Block 1 Unit 2 Of The Muara Karang Gas Power," 2020, [Daring]. Tersedia pada: http://156.67.221.169/id/eprint/3226.

[2] N. Gusnita dan K. S. Said, "Analisa Efisiensi dan Pemanfaatan Gas Buang Turbin Gas Alsthom Pada Pembangkit Listrik Tenaga Gas Kapasitas 20 MW," Sains, Teknol. dan Ind., vol. 14, no. 2, hal. 209–218, 2017.

[3] S. M. I Gusti Ketut Sukadana, "Teori Turbin Gas dan Jet Propulsi," hal. 52, 2015.

[4] A. P. Kusuma, "Analisis Efisiensi Termal Turbin Gas Pada Pagi, Siang Dan Malam Hari Dengan Beban Maksimal PLTGU Blok 2 UP Muara Karang," Anal. Efisiensi Termal Turbin Gas Pada Pagi, Siang Dan Malam Hari Dengan Beban Maksimal PLTGU Blok 2 Up Muara Karang, 2018, [Daring]. Tersedia pada: https://doi.org/10.1017/CBO9781107415324.004.

[5] M. W. Mubarrok, F. Teknologi, dan D. A. N. Bisnis, "Analisis Pengaruh Temperatur Masuk Kompresor Terhadap Efisiensi PLTG Pada Blok 2.3 PLTGU Grati," Anal. Pengaruh Temp. Masuk Kompresor Terhadap Efisiensi PLTG Pada Blok 2.3 PLTGU Grati, 2021.

[6] A. G. Haleonar Mycson Karusitio Silaban, "Analisa Performa Turbin Gas Tipe Cw251 B11 Pada System Pembangkitan Listrik Tenaga Gas Sektor Pembangkitan Bali," https://doi.org/10.20527/jtam_rotary.v2i2.2412, vol. 2, no. 2, hal. 161–170, 2020.

[7] D. K. Dewi, "Perhitungan Unjuk Kerja Turbin Gas Solar Saturn Pada Unit Pembangkit Daya Joint Operating Body Pertamina – Petrochina East Java (JOB P - PEJ)," 2015.

[8] "Pedoman tata niaga tenaga listrik edisi II," 2019.

[9] M. Çengel, Yunus A. Boles, Michael A. Kanoğlu, Thermodynamics_ an Engineering Approach. Ninth Edition.2019. 2019.

[10] dan H. Indra Yogaswara, Supari, "Analisis Efisiensi Operasional Sistem PLTGU Unit GTG 2.3 Di PT Indonesia Power Semarang Power Generation Unit," Anal. Efisiensi Oper. Sist. PLTGU Unit ... https//repository.usm.ac.id, hal. 1–10, 2020.