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Performance Analysis of Wartsilä Turbocharger W18V50SG at Gas Engine Power Plant Sumbagut-2 Peaker 250 MW

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ABSTRACT

A turbocharger is a device that uses the energy in the exhaust gas produced during combustion to increase the amount of air intake that goes into the cylinder. At gas engine power plant SUMBAGUT 2 PEAKER 250 MW, the use of a turbocharger is thought to be efficient because it can recycle combustion exhaust gases, whose pressure and temperature are still high, to rotate the turbine on the turbocharger. As a result, the compressor forcibly suctions air and delivers it to the combustion chamber cylinder because one requirement for good combustion results is that the air must be in a solid state. Thermal efficiency is another way to assess the efficacy of the gas generator engine's performance. With these conditions, a study was conducted with the goal of determining the working system on the turbocharger and calculating the efficiency of the Otto cycle with a compression ratio = 12 (maximum for the Otto cycle), at a peak load of 18,445 kW, engine speed of 500 rpm, ambient temperature (T 1) = 27° C, the mass flow rate of fuel (m _fuel) = 2814 kg/h 0.781 kg/s, then the thermal.

1. Introduction

Electrical energy is a vital source of energy for humans to carry out their everyday tasks more readily. Electricity is critical for home requirements, industry, schools, and so on. With continued economic and demographic expansion, the provision of power is a critical job for the present administration. The increase in electricity supply might come from either fossil-fuel power plants or renewable energy sources. According to Indonesia National Grid Electricity Company, namely PT PLN (persero) data till the third quarter of 2021, overall energy consumption in Indonesia reached 187.78 terawatt-hour (TWh), a 4.42% increase over the same time previous year. Load modification requests to gas engine power station are governed by the Load Management Center of PT PLN (Persero). The engine's performance is automatically adjusted in reaction to variations in load. The requirement that the power plant work well has led in the efficiency factor being highly significant and being the major topic of debate in every power plant. One of the critical elements in deciding the Gas engine power plant is a type of power plant that meets Indonesia's electricity demands. In 2019, the total

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installed power capacity of gas engine power plants in Indonesia was 2,842.03MW, accounting for 4.08% of total power plants. Gas engine power plant provides the advantages of a quick start-up time and adaptability to changing operational loads. The Consortium of PT Wijaya Karya Persero Tbk, TSK Electronica Y Electrucidad S.A, Spain, and PT. Sumberdaya Sewatama at the 250MW SUMBAGUT 2 PEAKER Gas Engine Power Plant in Meuria Paloh Village, Lhokseumawe. In this gas engine power plant, PT. Sumberdaya Sewatama handles all maintenance and operations in-house. In order to fulfill the demand for power in the northern portion of Sumatra, whereas this gas engine power plant is available (Sumbagut 2).

Gas Engine Power Plant is a generator that uses gas as the main fuel in the engine to trigger combustion in the engine cylinder and move the piston then rotate the engine shaft which is connected to the generator shaft so that it will generate voltage. Gas engine power plant consists of main parts, namely engine and generator, support system Balance of Plant (BoP), Auxiliary, distribution system, and control system. The BoP support system consists of a fuel system, cooling system, lube oil system, starting air system, as well as exhaust gas and charge air systems. The drive motor's fuel system is where a gas engine and a diesel engine vary most significantly from each other in terms of operation. The Otto cycle, which is a perfect cycle for a piston engine with spark ignition in a combustion engine, is the basis for how gas engines operate. With this ignition-ignition system, sparks from the spark plug are used to ignite the fuel and air combination. For each thermodynamic cycle, the crankshaft revolves twice while the piston passes through the engine cylinder in four stages (also known as a two-cycle engine) [1]. In the gas engine power plant, the exhaust gas which is still high in pressure and temperature is reused to rotate the side of the turbine coupled to the compressor, the turbine coupled to the compressor is the main component of the Turbocharger. A turbocharger is a centrifugal compressor that gets power from a turbine with its power source coming from engine exhaust gases. Usually used in internal combustion engines to maximize power output and engine efficiency by increasing the pressure of the air entering the engine combustion chamber during the combustion process. Turbocharger is a forced induction system by compressing the air flowing in the combustion chamber, the air is compressed with the aim that the air density becomes tenuous so that a lot of air can be entered into the combustion chamber.

This research is aimed to study the performance of Wartsilä Turbocharger W18V50SG at gas engine power plant by determining the working system on the turbocharger and calculating the efficiency of the Otto cycle with a certain compression ratio at a peak load session. The survey was conducted at Gas Engine Power Plant Sumbagut-2 Peaker 250 MW.

2. Methodology

2.1 Turbocharger Type ABB A175 - L37

A turbocharger is a device that increases the amount of air intake that enters the cylinder by harnessing the energy of exhaust gases produced by combustion. In order to enhance the pressure of the air entering the intake manifold, the turbocharger on the engine converts the pressure of the exhaust gases produced by combustion into mechanical energy to rotate the turbine connected to the compressor. An internal combustion engine's turbocharger is a part that is utilized to enhance the combustion process that takes place in the combustion chamber [1].

A turbine and compressor are the two major parts of a turbocharger. The turbine receives the exhaust gas that has been expelled from the cylinder through the exhaust manifold, which causes the turbine to revolve rapidly and power a compressor that is attached to the same shaft. The compressor draws air into the engine from the outside environment, compresses it, and increases the mass of air that enters the engine. This raises the effective pressure during combustion, which enhances engine power output and improves fuel efficiency. This procedure also raises the air temperature, thus hot, compressed air travels through the charge air cooler first to lower the temperature before entering the combustion chamber intake manifold.

A turbine is a rotary engine that converts fluid flow energy into useable motion energy. The most basic turbine engine is made up of a spinning component called the rotor, which is made up of a shaft with blades wrapped around it. The rotor rotates as a consequence of a fluid flow collision or as a reaction to a fluid flow. The turbine in gas engine power plant is utilized to help transform the energy from the engine exhaust gases into kinetic energy, spinning the shaft, which then drives the compressor. Because turbines create a lot of heat when they are running, they are generally manufactured of heat-resistant, durable metals [2].

Before the air reaches the combustion chamber, the compressor has a function to raise its pressure and temperature. The utilization of air in combustion, fuel atomization, turbine blade cooling, and turbine bearing lubrication seals are all examples. Depending on the flow direction, compressors and turbines can be distinguished from one another. The compressor on the turbocharger transforms the kinetic energy of air flow from the mechanical energy of the turbocharger shaft spinning. Because the compressor is positioned on the same axis as the turbine, it will revolve at the same speed as the turbine when the engine exhaust gases begin to turn the turbine.

The components of the ABB A175-L37 turbocharger shown in Figure 1. The exhaust gas from the internal combustion engine passes through the gas inlet casing [9] and is directed to the turbine wheel via the nozzle ring (10) (11). The turbine wheel directs the energy in the exhaust gases to a rotor connected to a compressor wheel (2). The exhaust gas is subsequently released into the atmosphere via the exhaust pipe, which is attached to the gas outlet casing (8). The compressor wheel (11) draws in fresh air and compresses it before pushing it into the cylinder. The air then passes through the diffuser (13) before exiting the turbocharger via the compressor casing (Air output casing) (14). Two radial bearings (Radial plain bearings) (3/6) positioned in the bearing case (12) between the compressor and the turbine move the rotor. The axial thrust bearing (4) is placed at the compressor's end. Plain bearings are linked to a central lubricating oil line that is generally fed by the engine lubricating oil circuit. The oil exit is always situated at the bearing casing's deepest point (12). The turbocharger has an oil tank built into the bearing casing (12). The oil tank continues to deliver oil to the rotor bearings until the engine stops/turns off; a lubricating oil system malfunction might cause the engine to shut down.

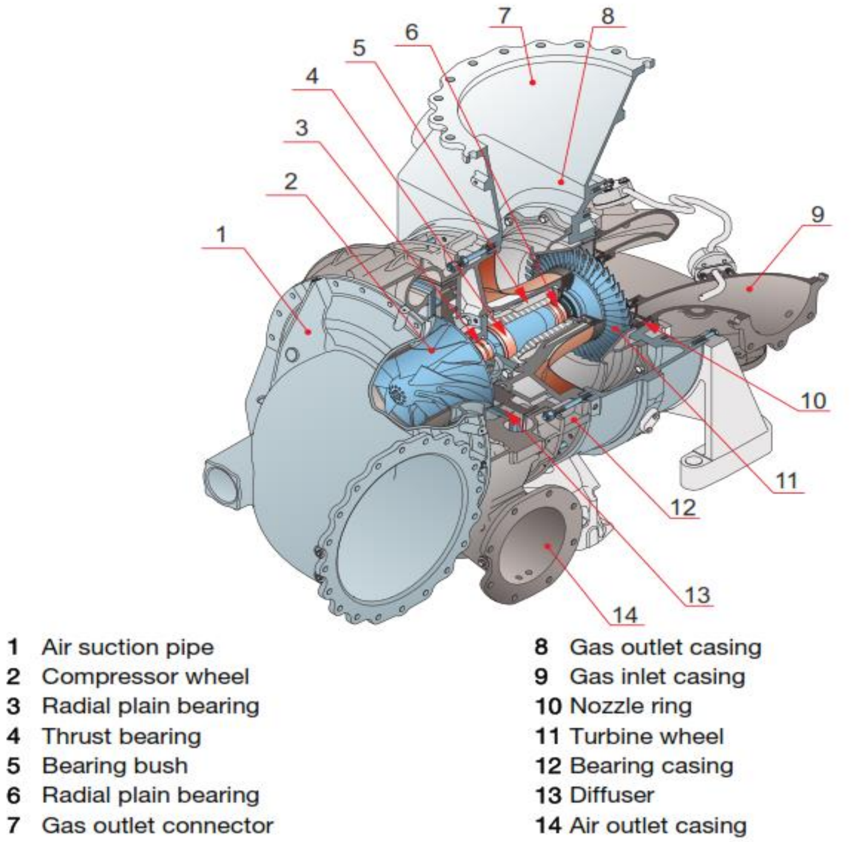

Fig. 1. Turbocharger type ABB A175 - L37

2.2 Wärtsilä Gas Engine

The Wärtsilä W18V50SG gas engine, made by PT. Wärtsilä Finland, is a gas-fired power generator. The code 18V50SG designates the kind of the engine of gas engine power plant, meaning it has 18 cylinders, a V-shaped cylinder configuration, a 50 cm cylinder diameter, and runs on natural gas fuel. This machine has a charge air cooler and a turbocharger. The suction step, compression step, effort step, and exhaust step are the four fundamental phases in the combustion process that take place in the combustion chamber every time or every time a single business operation takes place [3,6].

2.3 Otto Cycle Efficiency

Knowing the compression ratio is crucial before estimating thermal efficiency using the Otto cycle. The volume of the cylinder between the piston's bottom dead point (BDC) and top dead point is measured as the compression ratio (TDC). According to Wikipedia, the Otto cycle's maximum compression ratio is 12:1, whereas the diesel cycle's maximum compression ratio is 22:1. Figure 2 illustrates the ideal Otto cycle, which consists of two adiabatic and two constant volume processes [2,7].

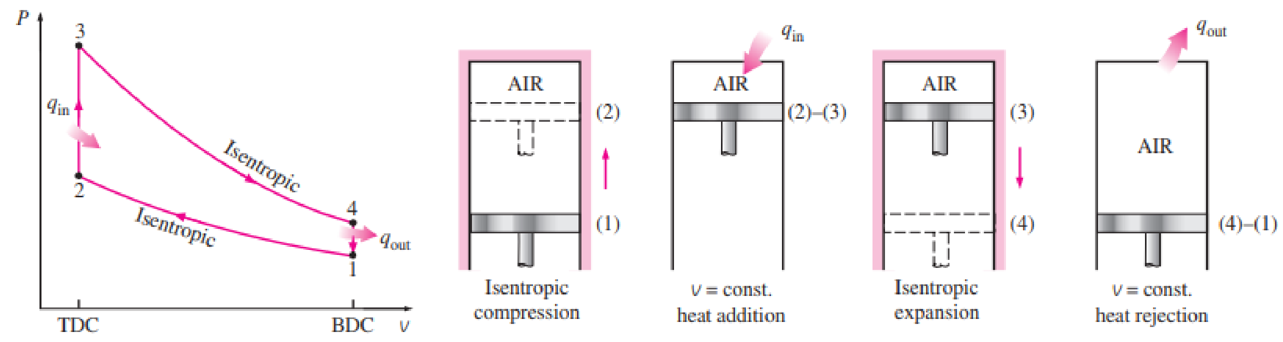

Fig. 2. Ideal layout of Otto Cycle

In state 1–2, an adiabatic process is in motion; in this phase, no heat is introduced into or removed from the system. The piston compresses isentropic as it moves from TDC to BDC. The specific volume of state 2 is calculated using the following equation.

$$\frac{V_{r2}}{V_{r1}} = \frac{V_2}{V_1} = \frac{1}{r} \tag{1}$$

T_(x) = upper temperature (K)
T_y = bottom temperature (K)
V_rx = Upper Specific Volume
V_ry = Bottom Specific Volume

In state 2–3, the external constant volume heat transfer to the air while the piston is at TDC. This procedure is meant to simulate the ignition of an air-fuel mixture and its subsequent rapid combustion. Before calculating the rate of energy entering the system (q in), first calculate the temperature of the combustion chamber or the temperature at state 3 (T3) using the following equation.

$$T_3 = T_2 + \left(\frac{\dot{m}_{fuel} \times LHV_{fuel}}{\dot{m}_{air} \times C_v}\right) \tag{2}$$

T_3 =Temperature at T3 (K)
T_2 =Temperature at T2 (K)
m˙_air =mass of airflow (kg\/s)
C_v =calor at constant volume (kJ\/kg.K)
m˙_fuel =mass airflow of fuel (kJ\/kg)
LHV_fuel =calor of fuelr(kJ\/kg)

To calculate the rate of energy / heat entering the system (qin) using the following equation.

$$\dot{q}_{in} = \dot{m}_{air} \times C_v \times (T_3 - T_2) \tag{3}$$

In state 3– 4, the isentropic expansion occurs adiabatically; no heat enters or exits during the process. The following equation can be used to calculate the value of the exhaust gas temperature or the temperature at state 4 (T4).

$$T_4 = \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = \left(\frac{r}{1}\right)^{\gamma-1} \tag{4}$$

r = Compression ratio
γ = Laplace constant number (1,307)
T_3 = Temperature at T3 (K)
T_4 = Temperature at T4 (K)

In state 4–1, finish the cycle with a constant volume process that removes heat from the air when the piston reaches BDC. This method states the rate of energy/heat output, and the following equation is used to calculate the value of the rate of energy/heat output.

$$\dot{q}_{out} = \dot{m}_{air} \times C_v \times (T_4 - T_1) \tag{5}$$

After determining the rate of energy/heat output (q _out), use the following equation to calculate the netto work value (Wnet).

$$\dot{W}_{net} = \dot{q}_{in} - \dot{q}_{out} \tag{6}$$

Then calculate the thermal efficiency (ηth) using the following equation.

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{q}_{in}} \tag{7}$$

Thermal efficiency is a dimensionless metric used to assess the performance of thermal equipment such as internal combustion engines. The energy collected from the energy source is represented by the incoming heat. The targeted output could be either heat or work, or both. Thermal efficiency should be between 0% and 100% when expressed as a percentage. The thermal efficiency of the engine will never be 100% due to inefficiencies such as friction, heat loss, and other variables [8]. Thermal efficiency of gas-fired power plants with capacities ranging from 15 to 100 MW is deemed to be good if it is between 30% and 46% [4,9].

Table 1
Gas Engine Specs [10]

Specification	Description
Machine Type	W18V50SG
Cylinder Configuration	18V
Cylinder Drill Hole	500 mm
Piston Step	580 mm
Average Piston Speed	9,7m/s (50Hz)/10m/s (60Hz)
Rotation Speed	500 rpm (50 Hz) / 518 rpm (60 Hz)
Installed Output	18.445 kW (50Hz) / 18.875 kW (60Hz)
Voltage	400 V (50 Hz)
Secondary Voltage	24 VDC
Oil Type	Wet (SHELL MySella S3N40)
Rotation Direction	clockwise
Dimension	
Long	18,7 m
Width	5,5 m
Height	6,2 m
Dry Weight	377 ton

Table 2
Turbocharger Specs [11]

Specification	Description
Type designation	A175-L37 XAC18357
Manufacturer	ABB Turbo System Ltd.
Weight	5600 kg
Speed	15000 rpm
Year of construction	2017

Table 3
Generator Specs [12]

Specification	Description
Type designation	AMG 1600SS12 DSE
Manufacturer	ABB
Output Power	21665 kVA
Voltage	11000 V
Current	1137 A
Speed	500 rpm
Overspeed	600 rpm
Power Factor	0.85
Connection	Start
Phases	3~

3. Results

3.1 Turbocharger Working System on Gas Engine Wärtsilä 18V50SG [13]

According to data that illustrates in Figure 3, with a load of 13,966 kW, ambient pressure 1005.5 Pa, ambient temperature 32.1°C, absolute humidity 19.8 g/kg, and a gas engine speed of 500 rpm, it can be determined that when the exhaust gas from combustion is carried by the exhaust manifold and directed to the turbine side of the turbocharger at a pressure and temperature that is still high, compressor spinning at 14,599 rpm on bank B and 14,641 rpm on bank A.

The compressor works by sucking air from the surrounding environment at 33°C. Before entering the air intake manifold, the air passes through the charge air filter (CAF) to be filtered in two stages, the first with a dry filter and the second with a wet filter, to ensure that the incoming air is truly clean. Before being introduced into the cylinder, the compressed air must first travel through the charge air cooler to be cooled to the proper temperature and pressure. Because of the mixing of air and fuel, the temperature within the cylinder rises to 49°C, and the pressure inside rises to 2.42 bar.

Depending on the load, the temperature and pressure in the cylinder or combustion chamber will change. The presence of three ingredients, or a fire triangle, consisting of fuel (LNG), heat, and solid air from the turbocharger, creates the conditions for combustion in the combustion chamber. During the intake stroke, air and fuel enter the combustion chamber together. Then, during the compression stroke, heat, air, and fuel are mixed in the ready-to-compress combustion chamber, and the spark plugs ignite, resulting in a power stroke due to the thrust of the heat from the combustion. The intake and exhaust valves are closed in this step. The piston transmits thrust to the connecting rod, which rotates the crank shaft. Furthermore, during the exhaust stroke, the intake valve is closed, while the exhaust valve is open. The residual combustion gases will be forced out to the exhaust manifold by the piston's action. The exhaust gas is sent back from the exhaust manifold to the side of the turbine, which is attached to the compressor on the turbocharger, and the compressor compresses the air back into the cylinder; this system is known as a circle loop.

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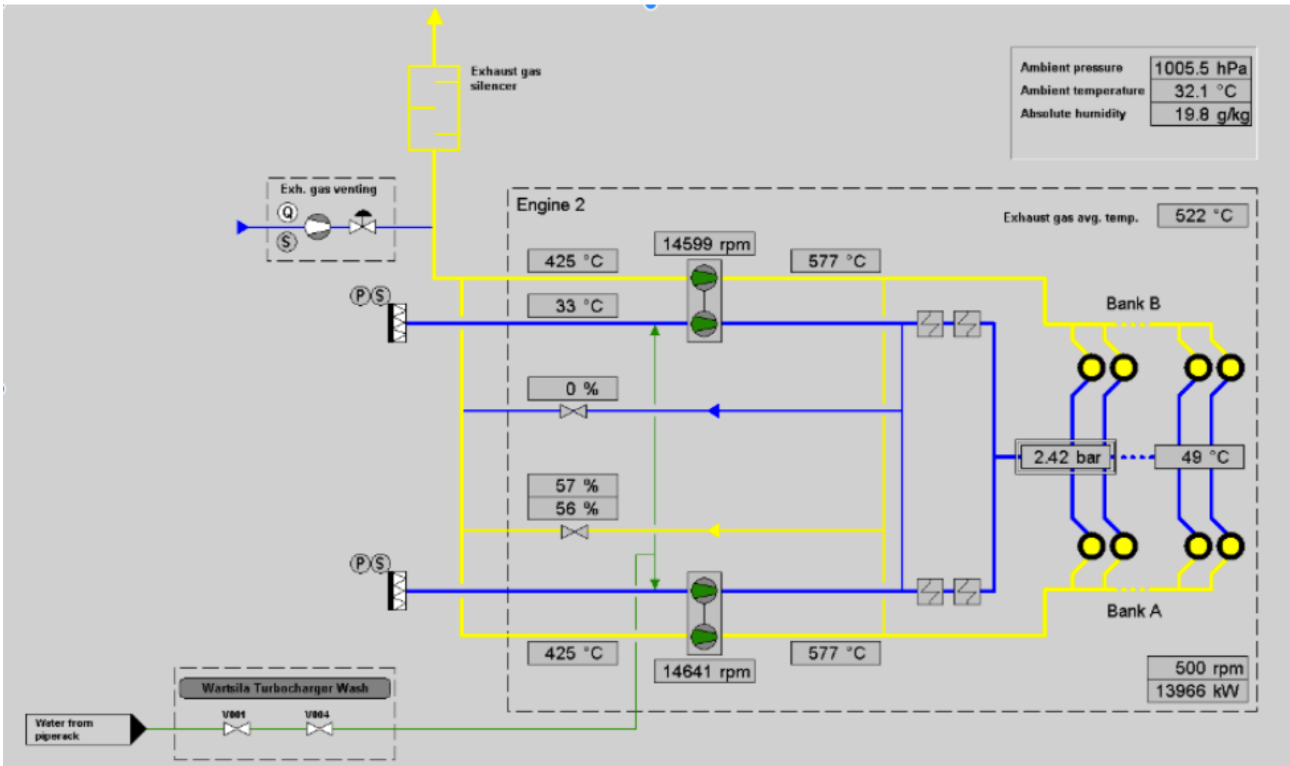

Fig. 3. Data of Wärtsilä Operator Interface System (WOIS) [14]

The Historical Trend shown in Figure 4 illustrates the efficiency of the turbocharger. The black graph shows output power at 14989.00 kW, the green and dark blue graphs show turbocharger A and turbocharger B's rotational speeds at 14771.00 rpm and 14749.00 rpm, respectively, the red graph shows the air temperature at the turbocharger's inlet at 34.20 °. The turbocharger's rotation follows the load requirement, thus if the load grows, so will the rpm of the turbocharger, even if the change in the graph on the rpm side is not very evident. The use of exhaust gas in the turbocharger increases engine performance due to the forced induction system of air compressed by the compressor to the cylinder, which increases the combustion that happens in the combustion chamber.

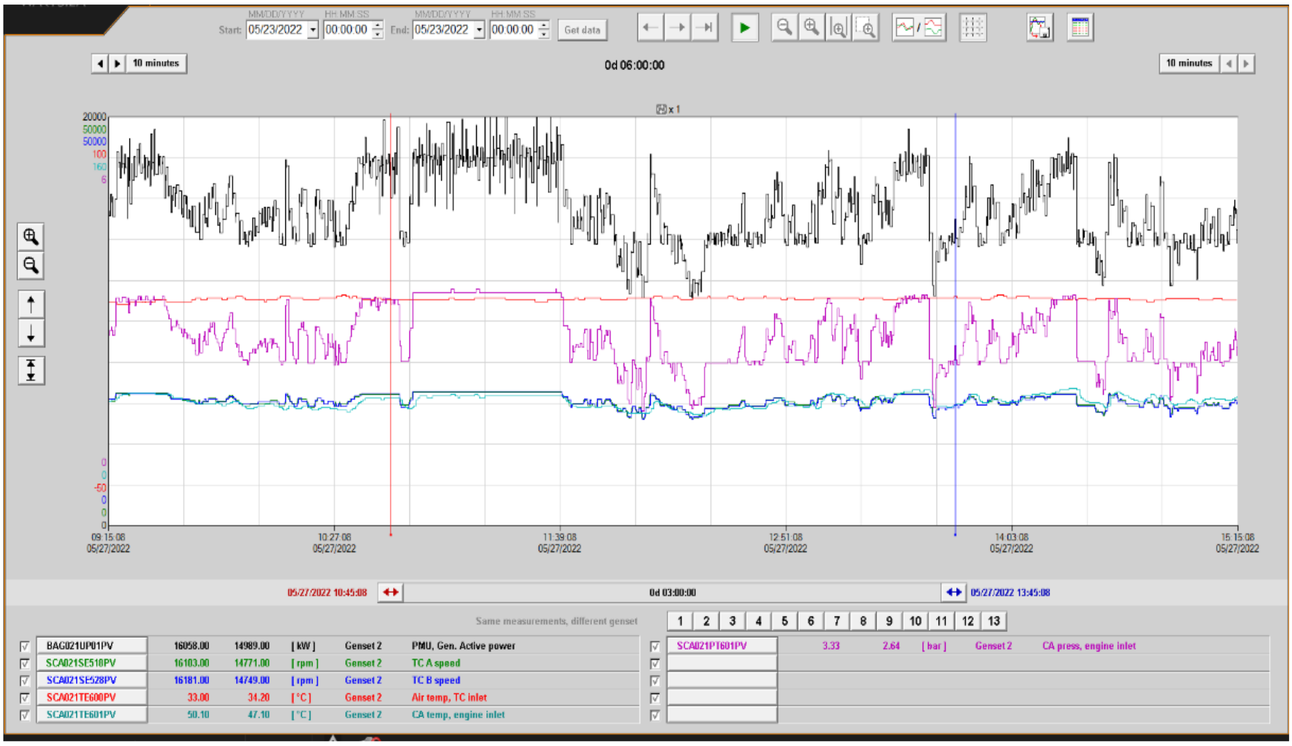

Fig. 4. Historical Trend of WOIS

3.2 Efficiency of Otto Cycle

The energy cycle was calculated using Otto cycle theory (Eq. (1) to Eq. (7)) and the operational data of the gas engine power plant on engine unit 2 with an initial state temperature/engine ambient temperature of 27°C. Table 4 lists of the gas engine log sheet.

Table 4
Gas Engine Log sheet [15]

Data	Value
Power Output	18.445 kW (peak load)
Ambient Temperature (T_1)	$27°C = 300\ K$
Exhaust Gas Temperature (T_4)	$522°C = 795{,}15\ K$
Calor of Fuel (LHV)	50.000 Kj/kg
Mass of fuel airflow ($\dot{m}_{fuel}$)	2814 kg/h ≈ 0,781 kg/s
Mass of airflow	70 kg/s
Laplace constant number (γ)	1,307
Compression Ratio (r)	12

Form the log sheet then we can calculate the Otto cycle (state 1–2, an adiabatic process, state 2–3, the external constant volume heat transfer, state 3– 4, the isentropic expansion, and state 4–1, constant volume process). The thermal efficiency of the Otto cycle is calculated at a peak load of 18.445 kW, engine speed of 500 rpm, compression ratio 12, fuel mass flow rate (m _fuel) = 2814 kg/h 0.781 kg/s, ambient temperature (T 1) = 27°C, and exhaust gas temperature (T 4) = 522°C. Then the thermal efficiency can be determined as follow.

$$\eta_{th} = \frac{\dot{W}_{net}}{\dot{q}_{in}}$$

$$\eta_{th} = \frac{17648{,}7kW}{39049{,}50\ kW} \times 100\%$$

$$\eta_{th} = 0{,}4520 = 45{,}20\%$$

4. Conclusions

The use of a Turbocharger on the gas engine power plant at SUMBAGUT 2 is considered efficient because it can reuse combustion exhaust gases whose pressure and temperature are still high enough to turn the turbine on the Turbocharger, causing the compressor to suck air forcibly and bring it to the combustion chamber cylinder, which is necessary for good combustion results. One of the requirements is that the air be solid. Exhaust gas emissions that can contaminate the air will be minimized as well since the exhaust gas released into the atmosphere is not as hot because it has previously been utilized by the turbocharger.

The thermal efficiency of the Otto cycle is calculated at a peak load of 18.445 kW, engine speed of 500 rpm, compression ratio 12, fuel mass flow rate (m _fuel) = 2814 kg/h 0.781 kg/s, ambient temperature (T 1) = 27°C, and exhaust gas temperature (T 4) = 522°C, resulting the thermal efficiency of 45.20%. Thermal efficiency of gas engine power plants with capacities between 15 -100 MW is considered to be good if it is between 30% and 46%.

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References
[1] Fakma, Muhammad Azhari, Yassir Yassir, and Zamzami Zamzami. "STUDI PENGARUH PERUBAHAN BEBAN TERHADAP PERFORMA MESIN GAS 18 MW PADA PLTMG SUMBAGUT-2 PEAKER." *Jurnal TEKTRO* 6, no. 1 (2022).
[2] MUHAMMAD, FADEL. "ANALISIS TEKNIS DAN EKONOMIS EFEK RASIO KOMPRESI PADA PEMBANGKIT LISTRIK TENAGA MESIN GAS (PLTMG) MENGGUNAKAN SIKLUS ENERGI OTTO (Studi Kasus: PT. PLN (Persero) ULPLTG/MG Balai Pungut)." PhD diss., UNIVERSITAS ISLAM NEGERI SULTAN SYARIF KASIM RIAU, 2021.
[3] Wärtsilä. "Engine Operation and Maintenance Manual DSCA00042559." (2019).
[4] Heywood, John B. "Combustion engine fundamentals." *1ª Edição. Estados Unidos* 25 (1988): 1117-1128.
[5] Moran, Michael J. "Fundamentals of engineering thermodynamics." (2014).
[6] I. Martinez. "Thermal Machine and Heat Engines." (1995).
[7] Demir, Murat Emre, and Ibrahim Dincer. "Development and heat transfer analysis of a new heat recovery system with thermoelectric generator." *International Journal of Heat and Mass Transfer* 108 (2017): 2002-2010. https://doi.org/10.1016/j.ijheatmasstransfer.2016.12.102
[8] Sayyaadi, Hoseyn. *Modeling, assessment, and optimization of energy systems*. Academic Press, 2020.
[9] Jenkins, Scott. "Fundamentals of Renewable Energy Processes." *Chemical Engineering* 120, no. 5 (2013): 9-10.
[10] Wärtsilä. "Manual book of Turbocharger type ABB A175 - L37. (Gas Engine)."
[11] Wärtsilä. "Manual book of Turbocharger type ABB A175 - L37. (Turbocharger)."
[12] Wärtsilä "Manual book of Turbocharger type ABB A175 - L37. (Generator)."
[13] Wärtsilä "Manual book of Turbocharger Working System on Gas Engine Wärtsilä 18V50SG."
[14] Wärtsilä "Data of Wärtsilä Operator Interface System (WOIS)."
[15] Wärtsilä "Gas Engine Logsheet."