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# Optimization Of Gas Turbine Performance 2.1 Using The Overhaul Combustion Inspection Method

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**Abstract**
Gas turbines are one type of internal combustion drive, the initial mover utilizes gas combustion as a fluid to rotate the turbine with internal combustion. Gas turbines at private companies producing electricity use the initial movers, namely gas turbines and steam turbines. Therefore, it is also called the "Steam Gas Power Plant/PLTGU". Private company especially in Block 2, uses two gas turbine units with Mitsubishi GT 2.1 specifications which are used as the initial drive of the generator. Types of overhauls in gas turbines are divided into three, including turbine inspection, combustor inspection, and major inspection. In maintaining the reliability of the GT 2.1 gas turbine, an overhaul combustion inspection was carried out in the combustion chamber because there was an increase in heat rate of 17.9% which caused a decrease in thermal efficiency and net turbine power of the GT 2.1 gas turbine by 17% and 2.1%. So steps are taken to optimize the GT 2.1 gas turbine with the combustion inspection method by repairing and cleaning the combustion bucket nozzle. Increased thermal efficiency by 27.8% or 27.13% to 36.01% from data before overhaul. This was also followed by an increase in compressor power and turbine power so that the net turbine power increased by 38% or 141,339. 35 hp to 195,246.54 hp.

**Keywords:**
Gas turbine, combustion inspection, thermal efficiency, turbine power.

## 1 Introduction

Electrical energy is one of the things that influence technological progress in the era of globalization like today. To improve the efficiency of power generation equipment that is very useful so that future energy availability can be achieved [1].The private company is a power plant that uses a gas turbine engine as a generator drive. Gas turbines are designed using a simple working principle where heat energy generated from the fuel combustion process is converted into mechanical energy and then converted into electrical energy[2].

The private company has 2 Gas Turbine (GT) units, each of which has an installed power of 250 MW, two Heat Recovery Steam Generator (HRSG) units, and 3 Steam Turbine (ST) units with a power of 70 MW. The total installed power at private companies is 710 MW which is used to supply the electricity needs of vital areas such as the State Palace, Soekarno-Hatta Airport, and the parliament building[3].

The gas turbine at a private company functions as a drive for electric generators that work in high temperatures during operation[4].The low efficiency of gas turbine plants is due to many factors which include operating model, poor maintenance procedures, age of the plant, discrepancies in operating data, high ambient temperature, and relative humidity [5]. Under these conditions, over time the performance of the gas turbine will continue to decline because the components and tools of the gas turbine have an Equivalent Operating Hours (EOH) operating hour limit[6].

An alternative to the Mitsubishi approach, which issometimes employed by other manufacturers,converts each start cycle to an equivalent number of operating hours (EOH) with inspection intervals[7]. Based on the equivalent hours count.Suppose the operating hours of the gas turbine are close to the EOH specified by the manufacturer[8].In that case, the gas turbine component will experience a decrease in performance, resulting in a decrease in net turbine power ($W_{nett}$) for GT 2.1 gas turbines by 31.1% and thermal efficiency for GT 2.1 gas turbines by 27.8%. To maintain the reliability of the gas turbine, performance tests are carried out and maintenance must be carried out periodically or preventive, predictive, and corrective to know the actual condition of the gas turbine [9].

Based on the observations above, research was conducted on the performance of the GT 2.1 gas turbine owned by a private company[3].This study aims to optimize the performance of current gas turbines and calculate net turbine performance ($W_{nett}$) and thermal efficiency ($\eta$thermal) based on thermodynamic principles, as well as compare data before and after combustion inspection [10].

## 2 Method

This research was conducted using qualitative methods where in field studies on theprivate company PLTGU system the data used in this study was obtained from several related parties, namely Central Control Room (CCR), Randal Maintenance Control Room (MCR), and engineering. This research is divided into two, namely, the calculation of gas turbine performance evaluation and gas turbine performance optimization. Table 1 is the specification data of the GT 2.1 gas turbine [3].

Table 1. Gas turbine GT 2.1 specification data

| | |
|---|---|
| **Turbine** | |
| Manufacture | Mitsubishi Heavy Industries |
| Gas turbine models | M701F |
| Type | GT 2.1 |
| Application | Generator drives |
| Speed | 3000RPM |
| Electrical power | 3 Phase, 270 Volts, 50 Hz |
| Stages | 4 |
| **Compressor** | |
| Type | Axial compressor |
| Stages | 17 |
| Max. TIP speed | m/s |
| Pressure ratio | 10:1 |
| **Combustors** | |
| Type | Annular |
| Fuel | Gas |
| Nozzles | 20 |
| **Generator** | |
| Machine type | Hydrogen indirect cooled |
| Output | 322,115 kVA |
| Voltage | 500V |
| Frequency | 50Hz |
| Speed | 3000RPM |

### 2.1 Brayton Cycle (Gas Turbine)

The data in Table 1 can be used to calculate the performance of gas turbines. A gas turbine is an engine whose working principle uses the Brayton cycle. The Brayton cycles on the PV andTs diagrams are shown in Fig. 1[11].

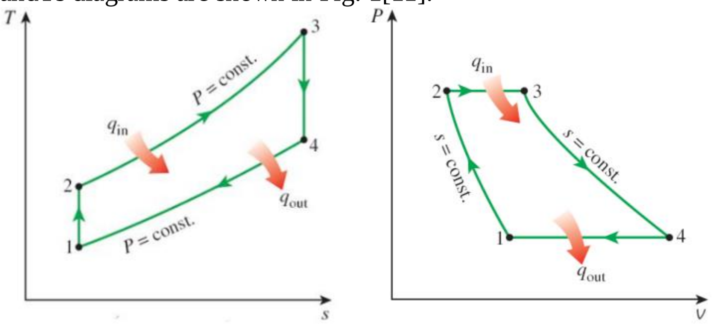


Fig. 1. PV diagram and Ts (ideal cycle) diagram.

The process that occurs in the Fig. 1 is as follows[12]:

1. Process 1-2: Isentropic compression process in compressor
2. Process 2-3: The combustion process at constant pressure (isobar) in the combustion chamber.
3. Process 3-4: The isentropic expansion process on the turbine.
4. Process 4-1: Heat release at constant pressure.

### 2.2 Gas Turbine Maintenance

Maintenance of gas turbine is carried out using method overhaul withseveraltypesofinspections[13]. Maintenance of gas turbines involves various inspection methods, with the overhaul process encompassing multiple types of examinations [14].

First, there is the combustion inspection, which entails the careful examination and maintenance of components such as fuel nozzles, combustor baskets, and transition pieces within the combustion chamber. Ensuring the cleanliness and functionality of open passages is crucial for optimal turbine performance [15].

Next, the turbine inspection, also known as hot gas path inspection, focuses on inspecting and repairing parts within the combustion chamber and the open cylinder of the gas turbine [16]. This includes cleaning and repairing turbine blades, diaphragms, and seals, as well as checking and repairing axial and journal bearings[17].

Finally, minor inspection involves a comprehensive visual examination of the entire turbine engine, starting from the compressor inlet and concluding at the turbine outlet. These minor inspections, conducted every 4000-8000 hours or based on Equivalent Operation Hours (EOH), play a vital role in maintaining the gas turbine's operational integrity [18].

### 2.3 Calculation Show Work Gas Turbine

In count show work gas tube, a necessary review of some of the parameters will be used for count among others as follows:

1. Compression process in the compressor
   To count the working compressor in the condition that actually got counted use the Eq. 1[19].
   $$W_{k\,aktual} = m_u \times (h_2 - h_1), hp \quad (1)$$
2. Combustion process in space burn
   On cycles Brayton, the combustion process equivalent is done with enter heat to cycle. To determine mark enthalpy burning can use Eq. 2 [20].
   $$(m_{up} \times h_2) + (m_f \times h_f) = (m_{up} + m_f) \times h_3 \quad (2)$$
3. Turbine expansion process
   For count work turbine in condition actual can count use Eq. 3[20].
   $$W_{t\,aktual} = m_g \times (h_3 - h_4), hp \quad (3)$$
4. Work turbine clean
   To count work turbine cleaning can use Eq. 4[21].
   $$W_{nett} = W_t - W_k, hp \quad (4)$$
5. Amount heat enter
   To count amount of heat, enter can use the Eq. 5[19].
   $$Q_{in} = m_f \times LHV, hp \quad (5)$$
6. Heat rate
   Heat rate is the ratio between the amount of energy consumed and with power generated by the load. To determine mark heat rate can useEq. 6[21].
   $$H_{rate} = \frac{m_e}{W_{nett}}, Btu/hp\text{-}hour \quad (6)$$
7. Usage material burn specific
   Consumption of material burn specific is a ratio between the rate genre mass material burned per unit of time with the power generated by the turbine burden. To determine mark consumption material burn specific can use the Eq. 7[22].
   $$SFC = \frac{m_f \times 60}{W_{nett}}, lb/hp\text{-}hour \quad (7)$$
8. Thermal efficiency
   Effective thermal efficiency is the ratio between the power generated by the turbine and with amount of heat entered. Todetermine mark thermal efficiency can use Eq. 8[23].
   $$\eta_{Therm} = \frac{W_{nett}}{Q_{in}} \times 100\%, \% \quad (8)$$

### 2.4 Research Flow

Research flow from optimization showsworkgas turbine GT 2.1 using the method of combustion inspection shown in Fig. 2[3].

The following is the research method used in our paper, employing field studies and literature review. The field study was conducted at a private company in one of the energy companies in Jakarta.

From this field study, data on gas turbines and compressor data were obtained. Before the overhaul, we conducted calculations and analyses of thermal efficiency, net turbine power, compressor power, and turbine power.

To enhance thermal efficiency, several actions were taken, such as examining combustion by cleaning and inspecting the combustion chamber. It took 20 working days to clean the nozzle debris during maintenance. Repairing cracks in the nozzle was also another step to improve thermal efficiency.

After the repairs, we re-evaluated and analyzed these parameters. When the results were satisfactory, we proceeded with the conclusion.

## 3 Results and Discussion

### 3.1 Evaluation Show Work Based on Data before Overhaul

After doingthecalculation, the evaluation shows work based on test report data 2015 with previous data overhaul with the use of Eq. 1 – Eq. 8, then it is obtained comparison results intheevaluation show work with test report data shownin Table 2and Fig. 3[3].

Table 2. Comparison evaluation showswork gas turbine GT 2.1 data test report with before overhauls data

| Parameters | Test reports data | Before overhauls data | Unit | Information |
|---|---|---|---|---|
| Fuel flow | 2391.71 | 2108.16 | lb /min | Down 1.1% |
| $W_{nett}$ | 205176.36 | 141339.35 | hp | Down 31.1% |
| Heat rate | 7951.56 | 9378.55 | Btu/hp-hour | Up 17.9 % |

| η the | 38.2 | 27.13 | % | Down 28 % |
|---|---|---|---|---|

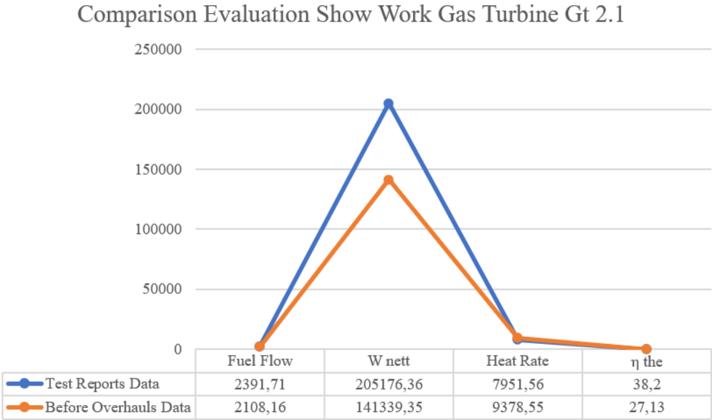


Fig. 3. Comparison evaluation shows work gas turbine 2.1.

The comparison of performance evaluation data for the gas turbine between the test report and the data after overhaul,is shown in the Fig. 4.

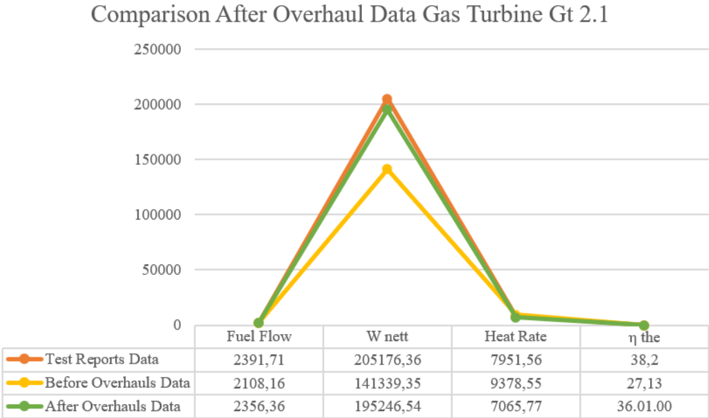


Fig. 4. Comparison after overhaul data gas turbine 2.1.

Based on the results of the calculation,theevaluation shows work on test report data with the data before overhaul is obtained results calculation declined performance with analysis, that is generated outputgas turbine GT 2.1 always fluctuates because customized with request production electricity from private companymain. Fuel flows experienceda decline of 1.1%.This caused cracks and dirt consequence of the deposition of the remainder material burn on the bucket nozzle combustion [20]. Thermal efficiency and power turbine clean, on gas turbine GT 2.1 experiencedadecline by 15.4 % and 31.1%. This is becausethereduction in fuel flow combustor will influence the consumption of energy (hate rate) in the gas turbine thenincreases performance on gas turbines that cause loss.

### 3.2 Optimization Show Work GT Gas Turbine 2.1

Optimization shows work gas turbine GT 2.1 is done usingcombustion inspection in space burn [18]. Combustion inspection is one typeofoverhaulon a gas turbine with the method of dismantling, inspecting, and repairing the fuel nozzle, combustor basket, transition pieces, and components of others who are in the combustor chamber. Opened sections must be cleaned carefully, checked, and repaired. On occasion, this spoon turbine level first can be checked from the hole place installation transition pieces. Combustion inspectionisalso called simple inspection because only done by checking to room burn course, which is shown (as shown in box red) in Fig. 5[3].

Activities undertaken during moment combustion inspection arecleaning and repairing the combustion nozzle bucket on the combustor, transition piece, manhole, and igniter as shown in Fig. 6[3]. After done combustion inspection there is the invention dirt remainder deposition material burn and crack (as shown in box red) that can influence the reduction in fuel flow on gas turbine GT 2.1 [24].

Fig. 5. Implementation combustion inspection on gas turbine GT 2.1.

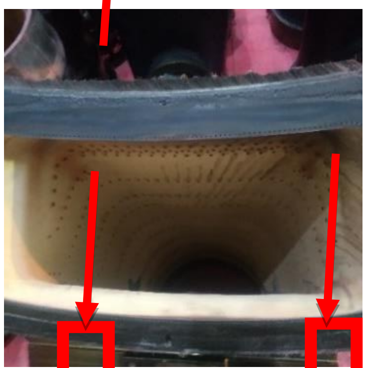

Fig. 6. Invention dirt and cracks in the combustion nozzle bucket.

After optimization shows work gas turbine with the use method of combustion inspection, the obtained results show work GT 2.1 gas turbine using operating data after overhaul as shown in the summary showing work gas turbine, obtained table comparison results optimization after overhaul with results evaluation before show overhaul work gas turbine GT 2.1 which shownin Table 3[3].

Based on the results comparison, the calculation optimization showswork gas turbine GT 2.1 obtained an increase in power turbine clean by 38.1% or 141,339.35 hpto 195,246.54 hp. Thermal efficiency by 27.8% or 27.13% to 36.01% with combustion inspection method in space burn turbine. So that at the same turbine output consumption material burnbecamelower compared to before he did an overhaul with method combustion inspection. Thisshow that the methodis effective in increasing power and efficiency in optimizing show work gas turbine GT 2.1[25].

Table 3. Comparison of data after overhaul with data before overhaul

| Parameters | Test reports data | Before overhauls data | After overhauls data | Unit | Information |
|---|---|---|---|---|---|
| Fuel flow | 2391.71 | 2108.16 | 2356.36 | lb /min | Up 2% |
| $W_{nett}$ | 205176.36 | 141339.35 | 195246.54 | hp | Up 38.1% |
| Heat rate | 7951.56 | 9378.55 | 7065.77 | Btu/hp-hour | Down 24 % |
| $\eta_{the}$ | 38.2 | 27.13 | 36.01 | % | Up 27.8 % |

## 4 Conclusion

Based on the results calculation evaluation show work on test report data with data before overhaul is obtained results calculation experience decline performance with analysis, that is generated output gas turbine GT 2.1 always fluctuates because customized with request production electricity from private companymain. Fuel flows experienceda decline of 1.1%. This caused cracks and dirt consequence of the deposition of remainder material burn on the bucket nozzle combustion. Thermal efficiency and power turbine clean, on gas turbine GT 2.1 experienced decline by 15.4 % and 31.1%. This because happen reduction in fuel flow combustor will influence consumption energy (hate rate) in the gas turbine experienced increase performance on gas turbines that cause loss. And the results from comparison calculation optimization show work gas turbine GT 2.1 increased power turbine clean by 38.1% or 141,339.35 hpto 195,246.54 hp. Thermal efficiency by 27.8% or 27.13% to 36.01% with combustion inspection method in space burn turbine. So that at the same turbine output so consumption material burn become morelow compared to before he did an overhaul with method combustion inspection. This show that the methodis effective in increasing power and efficiency in optimizing show work gas turbine GT 2.1.

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