Gas Turbine Performance

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Advanced Science Letters
Vol. 24, 9800–9802, 2018

Effect of Overhaul on Thermodynamic Performance of Gas Turbine Generator in Combined Cycle Powerplant

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The operational reliability of power generation systems should be maintained by carrying out periodic overhaul. This paper aims to determine changes in the performance of gas turbine generator before and after overhaul using first law thermodynamic concept. Performance analysis were conducted using operating data collected from the power plants at different load to determine the compressor efficiency, turbine efficiency, thermal efficiency, fuel consumption and heat rate. The highest increase after the overhaul in compressor efficiency was 1.36%, turbine efficiency 0.019% and thermal efficiency 0.805%. The largest fuel savings were 0.20 kg/s or equivalent to 17,280 kg/day natural gas.

Keywords: Brayton, Cycle, Gas Turbine, Performance, Thermodynamic.

1. INTRODUCTION

The availability of electrical energy in a country is closely related to economic growth in the country. Electricity consumption in Indonesia in the final sector by 2015 is around 200 TWh. Demand for electricity will continue to grow in line with economic growth and population growth. Growth in electricity demand is projected to reach around 520 TWh by 2050. The average electricity demand growth rate of 7.1% per year for the period 2015 to 2050. Based on the type of fuel used, fossil fuels still dominate the power source of power plants in Indonesia. Coal dominates fossil fuel consumption by 64%, followed by gas (23%), renewable energy (12%) and oil (0.1%).[1]

Gas turbines are widely used in gas power plants or combined cycles. The application of combination cycles is chosen because of its high efficiency, reaching a maximum of 60%.[2] In Indonesia, approximately 27.9% of power plants operate using gas turbines in gas power plants or combined cycles.[3] Gas turbines have the advantage of being able to start quickly and accommodate rapid load changes. This is important in the future because the use of renewable energy is predicted to be more and more varied.[2]

Based on the consideration of the fulfillment of electricity needs and the high cost of investing in the construction of new power plants, the existing power plants must be maintained by conducting periodic overhauls. This paper aims to determine changes in the performance of gas turbine generator in Indonesia Power Co. Ltd. using first law thermodynamic concept. Performance analyses were conducted using operating data collected from the power plants to determine the compressor efficiency, combustion engine efficiency, turbine efficiency, thermal efficiency of brayton cycles, turbine heat rate, and fuel consumption.

Analysis of power generation systems is essential to know the efficiency or change in performance. The common method used in analyzing the energy conversion process is by the first law of thermodynamics. Energy analysis also carried out in the industry to compare performance and optimize the equipment.[4] Research on the performance of gas turbine has been done by some previous researchers.[4,5,7,8]

2. METHODOLOGY

This research was conducted by observation and literature study. The gas turbine analyzed is GTG 1.3 in Indonesia Power Co., Ltd. which has a capacity of 109.65 MW, using natural gas. The operating conditions related to performance calculations are presented in Table I.

The enthalpy at points 1, 2 and 4 can be obtained from the air property table, while at point 3 can be obtained using Pr_3 from the following equation:[4]

$$\frac{P_{r3}}{P_{r4}} = \left(\frac{P_3}{P_4}\right) \tag{1}$$

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 1936-6612/2018/24/9800/003 doi:10.1166/asl.2018.13145

Table I. Operational data for GTG 1.3.

Load (MW)	Before overhaul						After overhaul					
	T_1 (°C)	T_2 (°C)	T_4 (°C)	P_2 (Bar)	P_4 (mBar)	$\dot{m}$ (kg/s)	T_1 (°C)	T_2 (°C)	T_4 (°C)	P_2 (Bar)	P_4 (mBar)	$\dot{m}$ (kg/s)
85	28	334	560	8.60	12.50	5.90	28	337	561	8.80	11.53	5.80
95	30	358	559	10.20	11.35	6.42	30	350	558	10.00	11.32	6.34
96	29	352	560	10.00	11.70	6.59	29	354	559	10.20	11.42	6.40
97	28	352	560	10.04	11.86	6.60	28	352	560	10.24	11.50	6.40

The work required by compressors and those produced by gas turbines can be calculated based on the energy conservation equation for open systems.[4]

$$Q - W = \Delta H + \Delta EK + \Delta EP \tag{2}$$

Compressor isentropic efficiency can be calculated by comparing the work required for isentropic compression with actual compression using this equation:

$$\eta_c = \frac{h_2' - h_1}{h_2 - h_1} \times 100\% \tag{3}$$

The heat generated during the combustion process can be calculated from the fuel consumption.

$$Q_{in} = \dot{m}f \cdot HV \tag{4}$$

Turbine isentropic efficiency can be calculated by comparing the actual work produced and theoretical work when the extraction of energy occurs isentropically using this equation:

$$\eta_t = \frac{h_3 - h_4}{h_3 - h_4'} \times 100\% \tag{5}$$

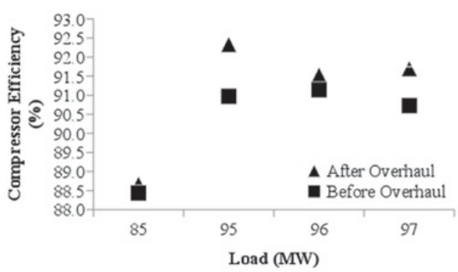

Fig. 1. Compressor efficiency versus load.

Heat rate can be calculated using this equation:

$$HR_{gt} = \frac{HV \cdot \dot{m}f}{GT_{\text{load}} \cdot 1000} \tag{6}$$

3. RESULTS AND DISCUSSION

3.1. Effect of Overhaul on Compressor, Turbine and Thermal Efficiency

The efficiency of the compressor increases after the overhaul. The increase of compressor efficiency after overhaul is influenced by decreasing out compressor temperature (T_2) and increasing compressor exit air pressure (P_2). The highest increase in compressor efficiency was 1.36% at 95 MW load.

Increased efficiency of the compressor is possible because during overhaul, blade, inlet air filter, etc. are cleaned. Dust, dirt, and oil-containing fumes in the power plant environment can clog compressor air filters. Obstruction of the air filter can decrease the mass flow rate of air entering the compressor and ultimately decrease the efficiency of the compressor.[5,7] In a gas turbine, about 50 to 60 percent of the total power generated by the turbine is used by the compressor, thus maintaining high compressor efficiency is an important factor for maintaining the effectiveness of the power plant.[8]

Turbine efficiency increases after overhaul, but the increase is not significant. The highest turbine efficiency improvement is 0.019% at 96 MW load. Cleaning of impurities on the turbine rotor blades and replacing the damaged blades made during the overhaul can improve the performance of the gas turbine. Fouling on the turbine blades and eroded turbine blades causes the extraction process not to be maximal. In addition, the crust on the blade surface may clog the cooling holes causing excessive heat on the turbine blades.[9]

Overall thermal efficiency increases after overhaul. This is influenced by the fuel consumption used after the overhaul is less than before the overhaul. The highest thermal efficiency increase of 0.805% at 97 MW load.

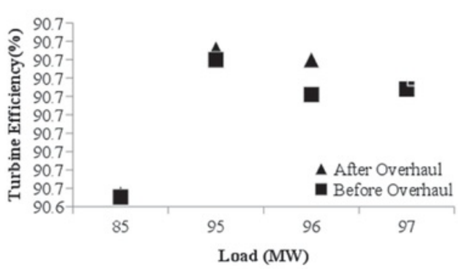

Fig. 2. Turbine efficiency versus load.

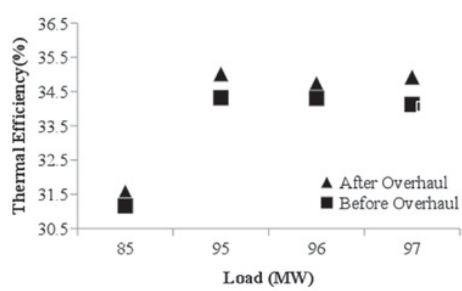

Fig. 3. Thermal efficiency versus load.

Adv. Sci. Lett. 24, 9800–9802, 2018

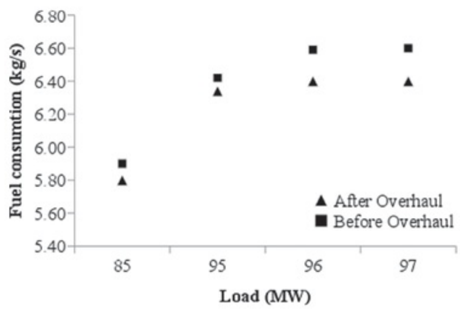

Fig. 4. Fuel consumption.

3.2. Effect of Overhaul on Fuel Consumption and Heat Rate

Fuel consumption after overhaul is less than before overhaul. This is possible because after the overhaul, the losses that exist in the GTG reduced so that fuel consumption is more effective. In the trendline graph shows that the greater the gas turbine power the fuel used will be more and more. The largest fuel savings were 0.20 kg/s at 97 MW load, equivalent to 17,280 kg/day. Due to the decrease in fuel consumption, the energy needed to generate power of 1 kWh becomes smaller. The largest heat rate drop was 415,270 kJ/kWh (3.03%) at 97 MW load.

4. CONCLUSION

Periodic overhaul can improve the performance of gas turbines. The effect of overhaul on gas turbine performance has been investigated. Compressor efficiency, turbine efficiency and thermal efficiency has increased, while the fuel consumption and heat rate decreased. The decrease of natural gas fuel consumption in 1 day can reach 17,280 kg/day.

Acknowledgments: The authors would like to appreciate the Vocational School Diponegoro University, Semarang, Indonesia for providing financial support for this publication.

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Received: 17 September 2017. Accepted: 22 October 2017.

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