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Turbine Exergy Efficiency of Patuha Geothermal Power Plant

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ABSTRACT

Patuha geothermal power plant is located in Bandung, West Java Province of Indonesia. The plant capacity is 59.88 MW, but currently the plant is only producing about 50 to 55 MW due to a shortage of steam. One of the reasons for this shortage is due to scaling in the third biggest production well, namely PPL-07. Today this well keeps supporting the plant production although the well should often be shut for washing, then heating up and so on. One of the concerns when PPL-07 is connected to the system is the turbine inlet steam quality degradation. To get the information about how this degradation is affecting the plant, exergy analysis of the turbine with and without PPL-07 needs to be done. The results of this analysis show that both of the turbine exergy efficiencies are above 95% with PPL-07 connected and not connected to the system.

1. INTRODUCTION

Patuha field is located in Bandung, West Java Province of Indonesia. The plant capacity is 59.88 MW with 8 production wells. Before the commissioning in 2014, the third biggest well, PPL-07, dropped due to calcite scaling in the wellbore and made the other wells operate beyond their designated supply for a while to provide the 109.26 kg/s of steam needed to prove the capacity.

Currently to increase the power production, two injection wells have been functioning as the production wells and give the contribution of approximately 1 MW per well. However, today the plant is only producing about 50 to 55 MW. The fluctuation of the plant production caused by the intermittent steam supply from the PPL-07.

Mechanical work-over, in conjunction with acid treatment, had been done to PPL-07, but it could not ensure the PPL-07's steam production. So to keep PPL-07 supporting the plant production the well should be shut for washing, then heating up and so on. One of the concerns when PPL-07 was added to the system is the steam quality degradation, and this work is aimed to compare the impact of PPL-07 to the power plant in terms of turbine exergy efficiency.

2. BASIC CONCEPTS

Exergy is the maximum work output that could theoretically be obtained from a substance at specified thermodynamic conditions relative to its surroundings (DiPippo, 2007). The equation for maximum work output can be obtained by combining the First and Second Laws of Thermodynamics. The equation for the First Law is (Aqui, 2005):

$$\dot{Q} - \dot{W} = \dot{m}\left[(h_2 - h_1) + \frac{1}{2}(v_2^2 - v_1^2) + g(z_2 - z_1)\right] \tag{1}$$

where $\dot{Q}$, $\dot{W}$, $\dot{m}$, h, v, and z are heat flow rate, rate of work, mass flow rate, enthalpy, velocity and vertical position, respectively.

Neglecting the effect of kinetic and potential energy the equation above becomes:

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) \tag{2}$$

The second law for the system is:

$$\dot{\theta} = \dot{m}(s_1 - s_2) - \dot{Q}/T_0 \tag{3}$$

where $\dot{\theta}$, s and T_0 are entropy production, entropy and absolute temperature of the surrounding, respectively.

Entropy production for reversible operation reduces to zero and makes equation (3) become:

$$\dot{Q} = \dot{m}T_0(s_1 - s_2) \tag{4}$$

Combining equations (2) and (4) gives the expression as follows:

$$\dot{W} = \dot{m}[(h_1 - h_2) - T_0(s_1 - s_2)] \tag{5}$$

Using condition 2 to stipulate that state 2 is identical to the surrounding state (dead state), so the maximum power output, called exergy ($\dot{E}$), is (DiPippo, 2007):

$$\dot{W}_{maks} = \dot{E} = \dot{m}[(h_1 - h_0) - T_0(s_1 - s_0)] \tag{6}$$

this equation can be written per unit mass as:

$$e = (h_1 - h_0) - T_0(s_1 - s_0) \tag{7}$$

Equation (6) will be used to calculate the exergy of geothermal fluid at the inlet and outlet of the turbine.

The exergy accounting equation for the turbine can be expressed as:

$$\Delta\dot{E} = \dot{m}e_1 - \dot{m}e_2 - \dot{W} \tag{8}$$

where $\Delta\dot{E}$ is the lost exergy and subscript 1 and 2 is subscription for inlet and outlet of the turbine respectively. Finally, the exergy efficiency (η) of the turbine can be expressed as follow:

$$\eta = \frac{\dot{W}}{e_1 - e_2} \tag{9}$$

3. EXERGY EFFICIENCY OF TURBINE

Patuha geothermal power plant's turbine is single flow, impulse design, condensing, with six stages and a 31" last stage blade. The turbine exhaust is connected axially to the direct-contact condenser through the turbine exhaust duct. The turbine rated gross output is 59880 kW and 3000 rpm of rated speed.

Figure 1: Steam Turbine

The turbine installation level is 2034 m with the designated ambient temperature at 15.2°C. Based on the data of November 2018, when PPL-07 well was not connected to the system, the steam entered the turbine at 87.54 kg/s, 7.37 bar and 99.65% steam quality. The condenser pressure was 0.0899 bar and generator output was 50.43 MW. The steam turbine output was 54.22 MW with the exergy at the inlet being 73.13 MW and 16.14 MW at the outlet. The total exergy lost in the turbine was 2.78 MW and exergy efficiency of the turbine was 95.13%.

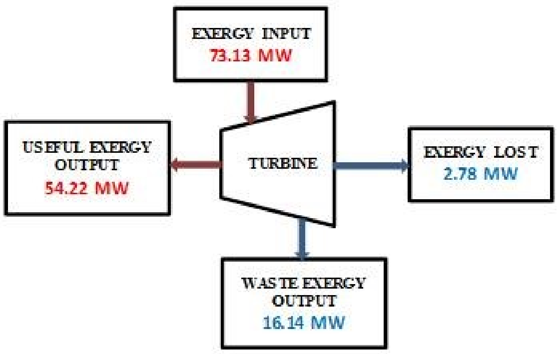

Figure 2: Turbine Exergy Balance without PPL-07

In December 2018, when PPL-07 was connected to the system, mass flow rate and pressure of the entering steam was increased to 95.93 kg/s and 8.04 bar respectively, but not the steam quality. Steam quality decreased to 99.1%. The condenser pressure was 0.1067 bar and generator output was 55.37 MW. The steam turbine output was 59.3 MW with the exergy at the turbine inlet being 80.95 MW and 19.33 MW at the turbine outlet. The total exergy lost in the turbine was 2.31 MW and the exergy efficiency of the turbine was 96.25%.

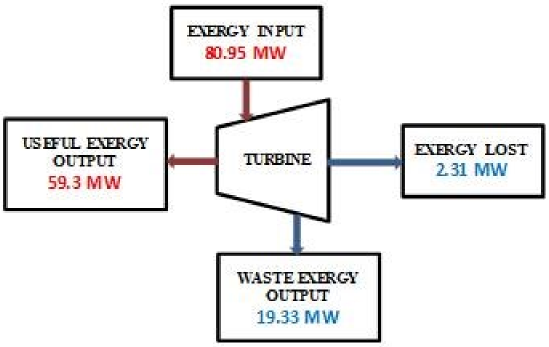

Figure 3: Turbine Exergy Balance with PPL-07

In summary, exergy lost in the turbine when PPL-07 was not connected to the system was higher than when it connected. When PPL-07 was not connected to the system, the exergy lost amounted to 3.8% of the total exergy input. Whereas when PPL-07 was connected to the system the exergy loss was reduced to 2.86%. These amounts of losses certainly determines the exergy efficiency of the turbine and made the exergy efficiency of the turbine with PPL-07 connected to the system higher than when it was not connected due to the higher steam pressure and mass flow rate even with lower steam quality.

4. CONCLUSION

Exergy efficiency of the turbine with PPL-07 connected to the system was higher than with PPL-07 not connected to the system. The steam quality degradation amounted to about 0.5%, but did not affect the turbine performance significantly.

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