GENERATOR, TURBINE AND THERMAL EFFICIENCY OF LUMUT BALAI GEOTHERMAL POWER PLANT

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ABSTRACT

Lumut Balai Geothermal Power Plant is a single flash plant which take high-pressure hot water from the reservoir into the low-pressure tank then using the resulting steam to turn the turbine. After turning the steam turbine condensed using a direct contact condenser before injection back into the reinjection wells, the condensation process is assisted by using Cooling Tower as Recirculating Cooling Water. During the operation, it is fundamental to calculate the efficiency of plant parameters to manage the production reliability in Lumut Balai geothermal field. Based on the integrated formulation during daily monitoring, there can be concluded that Lumut Balai Geothermal Power Plant has thermal efficiency is 2.35%, generator efficiency of about 84.39%, and turbine efficiency is 85%.

1. BACKGROUND

Lumut Balai Geothermal Power Plant uses a separated steam cycle. namely the vapor cycle which results are obtained from the phase separation in the fluid. The steam coming out of the wellhead is dominated by the liquid phase, through the vapor phase separator and the liquid phase will be separated naturally based on the density of the fluid using the cyclone method. The liquid phase, hereinafter referred to as hot brine, will be directly flowed to the re-injection well while the steam phase will be flowed into the steam vessel which will then go to the steam turbine through the mist eliminator. Mist eliminator serves to ensure that the steam fraction that will be sent to the steam turbine is guaranteed clean and dry and is then used in the calculation of the steam turbine power. This energy conversion system is called the separated steam cycle. This method is widely used in reservoir areas which are dominated by water.

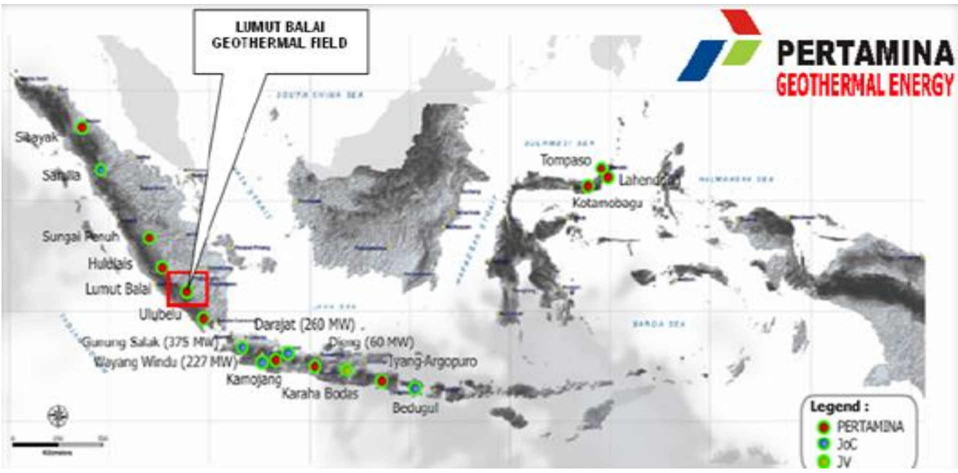

Figure 1: Lumut Balai Geothermal Field in South Sumatra, Indonesia (PGE, 2010)

2. THEORY

2.1 Thermal Power Plant Efficiency

Geothermal power plant efficiency closely depend on the type, feature, and the reservoir characteristics of the field. The formula of thermal efficiency which related to the energy input can be defined as shown below:

$$\eta_{act}\,(\%) = \frac{W}{\dot{m} \times h} \times 100$$

η_{act} = the energy input
W = the running capacity (kWe),
$\dot{m}$ = the total mass flow rate (kg/s), and
h = the reservoir enthalpy (kJ/kg).

The efficiency of geothermal power plant is affected by some parameters such as Energy Loss due to process, Non-condensable gas (NCG) content, heat loss from equipment, turbine and generator efficiency and power plant parasitic load (e.g. fans, pumps, and gas extraction system) (Moon et al, 2012)

2.2 Steam Turbine Efficiency

The efficiency of the steam turbine in a geothermal power plant can be seen from the lack of fuel in this case, namely dry steam which is used to turn the steam turbine so that the steam turbine will also rotate a generator to produce electricity per kWh. The electricity produced will later be sold to PLN for distribution to the public at large. The less fuel used, the higher the efficiency of the steam turbine and the more electricity that can be distributed later, and vice versa. Steam turbine efficiency in geothermal power plants is certainly much influenced by process variables and parameters.

So it is important according to the author as an operator at the Lumut Balai PLTP to find out the efficiency of the steam turbine as part of the first person to operate this PLTP, so that he is always able to operate this steam turbine within safe operating parameters to achieve the best efficiency value.

Total Incoming Power On Generator Formula :

$$P_{in} = P_{out} + P_{loss}$$

Pout	: Power out [W]
Pin	: Power in [W]
Ploss	: Total power loss [W]

$$x = \frac{S_2 - S_f}{S_{fg}} \times 100\% \qquad h_{2s} = h_f + x.h_{fg}$$

x	: Vapor fraction [%]
S_2	: Steam turbine output entropy [kJ/kg.K)]
S_f	: Entropy of vapor in the saturated state of liquid (liquid) [kJ/kg.K]
S_{fg}	: Entropy change from water to gas [kJ/kg.K]
h*2s*	: Enthalpy of isentropic steam at steam turbine exit temperature [kJ/kg]
h*f*	: Enthalpy of vapor in the state of liquid saturation (liquid) [kJ/kg]
x	: Vapor fraction [%]
h*fg*	: Enthalpy of change from liquid to gas [kJ/kg]

The performance of the steam turbine is obtained by calculating the enthalpy of steam entering the turbine [h1] with the isentropic enthalpy of steam leaving the steam turbine [h2s]. Steam turbine performance can be calculated by equation [11];

$$\text{Turbine performance} = h_1 - h_{2s}$$

h_1	: Enthalpy of steam at inlet of turbine [kJ/kg]
h_2	: Enthalpy of isentropic steam at outlet of turbine [kJ/kg]

The input power [Pin] is obtained by knowing the value of the mass flow rate and steam turbine performance which is formulated mathematically through equation [11];

$$P_{in} = \dot{m} \times (h_1 - h_2) \qquad P_{out} = \frac{P_{generator}}{\eta_{generator}}$$

P_{in}	: Steam turbine input power [kW]
P_{out}	: Steam turbine output power [kW]
$\dot{m}$	: Mass vapor flow rate [kg/s]
h_1	: Enthalpy of steam at inlet steam temperature [kJ/kg]
h_2	: Enthalpy of isentropic steam at the outside temperature of the steam turbine [kJ/kg]
ηgenerator	: Generator Efficiency [%]

2. RESULT

2.1 Generator and Turbine Power Calculation

The energy produced by the steam turbine at the Lumut Balai Geothermal Power Plant Unit 01 can be calculated using the enthalpy depreciation procedure. To calculate the performance of the steam turbine, the steam turbine inlet enthalpy value (h1) needs to be found and determined. The value (h1) is obtained from the TLV Toolbox engineering application information as well as from the steam table information of the Japan Society of Mechanical Engineering (JSME) where (h1) uses the steam turbine inlet pressure parameter in units of (kj/kg). The isentropic steam enthalpy leaving the steam turbine (h2s) can be calculated if the value of the steam fraction has been calculated (x). The value of the vapor fraction (x) can be calculated using equation [1]. The calculation that will be tried is an illustration of the operational parameters of the steam turbine on March 2, 2020 which later with the same calculation will be tried on all total samples for 27 days the illustrations are taken;

$$x = \frac{S_2 - S_f}{S_{fg}} \times 100\% \qquad x = H_1 - \frac{B_1}{B_2}(H_1 - H_2) \qquad S_{fg} = S_g - S_f$$

S_2, interpolation from steam table 12.4 saturated steam table :

H_1 = 6.896 [kj=kg°K]
H_2 = 6.821 [kj=kg°K]
B_1 = 5 – 4.3021 = 0.697 [barg]
B_2 = 5 – 4 = 1 [barg]
x = 6.896 - 0.697/1 (6.896-6.821)
x = 6.896 - 0.697/1 (0.075)
x = 6.896 - 0.05242
S_2 = 6.8435 [kj=kg°K] ; $S_2 = S_1$ (Ideal Process /Isentropic)

Fluid saturation entropy [S_f] from steam table 12.4 saturated steam table :

H_1 = 8.295 [kj=kg°K]
H_2 = 8.257 [kj=kg°K]
B_1 = 40 – 38.715 = 1.284 [°C]
B_2 = 40 – 38 = 2 [°C]
x = 8.295 - 1.284/2 (8.295-8.257)
x = 8.295 - 1.284/2 (0.038)
x = 8.295 - 0.024396
S_f = 8.2925 [kj=kg°K]

Gas saturation entropy [S_g] from steam table 12.4 saturated steam table :

H_1 = 0.5457 [kj=kg°K]
H_2 = 0.5725 [kj=kg°K]
B_1 = 40 – 38.715 = 1.284 [°C]
B_2 = 40 – 38 = 2 [°C]
x = 0.5457 - 1.284/2 (0.5457-0.5725)
x = 0.5457 - 1.284/2 (-0.0268)
x = 0.5457 + 0.01078
S_g = 0.55648 [kj=kg°K]

Steam dryness at last stage of steam turbine

S_{fg} = 8.2925 [kj=kg°K] - 0.55648[kj=kg°K]
S_{fg} = 7.73602 [kj=kg°K]
x = (6.8435 [kj=kg°K] - 0.55648[kj=kg°K])/(7.73602 [kj=kg°K])×100%
x = 81.26%

Then, with x = 81.26%, calculate h_2 at last stage of steam turbine : $h_2 = (1 - x)h_f + x.h_g$

h_2 = (1-0.8126)×162.172+0.8126×2571.24
h_2 = 2119.7805 [kj/kg]

Calculate $W_{ideal\ steam\ turbine}$ with formula : $W_{ideal\ steam\ turbine} = \dot{m}_1(h_1 - h_2)$

$W_{ideal\ steam\ turbine}$ = 110.99 [kg/s]×(2750.82[kj/kg]-2119.7806[kj/kg]
$W_{ideal\ steam\ turbine}$ = 110.99 [kg/s]×631.0294[kj/kg]
$W_{ideal\ steam\ turbine}$ = 70037.953 [kJ/s]
$W_{ideal\ steam\ turbine}$ = 70.04 MW

Calculate Generator Efficiency : $\eta_{generator} = \frac{Work_{actual}}{Work_{turbineideal}} \times 100\%$

$\eta_{generator}$ = (59.104 MW)/(70.104 MW)×100%
$\eta_{generator}$ = 84.39%

Calculate Turbine Efficiency : $\eta_t = \eta_{td} \times \left(a \times \frac{X_{in} + X_{out}}{2}\right)$

η_{td} = 0.85

Xin = 100.07
Xout = 100.00
a = 1
η_t = 0.85 x (1 x (100.07+100)/2) = 0.85 x 100.04 = 85%

By using the same calculation, then calculate (h_1) and (h_2) from the other data samples, so the enthalpy values (h1) and (h2) for all the total samples that have been taken are calculated ;

Table 1. Enthalpy Data Calculation of Steam Turbine

No	Date	Parameter			
		H_1	Unit	H_2	Unit
1	24-Feb-20	2750.82	[kj/kg]	2120.293	[kj/kg]
2	25-Feb-20	2750.83	[kj/kg]	2120.34	[kj/kg]
3	27-Feb-20	2750.86	[kj/kg]	2120.128	[kj/kg]
4	28-Feb-20	2750.84	[kj/kg]	2120.014	[kj/kg]
5	2-Mar-20	2750.82	[kj/kg]	2119.781	[kj/kg]
6	3-Mar-20	2750.83	[kj/kg]	2120.34	[kj/kg]
7	4-Mar-20	2750.84	[kj/kg]	2119.804	[kj/kg]
8	5-Mar-20	2750.83	[kj/kg]	2119.217	[kj/kg]
9	6-Mar-20	2750.84	[kj/kg]	2118.541	[kj/kg]
10	9-Mar-20	2750.83	[kj/kg]	2120.131	[kj/kg]
11	10-Mar-20	2750.84	[kj/kg]	2119.727	[kj/kg]
12	11-Mar-20	2750.83	[kj/kg]	2119.928	[kj/kg]
13	12-Mar-20	2750.85	[kj/kg]	2120.956	[kj/kg]
14	13-Mar-20	2750.86	[kj/kg]	2119.966	[kj/kg]
15	17-Mar-20	2750.93	[kj/kg]	2119.793	[kj/kg]
16	18-Mar-20	2750.93	[kj/kg]	2120.441	[kj/kg]
17	19-Mar-20	2750.97	[kj/kg]	2120.292	[kj/kg]
18	20-Mar-20	2750.94	[kj/kg]	2120.329	[kj/kg]
19	23-Mar-20	2750.96	[kj/kg]	2120.505	[kj/kg]
20	24-Mar-20	2750.97	[kj/kg]	2119.864	[kj/kg]
21	31-Mar-20	2750.95	[kj/kg]	2120.353	[kj/kg]
22	1-Apr-20	2750.94	[kj/kg]	2120.455	[kj/kg]
23	2-Apr-20	2750.96	[kj/kg]	2120.33	[kj/kg]
24	3-Apr-20	2750.94	[kj/kg]	2120.277	[kj/kg]
25	6-Apr-20	2750.96	[kj/kg]	2120.202	[kj/kg]
26	7-Apr-20	2750.96	[kj/kg]	2119.465	[kj/kg]
27	8-Apr-20	2750.98	[kj/kg]	2119.865	[kj/kg]

2.2 Generator and Turbine Efficiency Calculation

After obtaining the incoming and outgoing enthalpy data for the steam turbine, using the same calculation in the other sample data samples, after calculating the actual power value of the steam turbine, the load generated by the generator and the efficiency of the steam turbine;

Table 2. Turbine and Generator Power Calculation Data

No	Date	Parameter		Generator Efficiency (%)
		Wt (MW)	Load (MW)	
1	24-Feb-20	69.99514	59.18598	84.55726
2	25-Feb-20	70.01449	59.22385	84.58799
3	27-Feb-20	70.08102	59.23409	84.52229
4	28-Feb-20	70.04361	59.19753	84.51524

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5	2-Mar-20	70.04512	59.1827	84.49225
6	3-Mar-20	70.065	59.15486	84.42855
7	4-Mar-20	70.07949	59.2208	84.50518
8	5-Mar-20	69.99277	59.19407	84.57169
9	6-Mar-20	69.88224	59.21094	84.7296
10	9-Mar-20	69.95789	59.06775	84.43329
11	10-Mar-20	70.03031	59.03568	84.30018
12	11-Mar-20	69.85136	58.89563	84.31565
13	12-Mar-20	69.95732	58.95796	84.27704
14	13-Mar-20	70.19099	59.23613	84.39279
15	17-Mar-20	70.05816	59.22398	84.53544
16	18-Mar-20	70.15392	59.26193	84.47415
17	19-Mar-20	70.1409	59.29408	84.53567
18	20-Mar-20	70.10094	59.21045	84.46456
19	23-Mar-20	70.11076	59.25273	84.51303
20	24-Mar-20	70.07958	59.20479	84.48222
21	31-Mar-20	70.03399	59.15673	84.4686
22	1-Apr-20	70.08175	59.22341	84.50618
23	2-Apr-20	70.09958	59.21142	84.46757
24	3-Apr-20	69.95791	59.13618	84.53109
25	6-Apr-20	70.15295	59.20716	84.39725
26	7-Apr-20	70.09465	59.29076	84.58672
27	8-Apr-20	70.04726	59.22698	84.55288

2.2 Thermal Efficiency of Turbine Steam

Refer to the thermal efficiency formula from Moon et al, 2012, the thermal efficiency of Lumut Balai geothermal power plant can be calculated as follows :

$$\eta_{act}\,(\%) = \frac{W}{\dot{m} \times h} \times 100$$

m = 400 ton/hr = 100.8 kg/s
W = 59.500 kWh = 2479 kWe
H reservoir = 1050 kJ/kg

η_{act} = 2479 x 100 / (100.8 x 1050) = 247.900 / 105.680 = 2.35%

3. CONCLUSION

Based on the overall calculation and data monitoring of geothermal power plant and reservoir parameter of Lumut Balai field, these all can be concluded that :

- The efficiency of geothermal power plant is affected by some parameters such as Energy Loss due to process, Non-condensable gas (NCG) content, heat loss from equipment, turbine and generator efficiency and power plant parasitic load
- Lumut Balai geothermal power plant has the efficiency with :
  Thermal efficiency is about 2.35% (typical liquid dominated reservoir, medium enthalpy)
  Generator efficiency is about 84.39%
  Turbine efficiency is about 85%

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