

Reliability Analysis and Improvement Programs of Kamojang Geothermal Power Plant Unit 1

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ABSTRACT

Kamojang Geothermal Power Plant (GPP) Unit 1 has installed capacity of 30 MWe. As it functions as a base load system, Kamojang GPP ought to supply electricity continuously. This operation period excludes the requirement of repair or scheduled maintenance (periodic or corrective). Market demand encourages Indonesia Power (IP) management to improve the plant's reliability and availability of stable electricity supply.

Even though the plant has been operated for more than 30 years, Kamojang GPP Unit 1 still does not have a reliability model and failure predictions. The operation strategy can be specified from the pattern of reliability and failure predictions. Reliability improvement programs are expected to help maintain reliability and minimize the risk of forced outage. A statistic model based on Weibull Distribution-2 Parameters Method is proposed in order to determine the reliability model and failure predictions of the generator and the transformer.

Based on the model, the reliability of the generator and the transformer has been decreasing from its initial condition. The generator has a reliability value of 23%, while the reliability of the transformer reaches 12% within 245,748 hours of operation (equivalent to 30 years). Improvement programs for the generator are stator winding rewind in 2015 and generator cooling performance upgrade in 2016. Transformer improvements are oil regeneration in 2014 and replacement of the main transformer in 2015.

1. INTRODUCTION

Today's demand on electricity availability, capacity and clean power is increasing significantly along with the country development planning. Geothermal energy is one of the alternative solutions to reduce the impact of global warming and society's dependence on fossil fuels. Since it was commercially operated in 1982, Kamojang Geothermal Power Plant (GPP) Unit 1 has installed capacity of 30 MWe and is operated as base load system. This means that the plant should be operated continuously through the year except in terms of scheduled outage (periodic or corrective). Kamojang GPP supports Java-Bali electrical grid and supplies mainly to Region II of the grid.

Reliability is an important factor for the base load system. It maintains low operating costs and more stable power generation. Thus, reliability will offer more attractive prices through long-term agreements. So, reliability is a critical factor in Kamojang GPP due to the plant's function as the main foundation of the electrical system in Indonesia. Market demand encourages Indonesia Power (IP) management to improve the plant's reliability and availability of stable supply of electricity to the grid. The operation and maintenance strategy can be specified by knowing the reliability model and the current condition evaluation of equipment. Reliability improvement programs are expected to help maintain reliability and minimize the risk of forced outage. With plant reliability, electrical energy sales increment can be guaranteed.

This paper will discuss reliability model, current condition and reliability improvement program of Kamojang GPP's main equipment, especially the generator and the transformer.

2. KAMOJANG GEOTHERMAL FIELD

Kamojang geothermal field is located in Ibun Village, approximately 40 km from Bandung, the capital city of West Java. Similar to the other geothermal fields in Indonesia, Kamojang is also located in high terrain. It lies among the mountains of Gandapura, Rakutak, Masigit and Guntur. On average, Kamojang geothermal field has elevation about 1,500 m above sea level.

The development of Kamojang geothermal field actually already began in the colonial era. Netherlands East Indies Volcano drilled two exploration wells which produced dry steam from a shallow feed zone at about 600 m in depth and temperature of 237°C (Sudarmaji, et.al., 1995). Afterward, Kamojang reservoir was considered vapor dominated with temperature around 235-245°C and pressure at 34-35 bar abs. As of now, Kamojang is one of five vapor dominated reservoirs in the world.

Since 2008, with the introduction of Unit-4, Kamojang geothermal field produces a total of 200 MWe. Due to its steam consumption, additional 13 wells were drilled in order to secure a total steam potential of about 74 MW at the wellhead (Mawardi, 2010).

3. POWER PLANT PERFORMANCE

Figure 1 below shows the operation condition of Kamojang GPP Unit 1 with 30 MWe nominal output of the turbine. The operation data was taken daily for the period of 2008 – 2012. It gives a rough picture of the power plant's performance through the years. It also shows the performance of Unit-1 during its lifetime. Considerations of Capacity Factor (CF), Equivalent Availability Factor

(EAF), Equivalent Forced Outage Rate (EFOR) and Sudden Outage Factor (SdOF) are introduced to manage power generation quality and performance. It can be said that availability hours and operation conditions are the key to great performance.

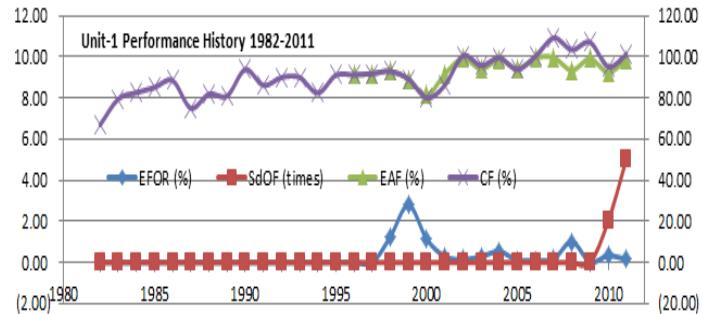


Figure 1: Performance history of Kamojang GPP unit 1.

4. RELIABILITY MEASUREMENT

Equipment reliability is a critical factor in any industrial process. A plant is expected to have an optimal production capacity with reliability and competitive maintenance cost. To improve power plant reliability, the system and subsystem should perform their proper function within a certain operation period and condition. Reliability measurements have been conducted for the generator and the transformer of Kamojang GPP Unit 1. This measurement is performed to determine reliability predictions and failure predictions. Even though the plant has been operated for 30 years, Kamojang GPP Unit 1 does not have a reliability model and failure predictions. Reliability characteristic of equipment can be determined by conducting a reliability assessment. The characteristic is considered as a reliability baseline and will be used further to specify the strategic initiative and improvement program due to reliability improvement and production optimization. A statistic model based on Weibull Distribution-2 Parameters Method is proposed in order to determine the reliability model and failure predictions of the generator and the transformer.

$$R(t) = e^{-(\frac{t}{\alpha})^\beta} \quad (1)$$

Where e , α , β , t are base of the natural logarithms, characteristic life, shape parameter and time to failure.

The number of equipment failures and operating hours is required in order to perform calculations. According to asset register criteria, the equipment should first be mapped into system and subsystem classification to get the appropriate failure data. Failure data concerns the one that may affect equipment degradation and production decrement. The failure data samples were taken from first commissioning at 1982 to 2012.

4.1 Generator

The generator is the main equipment in the Kamojang GPP. The generator's main function is to generate electricity with the principle of electro-magnetism. The generator type in Kamojang GPP is a synchronous generator with specifications of 30 MWe, 3,000 rpm, 50 Hz, output voltage 11,800 volt and 1,850 ampere. The cooling system type for the generator is an air cooled water system. Until now, the generator did not have a reliability prediction model. Reliability analysis should be performed on the generator, because it is an essential asset of the Kamojang GPP. This model can be used to optimize the maintenance strategy. This model also supports the performance analysis of the current generator condition, so that the risk of severe failure in the generator can be minimized. Failure of the generator could badly influence the cost activity of the plant and also the supply of electricity to the interconnection system. The generator is divided into 10 subsystems as shown in the Figure 2.

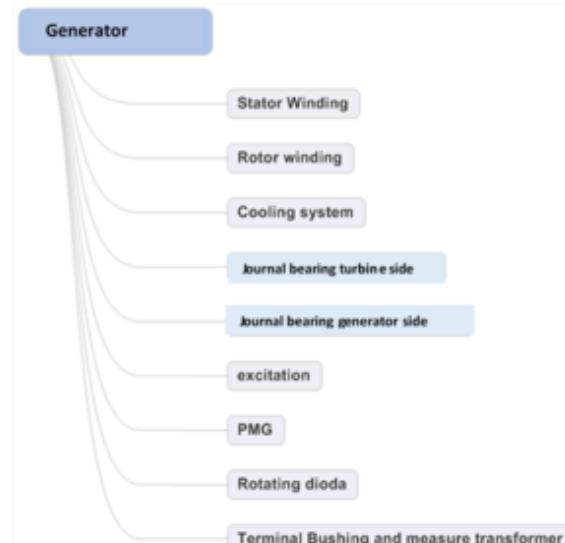


Figure 2: Subsystems of the generator.

Based on the operational data from 1982 to 2012, there are several failure numbers for the generator as is shown in Table 1. The operating hours is 245.784 hours. The value of β and α is obtained by using regression analysis. The result shows that the beta (β) value is 1 and alpha (α) value is 174482.07. As the result has been obtained for the reliability prediction model, the reliability value of the generator is found to be about 23% after 30-years of operation.

Table 1: Failure data for the generator.

No	Date	Failure Cause
1	July 22, 1985	Generator temperature outlet oil high
2	December 30, 1992	Excitation socket form AVR failed
3	February 3, 2001	Looseness in terminal of current transformer for generator Phase S
4	August 2, 2011	Fuse failure for excitation system
5	March 30, 2012	Insulation failure of rotor winding

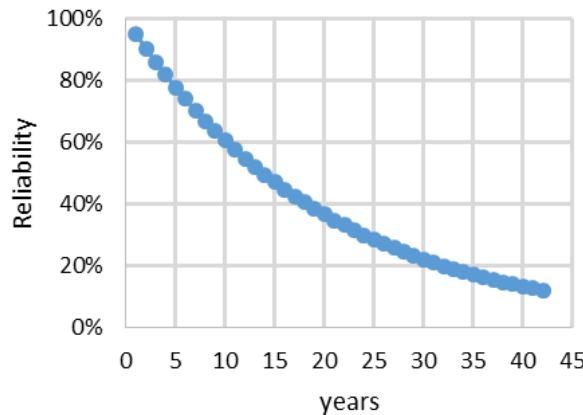


Figure 3: Generator reliability probability.

4.2 Main Transformer

The transformer is one of the critical equipment in Kamojang GPP; its criticality is as high as the generator's. The main transformer type is a step up transformer, with voltage rating of 11.8 kV/150 kV. The rated power is 40 MVA, 50 Hz frequency, with ONAN cooling system type. The transformer's main function is to step up the output voltage that is produced by the generator from 11.8 kV to 150 kV. The main goal of this is to reduce the voltage losses and obtain stable voltage. Detail specifications of the main transformer are shown in Table 2.

Table 2: Transformer specification.

Main Transformer specification	
Merk	: LEPPER DOMINIT
Type	: SDOR 40000/170
Output on All Tap	: 40000 KVA
Operation	: Continuous
Serial No	: 1218546
	: 2
Year	: 1979 IEC 76
Kind of Transf.	: 3 phase Power Transformer
Frequency	: 50 Hz
Cooling	: ONAN
Total Weight	: 77 Tons
Transport Weight	: 50 Tons
Weight of Oil	: 18.5 Tons
Core and Coil	: 39 Tons
Volume of oil	: 20500 Litres
Max.Ambient Temp	: 35 °

Similarly as for the generator, the main transformer does not have a reliability prediction model. The model can be used to optimize the maintenance strategy. This model supports the performance analysis of the current condition, so that the risk of severe failure in the transformer can be minimized. Transformer failure also influences the supply of electricity to the interconnection system and it usually requires a relatively long repair time. The transformer is divided into 10 subsystems as shown in the Figure 4.

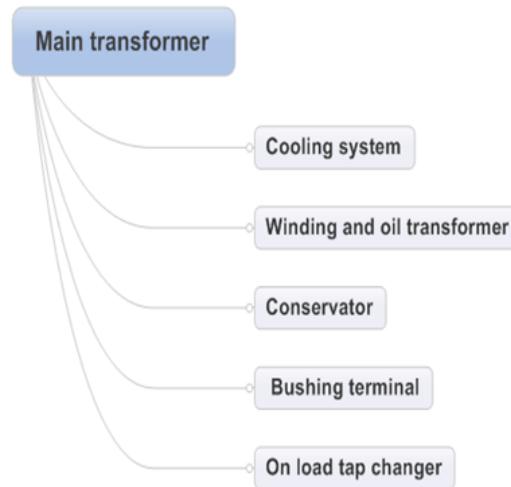


Figure 4: Subsystems of the transformer.

Based on the operational data from 1982 to 2012, the amount of failures of the main transformer can be found in Table 3. The operating hours is 245.784 hours. The β and α values are obtained by using regression analysis, which results in a beta (β) value of 0.97 and alpha (α) value of 107.228,23. The result of calculation gives the reliability prediction model, so that the reliability value of the transformer is maintained at about 12% after 30 year operation.

Table 3: Failure date for the transformer.

No	Date	Failure Cause
1	February 28, 1986	Overheat of winding transformer
2	September 21, 1986	Transmitter error on transformer
3	February 14, 2000	Internal failure
4	March 1, 2002	Oil leakage in high voltage side

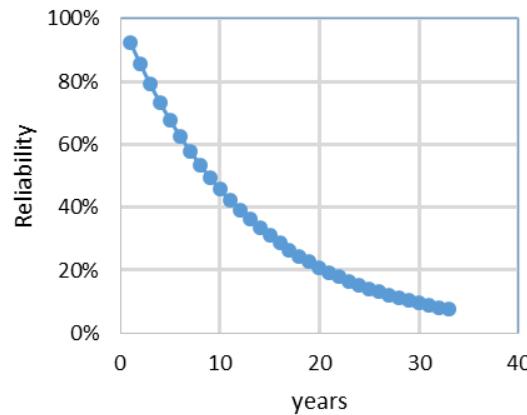


Figure 5: Transformer reliability probability.

5. RELIABILITY IMPROVEMENT PROGRAM

The result of the reliability calculation shows that the reliability probability value for the generator is about 23% and 12% for the transformer. This means that the failure risk will increase if the generator and transformer are operated continuously without any improvement of their maintenance strategy. Therefore, outage risk would increase too. Based on reliability data and performance analysis of the current condition, reliability improvement program is performed.

5.1 Generator Current Condition and Improvement Program

In order to determine generator performance, the assessment is conducted by testing the stator winding in offline mode. Thus, analysis is performed on the operation parameters of the generator. Several tests which are performed are tan delta, partial discharge, dielectric strength analysis, and stator winding temperature analysis.

Tan delta measurement carried maintenance data from 1998 until 2012 that the result of measurement as it is shown in Figure 6.

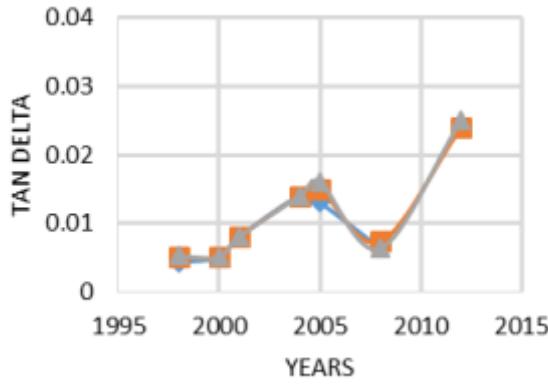


Figure 6: Tan delta measurement result.

The measurement result shows that the tan delta value increases by 0.0197 from 1998 to 2012. The increase of the tan delta value indicates that there is an increment on the number of voids in the winding insulation. It also indicates resistance value increment in the conductor layer that will lead to higher value of dielectric losses and accelerate the aging process at insulation. Tan delta values of individual phases are considerably higher than tan delta values of all three phases simultaneously tested. This is an indication of higher end-winding losses that could be caused due to the presence of contaminants on the end windings.

The partial discharge patterns provided below indicate slot end and surface discharge activity. The partial discharge patterns do not give any clear indication of dominant slot discharge activity. However, it seems that the slot end discharges have started progressing towards the slot region from the PD patterns.

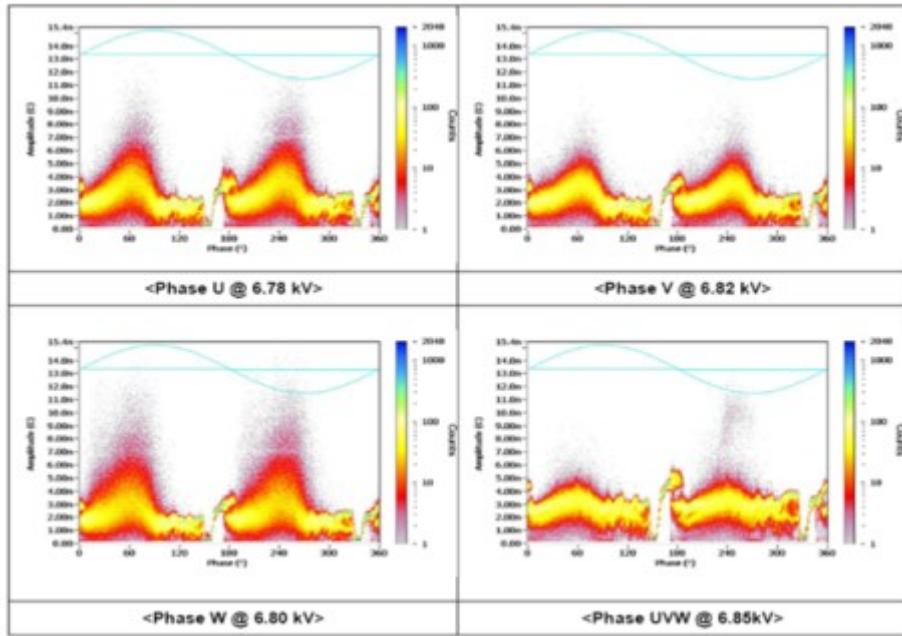


Figure 7: Partial discharge measurement result.

Dielectric strength reference standard returns the value of 40%, so that it is recommended to rewind stator windings before the dielectric strength declines to 40% of initial mean value. Considering the safety operation, when the estimated value has reached 45%, it is recommended to performed rewinding (Mitsubishi Electric Corporation reference No. CNB-4287-048). The data needed to perform the analysis is operating hours and start and stop. The result shows that dielectric strength value for the generator is about 30% as shown in Figure 8.

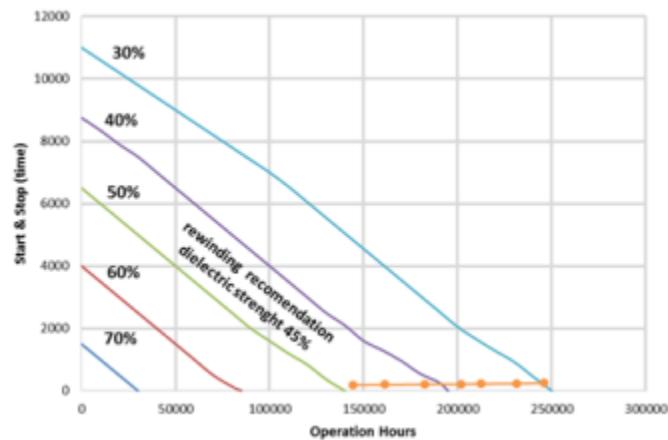


Figure 8: Dielectric strength graph.

The operation data shows that the stator winding maximum temperature in 1995 was about 83°C, while in 2012 the stator winding temperature had reached the amount of about 95°C. Stator winding temperature has increased by a total of 12°C from 1995 until 2012. This is due to the demand fluctuation on the system and affects the transmission voltage which has decreased significantly. This problem has negative impact on the generator as it produces more reactive power, thus heat increases. The generator cooling system cannot compensate that fluctuation. The increase of temperature will shorten the generator's life.

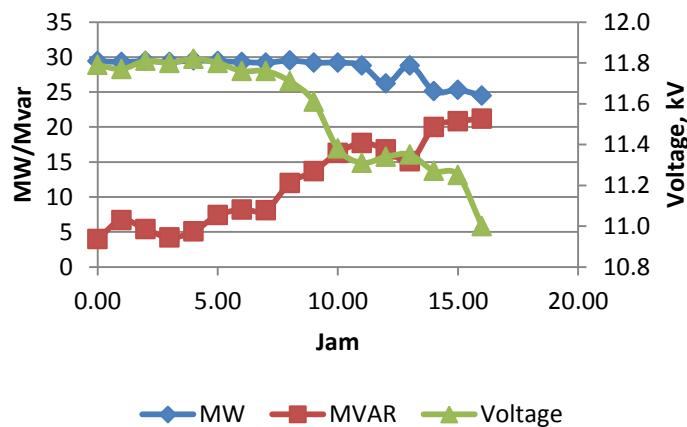


Figure 9: History of demand fluctuation in the system.

Based on the reliability prediction and current condition analysis, reliability improvement programs for generator are stator winding rewind in 2015 and generator cooling performance upgrade in 2016.

5.2 Transformer Current Condition and Improvement Program

The assessments conducted on the transformer are:

1. Oil transformer analysis such as dissolved gas analysis, water content, acidity, dielectric strength, furan test.
2. Short circuit test.
3. Operation condition analysis.

The performed assessments are used to determine the condition of the main transformer. The baseline is then taken into reliability improvement program considerations.

Oil analysis indicates that the water content in the transformer oil exceeds the standard value. The breakdown voltage of the transformer oil is at the level of not being permitted to be operated, while the transformer winding insulation is at the condition of accelerated ageing rate.

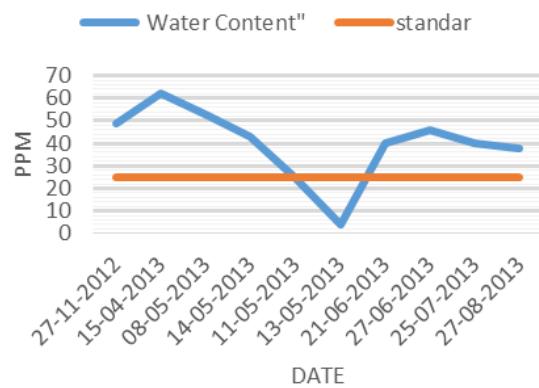


Figure 10: Water content in transformer oil.

The short circuit test shows that the resistance value of the winding is 2.74Ω . The result indicates that the winding resistance has increased by 2.1Ω compared to the resistance value of the factory test. This condition means losses increment in the transformer. Efficiency calculation shows the efficiency of the transformer has decreased by 3%. Transformer efficiency is an important factor, because the energy sales transaction point is located at high voltage side of the transformer.

Because of the demand fluctuation on the system, transmission voltage has decreased significantly. This gives temperature increment in the transformer winding of about 13°C from 2009 until 2012.

Based on the reliability prediction and current condition analysis, reliability improvement program for transformer is oil transformer regeneration in 2014. One thing to keep in mind is that due to high cost requirements in association with repair/reliability towards the end of life and performance degradation, it may be a good economic decision to consider replacement of main transformer in 2015.

6. CONCLUSION

1. Reliability analysis conducted shows that the generator has a reliability value of 23%, while the reliability of the transformer reaches 12% within 245,748 hours of operation (equivalent to 30 years).
2. Improvement programs for the generator are stator winding rewind in 2015 and generator cooling performance upgrade in 2016. Partial rewinding could be somewhat to refresh the overall generator condition to its best. It is important to solve the problem of cooling system due to imperfect condition of the interconnection grid.
3. Improvement programs for the transformer are oil transformer regeneration in 2014 and replacement of main transformer in 2015. Transformer condition will be essential to Kamojang GPP and in term of losses as IP sells net power to the interconnection grid.

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