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Fifteen Years (Mid-Life Time) of Wayang Windu Geothermal Power Station Unit-1: An Operational Review

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ABSTRACT

Wayang Windu Geothermal Power Station was constructed in 1997 with initial plan of 2 x 110 MWe. Unit-1 was completed in early 1999 but then mothballed due to the transmission line had not been ready yet. The Commercial Operation Date (COD) took place in June 2000. Unit-2 was postponed until 2007 because of the economic crisis.

Wayang Windu Unit-1 was the first geothermal unit that designed with capacity of more than 100 MWe and the biggest single unit geothermal steam turbine in the world. Because of this condition, Wayang Windu Unit-1 was operated with full monitoring and careful handling, including 6 years warranty from Fuji Electric on the last stage blades of the turbine.

After almost 15 years of successful operation, Wayang Windu Unit-1 indicates an excellent performance. The Availability Factor of the unit exceeds 96%. Even more, it reached 100% in 2010 and 2011 consecutively. The Plant Reliability Factor is never less than 99.5%. In term of Capacity Factor, Wayang Windu Unit-1 can generate electricity more than 95% to fulfill energy sales contract to Perusahaan Listrik Negara (State Owned Electricity Company). Forced Outage is minimized by maintaining the plant at the highest performance through implementation of Maintenance Management System (MMS).

Several optimizations have been made to improve the Wayang Windu Unit-1 capacity. The initiatives that came from the Operational and Maintenance Team have enabled the plant to be operated beyond its designed capacity. The 110 MWe rated capacity is now improved and able to generate 114 MWe up to 116 MWe gross within Original Equipment Manufacturer (OEM) specification.

The successful on balance of plant (BOP) improvement became criteria points to design Wayang Windu Unit-2, the identical unit with capability to interchange parts. These include modification of condenser nozzles, modification of turbine inlet pressure set point, and modification of cooling tower fan stacks. Improvement on SAGS design also contributes to provide high quality steam to minimize scaling problem that normally encountered in geothermal operation.

This paper provides experience in operating and maintaining Wayang Windu Unit-1 as the first largest single flash geothermal power station. The plant performance after reaching mid-life time operation is presented. Various aspects that related with the capability to achieve operational excellence are also described.

1. INTRODUCTION

Wayang Windu Geothermal Field took the name after Mount Wayang & Mount Windu, the two small lava domes without historic eruption history (Hochstein and Sudarman, 2008). The field is located at Pangalengan, approximately 40 km to the south of Bandung, the capital of West Java, Indonesia. The elevation lies between 1500 – 2100 m above sea level

Review on initial exploration from various sources by Hochstein and Sudarman (2008), Bogie et al. (2008), and Mulyadi and Ashat (2011) showed that early geological, geochemical and geophysical surveys had been conducted by Pertamina in 1981. The first deep exploration hole was drilled at WWA-1 (previous name was WWD-1) in 1991 to the west of the saddle between G. Wayang and G. Windu. WWA-1 had bottom temperature of 278°C at approximate depth of 1600 m (Ganda et al., 1992). Another deep exploration hole, called MSH-1, was drilled in 1993-1994 with approximate depth of 600 m, located about 5 km to the north of WWA-1. The two wells indicated the existence of shallow two-phase zone lying above a liquid-saturated deep reservoir (Hochstein and Sudarman, 2008).

The development of Wayang Windu field accelerated after the Indonesian government introduced fixed contract scheme that allow the development of Independent Power Producer (IPP) in 1994 (Hochstein and Sudarman, 2008). Under this scheme, large investors who were tied by Energy Sales Contract (ESC) to State Electricity Company (*Perusahaan Listrik Negara*/PLN), can develop a complete Geothermal Power Station that consist of steam production system and power generation system. The ESC for Wayang Windu Field was signed in December 1994 between PLN and Joint Operation Contract (JOC) of Pertamina and Mandala Magma Nusantara BV. Pertamina represented Indonesia Government to undertake exploration and exploitation of geothermal resources in Wayang Windu area, while Mandala Magma Nusantara BV, who served as contractor to Pertamina, was responsible for the production of geothermal energy and conversion of such geothermal energy to electricity, including the transmission of such electricity up to the metering point with PLN.

The drilling campaign in 1996 confirmed the existence of vapor-dominated reservoir as encountered from the previous exploration drilling. An initial resource potential of 220 MW (gross) development was secured with possible extension to 440 MW (gross).

Engineering, Procurement and Construction (EPC) contract with Sumitomo Corporation was signed in 1997 to construct 2 x 110 MW power stations. Asian economic crisis that badly hit Indonesia in the following year forced the Wayang Windu development to be scaled back to 1 x 110 MW (gross). All works associated with the second unit was suspended until 2007.

The construction of the first unit completed in August 1999. However, it was mothballed because the transmission line had not been ready. The commissioning was carried out in May 2000 and the commercial operation started one month later.

The shareholder of Wayang Windu project has changed several times. The first owner during early development in 1994 was Mandala Magma Nusantara BV, a joint venture between Magma Power Company with PT Okha Hutomo Satrya and Figear Limited. After the merger between Magma Power Company and California Energy, the contract principle party changed to Asia Power Ltd, a subsidiary of New Zealand's Brierly Investments Ltd. However, following Asia Power's failure to repay the loans, the Wayang Windu project was handed over to bank creditors (Deutsche Bank and Credit Suisse) after completion of the first unit.

In 2001, Unocal took over 50% of Wayang Windu project shares through its subsidiary, Unocal Global Venture. The remaining 50% owned by the banks through holding company Magma Nusantara Ltd. The lenders appointed Unocal as the operator of the power plant since then. Three years later, Star Energy acquired 100% shares of Wayang Windu project.

In 2012, Mitsubishi Corporation acquired 20% shares of Star Energy Geothermal Pte Ltd, the holding company of the Wayang Windu project. The shareholder remains unchanged up to the present.

2. WAYANG WINDU UNIT-1

2.1 Steamfield Above Ground System (SAGS)

Wayang Windu potential resource area is approximately 40 km^2 (Bogie et al., 2008). Modeling study on Wayang Windu field has been conducted by Mulyadi and Ashat (2011), and Asrizal et al (2006). The steam supply for Wayang Windu Unit-1 was taken from the two-phase zones and the deep liquid reservoir from the north and the central area of the field (Mulyadi and Ashat, 2011). There are 4 main production wellpads and 2 brine condensate injection wellpads. By taking the advantage of different elevation between production wellpads (± 1850 masl) and injection wellpads (± 1500 masl), no pump injection is required. Figure 1 presents the schematic diagram of Wayang Windu SAGS.

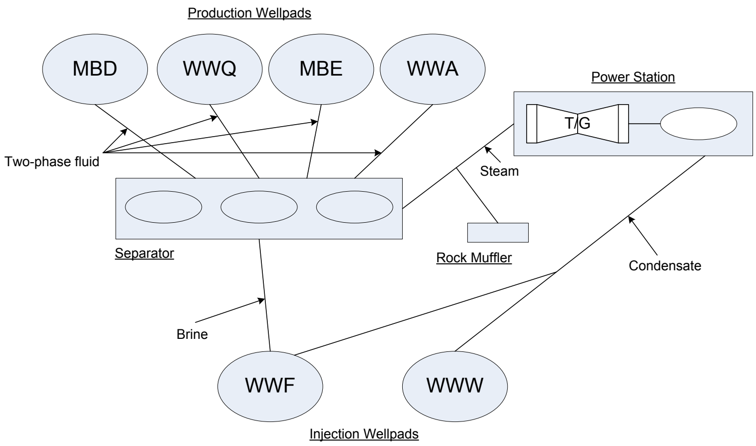

Figure 1: Schematic Diagram of Wayang Windu SAGS (Unit-1)

Centralized separator station is utilized to separate steam and water (also called brine) from the two-phase fluid. The design follows a typical Weber separator that firstly installed in Wairakei, New Zealand. There are 3 separator vessels for Unit-1 in which each is rated for 40 MWe. The vessel dimension seems to be an optimum combination between Bangma's design (1961) and Lazalde-Crabtree's design (1984). In this design, the mixture fluid enters the separator through a spiral inlet. As the fluid rotates, the water with higher density will move outward and downwards while the steam with lower density will move inward and upward. The steam will then exit through the outlet pipe. The water that accumulated at the bottom will be injected back in to the earth by gravity. Loop-seal is utilized to control the brine level within the vessel.

Utilizing centralized separator station near the power station results in less time for scrubbing any carried over materials. Hence, Wayang Windu installed large scrubbers between separator and turbine to ensure that both solid minerals and droplet water carryover can be minimized. There are 2 scrubber vessels for Unit-1 in which each is rated for 60 MWe. The scrubber design is similar to the Bottom Outlet Cyclone (BOC) separator design.

The pipeline system in Wayang Windu can be categorized into four: the two-phase pipeline, the steam pipeline, the brine pipeline and the condensate pipeline. The main two-phase pipelines from the wellpads to the separator are 36 inches carbon steel pipe with approximate distance of 4 km. The steam pipeline from the separator the power station is 40 inches carbon steel pipe with approximate distance of 1 km. The brine pipeline from the separator to the injection well is 30 inches carbon steel pipe with approximate distance of 8 km.

The condensate pipeline from the power station to the injection well is 16 inches carbon steel pipe. After experiencing some failures caused by internal corrosion, high density polyethylene (HDPE) material is used in some parts of the pipeline. The total length of condensate pipeline is approximately 9 km. The first 4 km has been replaced with HDPE pipeline.

Figure 2: Wayang Windu Separators

2.2 Power Station (PS)

The design of Wayang Windu Power Station follows a typical single flash geothermal plant. As the first geothermal unit with large capacity (Murakami et al., 2000), Wayang Windu enjoy 6 years warranty benefit from Fuji Electric on the last stage blades of the turbine. The turbine was design with output capacity of 110 MWe. The inlet and the outlet steam pressures are 10.2 bara and 0.12 bara respectively. The turbine is directly coupled with 137.5 MVA air cooled turbo-generator that supply power to 150 kV PLN's grid. The generator utilizes a typical brushless excitation system.

The turbine is a single casing reaction type with 8 stages in each flow. It adopts dual entries of steam. There are two main stop valves at each side of the turbine. Four governor valves of butterfly type are installed after the main stop valve to control the turbine speed. The opening and closing of these governor valves are controlled by the Electro Hydraulic Governor (EHG) Woodward 505.

The exhaust steam from the turbine goes to a direct contact spray type condenser located under the turbine. The cooling water to condense the steam was taken from the cooling tower. The condensate is pumped from the bottom of condenser to the cooling tower by two 50% duty hot well pumps. The non-condensable gasses (NCG) are removed by the gas removal system (GRS) and discharged to the atmosphere via cooling tower. The GRS is a hybrid system that consists of combination between steam ejectors and a liquid ring vacuum pump.

The cooling tower is a forced draught counter flow type. There are eight cells, each consists of an electric motor, a driven shaft, a gear reducer, a fan hub and a number of fan blades. The motor driven fans create a forced air flow through cooling tower that remove the heat from the condensate.

A simplified diagram of plant electrical system is given in Figure 3. For internal power consumption, the plant utilizes 6.3 kV system for major auxiliary plant supplies and 380 V system for general auxiliary equipments supplies. There are also 110 VAC system used to power the Distributed Control System (DCS), 125 VDC system used to power the switchgears control and 230 VDC system that activated only when AC power fails and the system runs on batteries.

There are 2 different bus bars for the 6.3 kV systems: the Unit-1 and the station. The station bus is also tied to Unit-2 bus to supply common load for the whole power plant. The purpose is to ensure that when one unit is under maintenance (during overhaul); the load still can be supplied by another running unit.

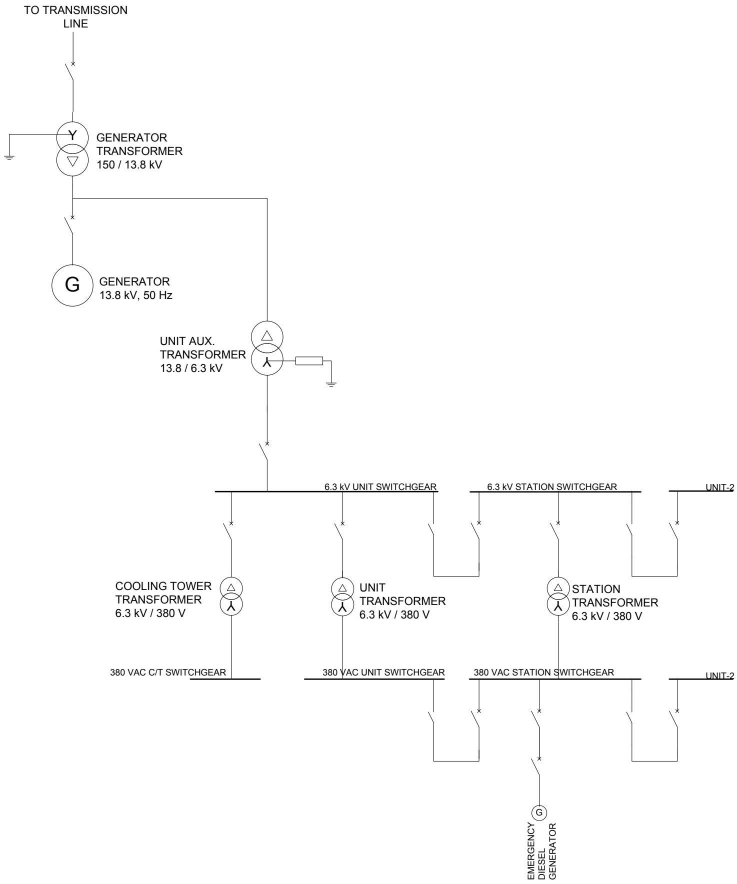

Figure 3: Simplified Single Line Diagram Wayang Windu Unit-1

3. OPERASIONAL EXPERIENCE

Wayang Windu Power Station was designed to be efficient and environmentally friendly in the use of steam for production processes by implementing Zero Venting Concept (see Figure 4). The main feature of this control concept is to maintain the stability of the steam pressure, minimize steam venting to the atmosphere and maximize generation output.

Figure 5 shows the generation statistic of Wayang Windu Unit-1 from COD until May 2014. After almost 15 years of successful operation, it is clearly seen that Wayang Windu Unit-1 indicates an excellent performance. The Plant Availability Factor of the unit is never less than 96% and reached 100% in 2010, 2011 and first semester of 2014. The Plant Reliability Factor always exceeds 99.5%. In term of Capacity Factor, Wayang Windu Unit-1 can generate electricity more than 95% to fulfill energy sales contract to PLN.

The key to achieve such an excellent performance is through implementation of Maintenance Management System (MMS). The MMS ensures that all equipment installed in Wayang Windu is well maintained and can be operated in safe manner. The MMS system cycle in Wayang Windu consist of six elements (see Figure 6):

- Master Equipment List (MEL) – Identification of all installed facilities and equipment.
- Reliability Centered Maintenance (RCM) – The process to conduct maintenance prioritization work according to risk, function and economic.
- Precision Maintenance (PM) – Standardization of all maintenance procedure by referring to internationals applicable code, government regulation, OEM manual and best practices.
- Maintenance Planning (MP) – Development of maintenance work plan and schedule based on work priority so that maintenance resources can be utilized effectively and efficiently.
- Life Data Analysis (LDA) – The process to analyze the performance and reliability of equipment to determine the effective maintenance schedule and strategy.
- Failure Root Cause Analysis (FRCA) – The process to conduct proper investigation during equipment failure so that the root cause can be determined and the failure recurrence can be prevented.

Proper implementation of the six elements above has resulted in a very minimum forced outage experienced by Wayang Windu Unit-1, creating a reliable and efficient plant.

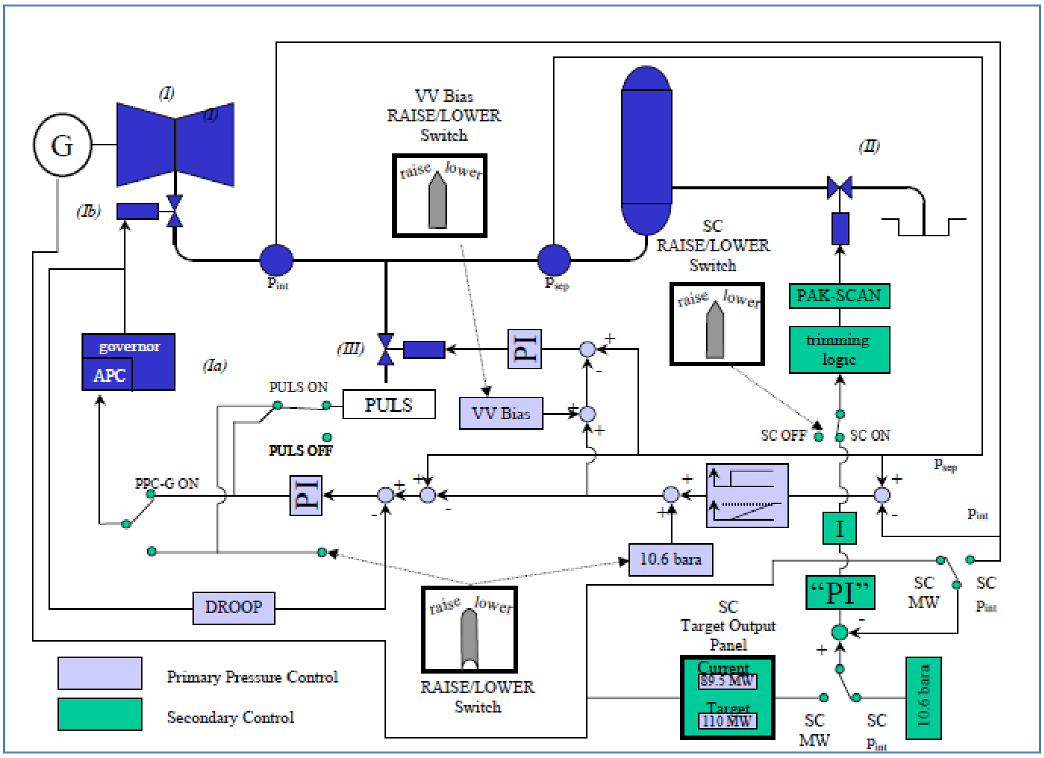

Figure 4: Zero Venting Concept – Integrated Pressure Control (Designed by Fuji Electric)

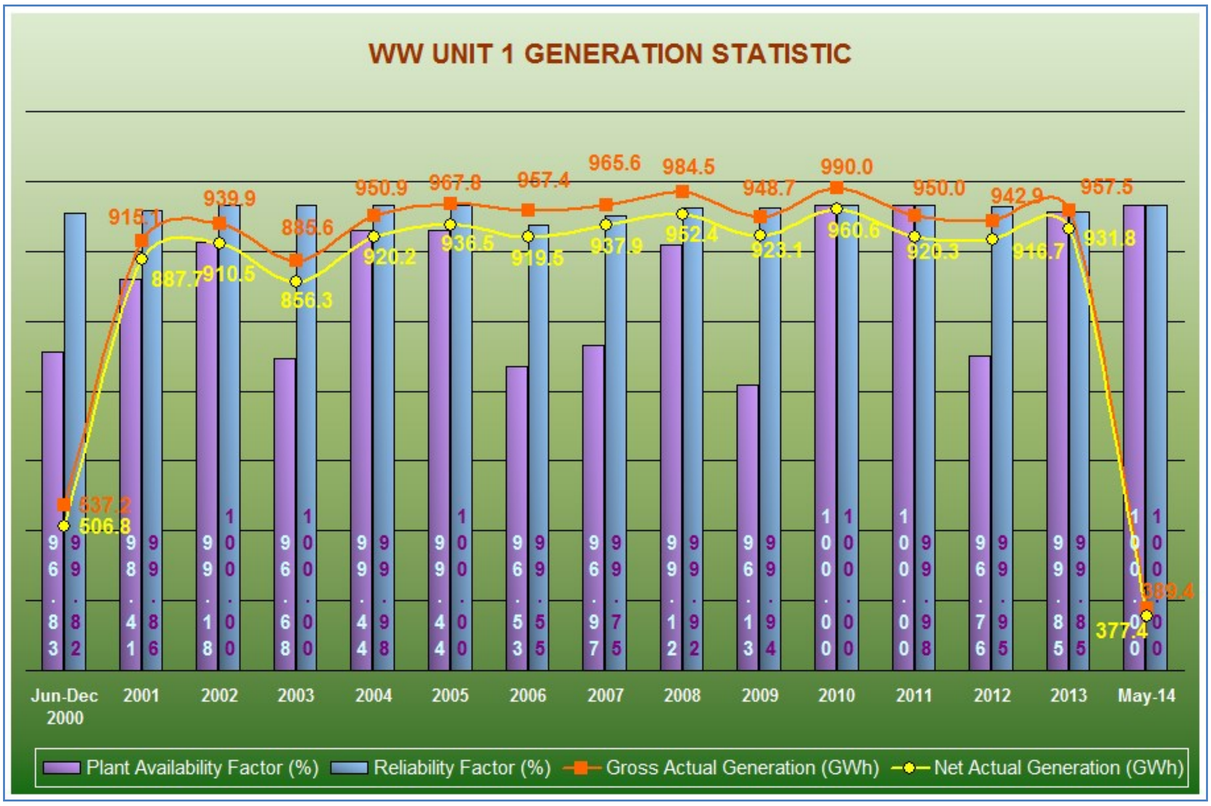

Figure 5: Wayang Windu Unit-1 Generation Statistic

Figure 6: Wayang Windu MMS Cycle Process

Motivated by the desire to create a more optimal plant, the Operational and Maintenance Team saw an opportunity to improve the plant capacity by conducting several modifications as described below.

a. Turbine Inlet Pressure Setting Modification

In the beginning of operation, the turbine inlet pressure of Wayang Windu Unit-1 settled at 10 bar. The turbine steam rate under this setting was 2 kg/s/MW. After fully understood the steam pressure characteristic, the setting was then modified to 10.2 bar. As a result of this change, the turbine steam rate decreased to 1.96 kg/s/MW. This means the same power output can be achieved with less steam consumption. Figure 7 shows the impact of turbine inlet pressure setting modification to generation output.

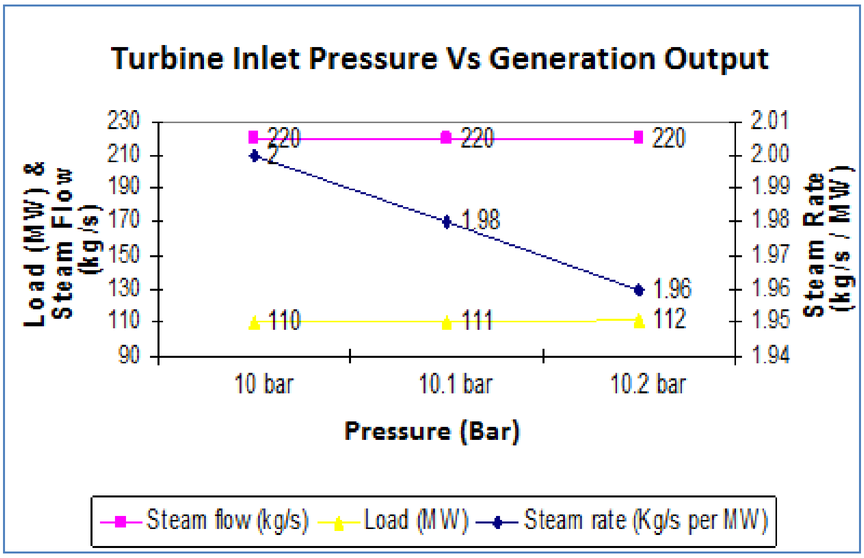

Figure 7: Wayang Windu Turbine Inlet Pressure vs Generation Output

b. Condenser Nozzles Modification

Gas Cooling Zone (GCZ) Nozzle condenser was modified to improve the condenser performance. The point of modification was to increase the size of the nozzle diameter (Zein et al., 2010). After this modification, the average condenser pressure reduced from 0.13 bara to 0.11 bara, resulting in less steam consumption rate and higher power generation output. Figure 8 shows the relations of steam rate and generation output before and after condenser nozzle modification.

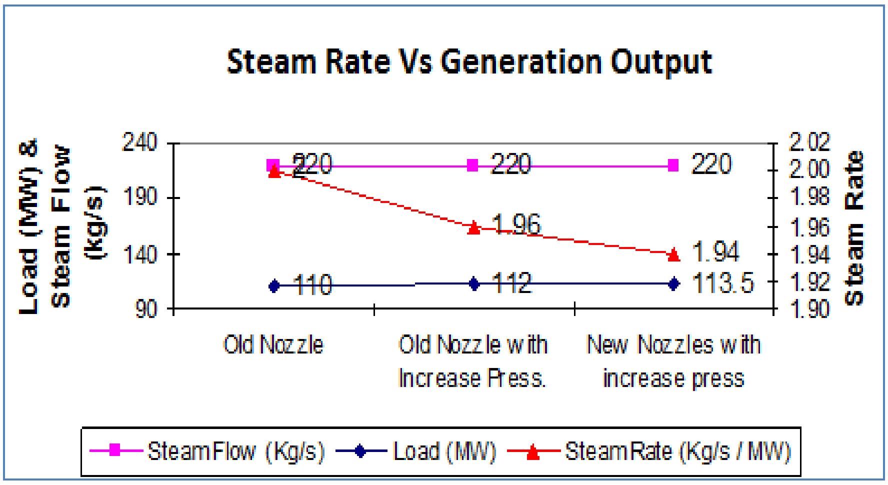

Figure 8: Steam rate after condenser nozzle modification

c. Cooling Tower Optimization

Cooling tower has an important role in the generation process. Problems that commonly occurred at cooling tower are cooling water pipe clogging, mostly by sulphur deposits, and fouling of condenser nozzles because of bugs or beetles which pass through the cooling tower exit screen. Maintaining the cleanliness of cooling tower water distribution pipe is carried out by controlling the sulphur deposits and performing regular cleaning. To avoid fouling problem due to bugs or beetles, fine wire mesh was installed at the cooling tower exit screen to act as a filter before the cooling water flow to condenser (Zein et al., 2010).

Other optimization that conducted at cooling tower of Wayang Windu Unit-1 is fan stack modification. The fan stack is modified by replacing the old fan stack with the higher one to improve the air flow performance. An improved cooling tower will produce lower cooling water outlet temperature. This improves the efficiency of the condenser and increases the turbine power output. Figure 9 shows the activity during Cooling Tower Fan Stack Modification.

Figure 9: The activity during fan stack modification

After modifications above were performed, the 110 MWe rated capacity of Wayang Windu Unit-1 is now improved and able to generate 114 MWe up to 116 MWe gross within OEM specification. Figure 10 shows the trends of Gross Capacity of Wayang Windu Unit-1 from 2000-2014.

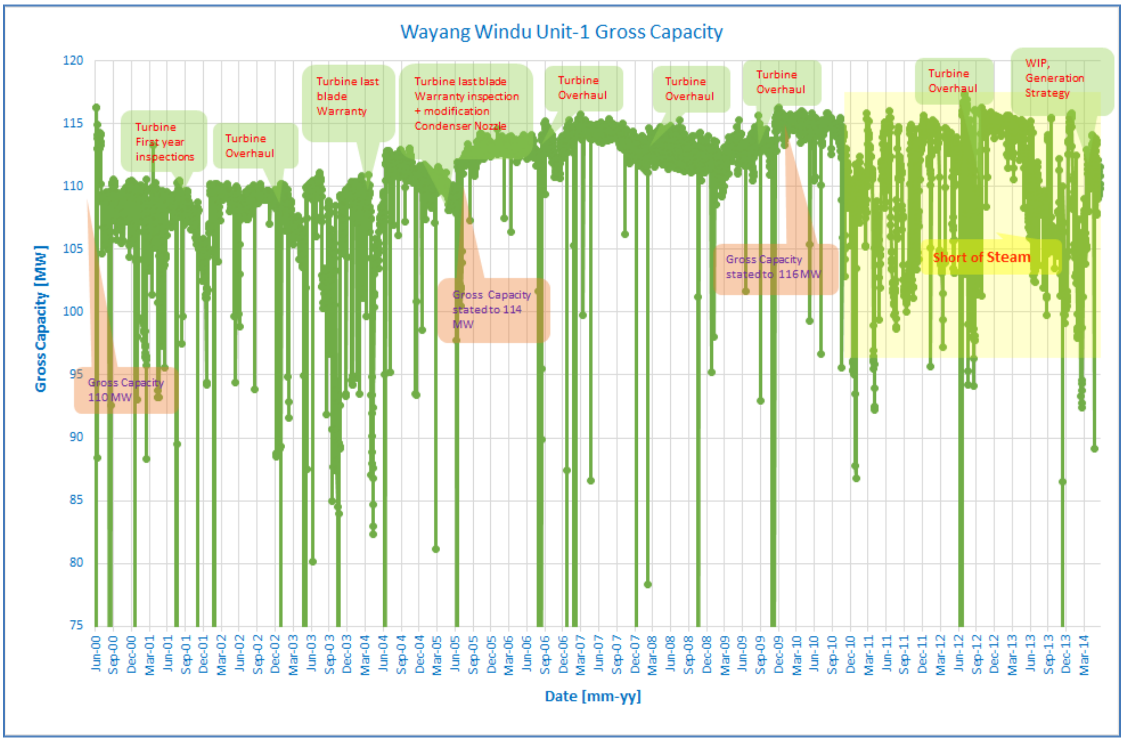

Figure 10: Gross capacity of Wayang Windu Unit-1 (2000 – 2014)

3. CONCLUDING REMARK

The Wayang Windu Unit-1 as the first largest geothermal power station has shown an impressive operation statistics. Although it is normal to observe a plant that deteriorates after more than 10 years in operation, Wayang Windu Unit-1 proves that such condition can be avoided by proper maintenance system. Even more, several improvements are still able to be conducted to enable the plant being operated beyond its designed capacity. This has created a new benchmark on the geothermal industry. The successful on Wayang Windu Unit-1 BOP improvement became criteria points to design Wayang Windu Unit-2, the identical unit with capability to interchange parts.

Considering the existing operational condition of Wayang Windu Unit-1, there is no doubt that the plant can continue generating power within the duration of ESC and beyond. Future challenge in the operation of Wayang Windu Unit-1 is the availability of the spare parts. Several years from now, some of the equipment might not be available or the models might have been superseded by changes in technology. Hence, acquiring the spares will be both cost and time challenging. This issue shall be identified and addressed as early as possible to ensure that Wayang Windu Unit-1 can consistently perform above expectation.

4. ACKNOWLEDGEMENT

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