MODIFICATION OF UNIT 1 COOLING TOWER (CT) TO IMPROVE THE CT PERFORMANCE IN STAR ENERGY GEOTHERMAL (WAYANG WINDU) LTD

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ABSTRACT

Unit 1 Cooling Tower (CT) in Wayang Windu Geothermal Power Plant has been operating since 2000. Extensive works have been conducted by Star Energy Geothermal (Wayang Windu) team in order to improve the performance of the CT while assuring excellent operational reliability. The first project in 2011 was replacing the CT fan stack with a higher version. Data from a Unit 1 CT performance test revealed a decrease of approach temperature by as much as 1.44°C, an increase of range temperature by as much as 1.92°C, and an increase of CT efficiency by as much as 5.17%. The impact was equivalent to a net generation improvement of 1.44 MW. The second project, carried out from 2014 till 2017, involved replacing the existing low reliability CT gearbox with a more reliable gearbox and increasing the number of fan blades. The CT upgrading project improved the CT thermal performance and the impact was equivalent to a net generation improvement of 0.40 MW.

1. INTRODUCTION

Wayang Windu Geothermal Power Plant operates 2 (two) geothermal steam turbine units. Unit 1, which has a capacity of 110 MWe, was the largest single cylinder turbine in the world when it was commissioned in year 2000. Unit 2, which has a capacity of 117 MWe and has an improved design compared to Unit 1, was commissioned in year 2009. Both units deliver the electricity to PLN (Indonesia's state electricity company).

1.1 Unit 1 CT Plume Recirculation Issue

The Unit 1 CT fan stack was designed with a height of 6 feet only and had relatively straight vertical panels which did not produce significant velocity recovery. On other hand, as the Wayang Windu Geothermal Plant is located in the mountains, the CT is exposed to swirling and shifting winds. These types of winds can force down the exiting plume (hot air) from the CT and it may be drawn back into the CT which increases the entering wet bulb temperature. This phenomenon is called recirculation. The increase of wet bulb temperature has the impact of decreasing of CT performance. Figure 1 shows the plume recirculation in Unit 1 CT.

In order to reduce the effect of plume recirculation, a new design with a higher fan stack was proposed. In addition, there was an opportunity to modify fan stack design to get higher fan blade efficiency. SEGWWL engineers conducted an engineering study based on available design data, simulation and experimental methods. The aim is that the new fan stack design will produce significant velocity recovery to convert some of the wasted velocity pressure energy at the top of the fan stack into useful work at the plane of the fan, and therefore fan efficiency will be increased. By improving fan efficiency, additional motor power can be made available to further increase the air drawn through CT and thus, overall CT performance can be improved.

Figure 1: Major plume recirculation in Unit 1 CT.

A detailed report on the Unit 1 CT fan stack replacement was published in a paper on Unit 1 Cooling Tower Fan Stack Replacement to improve CT Perfomance, presented at the World Geothermal Congress 2015, Melbourne, Australia.

1.2 Unit 1 CT Gearbox Low Performance Issue

Unit 1 CT gearboxes (brand: Sumitomo, model: PX8065R2Y-RRV) have been operating since commissioning in year 2000. This common industrial gearbox was designed with a low thermal Service Factor (SF) design of 0.96 (below the minimum thermal SF required of 1.0) and marginal mechanical Service Factor (SF) design of 2.04 (minimum requirement SF for CT is 2.0). Since the start of operations, gearbox failure has been identified with failure of gear teeth components after only 1 year of operations. Further investigation revealed that a poor cooling process and H_2S exposure in the gearbox breathing air were the causes of these failures. The oil cooling system used air withdrawn by a radial fan installed on the input shaft which produced low heat transfer due to the oil capacity and small size of the gearbox housing. Improvement works have been done by installing gas absorbent media on the breathing line, providing an additional oil tank to improve cooling performance and changing lubricant oil from a mineral type to a synthetic type. Although these approaches prolong the gearbox lifetime for up to 2 to 3 years of operation, however, more maintenance efforts and funds should be spent especially to purchase the gearboxes spare parts (which became listed as "obsolete" spare parts) and the synthetic lubricant oil. Due to the spare parts being categorized as "obsolete" spare parts, special spare parts manufacturing was required which resulted in a long delivery time and high spare part cost. Figure 2 shows a picture of failures of the CT gearboxes.

Figure 2: Severe gear tooth defect of CT gearbox

In order to improve the reliability of the CT gearbox, it was proposed to change the gearbox design, considering both the opportunity to improve the CT performance and economical capital cost. The engineering study and execution work of the CT upgrading project are reported in this paper.

2. ENGINEERING STUDY

Design of a cooling tower requires a combination of many engineering disciplines. Mechanical engineering, chemical engineering, and civil engineering disciplines contribute significantly in CT design. In this project, SEGWWL engineers conducted an engineering study based on available design data, simulation and experimental methods. The aim is that the new gearbox should have good reliability and maintainability to support the continuous operation of the Unit 1 power plant.

The scope of the engineering study was as follows:

- CT Gearbox Selection
- Fan blade performance simulation
- CT structure strength analysis
- Air flow measurement before and after modification
- Thermal imaging monitoring

2.1 CT Gearbox Selection

The criteria required of the Unit 1 CT gearbox for this project are described below:

- It is a common product for CT application and has already been used in many industries, especially power plants and chemical plants.
- The after-sales service can be provided promptly.
- Minimum modification of gearbox support is required.
- The gearbox load can be supported safely by the wooden structure of Unit 1 CT.

An Amarillo gearbox is chosen based on the above criteria. The Amarillo gearbox has been successfully used since the early 1970's in many cooling tower applications throughout the world. The spare parts could be purchased with lower cost and prompt delivery time. Table 1 shows gearbox comparison between Sumitomo gearbox and Amarillo gearbox for the same design application.

Table 1: Sumitomo and Amarillo Gearbox Comparison

Description		Existing Gearbox	Proposed Gearbox
Physical	Brand	Sumitomo	Amarillo
	Model	8065	1712
	Gear Ratio (Actual)	12.469 to 1	12.5 to 1
	Weight (Lbs/ kg.)	1500/ 680	2125/ 964
Fan data	Type	Hudson, Tuflite III	Hudson, Tuflite III
	Blade Number	8	8
	Output fan speed (rpm)	118.7	118.4
	Required power (kW)	113.03	113.03
Cost	Gearbox cost	USD $72,000	USD $35,000
	Maintenance cost in 5 years	USD $81,192	USD $12,370
Lubrication	Lubrication Method	Mechanical oil pump	Oil slinger
	Lubrication Quantity (liters)	55	80
	Lubricant	Mobile SHC XMV460 (synthetic)	Mobile DTE-BB (mineral)
	Oil cost (for 1 gearbox)	USD $1269	USD $269
	Oil Level Switch	GEM Oil Level Switch	Murphy Oil Level Switch
	Recommended Oil Change Frequency (hours)	2500	3000
	Cooling method	radial fan on input shaft	radiant cooling (oil capacity)
Rating	Motor Rated Capacity (HP/kW)	177/132	177/132
	Gear Reducer Rated Capacity (HP/kW)	360.7/269	422/315
	Mechanical Service Factor (2.0 minimum required)	2.0378	2.3841
	Thermal Service Factor (1.0 minimum required)	0.96	not required
	Thermal Service Factor de-rating for altitude	0.9	not required
	Thermal Service Factor de-rating for ambient temperature	0.87	not required

From the CT gearbox comparison in Table 1, it is shown that the cost of the Amarillo 1712 gearbox is about half that of the Sumitomo 8065 gearbox while the oil cost for the Sumitomo 8065 gearbox is almost 5 times that for the Amarillo 1712 gearbox. The Amarillo 1712 gearbox's maintenance cost is only 30% of Sumitomo 8065 gearbox's maintenance cost. Besides, the service factor rating of the Amarillo 1712 gearbox is higher than that of the Sumitomo 8065 gearbox and the thermal service rating of the Amarillo 1712 gearbox is designed to equal or exceed the service factor rating when the discharge air temperature is 120°F or less. So, it is highly recommended to choose Amarillo 1712 gearbox for this gearbox replacement plan.

Further study showed more options can be derived by choosing the Amarillo 1712 gearbox or using the same gearbox design as for Unit 2 CT (Marley 4000) for this plan so that the maintenance team only conduct maintenance on 1 type of gearbox and spare holding costs are reduced. Moreover, a larger capacity gearbox has more flexibility to drive more fan blades in order to obtain more air flow for CT air flow improvement if required.

However, there are some constraints that should be considered for CT air flow improvement as follow:

- Rated capacity of Unit 1 CT service transformer is 1900 kVA.
- Performance verification of balance of plant (BOP) equipment.
- CT wooden structure capacity to withstand load for heavier gearbox safely.
- Unit 1 cooling tower motor circuit breaker system.

Table 2: Amarillo and Marley Gearbox Comparison

Description	Option 1	Option 2
Brand	Amarillo, 1712	Marley, 4000
Gearbox cost	USD $35,000	USD $73,500
Gear Ratio (Actual)	12.5 to 1	12.98 to 1
Output fan speed (rpm)	118.7	114.0
Weight (Lbs/ kg)	2125/ 964	3200/1451
Mechanical Service Factor (2.0 minimum required)	2.3841	2.9717
Oil cost (for 1 gearbox)	USD $269	USD $235
Maintenance cost in 5 years	USD $12,370	USD $17,030
Change of Drive Shaft	Not required	Yes, cost USD$ 14,000
Modification of gearbox support	cost USD $ 3,000	cost USD $ 5,000
Modification of fittings (hub, coupling etc)	cost USD $ 5,000	cost USD $ 5,000
Flexibility to achieve higher CT performance	Limited	More flexible due to have larger gearbox capacity

Table 2 shows a specification comparison between the Amarillo 1712 gearbox and the Unit 2 Marley 4000 gearbox. From the table, it can be concluded that Option 2 (Marley 4000) has the best performance compared to the other options. With the highest SF of 2.971, the Marley 4000 can also give a better contribution to an increase in CT performance by driving more fan blades which will produce more air flow. This improvement can be achieved by replacing the existing electric motor with a higher capacity electric motor. However, with the constraint of the Unit 1 CT service transformer rated capacity, the power required to drive higher capacity electric motor is not adequate. There are 8 cells (cell A, B, C, D, E, F, G, H) in Unit 1 CT to support the CT operation. If all gearboxes in 8 CT cells are replaced, it requires a huge effort and high cost to conduct a CT Service Transformer upgrade and BOP equipment replacement. The performance of BOP equipment such as HWP, GRS etc are designed to achieve maximum generation of 116 MWe gross. Besides, more effort and structure strengthening works are also required to assure CT wooden structure is safe to withstand the additional load. Based on the selection criteria and constraints of existing equipment design, the project team proposed to change the gearboxes of 4 CT cells (A, D, E, H) from the Sumitomo 8065 gearbox to the Amarillo 1712 and gearboxes of 4 CT cells (B, C, F, G) from the Sumitomo 8065 gearbox to the Marley 4000 including electric motor upgrades with opportunity to install additional fan blades. See calculation of Unit 1 CT service transformer capacity in Table 3.

Table 3: Unit 1 CT Service Transformer Capacity

Item	Service	Space heater	Arranged by	Equipment				Plant rated operation					E
				Capacity	Quantity			Shaft power	Motor		D	Required capacity	
				kW	A	B	C	kW	Eff %	PF %		kVA	
1	Incomer feeder from C/T service TR		DSGE		1								ACB
2	Cooling tower fan A	S	DKP	151.8	1			121	94.1%	89.0%	1.0	170.56	ACB
3	Cooling tower fan B	S	DKP	214.4	1			121	94.1%	89.0%	1.0	240.90	ACB
4	Cooling tower fan C	S	DKP	214.4	1			121	94.1%	89.0%	1.0	240.90	ACB
5	Cooling tower fan D	S	DKP	151.8	1			121	94.1%	89.0%	1.0	170.56	ACB
6	Cooling tower fan E	S	DKP	151.8	1			121	94.1%	89.0%	1.0	170.56	ACB
7	Cooling tower fan F	S	DKP	214.4	1			121	94.1%	89.0%	1.0	240.90	ACB
8	Cooling tower fan G	S	DKG	214.4	1			121	94.1%	89.0%	1.0	240.90	ACB
9	Cooling tower fan H	S	DKG	151.8	1			121	94.1%	89.0%	1.0	170.56	ACB
10	Spare		DSGE				1						ACB
TOTAL LOAD (kVA)												1,645.84	
C/T SERVICE TRANSFORMER CAPACITY (kVA)												1,900.00	
SPARE CAPACITY (kVA)												254.16	

2.2 Fan Blade Performance Simulation

There are many data that can be obtained from fan blade performance simulation as follow:

- Air flow
- Thrust load
- Motor capacity required
- Fan blade load
- Blade noise level, etc.

Thrust load data is the main input data required for CT structure strength analysis along with weight of the new gearbox and electric motor. A sample of a fan blade performance simulation is shown in Figure 3.

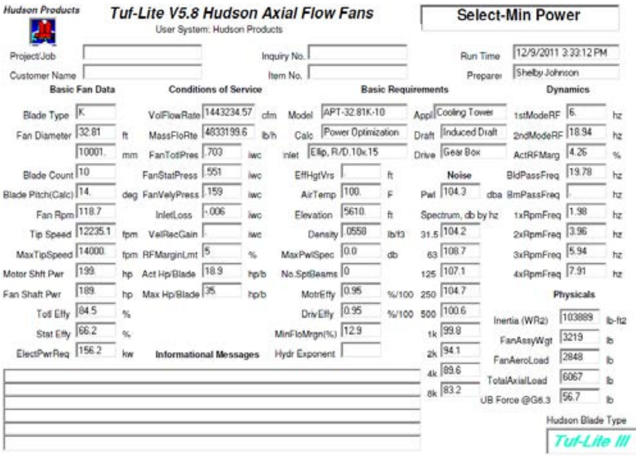

Figure 3: Fan Blade Performance Simulation

2.3 CT structure strength analysis

CT structure strength analysis was conducted to assure that the CT structure is strong enough to withstand the produced load while the CT is in operation. The flow chart for the CT structure strength analysis is shown in Figure 4.

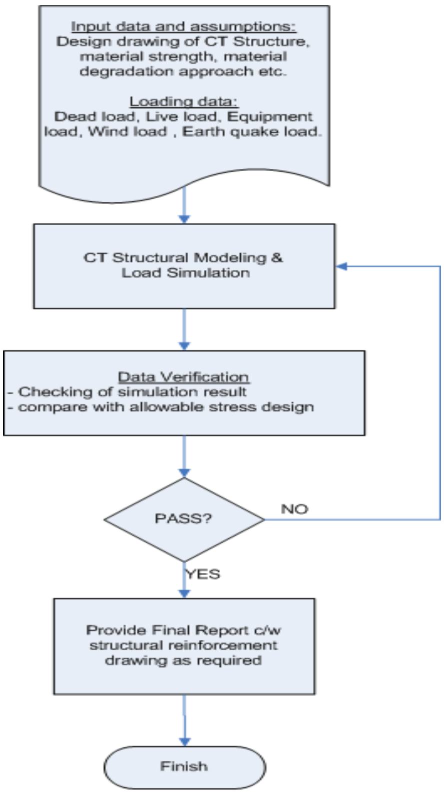

Figure 4: CT Structure Strength Analysis Flow Chart

2.4 Air flow measurement before and after gearbox replacement

Air flow measurement before and after gearbox replacement will be conducted to determine the improvement of CT performance. The resulting data will be compared with simulation data for further study.

2.5 Thermal Imaging Monitoring

Monitoring by using thermal imaging will be conducted to determine the change of water outlet temperature after the new gearbox and electric motor have been installed. The monitoring data is used to confirm the improvement of CT performance.

3. RESULT AND DISCUSSION

Simulation of fan blade performance provides technical data which will be used as input data for CT structure modeling, despite the static load data for the new gearbox and new electric motor being taken from the specification catalogue. The CT modelling will provide good technical data for studying the CT equipment upgrading design and to prepare a strategy to handle any technical issues which become obstacles in executing the project.

To assure the new gearbox and electric motor can be supported safely by the existing CT wooden structure, CT structure strength analysis was conducted by using the SAP program. By following the flow chart in Figure 4, there are several steps required to conduct structural analysis using the SAP program. The modeling of the CT fan stack and blades is shown in Figure 5.

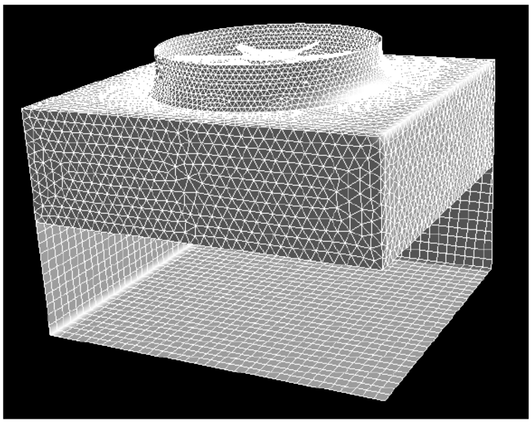

Figure 5: CT Fan Stack & Blade Modelling

After modeling of the CT structure, a loading simulation was conducted as shown in Figure 6. In this case, several loading simulations were conducted as follow:

- D
- D + L
- D + (W or 0.7E)
- D + 0.75(W or 0.7E) + 0.75L
- 0.6D + W
- 0.6D + 0.7E

Whereas: D = dead load, L = live load, W = wind load, and E = earthquake load

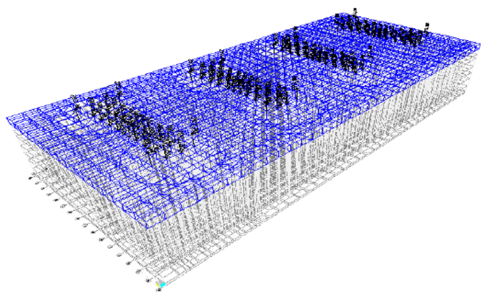

Figure 6: CT Structure Load Modelling

This simulation showed there is some reinforcement work required for the CT structure in order to provide safe operation of the CT. Figure 7 shows a drawing of wood reinforcement that should be conducted.

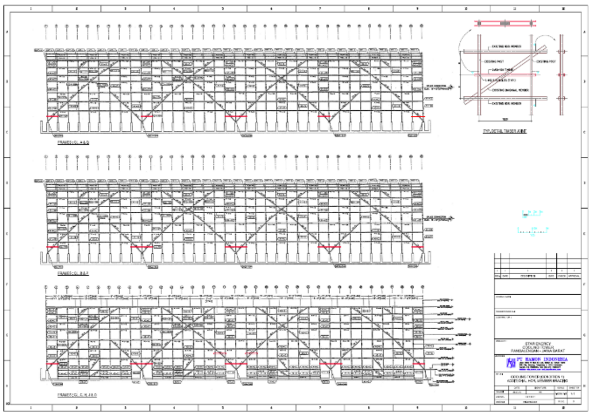

Figure 7: CT Structure Wood Reinforcement Point

The execution works were conducted with good preparation and completed within one month for each cell. The works were started by dismantling the existing torque tube, CT hub and fan blades; continued with modification of the torque tube frame (steel frame for gearbox and electric motor mounting), CT structure reinforcement work and reinstallation of the torque tube, hub and fan blades. The final step is assembly of drive shaft and final alignment between gearbox and electric motor. Figure 8 shows photographs of work execution.

Figure 8: Photographs of work execution

During CT cell commissioning and monitoring phase, CT outlet temperature and condenser pressure data were taken for comparison. It is revealed that the outlet water temperature after modification is lower than before modification and the condenser pressure after modification is lower than before modification as shown in Table 4. Trends of outlet water temperature data are also captured, which can be seen in Figure 9. Within a time period of 1 month before at November 2014 and after modification at January 2018, the decreasing water outlet temperature is shown by the trend chart. In addition, air flow measurement and thermal imaging monitoring were conducted. The point of thermal imaging measurement in shown in Figure 10.

Table 4: Water Temperature and Condenser Pressure Data Comparison

Time	Outlet Water (°C)	Design (°C)	Difference (°C)	Condenser Pressure (bara)
Before	27.76	23.50	4.26	0.126
After	26.62	23.50	3.12	0.117

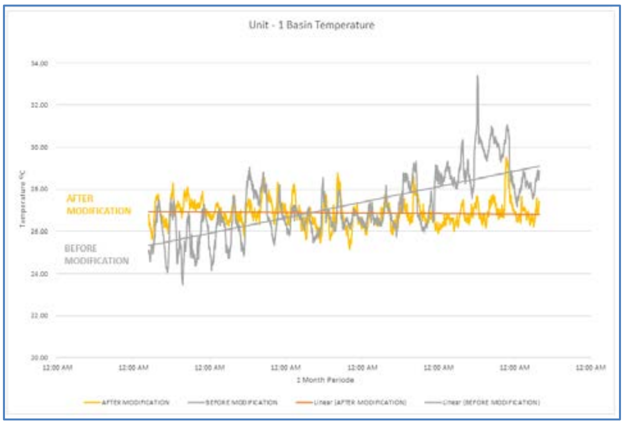

Figure 9: Trending of CT Outlet Water Temperature

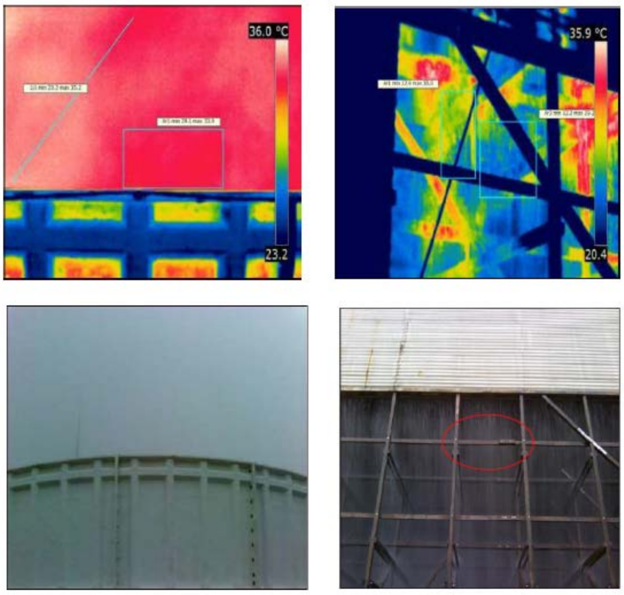

Figure 10: Thermal Imaging Measurement Point

As shown in Figure 11, significant improve of heat recovery from the new fan stack was revealed by the comparison of conditions before and after the CT upgrade project. The outlet plume temperature is hotter and the outlet water temperature is cooler after the project work. These data confirm the improvement of CT performance.

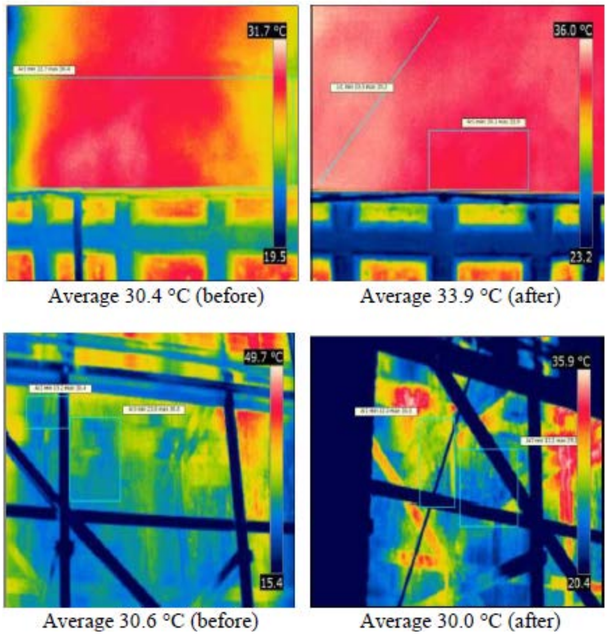

Figure 11: Thermal Imaging Data Comparison

4. CONCLUSION

The project of CT component upgrade, which was started in 2014 and ran until the end of 2017, was successfully conducted by replacing the low reliability gearbox with a more reliable gearbox and adding fan blades to improve the thermal performance of the cooling tower. The proposed budget was USD 800,000, but the real total capital cost for this project was USD 615,072, and so the cost saving was USD 184,928. The CT upgrading project improved the CT thermal performance and the impact was equivalent to a net generation improvement of 0.40 MW which provided additional daily revenue around USD 900/ day and the calculated BEP is 689 days.

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