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STUDY ON TURBINE INLET AIR COOLING BY CHILLED WATER FROM STEAM ABSORPTION CHILLER

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ABSTRACT

Output power and efficiency of gas turbines are influenced by ambient temperatures. Various studies prove that when ambient temperature rises the density of air decreases. This led to a decrease in the intake air mass flow to the turbine and consequently decrease in power output as power output is proportional to intake air mass flow rate. If no supplementary measures will be taken, both gas turbine output and efficiency drop. One of the measures that have been proposed is absorption chiller cooling for cooling of intake air of gas turbines. Absorption chiller cooling recovers heat from turbine exhaust gases, which it uses to produce chilled water in double effect lithium bromide absorption chiller. The chilled water is passed through a heat exchanger to cool the ambient air temperature. This proposed model is to be investigated using the operation data of the steam absorption chillers and turbines that are installed at the gas district cooling Universiti Teknologi Petronas. The operation data of the available steam absorption chillers and gas turbines will be used to establish the appropriate heat exchanger size for the proposed model. Simulation of the model using the available district cooling data will be done. The model could then be used for future prototype development of the system. The system would be useful for performance enhancement of gas turbines when ambient temperatures are high.

Keywords: gas turbine, efficiency, steam absorption chiller, gas turbine air intake, chilled water.

1. INTRODUCTION

Temperature of exhaust gas from gas turbines is usually very high, 460-540 °C. For this reason, several mechanisms have been suggested towards recovering the energy in the exhaust gas which would otherwise be lost to the environment and creating economic loss and environmental problems. Some of these studies included using the waste heat (i) to produce process steam, (ii) to directly drive steam absorption chillers [1], (iii) to produce steam, but then the steam will be used to operate steam absorption chillers [2-8], (iv) to produce steam, with the steam intended to either run a chemical process or operate a steam turbine, and (v) similar to case-1 but a different system used to recover the heat [9]. One interesting idea being investigated is the use of exhaust gas to cool the ambient air before it enters the compressor. Below are the key points related to this concept and highlighted in some of the literatures reported recently.

Popli *et al*. [2] evaluated the performance of three inlet air cooling options - (i) absorption chillers, (ii) conventional evaporative cooler[10], and (iii) vapor-compression chillers. The study was done using thermo-economic approach. They concluded that inlet air cooling using absorption chiller resulted in a better saving in energy. The reported payback period for the required retrofitting work was 1.3 to 3.4yrs only. The good performance from absorption chiller is also supported by the results reported in [8, 11].

Parametric studies related to inlet air cooling using waste heat were carried out using Engineering Equation Solver (EES). This was true in the works of Popli *et al*. [2] and Barrera *et al*. [9]. According to the stated reports, ambient temperature reduction to a minimum of 10 °C is possible regardless of relative humidity.

In almost all studies, electricity production increased by more than 10% [8, 12]. The factors included in the performance evaluation are mainly related to the gas turbine itself and flow sheet of the HRSG and absorption chiller [6, 8]. Constraints like off-peak hour tariffs and has not been taken into account.

Finally, as the preliminary literature review shows, the studies related to gas turbine inlet air cooling by absorption chillers are very limited. Besides, even though, thermal storage systems charged during off-peak hours and absorption chillers operating during on-peak hours are available, the merits of synchronizing TES and absorption chillers to reduce temperature of ambient air has not been reported yet. There is a promising case that heat exchanger for inlet cooling combined with proper operation scheduling might enhance energy saving.

Schematic diagram of a typical gas turbine power plant with inlet air cooling system is shown in Figure-1. It is comprised of a single shaft gas turbine generator, heat recovery steam generator, electric chillers, thermal storage, and heat exchanger for inlet air cooling. The gas turbine generates electricity from combustion of natural gas. While the main portion the generated electricity is used to support equipment outside the plant itself, a portion of it is consumed by electric chillers. Main role of the later systems is to produce chilled water for charging the thermal storage during off-peak hours. In general, such systems are capable of operating at high COP and provide a temperature as low as 6 to 7 °C. In the concept shown in Figure-1, the chilled water stored during off-peak hours is used to reduce temperature of ambient air before it enters to the compressor. As highlighted in many literatures, a 1

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°C reduction in inlet temperature may lead to a 1% increase in thermal efficiency, hence indicating the potential of inlet air cooling to efficiency enhancement of gas turbines. But nevertheless, the cost benefit analysis needs to be well investigated as the statement is based solely on the assumption that the TES is only charged during off-peak hours.

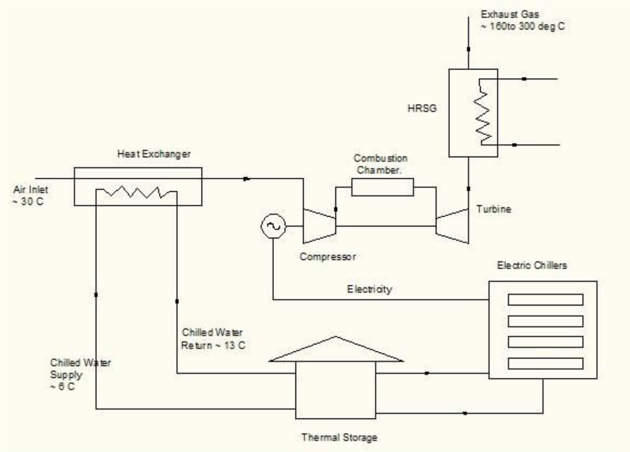

Figure-1. Inlet air cooling by chilled water from TS.

The second proposed idea is to create thermal potential in the inlet air cooling heat exchanger by directly using chilled water from absorption chillers. The chillers could be operated either by the exhaust gas from the gas turbine or steam from HRSG. Figure-2 shows an absorption chiller driven by steam from HRSG. As can be seen from the figure, in this case, the system can be operated during peak hours. One concern, however, is the limitation in the lowest temperature that can be achieved by the SAC. For crystallization reasons, it may not be possible to reach to a temperature of 6 to 7 °C like electric chillers. Therefore, the challenge will be to identify the possible temperature change without upsetting the normal operation either in the absorption chiller or gas turbine generator. In both Figure-1 and Figure-2, a counter current heat exchanger might be more effective than other kind of design.

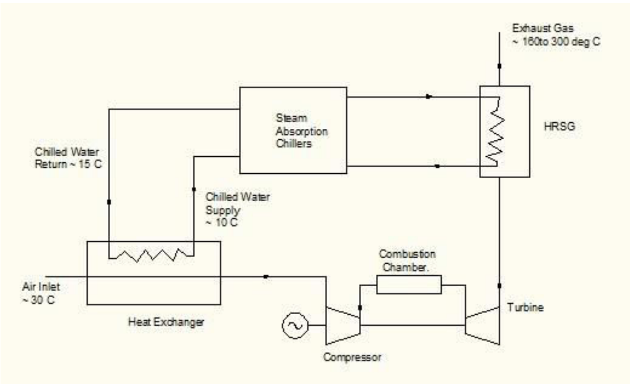

Figure-2. Inlet air cooling by chilled water from SAC.

2. PROBLEM STATEMENT

The main objective of the study is to configure the size of heat exchanger for cooling of turbine air intake using chilled water from steam absorption chiller to enhance the efficiency of gas turbine.

The study will estimate the approximately increased of GT efficiency with varying ambient temperature with reference data for Setiawan, Perak Malaysia to the ideal GT operating temperature of 24 °C. The historical data of 2015 power generated will be acquired from the UTP cogen plant and the ambient data to be obtain from the Meteorology Department of Malaysia.

3. METHODOLOGY

The project would be carried out according to the following procedure.

3.1 Data acquisition

Full analysis and quantifying the improvement needs information on a number of parameters. To this end, a data acquisition will be done on the following aspects:

- Environment data (temperature, humidity)
- Turbine air intake (flow rate, temperature, humidity)
- Chilled water temp at critical locations.
- Turbine power output and fuel consumption.

3.2 Formulate and simulate energy model

This particular step entails: identification of governing equations, formulation of energy model for heat exchanger, developing template, simulation of the model. Here emphasis will be given to the study of major losses and alternative approaches to efficiency enhancement.

3.3 Application of energy model to case study

In addition to the simulation done in the previous step, further study will be conducted by considering a case problem. One idea expel would be the Gas District Cooling plant in UTP. The scope will cover evaluation of the existing operating strategy and the potential for improvement as well as investigation of the improvement from inlet air cooling and any new proposal resulting from preliminary studies.

3.4 Comparative study

Here, the benefits from the proposed idea will be investigated. In order to verify if the benefit is operating point dependent, a parameter study will be considered, which is hoped suitable to cover part load operations and design changes.

To evaluate the GT performance, a schematic GT model as shown in Figure is to be used. The model consists the schematic diagram of standard GT cycle. Various states as shown in Table-1. Important parameters that were considered for the analysis are: atmospheric condition, air inlet temperature, fuel that enters the combustor, combustion gas entering the turbine and exhaust gas leaving the turbine.

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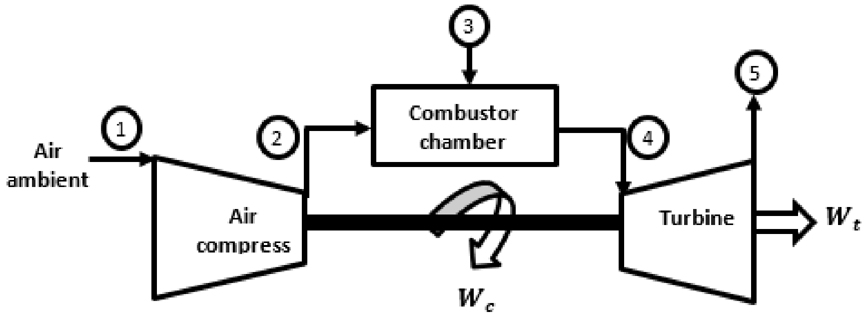

Figure-3. Schematic diagram of standard GT cycle.

Table-1. Summary of operating parameters.

State	Substance	**Mass flow rate** (kg/s)	**Temperature** (K)	**Pressure** (kPa)
1	Atmospheric condition.	-	-	-
2	Air at ideal outlet temperature.	$\dot{m}_{01}$	T_{01}	P_{01}
3	Fuel enters combustor chamber.	$\dot{m}_{02}$	T_{02}	P_{02}
4	Combustion gas enters the turbine.	$\dot{m}_{03}$	T_{03}	P_{03}
5	Exhaust gas leaves the turbine.	$\dot{m}_{04}$	T_{04}	P_{04}

The GT at UTP GDC was used for assessing the GT performance with changes in ambient air temperature. The data for the analysis was acquired from the Meteorology Department and UTP GDC plant. These data was analysed to determine the pattern of power generated with respect to GT performance with changes of temperatures.

To calculate the mass flow rate of air inlet, Equation 1 was be used [13]:

$$\dot{m}_{air} = \dot{m}_{exhaust\ gas} - \dot{m}_{fuel} \quad (1)$$

where $\dot{m}_{air}$is the mass flow rate of air, $\dot{m}_{exhaust\ gas}$ the mass flow rate of exhaust gas, and $\dot{m}_{fuel}$is the mass flow rate of fuel. The thermal efficiency of the GT was calculated using Equation 2[14]:

$$\eta_{th} = \frac{\dot{W}_{net}}{Q_{in}} \quad (2)$$

The specific work of the compressor is shown as in the following equation [15]:

$$W_c = \dot{m}_{air} C_{p(a)} \left(T_{out\ compressor} - T_{inlet\ compressor}\right) \quad (3)$$

where $T_{a,in}$ is the inlet air temperature, $C_{p,avg}$ and γ_c are the specific heat and specific heat ratios, both evaluated at the average temperature across the compressor, and r is the pressure ratio.

The power produced by the turbine can be estimated as:

$$W_{turbine} = \dot{m}_{exhaust\ gas} \cdot C_{pg} \cdot (T_{inlet\ turbine} - T_{outlet\ turbine}) \quad (4)$$

the thermal efficiency of the GT is calculated using Equation 4[14]:

$$\eta_{th} = \frac{\dot{W}_{net}}{Q_{in}} \quad (5)$$

From the above equation, the performance of the GT is determined as:

$$\eta_{th} = \frac{\dot{m}_{exha\ gas} C_{pg} (T_4 - T_2) - \dot{m}_{air} C_{p(a)} (T_2 - T_1)}{\dot{m}_{fuel} C_{pg} \cdot (T_3)} \quad (6)$$

4. RESULTS AND DISCUSSIONS

Initial study was done with regards to electricity generation by gas turbine at UTP. The hourly electricity generated by the GT for 20th Jan 2015, from 1am to 12pm is as shown in Figure-4. It is noted that the maximum electricity produced was 7114 kWh at 2 pm. It is also noted that minimum electricity generated from 1 am to 6 pm, which was 3000 kWh. The generated electricity increased to 6000 kWh from 7 am to 8 pm. The electricity generated then decreased after 8pm.

Analysis on ambient temperature was also done. The ambient temperature data obtained from Metrological Department recorded dry bulb temperature for 2015. The plot of minimum and maximum temperature for the year 2015 is as shown in Figure-5. It is noted that the lowest dry bulb recorded was at 7am 21.8°C and the highest recorded dry bulb was at 3pm with 32.1°C.

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Using equation 4 the efficiencies of GT are evaluated assuming various temperatures as shown in Figure-5. It can be observed that the efficiency of GT can be increased by lowering its input air according to the ISO standards. The plot indicates that the efficiency of GT increased by 28.3% as the inlet temperature of GT is lowered to 15 °C.

Based from initial findings as highlighted in the above paragraph turbine efficiency could be enhanced by decreasing the inlet air intake temperature. Taking into consideration the availability of chilled water thermal storage system at UTP, the turbine air intake cooling study will adopt cooling using chilled water from SAC system as shown in Figure-6. The parameters to be used are as per Table xx. Future work will involve sizing of appropriate plate heat exchanger for the case of 4.2MW GT with expected air intake of 15°C. the performance of the GT will then evaluated based on air intake of 15°C.

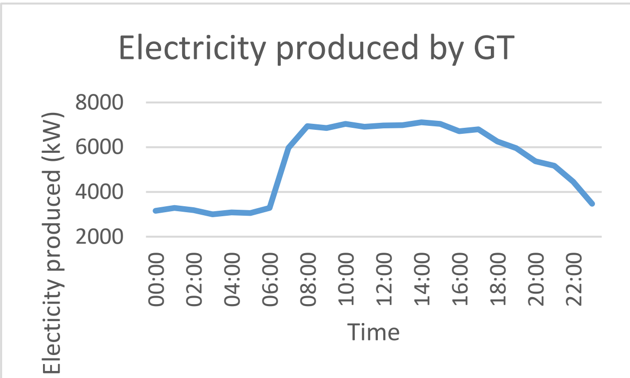

Figure-4. Electricity demand in UTP GDC.

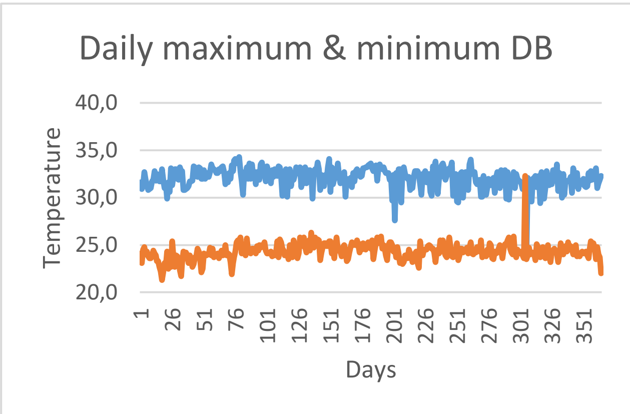

Figure-5. Recorded dry bulb for 2015.

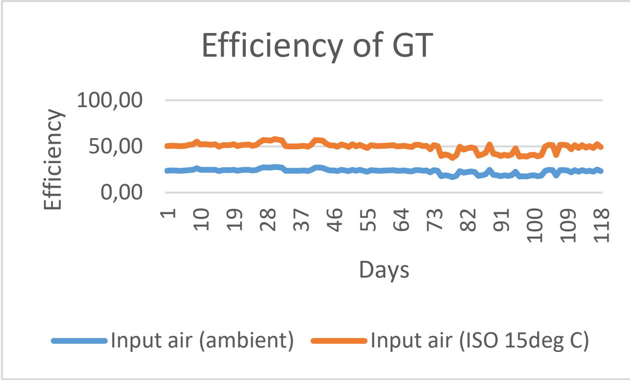

Figure-6. Efficiency of GT.

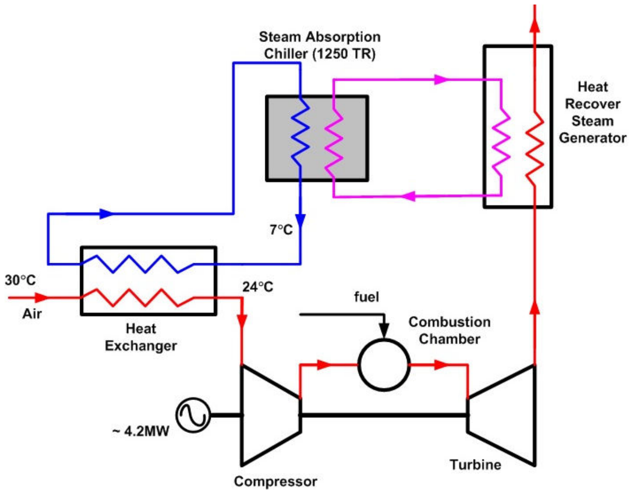

Figure-7. SAC system to cool the air inlet of GT.

Abbreviation and acronyms should be defined the first time they appear in the text, even after the have already been defined in the abstract. Do not use abbreviations in the title unless they are unavoidable.

5. CONCLUSIONS

Thus, in general there is variation of the GT efficiency effected by varying its inlet temperature. By observation of the ambient temperature, the highest dry bulb was recorded in between 2pm to 5pm, while the demand of power electricity also is at the peak in between 8am to 8pm. It is suggested that the decrement temperature of the ambient temperature economically provided by the TES. This system is expected to enhance the GT efficiency and concurrently its power output. With the usage of the TES, the cost of the operating system will be lower as the charging period of the TES is at night and which will be discharged at the peak hour demand during the day.

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