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Feasibility Study of Turbine Inlet Air Cooling using Mechanical Chillers in Malaysia Climate

Shahrul Nahar Omar Kamal[1], Didi Asmara Salim[2*], Mohd Sahril Mohd Fouzi[3], Danny Tam Hong Khai[4], Mohd Kamarul Yusri Yusof[5]

[1,2,3] *nshahrul@puo.edu.my, didi@puo.edu.my, msahril@puo.edu.my*
[4,5] *dannytam@shinryo.com.my, kamarul.yusri@shinryo.com.my*

Abstract

The performance of a gas turbine is dependent on the ambient air temperature. The gas turbine's power output is reduced and heat rate is increased as a result of higher air temperature. The warm and humid climate in Malaysia, with its high ambient air temperature, has an adverse effect on the performance of gas turbine generators. Turbine Inlet Air Cooling is a power augmentation technology for gas turbines, which reduces the turbine inlet air temperature thereby improving the power output and heat rate of the machine. In this paper the effect of Turbine Inlet Air Cooling using electric chillers, on the performance of the LM6000PD Gas Turbine Generator (43.5MW ISO rating) is evaluated in the context of the Malaysian climate. GT Pro software is used to evaluate the performance of the gas turbine generator with ambient air temperature cooled to 12°C. The ambient design points used for the sizing of the chillers are the 0.4% Evaporative (Design Point A) and the 0.4% Cooling (Design Point B) design points for Sitiawan, Perak as published by ASHRAE. It is observed that Design Point A results in a chiller capacity of 1950RT which is sufficient to satisfy the cooling demand of the Turbine Inlet Air Cooling system for approximately 98% of the operating hours in a year, while Design Point B yields a smaller chiller size of 1700RT which is capable of meeting the Turbine Inlet Air Cooling requirement for approximately 72% of the annual operating hours. In terms of Gas Turbine performance, the net power output is increased by 27.5% and 32.11% while the net heat rate is reduced by 2.8% and 3.74% for Design Points A and B respectively. The substantial improvement in gas turbine net power output and heat rate as predicted by the GT Pro demonstrate that Turbine Inlet Air Cooling using electric chillers is effective as a power augmentation technology in Malaysia.

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Keywords: Keywords; chiller systems; evaporative cooling; Turbine Inlet Air Cooling

*Corresponding Author: ddasmara@gmail.com

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Introduction

The gas turbine (GT) can be defined as an internal combustion engine which is consumed normal air and fuel to form the combustion to produce mechanical power to generate the electrical power. The performance of the GT is directly influenced by the turbine's inlet temperature, ambient temperature, and relative humidity [1]. The GT has a specific volume capacity according to manufacturer design. It depends on the air mass flow rate that enters the compressor in order to obtain a greater power output which is known as volumetric efficiency. With compressor inlet air cooling, the air density and mass flow rate as well as the GT net power output increase [2]. In order to achieve the best volumetric efficiency and density, the inlet air should be at an appropriate low temperature. Therefore, a technology called Turbine Inlet Air Cooling (TIAC) was introduced to decrease the inlet air temperature of the GT. Normally, this phenomenon is experienced by regions with the hot climate such as the Middle East and South East Asia. This natural characteristic has been overcome by several countries such as Iran (Middle East) and Thailand (South East Asia) by implementing the TIAC.

Several studies have been done on the TIAC technology recently. Andrea De Pascale et al. [3] mentioned that evaporative cooling proved to be a reliable option power augmentation in an integrated gasification combined cycle. With the introduction of the TIAC, power augmentation for GT is quite significant to the annual power output of the power plant [4]. Cheng Yang et al. [5] reported that GT combined cycle inlet fogging is superior in power efficiency at ambient temperature between 15°C to 20°C though a smaller profit margin is achieved when compared to inlet chilling. R Espanani et al. [6] found that by using the fogging method, the outlet power of the turbine is increased by about 6 MW and construction cost per kW is reduced USD 4. G. Komodi et al. [7] indicated that an almost linear trend can be obtained both in the electric power increase and in the electric efficiency increase as a function of the inlet air temperature when the chiller operates under nominal working conditions.

The implementation of the TIAC results in decreasing the GT inlet air temperature to 15°C [7]. The several methods applicable to decreasing the GT inlet air temperature are evaporative cooling; high-pressure fogging; absorption chiller cooling; mechanical refrigeration cooling and thermal energy storage (ice and water storage) [8]. However, not all stated methods were found to be suitable for implementation in regions with a hot climate such as the Middle East and South East Asia due to differences of relative humidity. Due to high relative humidity, more power is needed to remove the latent heat of the ambient air. Therefore the objective of this study is to investigate the feasibility of using the TIAC in Malaysia since it has a hot and humid climate throughout the year.

The temperature entering the GT compressor inlet is very dependent on the ambient condition of the location. Therefore the output performance of the GT can be improved by decreasing the inlet air temperature. There are several methods used by power plant operators or energy providers in order to decrease the GT inlet air temperature.

Nomenclature

AF_m	Mass Flow Rate of Cooled Air (kg/s)
CCL	Chiller Cooling Load (kW)
DB	Dry Bulb
GT	Gas Turbine
H_a	Enthalpy of Ambient Air (kJ/s)
H_c	Enthalpy of Cooled Air (kJ/kg)
LHV	Low Heating Value
RH	Relative Humidity
RT	Refrigeration Tonne
TIAC	Turbine Inlet Air Cooling
WB	Wet Bulb