Transient Characteristics Study of Gas Turbine Power Augmentation using Absorption Cooling Technique

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Abstract

The present work proposed a study of the characteristics of various parameters like dry bulb temperature (DBT), Turbine power (TP), Generator power (GP) and specific fuel consumption (SFC). The present work also shows a detailed comparative analysis of variation of characteristics parameters applied to simple cycle gas turbine and absorption cooling technique. To analyse the performance characteristics for the above comparison for a typical metrological year (TMY), transient simulation is carried out.

Keywords: - *Turbine Inlet Cooling, Transient Assessment, Absorption Chiller*

INTRODUCTION

The gas turbine cycle (Brayton cycle) produces the most electricity worldwide. In every country, gas turbines are widely used for power generation because of their quick starting and stopping ability compared to other cycles. The gas turbine cycle consists of the compressor, which compressed the atmospheric air to high-pressure air in the combustion chamber. Further, in the combustion chamber, high-pressure air is mixed with the fuel and finally combustible to produce flue gases of high pressure and temperature, which provides a gas turbine for power generation. This output power generation is directly proportional to the mass flow rate of the air. For, particular gas turbine cycle, the compressor has a fixed air volume to supply, so the gas turbine is a constant volume cycle. As the cycle consumes air directly from the atmosphere, the weather condition has directly affected the performance of the cycle. This means relative humidity and temperature of the atmosphere are the key parameters affecting the performance. So, gas turbine performance is critically affected by the different conditions such as warm and cold with dryness of the atmosphere.

In today's world, it is required to increase the performance of gas turbines to achieve efficient power generation. And one of the most implemented methods in the recent era to improve gas turbine cycle performance is to cool the air at the inlet of the compressor before it enters. Means turbine inlet cooling (TIC) technology is used to increase the efficiency of the gas turbine. Turbine inlet air cooling combines techniques and technology to cool down the incoming air to the compressor inlet. The approach will ensure maximum power output and save the fuel consumption and the pollutants of the Gas Turbine power plant, this leads to an increase in the density of the air and hence increase the power output. Various techniques for TIC, which are worked upon are as follows:

1. Evaporative cooler

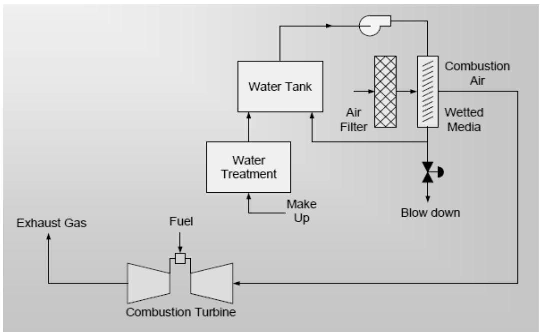

Figure 1 Schematic Diagram

2. Fogging system

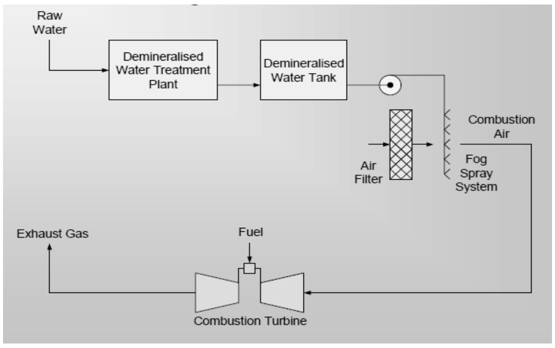

Figure 2 Schematic diagram of Fogging system

3. Mechanical refrigeration System

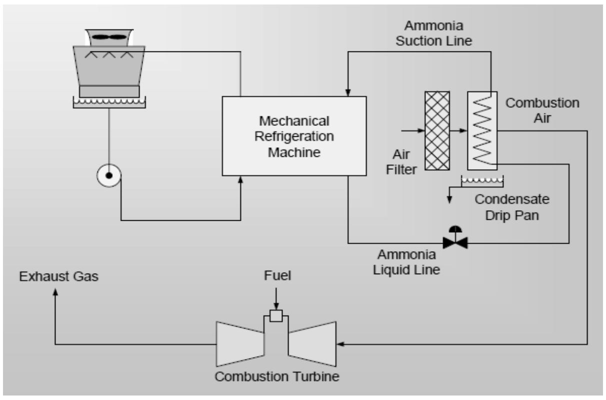

Figure 3 Schematic Diagram of Mechanical refrigeration system

4. Absorption chiller machine

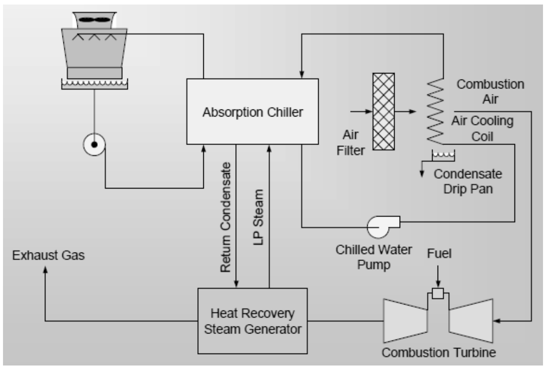

Figure 4 Schematic diagram of Absorption Chiller

A brief review on the advantages and drawbacks for each technology studied by [1] is shown in Table 1.

Table 1 A brief review on the advantages and drawbacks for various technologies

Technology	Benefits	Drawbacks
Evaporative Cooling The injection of water into the inlet air stream, thereby cooling the inlet air from its dry-bulb temperature to a point near to its wet-bulb temperature	• Very low unit capital cost • Simple and reliable design and operation • No limitation on time or duration of inlet air-cooling operation • Low parasitic power consumption • Low operational costs • Quick delivery and installation.	• Limited power gain due to the ambient wet-bulb limitation on inlet air temperature • High consumption of large amounts of purified water • High maintenance costs due to scaling and water treatment • Limited capacity improvement
High-Pressure Fogging Cooling to wet-bulb temperature at 100% humidity by high-pressure spraying of water droplets into	• Low capital cost • Excess fogging evaporates in compressor reducing turbine compressor work and increasing	• Limited power gain due to the ambient wet-bulb limitation on inlet air temperature

air-inlet ducts	turbine power • No limitation on time or duration of inlet air-cooling operation • Low annual maintenance time • Low parasitic power consumption • Quick delivery and installation.	• Higher water consumption than evaporative cooling • Requires demineralized water • Additional filters and drainage systems required • Limited capacity improvement
Absorption Cooling Utilizing the waste heat from the CT to drive the heat-driven refrigeration system for cooling the inlet air	• Not sensitive to ambient-air wet-bulb temperature • Potential use of recovered energy from the turbine • No limitation on time or duration of inlet air-cooling operation • Minimum parasitic electric power losses • Greater performance increase than evaporative or fogging	• High capital cost • High O&M costs • Limited inlet air temperature by turbine manufacturer (~9○C) • Complex system requiring expertise to operate and maintain • Not suitable for open-cycle turbines • Requires larger heat rejection (and cooling tower water) than other reference systems • Longer delivery and installation time cooling per day.
Mechanical Refrigeration The use of vapor compression refrigeration equipment to cool the inlet air	• Not sensitive to ambient-air wet-bulb temperature • No practical limitation on achievable inlet air temperature • No limitation on time or duration of inlet air-cooling operation • Relatively simple and reliable design and operation • Greater performance increase than evaporative or fogging	• High capital cost • Very large electric power demand during peak times • High O&M costs • Higher level of O&M expertise required • Long delivery and installation time • Requires additional chilled-water cooling circuit • Higher parasitic load than evaporative or fogging

It is challenging to achieve maximum power output in the existing Gas based power plants without increasing fuel consumption. Also, additional techniques (evaporative cooling and fogging system) that can increase the power output are less effective and subject to environmental conditions. This compelled us to find a suitable method of the inlet air chilling (Absorption Chiller), which can give augmented power output and decrease in specific fuel consumption of the Gas Turbine power plant. Compared with a mechanical chilling system, which uses electricity as a source of energy input, an absorption chiller uses hot water, steam or any waste heat as an input source of energy. This method makes absorption chiller a more viable option for the inlet air chilling technique for power augmentation. It is found that energy demand in the regions with ample sunlight is increasing day by day due to urban heat islands created in the densely populated area consuming energy for space cooling and heating loads. Absorption cooling systems become more viable options in such regions as partly solar energy can generate steam or hot water, which can be used as a source of energy for vapour absorption chiller to generate more power during summer seasons.

LITERATURE REVIEW

An analysis [2] was carried out by taking weather data of Bangkok indicates that reducing the temperature from ambient condition to 15 °C could help increase the instantaneous power output between 8 and 13%. In this analysis, intake air to the compressor was cooled using an absorption chiller. Also, the economic situation for such a cooling plant was justified as for 100 MW Gas Turbine plant during summer in peak hour maximum cooling load is equal to 3800 RT (tonnes of refrigeration) due to which maximum increase in the power output for the same period is 13 MW. To meet the increment in the power output by installing a gas turbine cycle, it will cost four times than the intake air cooling solution.

Similar work was reviewed in - [1] approximately 42% of the Saudi Electric Company's (SEC) annual energy sales are generated by combustion turbines. Yet, the turbines experience a 24% decrease in system capacity during the summer due to ambient air temperatures up to 50 °C. Experience with absorption chiller cooling in countries with ambient air temperatures over 40 °C showed that aqua- ammonia absorption chillers could reduce inlet air temperatures to around 10 °C.

Assessment of power augmentation has been carried using Simulink and NARX models, Gate Cycle™, C++ programming, TRNSYS and various in-house developed code[3]–[9]. Also, techno-economic analysis was carried out using actual data[10]–[17]. India has six different climatic regions, namely Arid, Semi-Arid, Tropical Wet, Tropical Wet and Dry, Humid sub-tropical and Montane. According to the central electricity authority, 11% of its thermal power plants are gas-based. However, no literature has comprehensively studied gas-based power plants in India and their techno-economic assessment. India is blessed with solar energy adequacy, but it still depends on the coal-based thermal power plants for about 55% of its electricity requirement [18]. Air conditioning currently accounts for roughly around 40–60% of peak power demand in summers in the major Indian cities like Ahmedabad, Mumbai, New Delhi, etc., where there is the greatest concentration of air-conditioned buildings. However, the capacity of power plants cannot be increased with such rates, and hence power augmentation techniques are required. Air cooling through Gas Turbine Inlet using an absorption chiller is one of the techniques used to increase power production in Gas turbine Power plants.

Moreover, solar energy, abundant in nature during the summer season, can also be utilised to power the absorption chiller machine (VAM) to generate cooling water. This cooling water will be used to cool the Turbine inlet air. A schematic diagram is shown in Figure 4.

METHODOLOGY

In the current article, a simple gas turbine power plant cycle performance analysis was carried out in Ahmedabad, Gujarat. The short assessment work is carried out using TRNSYS software. The simulation of the gas turbine cycle was carried out for both without inlet cooling and with inlet cooling conditions on the software. Figure 6 shows the simple cooling gas turbine cycle, and figure 7 indicates the inlet cooling gas turbine cycle on the user interface window of the TRNSYS software.

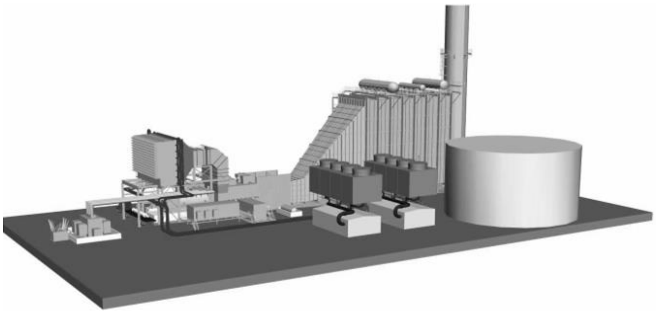

Figure 5 Model of Gas turbine power plant (York Manual)

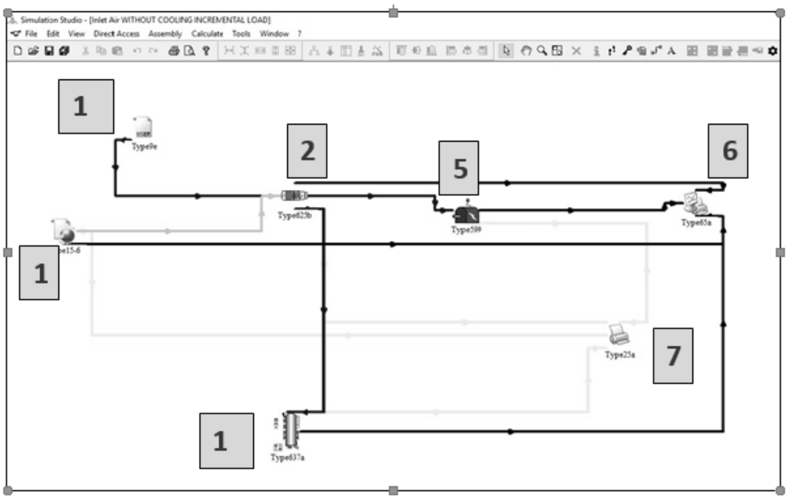

Figure 6 TRNSYS Model of Simple open cycle gas turbine power plant

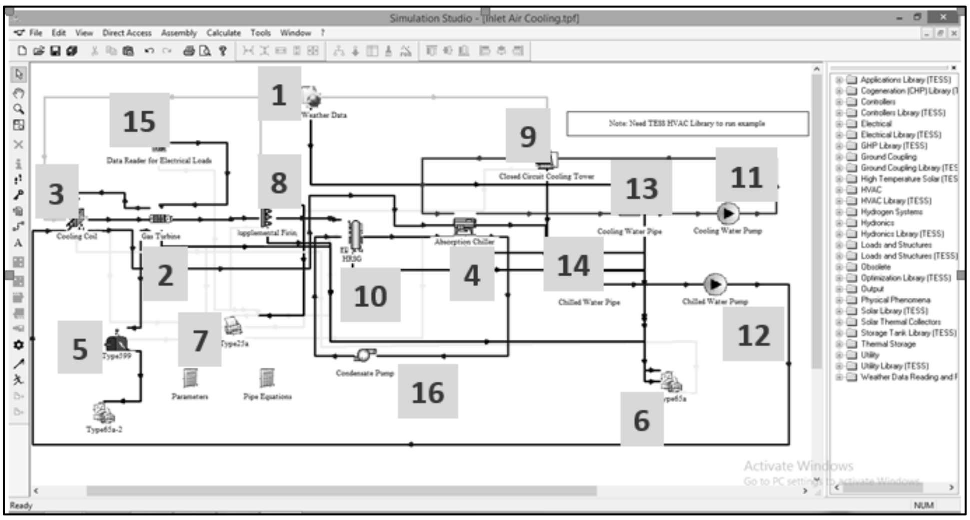

Figure 7 TRNSYS Model of Gas turbine power plant with inlet air cooling

In figures 6 and 7, the components shown are noted with numbers for identification purposes. The components indicated by numbers are in Table 2:

Table 2 Notations of components in TRNSYS software in Figure 6 and Figure 7

Sr. No.	Components	Sr. No.	Components
1	Weather Data	9	Cooling Tower
2	Gas Turbine	10	HRSG
3	Cooling Coil	11	Cooling Water Pump
4	Steam fired double-effect absorption chiller	12	Chilled Water Pump
5	Generator	13	Cooling Water Pipe
6	Output plotter	14	Chilled Water Pipe
7	Output Printer	15	Electrical Data Reader
8	Supplementary Firing	16	Condensate Pump

For performance analysis in simulation, gas turbine parameters are considered for the LM6000 gas turbine from the reference article [19]. From the reference article, required data for input of gas turbine and simulation was carried out.

Table 3 Output parameters obtained from the TRNSYS analysis

Output data files generated from simulation in TRNSYS	
(37 Columns & 8760 Rows) Excel file contains the below-mentioned parameters:	
Time (in hours)	Generator Power (kJ/hr)
Exhaust Temperature (°C)	Electrical Load (kJ/hr)
Mass Flow Rate of Exhaust (kg/hr)	Steam Outlet Temperature (°C)
Mass Flow Rate of Air (kg/hr)	Mass Flow Rate of Steam (kg/hr)
Mass Flow Rate of Fuel (kg/hr)	Steam Enthalpy (kJ/Kg)
Dry Bulb Temperature (°C)	HRSG Heat Transfer Rate (kJ/hr)
Cooled Air Temperature (°C)	Cooling Water Temperature (°C)
Cooled Air Flow Rate (kg/hr)	Chilled Water Temperature (°C)
Supplementary Supply Energy (kJ/hr)	Auxiliary Power (kJ/hr)
Supply Outlet Temperature (°C)	Generator Efficiency
HRSG Outlet Temperature (°C)	Absorption chiller coefficient of performance
Turbine Power (kJ/hr)	SFC Specific Fuel Consumption

RESULTS AND DISCUSSION

To get a better conclusion from the output data, simulation has been considered for a one-year time duration, and a month-wise analysis had been carried out.

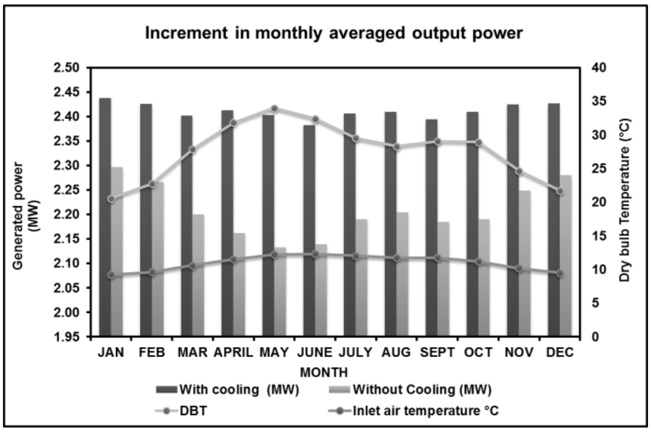

Figure 7 Monthly average Output of Gas turbine power plant at Ahmedabad, India

Referring to figure 7, it is observed that there is an 11% increment in the output power of the Gas Turbine power plant in May. This is concurrent with an increment in the power consumption during this month due to the summer season.

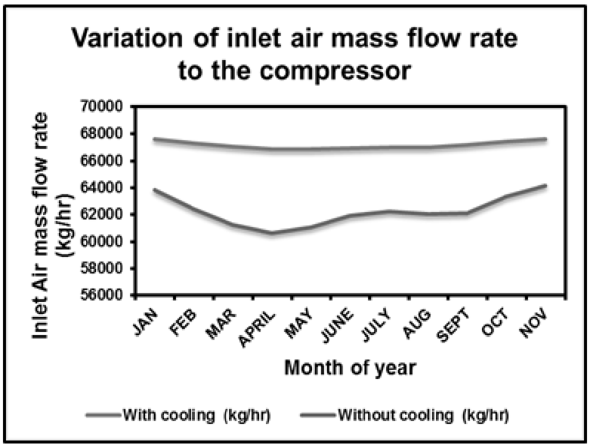

Figure 8 Month-wise variation in Inlet air to gas turbine

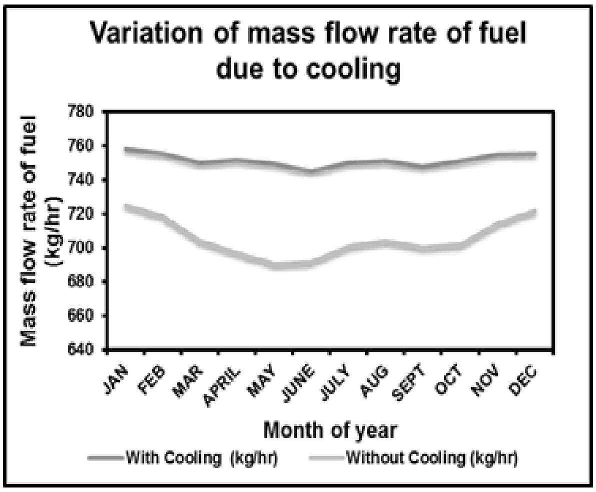

Figure 9 Month-wise variation in corresponding fuel input required

As shown in figure 8 and 9 the amplitude of variation in the mass flow rate is reducing in the case of inlet air cooling. Hence a stable supply of power to meet the base load demand of power can be fulfilled using inlet air cooling technique. It should be noted that there is an increase in the net power generation as well as reduction in the specific fuel consumption.

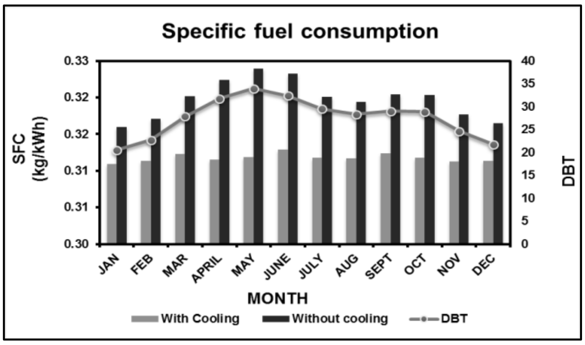

Figure 10 Month-wise variation in specific fuel consumption of Gas Turbine Power

As shown in figure 10, as dry bulb temperature increases the difference between the specific fuel consumption with and without cooling increases and hence more benefit is gained for summer season.

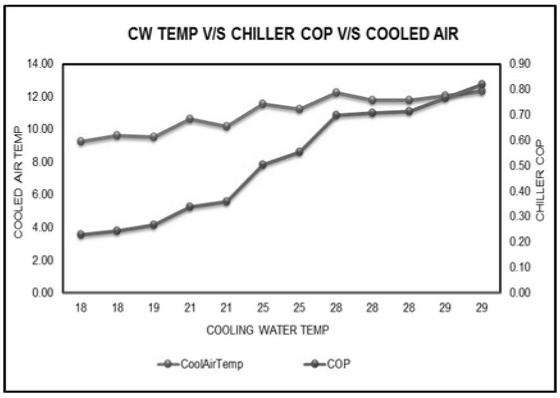

Figure 11 Optimum value of cooling water for Absorption chiller

CONCLUSION AND FUTURE SCOPE

- Using the inlet air cooling technique with an absorption chiller makes it possible to generate a 10% increase in output of a simple gas turbine power plant 3.6 MW.
- The overall plant efficiency is increased by 0.5% by cooling the inlet air supply of the gas turbine power plant.
- Also, conclude that cumulative net saving is 27.8 million INR per Annum.
- Using absorption chiller specific fuel consumption also decreases by 20-50 %,

which will reduce the pollution and be helpful to the environment.

- For Ahmedabad as location, chiller COP is highest at 29℃ cooling water temperature.
- Using the same technique and simulation tool, it is possible to simulate an industrial gas turbine LM6000 model.
- Also, LM6000 turbine output characteristics can be studied when the absorption chiller (used for inlet air cooling) will be coupled with appropriate solar energy collectors.

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