BETTER POWER GENERATION FROM GAS TURBINE ALONGWITH IMPROVED HEAT RATE

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Abstract

Performance of a Gas Turbine is largely dependent on inlet air temperature. Gas Turbines are constant volume machines. At a given shaft speed they always move the same volume of air. But the power output of a turbine depends on the flow of mass through it. This is precisely the reason why on hot days, when air is less dense, power output falls off. A rise of one degree Centigrade temperature of Inlet air decreases the power output by 1% and at the same time heat rate of the turbine also goes up. This is a matter of great concern to power producers. Many techniques have been developed to cool Inlet air to Gas Turbine. Traditionally, Gas Turbine inlet air has been cooled by either mechanical chillers or media type evaporative coolers .It is also important to note that power consumption to cool inlet air is also of concern since it decreases the net power output of a Gas Turbine .In mechanical Chiller auxiliary power consumption is very high compared to media type evaporative coolers. Efficiency of evaporative cooler largely depends on moisture present in the air. Higher the moisture in the air lesser the advantage from it.

Use of Geo exchange Systems can provide energy- efficient cooling by using underground pipes, filled with water solution because the underground temperature is quite low than ambient temperature and relatively constant round the year. Circulation of water in closed loop pipe system will extract heat from the inlet air to Gas Turbine and disperse the same into the earth. This will reduce sensible heat from the inlet air, which gives more benefit. After reduction in dry bulb temperature we can take advantage from Fog system /Evaporative Cooler. Using a combination we can get much more benefit. This will not only improve power output but also improve the heat rate of the Gas Turbine.

Body of Paper

All manufacturers of Gas Turbines design the Gas Turbine with respect to ISO ratings which includes following:

(a) Temperature of Inlet air to the Compressor should be 15^0 C
(b) The Machine will run at Sea Level
(c) There are no inlet and outlet pressure losses
(d) Relative Humidity should be 60%

The buyer invariably compares various options available based on declared ISO ratings as specified by the manufacturer with respect to Output and Heat Rate. The next step involves the buyer asking the supplier for Correction Factor Curve taking into consideration his site conditions. Based on this, the buyer selects the model.

Irrespective of the Correction Factor Curve for his site conditions a buyer gets no discount for derated Output and Heat Rate, which is a universally accepted fact. Conditions. In a tropical country like India, where ambient temperature remains around 35^0 C, output of the Gas Turbine falls by 20% and increases fuel consumption by 12.5%. This is of immense concern for all users where the ambient temperature significantly deviates from ISO conditions. Many methods and efforts currently being employed to minimize the adverse effect of higher Inlet air temperature.

<u>Factors affecting Performance of Gas Turbine:</u>
The performance of Gas Turbine viz. the power output, and the heat rate (measure of efficiency, i.e. the amount of energy consumed per kWh of electricity produced) depends on the following major parameters:

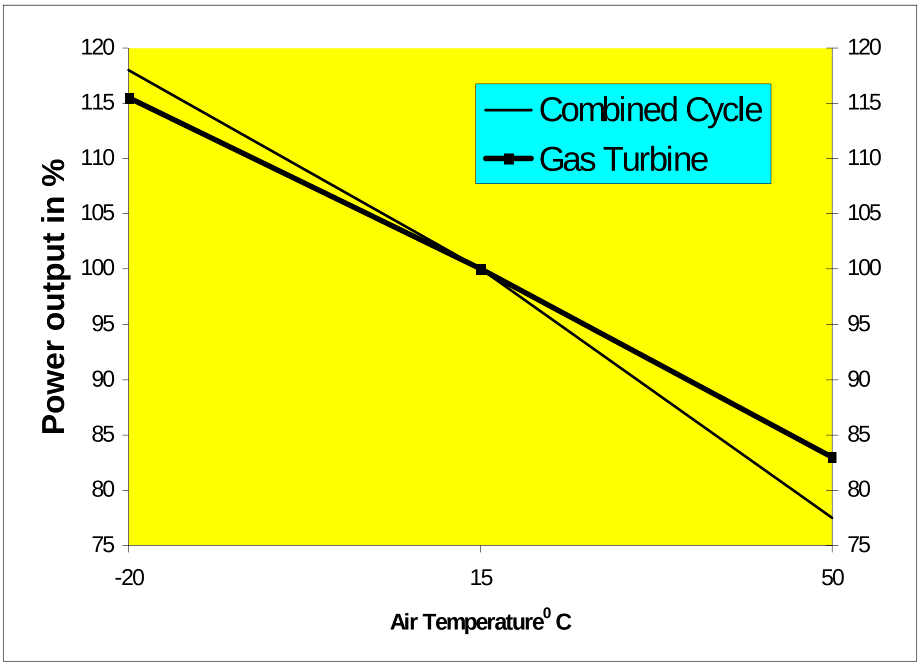
1. Site altitude i.e. atmospheric pressure

2. Inlet pressure drop in the filters and intake system
3. Outlet pressure drop in the HRSG (Heat Recovery Steam Generator)
4. Site design temperature
5. Site design Relative Humidity corresponding to the site design temperature.

Impact of Higher Inlet Air temperature on Gas Turbine Performance

A gas turbine is a constant volume machine i.e. the volume of air compressed is fixed, irrespective of ambient temperature. Hence, as the temperature of air rises the density of air decreases and the mass flow rate of compressed air gets reduced. The power output of the Gas Turbine is proportional to the mass flow rate of air. Thus as the ambient temperature increases, the power output decreases. Further, the efficiency of the gas turbine also falls, as more power is required to compress warmer air. For a given site and the configuration, the first three parameters are constant and can not be changed. However, it is possible to alter the other two parameters and obtain a higher output and improved efficiency by cooling the air before it is admitted in the Gas Turbine compressor section.

Impact of higher ambient Air Temperature is very well spelled in a given figure-1 below:
Performance of various Gas Turbine Model with respect to Inlet Air Temperature



MODEL		GT10B			Frame 5 (5371 PA)			Frame 6 (6561 B)			*LM 6000PC		
Inlet Temp	C	15	35	40	15	35	40	15	35	40	15	35	40
GT Power	MW	23.1	20.1	18.9	25.2	21.4	20.4	38.6	33.5	32.3	40.9	31.9	27.4
GTG efficiency	%	33	32.11	31.8	28	26.4	25.9	31.5	30.3	30	40.6	37.8	35.4
Decrease in power w.r.t 15 C	%	0	13	18	0	15.1	19.2	0	13.1	16.3	0	22	32.9
Decrease in efficiency w.r.t 15 C	%	0	3	4	0	5.82	7.64	0	3.8	5.04	0	7.04	12.9

Note- Basis for above analysis
Fuel Distillate GT10B, Frame5, Frame 6 :Industrial
Relative Humidity 60% *LM 6000PC: Aero-Derivative
Elevation 0 meters

Exhaust pressure loss 22mbar

Effect of Inlet Air temperature varies from turbine to turbine. *Aero -Derivative Turbines are more sensitive than Industrial Heavy Duty type .

Methods currently adopted by Industry;

Industry has implemented various techniques to reduce ambient temp. They are as follows:

(1) **Vapor Compression** –
Various refrigerant type air-chilling systems are available in the market. The biggest advantage of this is that one can reduce temp of inlet air up to 15^{0}C .The biggest disadvantage in this system is higher power consumption to cool Inlet Air and pressure drop in the air, thus adversely affecting the performance of compressor.

(2) **Vapor Absorption Chillers-** Steam is used to give the chilling effect and one can achieve 15 c inlet air temperature. This system consumes steam which reduces output of the steam Turbine .It also reduces the Inlet air pressure which adversely affects the performance of Compressor.

(3) **Evaporative coolers-**Evaporative cooling works on the principle of reducing the temperature of an air stream through water evaporation. The process of converting water from liquid to a vapor state requires energy. This energy is drawn from the air stream, the result being cooler and more humid air. The effectiveness of an evaporative cooling system depends on the surface area of the water exposed to the air stream and the residence time. Performance of the system is restricted by the amount of moisture present in the air .It works well in low humidity area.

(4) **High Pressure Fog system -**It is one of the recent technologies employed for Inlet air-cooling. It is similar to evaporative cooling, but instead of using water as an evaporative medium, the water is atomized into billions of super-small droplets thereby creating a large evaporative surface area. With Fog overcooling arrangement, one can generate more power. Once the fog evaporates in the compressor, it cools and makes the air denser. This accelerates the total mass flow of air through the turbine, giving an additional power boost. However the limits of Fog overcooling system have not been fully investigated .One possible drawback of overcooling in case of water droplets being too large, is the possibility of the compressor section getting eroded. In general Fog cooling gives a power boost of about 0.5% for every 1^{0}F of cooling (0.9% per^0 C) .Fog inter cooling gives a power boost of about 5% for every 1% (of air mass flow) of fog injected.

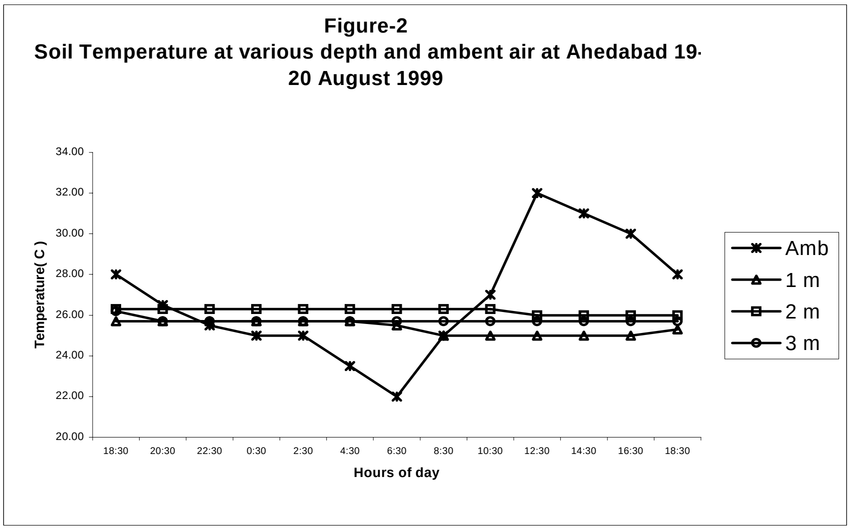
Factors to be considered for selecting the technology:

(a) Capital Cost
(b) Maximum achievable cooling range
(c) Auxiliary power/steam consumption
(d) Reliability of the system

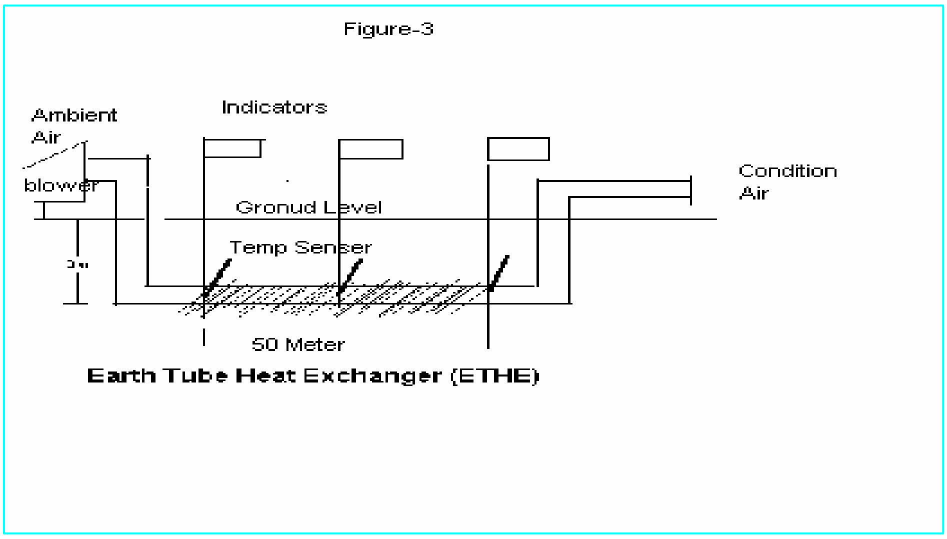
All the above methods have been tested and users either use one of them in isolation or in combination with a second one for better output & heat rate from the Gas Turbine.

EARTH TUBE HEAT EXCHANGER (ETHE)– A New method of cooling inlet air to Gas Turbine.

ETHE is a device that permits transfer of heat from ambient air to deeper strata of soil and vice versa. ETHE is based on the well-known fact that while ambient temperature varies cyclically (daily), the temperature of soil beyond a depth of around 2 meter remains virtually constant .For instance; Fig-2 shows the variation of temperature in Ahmedabad city of INDIA during a day in August. It is seen that while the ambient temperature fluctuated by 10^0 C, rising to 32 ^{0}C during day time and falling to 22 ^{0}C during early morning, temperature at 3-meter depth remained virtually constant at 25.7^0 C . It was thus observed that the temperature wave dampens as it moves through the layers of soil. This pattern persists through the year. Though seasonal variations do occur, fluctuation in deep soil temperature remains minimal as compared to a ambient. ETHE is used in Europe and North America to condition (cool and heat) the air in greenhouses, poultry and piggery buildings, etc.



One of the experimental units installed at Ahmedabad consists of a 50 m long tube of 10 cm diameter, buried at 3 m depth in the ground. See Fig-3 .The tube is provided with fins to increase its heat exchange power. A blower pumps the ambient (hot) air through the tube. When air emerges from the other end, it gets cooled to nearly the same level as the soil temperature .On this location, temperature of soil at 3 m depth is 25.7 ^{0}C and remains virtually constant.



In order to understand benefits from each method, ABB STAL GT10B model has been considered for all calculation purpose.

>> Cooling Load Calculation for Bringing Inlet Air Temp to 15^{0} C from 35^{0} C (at 60% RH)

Total Cooling Load = $\frac{\text{Mass of air x Change in Enthalpy}}{\text{3024 Kcal}}$

$= \frac{\text{72 Kg/Secx3600 x13.89 Kcal/Kg of air}}{\text{3024 Kcal}}$

=1000 TR

Thus to reach 15^{0} C from 35 ^{0}C, GT10B requires 1000 TR cooling load.

>> At this stage it is necessary to understand power consumption in each Method

(a) **Vapor Compression (VAC)-** The total power consumption would be 1200 kW(@ 1.2KW/TR) , considering Chilled water circulation pumps, Cooling water circulation pumps, Chillers compressor and Cooling Tower Fan .

(b) **Vapor Absorption Heat Pump (VAHP)-** A typical double stage steam based absorption Machine consumes both Steam & Power as follows.

Machine Capacity	1100 TR
Steam Consumption @ 5.5 Kg/Ton at 8 bar	5.5 TPH
Reduction in Power from Steam Turbine	1000 kW
Chilled water Circulation pump	90 kW
Refrigerant Pump	15 kW
Cooling Water Pump	150 kW
Cooling Tower Fan	60 kW
Total Loss of Power	1315 kW

>> The above data is based on Thermax made 1110 TR VAHP machine installed at Core Healthcare LTD.

(c) **High Pressure Fog System**- The power required to cool inlet air from 35^0 C to 29^0C with 95% RH would be 17 kW as per design offered by MEE FOG –USA for GT10B

(d) **Earth Tube Heat Exchanger**- In case of this one needs to study soil strata w.r.t temp profile & Conductivity .The following calculations have been made taking into account , various secondary sources of information available :

>> Mass of Air to be handled –GT10B consumes 73 Kg/sec at 35^0C & 60% RH. Based on Psychometric Chart total volume to be handled in terms of CFM would be 150000 CFM.

>> In our calculation three 50,000 CFM air blower have been considered instead of single 150000 CFM blower.

>> Air Velocity is considered 2550 feet per min. A pressure drop of 35 mm of water for travel of 1000 Feet in 60" die pipe has been considered.

>> Power consumption for each blower would be 33 kW. Thus total power consumption for handling of 150000-CFM volume of air would be 100KW.

>> Delivery pressure of air at inlet plenum of Gas Turbine would be little more than atmospheric pressure.

>> With Indian Context, Cost of Developing this Technology will be in the range of 0.7 Million USD

This arrangement will cool inlet air from 35^0 C to 27^0 C. In this method power consumption will remain constant irrespective of ambient condition. In hot summer, even when the temp reaches to 40^0 to 45^0 C, it will cool up to 27^0 C under Indian climatic conditions Power consumption will also remain almost same.

Major advantages of this Method are –

>> It is an Eco- friendly technology
>> Less running cost and is maintenance free
>> Can use in combination with other methods for maximum benefit.
>> System can be developed locally without much dependency on others

Major disadvantages are
>> Initial design and installation requires a lot of attention
>> A tailor made design is essentially required since soil strata varies from place to place.

In order to get maximum benefit, use of ETHE in combination with other methods, gives better economies. The initial Cooling Load will be taken care of by ETHE and the other method when used in combination will take care of the balance-cooling load.

Benefit derived from various technologies is quantified in table given below.

		VAC	VAHP	*FOG SYSTEM	ETHE	EHTE+FOG System*	EHTE+VAC

Power at 35^{0}C	kW	20097	20097	20097	20097	20097	20097
Power at 27^{0}C	kW				21252		
Power at 29^{0}C	kW			21559			
Power at 21^{0}C	kW					23407	
Power at 15^{0}C	kW	23100	23100				23100
Increase in Power Output	kW	3003	3003	1462	1155	3310	3003
Auxiliary Power Consumption	kW	1200	1315	17	100	117	820
Net Gain In Power output	kW	1803	1688	1445	1055	3193	2183

* With 1% fog injected into the compressor section for inter cooling

From above table it is clear that on development of commercial package for ETHE, Gas Turbine user will be able to cater more benefit in combination with others.

CONCLUSION: Use of ETHE technology is not only eco-friendly but it is also economical both in terms of capital cost and running cost .In a region where moisture percentage in soil is higher, ETHE technology gives best performances.