Detail Analysis On Performance & Efficiency Enhancements in Gas Turbine

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***Abstract*: To study and analyze the various performance enhancement methods of Gas turbine by using engineering concepts. SOP is the way to make safe operation, performance & efficiency enhancements of a gas turbine. Some of the parameters given by equipment vendor and then deriving some methods for the prepare SOPs for enhancements of performance.**

There were some problem envisaged for enhancements performance and efficiency of the gas turbine. The problem is like that the quantity of inlet air. Inlet air filters differential pressure high fouling of the compressor, high inlet air temperature, exhaust flue gas temperature high something like that.

Keywords: Gas Turbine, Performance & Efficiency, Nozzle,

I. INTRODUCTION

We can say that the Gas Turbine efficiency depends on the compression ratio of the compressor &working fluid. The efficiency increase with the increase in compression ratio. Due to that we can apply the different methods for improving the performance of the gas turbine by using fogging system in which decrease the inlet air temperature due to the density of the air is increase& it can compress sufficiently & get higher compression ratio for the better performance of the gas turbine. Then other method is water wash compressor. It prevents the fouling of the compressor after 8000 hours running the water wash is carried out. In this method compressor washing done.

This method is done by two ways.
1) Off line water wash
2) Online water wash

So by applying &analyse these methods we can enhance the performance of gas turbine & improve life, power production & decrease the breakdowns. [1]

II Literature reviews:

A large number of configurations of gas turbine based thermal power plants are possible. A vast quantity of literature is available on this topic however; here it is restricted mainly to those power plants which are associated with recovery and utilization of waste heat as a modes of operation to enhance the power plant performance.

[2008] Mosafa A.H. et al. [28] have demonstrated that in recent decade, more attention has been paid to reheat gas turbine cycles because of their high exhaust gas temperature. The results show that decreasing pinch point temperature difference makes both energetic and exergetic efficiency increase. They also show that with larger process steam pressure, exergetic efficiency increase significantly but energetic efficiency decreases. These efficiencies are less affected by variation of final temperature difference. However decreasing the final temperature difference makes the mass flow rate of steam increase. Thus for optimum design of HRSG in a combined system such as 37 cogeneration gas turbine cycle with reheat, a proper value of the mentioned parameters must be chosen depending on the demand for power or heat in different situation.

[2007] Layi Fagbenle R. et al. [18] have carried out thermodynamic analysis considering both the first and the second laws of thermodynamics on a 53 MW (net) biogas-fired integrated gasification steam injected gas turbine (BIG/STIG) plant. The energy utilization diagrams (EUDs) for the plant and for the reaction subsystems have also been considered, revealing both problems and potentials for improvement. The analysis indicates a thermal efficiency of about 41% (power based) and 45% (power and recovered heat based) but that the exergy loss in the combustion chamber was largest at about 79% of the total system exergy loss.

[2007] Roumeliotis I. and Mathioudakis K. [37] have presented experimental work concerning the effect of water injection on a compressor stage. The effect on compressor stage performance and stability is examined for water injection up to 2%. The behavior of the airflow in the blade rows is examined through aerodynamic measurements. The results indicate that although the water injection appears to not have any significant effect on the flow pattern and to stage pressure rise and stall margin, there is a measurable effect on compression efficiency, which seems to result mainly from losses of a mechanical nature and water acceleration. The efficiency degradation is found proportional to the water ratio entering the engine.

[2004] To attain the highest performance of gas turbine cogeneration plants, it is necessary to rationally select the numbers and capacities of gas turbines and auxiliary equipment in consideration of their operational strategies corresponding to energy demands which change with season and time. The evaluation of the effects of these alternatives on the performance is an important work for designers. However, it takes much time to conduct the work thoroughly. In this paper, the effects of the aforementioned alternatives on the operational performance of gas turbine cogeneration plants are evaluated using the optimization tool in terms of many criteria including operational cost, energy consumption, and CO2 emission. It is demonstrated that the tool is very effective to evaluate the performance rationally, flexibly, and easily.

[2003] Zaporowski B. and Szczerbowski R., [53] have performed in this paper, multivariate simulation calculations for the following natural-gas fired combined heat-and power plants with gas turbines: (1) a gas-steam combined heat-and-power plant with an extraction-condensing steam turbine, and (2) a gas-steam combined heat-and-power plant with a back-pressure steam-turbine. For these systems, mathematical models of the behaviors of their basic elements, such as: the block of the gas turbine (compressor, combustion chamber and gas turbine), heat-recovery steam generator and steam-turbine cycle were developed. On the basis of elaborate mathematical models, a computer program performed multivariate simulation calculations. For each variant, the following factors were calculated for particular types of combined heat-and-power plants: energy efficiency, efficiency of electric-energy generation, cogeneration index and cogeneration factor.

[2003] Joao O. S. Parente, Alberto Traverso and Aristide F. Massardo [15] have developed the direct thermo-economic analysis for the assessment of the performance of mixed gas-steam cycles such as the steam injected cycle (steam injected gas turbine, STIG), regenerated water injected (RWI) cycle, and humid air turbine (HAT) or evaporative cycle. These results were compared to the data of a conventional two-pressure level combined cycle considered as representative of the state of the art of high efficiency conversion systems. A new representation proposed by the authors, such as cost of electricity versus cycle efficiency or internal rate of return versus electric efficiency, was used to demonstrate the main features of these types of innovative energy plants.

[2005] Andreas Poullikkas [1] has presented in this work an economic evaluation of the operating cost and the water economy of the various commercial MAST (mixed air steam turbines) technologies is carried out. For the water requirements the analysis takes into account either the use of a reverse osmosis desalination plant or the use of a water recovery condenser. The two simulation tools used are the IPP (independent power 49 producers) optimization algorithm and the CAROC (computer aided reverse osmosis calculations) optimization algorithm. Both software tools take into account the capital cost, the fuel cost and the operation and maintenance (O&M) requirements of each candidate scheme (MAST plant or RO desalination plant accordingly) and calculate the least cost configuration. The results indicate that when natural gas is used as a fuel it is more cost effective than gasoil. Also, by the integration of water recovery condenser the operating cost is slightly less than in the case of the use of a reverse osmosis desalination plant. Lastly, the least cost MAST technology is the LOTHECO cycle (Low Temperature Heat Combined cycle) with natural gas.

[2005] Yadav R. and Sreedhar Yadav P. [48] have given various possibilities to achieve the enhancement of power output, substantial reduction in NOx emission and improvement in plant thermal efficiency of a gas turbine plant and its variants, humid air gas turbine cycle power plant is one of them. The paper deals with the thermodynamics study of humid air gas turbine cycle power plants based on first law. Using the modeling and governing equation, the parametric study has been carried out. The result obtained is helpful in designing the humid air gas turbines (HAT), which are used as peaking units. The comparison of performance of humid air gas turbine cycle shows that it is superior to basic gas turbine cycle but inferior and more complex to steam injected cycle. There is an appreciable enhancement in the humid air injected (HAI) cycle specific work (12 to 16 percent) and efficiency (2 to 4 percentage point) over the basic gas turbine (BGT) cycle at the cost of complexity of plant.

III Basic AIM and Objectives:

As a part of environmental, the performance of gas turbine will contribute some extent. So the improvement of the efficiency by using various parameters will be more effective. Also achieve healthy operations and minimum breakdown.

To study of the analysis in standard operating procedure. Now, day the gas turbines are widely used in the refinery & captive power plant. For its easy operation & reliability of operation. But Efficiency of the gas turbine is 30 to 40% when it’s run in open cycle. So how we can increase the efficiency of gas turbine by applying different methods.

IV Problem Specifications:

- Increase the life of whole primary and secondary gas turbine, its equipment & circuits.
- Improve the protection & safety of the system.
- Less breakdown & black outs of power plant.
- Improve the life of gas turbine against the fire & explosion by fire protection system.
- Increases the quantity of the power produced and decreases the cost of the power production.

V Components/ Materials / Tools required and its specification:

Gas turbine:

In gas turbine plant, air is used as the working fluid. The air is compressed by the compressor to increase the pressure of the air. The pressurized air is then passed through the combustion chamber where the air is heated to a high temperature. The heart is added to the air by burning the oil in the combustion chamber or by the air heaters. The hot and high pressure air is then expanded in the gas turbine which drives the alternator to convert the mechanical energy in to electrical energy. The exhaust gases are passed through the regenerator to heat the compressed air and then they are released to the atmosphere.

The Compressor, gas turbine and alternator are mounted on the same shaft, so part of the driven power is used to drive the compressor once the plant has been started. Gas power plants are used as standby plants for hydro-electric power stations where these can be operated at peak loads.

Components of a Gas turbine power plant:

1. Compressor
2. Regenerator
3. Combustion chamber
4. Gas turbine
5. Alternator
6. Starting motor

The schematic block diagram of gas power plant is shown in below figure.

1. Compressor:

The compressor used in gas power plant is Axial flow compressor. The air atmosphere pressure & temperature is drawn by the rotating compressor through a filter house which removes the dust and impurities of the air. The rotary blades in the compressor push the air through the stationary blades to raise its pressure and also increase its temperature. Thus the air with high pressure and temperature is at compressor output.

2. Regenerator:

A regenerator is a device which recovers the heat from the exhaust gases to heat the entering air of the compressor. The exhaust gases passes through the regenerator before releasing in to the atmosphere. Numbers of tubes are provides in a shell of the compressor. The compressed air passes through these tubes & exhausts gases came out from the gas turbine its passes through the shell side which transfers heat to the compressed air and also increases the temperature of the entering air. It reduces the fuel consumption and improve the thermal efficiency of the plant.

3. Combustion chamber:

This is one of the important components of the gas power plant. High pressure air from the compressor is entered in a combustion chamber. The air from regenerator is mostly heated which is not adequate to drive the gas turbine. Hot air with high pressure gas can only drive the gas turbine. So this reason in combustion chamber the compressed air is heated up to high temperature (3000 F). The heat addition processes done to the air by burning oil which is injected through a burner in to the combustion chamber at high pressure. The heated air with high pressure and high temperature is then applied to gas turbine.

4. Gas turbine:

Gas turbine is the main component of the gas power plant. The hot air with high pressure and temperature is passed through gas turbine. The gases are expanding in the gas turbine blades. This causes the rotation of blades to the intended mechanical work. After expanding, the exhaust gases with the temperature about 998 F are applied to the regenerator.

5. Alternator:

Alternator is directly coupled with the gas turbine portion same as in the case of steam power plant. Alternator converts the mechanical energy of the gas turbine in to electrical energy. The output generated electrical energy is passed through to the grid to a generator, transformer, isolators and circuit breakers, and other elements.

6. Starting motor:

The starting motor is placed to start the compressor before starting the plant. This works as the initial driving component for the compressor. The starting motor is coupled to the same shaft of the gas turbine for this purpose. Once the gas turbine starts rotating, some part of the mechanical energy is used to drive the compressor and the starting motor is turned off. The starting motor is driven by the batteries.

VI Actual implementation:

Data collection from various resources:

Here the collection of various data related to Gas turbine by visiting in plant, from the various operation and maintenance vendor manuals and reference books.

Identifying factors affect the Gas turbine performance:

a) Inlet Air temperature
b) Humidity
c) Altitude
d) Inlet differential pressure drop
e) Exhaust differential pressure drop

a) Inlet Air Temperature:

The performance of gas turbine is always rated to ISO standard condition of 15oC and relative humidity (RH) of 60%. When the gas turbine is operated at ambient condition of relatively low temperature of 24oC and RH of 60%, there is a potential decrease of power output by about 6.3%, accompanied by a 1.8% drop in thermal efficiency and a 1.8% increase in specific fuel consumption when compared to the performance at ISO standard condition. (Chart -1: air flow temperature)

b) Humidity:

Humidity in air also affects output and heat rate. In the past, this effect was thought to be too small to be considered. Humidity effect is a result of the control system approximation of firing temperature used on heavy gas turbines. Single-shaft turbines that use turbine exhaust temperature biased by the compressor pressure ratio to the approximate firing temperature will reduce power as a result of increased ambient humidity. The power will actually increase as fuel is added to raise the moist air to the allowable temperature.

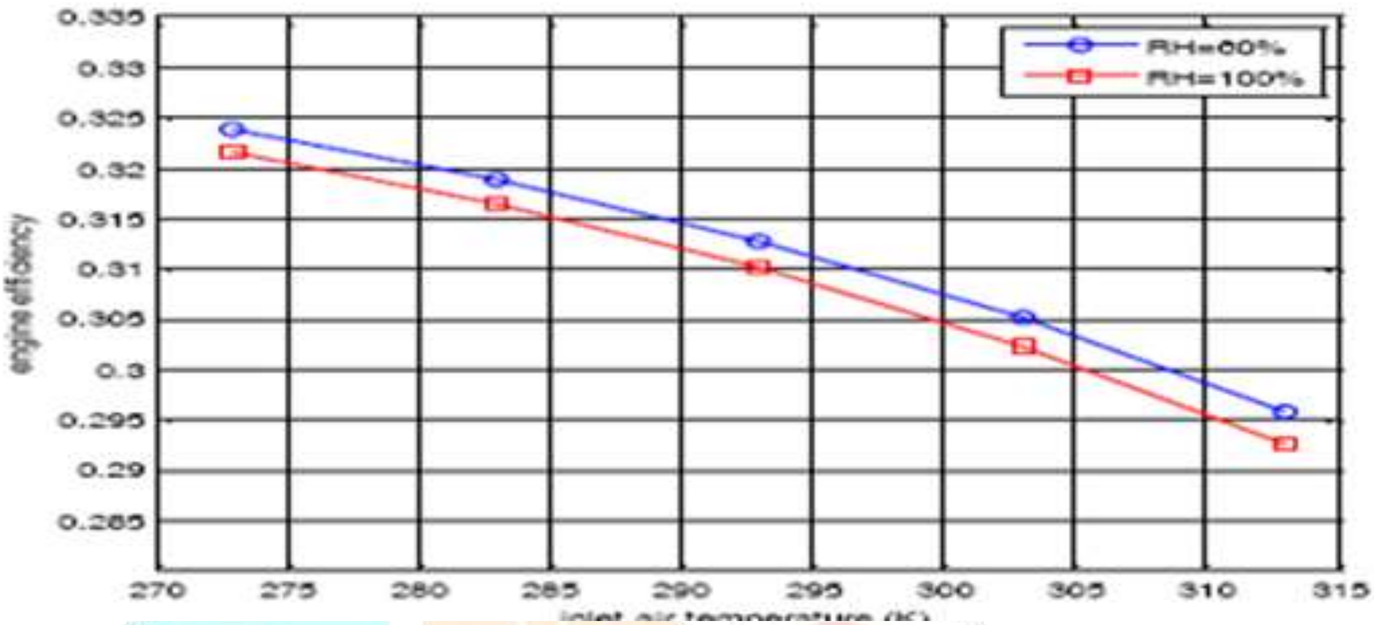
c) Fuel Heating:

Heated fuel results in higher turbine efficiency due to the reduced fuel flow required to raise the total gas temperature to firing temperature. Fuel heating will result in slightly lower gas turbine output because of the incremental volume flow decrease. The source of heat for the fuel typically is the feed water. Since use of this energy in the gas turbine fuel heating system is thermodynamically advantageous, the combined cycle efficiency is improved by approximately 0.6%.

d) Altitude:

The power loss for every 1000 ft. of altitude is 3% to 4%. A change in altitude causes a change in density and therefore has effect of reducing output. If inlet and exhaust are at same altitude the pressure ratio and expansion ratio are not affected. For better performance of gas turbine sea level is better.

e) Inlet differential pressure drop:



If 1 Inch of WC pressure increase inlet duct loss and result in 0.50% decrease power output. Increase in inlet differential pressure will reduce of compressor mass flow.

f) Exhaust differential pressure drop:

If 1 Inch of WC pressure increase in exhaust will result in 0.15% drop in power output. An increase in the exhaust differential pressure would cause a change in the turbine expansion ratio for a single shaft constant speed machine which reduces the amount of work extracted from turbine and will result in a higher exhaust temperature.

Chart -1: air flow temperature

Gas Turbine power output s affected by two parameters namely 1) Ambient temperature air & density of air 2) Speed of Gas Turbine is frequency of system These parameters affect the mass of the air handled by compressor and turbine which finally affects the output of the Gas Turbine Since Gas Turbine is a constant volume now machine higher ambient temperature results in lower density of air and hence lesser mass handled by the compressor & ambition. which gives lesser Gas Turbine output Lower the ambient temperature results in higher density of air & higher encases handled by the compressor & turbine which give higher Gas Turbine Output Gas Turbine inlet air fogging system reduces the inlet air temperature at the compressor suction by evaporative cooling method.

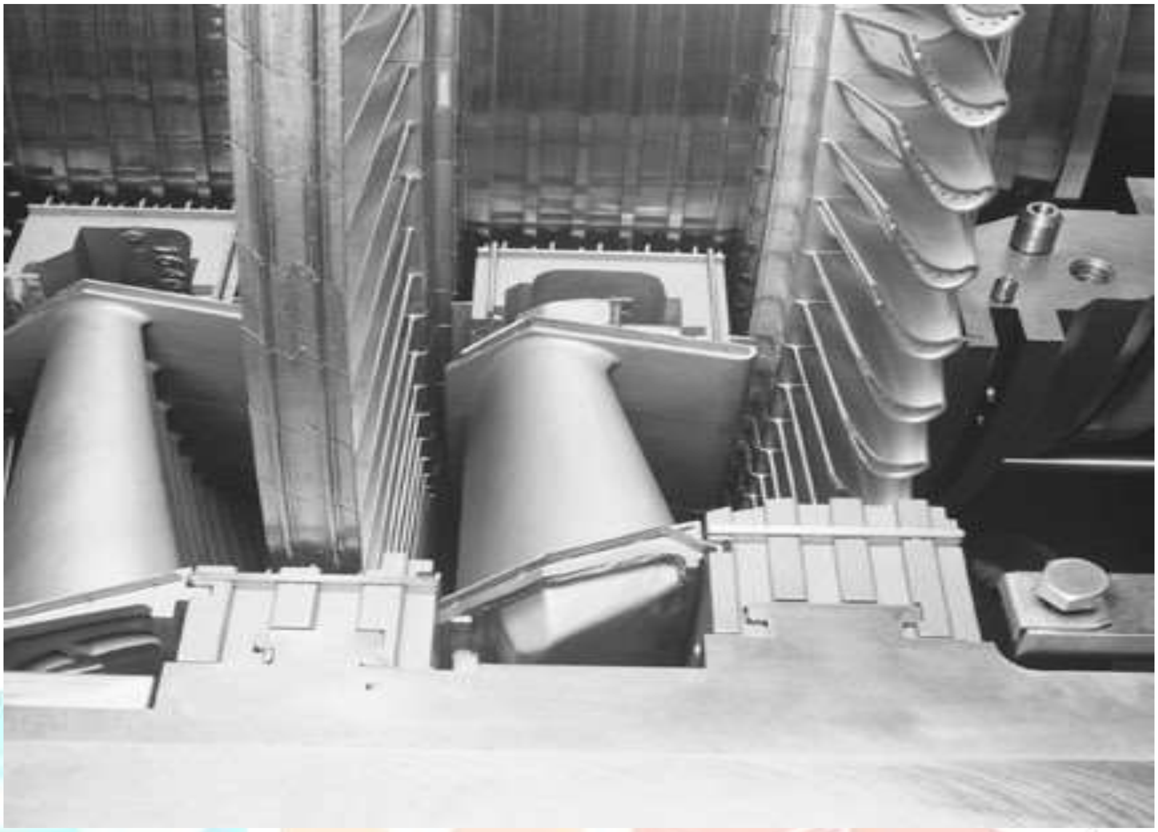


Figure Fogging nozzles

- **Description**

High pressure water from positive displacement pumps is sprayed by fogging nozzles in vary fine particles size microns max) m air flow path inside inlet air duct The nozzles brave impaction pins which atomize water particles into a fine mist. The temperature of the water particles reduces due to expansion in nozzles these cooled fine particle absorb heat from air the water particles evaporate to a heat extent and coals down the incoming ambient air. When ambient air is cooled up to its wet bulb temperature the air achieves complete saturation any further reduction in air temperature will cause expansion in nozzles. These cooled fine particles absorb heat from air. the water particles evaporate to a great extent and cools down the incoming ambient air When ambient air is cooled up to its wet bulb temperature the air achieves complete saturation.

Any further reduction in air temperature will cause condensation of water particles In GT parlance this is often referred to as over fogging la GT, cooling effects of over fogging is not due to reduction in temperature of air but reduction in temperature of water due to expansion in nozzles. Thereby cooling of mixture (air & water) takes place which is measured by sensors mounted on the turbine inlet duct Thus, during over fogging. Temperature of water particles will be less than the wet Bulb temperature of air this will result in much higher density of water particles which is harmful to the compressor blades.

- **Observation Tables:**

Sr. No.	Inlet Air Temperature (K)	Specific Fuel Consumption (Kg/KW.hr) @ RH - 100%	Specific Fuel Consumption (Kg/KW.hr) @ RH - 60%
1	272	0.234	0.233
2	282	0.237	0.236
3	292	0.243	0.241
4	302	0.249	0.247
5	312	0.257	0.254

Pump-1 A & B operates at a time i. e. one in operations and one as stand-by.

- **Data collection of Fogging skid:**

Two weather stations measure atmospheric Dry Bulb Temperature and Relative Humidity. The In-built software /PLC calculate the Wet Bulb temperature.

- Operating pressure = 2000 psi(140kg/cm2)
- Fog droplet size = 14 microns
- Number of nozzles = 320
- Nozzle flow rate = 0.17 LPM per nozzles
- Water flow per stage = 3.4 LPM
- Total skid flow = 54.5 LPM
- Minimum cooling = 1deg. C
- Cooling capacity = 16deg. C
- Cooling stages =16 stages
- Pump skid Power requirement = 3HP*2+5HP*1+7.5HP*3
- Dry Bulb Temperature = 36deg. C
- Relative Humidity = 35% then other
- Calculated Wet Bulb Temperature = 21deg. C
- Now, Available cooling or depression = 36- 21=15deg. C

- To prevent over fogging a margin 2 deg. C is kept above available cooling or wet bulb depression.

- So actual number of Fogging stages in service will be 5-3 = 13 deg. C.
- To achieve 13deg. C cooling following pumps will be remaining in normal operation
- Pump → 1A or 1B will run whichever is selected provides 1deg. C cooling
- Pump → 2 + MOV will remain Off
- Pump → 3 will run provides 4deg. C cooling
- Pump → 4 will run Provides 5deg. C cooling
- Pump → 5 will run Provides 6deg. C cooling

- **Safety Health & Environment:**

- Use all personal protective items:
- Wear safety helmet, safety shoes, gloves, ear muffs ear plugs and safety goggles
- Ensure no PTW is pending on the system by checking with - SFE/PE.
- Ensure at least one 10 kg DCP cylinders are unplaced besides the skid.
- Ensure that no air/ DM water leaks from fogging skid.

- **Water wash system in Gas turbine:**
- **Purpose:**

The Turbine efficiency depends much on the efficiency of the compressor whose performance deteriorates over a period of time. This is due to deposition of air bam immunities on the compressor blades. which can be effectively removed by water washing Hence non lay the Gas Turbine compressor is required to be washed after every 8000 running hours or during available shutdown on-line water wash is also carried-out at pre-determined ultralow, when beat machine measures due to compressor fouling rate and description The Water wash system uses a Gas turbine plays a vital role in operating the unit at economical Heat rates. The system consists of a water wash tank a water pump, a detergent tank and a detergent pump Normally DM water is to be filled up in m the tank and detergent as specified the Manual is to be filled up in the detergent tank. All The Eight Gas Turbines have off-line water wash facility There are two types 1) on-line water wash system Low pressure Type 8kg/cm2 water is sprayed during on-line water wash This system is applicable for GT-1, 5. 6, 7, 2) High pressure Type 60 kg /m2 water is sprayed during on-line water wash. This system us applicable for GT-1, 2, 3, 8

- **Description:**

  - Gas Turbine compressor can foul after a period of time hence compressor is required to be cleaned by water to improve the efficiency of compressor.
  - Water need can be derived from the parameters like GPD, MW and heat rate, if all three parameters are dropped down to the considerable low value than the rated value then water wash can help to improve these parameters.
  - Normally water wash is a good practice after every combustion inspection Le after every 8000 fired hours.
  - In the modern days Gas Turbine On line water wash systems are available if these systems are used effectively deterioration of compressor parameters can be minimized thus Gas Turbine can be run at the higher efficiency.
  - In the modern days Gas Turbine On- line water wash systems are available .if these systems are used effectively deterioration of compressor parameters can be minimized, thus Gas Turbine can be run at the higher efficiency.

- Collecting data of water wash system:

The following data collection for water wash system:

- Power output = 134.4 Mw
- Lower calorific value of fuel = 45679 kJ/kg
- Atmospheric pressure = 1.013 bar
- Pressure loss @air intake filter = .008 bar
- Air flow rate = 408.7 kg/s
- Compressor outlet temperature = 360 deg. C
- Pressure ratio = 13.8
- Combustion chamber inlet pressure = 13.183 bar
- Fuel gas flow rate = 8.3 kg/s
- For compression process = Cp = 1.005kJ/kg.k

Scope of Future Study:

- Gas turbine being the rotating and power generating equipment with provision of facility to used different types of fuels, so further study can be done on,
- Further study on low emission Gas turbine technology for hydrogen-rich sync gas.
- Implementation of various energy conservation techniques to various drives to reduce the self-power consumption.
- Optimizing in Gas turbines repair outages through condition monitoring and advanced instrumentation.

Problem solved:

- Increase the heat rate in inlet air temperature
- Improve the efficiency of the system
- Increase the density of entering air in gas turbine
- Quick delivery can be possible
- More economical condition of plant

Features:

- Gas turbine experiences a degradation of performance due to deposition on compressor and turbine sections.
- Fouling of compressor and turbine blades results reduce in thermal and power output.
- Compression deposition due to ingested air.
- Turbine section deposition occurs as a result of type and treatment of the fuel being f red.

Limitations:

- This fogging skid will not cool the ambient air below 15 deg C.
- This fogging skid is designed to cool air up to available wet bulb temperatures over fogging results in higher droplet size which is harmful to compressor.
- Done after shutdown of gas turbine.

- OFF-LINE washing done if long period of stand-by is foreseen or if compressor performance degraded by 10%.
- Washing done by detergent water solution injected at the compressor inlet while rotor is at lower speed (i.e. cranking).
- Temperature difference between wash water and wheel space should not be high (i.e. 67 deg 'C).

Conclusion:

With this study we can conclude that the gas turbine efficiency depends on the compression ratio and of the working fluid (air). The efficiency increases with the increase compression ratio. The Brayton cycle specific output increases with a decrease in the gas turbine inlet temperature. The gas turbine output increases with an increase in the working fluid (air) mass flow rate. During normal operation water wash as per recommended running hours will also increase the efficiency of the gas turbine. Also use of gas turbine in combine and co-generation mode with minimum heat loss for highest plant efficiency.

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