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A Review on Thermal Investigation of Open-Cycle Gas-Turbine Power-Plant with Regenerator

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***Abstract*- This intensive parametric study was conducted based on the fundamental of thermodynamics and gas turbine relations considering the effect of the operation conditions (ambient air temperature, regeneration effectiveness and compression ratio). It was found that adding regeneration to the simple gas turbine cycle results in an increase in the thermal efficiency of cycle. It was also found that including regeneration in gas turbine cycle results in an increase in the output power of the cycle, and it results in a decrease in the exhaust gas temperature. The effect of the regeneration effectiveness was also predicted. It was found that increasing of regeneration effectiveness results in an increase in the output power of the cycle. It was also found that the cycle thermal efficiency increases with increasing of the regenerative effectiveness. The effect of ambient air temperature was also predicted. Increasing of the ambient air temperature results in a decrease in the thermal efficiency of the cycle.**

***Keywords*- Gas turbine, power plant, thermal analysis, regeneration.**

I. INTRODUCTION

Gas turbine regenerators are usually constructed as shell and tube type heat exchangers using very small diameter tubes, with the high pressure air inside the tubes and low pressure exhaust gas in multiple passes outside the tubes. The thermal efficiency of the Brayton cycle increases as a result of regeneration since the portion of energy of the exhaust gases that is normally rejected to the surroundings is now used to preheat the air entering the combustion chamber. This, in turn, decreases the heat input (thus fuel) requirements for the same network output. Note, however, that the use of a regenerator is recommended only when the turbine exhaust temperature is higher than the compressor exit temperature. Otherwise, heat will flow in the reverse direction (to the exhaust gases), decreasing the efficiency.

This situation is encountered in gas turbines operating at very high-pressure ratios [5]. A regenerator with a higher effectiveness will save a greater amount of fuel since it will preheat the air to a higher temperature prior to combustion [6]. However, achieving a higher effectiveness requires the use of a larger regenerator, which carries a higher price tag and causes a larger pressure drop because shaft horsepower is reduced. Pressure drop through the regenerator is important and should be kept as low as practical on both sides. Generally, the air pressure drop on the high-pressure side should be held below 2% of the compressor total discharge pressure. The effectiveness of most regenerators used in practice is below 0.85. The thermal efficiency of an ideal Brayton cycle with regeneration depends on the ratio of the minimum to maximum temperatures as well as the pressure ratio. Regeneration is most effective at lower pressure ratios and low minimum-to-maximum temperature ratios [7]. A parametric study of the effect of compression ratio, ambient temperature, turbine’s inlet-temperature (TIT), the effectiveness of regenerator, compressor efficiency, and turbine efficiency on the performance of the regenerative gas turbine cycle and comparison with simple cycle [3].

II. OPEN CYCLE GAS TURBINE PLANT

A simple open cycle gas turbine consists of a compressor, combustion chamber and a turbine as shown in the below figure. The compressor takes in ambient fresh air and raises its pressure. Heat is added to the air in the combustion chamber by burning the fuel and raises its temperature.

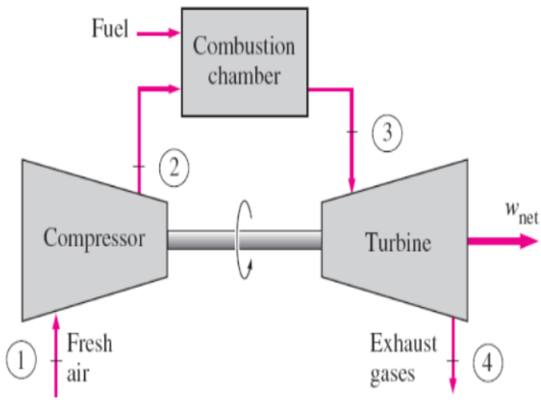

Fig. 1 Simpleopen cycle gas turbine plant

The heated gases coming out of the combustion chamber are then passed to the turbine where it expands doing mechanical work. Some part of the power developed by the turbine is utilized in driving the compressor and other accessories and remaining is used for power generation. Fresh air enters into the compressor and gases coming out of the turbine are exhausted into the atmosphere, the working medium need to be replaced continuously. This type of cycle is known as open cycle gas turbine plant and is mainly used in majority of gas turbine power plants as it has many inherent advantages.

Advantages:

- Warm-up time: Once the turbine is brought up to the rated speed by the starting motor and the fuel is ignited, the gas turbine will be accelerated from cold start to full load without warm-up time.
- Low weight and size: The weight in kg per kW developed is less.
- Fuels: Almost any hydrocarbon fuel from high-octane gasoline to heavy diesel oils can be used in the combustion chamber.
- Open cycle plants occupy less space compared to close cycle plants.
- The stipulation of a quick start and take-up of load frequently are the points in favor of open cycle plant when the plant is used as peak load plant.
- Component or auxiliary refinements can usually be varied in open cycle gas turbine plant to improve the thermal efficiency and can give the most economical overall cost for the plant load factors and other operating conditions envisaged.
- Open cycle gas turbine power plant, except those having an intercooler, does not need cooling water. Therefore, the plant is independent of cooling medium and becomes self-contained.

Disadvantages:

- The part load efficiency of the open cycle gas turbine plant decreases rapidly as the considerable percentage of power developed by the turbine is used for driving the compressor.
- The system is sensitive to the component efficiency; particularly that of compressor. The open cycle gas turbine plant is sensitive to changes in the atmospheric air temperature, pressure and humidity.
- The open cycle plant has high air rate compared to the closed cycle plants, therefore, it results in increased loss of heat in the exhaust gases and large diameter duct work is needed.
- It is essential that the dust should be prevented from entering into the compressor to decrease erosion and depositions on the blades and passages of the compressor and turbine. So damages their profile. The deposition of the carbon and ash content on the turbine blades is not at all desirable as it reduces the overall efficiency of the open cycle gas turbine plant.

III. LITERATURE SURVEY

Odinikuku (2018)focused on the analysis and performance evaluation of a gas turbine power plant. The gas turbine power plant was evaluated using thermodynamic principles and the technical data of the plant. The data used for the study were obtained from the plant records of Delta III GT9 plant. The results of the analysis for a period of twelve (12)months (January to December, 2016) show that 92% of the expected capacity was available in the period under study.

The thermal efficiency of the plant ranged from 26% to 32%, and the plant's capacity factors ranged from 68% to 80%.The reliability of the plant ranged from 21% to 98% (average 58%). For the period under study, only 20 MW of energy (power) was lost out of the expected power of 240 MW. The study revealed that the above performance parameters analyzed for Delta III GT9 plant are within the range of best industrial practice. Also, the efficiencies achieved for the period under study are within the best international value for a single cycle gas turbine plant.

Kumar et al. (2017) had done the thermodynamic performance analysis of an open cycle gas turbine power plant has been performed. The mathematical formulation for the specific work and efficiency were derived and analyzed. The effect of operating parameters like the ambient temperature, relative humidity, compressor pressure ratio, turbine inlet temperature(TIT), isentropic efficiencies of compressor and turbine on the thermal efficiency, power output and heat rate of a gas turbine plant are studied. An in-house code in Matlab has been developed. The data generated using the code have been utilized to draw different relevant graphs. The results show that the compression ratio, ambient temperature, air to fuel ratio as well as the isentropic efficiencies can strongly influence the thermal efficiency. In addition, the thermal efficiency and power output decreases linearly with increase of the ambient temperature and air to fuel ratio. Also, the specific fuel consumption and heat rate increases linearly with increase of both ambient temperature and air to fuel ratio. Various techniques to improve the performance of gas turbine are also discussed.

Omar et al. (2017) investigated the effect of regeneration on the output power and the thermal efficiency of the gas turbine power plant. The effect of ambient air temperature, regeneration effectiveness, and compression ratio on the cycle thermal efficiency was also investigated. An existed gas turbine power plant of AL ZAWIA is used as a base in this study, and the calculations were carried out utilizing MATLAB code. This intensive parametric study was conducted based on the fundamental of thermodynamics and gas turbine relations considering the effect of the operation conditions (ambient air temperature, regeneration effectiveness and compression ratio). It was found that adding regeneration to the simple gas turbine cycle results in an increase in the thermal efficiency of cycle. It was also found that including regeneration in gas turbine cycle results in an increase in the output power of the cycle, and it results in a decrease in the exhaust gas temperature. The effect of the regeneration effectiveness was also predicted. It was found that increasing of regeneration effectiveness results in an increase in the output power of the cycle. It was also found that the cycle thermal efficiency increases with increasing of the regenerative effectiveness. The effect of ambient air temperature was also predicted.

Vasserman et al. (2017)analyzed three new methods of increasing efficiency of turbine power plants are described.Increasing average temperature of heat supply in steam turbine plant by mixing steam after over heaters with products of combustion of natural gas in the oxygen. Development of this idea consists in maintaining steam temperature on the major part of expansion in the turbine atlevel, close to initial temperature. Increasing efficiency of gas turbine plant by way of regenerative heating of the air by gas after its expansion in high pressure turbine and before expansion in the low pressure turbine. Due to this temperature of air, entering combustion chamber, is increased and average temperature of heat supply is consequently increased. At the same time average temperature of heat removal is decreased. Increasing efficiency of combined cycle power plant by avoiding of heat transfer from gas to wet steam and transferring heat from gas to water and superheated steam only. Steam will be generated by multi stage throttling of the water from supercritical pressure and temperature close to critical, to the pressure slightly higher.

Leon et al. (2015) presented a thermodynamic model for a hybrid solar gas-turbine power plant All the subsystems of the plant are modeled, taking into account the most important losses sources: those coming from heat losses in the solar subsystem, those in the combustion chamber, those associated to the Brayton cycle, and those heat losses in the heat exchangers connecting subsystems.

Analytical expressions for the overall plant efficiency and its power output are obtained in a general form, for whichever solar share from the pure combustion mode when solar irradiance is null or small, to the eventual case in which only solar heat input would be enough to ensure that the working fluid reaches the turbine inlet temperature. The gas-turbine model is validated by direct comparison of the model predictions with the output parameters of a commercial turbine. Results are very promising. The real parameters of an existing experimental thermos solar plant are considered and its performance records in stationary irradiance conditions are obtained. A sensitivity analysis of the influence of several turbine losses is performed: recuperator, turbine, compressor, and pressure losses. Finally, the influence of the pressure and temperature ratios on the overall plant efficiency and the fuel conversion rate is discussed. This kind of thermodynamic analysis is necessary in order to design efficient as well as commercially interesting new generations of plants of this type.

IV. CONCLUSION

Gas turbine regenerators are usually constructed as shell and tube type heat exchangers using very small diameter tubes, with the high pressure air inside the tubes and low pressure exhaust gas in multiple passes outside the tubes. The thermal efficiency of the Brayt on cycle increases as a result of regeneration since the portion of energy of the exhaust gases that is normally rejected to the surroundings is now used to preheat the air entering the combustion chamber. This, in turn, decreases the heat input (thus fuel) requirements for the same network output. Note, however, that the use of a regenerator is recommended only when the turbine exhaust temperature is higher than the compressor exit temperature. Otherwise, heat will flow in the reverse direction (to the exhaust gases), decreasing the efficiency. This situation is encountered in gas turbines operating at very high-pressure ratios.

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