Thermodynamic Analysis of Combined Cycle Power Plant to Enhance its Performance

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Abstract: - Combined cycle is an alternative to utilize the lost heat energy. A great amount of energy gets lost through the exhaust of simple power plant cycle. This heat energy is enough to run another cycle which leads to an increase in the overall efficiency of the power plant. In this manner, not only the efficiency of the plant increases but also it helps to reduce air pollution and global warming. This paper is a thermodynamic analysis conducted in order to enhance the performance of combined cycle. The result shows that gain in network output is about 41% when the temperature at the inlet of the turbine of topping cycle increases from 1000K to 1200K. The gain in net efficiency of the cycle is from 15% to 28%.

Keywords – Combined cycle, Compression Ratio, Topping cycle, Turbine inlet temperature.

I. Introduction

The basic principle of the Combined Cycle power plant has a compressor, combustion chamber and a gas turbine (GT) which is coupled to generator to generate electricity and the waste exhaust heat energy is used to make steam and it is used to generate additional electricity via a steam turbine. Modern life depends upon energy which is crucial to achieving sustainable development. Nowadays, it becomes more evident that clean, climate-friendly, and affordable energy technologies must be deployed as rapidly as possible. Energy access for all will require making available basic and affordable energy services using a range of energy resources and innovative conversion technologies while minimizing Green House Gas (GHG) emissions, adverse effects on human health, and other local and regional environmental impacts.

From the diagram, First cycle is the same as the simple cycle gas turbine plant. An open circuit gas turbine has a compressor, a combustor and a turbine. The output temperature of flue gases is very high. This is therefore high enough to provide heat for a second cycle which uses steam as the working medium i.e. thermal power station. This paper will discuss thermodynamic and technical factors of combined-cycle parameters. It is an overview of the operational flexibility of modern combined cycles.

II. LITERATURE REVIEW

Sipeng Zhu [1] conducted a theoretical study on the thermodynamic processes of a bottoming Rankine cycle for engine waste heat recovery. The results showed that working fluid properties, evaporating pressure and superheating temperature were the main factors influencing the system design and performances.

Iacopo et al. [2] introduced a specific thermodynamic analysis in order to perform an efficient match of a vapor cycle. A second law analysis of the cycles was conducted while the analysis of the study reveals that there is 12% increase in the overall efficiency.

A.L. Polyzakis et al. [3] introduced the optimization of the combined cycle power plant reheated cycle. The results of their study revealed that reheated gas turbines are the most desirable.

Wengu o XIANG et al [4] investigated the improvement and the efficiency of Gas Turbine Combined Cycle (GTCC) plant in China. Their result showed that increasing the heat recovery steam generator (HRSG) inlet temperature has less improvement in steam cycle efficiency.

Nico Woudstra et al. [5] investigate three system established for this purpose and modeled using the computer program Cycle-Tempo.
H.G. Zhang et al. [6] analyzed small-scale Organic Rankine Cycle (ORC) in order to harness the waste heat coming from an internal combustion engine. Guopeng Yu et al. [7] introduced a simulation model that is based on Organic Rankine Bottoming Cycle system of a diesel engine. The main purpose of their system is to recover the waste heat that came from the gas engine exhaust. Boonnasa et al. [8] evaluate methods of enhancing the capacity of an existing combined cycle power plant in Bangkok, Thailand. A steam-absorption chiller is proposed to cool the ambient gas turbine inlet air to 15 °C. The power gain is expected to be about 10.6% with a payback time of 3.8 years. Nasser and El-Kalay [9] proposed the use of a simple Li-Br heat-recovery absorption system to cool the air intake of a gas turbine compressor in Bahrain to compensate for the 30 °C summer to winter variation in ambient temperature. They calculated that heat from the exhaust gases can decrease a 40 °C ambient inlet air temperature by 10 °C, giving a power increase of 10%.

Bies et al. [10] studied the use of a lithium bromide double-effect absorption chiller to cool warm ambient air entering a gas turbine compressor. Mohanty and Paloso [11] studied a similar system for a 100MW gas turbine in Bankok, taking the inlet temperature down to 15 °C. They achieved instantaneous power output increases of between 8 and 13%, with an overall increase of 11%.

Kakaras et al. [12] developed a computer simulation a simple cycle gas turbine and a combined cycle plant. They examined the effect of ambient air temperature on output and efficiency, showed how the 40 to 45 °C ambient temperatures common in Southern Europe cause losses in excess of 20%, and demonstrated the potential gains from integrating evaporative media and absorption chillers. Evaporative cooling changes physical state along the adiabatic line and limits before 100% relative humidity is achieved. The advantage of the proposed absorption system is that, independent of ambient air conditions, it can cool intake air to a specific constant temperature and consistently increase plant output. Ameri and Hejazi [13] report that there are more than 170 gas turbine units in Iran with a combined capacity of 9500 MW, but hot weather during the summer results in 1900 MW losses. They conducted an economic analysis of a gas turbine intake air-cooling system in the Iranian Chabahar power plant. The system described uses a steam-absorption chiller and output power was increased by 11.3%.

III. COMBINED CYCLE POWER PLANT DESCRIPTION

The thermodynamic cycle under analysis is the combination of two cycles: one is a primary cycle, which is termed as topping cycle working on Brayton cycle, and the exhaust of this cycle was used to run the second cycle termed as bottoming cycle. The bottoming cycle works on Rankine cycle.

In topping cycle, air at atmospheric pressure (p₁) and temperature (T₁) at point 1 enters the compressor, where it compresses to high pressure (p₂) and temperature (T₂). The high pressure and high-temperature air enters the combustion chamber. The air temperature (T₃) after passing through the combustion chamber increases because it gains heat from the gas fuel. After leaving the combustion chamber the combustible product of combustion chamber at high pressure (p₃) and high temperature (T₄) enters the turbine where combustible product expand to the temperature (T₅). After leaving the turbine, the temperature of the exhaust gasses is still very high and the amount of energy that these gasses carried out is very high. If these gasses directly exhaust to the environment, they contribute to the global warming as well as energy loss. So in order to extract the energy from these gasses, water is directed to pass through the heat recovery boiler to generate steam. In bottoming cycle, steam expands in the turbine to generate additional power.

1. Analysis of Topping Cycle:

   Turbine work \( W_{th} = m_s C_p(T_4 - T_3) \)  \( \text{(1)} \)

   Compressor work \( W_{Cp} = m_s C_p(T_2 - T_3) \)  \( \text{(2)} \)

   Network of Topping cycle \( W_{net} = (W_{th}) - (W_{Cp}) \) \( \text{(3)} \)

2. Analysis of Bottoming Cycle:

   Steam Turbine work \( W_{th} = m_s (h_1 - h_2) \) \( \text{(4)} \)

3. Analysis of Combined Cycle:

   Combined cycle plant efficiency \( = (W_{net}+W_{th})/Q \) \( \text{(5)} \)

IV. COMPUTER SIMULATION

The topping, bottoming and combined cycle network efficiencies for the considered configurations have been investigated parametrically by using first and second laws of thermodynamics. The commercial MATLAB R2015a has been used to get a solution for all parametric functions which have been described by analytical expressions and then all succeeding parameters and functions are simulated and implemented. The result shows that gain in network output is about 41% when the temperature at the inlet of the
turbine of topping cycle increases from 1000K to 1200K. The gain in net efficiency of the cycle is from 15% to 28%.

V. DISCUSSION AND RESULTS

In this study, combined cycle power plant is numerically simulated to evaluate and enhance the performance of the power plant.

Variation of heat supplied by combustion chamber with a compression ratio of topping cycle at \( m_{ab}=50\text{kg/s} \) and \( m_{ab}=70\text{kg/s} \) are respectively drawn for different value of TIT=1000K, TIT=1100K and TIT=1200K. It is clear from these figures that for \( m_{ab}=50\text{kg/s} \) the heat supplied by combustion chamber increases with compression ratio. Whereas, for \( m_{ab}=70\text{kg/s} \) the heat supplied by combustion chamber decreases with compression.

The effect of the compression ratio of topping cycle on energy efficiency at \( m_{ab}=50\text{kg/s} \) and \( m_{ab}=70\text{kg/s} \) gives that the energy efficiency of topping cycle increases significantly with turbine inlet temperature independently of mass flow rate and compression ratio, this can be attributed to the fact that the turbine inlet temperature augments significantly the heat supplied as proved in the graph.

The variations of the network \( W_{net} \) for the topping cycle with energy efficiency for different value of TIT=1000K, TIT=1100K and TIT=1200K at \( m_{ab}=50\text{kg/s} \) and \( m_{ab}=70\text{kg/s} \) are respectively drawn. It indicates that the network \( W_{net} \) for the topping cycle increases meaningfully with turbine inlet temperature.

Figures exhibit respectively the effect of energy efficiency on the network \( W_{net} \) for the combined cycle. It is clear that higher energy efficiency and higher network are obtained only for the advanced value of turbine inlet temperature for both cases \( m_{ab}=50\text{kg/s} \) and \( m_{ab}=70\text{kg/s} \).

VI. CONCLUSION

A thermodynamic analysis for a combined cycle power plant has been explored parametrically and a performance evaluation has been efficiently applied. The results improve the understanding of the combined cycle power plant behavior and its performance.

The turbine inlet temperature helps to increase expressively the network and the energy efficiency of the combined cycle and the heat supplied by combustion chamber decreases with compression ratio.

VII. REFERENCES


