Analysis and Modeling of a Combined Cycle Power Plant Using Graph Theory

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ABSTRACT

Graph theory is a well established tool for the analysis of any system. For the graph theory system has to be divided into sub systems and factors have to be identified for the analysis. In the present work some of the attributes are identified for the application of graph theory. A proper identification of the attributes helps in precise evaluation of selection of combined cycle power plant systems. As the number of attributes increases, the performance characteristics of such systems are represent precisely and the selection of gas turbine system becomes more reliable. However, with increase in number of attributes, usage of dedicated computer programs becomes more indispensable for efficient evaluation and selection of combined cycle power plant systems. Generally, the attributes of combined cycle power plant systems can be classified either by different subsystem of the combined cycle power plant system or by the different performance characteristics of the combined cycle power plant system as well as matching of its subsystems. For the identification of attributes two methods are adopted. Some of the attributes are identified from the literature and for some attributes a computer program was made. Results obtained from the program also give us new attributes.

KEYWORDS

1. Ach
2. amb
3. avg.
4. aph
5. IAt
6. COP
7. CCPP

INTRODUCTION

In March 2015, the installed power generation capacity of India stood at 147,000 MW while the per capita power consumption stood at 612 kWH. The country's annual power production increased from about 190 billion kWH in 1986 to more than 680 billion kWH in 2006. The Indian government has set an ambitious target to add approximately 78,000 MW of installed generation capacity by 2012. The total demand for electricity in India is expected to cross 950,000 MW by 2030. Current installed capacity of Thermal Power (as of 12/2008) is 93,392.64 MW which is 63.3% of total installed capacity. Current installed base of Coal Based Thermal Power is 77,458.88 MW which comes to 53.3% of total installed base. Current installed base of Gas Based Thermal Power is 14,734.01 MW which is 10.5% of total installed base. Current installed base of Oil Based Thermal Power is 1,199.75 MW which is 0.9% of total installed base. The electricity generation growth rate in India was 6.4% in the 2007-08 and 2.8% in the year 2008-09 with respect to base year 1993-94 (The Hindu, 13.05.08).

The state of Maharashtra is the largest producer of thermal power in the country. Combined cycle power plants in India are located at Dabhol (2150 MW), Dadri (409 MW), Karuppur (120 MW), Kathalguri (97 MW), Kayamkulam (360 MW), Regency (59 MW), Tanirbavi (220 MW), Valuthur (187 MW). India is one of the pioneering states in establishing hydro-electric power plants, The power plant at Darjeeling and Shimla (Shivanasamudra) was established in 1898 and 1902 respectively and is one of the first in Asia. The installed capacity as of 2008 was approximately 36647.76 MW. The public sector has a predominant share of 97% in this sector. Currently, seventeen
nuclear power reactors produce 4,120.00 MW (2.9% of total installed base). Current installed base of Renewable energy is 13,242.41 MW which is 7.7% of total installed base with the southern state of Tamil Nadu contributing nearly a third of it (4379.64 MW) largely through wind power. Electricity losses in India during transmission and distribution are extremely high and vary between 30 to 45%. In 2004-05, electricity demand outstripped supply by 7-11%. Due to shortage of electricity, power cuts are common throughout India and this has adversely effected the country's economic growth. Theft of electricity, common in most parts of urban India, amounts to 1.5% of India's GDP. Despite an ambitious rural electrification program, some 400 million Indians still have no access to electricity. While 80 percent of Indian villages have at least an electricity line, just 44 percent of rural households have access to electricity. According to a sample of 97,882 households in 2002, electricity was the main source of lighting for 53% of rural households compared to 36% in 1993. India has five regional grids and each grid is monitored and operated by a regional dispatch center. The inter-regional transmission capacity is around 17 GW which is inadequate and leads to network congestion. To address this issue, the Government plans to increase the inter-regional capacity to 37 GW by 2012. In addition to congestion, power transmission across several utility systems or zones leads to accumulating utility or zone access charges or ‘pan caking’

Mathematical Modeling and analysis of the WHRB

In recent years a great deal of attention is focused on the efficient utilization of energy resources with minimum heat loss. The persistent need to conserve the fast depleting energy resources, and to use them in a more efficient manner has renewed the interest in devices that can utilize heat from waste flue gases from various industries. The flue gases on the virtue of being at a higher temperature relative to the surroundings and having a higher mass flow rate, possess considerable amount of available energy, which if not utilized properly will lead to huge undesirable energy loss. During the last two decades there has been considerable attention, on to utilize heat from flue gases for various applications and to optimize the units which are used to absorb heat from waste flue gases. Waste heat recovery boiler is the component of the bottoming steam cycle, which absorbs energy of exhaust gas of the gas turbine and produces steam suitable for the process or for further electricity generation by a steam turbine.
Power plant engineers can design their own HRSGs and the bottoming steam cycles at the initial stage. On the other hand, gas turbine is not made to order and steam turbine is selected according to the condition of the steam delivered from a HRSG. In this respect, the design of a HRSG is indispensable to the improvement of the overall system.

Table 1. WHRB energy distribution

<table>
<thead>
<tr>
<th>Surface</th>
<th>% of Total Area of Pressure Parts</th>
<th>% of Total Heat transfer to Pressure Parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economizer</td>
<td>19.6</td>
<td>7.28</td>
</tr>
<tr>
<td>Boiler (Including water walls)</td>
<td>28.8</td>
<td>66.97</td>
</tr>
<tr>
<td>Superheater</td>
<td>51.6</td>
<td>25.75</td>
</tr>
<tr>
<td>Total</td>
<td>100.0</td>
<td>100.0</td>
</tr>
</tbody>
</table>

The gas side pinch point temperature ($T_p$) and economizer exit temperature ($T_{EO}$) are calculated by assuming the drum saturation pressure ($P_{Drum}$).

\[ T_p = T_{DRUM} + PP \]
\[ T_{EO} = T_{DRUM} - AP \]  

The steam generated for each kg/sec of exhaust gases can be determined by applying mass and energy conservation principles across the superheater and evaporator.

\[ M_w = \frac{M_{GEX} \times C_{PG} (T_{GEX} - T_p)}{(h_{ST} - h_{EO})} \]  

The WHRB, being considered is a non-firing boiler. Therefore the heat transfer is predominantly by convection. It is customary to neglect the radiative heat transfer, particularly because the reduction in heat transfer due to soot deposition/ fouling etc. is also ignored and it is assumed that these two approximately compensate each other. The heat across each section of boiler can be estimated as follow:

\[ Q_{ECON} = M_w (h_{EO} - h_{FW}) \]  
\[ Q_{EVAP} = M_w [h_{FG} + C_{PW} (T_{DRUM} + T_u)] \]  
\[ Q_{SUPR} = M_w (h_{ST} - h_{G}) \]  

The flue gas temperature in the stack can also be estimated on the basis of the heat balance across economizer.

\[ T_{STACK} = T_p - \frac{M_w (h_{LPEO} - h_{FW})}{M_{GEX} \times C_{PG}} \]  

A low stack temperature is always desirable from the point of waste recovery. However to avoid the corrosion from moisture formation in economizer, the minimum temperature should always be kept higher than the acid dew point temperature. Also, the size of economizer depends on the stack temperature which has therefore to be justified on the economic consideration.

**STEAM EXTRACTION**

To increase the efficiency of steam cycle open type and closed type feed water heaters are employed. In open or direct-contact-type of feed water heater the extraction steam is mixed directly with incoming sub-cooled feedwater.
heater to produce saturated water at extraction steam pressure. In closed type feedwater heater, feedwater passes through the tubes and the bled steam, on the shell side, transfer its energy to it and condenses. With reference to the following diagram and starting with low pressure heater, the drain at 13 is pumped forward to the main feedwater line, enters it at 14 and mixes with the exit water from that heater at 7, resulting in a mixture at 8. The water at 8 enters the high-pressure heater and is heated to 9. The drains leaves the heater at 11, is pumped to 12 and mixes with feedwater at 9 resulting in full feedwater flow at 10 which now goes to steam generator. It may be noted that on T-s diagram point 8 is closer to 7 than 14. It is because the main feedwater flow at 7 is greater than the drain flow from the point 3 to 14.

![Schematic flow diagram of nonideal superheat Rankine cycle with two closed-type feed water heaters with drains pumped forward.](image)

**Figure.3. Schematic flow diagram of nonideal superheat Rankine cycle with two closed-type feed water heaters with drains pumped forward.**

**RESULT ANALYSIS**

**Compressor attributes**

In a gas turbine system, the intake air is initially compressed in the compressor to increase its pressure and temperature. The performance of the compressor significantly affects the overall performance of the gas turbine system. Since, the energy transfer during the flow of air compressor takes place, the thermodynamic as well as aerodynamic and mechanical design and factor effecting these parameters play a significant role in the performance of the compressor. The various attributes identified effecting the compressor design and performance are:-

1. Types of compressor (centrifugal or axial flow)
2. Design of inlet guide vanes
3. Compressor pressure ratio

As may be seen from the following figure that cycle pressure ratio is having direct effect on the temperatures at the various points of gas turbine cycle. It may be seen that with increase in cycle pressure ratio all the temperature get altered. In the present analysis TIT is fixed.
Figure 4. Change in various temperature with change in cycle pressure ratio

Further in the following figure effect of cycle pressure ratio may be seen on the mass of the air entering the compressor.

Figure 5. Change in mass of air entering compressor with change in cycle pressure ratio

4. Stage temperature rise
5. Stage loading
6. No. of stages
7. No. of spools in compressor
8. Rotational speed
9. Mass flow of air

Mass of the air entering the compressor is also affected by the ambient air temperature also. As the ambient air temperature is increased, mass of the air entering the compressor also increases.
Number of steam extraction is having very large effect on the performance of gas turbine and as well as on the performance of steam turbine. As may be seen in the following figure that as we go for double steam extraction from single steam extraction then mass of air entering compressor also get altered.

CONCLUSION

Combine cycle power plant is a developing system so that the new attributes are identified with new researches. A Survey can be done to identify new factors taking role in the performance of Combine cycle power plant.

REFERENCES


