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Modeling and Analysis of Thermal Efficiency of Gas Turbine Power Plant Using Graph Theory and Matrix Method

Dr. B. K. Roy[1] and Dr. Rakesh Rajpal[2]

[1]**Principal, Gyan Ganga Institute of Technology and Sciences, Jabalpur, (MP)**
barunrai_hbti@rediffmail.com

[2]**Professor, Ganga Technical Campus, Bahadurgarh, Jhajjar, Haryana, India**
rajpal.rakesh@gmail.com

Abstract

Power generation is an important issue today. Gas turbines have turned out to be one of the most interesting techniques for electric power generation. It can be used in several different modes in industries such as power generation, oil and gas, process plants, aviation as well as domestic and smaller related industries.

The use of gas turbine for electrical power generation has changed dramatically in recent years. In 1970s, gas turbines (particularly in Great Britain and North America) were primarily used for peaking and emergency application; aero derivative units with a heavy duty power turbine were widely used. One of the outstanding advantages of this type was its ability to produce full power in cold in less than 2 minutes, although this capability should be used only for emergencies because thermal shock will greatly reduce the time between overhauls.

In India, thermal power is the largest source of power. About 75% of electricity consumed in India is generated by thermal power plants. More than 50% of India's commercial energy demand is met through the country's vast coal reserves. Public sector undertakings, National Thermal Power Corporation and several other state level power generating companies are engaged in operating coal based thermal power plants. The objective of present research work is to analyze the effect of Operating /performance Parameters on the thermal efficiency of Gas Turbine Power Plant. Also it is useful for finding the critical factor among different performance parameters of GTPP.

Keywords: *Power generation, gas turbine for electrical power generation, thermal power*.

Introduction

Power generation is an important issue today. Gas turbines have turned out to be one of the most interesting techniques for electric power generation. It can be used in several different modes in industries such as power generation, oil and gas, process plants, aviation as well as domestic and smaller related industries.

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The state of Maharashtra is the largest producer of thermal power in the country. 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. There are different types of Thermal power plants based on the fuel used to generate the steam such as coal, gas, Diesel etc. As on July 31, 2012, and as per the Central Electricity Authority the total installed capacity of types of power plants in India are plotted as:

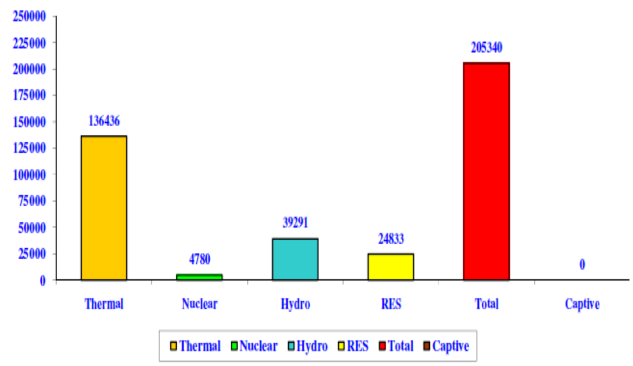

Fig. 1.1: All India generating installed capacity (MW)

Capital costs of generation plants vary according to the plant basis. Typical costs (2010) per MW are

- Coal-based plant: INR 3.8 to 4 crore.
- Gas-based plant: INR 3.5 crore.
- Hydro: INR 5 crore.
- Wind: INR 5-6 crore.
- Nuclear: INR 6 crore (going by the project cost for PWR and PHWR reactors).

Of the various means of producing mechanical power the turbine is in many respects the most satisfactory. The absence of reciprocating and rubbing members means that balancing problems are few, that the lubricating oil consumption is exceptionally low, and that reliability can be high the inherent advantages of the turbine were first realized using water as the working fluid, and hydro-electric power is still a significant contributor to the world's energy resources. Around the turn of the twentieth century the steam turbine began its career and it has become the most important prime mover for electricity generation. Steam turbine plants producing well over 1000 MW of shaft power with an efficiency of 40 per cent are now being used. Steam turbines were widely used in marine applications, but could not compete with the thermal efficiency of the diesel engine when fuel costs became important in the mid1970s; they are still used, however, in nuclear-power aircraft carriers and submarines. In spite of its successful development, the steam turbine does have an inherent disadvantage. It is that the production of high-pressure high-temperature steam involves the installation of bulky and expensive steam generating equipment, whether it be a conventional boiler or nuclear reactor.

The significant feature is that the hot gases produced in the boiler furnace or reactor core never reach the turbine; they are merely used indirectly to produce an intermediate fluid, namely steam. A much more compact power plant results when the water to steam step is eliminated and the hot gases themselves are used to drive the turbine. Serious development of the gas turbine began not long before the second world war with shaft power in mind, but attention was soon transferred to the turbojet engine for aircraft propulsion. The gas turbine began to compete successfully in other fields only in the mid 1950s, but since then it has made a progressively greater impact in an increasing variety of applications.

The gas turbine engine is a complex assembly of a variety of components that are designed on the basis of aero thermodynamic laws. The design and operation theories of these individual components are complicated. The complexity of aero thermodynamic analysis makes it impossible to mathematically solve the optimization equations involved in various gas turbine cycles. At the early stage of gas turbine developments, experimental tests of prototypes of either the whole engine or its main components were the only method available to determine the performance of either the engine or of the components. However, this procedure was not only costly, but also time consuming. Therefore, mathematical modeling using computational techniques were considered to be the most economical solution. A gas turbine engine essentially consists of the following component parts: (i) intake, (ii) compressor, (iii) combustion chamber, (iv) turbine, and (v) engine auxiliaries, such as fuel pump, lubrication pump, electrical power supply, starting gear, and control system.

In order to produce an expansion through a turbine a pressure ratio must be provided, and the first necessary step in the cycle of a gas turbine plant must therefore be compression of the working fluid. If after compression the working fluid was to be expanded directly in turbine, and there were no losses in either component, the power developed by the turbine would just equal that absorbed by the compressor. Thus if the two were coupled together the combination would do no more then turn by the addition of energy to raise the temperature of the working fluid prior to expansion. When the working fluid is air a very suitable means of doing this is by combusting of fuel in the air which has been compressed. Expansion of the hot working fluid then produces a greater power output from the turbine, so that it is able to provide a useful output in addition to driving the combustion turbine in its simplest form. The three main components are a compressor, combustion chamber and turbine, connected together.

In practice, losses occur in both the compressor and turbine which increase the power absorbed by the compressor and decrease the power output of the turbine. A certain addition to the energy of the working fluid, and hence a certain fuel supply, will therefore be required before the one component can drive the other. This fuel produces no useful power, so that the component losses contribute to a lowering of the efficiency of the machine. Further addition of fuel will result in a useful power output, although for a given flow of air there is a limit to the rate at which fuel can be supplied and therefore to the net power output. The maximum fuel/air ratio that may be used is governed by the working temperature of the highly stressed turbine blades, which temperature must not be allowed to exceed a certain critical value. This value depends upon the creep strength of the materials used in the contrition of the turbine and the working life required.

Objective

The objective of present research work is to analyze the effect of Operating /performance Parameters on the thermal efficiency of Gas Turbine Power Plant. Also it is useful for finding the critical factor among different performance parameters of GTPP.

Literature Review

Naresh et al. (2011) presented the quality evaluation of a gas turbine system by considering its different characteristics which govern the qualitative aspects of the gas turbine system. By using graph theoretic approach, gas turbine system has been modeled and various attributes contributing to the quality of the gas turbine system have been identified. A digraph of characteristic attributes is developed at system as well as sub system level and a single permanent function is proposed which is used for evaluation of quality of gas turbine.

Rahman et al. (2011) presented the parametric study of thermodynamic performance on gas turbine power plant. The variation of operating conditions (compression ratio, turbine inlet and exhaust temperature, air to fuel ratio, isentropic compressor and turbine efficiency, and ambient temperature) on the performance of gas turbine (thermal efficiency, compressor work, power, specific fuel consumption, heat rate) were investigated. The programming of performance model for gas turbine was developed utilizing the MATLAB software. The results show that the compression ratio, ambient temperature, air to fuel ratio as well as the isentropic efficiencies are strongly influence on the thermal efficiency. In addition, the thermal efficiency and power output decreases linearly with increase of the ambient temperature and air to fuel ratio. However, the specific fuel consumption and heat rate increases linearly with increase of both ambient temperature and air to fuel ratio.

Ahmadi and Dincer (2011) used a modified version of evolutionary algorithm (non-dominated sorting genetic algorithm (NSGA-II)) for multi objective optimization of a Gas Turbine power plant. The design parameters considered were air compressor pressure ratio, compressor isentropic efficiency, gas turbine isentropic efficiency, combustion chamber inlet temperature and gas turbine inlet temperature. Results showed that by selecting proposed sets of design parameters 33.56% increment in the total exergy efficiency is achieved while this values from multi objective optimization leads to decrease the environmental impacts of the plant for about 50%.

The summary of the literature review showing the application of graph theoretic approach is given in Table below:

S. No.	**Name of the authors**	**Year**	**Problem description**	**Attributes/Factors**
1	NareshYadav, I.A. Khan & Sandeep Grover	2011	Quality evaluation of gas turbine system	Functional performance, operational availability, serviceability, operational flexibility, life cycle cost
2.	NareshYadav, I.A. Khan & Sandeep Grover	2010	Evaluation and selection of power plants	operational and economic characteristics
3.	NareshYadav, I.A. Khan & Sandeep Grover	2010	Modeling and analysis of simple open cycle gas turbine	Open cycle gas turbine parameters
4.	Nilanjan Das Chakladar, Ranatosh Das & Shankar Chakraborty	2008	Selection of nontraditional Machining processes	Tolerance and surface finish, material removal rate, power requirement, shape feature, and work material type
5.	S.P. Bhosle and S.K. Basu	2008	Decision making in assessing the cycle cost and reliability growth of a productive asset	Simulation cost, maintenance cost, operating cost, cost of modularity of design, acquisition cost, and reliability effort function
6.	Mohd Nishat Faisal	2007	Mitigation of risk in supply chain environment	Information sharing, supply chain agility, aligning incentives, strategic risk planning, risk sharing supply chain, etc
7.	R.Venkata Rao and K.K.Padmanabhan	2006	Selection, identification and comparison of industrial robots.	Purchase cost, load capacity, velocity, repeatability, number of degrees of freedom and man-machine interface.
8.	R.Venkata Rao	2006	Selection of material for an engineering application.	Ultimate tensile strength, cost of material, density, hardness, thermal conductivity and corrosion resistance
9.	R.Venkata Rao and	2006	Selection, identification, and comparison of metal	Tool life, main cutting force, surface finish, cost per unit volume

	O.P.Gandhi		cutting fluids.	of metal removed, and cooling capacity.
10.	R.Venkata Rao	2006	Evaluation of flexible Manufacturing system..	Total cost involved, floor space required, number of employees, throughput time, product mix flexibility, and routing flexibility.
11.	R.T.Durai Prabhakaran	2006	Modeling and analysis of polymer composite products.	Resin system, reinforcement system, processing equipments, tooling system, and product design.
12.	R.T Duari Prabhakaran	2006	Design of composite products through concurrent design approach	Design for minimal weight, DFE, DFM, DFR, design for material inserts, and design for quality.
13.	R.T Duari Prabhakaran	2006	Structural modeling and analysis of composite product system	Resin system, reinforcement system, processing equipment, tooling system, and product design.
14.	R.K.Garg	2006	Evaluation, comparison and selection of power plants.	Capital cost, electricity generation cost and plan load factor
15.	Sandeep Grover	2005	Performance measurement of human resource in TQM Environment	Employee, employer, customer and supplier.
16.	Sushma Kulkarni	2005	Performance evaluation of TQM in Indian industries.	Infrastructure, top management support, strategic planning, employee empowerment, and customer satisfaction

Methodology

The mathematical modeling of gas turbine power plant/ system for the proposed work can be explained in two phases viz.

(1) Modeling of gas turbine

(2) Modeling of graph theory

The Graph theoretic approach evaluates the permanent qualitative index of a gas turbine power plant in terms of single numerical index, which takes into account the individual effect of various performance parameters and their interdependencies while analyzing and evaluating the GTPP. The various steps of the proposed approach, which would be helpful in evaluation of the GTPP, are enlisted in sequential manner as below;

1. Identify the various performance parameters (attributes) which affect the thermal efficiency of the GTPP

2. After the identification of contributing parameters, their interrelation / interdependences are considered.

3. Develop a digraph by considering attributes (performance parameters) as nodes and the interrelation of attributes as edges.

4. Develop a performance parameter matrix on the basis of digraph developed in step 3.This will be of size N × N, with diagonal elements representing performance parameters and the off-diagonal elements representing interaction among them.

5. Obtaining the permanent function from the permanent matrix to characterize the gas turbine power plant /gas turbine system.

6. Assign the quantitative value for the attributes (performance parameters) and their relative importance (interrelation).

7. Calculating the numerical indices by substituting the value of attributes and their relative importance in the permanent function.
8. Document the results for future analysis/reference.

Based on the methodology discussed above, the organization can evaluate the extent of parameters present in GTPP.

Finding And Conclusion

The minimum and maximum values for the GTPP efficiency index give us an overview of the index value between which the efficiency of power plant may vary. For a particular case, we will be getting some value of efficiency index with comparison from the minimum and maximum value of efficiency index. We may estimate the performance for the present case. Any improvement in the power plant will give us a new index value and this new value will give us an idea, which how much we are nearer to the maximum value.

Graph theory is a multi attribute decision making (MADM) process, with the help of this we can find out the following:

- Critical factor for different performance parameters of GTPP
- Order of criticality / severity of performance parameters
- Selection of power plants on the basis of thermal efficiency
- Improvements can be judged. We may compare input parameters.
- By the application of Graph Theory and Matrix Method, we have identified the critical performance parameters affecting the thermal efficiency of gas turbine power plant. In the present work, inlet air temperature and turbine inlet temperature are the most critical factors affecting the thermal efficiency of gas turbine power plant.

Conclusion

The results of the model application using the data, demonstrates that, once a complete set of criteria for power plant selection, along with set of alternatives and their threshold values are laid out, graph theoretical methodology can be applied. This methodology allows a decision maker to perform, not just a general analysis, but also other various focused analyses regarding his personal preferences. Literally, the decision has unlimited choices in exploring the influences of various different sets of attributes to final decision. In depth issue specific analyses, including sensitivity test, can be performed without any major adjustments. These findings validate the effectiveness of the model, that it is capable of solving complex multi-attribute decision problems, incorporating both quantitative and qualitative factors. The usefulness of this model, however, can be ascertained through extensive field testing.

Future Scope

- Mathematical modeling may be done to find out the more inter-relations which would lead to the more accuracy in the calculation of permanent function value.
- The gas turbine power plant system can be divided into different subgroups and different values of permanent functions can be evaluated.

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