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Study and Analysis of the Effect of Operating/Performance Parameters on the Thermal Efficiency of Gas Turbine Power Plant

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Abstract: **The main objective of this dissertation is to identify the barriers in increasing the thermal efficiency of Gas Turbine based power plants i.e. GTPP. The barriers in technology transfer implementation have been identified from literature review. These barriers may be of market, cultural, human resource .management, financial, economical, attitudinal, environmental, geographical and technological type. Technology transfer barriers threats the movement of physical structure, knowledge, skills, organization value and capital from the developed to developing countries. Clear understanding of these barriers may help the practitioners to find out various ways to deal with them. This may further facilitate successful implementation of technology transfer. Technology transfer may be said to be successful if Transferor (seller) and the transferee (buyer) can effectively utilize the technology for business gain. The transfer involves cost and expenditure that should be agreed by the transferee and transferor. The process is affected by various factors that hinder Technology Transfer. These factors named Barriers. In the present work, Interpretive Structure Modeling(ISM) is used for the analysis and comparison of various factors important for Technology Transfer. The important parameters are identified and self-interaction matrixes proposed with the help of Interpretive Structure Modeling which evaluates the inhibiting power of these parameters. This index can be used in comparison of different factors responsible for Technology Transfer processes.**

Keywords: **Gas Turbine Power Plant, Interpretive Structure Modeling(ISM), increasing the thermal efficiency of Gas Turbine based power plants i.e. GTPP.**

1. 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.

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. Apart from NTPC and other state level operators, some private companies are also operating the power plants. As on July 31, 2010, and as per the Central

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Electricity Authority the total installed capacity of Coal or Lignite based power plants in India are 87093.38 MW. While in March 2009, the installed power generation capacity of India stood at 147,000 MW and the total demand for electricity in India is expected to cross 950,000 MW by 2030.

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:

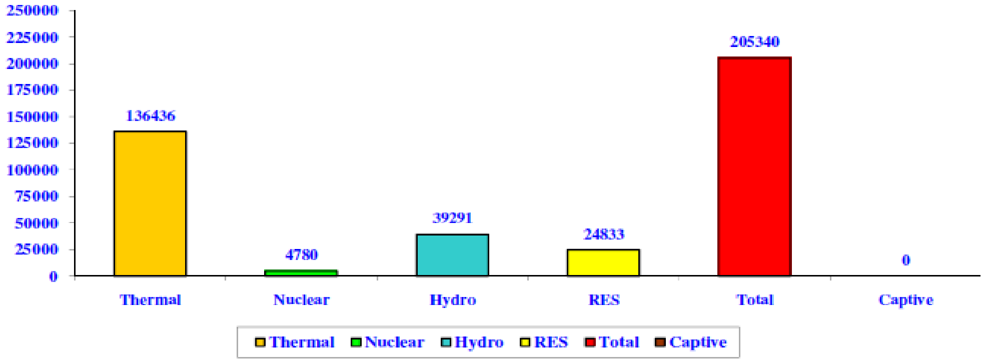

Fig. 1.1: All India generating installed capacity (MW)

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.

2. PROBLEM FORMULATION

From the literature, it is found that various researchers determined the individual effect of performance parameters on thermal efficiency of a GTPP, but they did not consider the interrelations/interdependencies of parameters. Also they did not consider the most critical factor or order of criticality for performance parameters effecting the thermal efficiency of gas turbine power plant which leads to develop a unified approach, which will enable power plant development team to consider all the attributes and their relative importance concurrently in an integrated manner for optimum selection of a power plant. Also, this research will be helpful in developing a suitable permanent index. The minimum and maximum values of the permanent index give us an overview of the index value between which the efficiency of power plant may vary.

3. 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.

4. MATHEMATICAL MODELLING

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

Modeling of gas turbine:

Although thermodynamic / mathematical modeling of gas turbine is done by various researchers as seen in literature review, but for the better understanding of the present research work the thermodynamic modeling can be explained as:

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AIR COMPRESSOR:

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 power plant. Since, the energy transfer during the flow of air compressor takes place, the thermodynamic as well as aerodynamic and mechanical design and factors affecting 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 Stage temperature rise
4. No. of stages
5. Rotational speed
6. Type and no. of blade
7. Weight of rotor
8. Blades efficiency
9. Isentropic efficiency of compressor
10. Mass flow of air

Mass of the air entering the compressor is also effected by the ambient air temperature also. As the ambient air temperature is increased, mass of the air entering the compressor also increases.

The ideal and actual processes on the temperature-entropy diagram are represented in full and dashed line respectively as shown in figure 2(b).

The compressor pressure ratio (r_p) can be defined as (Al-Sayed, 2008):

$$r_p = \frac{p_2}{p_1} \qquad (3.1)$$

Where, p_1 and p_2 are compressor inlet and outlet air pressures, respectively.

It is assumed that the compressor efficiency is represented by η_c. The isentropic efficiency for compressor in the range of 85 to 90٪ is expressed as (Rahman et al., 2011):

Isentropic compressor efficiency, $$\eta_c = \frac{T_{2s} - T_1}{T_2 - T_1} \qquad (3.2)$$

Where T_1 and T_2 are compressor inlet and outlet air temperature respectively, and T_{2s} compressor isentropic outlet temperature.

The final temperature of the compressor is calculated from equation (3.3) (Rahman et al., 2011):

$$T_2 = T_1 \left(1 + \frac{r_p^{\frac{\gamma-1}{\gamma}} - 1}{\eta_c} \right) \qquad (3.3)$$

Where γ is adiabatic index for air. So, the work of compressor (W_c) when blade cooling is not taken in to account can be calculated [11] as:

$$W_C = \frac{C_{pa} T_1 \left(1 + r_p^{\frac{\gamma-1}{\gamma}} - 1 \right)}{\eta_m} \qquad (3.4)$$

Where C_{pa} is specific heat of air and η_m is the mechanical efficiency of compressor.

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5. COMBUSTION CHAMBER

The air with pressure and high temp. as received from the exit manifold of the compressor is fed to the combustions chamber in atomized form. Due to high temperature of air, the fuel droplets get ignited and generate thermal energy. Due to which the temp. of the hot fluid medium in the combustor increases. Higher is the peak temp achieved in the combustion chamber, higher is the efficiency of the gas turbine. Since, the peak firing temperature is achieved with in combustion chamber, it's become essential to design the combustor to perform for peak temperature loadings.

It is clearly important that combustor developments should keep pace with improvements in other key engine components. Thus, reduction of combustor size and weight will remain an important requirement for aero engines, where as the continuing trend toward higher turbine inlet temperatures will call for a closer adherence to the design temperature profile at the turbine inlet. Simultaneously, the demand for greater reliability, increased durability, and lower manufacturing, development, and maintenance costs seems likely to assume added importance in the future. To meet these challenges, the search goes on for new materials and new methods of fabrication to simplify basic combustor design and reduce cost. The search has already led to the development of advanced wall-cooling techniques and the widespread use of thermal barrier refractory coatings within the combustion liner.

The various attributes affecting the design and performance of combustion system are:-

1. Type of Combustor
2. Combustor loading
3. Combustor inlet temperature
4. Combustor line material properties
5. Nature of fuel
6. Combustor efficiency
7. Combustor Pressure loss
8. Peak Temperature combustor
9. Combustion Stability
10. NO_x emission level

It is desired that NO_x emission level in the plant should be as low as possible. As the cycle pressure ratio increases concentration of nitrogen get changed. In the similar manner cycle pressure ratio effects the concentration of other constituents also.

From the energy balance in the combustion chamber:

$$m_a C_{pa} T_2 + m_f LHV + m_f C_{pf} T_f = \left(m_a + m_f\right) C_{pg} TIT \qquad (3.5)$$

Where, m_a is air mass flow rate (Kg/s), m_f is air mass flow rate (Kg/s), LHV is low heating value, T_3 = TIT = turbine inlet temperature, C_{pf} is specific heat of fuel and T_f is temperature of fuel.

After manipulating equation (5), the air to fuel ratio (AFR) is expressed as:

$$AFR = \frac{m_a}{m_f} = \frac{LHV - C_{pg} \times TIT}{C_{pg} \times TIT - C_{pa} T_2} \qquad (3.6)$$

6. GAS TURBINE

The Heat Content of the gases obtained at the exit of the combustor is converted into work output through energy transformation in the gas turbine. The performance of the gas turbine in the system is measured in terms of several attributes and is governed by the attributes of other matching turbo machinery components within the system. The design of various subsystems of the turbine contributes in the desired gas turbine performance. The various attributes as

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identified which affect the design and performance of the gas turbine taking thermodynamics, aerodynamic and mechanical design constraints in to account are:

1. Degree of Reaction
2. Turbine inlet Temperature
3. Gas turbine expansion ratio
4. Number of Blades
5. Blade Efficiency

The isentropic efficiency for turbine in the range of 85 to 90% is expressed as (Rahman et al., 2011):

Isentropic turbine efficiency, $$\eta_t = \frac{T_3 - T_4}{T_3 - T_{4s}} \quad (3.7)$$

Where T_3 and T_4 are turbine inlet and outlet air temperature respectively, and T_{4s} turbine isentropic outlet temperature.

7. THERMAL EFFICIENCY OF GAS TURBINE POWER PLANT

Factors related to the efficiency may be identified either with the help of thermodynamic model of plant or with the help of experts in this area. Thermo economic model gives an optimum solution for best efficiency and cost. The graph theoretic mathematical model is a proven tool for the understanding of the plant as a whole, its systems, subsystems, and their interconnections/interdependences (visual analysis and synthesis of the plant, identification of critical components and critical interconnections, and so on). The graph theoretic model can also include human beings (operators, manufacturer, designers, maintenance personnel, engineers, and managers) and environmental aspects. The procedure permits the development of a model of the plant or its systems/subsystems or sub subsystems of each subsystem up to component level. Before understanding the concept of thermal efficiency we have to understand the basic cycle operation of gas turbine. Almost all the gas turbines works on Brayton cycle which consist of four processes namely:

(a) Process (1-2) – isentropic compression of air

(b) Process (2-3) – constant pressure energy addition

(c) Process (3-4) – isentropic expansion

(d) Process (4-1) – constant pressure energy rejection

The pressure-volume (P-V) and temperature-entropy (T-S) diagrams are shown in fig. 3.1 (a) and 3.1 (b):

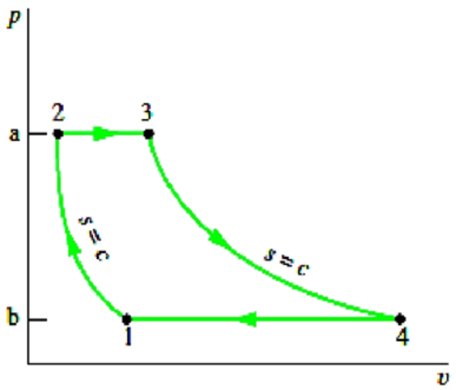

Fig. 3.1 (a): P-V diagram

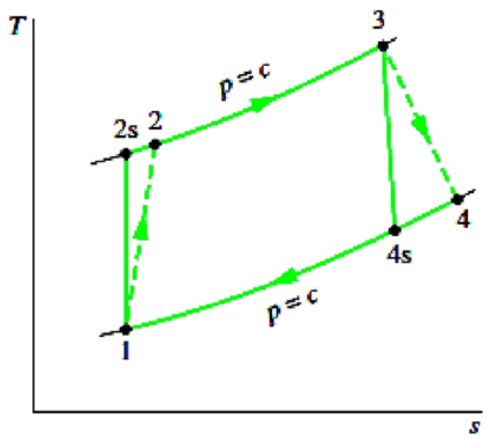

Fig. 3.1 (b): T-S diagram

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According to steady flow energy equation, $q = mC_p dT$

From figure 2(a)

$$\text{Heat added, } q_{23} = mC_p\left(T_3 - T_2\right) = C_{pa}T_1\left(1 + \frac{r_p^{\frac{\gamma-1}{\gamma}} - 1}{\eta_c}\right)$$

Heat rejected, q41 = $q_{41} = mC_p\left(T_4 - T_1\right)$

Thermal efficiency, $\eta_{th} = \frac{heat\ added - heat\ rejected}{heat\ added}$

$$\eta_{th} = \frac{mC_p\left(T_3 - T_2\right) - mC_p\left(T_4 - T_1\right)}{mC_p\left(T_3 - T_2\right)}$$

$$\eta_{th} = 1 - \frac{T_4 - T_1}{T_3 - T_2} \tag{3.8}$$

For isentropic processes

$$\frac{T_{2s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \tag{3.9}$$

$$\eta_{th} = 1 - \frac{T_1}{T_{2s}} \tag{3.10}$$

$$\eta_{th} = 1 - \frac{1}{\left(r_p\right)^{\frac{\gamma-1}{\gamma}}} \tag{3.11}$$

8. METHODOLOGY

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).

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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.

Identification of performance parameters affecting thermal efficiency:

Through the literature review, it is found that a good amount of work was devoted in studying the effect of design parameters on the performance of a gas turbine power plant. There are various performance parameters which affect the thermal efficiency of GTPP. Some of the important parameters are:

(i) Inlet Air Temperature:

A gas turbine is a constant volume machine i.e. the volume of air compressed is fixed, irrespective of ambient air temperature. Hence, as the temperature of inlet air to compressor rises, the density of air decreases and mass flow rate of compressed air gets reduced. The power output of GTPP is proportional to mass flow rate of air. Thus, as the ambient temperature increases, the power output decreases. Further, the thermal efficiency of the GTPP also falls, as more power is required to compress warmer air. Thus, when the ambient temperature decreases the thermal efficiency increases and vice versa.

Inlet air temperature affects other parameters of GTPP like -

- As inlet air temperature increases pressure ratio of compressor decreases or vice versa (acc. to equation 3.9).
- As inlet air temperature increases TIT of turbine decreases or vice-versa.
- As inlet air temperature increases isentropic compressor efficiency increases or vice versa (acc. to equation 3.2).
- As inlet air temperature increases isentropic turbine efficiency decreases or vice versa (acc. to equation 3.7).

(ii) Compression / pressure ratio:

In a gas turbine power plant, the intake air is initially compressed in the compressor to increase its pressure. Pressure ratio is defined as the ratio of pressure after compression (P_2) to the pressure before compression (P_1). Pressure ratio is an important parameter of GTPP. The thermal efficiency of GTPP increases with the increase of compression ratio [equation 11]. It affects the other parameters of GTPP like:

- Pressure ratio affects TIT as $TIT = T_3 = T_4 \left(rp^{\frac{\gamma-1}{\gamma}} \right)$

  As pressure ratio increases TIT also increases and vice versa.

- The pressure ratio affects the compressor and turbine isentropic efficiencies, further explained in (acc. to equation 3.12 & equation 3.13).
- As pressure ratio increases isentropic compression efficiency decreases while isentropic turbine efficiency increases.

The reason behind the above statements is, during the compression process as defined by a polytropic path, there is an increase in the inlet temperature to each compression stage due to irreversibility in the previous stage, thus resulting in increased compression work [11].

However in turbines this increase in temperature will be recovered partly by expansion in next turbine stage and this explains the different trends in isentropic efficiencies for the compressor and turbine [11].

(iii) Turbine inlet temperature (TIT) :

The limiting factor to the maximum power to weight ratio a gas turbine can reach is the metallurgical tolerance of the alloys used in the hot section of the gas turbine. Ceramic coatings on the surfaces of the turbine airfoils can increase the peak temperatures these airfoils can tolerate, however ceramics have brittleness characteristics that have not been totally

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overcome yet. So the "ruling parameter" is turbine inlet temperature (TIT). TIT in turn is a function of the turbine flame/ firing temperature, compression ratio, mass flow, and centrifugal stress. So these factors limit size and ultimately, efficiency. A rough rule of thumb is that 55°C (100°F) increase in firing temperature gives a 10 to 13 percent power output increase and a 2 to 4 percent efficiency increase. The combustion chambers and the turbine first stage stationary nozzles and blades are therefore the most critical areas of the turbine that determine its power output and efficiency.

Highest TIT is decided by the metallurgical stress bearing capacity of turbine blade material. With the higher TIT larger is the fuel consumption and work obtained in the cycle and cycle efficiency also increases. Thus, as the turbine inlet temperature increases, power output and thermal efficiency increases [8]. In the present analysis, the effect of turbine inlet temperature on other factors is not taken.

(iv) Isentropic compressor efficiency:

The efficiency of any machine, the object of which is the absorption or production of work, is normally expressed in terms of the ratio of actual and ideal work transfers. Because turbo machinery are essentially adiabatic, the ideal process is isentropic and the efficiency is called isentropic efficiency. Since isentropic efficiency considers only the start and end states of the compression and expansion processes and pays no attention to the actual paths, the compression and expansion processes take. Since work is not a property, it depends on the actual path.

Isentropic compressor efficiency is defined as the ratio of ideal compression work to the actual compression work [11].

i.e., $$\eta_C = \frac{ideal\ compression\ work}{actual\ compression\ work} \quad (5.1)$$

The isentropic compressor efficiency considers only the start and end state of compression process while polytropic process considers the compression process in infinitesimally small steps. The value of isentropic compressor efficiency in terms of polytropic efficiency is given by [11].

$$\eta_C = \frac{rp^{\frac{\gamma-1}{\gamma}} - 1}{rp^{\frac{\gamma-1}{\eta p \cdot \gamma}} - 1} \quad (5.2)$$

Where, η_p is the polytropic efficiency.

GT performance is affected by component efficiencies. The thermal efficiency increases with the increase of compressor efficiency (acc. to equation 3.12).

(v) Isentropic turbine efficiency:

Isentropic efficiency is defined as the ratio of actual expansion work to ideal expansion work [11].

i.e., $$\eta_t = \frac{actual\ expansion\ work}{ideal\ expansion\ work}$$

The value of isentropic compressor efficiency in terms of polytropic efficiency is given by [11]

$$\eta_t = \frac{1 - \frac{1}{rp^{\frac{\gamma-1}{\gamma} \cdot \eta p}}}{1 - \frac{1}{rp^{\frac{\gamma-1}{\gamma}}}} \quad (5.3)$$

Where ηp is polytropic efficiency of turbine.

(vi) Air to Fuel Ratio (AFR):

Air to mass flow rate is defined as the ratio of air mass flow rate to the fuel mass flow rate i.e.,

$$AFR = \frac{ma}{mf}$$

Where m_a is mass flow rate (Kg/s) and m_f is fuel mass flow rate (Kg/s)

From the literature survey [Rahman et al.] it is found that the thermal efficiency decreases with the increase in AFR and vice versa. Also AFR affects the TIT (acc. to equation 3.6). As AFR increases TIT decreases and vice versa.

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Thus, the six performance parameters (effecting thermal efficiency of GTPP) taken for the present research work are:

(i) Inlet Air Temperature

(ii) Compression / pressure ratio

(iii) Turbine inlet temperature (TIT)

(iv) Isentropic compressor efficiency

(v) Isentropic turbine efficiency

(vi) Air to Fuel Ratio (AFR)

Table 5.3: Summary of maximum and minimum value of permanent function indices

Sr.no.	Performance parameter	Value of maximum VPF	Value of minimum VPF
01	Inlet air temperature (IAT)	83160	9240
02	Compression pressure ratio (CR)	68250	9450
03	Turbine inlet temperature (TIT)	83160	9240
04	Isentropic compressor efficiency (η_C)	58800	8400
05	Isentropic compressor efficiency (η_t)	59400	6600
06	Air to fuel ratio (AFR)	69300	7700

9. RESULTS AND DISCUSSIONS

- Graph Theory and Matrix Method is a multi-attribute decision making method (MADM) which is successfully applied on the roller burnishing process.

- By the application of Graph Theory and Matrix Method, we have identified the critical performance parameter affecting the thermal efficiency of gas turbine power plant. In the present work, number of passes is the most critical parameter having value of maximum variable permanent function = 85725.

- Graph Theory and Matrix Method is used in the selection of an improved process among various roller burnishing processes by the comparison of variable permanent functions of the different processes.

- The Graph Theory and Matrix Method is used in the arrangement of the parameters according to their relative importance in the process. The sequence of parameters in our work is number of passes, feed direction, workpiece material, feed rate, coolant, burnishing speed.

- If some improvement is done in the parameters affecting the surface roughness of the process, then we can compare the improved process with the previous process.

10. CONCLUSION & FUTURE SCOPE

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 roller burnishing process can be divided into different subgroups such as surface roughness, hardness, stress value etc. and different values of permanent functions can be evaluated.
- Graph theoretic approach can be applied on various machining process.
- Complex manufacturing processes can be compared by the application of graph theoretic approach by comparing their permanent function values.

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