Thermo-Economic Analysis of A Combined Cycle Thermal Power Plant

A

Dissertation

Submitted in Partial Fulfilment of the Requirements for the Award of the degree of

Master of Technology

in

(Thermal Engineering)

Submitted

By

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CANDIDATE'S DECLARATION

I, GAURAV, Roll No. 2K19/THE/22 student of M.Tech (Thermal Engineering), hereby declare that the project Dissertation titled "**Thermo-Economic analysis of a combined cycle thermal power plant**" which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any degree, Diploma Associateship, fellowship, or other similar title or recognition.

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This is to certify that Project Dissertation entitled "**Thermo-Economic analysis of a combined cycle thermal power plant**", which is submitted by GAURAV, RollNo.2K19/THE/22 Department of Mechanical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of Degree of Master of Technology is the record of the project work carried out by the student under our supervision. To the best of our knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

PROJECT GUIDE

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Place: Delhi

ACKNOWLEDGEMENT

I, GAURAV, take this momentous opportunity to express my heartfelt gratitude and highly esteemed main guide DR. Anil Kumar, Associate Professor, Department of Mechanical Engineering, Delhi Technological University for providing us an opportunity to present our project on "**Thermo-Economic analysis of a combined cycle thermal power plant**". I with full pleasure converge our heartiest thanks to Professor SK Garg, HOD, Department of Mechanical Engineering, Delhi Technological University for the invaluable advice and whole hearted cooperation without which this project would not have seen the light of day. I attribute the heartiest thanks to all the faculty of the Department of Mechanical Engineering and friends for their valuable advice and encouragement.

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ABSTRACT

Energy drives modern growth. All systems rely on it. Historiography shows that countries with limited energy grow more slowly. Increase energy availability. Our nation is similar. Too long, our nation has been energy-deficient. We must alter this. Scientists worldwide are working to increase energy supplies. New energy-creation strategies are investigated constantly. Globally, renewable energy development is accelerated. Researchers are reducing reliance on fossil fuels for power. Sustainability of electricity production is also a concern. If natural resources aren't used properly and effectively, they may become uneconomical.

Today, fossil-fueled thermal power plants produce much of the world's energy. To make the process "sustainable," we must reduce our reliance on fossil fuels. Analysing existing thermal power plants helps us find ways to enhance their efficiency. Increasing energy output per unit of fuel should reduce capital and operational costs. This is the basis for THERMOECONOMIC ANALYSIS OF POWER GENERATION SYSTEMS, especially COMBINED CYCLE SYSTEMS (CCPP). This analysis addresses physical and intangible costs and thermal power plant efficiency. As a system's operating temperature rises, its thermodynamic efficiency improves. Many design aspects must be moved. This research evaluates combined cycle power plant thermo-economics. Prior study provided temperature, pressure, mass flow rate, work generated, and plant efficiency (which will be discussed in the Literature Review). MATLAB/Simulink was used to simulate the power plant's segments and subassemblies. These models are verified with CCPP data. Parametric study used the proven model to predict plant performance.

CHAPTER 1 INTRODUCTION

1.1 Background

As the human population increases, natural resources become increasingly limited. Urgent, practical, and effective methods must be developed to preserve and increase their availability. Methods requiring due attention include minimising their use, locating replacements, and applying more efficient and environmentally friendly procedures.

The utilisation of energy by humans has dominated the scene for numerous millennia. In the past 150 years, however, the per capita energy consumption has gained enormous importance. Today, energy is the driving factor behind nearly all technological advancements. The goal of the global community is to generate more and more energy from available resources. Thermal plants that utilise coal, natural gas, and liquid fossil fuels are still prevalent. Energy in the form of electricity has become one of the most vital aspects of human existence. In light of the fact that a power outage cripples modern life, it is difficult to overstate the importance of electricity. Its manufacture necessitates substantial capital expenditures and operational expenses, as well as technological expertise. In addition, it poses many risks to males at work. For electricity generation to be cost-effective, sound, sophisticated, efficient, and proven technological knowledge is required. A robust power generation business is required for a pleasant lifestyle in the current day. Any nation's progress and prosperity are contingent on the amount of energy it generates. Consequently, the electricity industry is considered a priority sector. The economics and efficiency of the production process of a complex energy system may be studied as a function of resource usage. Thermoeconomics and its applications can help us create designs that are more effective and energy-efficient. A simple economic analysis focuses on the fixed and operating costs of power plant operation. However, this research does not disclose a foundation for attributing these costs in percentage terms to specific processes or subsystems. Thermodynamic analysis, on the other hand, assesses the efficiencies of the various components and finds the regions that create inefficiencies. However, it fails to provide a macro-level understanding of their effects on the production process and accompanying economic consequences. The thermoeconomic analysis is unrestricted by the limitations imposed by the economic and thermodynamic analyses. It proposes a method for combining the economic and thermodynamic analyses, resulting in a cost-optimized better design.

1.2 Energy Scenario

Because contemporary growth is based on the sources and supplies of energy, the demand for energy is escalating rapidly. This expanding energy demand has prompted the search for alternative and renewable energy sources. Scientists and researchers are simultaneously attempting to improve the efficiency of their present systems.

The International Energy Outlook 2016 forecasts a considerable increase in global energy consumption between 2012 and 2040, a span of 28 years. During this time, it is anticipated that the global energy demand would rise from 549 quadrillion Btu to 815 quadrillion Btu. This equates to a 48 percent increase between the years of 2012 and 2040. Numerous nations have enacted "Clean Power" projects that may reduce fuel consumption or boost power output by employing newer and better technology in existing thermal power plants fueled by fossil fuels. These efforts may include the following:

Enhancing the thermal/energetic performance of sources

Retrofitting existing thermal power stations

Converting basic cycle plants to mixed cycle

An increase in demand side exergetic efficiency results in a reduction in demand.

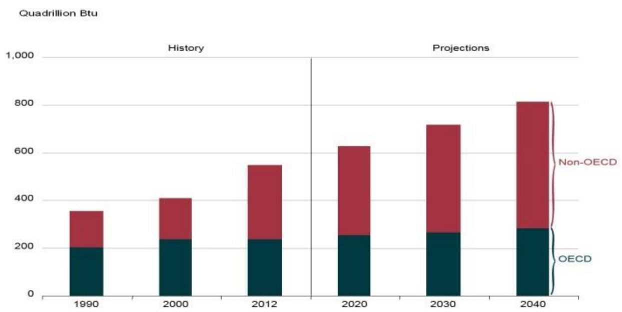

Figure 1World Energy Consumption 1990-2040 (Source: EIA, USA)

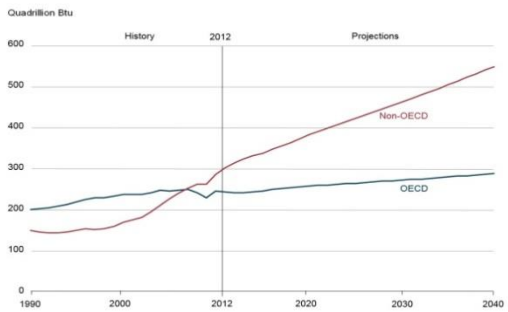

Figure 2Projected World Energy Consumption by region 1990-2040 (Source : EIA, USA)

International Energy Outlook forecasts that fossil fuels will account for 78 percent of global energy demand by 2040, including petroleum, natural gas, and coal.

In 2040, when its share of the world's total energy consumption reduces from 33% in 2012 to 30%, the world's biggest energy source will see just a little decrease in utilisation.

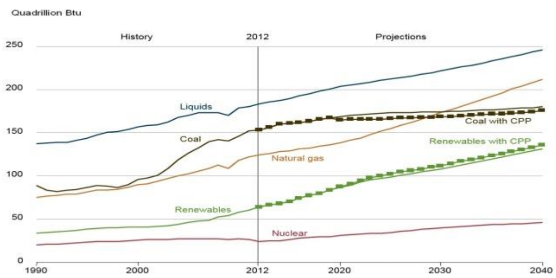

Figure 3World Energy Consumption by Energy Source, 1990-2040 (Source : EIA, USA)

According to studies, India and China will account for a significant portion of the expected growth in energy demand. This is the result of population expansion and fast industrialisation in these and other developing economies. As a result, the proportion of global energy consumption accounted for by emerging nations might reach 50 percent. However, mature economies will have a far smaller rise in energy demand.

1.3 Combined Cycle Power plant

The gas and steam turbines each have their own separate cycle in the combined cycle. In the Brayton cycle, the gas turbine is used, while the steam turbine is used. While the Rankine cycle employs steam, the Brayton cycle uses a mixture of air and fuel. Depending on the number and kind of gas turbines or steam turbines used, the layout of a combined cycle gas turbine power plant might vary. Different mixed cycle power facilities have different types of heat recovery steam generators (HRSGs). Circulation type, pressure phases, and additional firing can all be used to categorise an HRSG. Both condensing and noncondensing (back pressure) steam turbines exist. Thus, the choice of a particular combined cycle power plant is influenced by a number of factors. Both the steam turbine and the gas turbine are capable of generating power. Heat from the gas turbine is transferred to steam, which powers a steam turbine to produce electricity, all through the HRSG system. As a result, the name "Combined Cycle Gas Turbine Power Plant" was coined to refer to the fact that both the gas and steam turbines generate energy. Both cycles may be seen as part of a larger cycle, which is easy to see. There are inherent advantages to the linked cycle because of its complementary nature. The following are a few of them:

- Improved thermal and exergy performance. Improved factor of plant loading
- Allow for a wide range of options.
- A higher level of reassurance
- low operating and maintenance costs
- Installation time is reduced due to the ability to "pre-engineer" the parts.
- Future-oriented due to ongoing research and development.

As one of several practical approaches to reduce the growing global energy demand, the use of combined cycle has been widely recognised and accepted, resulting in huge gains in energy output. The following bar graph depicts the benefit as a consequence:

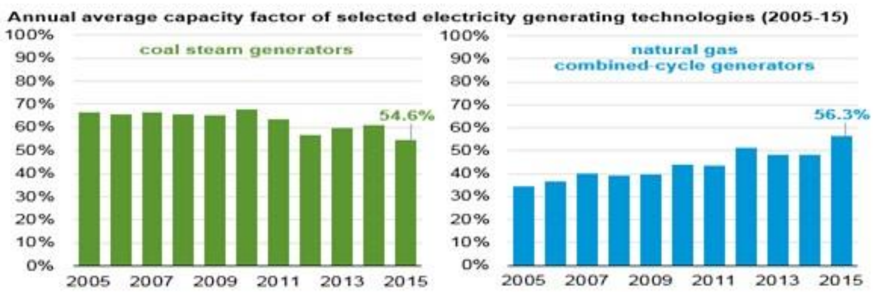

Figure 4 Annual average capacity factor of selected electricity generating technologies

The year 2015 may be considered a turning point for Combined Cycle Power Facilities, as the average capacity utilisation of such plants in the United States was about 56 percent, which is almost a percentage point higher than coal-based steam power plants.

1.4 Objectives ofResearch

(i) Estimate the economic viability of a combined cycle gas turbine power plant

(ii) Provide details on the exergy destruction and exergy losses, as well as their location.

(iii) Defining and identifying pertinent parameters and relating them to a set of constraints and objective functions in order to undertake parametric optimisation.

(iv) Potential for future research in linked areas of combined cycle power plant

1.5 Statement of Problem and Its Genesis

Analysis of thermal energy systems in the 1960 and '70 years was done using thermoeconomics in its simplest form (Evans, 1962; Tribus et al.1960; Obert & Gaggioli,1960 , 1960;Tribus and Evans,1963, El-Sayed and Aplenc, 1970; El-Sayed and Evans, 1970). Tribus coined the term thermoeconomics in 1960. The research and use of thermoeconomic analysis made major strides in the 1980s and 1990s. Since then, several combined-cycle power plants have already had their exergy studies completed. Darwish, Al-Najem and Al-Ahmad (1993), Al-Suliman & Ismail (1995), and El Nashar (1993). The improvement of thermal energy systems has also been the subject of research. (Wepfer, 1979; El-Sayed, 1996). Thermoeconomic analysis calculates the cost per unit of energy produced by combining economic and thermodynamic analyses. The scientific community agrees that energy use and production costs may be connected.. Several studies have been conducted, including those by Kota, Tsatsaronis, and Gaggioli and ElSayed (1987). (1990). For the most part, energy efficiency is a comparison between the actual and ideal processes. Quantitative data on energy can be obtained by energy analysis, but no qualitative information can be gleaned from it. Energy losses may be identified and quantified using exergy, a property derived from energy. In this way, exergy provides data about energy that is both quantitative and qualitative at the same time.

Structural Theory can be used to replicate the results of exergy-based cost-distribution methods when two or more co-products exist (Erlach, 1998; Erlach, Serra and Valero, 1999). Since Structural Theory is the standard and universal mathematical framework, all concepts and methodologies are built on it.

A mixed cycle power plant consists of steam and gas turbines that are linked together. Subassemblies for each turbine are also included. Compounding the difficulty, a combined cycle power plant study must take into account every component of both turbines. According to the literature, these plants' subsystems are often investigated without taking intercomponent interactions into account. As a result, any energy losses that could have been avoided due to component interaction cannot be identified or measured. According to First Thermodynamics, the systems have been extensively explored.

1.6 Research Plan and Methodology

1.6.1 Energy and Exergy Analysis

A mathematical model of a combined cycle power plant was developed for these assessments. A combined cycle power plant includes gas turbines and steam turbines for power generation, as well as a compressor, combustion chamber, re-heater, HRSG (Heat Recovery Steam Generation), and other auxiliary components. Analyses of energy and exergy were performed on both single-stage and multi-stage compressors. To reduce the workload of the compressor, optimal pressure steps were used. To conduct the analysis, perfect intercooling and intercooler efficiency, with or without pressure drop in the intercooler, were introduced. In addition, the pressure drop in the reheater was used to assess the difference between the work performed and the turbine's efficiency.

Bawana, Delhi, combined cycle power plant uses fuel with a calorific value of 43,500 kJ/kg. For the purpose of analysis, fuels having the same properties as those employed in this power plant were evaluated. With and without pressure loss in the combustion chamber, analyses were conducted. At preset pressures and temperatures, the turbine outlet exhaust gases were utilised to produce steam in the HRSG without the use of fuel. It was determined how much steam the HRSG could produce with or without extra heating. In the event that an HRSG failed to produce steam, its exhaust gases were sent to a second HRSG operating at lower specified pressures and temperatures. It was computed how much work the steam turbine performed and how efficient it was.

1.6.2Economic Analysis

An energy and exergy study is performed to establish the optimal operating point of the plant for maximising thermoeconomic advantages. It has been shown beyond a reasonable doubt that thermodynamic optimisation conserves energy/exergy and produces greater power. However, the economic viability of this optimal position established merely from thermodynamic analysis is uncertain.

An economic study is conducted to estimate the optimal cost of electricity generation. The economic analysis considers fixed expenses such as capital costs, land and construction costs, machinery costs, and auxiliary costs, among others. It includes variable expenses such as fuel costs, wear and tear, interest charges, depreciation costs, maintenance costs, labour costs, administrative costs, overheads, losses, etc.

In order to do an exergo-economic analysis, all of these expenses are translated to unit energy/exergy costs.

1.6.3 Optimization

Optimization from a scientific viewpoint has different connotations under different working conditions, resource availability, cost implications, environment considerations, sustainability index, fuel availability, maintainability& reliability, social & cultural considerations, technological advancements, and many other parameters, depending on the need of the hour. Any optimisation procedure can only accommodate a certain number of parameters, which is readily apparent. The researcher must next continue to optimise a system after determining the relative importance of the several parameters that might be examined. Consequently, a system may have varied optimal operating settings depending on the optimisation criterion chosen.

The scope of the present study includes thermodynamics and economics. A variety of factors are highlighted for future investigation in each of these areas. The optimisation analysis is predicated on a trade-off between these two fields of research. Thermoeconomic Analysis refers to a type of analysis that integrates thermodynamics and economics.

1.6.4 Steps at a Glance

1. Identify the actual combined cycle power plant upon which this study is based.

2. accumulating real plant data

3. mathematical modelling of the plant's many assemblies and subassemblies

4. Reasonable price evaluation of plant products based on physical characteristics.

5. Global and local optimisation of individual component characteristics to reduce final product costs and conserve energy.

6. Identification of inefficiencies and computation of their economic impacts in operational plants, i.e., thermoeconomic diagnostic of plant operation.

7. Evaluate many design possibilities through parametric iterations

8. integrating economics and thermal analysis

CHAPTER 2 LITERATURE REVIEW

A huge number of research articles on Energy, Exergy, and Economic analysis in power plants were analysed in order to comprehend the state-of-the-art in power plant technology and identify research gaps. This data was utilised to determine the direction of this study. The researched literature included thermodynamics with respect to energy, exergy, and thermoeconomic analysis.

The origins of the term "exergy" date back many decades. The Second Law of Thermodynamics was developed in 1824 by French physicist and scientist Sadi Carnot, one of the pioneers of modern thermodynamics. He conceptualised the Carnot Engine, sometimes regarded as a "perfect" engine. He said that a portion of the available calories for producing productive labour is wasted in every actual procedure. Later in 1951, scientists James Prescott, Joule, and Lord Kelvin confirmed this theory. William Gibbs, an American chemical engineer, developed the notion of Gibbs Free Energy in 1876, which is a measure of the "maximum achievable work" in any process. Tait and Kelvin presented ideas comparable to Gibbs's much earlier in 1868, although they did not elaborate. Even though he was working with the caloric theory, Sadi Carnot proposed in 1824 that a portion of the calorie available for doing productive labour is wasted in every actual operation.

Since the beginning of the 20th century until about 1960, the question of how to establish a combination of the first and second laws of efficiency persisted. Darrieus, Hauser, Hegelmann, Grassmann, Frieder, Lange, Schmidt, Grassmann & Kammerer, Nesselmann, Mattarolo,Gourdet, Proust, Glaser, Rosin, and Fehring are among the noteworthy scientists in this setting.

William John Macquorn Rankine first used the thermodynamic cycle, which turns heat into work, in calculations in 1854. He created the hypothesis for heat engines. This Rankine cycle, which employs water as its fluid, generates around 85 percent of the world's electricity. Throughout the succeeding decades, the notion of "useful energy" was incorporated into a variety of innovative plans. Zaron Rant coined the term "EXERGY" in 1956 to describe the "work capacity" of any energy system. Subsequently, the term exergy was used interchangeably with "available energy" in numerous nations, achieving near-universal approval in the process. George Tsatsaronis proposed the word in 1983. "exergoeconomics" to characterise the combination of exergy and economic analysis.

Tsatsaronis suggested in 1993 that the word "thermoeconomic" be used to unify thermodynamic and economic study. In this analysis, any exergy inefficiencies or irreversibilities are defined by an economic value or a penalty function. This approach has been widely utilised in exergoeconomic analysis for around four decades. Such an advanced examination is based on techniques including "cost accounting" and "optimisation approaches."

By 1960, the notion of EXERGY was sufficiently developed. The First Law efficiency gave way to the Second Law efficiency as EXERGY evolved. Through the lens of the Second Law of Thermodynamics, scientists were now compelled to redefine efficiency. Numerous scientists pioneered this endeavour. Lotka in 1921, Keenan in 1932, Brodyanski in 1973, Kotas in 1985, Bejan in 1986, Tsatsaronis in 1986, and Szargut in 1988 are notable examples. Rapidly, it became apparent that thermodynamic analysis alone was insufficient to create a realistic system, implying that a thermodynamically accurate system may not be economically feasible. This notion spawned the idea of thermoeconomics, in which thermodynamic and economic research were combined to determine the optimal operating settings. Tsatsaronis and Winhold, 1985,1986; Valero et al., 1986,1996,2006; Bejan et al.,1996,1997,1998, Marc Rosen and Dincer 2003, 2004 were the pioneers in this field. Such an approach was also known as Thermoeconomics, Exergoeconomics, Second Law Costing, and Cost Accounting, among others.

2.1 Development of Combined Cycle Power Plant

The development of a combined cycle power plant may be roughly split into the three time periods listed below:

2.1.1 Evolution

The foundation of the combined cycle power plant is the gas turbine. In 1550, Leonardo da Vinci proposed the concept of a smoke mill, which was likely the first baby step in the creation of the current gas turbine. In 1791, when John Barber was granted a patent for the combustion turbine, the first ideas resembling a gas turbine may be traced back to the 18th century. John Dumball introduced the concept of turbines with many stages in 1808. M.Bresson made a further development in 1837 by heating and compressing air and then pushing it into the combustion chamber, where air and fuel combine. In 1850, Fernimough conceived of a steam and gas turbine hybrid. However, these early systems had significant limitations, since the power required to operate a compressor exceeded the output power. In 1872, two scientists named Franz Stolze and Charles Curtis submitted a patent application for a more sophisticated form of combustion turbines. Zoelly, Curtis, and Rateau made significant contributions to the development of the technique about 1895. Rene Armengaud and Lemale conceived and constructed a prototype gas turbine in France in 1903.

William LeRoy Emmet hypothesised in 1914 that mercury vapour rather than steam may be used to power a turbine. General Electric developed and operated power stations designed by William Le Roy Emmet between 1923 and 1950. Hans Joachim Pabst von Ohain and Frank Whittle developed gas turbine-based jet engines between 1937 and 1941.

2.1.2 Progression

Dr. Adolf Meyer created the very first simple cycle gas turbine in 1939. This had an efficiency of 18 percent, a TIT of 540 degrees Celsius, and an exhaust temperature of just 240 degrees Celsius. General Electric Company erected a 3.5 MW gas turbine in June 1949, utilising the exhaust temperature to heat the steam unit's feed water. Dr. Claude Seippel and Bereuter were pioneers in the development of the combined cycle power plant between 1956 and 1960. They created around seven functional combinations of gas turbines and steam turbines.

The notion of "heat recovery" was included into the combined cycle concept in the 1960s. The Great Northeast Blackout of 1965 made the United States aware of the severity of the power deficit crisis. This resulted in significant breakthroughs in combined cycle gas turbine power plant technology and prompted the United States to aim towards exponentially boosting its power output.

2.1.3 Maturation

In 1971, GE erected a 340 MW combined-cycle power plant (plant powergen.gepower.com). David. L. Chase (General Electric Power Systems).

Wunsch proposed a categorisation for combined cycle power plants in 1978. The classification of the gas turbine was either "unfired" or "supplementary firing." The steam cycle was divided into single, dual, and triple pressure categories.

At the end of the 1980s, combined cycle power plants with thermal efficiency more than 50 percent became a reality.

Between 1980 and 1986, the discovery of vast gas reserves increased interest in the combined cycle power plant.

Combined cycle power plants surpassed 60 percent efficiency by the end of the 1990s.

By the end of the 20th century, the Turbine Inlet Temperature (TIT) had risen to almost 2500 degrees Fahrenheit.

The current success of gas turbines and combined cycle power plants can be attributed to advancements in metallurgy, hot gas cooling methodology, increased pressure and temperature of steam cycles, electrical & electronic engineering, interdisciplinary technologies, gas availability, pollution norms, sustainability index, government policies, low capital and operations cost, higher efficiencies, etc.

The thermoeconomic study of a combined cycle power plant demonstrates that the increase in costs caused by modifying some parameters, such as TIT, cancels out any thermodynamic gains. The operating cost and cost of transitioning to new technologies must be related to the thermodynamic advantage. The technology for combined cycle power plants has reached maturity.

In its 2008 report, the IEA estimated a demand for around 110 GW per year of additional combined cycle power plant capacity for the period 2005-2050.

Recent technological improvements have made feasible a TIT of 1600 °C or even higher. Despite their growing advantages, the modern gas turbines used in combined cycle power plants are susceptible to running under unexpected loads.

In June of 2016, GE and EDF Energy successfully completed the most efficient combined cycle power plant at the world in Bouchain, France. The plant attained a record-setting maximum efficiency of 62,2 percent, according to the Guinness Book of World Records (www.gereports.com).

Recent advancements in combined cycle power plant technology are intended to enable the absorption of demand variations and the utilisation of renewable energy sources, in accordance with the Paris COP21 agreement in which 195 nations have committed to reducing glasshouse gas emissions. Combined cycle power plants are the least expensive to construct and instal compared to all other alternatives. Start-up times have decreased significantly, and nearly no other technology can generate several thousand megawatts (MW) so quickly (Victor Rodgers July 2016 article titled Combined-Cycle Power Plants: Is their Reign Assured: Engineering 360 degrees)

Among the promising research topics for combined cycle power plants are the following:

- Increasing maximum TIT to at least 1600 °C
- Increasing exhaust gas temperature to at least 650 degrees Celsius
- Incorporating innovative cooling techniques
- Utilization of ceramics and enhanced thermal barriers.
- Utilization of supercritical pressure HRSG
- Use of sophisticated control systems
- Aerodynamic improvements to the compressor and turbines
- Utilization of modern metallurgy

It is imperative that any future research builds on the already existing body of work in this area. As a result, it is essential to review the literature that is accessible. Therefore, the goal of this literature review is to identify the settings, parametric ranges, assumptions, limitations, etc., under which similar studies on combined cycle power plants have been carried out by other researchers.

Many studies have been conducted on optimising the performance of a freestanding gas turbine (Topping Cycle), a steam turbine (Bottoming Cycle), and a mixed cycle power plant. The First Law of Thermodynamics was the primary basis for optimisation in the early years.

To mark the commencement of sustainable electrical power generation, 1939 might be deemed the year. A gas turbine with a capacity of 4 MW was the first to be installed at Neuchatel Municipal Power Station in Switzerland. From Baden in Switzerland, a.g. Brown Boveri created it. The United States quickly recognised the potential of this finding following the installation of Europe's first gas turbine and developed better materials and protective coatings to allow turbine blades and other components to withstand higher TIT levels. Combined Cycle Journal, 4th quarter of 2013 This might lead to a boost in productivity. As the paper points out, gas turbine capacity has grown from four megawatts (megawatts) to 470 mw, simple cycle efficiency has risen from 17 to 44 percent, and compression ratios have gone from 4:1 to 41:1. However, this does not mean that just increasing or modifying a single parameter would automatically improve the overall performance of the system.

2.2. Energy Analysis

Energy analysis is concerned with the movement of energy into or out of the environment in relation to thermodynamic inefficiency. Thermodynamic study leads us to the conclusion that all components of the power plant lose energy. This research offers no insight into the location of these losses. A simple energy analysis may offer incorrect information on the origin and location of the greatest inefficiencies.

The greatest turbine inlet temperature utilised by Glenn [190] was 1 000 °C.

Because the efficiency of a "cooled" turbine is lower than that of a "uncooled" turbine, he calculated that raising the TIT alone would not result in greater efficiency. He hypothesised that if any heat wasted in the gas cycle could be used in the steam cycle, the total efficiency would rise. This straightforward reasoning became the foundation for the creation of combined cycle power plants.

Dillip Kumar Mohanty et al. [46] examined the impact of various operational settings on thermal efficiency and output work. Considered are TITs up to 1900 K and pressure ratios between 4 and 10.

Nihed et al. [165] provided a report on the comparative performance of simple and combined cycles with varied steam injection, compressed air cooling, and steam extraction configurations. 18 to 20 compression ratios and an input temperature of 15 degrees Celsius were investigated.

Numerous scientists afterward used both the First and Second Thermodynamic Laws to optimise their work. For a long time, "energy analysis" has been used to describe this type of investigation. As a result of the differences in effectiveness between these two methods, the term "exergy" was coined to describe the "quality" of "energy." The difference between energy and exergy was made clear by this incident. Exergy is a measure of a person's ability to do work with the energy that is available to them.

2008 saw a research by Srinivas et al. [215] that examined the thermodynamics of a combined cycle that included a steam-injected gas turbine (STIG). The efficiency of the gas cycle increases, whereas the efficiency of the steam cycle decreases when steam is injected. However, a change in parameters might lead to a situation where the increase in gas cycle efficiency outweighs the loss in steam cycle efficiency.

Srinivas and colleagues The deaerator performed the same role. The ideal pressure ratios for compressors with SP, DP, and TP HRSG designs at 1200 °C are 8, 10, and 12, respectively. SP, DP and TP at 200 bar steam turbine input pressure were determined to have optimum deaerator pressures of 1, 3, and 5. According to a parametric analysis, the gain in efficiency reduces as we move from SP to DP to TP HRSG designs.

Using a closed-loop steam-cooling system to keep the blades cold, Sanjay et al. [204] conducted an energy and exergy study on a combined cycle gas turbine with reheat. This design achieved more thermal efficiency and specific work than the basic gas-steam combined cycle with air-film cooling. It's been around for a while now.

It has also been shown that reheat pressure is a crucial design factor whose exact value leads to optimal efficiency. Component-by-component evaluation of such a plant architecture based on exergy analysis suggests that the combustion chamber is the most inefficient component at roughly 30 percent, followed by the gas turbine at 4 percent.

Naradasu Ravi Kumar et al. [161] studied the HRSG thermodynamic performance of a combined cycle power plant. There were studies done for pressure ratios of 0 to 40 and turbine inlet temperatures (TITs) of 1000 to 1500 K. A dual-pressure HRSG was shown to be more efficient due to a reduction in irreversibility.

Higher compression ratios, according to Thamir K Ibrahim et al. [225], increase the significance of TIT. With a rise in TIT from 1150 to 2050 K, the total thermal efficiency for high compression ratios of 6 to 24 improves from 54.8 to 61.3 percent.

At the time, there were various other designs for the combined cycle power plant by Rolf Kehlhofer [111], including one with only an induction motor and one that had an electric heater as well as two with induction motors that could only be used in conjunction with the induction motor. Pinch point and condenser pressure were studied to see how they affected the efficiency of a waste heat boiler. An efficient gas-powered, double-pressure system was in place. Over 40% more power was produced by the unit that had prohibited supplementary firing. Mainly because the output power of the steam turbine was tripled, this was possible.

Using the Brayton cycle and a 33 MW gas turbine power plant, Abam et al. [42] developed a model. Each component and the overall system were studied for exergy. Combustion chambers and gas turbines both deplete energy, but combustion chambers do so at a higher rate. There was a strong correlation between exergy efficiency, exergy destruction, and a number of other important parameters, including ambient temperature and TIT, according to the findings.

Numerous studies have examined the effects of variables such as temperature, pressure, humidity, and altitude on things like intake and exhaust losses as well as water temperature. Gas turbines are used to extract air from the atmosphere. The mass flow rate of air is affected by changes in air density, which in turn influences the efficiency of a power plant's turbines. The physical location of a power plant has a considerable influence on its performance, as is well-known [119,146,160]. Air from the outside world is heated as it enters the compressor, resulting in a rise in temperature of the air. After that, it is delivered to the combustion chamber where it will be used for combustion purposes. When operated at 15°C instead of 45°C, most gas turbines produce 30% more power. At 45 degrees Fahrenheit, this means that the cost of establishing a new power plant is around 30 percent more expensive.

Naeim Farouk and colleagues [160] found that efficiency and output power change with the surrounding environment.

The rate at which fuel is consumed and the economics of a plant are affected by the extent of changes in the surrounding environment. They discovered that the air mass flow rate drops when the density of the air lowers due to an increase in temperature, resulting in a decrease in output power. Higher temperatures necessitate a greater effort from the compressor to compress air, which reduces its overall efficiency. It was found that at 28.5° C, the efficiency was 36.48 percent, however this decreased as the temperature went up.

2.3 Research Gaps

The following gaps are identified in the extant literature on combined cycle power plants:

- Combined cycle power plant subsystems are often evaluated independently, ignoring their interdependence.
- Very little is known about the process of energy quality decline and the accompanying penalty function.
- Few data exist on the productive structure of the closed cycle power plant
- The relationship between expenses and physical importance (losses) is not well-established.

Therefore, extensive study is required for the development of a thermoeconomic framework that provides a strong connection between costs and physical relevance.

2.4 Research Problem

Integrated thermodynamic and economic study of a combined cycle power plant and its components to discover the optimal point.

CHAPTER 3 COMBINED CYCLE GAS TURBINE MODELING & SIMULATION

3.1 Thermal Power Stations

Chemical combustibles are burned in a thermal power plant to produce energy. The most common use of fossil fuels for this purpose is coal, natural gas, and crude oil.

In a thermal power plant, energy is converted in three stages. The chemical energy of a combustible fuel is turned into heat through the combustion process in a boiler or a burning chamber. The heat is converted to mechanical energy during the expansion of gas in a revolving apparatus. An electrical generator is powered by this circular mechanism. Engines, steam turbines, and gas turbines are all examples of spinning machines.

Steam turbine thermal power plants are often designed for large-scale, continuous operation to meet the needs of the base load. Electricity generated by gas turbines is used in

For peak-load applications, "rapid reaction" units are needed. Typically, combustion engine-powered power plants are small and utilised only for local supply or cogeneration purposes. Thermal power plants are a major source of electricity generation across the world.

Thermal power plants have the advantages of readily available fuels and well-proven technology over other types of power generation. But the release of harmful pollutants is a major environmental issue. Excess heat generated by a real thermodynamic cycle is vented into the surrounding atmosphere (atmosphere, ponds, river, lake or sea etc.). Solid pollutants like fly ash and gas pollutants like nitrogen, nitrogen oxides, sulphur oxides, and carbon dioxide can be found in the flue gas from fossil fuel combustion. Airborne particulate matter (PM10) is a potential health hazard that should be avoided at all costs. As a result, the overall efficiency ranges from 30 to 40%. In order to lessen the harm they do, thermal power plants have been "greened" and a variety of practical solutions have been created. The efficiency of power plants can be improved by regenerative features or simultaneous cogeneration of electricity and heat (CHP). The terrain may be less exploited if the power plant is located near a fuel source (mine) and reforestation. In the construction industry, solid waste may be repurposed for raw materials. It is possible to clean up polluted air and flue gases by using pollution control devices such as electrostatic precipitators (ESP), bagfilters (BF), and fabric-filters (FF). Flue gas de-nitrification and de-sulfurization reduce nitrates and sulphides in the waste stream. It's also possible to use technology like "carbon capture" and storage techniques in this strategy.

3.2 Technological Scheme Of Steam Power Station

The Rankine cycle is a basic steam thermal power plant principle. The boiler, steam turbine, condenser, and main feed pump are the most important technological components. Some of the most important supplementary machinery and equipment are: cooling towers, chimneys, and several other auxiliary components.

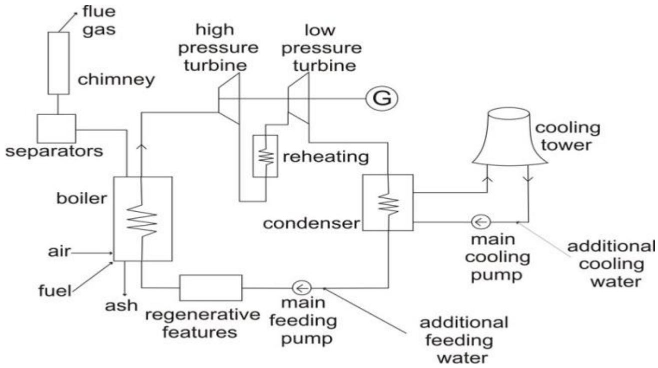

Figure 5Basic technological scheme of steam power station

Power plants with a single gas turbine and no steam cycle are sometimes built for emergency or peaking power output. A substantial amount of money is spent on energy because of the decreased thermal efficiency.

Energy generated by the Brayton Cycle gas turbine is combined with that generated by the Rankine Cycle steam generator to produce power (HRSG). Natural gas, synthetic gas, or fuel oil are the most common fuels used to feed the gas turbine at this nuclear power station.

Gas turbines and steam turbines are used in a mixed cycle power plant. When constructing a mixed cycle power plant, the most important components are a combination of gas turbine and steam turbine generators.

In a combined cycle system, instead of releasing exhaust gas into the environment, the gas turbine generator exhaust is directed to a heat recovery steam generator. The boiler is warmed by the hot exhaust gas, which eliminates the need for extra fuel and allows water to be converted to steam without it. The steam turbine is powered by superheated steam, which creates energy via a generator.

It is more efficient to run a combined cycle than to run a standard thermal plant and a gas turbine plant of equal size. Aside from saving money on fuel, it also reduces operating costs by using waste heat or exhaust heat from gas turbines to create more electricity. For the most part, medium- and base-load power plants make use of combined cycle technology.

3.3 Analysis of Simple Gas Turbine Cycle

Gas turbines run on the Brayton cycle, which is their underlying operating principle. There are two isentropic processes in this cycle, and two isobaric processes in the other two. isobaric reactions occur in both combustor systems of the gas turbine and the HRSG. A gas turbine's compressor and expander are both isentropic processes, which represent compression and expansion. The air-standard Brayton cycle's first rule of thermodynamics is illustrated in the following equations:

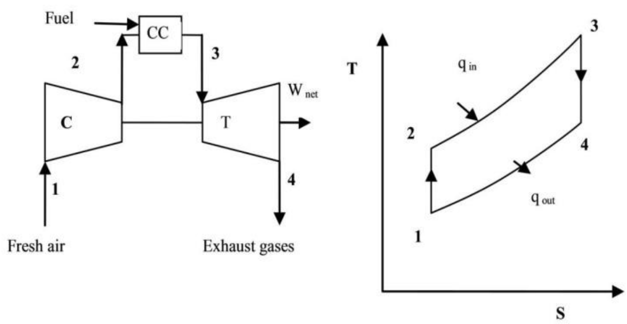

Figure 6Schematic and T-S diagram of Simple Gas Turbine Plant

Compressor work $$W_{12} = h_2 - h_1 = m_a C_p (T_2 - T_1)$$

Turbine work $$W_{34} = h_3 - h_4 = (m_a + m_f) C_{pg} (T_3 - T_4)$$

Net Work output $$W_{Net} = \text{Turbine work} - \text{Compressor work} = W_{34} - W_{12}$$

$$= [(m_a + m_f) C_{pg} (T_3 - T_4)] - [m_a C_p (T_2 - T_1)]$$

Heat supplied $Q_{23} = h_3 - h_2 = (m_a + m_f) C_{pg} T_3 - m_a C_p T_2$

Efficiency $\eta = \dfrac{\text{net work input}}{\text{heat supplied}}$

$$= \frac{W_{34} - W_{12}}{Q_{23}} = \frac{(m_a + m_f) C_{pg} (T_3 - T_4) - m_a C_p (T_2 - T_1)}{(m_a + m_f) C_{pg} T_3 - m_a C_p T_2}$$

3.4 Simulation Model of Combined Cycle Power Plant

MATLAB/Simulink has been used to model a single-shaft gas turbine. There are various control units that may be deciphered using this concept. Using Simulink, the whole process of a gas turbine may be analysed by modifying the gas turbine settings and examining the variation in efficiency in combined cycle power plants. There is also a theoretical study of the effect of temperature management, as indicated in table 1, which has been proven by sketching numerous curves as well as providing extensive comments.

Table 1Real time basic data of the power plant studied

Power Plant	Unit Name	Capacity MW	Generation (MW)
Combined cycle power plant-Bawana	UNIT-1	216	0.00
Combined cycle power plant-Bawana	UNIT-2	216	-1.00
Combined cycle power plant-Bawana	UNIT-3	216	186.00
Combined cycle power plant-Bawana	UNIT-4	216	-4.00
Combined cycle power plant-Bawana	STG-1	253.6	0.00
Combined cycle power plant-Bawana	STG-2	253.6	105.00

Unit-wise generation of power plant-Bawana,Delhi at 10/7/2016 12:09:49 PM

Studies of model alterations describing numerous components and related factors are required to maximise the combined cycle power plant's performance. With this, we were able to design blocks depicting the gas and waste heat recovery boilers as well as steam turbines and temperature transducers.

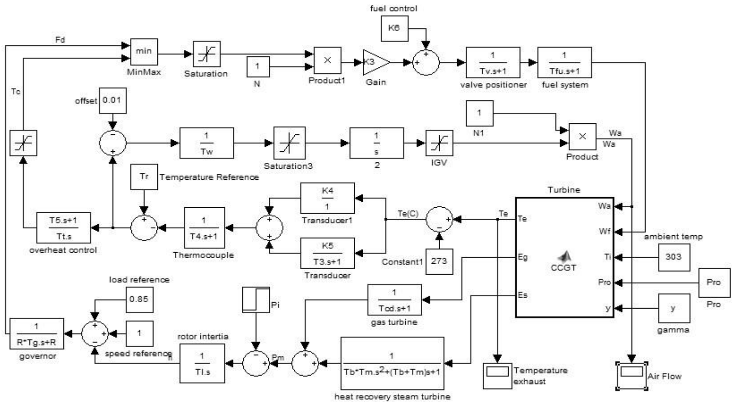

Figure 7Simulink Model of Combined Cycle Power Plant

3.4.1 Rotor Speed/Load Control Block

The rotor speed/load control block is shown in Figure 8. A reference load is used to establish the fuel demand Fd in this block.

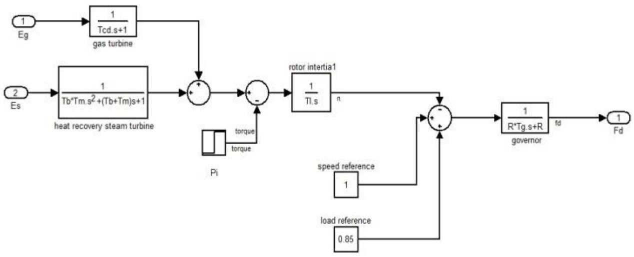

Figure 8Rotor Speed/Load Control Block

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3.4.2 Gas Turbine Temperature Control Block

Figure 9 shows a gas turbine's temperature control block. A gas turbine's exhaust temperature (Te°C) is monitored and controlled by this device to keep it from overheating and causing damage. Various thermocouples and transducers are used to monitor the temperature.

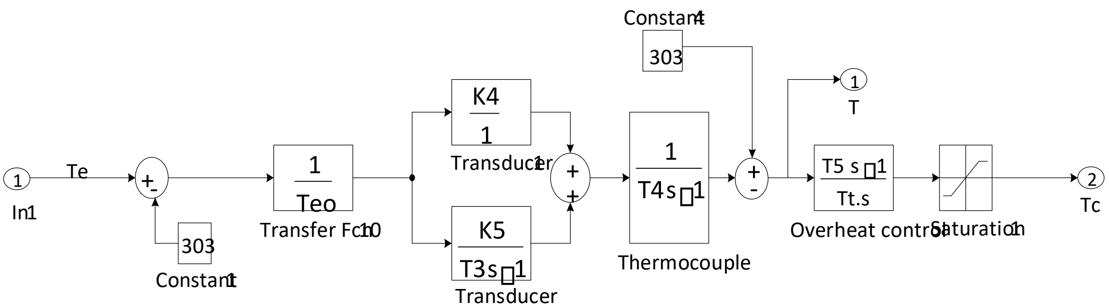

Figure 9 Gas Turbine Temperature Control Block

3.4.3 Gas Turbine Fuel Control Block

The gas turbine fuel control block is seen in Fig. 10. It is used to ensure that the valve is in the correct position to release the correct amount of gasoline. As the mass of fuel flow mf increases, so do the functions that need to be performed.

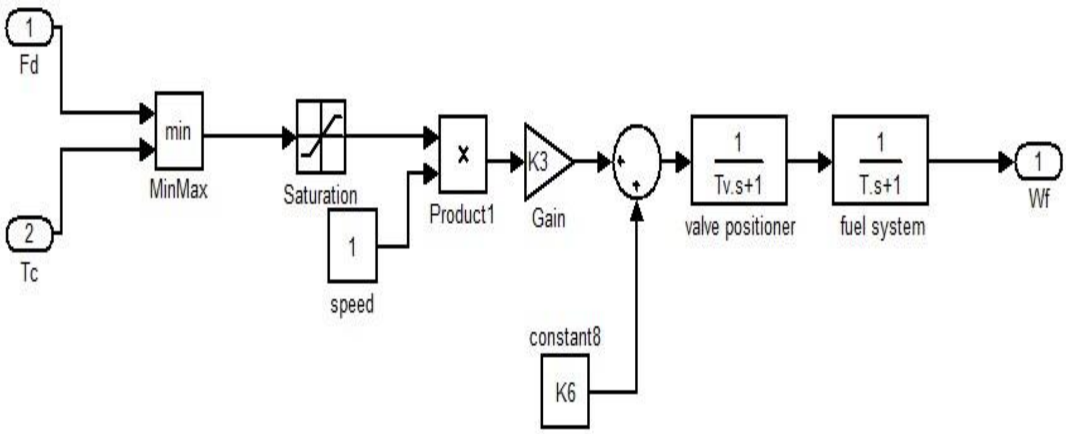

Figure 10Gas Turbine Fuel Control Block

3.4.4 Gas Turbine Air-Mass Control Block

The air-mass control block is seen in Fig. 10. In order to achieve a desired exhaust temperature below a reference temperature, this block controls the air flow in the gas turbine. Compressor inlet guide vanes are used to accomplish this (IGV). Using a reference temperature, the exhaust temperature of the gas turbine Te is measured. Depending on the gas turbine's exhaust temperature, the air-mass control block changes the IGV aperture. The exhaust temperature of the gas turbine is controlled by the mass of air flow that is supplied into the gas turbine.

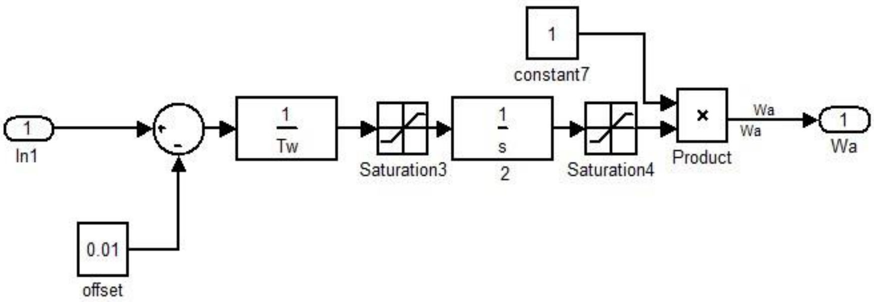

Figure 11Gas Turbine Air-Mass Control Block

3.5 Validation of the Model

In this chapter, we provided the equations and the MATLAB/Simulink model that were used to examine the behaviour of a combined cycle power plant under various situations by changing the parametric values.

Overall efficiency and gas turbine efficiency are shown in Fig. 12 when the steam turbine efficiencies are varied at various steam turbine efficiency levels. Gas turbine and/or steam turbine efficiency improves the overall efficiency of the combined cycle. However, if the efficiency of the steam turbine is considered to be constant, an increase in the efficiency of the gas turbine leads to an increase in the combined cycle process' overall efficiency.

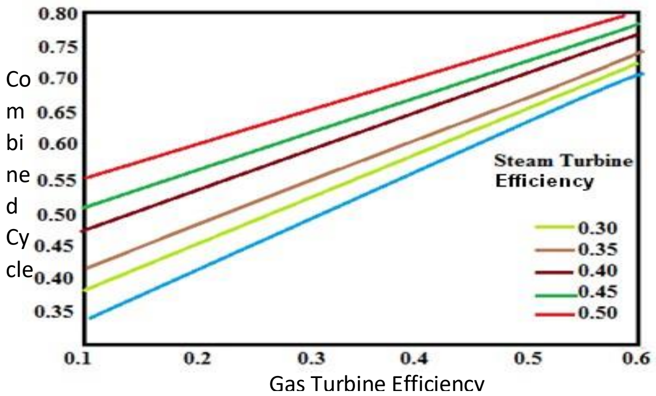

Figure 12Combined Cycle Efficiency v/s Gas Turbine Efficiency

Figure 13 depicts the relationship between the maximum permissible loss in steam turbine efficiency and the efficiency ratio of the gas turbine. As the gas turbine efficiency improves, the combined cycle's overall efficiency also gets a boost from it. Because the exhaust from the gas turbine process is used in the steam turbine process, a change in gas turbine efficiency would have an impact on the steam turbine process. The total efficiency of the two efficiencies is determined by their individual values. Overall efficiency of the combined cycle decreases if the steam turbine efficiency is lower than that of the gas turbine. While the gas turbine's efficiency remains the same, if the steam turbine's efficiency drops in 'B', overall cycle efficiencies increase by the same amount.

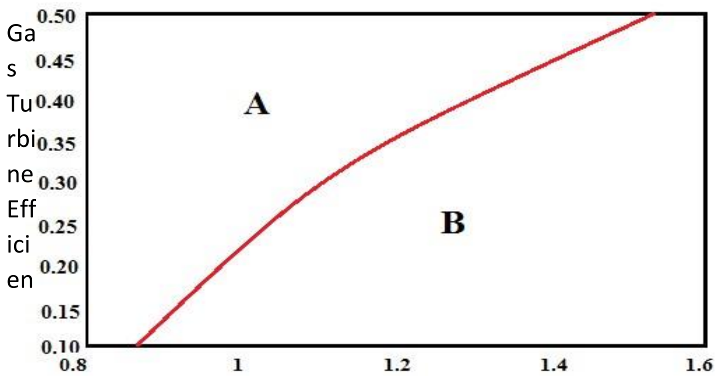

Figure 13Rate of change in Steam Turbine Efficiency v/s Gas Turbine efficiency

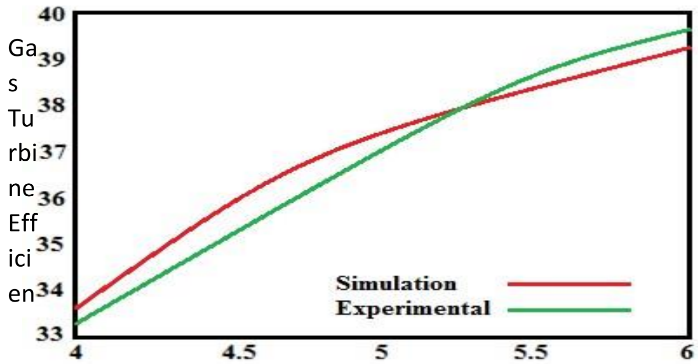

Figure 14 Rate of Change in Steam Turbine Efficiency v/s Gas

With the pressure ratio fixed, Fig 14 demonstrates the change in gas turbine efficiency with the maximum cycle temperature ratio (T3/T1). It shows that increasing the basic gas turbine cycle's maximum temperature ratio increases gas turbine efficiency. This temperature ratio may, however, be adjusted by either raising T3 or reducing T1. The gas turbine's mechanism allows for a certain amount of T3 enhancement. Damage to the gas turbine can occur if the temperature rises over this point. The gas turbine intake can be cooled using different coolers to reduce T1.

T3/T1 has been determined to reach a maximum value of 5.5, according to actual data from a combined cycle power plant. The plant can no longer work if the limit is exceeded. Thus, this is the best possible value.

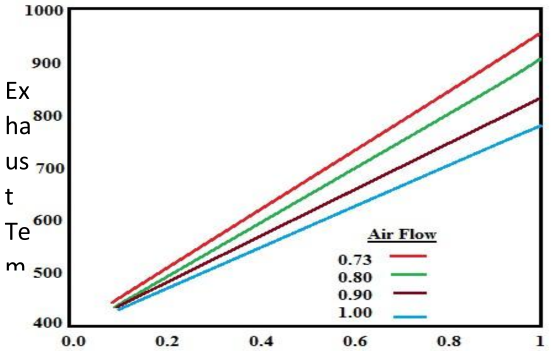

Figure 15 Exhaust Temperature v/s Fuel flow

Fuel flow per unit (pu) affects the exhaust temperature of the gas turbine, as seen in Fig 15. The availability of thermal energy increases as the exhaust temperature rises with increasing mass of fuel flow. In other words, as fuel mass flow increases, the temperature at which fuel enters the turbine rises. The gas turbine might be damaged if the exhaust temperature is too high. The exhaust temperature may be controlled by increasing the air flow. Fuel flow can be increased in tandem with an adequate increase in air flow, resulting in a reduction in exhaust temperatures.

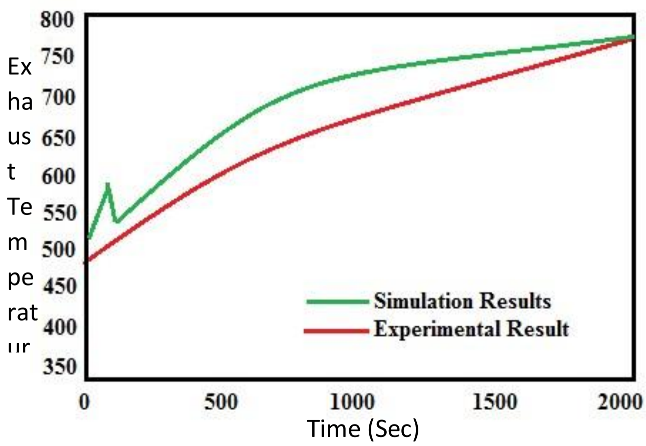

Figure 16Exhaust Temperature (K) v/s Time

Figure 16 shows the time-dependent fluctuation in exhaust temperature between the simulated and experimental (real-world plant data) results. A 10% discrepancy between the simulated and experimental findings was found to be a fair agreement in this study. The parametric analyses of the combined cycle power plant are carried out using the validated model in the following chapters.

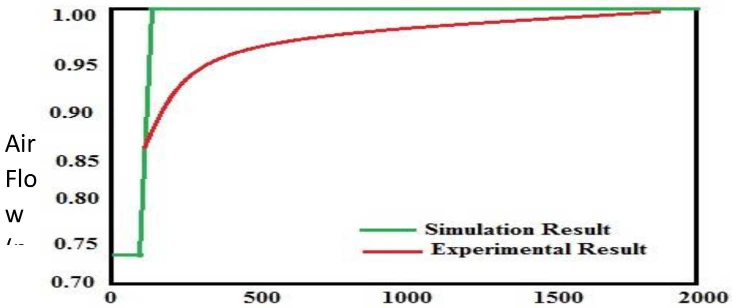

Figure 17Air Flow (p.u.) v/s Time

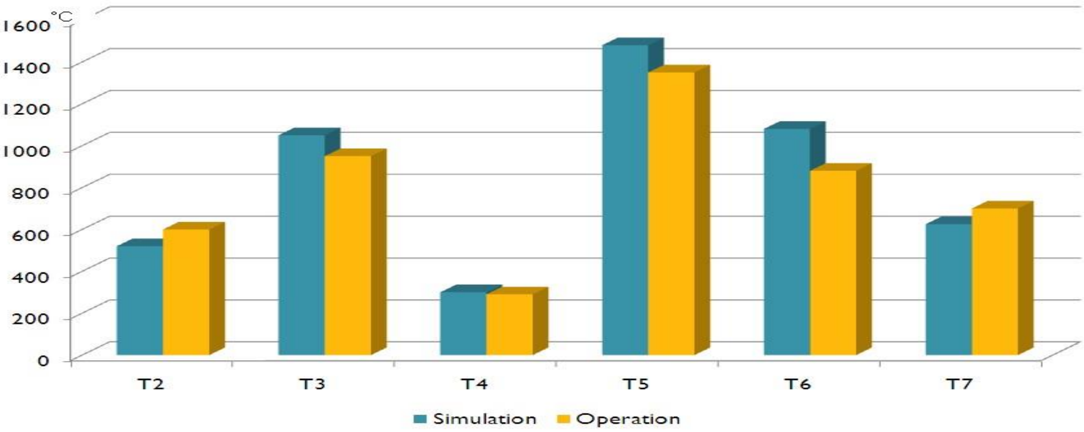

Figure 18Variation in Gas Temperature °C

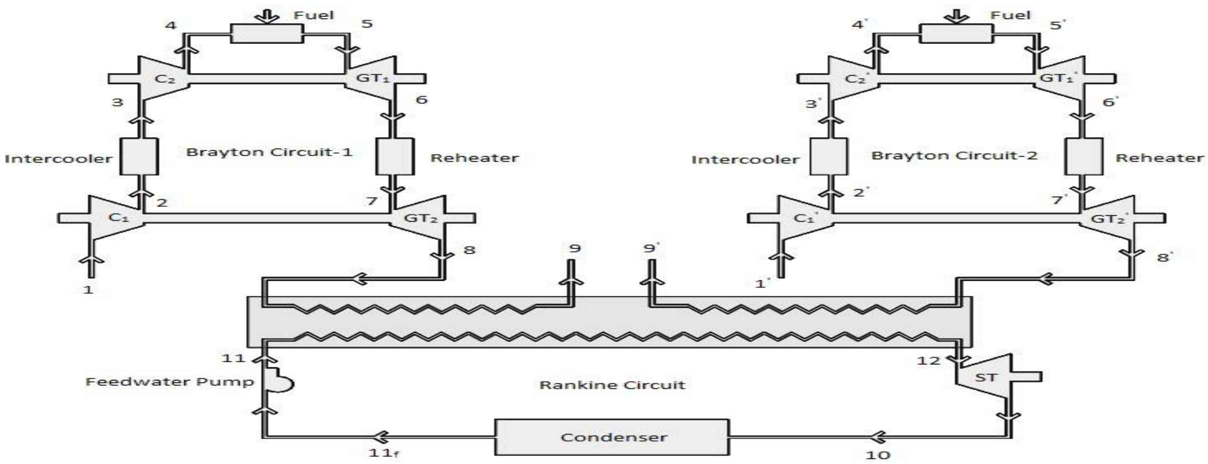

Figure 19Actual combined cycle power plant Power Plant (2 Gas Turbines - 250 MW x 2 and 1 Steam Turbine - 250 MW x 1)

CHAPTER 4 ENERGY ANALYSIS

4.1 Introduction

The examination of a power plant begins with an analysis of its energy use. To carry out this investigation, a precise mathematical model is required. There should be no problem with this model assimilating and producing findings that are near to the actual/experimental data from the power plant.

Our combined cycle power plant's energy flow model was developed using a Matlab/Simulink model, and the specifics of that model may be found within these pages. When examining the power plant under consideration, different components such as the compressor, regenerator, combustor, gas turbine, heat recovery steam generator, and steam turbine were assessed.

It was decided to use Delhi's Bawana combined cycle power plant as a reference point for this investigation. As a result, data on the energy exchange between the various components was gathered. The mathematical model of the combined cycle power plant was validated using the data received. A total of two gas turbines (2 x 250MW) and one steam turbine make up this power facility (1 x 250 MW).

A pre-study using actual power plant data and setup confirmed the model. The validated model was used to study the various parameters in order to identify the ideal values.

4.2 Gas Turbine Work

The compressor uses a portion of the gas turbine's power to operate. The remaining effort is put to use in the generating of electricity. The gas turbine network has been taken into account in this study. Using the validated model, we investigated and evaluated the power plant's performance under a variety of conditions. The net output of a gas turbine power plant is depicted in the figure below.

For various air-to-fuel ratios and bypass ratios, the (kJ/cycle) net gas turbine work as a function of pressure ratio is depicted in Figure (kJ/cycle). From 2 to 30 the pressure-to-air-to-fuel ratio was changed in 2 step increments, and from 50 to 130 in 10 step increments.

The net work generated by the gas turbine every cycle rises with increasing pressure ratio for a given air fuel ratio. However, when the pressure ratio rises, so does the marginal increase. With an increase in air-to-fuel ratio, the net work produced by the gas turbine falls. Since more air needs to be compressed, the compressor's workload increases as the air fuel ratio rises.

Regardless of whether a bypass ratio is used or not, the general tendency remains the same. Bypass ratio and air fuel ratios can alter the trend. Here, the net work produced every cycle by the gas turbine decreases with increasing pressure ratio beyond a particular threshold. As a result, the gas turbine cannot operate since the work required is more than the work received in some circumstances. As a result, a less quantity of energy is available for the turbine because of the HRSG's use of the available resources. It's also true for lower air-fuel ratios, although the effect is less obvious because of the reduced amount of work done in the compressor.

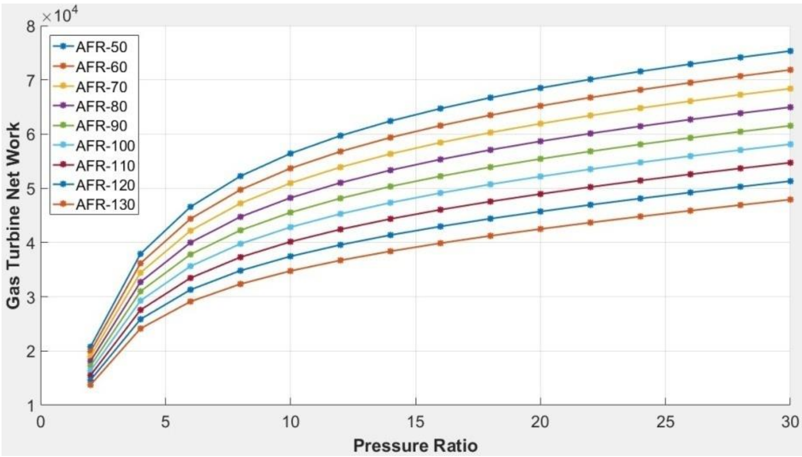

Figure 20 Gas Turbine Net Work(kJ/cycle) v/s Pressure Ratio for various Air Fuel Ratio

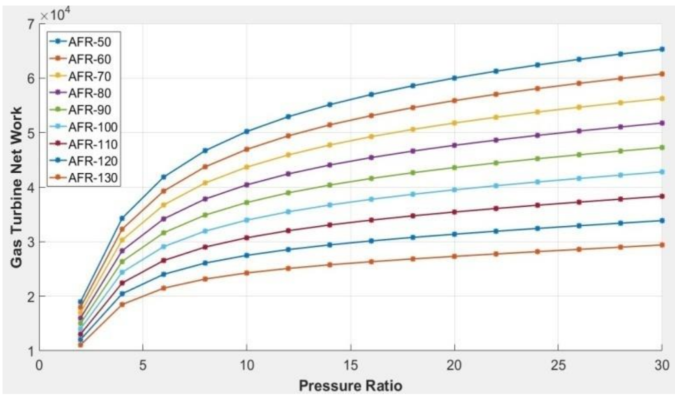

Figure 21 Gas Turbine Net Work v/s Pressure Ratio for various Air Fuel Ratio (With 5%

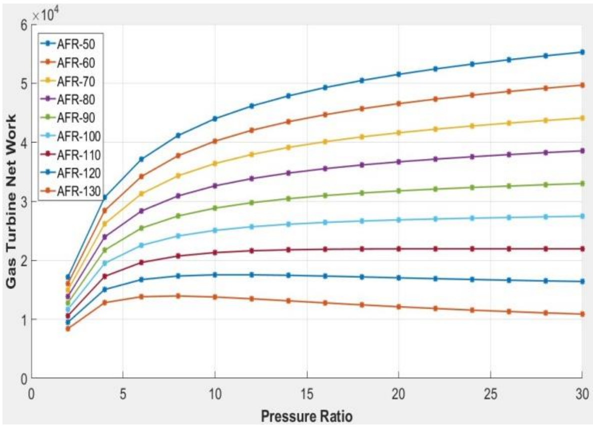

Figure 22Gas Turbine Net Work v/s Pressure Ratio for various Air Fuel Ratio (With 10% Bypass Ratio)

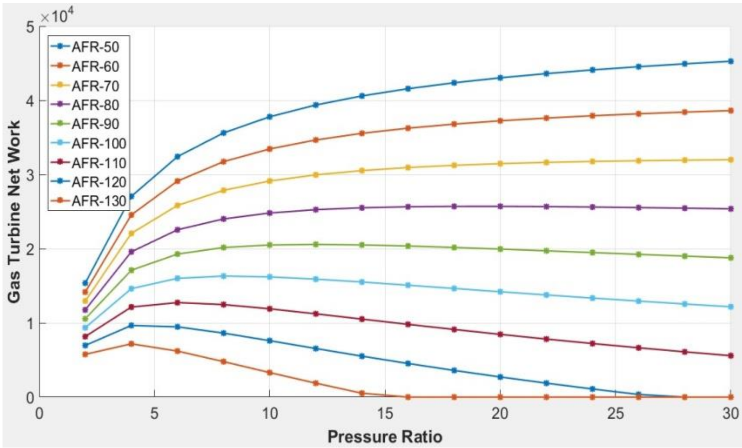

Figure 23Gas Turbine Net Work v/s Pressure Ratio for various Air Fuel Ratio (With 15% Bypass Ratio)

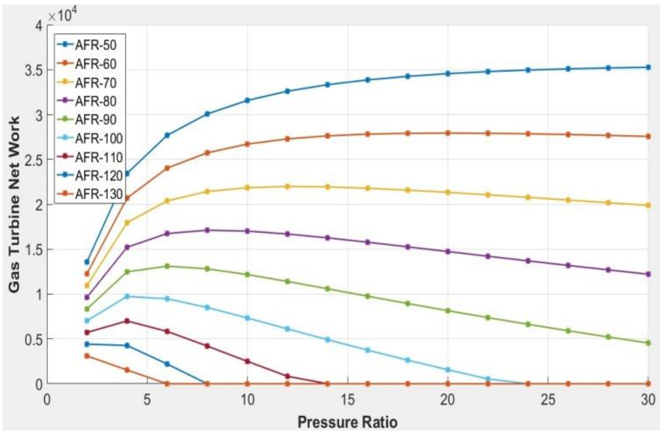

Figure 24Gas Turbine Net Work v/s Pressure Ratio for various Air Fuel Ratio (With 20% Bypass Ratio)

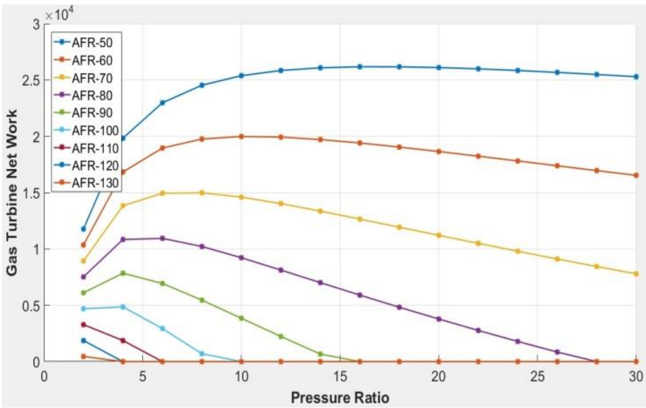

Figure 25Gas Turbine Net Work v/s Pressure Ratio for various Air Fuel Ratio (With 25% Bypass Ratio)

With and without a bypass ratio, a gas turbine's net work in (kJ/cycle) is shown in the graph. From 5 to 30 and 50 to 130, the pressure and air fuel ratios were varying in increments of 5.

With an increase in air-to-fuel ratio, the net work produced by the gas turbine falls. However, when the air fuel ratio rises, the marginal drop becomes more pronounced. The net work produced by the gas turbine every cycle rises with higher pressure ratios for a given air fuel ratio. A gas turbine produces greater work owing to increased temperatures and pressure ratios, which results in more accessible energy at turbine intake.. However, the amount of work done in the compressor increases as the pressure ratio increases, thus the net increase is smaller. Figures also show that the marginal gain decreases as the pressure ratio increases.

With or without a bypass ratio, the tendency persists. When the pressure ratio is raised, however, the pattern changes, and the net work generated by the gas turbine each cycle decreases as the pressure ratio rises. Gas turbine operation is not possible in some instances because more effort is expended than is generated. Energy that could have been used to power a turbine has instead been diverted to the heat recovery system (HRSG). Lower air fuel ratios have the same effect, but the impact is less severe since the compressor has to do less effort.

The graph shows that when the air fuel ratio increases, the net work produced by the gas turbine decreases, and all of the curves eventually converge before diverging in the other way. Air fuel ratios of 115, 85, 60, and 50 occur for 10%, 15%, 20%, and 25% bypass ratios accordingly.

For an air-to-fuel ratio of 120:1, the net work produced by the gas turbine each cycle drops to zero at a bypass ratio of 15%.

A gas turbine with a 20% bypass ratio produces zero net work per cycle at a pressure ratio of 5, 10, 15, 20, 25 and 30 for air fuel ratios of 130, 120, 110, 110 and 100.

It is shown in Fig. that for bypass ratios of 5, 10, 15, 20, 25 and 30, the net work produced by the gas turbine for a cycle of 25% becomes zero, but at air fuel ratios of 120% (100%) (90%) (90%) (80%).

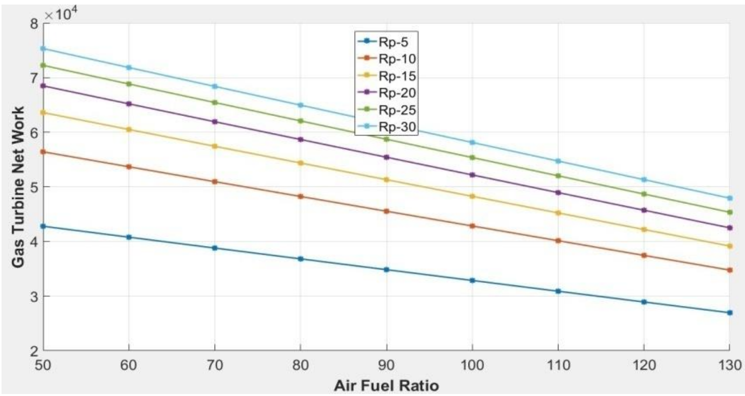

Figure 26Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (Without Bypass Ratio)

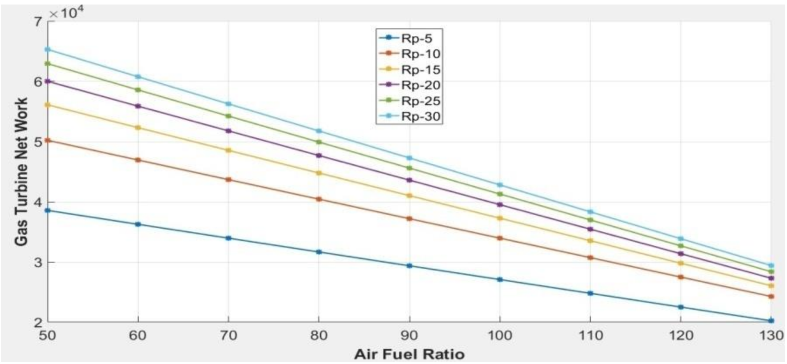

Figure 27Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (With 5% Bypass Ratio)

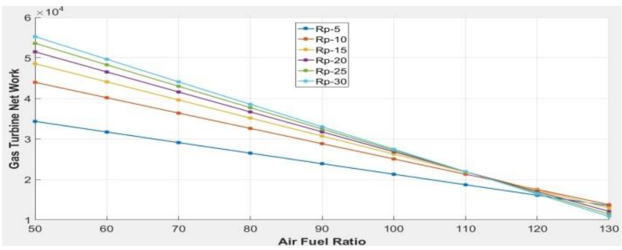

Figure 28Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (With 10% Bypass Ratio)

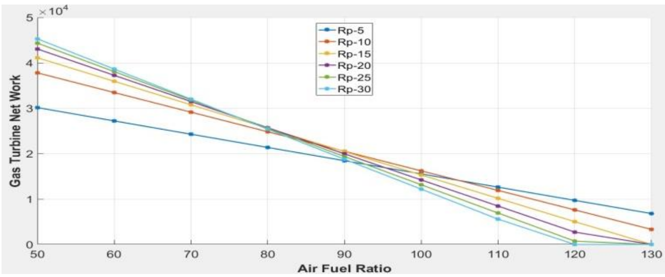

Figure 29Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (With 15% Bypass Ratio)

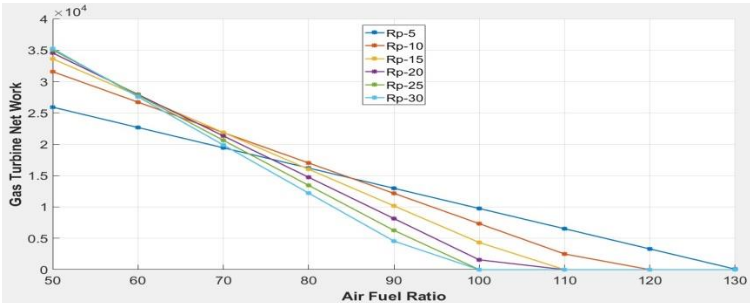

Figure 30 Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (With

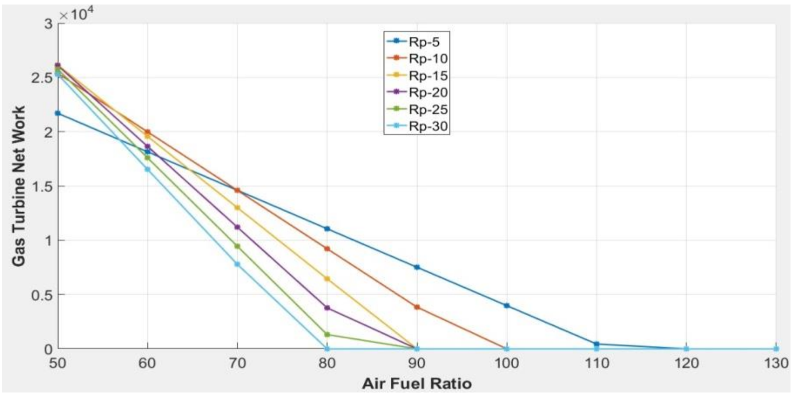

Figure 31Gas Turbine Net Work v/s Air Fuel Ratio for various Pressure Ratio (With 25% Bypass Ratio)

Pressure ratio is shown as a function of (kJ/cycle) net work for gas turbine power plants with varied bypass and air fuel ratios. To go from 0 to 25%, we increased the pressure ratio by 2 percentage points and decreased it by 5 percentage points.

As the pressure ratio rises for a certain bypass ratio, the gas turbine's net work per cycle increases. However, when the pressure ratio rises, the little increase becomes smaller and smaller. A set air-fuel ratio and greater bypass ratios may keep it steady or even drop over a certain pressure ratio. In general, when the bypass ratio is increased, the net work produced by the gas turbine for a given pressure ratio decreases. To put it another way, the amount of gas accessible for the gas turbine is reducing, but the input temperature of the turbine remains the same, despite the fact that gas is being diverted to the HRSG.

For all air fuel ratios, this tendency persists. With increased air fuel ratio and greater bypass ratios, the tendency shifts. In this case, the net work produced each cycle from the gas turbine decreases as the pressure ratio increases. When it reaches zero, it means that running a gas turbine isn't practical since more labour is required than is generated. This is because less energy is available at the turbine as a result of the bypassing of available energy to HRSG. Beyond a certain threshold, it is not possible for a gas turbine to run without gas. This is the ideal air fuel ratio.

The amount of work generated each cycle from the gas turbine grows as the pressure ratio increases up to a pressure ratio of 25, which is advantageous. There is nothing further to report. A pressure ratio of 20 is required for a 25 percent bypass ratio to do the same amount of work.

The pattern continues for air fuel ratios of 60 and 70, but the work reduces after pressure ratios of 12 and 8, respectively, for a bypass ratio of 25 percent, as shown in figs. 4.14 and 4.15. Despite the fact that the trend for air-to-fuel ratios of 80 percent is unchanged, bypass ratios of 15 percent are

The work reduces by 20% and 25%, respectively, with pressure ratios of 28, 10 and 6.

When the bypass ratio is 25% and the pressure ratio is more than 28, the work is nil.

The tendency continues for air fuel ratios of 90. For bypass ratios of 15%, 20%, and 25%, the work begins to decrease at pressure ratios of 12, 6, and 4 correspondingly. At a pressure ratio of 16 and above, the percentage of bypass becomes zero. The upward trend continues for an air fuel ratio of 100. After pressure ratios of 9, 4, and 4 are reached, work decreases for bypass ratios of 15%, 20%, and 25%, respectively. Pressure ratios of 24 and 10 are reached when the bypass ratio is 20% or 25%. The upward trend in air-to-fuel ratios of 110 continues. For bypass ratios of 15%, 20%, and 25%, the work begins to decrease at pressure ratios of 6, 4, and 2 correspondingly. Pressure ratios of 14 and 6 are reached when the bypass ratios are 20% and 25%.

The tendency continues for air fuel ratios of 120. Pressure ratios 10, 4,4 and 2 are when the work begins to decline for bypass ratios of 10%, 15%, 20%, and 25% correspondingly. Beyond pressure ratios of 26, 8, and 4, it becomes zero for bypass ratios of 15%, 20%, and 25%, respectively.

The tendency continues for air fuel ratios of 130. It is at this point that the work begins to decrease for bypass ratios of 10%, 15%, 20%, and 25%, respectively. Beyond pressure ratios of 16, 6, and 4, it reaches zero for bypass ratios of 15%, 20%, and 25%, respectively.

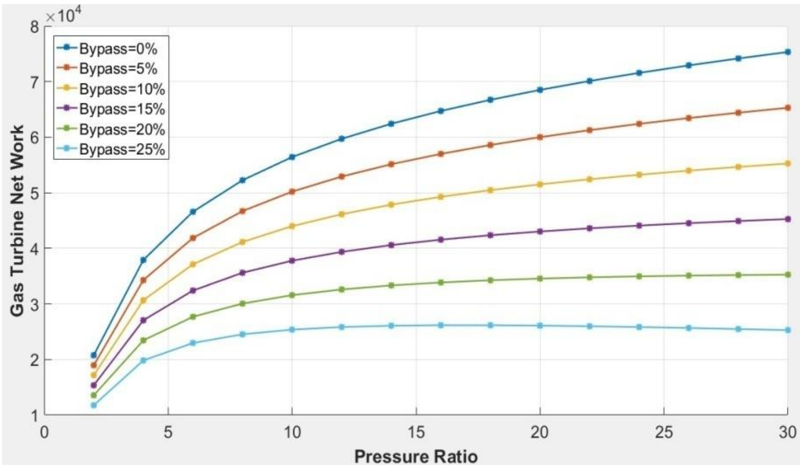

Figure 32Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel Ratio 50)

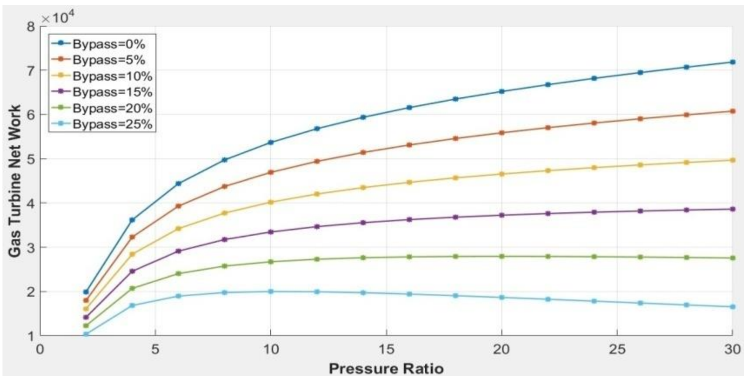

Figure 33 Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel

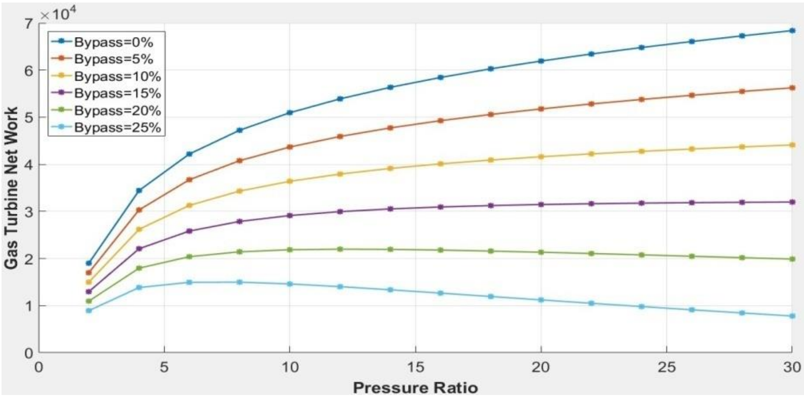

Figure 34Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel Ratio 70)

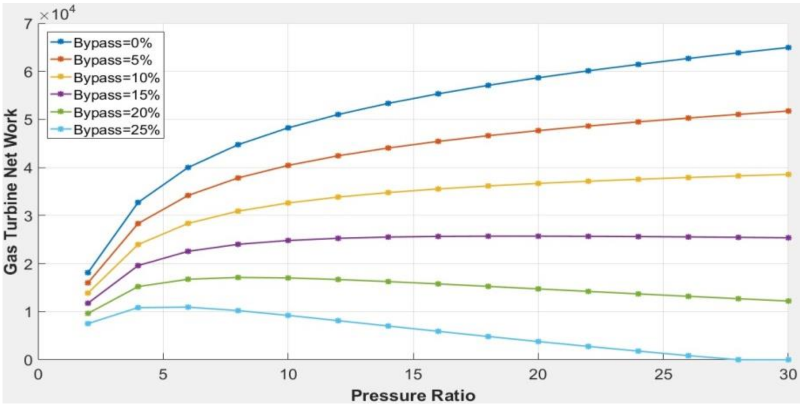

Figure 35 Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel

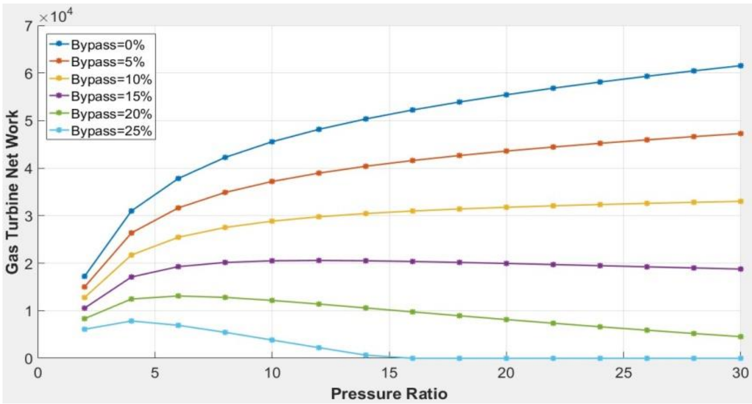

Figure 36Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel Ratio 90)

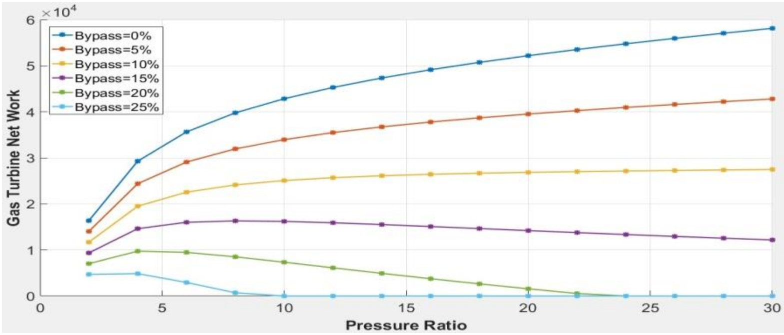

Figure 37 Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel

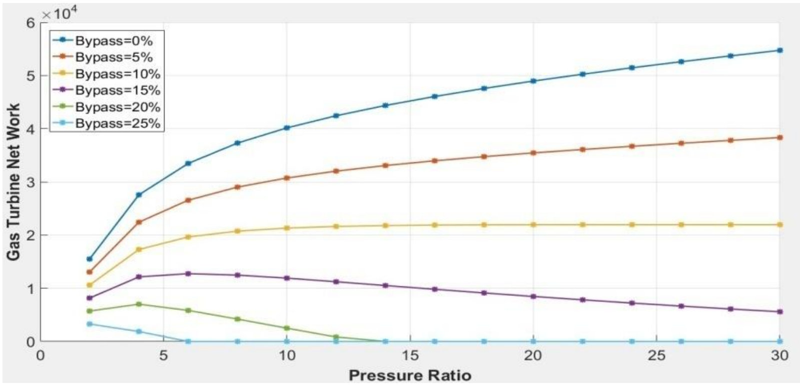

Figure 38Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel Ratio 110)

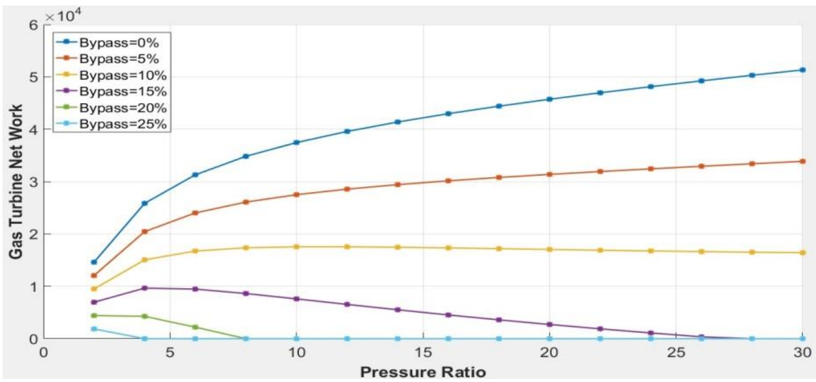

Figure 39 Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel

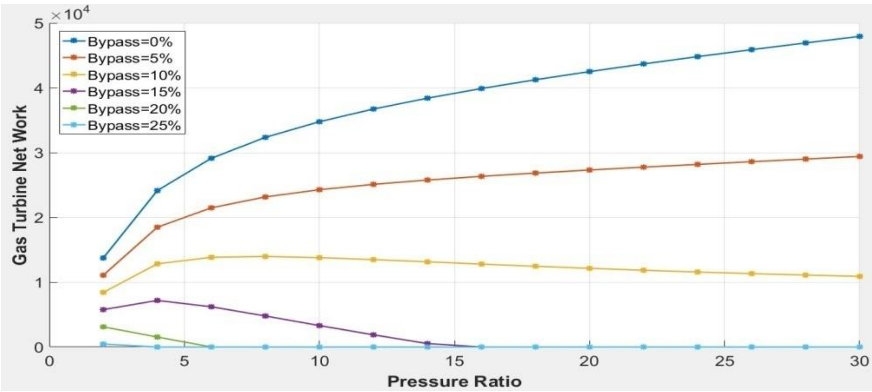

Figure 40Gas Turbine Net Work v/s Pressure Ratio for various Bypass Ratio (Air Fuel Ratio 130)

CHAPTER 5 THERMOECONOMIC ANALYSIS

5.1 Introduction

Combined cycle power plants are the subject of the current chapter, which examines both economics and thermodynamics in tandem. The optimal operating point of the plant is discovered via the use of energy and exergy analysis. Optimization based entirely on thermodynamic factors conserves energy/exergy in order to increase power generation.

Although this ideal position may not be financially practical, it is a good place to start.

The most cost-effective way to generate electricity is determined through economic analysis. Capital, land, machinery, and ancillary equipment are all included in this research (fixed cost). It also takes into account other costs, both direct and indirect, such as fuel, wear and tear, interest, depreciation, maintenance, labour, administration, overhead, and other losses and theft-related costs, for example.

Unit energy/exergy costs are used to do the exergo-economic analysis of all these expenditures.

The term exergy refers to the energy that can be used. The 'unavailable' energy due to dead state temperature is subtracted from the energy to arrive at this value.

The verified model has been subjected to exergy and energy analysis in the preceding chapters.

MATLAB/Simulink was used to create a thermo-economic model for a combined cycle power plant. Compressor, regenerator, combustor, combined cycle power plant, and heat recovery steam generator were the primary components, as previously stated. During the pre-study, the model was compared to real-world data from the plant. With this verified model, several parameters have been analysed in order to discover which one is best.

5.2 Mass of Fuel

Combination cycle amount of fuel (kg) vs. pressure ratio is depicted in Figure 41, which ranges from 2 to 30 in increments of 2.

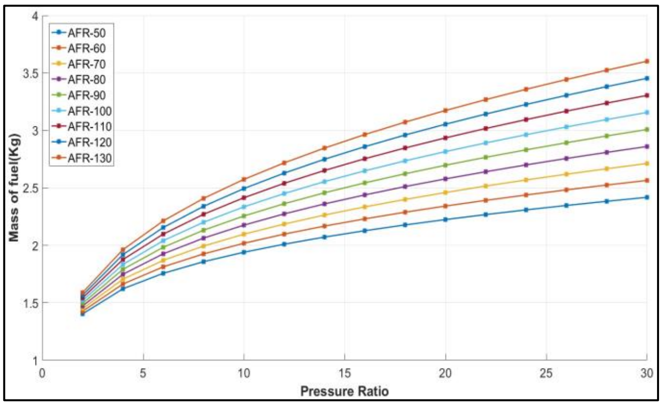

Figure 41Mass of Fuel (kg) v/s Pressure Ratio at various Air Fuel Ratio

The sum of and equals the total amount of fuel used. While the weight remains constant at 1 kg, the pressure ratio changes. Figure 41 indicates that when the pressure ratio rises, so does the amount of fuel consumed. This is due to the fact that reheating the gas to its initial temperature now necessitates using more fuel.

Additionally, when the air fuel ratio rises, so does the fuel need. This is due to the fact that it takes more heat to raise the temperature of a larger mass of gases, as the turbine inlet temperature lowers as the air fuel ratio is increased. At larger ratios, the mass of fuel continues to rise as the pressure ratio rises, which is more noticeable. This demonstrates that at larger pressure ratios, the marginal gain in fuel mass is substantially higher.

5.3 Work And Efficiency

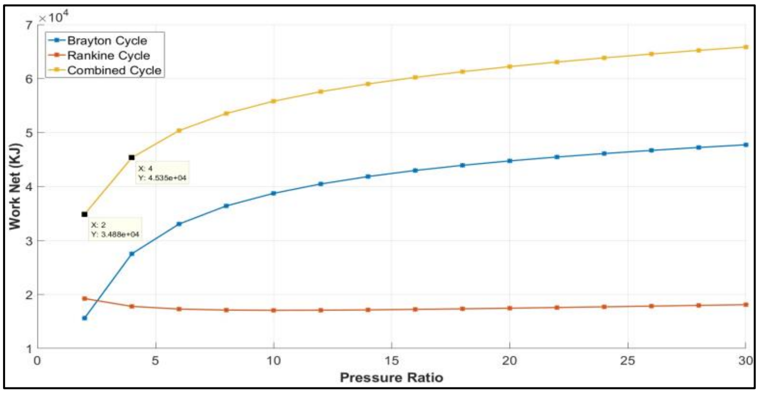

Figure 42Net Work v/s Pressure Ratio for various cycles

Figure 42 shows how the pressure ratio affects the net work produced by Brayton, Rankine, and Combined (Brayton and Rankine work combined) cycles.

Pressure Ratio	Mass of fuel used (Kg)	Outlet Temperature From Turbinem T8 (K)	Mass of Fluid Circulated (Kg)(Rankine)	Net Work Rankine * 10^4 (KJ)
2	1.5892	882.7419	22.6063	1.9249
4	1.9622	846.5876	20.9059	1.7801
6	2.2124	833.9118	20.3279	1.7309
8	2.4086	828.7335	20.1074	1.7121
10	2.5734	826.9343	20.0474	1.707
12	2.7174	826.9307	20.0723	1.7092
14	2.8462	827.9772	20.1466	1.7155
16	2.9637	829.6767	20.2513	1.7244
18	3.0721	831.7987	20.3755	1.735
20	3.1731	834.201	20.5125	1.7466
22	3.2679	836.7915	20.658	1.759
24	3.3576	839.5089	20.809	1.7719
26	3.4427	842.3104	20.9636	1.785
28	3.524	845.1664	21.1204	1.7984
30	3.6018	848.0552	21.2784	1.8119

Figure 43Mass of Fuel at various Pressure Ratios

As seen in Fig 42, the output of the Rankine cycle is almost exactly the same. An initial decline from 2 to 10 is followed by a steady rise up until the pressure ratio of 30. This cycle relies on the amount of fuel used in the Brayton cycle, as well as on the temperature and mass flow rate of exhaust gases from the gas turbine. Fig. 43 demonstrates that as the pressure ratio increases, the mass of fuel used increases as well. For pressure ratios of 2 to 8, the gas turbine output temperature drops rapidly, and then shows a slow fall from pressure ratios 8 to 12, after which it begins to rise again. Figure 42 depicts the combined effect of the two elements.

In terms of the Brayton cycle, the net work done shows a steady increase. As the pressure ratio increases, the marginal gain in work output decreases. It's because, at high pressure ratios, the difference between the turbine and compressor work becomes more or less static.

Between pressure ratios of 2 and 3, the net work output of the Brayton cycle is equivalent to the Rankine cycle. According to the figure 42, it is not required that the combined net work be the highest in order to reach this position.

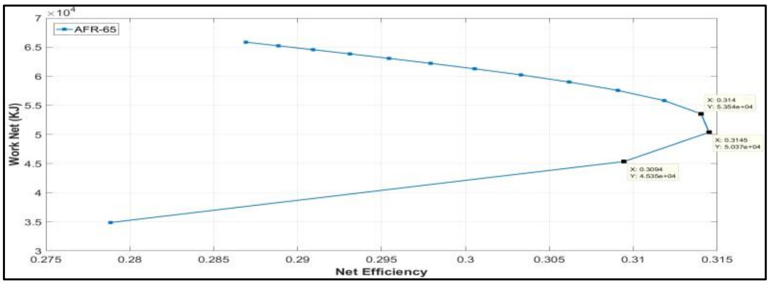

Figure 44Net Work v/s Net Efficiency at Air Fuel Ratio of 65

At an air fuel ratio of 65, which is regarded optimal, Fig 44 shows the net work generated as a function of the combined cycle efficiency. Additionally, a larger value of net work generated indicates that the plant is being operated at a high pressure ratio, regardless of the unit's efficiency. FIG. 44 further illustrates how a pressure ratio of 6 with a 65:65 air fuel ratio yields a maximum net efficiency of 31.45%, resulting in a net work output of 5.0376xkJ. The efficiency decreases when the pressure ratio rises over 6, even if the net work increases.

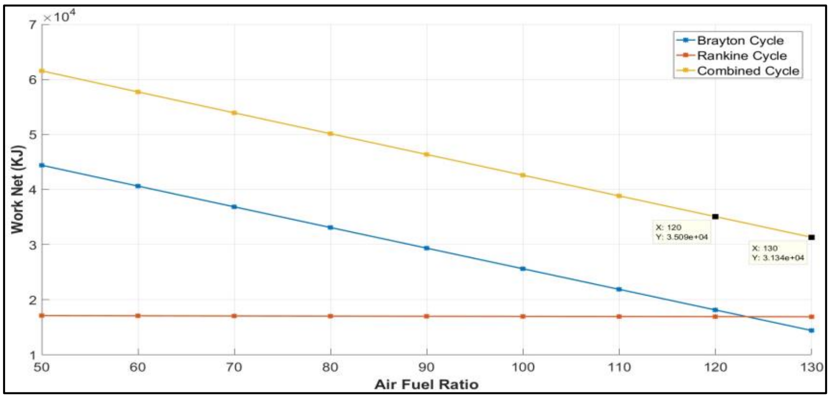

Figure 45Net Work v/s Air Fuel Ratio at Pressure Ratio of 10

As the air fuel ratio changes from 50 to 130 in increments of 10, the net work output of Brayton, Rankine, and Combined (Brayton and Rankine considered together) cycles is depicted in Fig. 45. When the plant is running at the lowest air fuel ratio of 50, the plant is able to produce the most net work output. Because of the blade material's metallurgical constraints, this isn't a feasible option, hence the least viable air fuel ratio is used instead.

Air Fuel Ratio	Mass of fuel used (Kg)	Outlet Temperature From Turbinem T8 (K)	Mass of Fluid Circulated (Kg)(Rankine)	Net Work Rankine * 10^4 (KJ)
50	1.9398	946.3475	20.1183	1.7131
60	2.0179	860.2134	20.0684	1.7088
70	2.0966	798.3425	20.0283	1.7054
80	2.1757	751.7483	19.9944	1.7025
90	2.255	715.3946	19.9646	1.7
100	2.3344	686.2397	19.9377	1.6977
110	2.414	662.3379	19.9129	1.6956
120	2.4937	642.3868	19.8896	1.6936
130	2.5734	625.4816	19.8675	1.6917

Figure 46Mass of Fuel at various Air Fuel Ratios

As the air-fuel ratio grows, the Rankine cycle's net output remains almost exactly the same, but it does increase somewhat. Fuel mass and exhaust temperature from the gas turbine are the primary factors influencing the Rankine cycle's output. The amount of fuel burned grows over time, yet the temperature at the turbine's exhaust falls, as seen in Fig. 46. The overall result is that the change in output is practically exactly the same.

The net work done in the Brayton cycle is continually decreasing, as seen in fig. 45. The combined cycle is depicted by the highest curve, which is the product of the two curves seen below it. The net work obtained from the two cycles is likewise shown to be equivalent for an air fuel ratio of 120 to 130.

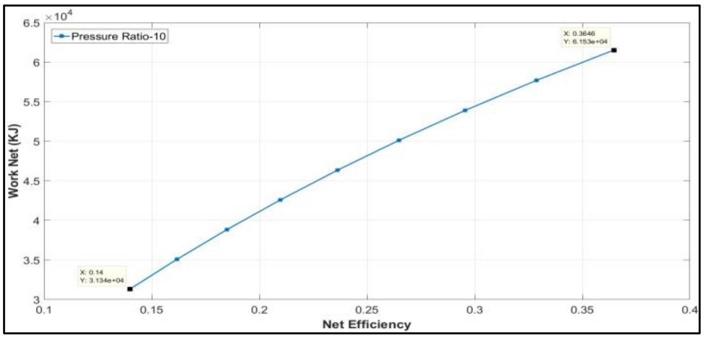

Figure 47Net Work v/s Net Efficiency at Pressure Ratio 10

Net work done versus combined cycle efficiency is depicted in Fig. 47, where the pressure ratio is 10.

The higher the value of net work done, the lower the air fuel ratio and the worse the efficiency of the plant. As a result, the rightmost point corresponds to the lowest air-fuel ratio possible.

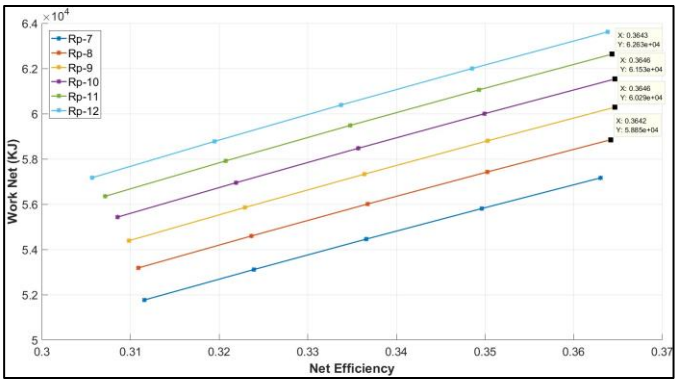

Figure 48Net Work v/s Net Efficiency at various Pressure Ratio

Net work done vs combined cycle efficiency for pressure ratios ranging from 7 to 12 is shown in Fig 48 in increments of one. In four-step increments, the air-fuel ratio is shifted from 50 to 66.

No matter how efficient the plant is, a larger net work done figure indicates that the air fuel ratio is poor. This suggests that the air fuel ratio is 50 at the rightmost position, and 66 at the leftmost point in this example. The efficiencies for various pressure ratios are provided assuming that the plant is run at the lowest possible air fuel ratio. Figure 48 shows that the highest efficiency occurs at pressure ratios of 9 and 10, and the maximum value is 36.46 percent, even if the work is not ideal at this point. Therefore, a careful choice must be made between thermodynamic work and operational efficiency in order to obtain a more cost-effective and feasible plant operation.

5.4 Units (kWh) Produced per Cycle

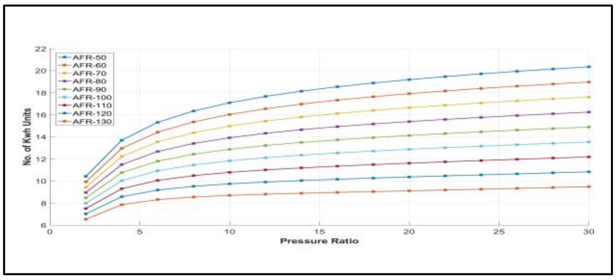

Figure 49kWh units v/s Pressure Ratio at various Air Fuel Ratio

Fig. 49 shows how many units of power are generated each cycle as a function of the pressure ratio for varied air fuel ratios.. The pressure ratio ranges from 2 to 30 in increments of 2 for a certain air fuel ratio. The air-to-fuel ratio may be adjusted in stages of 10 from 50 to 130.

As the air fuel ratio grows from 50 to 130, the number of units generated (per cycle) falls in general. Increased air supply increases the work of the compressor and the turbine. Nonetheless, the compressor work is increasing at a far faster rate than the turbine work is increasing. Net work output or kWh taken from a combined cycle is reduced as a result of this. The marginal rise in the number of units generated with increasing pressure ratio is also observed for a certain air fuel ratio. This means that at lower pressure ratios, the increase in units produced is greater than for higher pressure ratios.

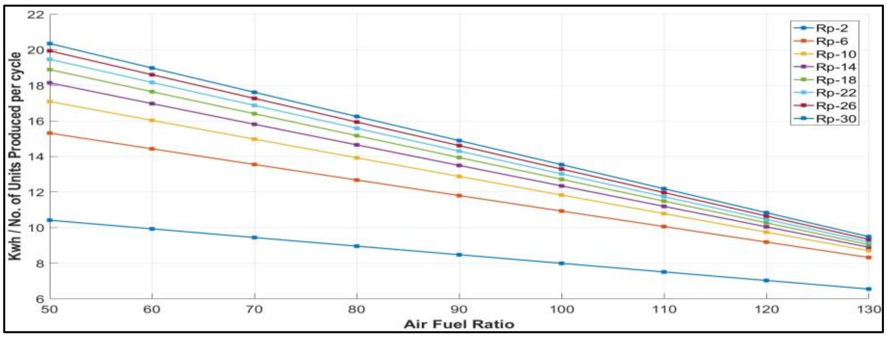

Figure 50kWh units v/s Air Fuel Ratio at various Pressure Ratio

It is shown in Figure 50 that for different pressure ratios, the number of units of power produced (per cycle) is a function of the air-to-fuel ratio. The air-to-fuel ratio ranges from 50 to 130 in 10-point increments for a given value of the pressure ratio. In four-step increments, the pressure ratio is increased from 2 to 30.

In general, the kWh value drops as the air fuel ratio grows from 50 to 130 for a certain pressure ratio. This is because the compressor and turbine work harder when there is more air flowing through them.

A big gap between the graphs indicates that the kWh generated increases dramatically at lower pressure ratios. This phenomena eventually decreases as the pressure ratio increases. An explanation for this finding may be found in fig. 50 which indicates that the rate of growth in net kWh production for a given air fuel ratio falls as the pressure ratio rises. Because the increase in kWh output isn't economically viable, it's not possible to run at high pressure ratios. In reality, the installation and setup expenses would climb significantly, resulting in a decrease in earnings.

5.5 Plant Factor & Economic Plant Load Factor

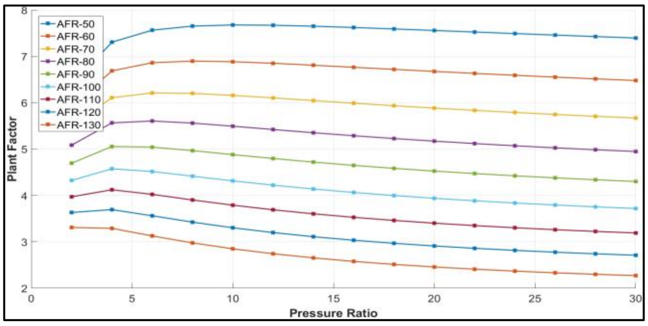

Figure 51Plant Factor v/s Pressure Ratio at various Air Fuel Ratio

The Plant Factor is the ratio of Selling Price to Input Cost for each cycle of production. As the pressure ratio rises, so does the net work production, as seen in Fig. 49. However, when the price of fuel and the cost of depreciation rise, so does the cost of input each cycle.

When the pressure ratio is increased to a certain point, the plant factor increases and then gradually declines, as shown in fig 51. A rise in output compensates for a higher input cost at first, but as the pressure ratio rises, fuel prices take over, resulting in a progressive fall in the plant's factor of production. Air fuel ratios ranging from 50 to 90 seem to follow this pattern. The lower the air-fuel ratio, the lower the net work production of the cycle, and the larger the quantity of fuel required for the cycle's sustenance. Furthermore, this explains why the plant factor falls as the air fuel ratio rises.

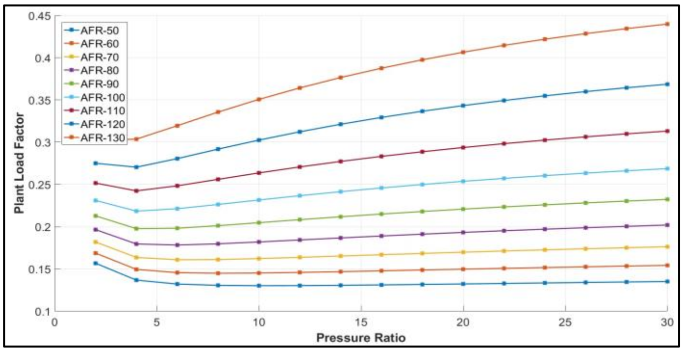

Figure 52Economic Plant Load Factor v/s Pressure Ratio at various Air Fuel Ratio

With varying air-to-fuel ratios (as shown in Fig. 52), we can see how Economic Plant Load Factor changes. When the air fuel ratio is varied from 50 to 130 in steps of 10, the curves are plotted with steps of 2 for the pressure ratio and steps of 2 for the fuel ratio. In order to calculate the gasoline costs, Rs.6 per kilogramme was used.

Relative Input Cost/Selling Price ratio is a measure of economic plant load factor. Fig. 52 is an example of a similar type of analysis.

In general, as the pressure ratio increases, so does the net work production. In addition, fuel prices and depreciation expenses are on the rise, which raises the input cost each cycle and consequently the load factor. Up to a particular pressure ratio, it is noticed that the economic plant load factor drops. As a result, the rise in input costs is offset by an increase in net production. Consequently, the plant load factor begins to rise gradually as fuel prices and other input expenses begin to exert a significant influence.

To be sure, keep in mind that this tendency only applies to lower air-to-fuel ratios, such as those ranging from 50 to 90. Although the curves are continually growing in nature for larger air-fuel ratios, the quantity of fuel required for the cycle's sustenance is considerable and the net work production of the cycle decreases in general. Furthermore, the plant load factor rises as the air fuel ratio increases. The divergence between the curves is bigger at lower air fuel ratios, indicating a greater disparity between the plant load factor values for a specific pressure ratio. As the air-to-fuel ratio rises, this discrepancy narrows. Because the numerator (Input Cost) is rising and the denominator (kWh) is falling, this is the case.

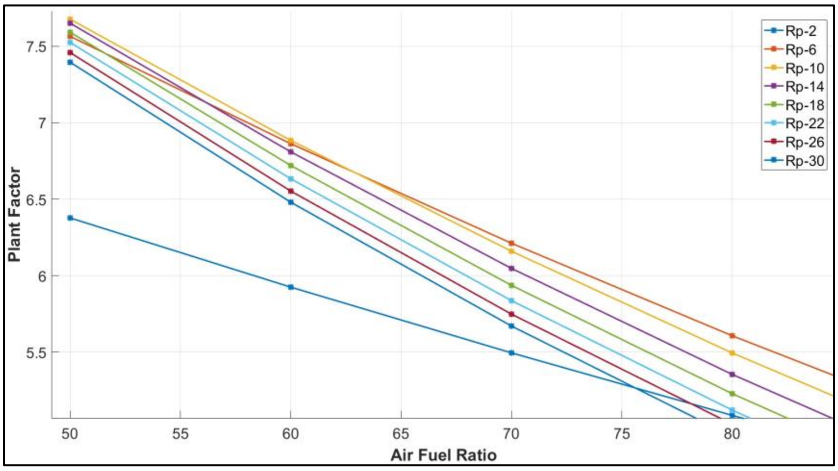

Figure 53Plant Factor v/s Air Fuel Ratio at various Pressure Ratio

Figure 53 shows the value of the plant factor as a function of the air-to-fuel ratio at various pressure ratios. It is possible to change the air-fuel ratio in stages of 10 and the pressure ratio in steps of 4. The Selling Price lowers as the air fuel ratio increases, and the net work output or kWh generated decreases as a result. Fuel costs rise, but depreciation costs fall as the air fuel ratio rises, which has a negligible effect on input costs per cycle. The plant factor would therefore decrease for all pressure ratios.

However, at lower pressure ratios, the drop in plant factor is more gradual than for higher pressure ratios. So, since a plant's factor is directly dependent on the amount of electricity produced, the kWh produced decreases gradually with an increase in air fuel ratio for lower pressure ratios.

The curve for a pressure ratio of 6 is above the curve for a pressure ratio of 2 for air fuel ratios between 50 and 60. Thus, between pressure ratios 2 and 6, there is the greatest rise in selling price (and thus plant factor). If you have an air fuel ratio of 60, you'll see that the plant factor for each of these curves is equal at this point.

The marginal increase between the plant factor values for a specific air fuel ratio is less for lower air fuel ratios. As the pressure ratio value rises, this discrepancy narrows. This is due to the fact that the numerator (kWh) is stabilising at greater pressure ratios while the denominator (Input Cost) is growing. There will be some reduction in plant factor as a result, although it will be small.

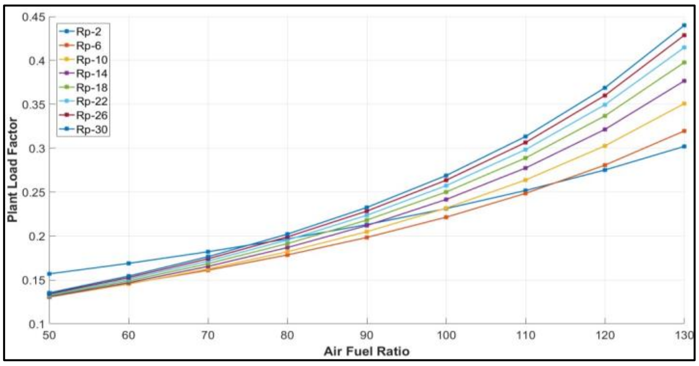

Figure 54Economic Plant Load Factor v/s Air Fuel Ratio at various Pressure Ratio

As seen in Fig. 54, the Economic Plant Load Factor (EPLF) is a function of air fuel ratio and pressure ratio. Every ten points the air fuel ratio increases by ten points. The pressure ratio may be adjusted in stages of four from 2 to 30. Rs. 6 per kilogramme of gasoline was used as a base estimate.

In general, the selling price reduces as the air fuel ratio increases, and the net work output or kWh generated declines. Fuel costs rise, but depreciation costs fall as the air fuel ratio rises, which has a negligible effect on input costs per cycle. As a result, for all pressure ratios, the plant load factor rises as the numerator rises and the denominator falls. Lower pressure ratios have a more progressive increase in plant load factor than higher pressure ratios. Examining fig. 50, we can see why this is the case. Since plant load factor changes inversely with kWh generated, a steady drop would lead to a gradual rise in the slope of the curve or in kWh for lower air fuel ratios.

The economic plant load factor for a pressure ratio of 2 is higher than that of a pressure ratio 6 for air fuel ratios of 50 to 60, as well. This is because pressure ratios between 2 and 6 show the greatest increase in selling price (and, as a result, the greatest fall in economic plant load factor value). As the air fuel ratio rises, the kWh vs. air fuel ratio curves converge for two successive pressure ratio values, resulting in the same economic plant factor.

It has been shown that with lower air fuel ratios, there is a bigger divergence between the curves (with rising pressure ratios) for a certain value of air fuel ratio. As the pressure-to-volume ratio rises, this discrepancy narrows. This is due to the fact that the denominator (kWh) is stabilising at greater pressure ratios, while the numerator (Input Cost) is rising at the same rate. In this way, a rise in the load factor of the economic plant would be quite modest.

CHAPTER 6 CONCLUSION

6.1 Conclusion

The combined cycle power plant's energy analysis and optimization were carried out. Combined cycle power plant data was retrieved from the Bawana power station in Delhi. MATLAB/Simulink model validation was done on this data and parametric investigations were conducted. It was found that the amount of additional heating had a significant impact on the performance of the top and bottom of the cycle as well as on the total cycle output. The following are the findings:

A. The results of the suggested MATLAB/Simulink model were quite close to the actual real-time plant data given.

B. The input temperature of the topping cycle's turbine grew as the gas turbine pressure ratio increased, but it fell as the degree of additional heating and the air fuel ratio increased.

C. The HRSG temperature rose with an increase in pressure ratio (Rp) and additional heating at a certain air-fuel ratio (AFR) (za). At a pressure ratio (Rp) of 20, and with a supplemental heating factor of 0, it reached its maximum value.

D. The HRSG temperature rose as the air fuel ratio decreased for specific pressure ratio and supplemental heating degree values.

E. Rises in supplemental heating (za) have little effect on the air fuel ratio at pressure ratios greater than 12; nonetheless, the rate of steam production increases as za increases.

F. The rate of exergy destruction increases as the compressor's incoming air temperature rises. Exergy destruction is accelerated when the temperature rises due to the fact that the volume of air increases, which necessitates more effort from the compressor.

G. Increases in pressure and reductions in supplemental heating and air fuel ratios improve combined cycle power plant specific work and thermal efficiency.

H. A decrease in the temperature at the turbine intake leads to an increase in exergetic efficiency as the air fuel ratio rises at a certain inlet temperature.

I. An increase in pressure results in a reduction in a given rate of exergy destruction at a lower air fuel ratio compared to an increase in this rate at a higher air fuel ratio.

J. The kWh value drops as the air fuel ratio increases at a certain pressure ratio.

K. For exergetic and thermo-economic analyses, the optimal point of operation is not the same.

6.2 Future Scope of Work

I. m gas turbines and n steam turbines may both be subjected to thermoeconomic analysis.

II. Gas turbine and steam turbine optimization can be performed.

III. Super Thermal Power Plants (STPPs) can be subjected to thermoeconomic analysis and optimization.

IV. Thermoeconomic evaluation and optimization of organic power plants are possible.

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