Improving Thermal Power Plant Efficiency

Bandi Dayasagar, Madhu Latha Nookabathina, Maddu Murali Krishna, Pilli Praveen, Akkimsetti Somaraju

Abstract*: Energy is the most important requirement for the growth and development of a nation since it is the basic necessity for every sector. The most common form of energy used is electricity. Electricity is the form of energy that is used both commercially and non-commercially. Thus, generation of electricity is the most significant requirement. Thermal electric power generation is one of the major methods for generation of electricity. But generation of electricity is it enough. It has to be done in the most effective and efficient manner. Owing to acute importance of electricity, it is important that it is done in the most efficient manner so that losses are minimized, outputs are maximized, optimum utilization of resources is done and reduction in the overall cost of the power plant can be achieved. Such outputs are even more important in the present era where sustainable development has become the most important requirement. The present research will analyze the factors affecting efficiency of a power plant. The study will further analyze the effect of operational practices & choice of fuel on efficiency of thermal power plant and the technologies available for improving the thermal power plant efficiency. The research will analyze the ways to optimize the thermal power plant through review based and theoretical analysis.

The present research will be a review based work wherein an in depth analyses of the existing literature will be done. The conceptual model thus formed from the review will then be verified through qualitative analysis using thematic analysis method. The respondents (N=8) will be acclaimed professors and research associates in the field of thermal energy. Based on the findings from the review and qualitative analysis, conclusion will be drawn and discussion will be presented wherein all the research questions will be answered. Finally, the future prospective based on the present research will be presented.

Keywords* : *Thermal power plants, Efficiency, Electricity, Optimization of Power Plants

I. INTRODUCTION

Generation of electricity is of at most importance to mankind due to the immense dependence of human race on electricity. Generation of electricity is not an easy task, and requires huge investments in terms of finances and resources at the expense of environment. Since there are so many aspects associated with the generation of electricity, it is of great importance that the process of generation of electricity is of maximum efficiency and effectiveness. Since generation of electricity is mostly contributed by thermal power plants globally, there efficiency is to be maintained and to be improved even more with changing technology and related developments.

The efficiency of a power plant states that the output of the power plant relative to the heat value of the fuel used (total electrical efficiency).

The efficiency of a power plant presents its ability to use fuel for generation of electricity. The better is the use of the fuel; the greater is the efficiency of the thermal power plant. the efficiency of a power plant can be defined as “the percentage of energy contained in the fuel that is converted into electricity. The rest is lost through conversion or in the form of exhaust heat. The greater the efficiency, the less carbon dioxide (CO2) emits per generated kilowatt-hour”. The efficiency of power plant can be improved by reducing the above stated “rest” in the definition.

Thermal power plants are known to undergo a lot of wastage. As a matter of fact, thermal power plants cannot transform all of their heat energy into electricity which then reduces their efficiency. For example, the loss of heat from gas turbine power plants with exhaust gases leads to reduction in its thermal efficiency. The loss of energy in the environment not only causes financial losses but also degrades the environment. Further, it hits hard on the sustainable development of human race. This is because the fuel which is mainly non-renewable, is not being utilized to its fullest thereby wasting the important resources. Finally the commercial aspect comes into picture that is the ever increasing demand of electricity in the world. To meet the increasing demand, with presence of limited resources at expense, all the efforts are to be made to increase the efficiency of thermal power plants.

II. PROBLEM STATEMENT

Increasing demand of energy in form of electricity, sustainable development and maintain the quality of environment are there major requirements of the changing world the human race lives in. The speed with which the human race has developed in the past few decades is commendable. Be it and sector, any industry, any sphere of life, the growth is unstoppable.

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In all this, the most basic requirement for this continued development and growth is electricity. All the achievements and developments are dependent on electricity including commercial and non- commercial. Thus, the demand of electricity is increasing with each passing day. But the resources of meet this demand that is generation of electricity is limited.

If the production of electricity is increased, then the degradation of environment will also take place with the same speed. This is due to release of poisonous green-house gasses in the environment. Finally, if the production of electricity is increased then it will contribute to over utilization of already limited non- renewable resources. Thus, steps have to be taken to improve the efficiency of existing resources that is efficiency of the thermal power plants globally

A. Significance of the Research

The aim of the research is to study and analyze the ways and methods in which the efficiency of the thermal power plants can be increased. The objectives have been defined below:

- To conduct a detailed review of factors affecting efficiency of a power plant.
- To conduct a detailed study of the methods and technologies Available for improving the thermal power plant efficiency.
- To Analyse and suggest the methods and technologies available for improving the thermal power plant efficiency

III. RELEVANT LITERATURE

The Relevant literature chapter in this sections of the study reviews and analysis the scholarly sources available on increasing the efficiency of thermal power plants. It presents an overview of concepts, key findings and developments made so far in this area. The literature review has facilitated in creating a base for the present research.

A. Factors Affecting Efficiency of a Power Plant

it was found that the maximum level of loss of energy occurs in the boiler and condenser. It was further stated that the cost of destruction of exergy is more in the turbine and boiler than in any other parts of the plant. As far as natural-gas-fired power plant is considered, the combustor comes up to be the chief source of exergy destruction. In a Combined-Cycle Power Plant, the highest destruction of exergy takes place in combustion chamber as per the findings of the study. The power plant efficiency can be increased by applying new techniques like working under supercritical conditions. This amount of saving power can be derived by operating the power plant with increased efficiency demands. The issue is that most of the materials cannot work under such high temperature and pressure. This problem can be resolved if the metallurgical scientists suggestively succeed in the development of new material that can survive greater pressures and temperatures.

the author suggested boiler, turbine and alternator to be the three chief components of a thermal power plant. Thus, the whole efficiency of a thermal power plant is dependent on the efficiencies of these three components. Energy and exergy is used to find the efficiency of components in a power plant. The study found that the turbine and boiler witness the maximum energy loss. Thus, turbine and boiler should have proper maintenance. Factors like the fuel used for combustion, age of the power plant, varying load and type of boiler lose the efficiency which is mainly an outcome of mechanical wear on variety of components. This leads to heat losses leading to reduction in efficiency. Thus, it is extremely important to periodical checks and maintenance of plant equipment. Further, it was found that the maximum efficiency of a thermal power plant is dependent on the technical difficulties under unpredictable and random conditions.

in a coal based power plant, the heating value of coal plays a role in the efficiency of the plant. The more is the heating value of the coal, the more is the amount of coal that must be burned to generate a given heat input. This increases the auxiliary electricity consumption to run coal grinding equipment, pumps, conveyors and other equipment. This decreases the efficiency of the system. Further, the study stated that maintenance and operating practices can also impact thermal efficiency.

the efficiency of thermal power plants decreases over time as components and systems degrade with age and use. Maintenance practices can slow down the loss of efficiency, but efficiency of older power plants cannot be as good as that of newer plants. This is because new plants are technologically more advanced involving minimal or no wear and tear. But old power plants cannot be simply replaced with newer plants since neither it is cost effective nor it is sustainable and resourceful. Thermal power plants which emit less CO_2 per unit of electricity produced are more efficient. This is because these use less fuel. Thus, use of fuel and emission of greenhouse gasses impact the efficiency of a thermal power plant to a great extent. The study summarized .that the major improvements in efficiency would require reduction in emission in GHG. This can be achieved by major retrofits in technology, or adoption of more efficient fuel like natural gas or biomass as a fuel.

B. Effect of Operational Practices on Efficiency of Thermal Power Plant

The aim of the study was to conduct an audit analysis of the efficiency of the 210MW coal-based power plant. It was found that the plant has a capacity of producing 210 MW of electricity every day but in reality it was producing around 170 MW to 180 MW of electricity only. This means that it was under producing and was not being used to its full potential. The distribution of losses of exergy (energy available to be used) in the parts of the power plant was assessed. The maximum power loss of 49.92% was found to take place in the condenser when the comparison between the energy losses and the exergy losses of the plant's individual parts was conducted. Further, it was found that the maximum exergy loss of 68.27% was happening in the boiler. The analyses were also carried out one by one by inactivating the heater. The researchers suggested that the exergy valuation can be resourceful in defining ways to enhance the efficiency of current plant design and other plant activities while energy equilibrium transfers heat between the device and its environment. The study further

stated that exergy-based *operating and* maintenance options present to be more efficient in improving efficiencies in working power plants. the efficiency of electricity generating cycle can be increased by any of the three ways that is by increasing the pressure of the boiler, by decreasing the pressure of the condenser or by increasing the input steam temperature. Apart from increasing the efficiency of steam cycle, other options to increase the efficiency of thermal plant are also available. There is a combined cycle power plant which reprocesses the gas turbine's waste heat. Then there is a cogeneration power plant wherein energy of the fuel is sequentially converted into two or more useable forms. These changes in thermal power plants increase the efficiency of thermal power plants. There are natural gas power plants as well. Further, there are other methods like recovery of heat from economizer, improving the air-fuel excess ratio, combustion air preheating, using combination of fuels and air.
In a project performance assessment report on Thermal Power Efficiency focused on improving efficiency of thermal power plants and reducing greenhouse gases. For this project, three provinces of China were selected namely Shandong, Shanxi and Guangdong. The China Thermal Power Efficiency project required to decrease coal utilization and greenhouse gas emissions per unit of electricity in three Areas in China namely Shanxi, Shandong and Guangdong. These were selected on the basis of their present dependence on coal fired power along with their demographic and economic importance. The main aim of the project was to find ways of improve thermal existing power plants. The increasing demand of power in China has been relied heavily on domestic coal production. Owing to this, the country is witnessing rapid expansion of local thermal power generation plants using coal as fuel which is causing adverse environmental impacts.
In the figure below, the theory of change has been presented which was adopted in the project. It presents as to how small improvements in technology in the thermal power sector in China could have substantial economic and environmental benefits.

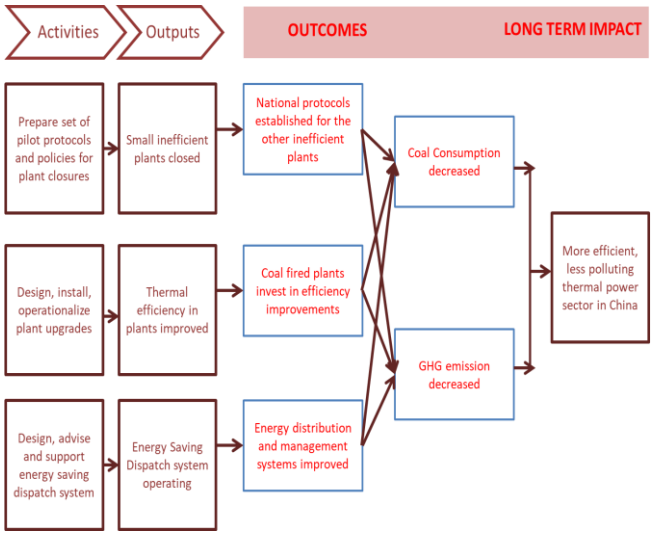

Fig.1 The theory of Change Adopted by China with Support of World Bank

The result of this project proved to be a success. The improvements made in the three target thermal power plants reduced the emission of GHG and increased the efficiency of power plants along with cost savings in coal consumption. The improvements included implementation of rehabilitation of integrated plant efficiency, peak cooling technologies, recovery of waste heat, and CHP conversions. In Shanxi, the improvements made involved capital improvements to rotor calibrations, frequency convertors, updates to pumps, fans and condensers and boiler insulation adjustments.
recovering the lost heat thereby increasing on-site power generation capacity and efficiency in gas turbines. In this study, the researchers' used R245fa Rankine cycle to recover waste heat from gas turbine power plant. The study found that an additional 5.2MW that is 23% extra of net power can be generated. increasing efficiency of gas turbines power plants with cooled air intake, it was found that it led to an average increase of 12.25% in the plant power output power. Herein the intake temperature of compressor was reduced by using external cooling system. The system was applied to GT power plant, As an outcome of the newly integrated system, it was found that efficiency of power plant was increased by 6%. This led to a savings of 1.3 million metric standard cubic feet per day (MMSCFD) of natural gas. Further, 457 tons of CO2 emissions was avoided per year. Apart from the several studies conducted on ways to increase efficiency of thermal power plants, there are certain ISO standards as well that suggest on methodologies to increase the efficiency. The figure below presents a process for iterative improvements.

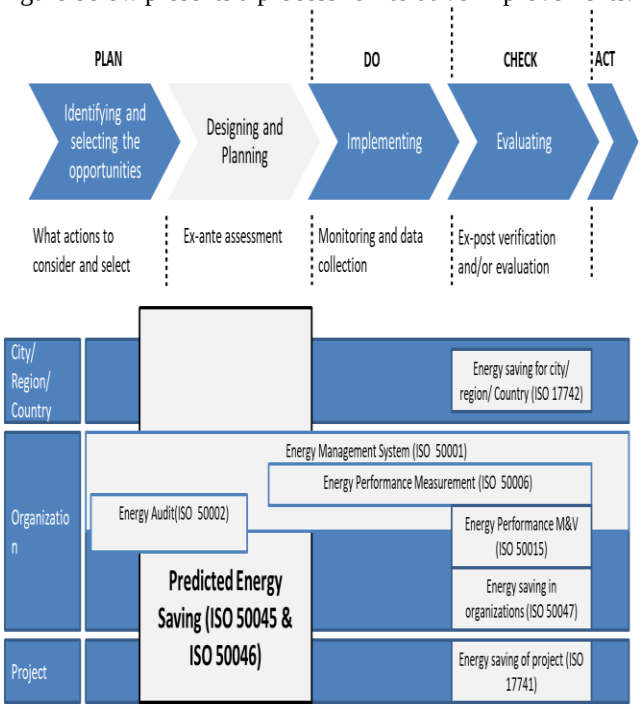

Fig.2 General Process for Iterative Improvements

C. Optimization of Thermal Power Plant-Technologies Available for Improving Efficiency

to improve the efficiency of power plant, efficiency of the Rankine cycle has to be improved. The efficiency of the Rankine cycle can be improved by optimizing the pressure at the boiler, steam temperature and the pressure at the turbine outlet. The temperature at which boiling takes place is increased by increasing the main steam pressure at the boiler which raises the heat added to the steam. This increases the efficiency of the system but with a flaw that is it increases the wet steam at the turbine outlet. This leads to the corrosion of turbine blade which then reduces the efficiency of the system. A solution to this decreasing efficiency can be compensated via using a reheat cycle. The reheat cycle stops the wet steam formation at the high-pressure turbine outlet. The larger second turbine in the reheat cycle decreases the harm caused by moisture to the blades and has a lower pressured output thereby increasing the efficiencies of the system. The other way to increase efficiency of thermal power plant is raising the heat of the boiler's steam input. As the temperature of the feed water is raised, the amount of heat input required of the boiler is reduced. A feed water heater is used to heat the wet steam leaving the feed water and the extraction steam. This system is called the regeneration cycle. The regeneration cycle consists of many high and low-pressure feed water heaters along with a deaerator for heating and removing air. The efficiency of the cycle is enhanced by increasing the number of feed water heaters. The use of a reheat cycle provides the benefit of evading corrosion and frictional losses in the turbine and the regeneration cycle increases the thermal efficiency. Therefore, combining these two cycles in form of a regenerative reheat cycle can improve the efficiency as well as facility operation.

understanding the influence of heat recovery of blow down of the boiler on the total efficiency of Rankine cycle of power plant. Herein the energy and exergy investigation of boiler blow down heat recovery was conducted. A steam power plant in Iran was selected for the research. For conducting the research and increase the plant efficiency, two optimization algorithms were used namely genetic algorithm and particle swarm optimization algorithm. The decision variables used in the study were pressure and temperature of boiler outlet stream and extraction pressure from steam turbine. The results found that using blow down recovery technique, 0.72% increase in the net generated power was observed. Also energy efficiency of the system increase by 0.23 and that of exergy increased by 0.22. The outlet steam of boiler temperature and pressure is presented a higher impact on the exergy efficiency of the system in respect to the other decision variables. In this paper, a flash tank was used to recover the wasted energy from blow down water. It was found that the flash tank enhanced the net power by 0.72%. Further, as a resultant of using flash tank, the energy efficiency of the system increased from 31.68% to 31.91% while saving 25444.47 cubic meters water per year. In terms of exergy efficiency, a 0.72% increase was achieved.

A research was conducted to improve the utilization neural network based optimization strategies to improve the efficiency of boiler in coal fired power plant. The researcher concentrated on removing combustion related problems such as slagging to enhance the use of neural network based optimization strategies. Slagging can decrease the boiler efficiency and can have extreme impacts on heat transfer rate. Further, slag build-up is difficult to measure. Consequently, the research presented a method of integrating non-dominated sorting genetic algorithm (NSGA II) based multi-objective optimization with computational fluid dynamics (CFD) to reduce or even avoid slagging inside a coal fired boiler furnace. Such approach facilitates in improving boiler combustion efficiency thereby increasing the efficiency of the power plant. The suggested process optimizes and controls the fields of flue gas properties like velocity of primary and secondary air and temperature field inside a boiler by adjusting the temperature in a coal fired power plant boiler control systems. a research to calculate the power loss of a steam turbine in a cogeneration power plant which was easily applicable in industrial practice. The research was done in a 10 megawatts combined cycle gas turbine power plant. The calculation process suggested by author does not require any special additional measurements and are applicable in real industrial conditions. ways to reduce the power plants start-up power by optimization of auxiliary power consumption. The author suggested that in thermal power plants, different auxiliaries like pumps and compressors, consume a part of energy generated by the thermal power plant. This consumption is very high. The reason for this condition can be attributed to aspects in the power plant like bad design of the equipment or poor operation. Thus,

the researcher in the study tried to improve the efficiency of these auxiliaries. To improve the performance of the pumps, researcher suggested methods like de-staging, impeller trimming, and installation of variable frequency drives. For improving the efficiency of compressor, the researcher suggested to select the receiver or the storage tank of appropriate size which can fit even in the times of high demand so that the pressure drop below the minimum required pressure can be avoided. The drop in the pressure causes the tools in an improper way which then decreases the efficiency of the system. Also, the energy which is then required to increase the pressure to the appropriate point can be saved and used in generation of power. Further, the layout and design of the air delivery system should be a straight path thereby avoiding looping and sharp bends. This is because looping and sharp bends reduce the pressure thereby reducing the efficiency of the system. The author suggested using series of multiple small compressors instead of a single big compressor. This increases the efficiency. Also, whenever not required, some of the smaller compressors can be turned off thereby saving energy. The author further suggested undergoing regular repair of the leaks (even the smallest ones) so that the air is not lost and pressure in the compressor is maintained.

The effect of Heat Recovery Steam Generator (HRSG) pressure levels on exergy efficiency of combined cycle power plants. The researcher acquired the change in the heat recovery steam generator at different pressure levels. Two

pressure levels and three pressure levels in the same generator were studied. The researcher concurrently calculated and compared the exergy of both pressure levels. Therefore, three types of gas turbine combined cycles, by means of the same gas turbine as a topping cycle are estimated. The results presented that the heat transfer causing exergy destruction and the stack gas exergy decrease as the number of pressure levels of steam generation increases. Also, the increases the heat recovery from the flue gas as a resultant of the increase of pressure levels of steam generation in HRSG leads to increase in the energetic efficiency of the cycle. The study found that as the number of pressure levels of steam generation in HRSG increases, the exergy destruction rate of the cycle decreases. The economic analysis found that increasing the number of pressure levels of steam generation increases specific investment cost and the total investment cost of the plant by almost 4% and 6% respectively. It also leads to the increase in the net present value of the plant by 7% for triple pressure reheat when compared with the double pressure. Thus the study stated that economically it is justifiable in HRSG to increase the number of pressure levels of steam generation.

Many researchers have conducted researches to optimize the numerous parameters in heat recovery steam generator to increase efficiency of combined cycle power plants

Based on the literature review conducted, following conceptual framework has been designed.

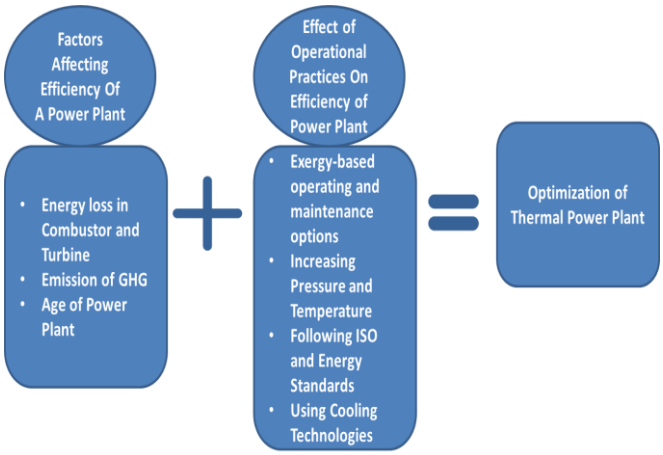

Fig.3 Conceptual Framework

It can be inferred from the literature review that in this age of increasing demand of power in form of electricity, it is very important to increase the efficiency of the thermal power plants. The study recognized many factors that impact the efficiency of thermal power plant. Also there are many operational practices that impact the efficiency. Thus, the framework derived from the literature review in the present study suggests that if the factors the effect the efficiency of a thermal power plant and the operational activities impacting the efficiency are combined, the optimization of the thermal power plant can be conducted which will ultimately lead to increased efficiency of thermal power plants.

IV. RESEARCH METHODOLOGY

Out of three basic types of research methods that is Exploratory, Descriptive and Explanatory, the present research is of exploratory type. The present research is based on wide exploration of the view on the ways to increase efficiency of a thermal power plant. Thus exploratory study is the most appropriate method as it allows the research to be versatile and flexible and does not bounds it to quantitative aspects.

Deductive and Inductive are the two approaches that are used in a research. Inductive approach focuses on the research questions to narrow down the research and provides a generalized conclusion while starting from a relatively specific start whereas deductive approach deduces the conclusion from a relatively generalized principles. In the present research, inductive approach has been adopted. This is because the researcher wanted to present generalized conclusion involving ways and methods to improve the efficiency of a power plant rather than concentrating of some deduction and focusing on a single outcome. Out of all the research strategies available, interview strategy has been adopted in the preset research.

A. Sampling Size and Design

In the present research, a sample size of 6 respondents was selected who were then interviewed. Further, out of the two types of sampling methods i.e. Probability and Non-Probability sampling,

Table 1 : Demographic Profile of the Respondent

Name	Age	Job Title	Experience in present position	Tenure in power industry
Respondent A	55 Years	Chief Manager- Operations and Management	2 Years	28 Years

Respondent B	56 Years	Senior Manager	3 Years	25 Years
Respondent C	59 Years	Chief Project Manager	4 Years	31 Years
Respondent D	51Years	Senior Manager	3.5 Years	23 Years
Respondent E	49 Years	Senior Manager	2 Years	23 Years
Respondent F	48 Years	Manager- Operations	4 Years	19 Years

non-probability sampling has been used in this research. In Non-Probability sampling, every component in the population does not get equal opportunity to get selected. Further the purposive sampling method has been used. Purposive sampling is a method wherein respondents are selected from the population by the researcher on purpose. This is done to focus on the part of the population that is of most use to the research. The present research has purposefully selected the operations manager of different thermal power plants.

B. Measuring Instrument

The measuring instrument is the questionnaire that is used to collect the data. In a questionnaire, the data is collected from the respondents in a pre-defined manner The measuring instrument used in the present study is a Qualitative Questionnaire. The questionnaire has been designed in such a way that the most appropriate data is collected and all research questions are covered so as to meet the end goal of the research. The questionnaire was divided into 2 parts, Demographic Profile of respondents (Section A) and Efficiency of the thermal power plant (Section B).

The demographic profile of the respondents is as follows-

C. Data Analysis Procedures

For the analysis of the transcripts, thematic analysis was conducted. Herein the transcripts were studied and the themes were identified from them. Following process was followed-

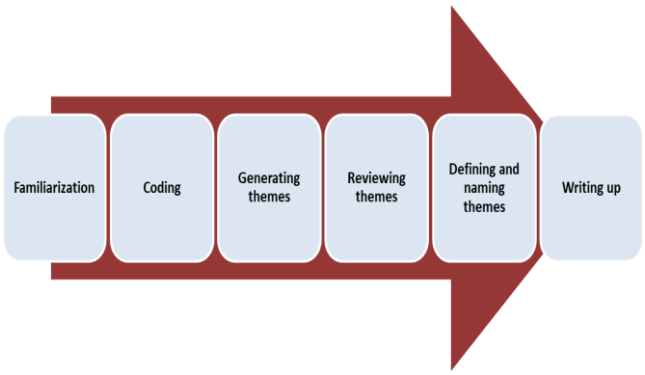

Fig.4 Steps of Thematic Analysis

V. QUALITATIVE ANALYSIS

This chapter presents the qualitative analysis conducted in the present research. qualitative analysis was done through the interview method wherein primary interviews were conducted with six operational managers working in different power plants in Asia. In this chapter, firstly socio-demographic distribution of the respondents has been presented followed by thematic analysis and finally discussion has been presented.

A. Factors that impact the efficiency in Thermal Power Plants

Increasing efficiency of a thermal power plant is the most important aspect to deal with in the power industry in the present time. But before trying to increase the efficiency, it is important to understand as to what are the factors that actually impact the efficiency or are responsible for reducing the efficiency of a thermal power plant. Responding to this question, Respondent B stated that "Type of boiler, varying load, power plant age are some factors that tend to lose efficiency with time. Thus, it is important to maintain these in order to maintain and/ or increase the efficiency. Further, Most of the loss in efficiency due to mechanical wears on variety of components, resulting heat losses. Therefore, it is necessary to check all the equipment periodically". As a matter of fact, with time, all the mechanical aspects are prone to wear and tear. As the time passes, the mechanical components deteriorate and can lead to decreased efficiency. Discussing on the same aspect, Respondent D explained "Every power plant losses their efficiency due to its continuous operation, age and many other reasons. After years of operation, a plant will no longer be operating at best practice levels leading to decreasing efficiency. decreasing in efficiency causes an growth in the carbon dioxide emission. Thus, increase in carbon di oxide emission also leads to decrease in efficiency of power plant".

Aging power plant undergoing wear and tear thereby causing reduction in efficiency has been studied by wear and tear with age of plant leads to heat losses leading to reduction in efficiency. Thus, it is extremely important to conduct checks and maintenance of plant equipment in continuous manner. Carbon dioxide is a culprit in reduction of efficiency because the basic concept of conversion of electricity from fuel takes place when energy in the fuel is converted into electricity and rest is lost in form of releases. This release consists of CO_2 primarily. Thus, if CO_2 emission is reduced it will mean that more energy in the fuel will be converted into electricity leading to increase in the efficiency of the thermal power plant. This aspect of reduction of CO_2 emission to increase efficiency of power plants is a major area of research. review on the ways to decrease the emission of CO_2 from thermal power plants has been done which states that CO_2 reduces the efficiency of thermal power plants while degrading the quality of environment.

B. Equipment or parts in power plant that majorly impact the efficiency

Not only operational and technical aspects, but mechanical aspects of power plant system also impact thermal power plant efficiency system. This is because a thermal power

plant is made up of many equipment and run on many cycles which then impact the efficiency as well. Discussing about the equipment and their impact on efficiency, Respondent E stated that "Turbines go through energy losses due to factors like main steam pressure, main steam temperature, and reheating steam temperature and exhaust pressure". Losses in the turbine can be attributed to quality of the steam and pressure. Thus measure to improve the quality and maintaining the pressure in turbine should be applied to increase the efficiency of the thermal power plant. On discussing further on the equipment, Respondent F explained "Thermal power plant runs on the Rankine power cycle which works on some major components namely Boiler, Expander, Condenser, turbine and pumps. These components tend to lose heat which then reduces the efficiency of the system. If a power plant is able to minimize these losses then ultimately the efficiency will increase". Both boiler and condenser play a very important part in operations of power plants. While condenser acts as a heat sink, boiler acts as a heat source. It is important to operate condenser at optimum variables in order to achieve maximum efficiency in form of output and while providing minimum input to the plant. The operating conditions of condenser have huge impact on the heat rate value and maximum generated power. the heat rejection through the condenser are mostly responsible for heat losses in thermal power plant. Respondent F further stated that "In boiler, efficiency has a great influence on heating related energy savings. It is Consequently important to maximize the heat transfer to the water and minimize the heat losses in the boiler. Firstly, it is necessary to identify where energy wastage is likely to occur." Thus, it is important to optimize the operation of a boiler in a thermal power plant. A huge amount of energy is lost through flue gases. This is because all the burning fuel produces heat which cannot be completely transferred to steam or water in the boiler. Thus, the heat not transferred is lost in form of wastage. the maximum loss of the heat from the boiler takes place as heat in the waste gas released in the atmosphere which if recovered can lead to huge energy savings potentially increasing the efficiency of the thermal power plant.

C. Major practices to improve the efficiency of Thermal Power plant from operational point of view

Operational changes done in a thermal power plant can also increase the efficiency. On being asked about different operational changes to be conducted in a thermal power plant to increase the efficiency, Respondent A suggested "The supercritical/ultra-supercritical plant is now great importance because operating the plant at higher temperature and pressure can increase its efficiency, potentially lowering the amount of fossil fuel consumed and the emissions generated". Super critical power plants are known for increasing the efficiency of the power plant since in such plants the water becomes a supercritical liquid due to exposer to very high temperature and pressure. Thus, the energy required to convert water into steam is reduced there by increasing the efficiency of electricity production. This then requires lesser fuel owing to lesser emission of CO_2. Respondent A further stated that "The larger the temperature difference over which a thermal power plant operates, the more efficient it can be. Steam power plants use pressurized, superheated steam generators to Enhancement the temperature and pressure of the steam to improve efficiency. After the steam exits the turbine and is condensed back to water, it is passed through a series of heat exchangers to bring out the last drop of residual heat energy". When plant operates at high temperature and pressure its efficiency increases. Further, loses of heat and pressure are also to be maintained. This is because when the loss or leakage of temperature and pressure takes place, the system moves away from the optimum conditions of operations. In order to achieve those optimum conditions of required temperature and pressure, the system uses more energy there by reducing the efficiency of the entire system. the efficiency of electricity generating cycle can be increased by any of the three ways that is by increasing the pressure of the boiler, by decreasing the pressure of the condenser or by increasing the input steam temperature. On discussing other operational aspects, Respondent C stated that "All high energy lines should be properly insulated to decrease the heat loss. There should be no leakages in high energy lines. Leakage in condenser should be checked on frequent interval as it will decrease the vacuum. The leaked out steam does not contribute to the power generation and is wasted thus decreasing the overall efficiency. Hence, leakage must be reduced which can be done by continuous real time monitoring of boiler, pipes, heat exchanger and other similar aspects using advanced software and computation technologies.

Moreover, the seals of boiler, pipes must be inspected frequently". Many a times, small leaks develop in the pipes in the boiler or condenser which provide the passage to the heat to escape. This reduces the efficiency of the power plant. This leakage can be created as an output of internal or external corrosion due to high temperature and high pressure steam or the high steam flow rate. Long term heating of the tubes or pipes that is above the permissible level also creates leaks. suggested data driven method of leak detection in boilers in form of a fault diagnosis algorithm.

D. Technologies to be used to optimize the Thermal Power Plants to increase efficiency

Over huge research that are being conducted to optimise the operations and performance of the thermal power plants, the respondents were asked to suggest the technologies that can improve the efficiency of the thermal power plant. Respondent C suggested use of data driven technology to maintain and improve the efficiency of power plant. Respondent C stated that "Operational data analysis may be conducted by either by offline analysis, which grabs past operational data for a given period in bulk to analyse and extract points that will help improve thermal efficiency and online analysis, which uses real-time operational data of the unit in production to conduct analyses and implement operational changes as required to improve thermal efficiency". With increase in the use of digital computation and data dependence, increasingly sophisticated operation of thermal power plants are being driven by technologies like big data cloud computing and other such new age technologies. Big names like General Electric

(GE) have already started to collect and combine vast amounts of data of thermal power plants by sophisticated technologies like cloud-based services with intelligent analytics. suggested data driven method of leak detection in boilers in form of a fault diagnosis algorithm. Respondent F continued the discussion and stated that "An exergy analysis should be conducted to better understand the components which produce maximum irreversibility and optimization of such components should be taken up first". the effect of Heat Recovery Steam Generator (HRSG) pressure levels on exergy efficiency of combined cycle power plants. The researcher acquired the change in the heat recovery steam generator at different pressure levels. Two pressure levels and three pressure levels in the same generator were studied. The researcher concurrently calculated and compared the exergy of both pressure levels. The results presented that the heat transfer causing exergy destruction and the stack gas exergy decrease as the number of pressure levels of steam generation increases.

VI. RESULTS AND DISCUSSIONS

The qualitative analysis was conducted in the present study to understand the practical aspects of increasing the efficiency of the thermal power plants. The analysis of the transcripts collected while interviewing the respondent found various ways and methods via which the efficiency of a thermal power plant can be increased. On analysing the factors that impact the efficiency of the power plant, it was found that all the mechanical aspects are prone to wear and tear. As the time passes, the mechanical components deteriorate and can lead to decreased efficiency. The study stated that wear and tear with age of plant leads to heat losses leading to reduction in efficiency. Thus, it is extremely important to conduct checks and maintenance of plant equipment in continuous manner. Finally, if CO2 emission is reduced it will mean that more energy in the fuel will be converted into electricity leading to increase in the efficiency of the thermal power plant. On analyzing the equipment or parts in power plant that majorly impact the efficiency, it was found that losses of energy take place in turbines, boiler and condenser. Operational changes done in a thermal power plant can also increase the efficiency. Super critical power plants are known for increasing the efficiency of the power plant. When the loss or leakage of heat takes place in form of temperature and/ or pressure, the system moves away from the optimum conditions of operations. In order to achieve those optimum conditions of required temperature and pressure, the system uses more energy there by reducing the efficiency of the entire system. Many a times, small leaks develop in the pipes in the boiler or condenser which provide the passage to the heat to escape. Thus, it becomes important to keep a check on the leaks being developed. This can be done by adoption of data driven method of leak detection. Finally, as far as technologies to be used to optimize the thermal power plants to increase efficiency are concerned, sophisticated operation of thermal power plants are being driven by technologies like big data cloud computing and other such new age technologies. Such technologies rely on the data to be collected in the real-time basis. Such technologies are capable to detecting the faults, if any, on real time basis thereby facilitating in increasing and maintaining the efficiency of thermal power plant. The figure below presents a pictorial representation of an improvement loop involving real time monitoring of operational data.

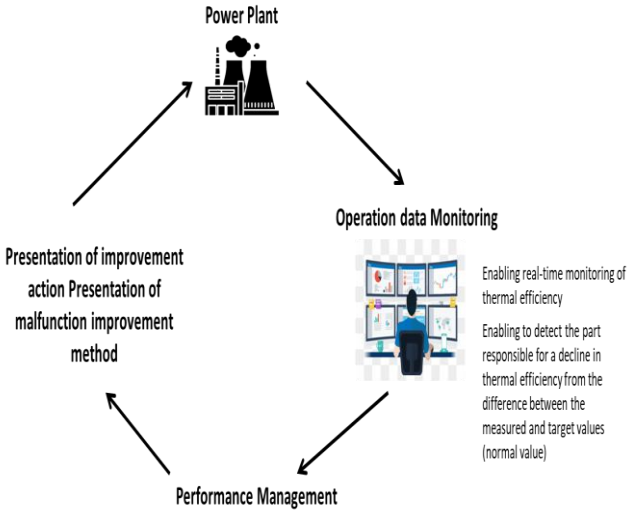

Fig.5 Improvement loop involving real time monitoring of operational data

Also, exergy analysis can be used to highlight and find the components that generate highest irreversibility and optimization of such components should be done in the earliest possible time to avoid loss of efficiencies any further. Based on the above discussion, following approach have been found to maintain and /or improve thermal efficiency of a power plant.

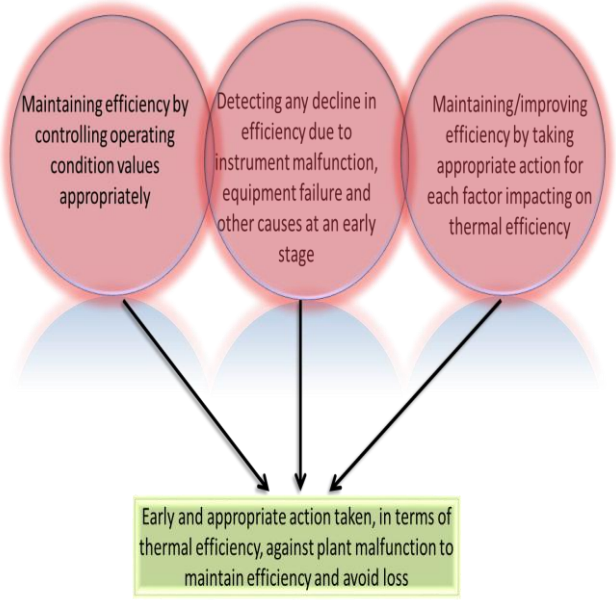

Fig.6 Maintenance Approach to increase efficiency of Thermal power plant

VII. CONCLUSION

A. What are the factors affecting efficiency of a power plant?

The researcher underwent a huge analysis of the available literature on factors affecting efficiency of thermal power plant and it was found that the maximum level of loss of energy occurs in the boiler and condenser. Combustor comes up to be the chief source of exergy destruction that is the highest destruction of exergy takes place in combustion chamber. Further, it was found that turbine and boiler also witness a huge energy loss. . Factors like the fuel used for combustion, age of the power plant, varying load and type of boiler lose the efficiency which is mainly an outcome of mechanical wear on variety of components. Also, the heating value of coal plays a role in the efficiency of the plant. The more is the heating value of the coal, the more is the amount of coal that must be burned to generate a given heat input. Finally, Thermal power plants which emit less CO2 per unit of electricity produced are more efficient. This is because these use less fuel. The results of the primary analysis found that all the mechanical aspects are prone to wear and tear. As the time passes, the mechanical components deteriorate and can lead to decreased efficiency. Finally, if CO2 emission is reduced it will mean that more energy in the fuel will be converted into electricity leading to increase in the efficiency of the thermal power plant. the ways to decrease the emission of CO2 from thermal power plants has been done which states that CO2 reduces the efficiency of thermal power plants while degrading the quality of environment.

B. What are the methods and technologies available for improving the thermal power plant efficiency

Thermal plant efficiency can be improved by making some operational changes and use of new emerging technologies. Some of these methods were explored in this research. Exergy valuation can be resourceful in defining ways to enhance the efficiency of current plant design and other plant activities while energy equilibrium transfers heat between the device and its environment. Exergy-based operating and maintenance options present to be more efficient in improving efficiencies in working power plants. The operational aspects that can further enhance the efficiency of a power plant are by increasing the pressure of the boiler, by decreasing the pressure of the condenser or by increasing the input steam temperature. Some other operational factors include recovery of heat from economizer, improving the air-fuel excess ratio, combustion air preheating, using combination of fuels and air. As a matter of fact, economizer are machines that make the system more efficient facilitating in saving and recovering energy from input fuel. Further, implementation of rehabilitation of integrated plant efficiency, peak cooling technologies, recovery of waste heat, and CHP conversions are some other operational techniques that are helpful in improving the operational efficiency. These techniques have already been applied in the coal powered power plants in China. While talking about the operational aspects leading to increased efficiency, one of the most common and important aspect is maintenance of the plant. It is important that the power plant undergoes regular checkups and updates. This is because; power plants are constantly in exposer to the steam and heat at high temperature and pressure. There in continuous wear and tear leading to leaks causing energy losses. Thus, it becomes important to have frequent maintenance sessions so that equipment can be maintained and replaced as per requirement. Finally, improvements in the most basic aspect of power plant that is Rankine cycle can do wonders. Rankine cycle is the operational cycle used in the power plant to generate electricity. recovering the lost heat thereby increasing on-site power generation capacity and efficiency in gas turbines. In this study, the researchers' used R245fa Rankine cycle to recover waste heat from gas turbine power plant.

C. Are the methods and technologies Available for improving the efficiency of thermal power plant impact the optimization of the thermal power plant

The present study found that if the factors that impact the efficiency of the thermal power plant are identified and are exposed to the improved operational practices then it can lead to optimization of the thermal power plant. If the efficiency of Rankine cycle in increased then the overall efficiency of the thermal power plant can be enhanced. The efficiency of the Rankine cycle can be improved by optimizing the pressure at the boiler, steam temperature and the pressure at the turbine outlet.

This can be achieved by introduction of reheat cycle. in the reheat cycle decreases the harm caused by moisture to the blades and has a lower pressured output thereby increasing the efficiencies of the system. Further, regeneration cycle can also be introduced to achieve the state of increased efficiency. Finally, a regenerative reheat cycle (combination of reheat cycle and regeneration cycle) can improve the efficiency as well as facility operation. Apart from this latest computer based technologies like neural network based optimization strategies can be used to improve the efficiency of boiler in coal fired power plant. Then primary analysis conducted in the study also suggested that Finally, as far as technologies to be used to optimize the thermal power plants to increase efficiency are concerned, sophisticated operation of thermal power plants are being driven by technologies like big data cloud computing and other such new age technologies. Many other operational aspects can be used to improve the optimization which is very basic yet impactful like selection of the receiver or the storage tank of appropriate size which can fit even in the times of high demand so that the pressure drop below the minimum required pressure can be avoided. the layout and design of the air delivery system should be a straight path thereby avoiding looping and sharp bends. This is because looping and sharp bends reduce the pressure thereby reducing the efficiency of the system. The author suggested using series of multiple small compressors instead of a single big compressor. This increases the efficiency. Also, exergy analysis can be used to highlight and find the components that generate highest irreversibility and optimization of such components should be done in the earliest possible time to avoid loss of efficiencies any further as per the primary analysis conducted in the present study. the effect of Heat Recovery Steam Generator (HRSG) pressure

levels on exergy efficiency of combined cycle power plants and supported the findings of the present research.

VIII. LIMITATIONS AND FUTURE SCOPE OF STUDY

One of the major limitations present in the present research is that for the primary analysis, the number of people interviewed was comparatively small. Another limitation is that the study took into consideration the perception of the managerial level respondents. The insights from the ground level staff can shed even more light on the factors that are responsible for decreasing efficiency or the aspects that can lead to increased efficiency.

Future scope of this research can involve real time data before and after the changes done in the operational practices suggested I the present research. That would give an insight on the ground level struggles and practicality of the suggestions. Quantitative techniques can be involves to get results that are accurate and quantifiable.

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