Chapter 1

INTRODUCTION

1.1 Current Power Generation Scenario

Historically major advances in human civilization have been accompanied by an increase in the rate of energy consumption. An unprecedented increase in the level of economic activity has strongly correlated with the increased energy usage. Over the past several years, revolutionary and wide-spread changes have occurred globally within the power generation industry. Deregulation, linked with declining reserve margins, imposition of stringent environmental regulations and climatic temperature extremes have resulted in new economic plant operation considerations for both the operators of existing power plants and for the developers of new power plants. Increase in summer peak period power demands, the duration of the peak period and the ever-increasing peak energy rates (Rs/kWh) have forced the owners and operators of existing power plants and developers of Combined Cycle Power Plants (CCPP) to seek new power enhancing alternatives for optimizing plant performance and for increasing the revenue.

Gas turbines typically lose performance and efficiency as ambient temperatures increase because warm air is less dense than cooler air. This makes less air mass flow per unit volume available through the turbine system. Denser inlet air allows a gas turbine to achieve higher mass flow rate, resulting in increased efficiency and power output, meaning - added revenue at lower cost. Also, improved efficiency leads to lower CO₂ emissions. The problem of higher ambient conditions can be tackled by implementing a suitable turbine inlet air cooling system in the plant.
1.2. Motivation for the Thesis

As stated earlier, the marketplace for electric power has become highly dynamic and competitive in nature in the backdrop of deregulation of power generation, declining fuel reserve margins, environmental regulations, climatic temperature extremes and the introduction of Availability Based Tariff (ABT). In such an environment, having the flexibility to augment gas turbine power output during periods when there is high tariff rates is of paramount importance to the profitability of the utilities. Efficient, clean and less expensive to implement than most other alternatives, combined cycle power plants offer a blend of operational attributes that makes it the best choice for power production. The output and efficiency of a CCPP decrease with an increase in the ambient temperature. Combustion gas turbines are constant volume engines whose power output is proportional to the combustion air mass flow. Thus there is a strong influence of the ambient temperature on gas turbine and combined cycle performance. It is estimated that, for a gas turbine, the produced power output drops from approximately 0.54% to 0.90% for every 1°C of ambient air temperature rise [52]. Also there is a corresponding loss in efficiency. Figure 1.1 shows the percentage variation in power output and heat rate with respect to the change in ambient temperature. Especially in tropic climatic conditions of India with extreme variations, it becomes mandatory to implement various power augmentation and efficiency improvement techniques to meet these challenges. Considering these challenges, the thesis develops a simulation model for the detailed analysis of various turbine inlet cooling technologies for a typical combined cycle power plant. A 350 MW unit operated by the Rajiv Gandhi Combined Cycle Power Plant of National Thermal Power Corporation (RGCCP-NTPC), India was selected for the case study and analysis. Environmental and economic analyses related to these technologies were carried out to study the feasibility of implementation.
1.3 Objectives of the Thesis and Methodology

In the light of the facts presented earlier, the objectives of the thesis are stated below. A brief methodology of how the objectives are achieved is also given.

a) Modeling of the dual pressure CCPP and the validation of the model using a 350 MW unit operated by RGCCP-NTPC, India

- An in-depth literature review has been carried out for getting acquainted with the latest developments in the field.

- A simulation model of the plant has been developed and validated with an existing plant in operation.

b) Detailed investigation on the implementation of various turbine inlet cooling methods in the plant.
Five methods have been analyzed and investigated.

The simulation model has been extended to analyze the various TIC methods.

c) Environmental Analysis of the various suggested methods carried out, giving importance to the most harmful pollutants, CO$_2$ and NO$_x$.

d) The optimization of the plant effectiveness with environmental constraints has been carried out.

e) Economic analysis of the implementation of various TIC methods has been conducted for assessing their viability of implementation.

1.4 Scope of the Thesis

The scope of the thesis is limited to the following:

- The analysis has been carried out on an existing power plant with dual-pressure system.

- Of the various available TIC methods, only five prominent methods have been selected for investigation within the available climatic and technical restrictions.

- The environmental analysis is concentrated only on the major harmful pollutants, namely, CO$_2$ and NO$_x$
• The economic analysis has been carried out with the various parameters and factors relating to the Indian conditions only.

1.5 Contributions of the Thesis

Following are the major contributions achieved based on the research undertaken:

• A thorough literature review of the power generation by combined cycle power plants and the various turbine inlet cooling methods have been undertaken.

• A simulation model for the analysis of the plant under study with and without a turbine inlet air cooling system has been prepared and parametric study carried out for the assessment of the effectiveness of various TIC methods.

• An environmental analysis on the effect of pollutants has been carried out keeping in mind the present legal regulations and the effectiveness of turbine inlet air cooling methods. The study optimizes the output/efficiency within the mentioned restrictions.

• An economic analysis evaluates the various TIC methods to assess the viability of implementing the technique in the plant under study.

1.6 Organization of the Thesis

The thesis is organized in seven chapters. The contents of each chapter are presented below in brief:

Chapter 2 gives a detailed literature review. It comprehends the latest developments in the field of combined cycle plants and its importance in the power generation scenario.
The reasons for degradation in output and efficiency with increase in ambient temperature are discussed. Various research studies conducted in the field of power and efficiency enhancement techniques are covered in full depth. The real data of turbine inlet cooling methods at certain prominent installation sites are presented and discussed at the end of this chapter.

Chapter 3 lists out and describes the current technologies available in the field of turbine inlet cooling methods. The chapter covers the following turbine inlet cooling and power enhancement techniques.

1. Evaporative Cooling-Media Based
2. Evaporative Cooling-Fogging System
3. Over Spray Fogging
4. Evaporative Cooling of Pre-Compressed Air
5. Refrigeration Cooling- Mechanical Chiller
6. Refrigeration Cooling- Absorption Chiller
7. Thermal Energy Storage(TES) Systems
8. Swirl Flash System (Patented)
9. LNG Evaporation System
10. Indirect Evaporative Cooling (Patented)

Chapter 4, presents an overview of the major environmental issues and concerns associated with modern technology, in particular, the power generation field.

In Chapter 5, the detailed theory and procedure for arriving at a simulation program to analyze the combined cycle power plant is discussed. The complicated design of the combined cycle power plant with many components is modeled using interconnected successive information flow diagrams. The developed model is validated with that of the installed plant.

Chapter 6 covers the results of the in-depth analysis carried out on the developed model. The performance improvement is analyzed for various inlet cooling techniques. The results of the environmental and economic analysis are also presented here. An attempt
has been made to optimize the energy system by quantifying and introducing environmental aspects into the model.

A separate summary is provided for each part of the analysis.

The summary of the entire work and conclusions based on the thermal, environmental and economic analysis of the combined cycle plant and the optimization procedure are highlighted in chapter 7. At the end of the chapter, various relevant topics on which further investigations may be required are also suggested.