CHAPTER 1

INTRODUCTION

1.1 GENERAL

World-wide power scenario

The economic progress and the standard of living of any country depend on a number of factors, of which the potential for electricity generation is vital. The production and conservation of any form of energy be it conventional like thermal, hydro, nuclear, etc, or alternate sources can be said to be the backbone for the development of a country that enables technical innovation and productivity growth. Although, there has been a tremendous achievement in the energy sector, there still remains much to be done and in particular to cope with rapidly increasing population, urbanization, demands for the use of modern appliances, machines, etc. This has resulted in researchers, Engineers and Scientists to focus on the generation and conservation of electrical energy.

Power Generation Scenario in India

The electricity sector in India supplies the world's 6th largest energy consumer, accounting for 3.4% of global energy consumption by more than 17% of global population as per the Ministry of Power, Govt. of India. The present total installed capacity of power generation in India has reached about 167000 MW (Megawatts) with a peak demand shortage of around 14% and an energy deficit of 9% in the country. The projected power generation
for the year 2012 is about 220000 MW against which the projected power generation through renewable energy is about 12,400MW (refer Appendix -1). As such the total contribution of power to the grid through renewable energy source is about 10%, with a tremendous scope for further improvement. During the operation of a conventional thermal power station, large amount of heat is rejected in the environment either through the cooling circuits (steam condensers, cooling towers, diesel engine radiators etc.) or through the exhaust gases (gas turbines, diesel engines, Otto engines etc.). It is possible that a large portion of this heat may be recovered and re-utilized. In particular, conventional power stations have an efficiency of 30-45%, whereas, CHP System systems have an efficiency of 80-85%. Based on such initiatives, CHP System power plants have been implemented in various continuous process industries like sugar, textile, steel etc.

In a proper comparison (serving the same energy needs through both alternatives), CHP System / CHP System uses 15-20% less energy, and contributes an equivalent amount of emission reductions, compared to the production of electricity and heat in separate facilities, i.e. a thermal power plant and a modern boiler. Therefore, at present the interest in CHP System has been gaining rapid momentum thus, resulting in new governmental regulations, and keen interest in research in investigating into the potential of CHP with new technologies or market situations as pointed out by Paepe and Mertens (2007).

The main discussion on Co-generation power plant / CHP System in India have centered on two compelling issues:

1. Co-generation power plant / CHP System is relatively an inexpensive means to augment conventional power supplies and energy conservation. This can reduce costs, and possibly
increase profits, while reducing or avoiding the pollution attendant with fossil fuel utilization which looks attractive.

2. The need for electrical power in India clearly justifies industrial CHP System which is technically and economically feasible.

The major obstacles will have to be overcome before CHP System in India’s industrial sector can effectively be exploited. This primarily relates to the issues with power purchase agreements between the industries and the local utility. The establishment of a firm purchase power price over the life of the project is the principal issue affecting CHP System economics. Other issues that need to be resolved between potential industrial co-generators and the utilities include:

a. The absence of regulatory incentives for the utilities to purchase private power

b. Utility apprehensions regarding the reliability and availability of privately generated power

c. Grid synchronization.

The total fuel consumption is significantly reduced when “CHP System” or “combined heat and power” is applied. CHP System is defined as the combined generation of electric (or mechanical) and thermal energy from the same initial energy source. The basic design of the plant consists of the selection of power cycle parameters, the number of units and capacity of the boilers and turbo generators. The techno economical viability depends on the correct selection of the technology and adopting higher cycle parameters. The issues relating to the selection of the CHP System capacity, the number of units and the design of various other systems such as boiler, fuel handling
system, the water system etc., needs careful attention. There are no technological constraints in adopting high pressure cycles for the process plant CHP systems.

A reliability assessment of such a complex system with certain uncertainties is required to establish the techno-commercial viability of the system. Herein, the term reliability is the capability of an asset to continue to perform its intended function. Amongst various tools for reliability assessment, fault tree analysis and weibull distribution are extensively used to assess the combinations of the undesired events in the context of system operation and its impact on environment that can lead to the unacceptable state of the system.

In this study, reliability assessment is carried out on CHP system using Fault Tree Analysis, besides weibull distribution, enhanced ladder control logic system and taguchi method. This study is carried out to establish the reliability of power source to the public utility grid from CHP system installed in a textile and sugar mill.

1.2 OBJECTIVE OF THIS STUDY

As per Central Electricity Authority of India, there is an urgent need for substantial contribution of power from renewable energy source to the augment power deficit from conventional energy source. Therefore, it is necessary that an analysis on the reliability of power generated from the CHP system is established. Hence, the objective of the present work is primarily on Reliability Studies on two CHP Systems installed in a Textile and Sugar Mill. The major objective of the present work is primarily on Reliability Studies on two CHP Systems installed in a Textile and Sugar Mill.
The following is the scope of the present study:

1. To collect the failure data, restoration time and quantification of the same in both the mills.
2. To conduct Fault Tree Analysis on the entire System and Sub-systems.
3. To apply the Weibull Distribution on mean time between failure (MTBF) and mean time to restoration (MTTR) of the entire System and Sub-systems.
4. To develop and integrate ladder control logic system and determine process output points using cause and effect matrix.
5. To conduct Design of Experiments using Taguchi method and develop contour and surface plots.
6. To perform system availability and identify weak links in the CHP System for improving the overall system efficiency.

By systematically implementing the above techniques, the reliability/availability assessment of the CHP system can be established.

1.3 CHP SYSTEM TECHNOLOGIES

1.3.1 General

Typical CHP system consists of an engine, steam turbine or combustion turbine that drives an electrical generator. A waste heat exchanger recovers waste heat from the engine and/or exhaust gas to produce hot water or steam. The CHP system produces a given amount of electric power and process heat with 10% to 30% less fuel than it takes to produce the electricity and process heat separately. There are different types of CHP system techniques which are referred to as the quantum of heat required for the main
process and balance for power generation. Most CHP systems may be labeled either as “topping systems” or as “bottoming systems”, which is based on operating temperature conditions and production of electricity as referred in Figure 1.1.

![Diagram of Topping and Bottoming Systems]

**Figure 1.1 Indicative temperature levels for CHP System systems**

### 1.3.2 Topping Cycle Plants

A topping cycle plant generates electricity or mechanical power first. Facilities that generate electrical power may produce electricity for their own use and then sell any excess power to a utility. There are four types of topping cycle CHP systems.

1. The first type burns fuel in a gas turbine or diesel engine to produce electrical or mechanical power.

2. The second type of system burns fuel (any type) to produce high-pressure steam that then passes through a steam turbine to produce power.
3. The third type burns a fuel such as natural gas, diesel, wood, gasified coal, or landfill gas.

4. The fourth type is a gas-turbine topping system. A natural gas turbine drives a generator.

1.3.3 Bottoming Cycle Plant

Bottoming cycle plants are much less common than topping cycle plants. In these types of plants, a waste heat recovery boiler re-captures waste heat from a manufacturing heating process. This waste heat is then used to produce steam that drives a steam turbine to produce electricity. Since fuel is burned first in the production process, no additional fuel is required to produce electricity. The CHP System energy conversion management is indicated in Appendix 2.

1.4 FAILURE CAUSES, MECHANISMS AND ROOT CAUSES

Failure causes may be classified in relation to the life cycle of an item as, wherein, the various failure causes are defined and indicated in Figure 1.2.

1. Design failure: A failure due to inadequate design of a component / item.

2. Weakness failure: A failure due to a weakness in the component / item itself when subjected to stresses within their stated capabilities.

3. Manufacturing failure: A failure due to non-conformity during manufacture to the design of a component / item or to specified manufacturing processes.
4. Ageing failure: A failure whose probability of occurrence increases with the passage of time, as a result of processes inherent in the component/item.

5. Misuse failure: A failure due to the application of stresses during use which exceed the stated capabilities of the component/item.

6. Mishandling failure: A failure caused by incorrect handling or lack of care of the component/item.

A severity ranking is often required as part of FMEA and similar techniques like FTA to be able to make priorities. A severity ranking of failure modes is also an essential part of the failure cause classification.

Figure 1.2 Failure cause classification.

The Appendix 3 indicates the real time failure data and type of failure of respective systems and subsystems of CHP Systems considered in this study.
1.5 RELIABILITY ENGINEERING PRINCIPLES

1.5.1 General

Reliability is the probability of equipment or processes to function without failure when operated correctly for a given interval of time under stated conditions. Equipment and processes failures occur due any of the causes classified above leading to system unreliability problems. Failures demonstrate evidence of lack of reliability. Reliability problems are failures, which has financial implications on a business enterprise. Failures in most continuous process industries are measured in downtime for the process. Acquiring reliability data is possible only with accurate failure data based on which good reliability assessments can be taken and improvements implemented. The acquired reliability data can be converted into uncomplicated, figure-of-merit, performance indices.

1.5.2 Reliability Tools / Techniques

A few reliability engineering tools / techniques are presented below:

Decision trees: Decision trees are useful for merging the probability values for success and failure with financial results to arrive at the expected monetary result. Decision trees are good tools for assessing failure uncertainty in accounting terms.

Bathtub curves: These simple, highly idealized curves reflect birth problems, chance failures during the useful life phase, and death problems for a population of components or assemblies.

Reliability block diagrams: Every plant has equipment and processes failures resulting in a domino effect of more problems. Reliability
block diagrams reduce system complexity into simplified models for studying problems and gaining insight into means of economic improvements.

**Failure modes effect and fault tree analysis:** Failure modes effect analysis (FMEA) is an analysis tool for evaluating reliability by examining expected failure modes to find the effects of failure on equipment or systems. FMEA is an inductive tool that starts at identifying possible failure modes and indentifying its severity and consequences on the system.

**Fault tree analysis:** (FTA) is a deductive reliability analysis tool for evaluating reliability driven by top level views of what will fail and searches for root causes of the top level event. FTA provides both reliability assessments and fault probability perspectives.

**Probability plots:** The chaos of failure data can be converted into straight line plots of time-to-failure against cumulative chances for the failure. Weibull probability charts are the tool of choice for reliability work, because Weibull probability charts often tell about failure modes (how components die, i.e., infant mortality, chance failures, or wear out failure modes). Of course once important information about failure modes is identified and then strategies are set for guiding root cause analysis to solve the true cause of failures rather than wasting time and money working on symptoms of failures.

**Design reviews:** Assessing reliability of projects during design phase reviews requires a critical look at equipment details to determine if reliability has been built into the design for meeting performance goals required by the project. Design reviews for reliability require many different disciplines to view the assessments at the three typical milestones: of 1) initial design, 2) completion of development (pilot plant) testing, and 3) preparation of drawings including process flow drawings.
In line with the design reviews and process flow drawings, further analysis using integrating enhanced ladder control logic and taguchi method would help in determining the optimum availability of the CHP system.

1.5.3 Industrial Control System

The following are the general types of industrial control system used in industrial process and production activities:

a. Supervisory Control and Data Acquisition (SCADA) systems: use open-loop control with sites that are widely separated geographically.

b. Programmable Logic Controller (PLC): evolved out of a need to replace racks of relays in ladder form because these relays were not particularly reliable, difficult to rewire, and difficult to diagnose.

c. Distributed Control Systems (DCS): generally refer to the particular functional distributed control system design that exists in industrial process plants (e.g., oil and gas, refining, chemical, utility power, etc). The loop controls can be extended all the way to the top level controllers in a DCS, as everything works in real time.

For selection and configuring any process control system, developing a cause and effect matrix is mandatory to predetermine the effectiveness of the control system. Some of the benefits of constructing a Cause-and-Effect Matrix are as follows:
1. Helps to determine the root causes of a problem or quality characteristic using a structured approach.

2. Encourages and utilizes group participation and knowledge of the process.

3. Uses an orderly, easy-to-read matrix

4. Indicates possible causes of variation in a process.

5. Increases knowledge of the process by helping to learn more about the factors at work and how they relate.

6. Identifies areas where data should be collected for further study.

In this study, integration of enhanced ladder control logic to the existing distributed control system and cause and effect matrix is envisaged to determine the total process output points.

1.5.4 Design of Experiments (DOE) - Taguchi Method

The term experiment is defined as the systematic procedure carried out under controlled conditions in order to discover an unknown effect, to test or establish a hypothesis, or to illustrate a known effect. When analyzing a process, experiments are often used to evaluate which process inputs have a significant impact on the process output, and what the target level of those inputs should be to achieve a desired result (output). There are three aspects of the process that are analyzed by a design of experiment, which are as follows:

i. Factors, or inputs to the process

ii. Levels, or settings of each factor

iii. Response, or output of the experiment
The following is a summary of some of the most common DOE types.

1. Factorial Designs: In factorial designs, multiple factors are investigated simultaneously during the test. The objective of these designs is to identify the factors that have a significant effect on the response, as well as investigate the effect of interactions.

2. Taguchis Orthogonal Arrays: Taguchis orthogonal arrays are highly fractional designs, used to estimate main effects using only a few experimental runs. These designs are not only applicable to two level factorial experiments, but can also investigate main effects when factors have more than two levels. Designs are also available to investigate main effects for certain mixed level experiments where the factors included do not have the same number of levels.

3. Response Surface Method Designs: These are special designs that are used to determine the settings of the factors to achieve an optimum value of the response.

Amongst the above types, taguchi method with contour and surface plots has been considered in this study. Due to non availability of CHP system for such exhaustive testing purposes, only theoretical analysis is carried out with due recommendations for implementation. Further, the design of experiment methods like taguchi method as per Otto Kevin (1996) has been carried out to determine the optimum system availability by varying the system mean time to restoration (MTTR).
1.6 OVERVIEW OF THE THESIS

The thesis comprises of six chapters including introduction and the overview of the thesis is given below:

Chapter 2: Deals with a comprehensive literature review on the chosen problem.

Chapter 3: Explains the type of cogeneration (CHP) systems and base line data Reports on overview and specific details on the CHP system and other base line data considered in this study.

Chapter 4: Presents the details on the Reliability and Availability Assessment Methodologies that covers development and application of Fault Tree Analysis and Application of Weibull Distribution, Selection and Integration of Ladder Control Logic to Process Controller with Cause and Effect Analysis and by using Taguchi method with Contour and Surface Plots to determine the system availability

Chapter 5: Depicts the details of the analysis of the results and a comprehensive discussions.

Chapter 6: Summarizes the conclusion drawn from this research work and future scope on improvising the reliability of cogeneration (CHP) systems. Overall Conclusions drawn from the present study