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Best Practices Manual for
Indian Supercritical Plants: An Abstract

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Best Practices Manual for Indian Supercritical Plants: An Abstract

The demand for electricity is rapidly increasing in India as economic growth continues on a forward path. Coal remains the fuel of choice for electricity generation and much of the new demand is expected to come from coal-fired power plants. Fifty nine percent (135 GW) of the existing 229 GW power generated in the country comes from coal-fueled power plants. An additional 71 GW of electricity is planned in the next five years and much of this, nearly 69 GW, will come from coal-based plants. Most of the existing coal-fired plants are subcritical units operating around 34 percent or less in efficiency.

The next generation of coal plants is expected to have Supercritical (SC) and Ultra Supercritical (USC) units which have an efficiency of 38-45 percent depending on the design, operating parameters and ambient conditions. In July 2008, India released its first National Action Plan on Climate Change (NAPCC) outlining existing and future policies and programs addressing climate change mitigation and adaptation. The plan pledges that India's per capita greenhouse gas emissions "will at no point exceed that of developed countries even as we pursue our development objectives."

The Plan's broad goals are consistent with sustainable development (environmental protection, stewardship, economic growth and societal benefits) and energy security. One of the elements of the NAPCC is to raise the efficiency level of power generation. Supercritical and Ultra Supercritical plants will meet those expectations and help raise the national average efficiency of Indian coal-fired plants to a 40 percent level over two decades. This will significantly reduce coal consumption and help reduce the carbon footprint in the country.

This Best Practices Manual is a compilation of the lessons learned and the experience gained from operating such plants over the last fifty years in U.S. utilities. The early deployment in the United States with SC and USC plants will help in learning and gaining expertise to be able to operate these plants safely, efficiently and reliably to make a major contribution to the growth of the Indian power sector.

The manual was prepared by a team of technical experts from the U.S. and NTPC. Information from various sources and the personal experience of the core technical team are incorporated.

The primary objective of the Best Practices Manual is to help Indian power producers to:

- Reduce greenhouse gas emissions
- Sustain economic growth
- Improve safety and productivity in the workplace

Information is provided under separate chapters that address four key relevant areas of interest:

1. Introduction and overview of the current status of SC and USC units worldwide
2. Reduction of greenhouse gas emissions in India by improved efficiency
   a. Water Consumption
   b. Boiler Performance Analysis
   c. Turbine Cycle Performance Analysis
3. Sustain economic growth in India through improved fleet reliability
   a. Startup and Shutdown
   b. Water Chemistry
   c. Addressing Boiler Reliability
4. Adapt "Best Practices" to improve workforce safety and productivity
   a. Work Process Management for Improved Availability
   b. Plant Safety Considerations

The manual will provide valuable guidance on implementing proven best practices so that the new SC and USC fleet will operate at optimum performance levels and meet or exceed the design expectations.

The summary of the chapters is mentioned in the following sections. Annex 1 lists the complete Table of Contents of the Full Version of Best Practices Manual which will be released subsequently.

1.1 Startup and Shutdown

While supercritical units have been operating for many decades, supercritical Benson boilers have not been the choice for many utilities in the U.S. The situation has however changed recently. For example, Duke Energy and American Electric Power (AEP) have selected a Benson design for their supercritical unit at Cliffside and Turk plants, respectively. Other U.S. utilities have done the same, as the Benson design has distinct cyclic operation advantages.

It appears that the new generation of supercritical units in India will be mostly of the Benson design. The Benson design offers many superior features when compared to the earlier generation of supercritical units. Speed of start up, fewer thermal transients, the simplicity of the startup system, the ability to easily cycle load and improved reliability are examples of operational attributes that favor the use of a Benson design.

In India, the units would not be cycled nearly as much as in the U.S. India has a generation deficit of such proportions that all of the supercritical units will be considered “base loaded” for the near future. However, there will come a time in the life of these units that they will see some cycling to lower load and even some reserve shutdowns at certain times of the year. The Benson design will allow for this type of future cycling style of operation.

In the U.S., even the most efficient of the earlier class of supercritical units are required to cycle and experience routine shutdowns periodically. Even the newer class of supercritical units will need to cycle to lower loads on a routine basis. A number of recent combined cycle plants have followed this trend. Because of this, the supercritical plant operators are very experienced at hot and warm starts as well as shutdowns.

This chapter provides a list of best practices for supercritical plant startup and shutdown operation.

1.2 Water Consumption

Water availability for power production is becoming constrained in many parts of the world. The challenges faced in India are no different from those from the rest of the world.

Today, a wide variety of processes and technologies are being deployed in power plants to recover, recycle and re-use water. The three major areas where water is consumed in a power plant include: steam production; condenser cooling, and bottom ash transport. Wet or dry flue gas desulfurization (FGD) systems for sulfur dioxide removal from the flue gas also consumes a significant amount of water. Plant designs can vary depending on site water availability. However, by adopting “best practices,” water consumption can be reduced at most sites.

The first step in water reuse and conservation is to route the cooling water blow down to a disposal pond, from which treated water can be recycled back into the plant. Similarly, slurry from ash and gas handling systems can be handled in a similar fashion. Other steps that can be adopted to promote water re-use include using waste-water treatment, reverse osmosis, evaporation, and zero liquid discharge systems.

This chapter starts with an overview of water consumption issues and then breaks down the major areas where water is consumed in different processes. Then, best practices that can be adopted in supercritical plants to conserve water are discussed.

Case studies from plants in the United States that operate zero liquid discharge systems are presented.

1.3 Water Chemistry

Water chemistry impacts all water or steam touched equipment. A power generating facility cannot operate reliably without a quality water chemistry program. Water chemistry expectations and limits should be established utilizing the best available technology. Best practices outlined in this water chemistry section include action levels for the operator at specified limits to ensure good quality control of plant water chemistry to protect the equipment. Oxygenated treatment is recommended as the best water chemistry program to provide reliable long-term operation of a supercritical unit.

Reliable operation of a supercritical unit requires specifying and installing accurate, precision chemical instrumentation, and developing and implementing a quality maintenance program to retain its integrity. The ultimate objective is to ensure that the instrumentation will provide the reliability necessary to enable the operators of a supercritical facility to make correct decisions about the status of the equipment.

USAID PACE-D TA Program Study Tour to U.S. in July 2013: Control Room at AEP Amos.

Two pathways to accomplish this task include setting up a routine maintenance program and structure that assigns responsibility for maintaining the equipment such that it can be accomplished in a reliable and cost effective manner. The optimal structure for each organization varies so this section provides the criteria that should be considered when establishing such a program. A typical routine maintenance program is also recommended.

Steam generator tube failure is the leading cause of unavailability in power generating facilities. It is therefore imperative to be attentive to the root causes of tube failures. Four typical causes of tube failure are addressed in this section. Those causes are ID Pitting, Stress Corrosion Cracking, Corrosion Fatigue, and Waterwall Cracking. Chemical cleaning best practices are recommended to ensure a clean steam generator to minimize the potential of OD waterwall circumferential cracking. Strict adherence to the water chemistry limits and action levels defined and recommended in Section 5.1 of the full report are required to maximize optimal boiler tube reliability. Utilizing a reheat drying procedure is recommended as part of the unit shutdown procedure to reduce its potential for reheat superheater pitting caused by moisture remaining in the reheater during shutdown.

Many of the corrosion problems found in boilers/steam generators and turbine blades can be traced back to condenser leaks. Leaking condenser tubes allow cooling water to enter the condensate and feedwater supply. Any contaminants introduced to the condensate and feedwater supply can become active components of numerous corrosion mechanisms. Condenser leaks are typically the major cause of contamination to the condensate and feedwater systems.

Mechanical and corrosion mechanisms that can result in condenser tube failure are addressed. Recommended best practices to ensure condenser reliability include Eddy Current Testing (ECT) to determine the remaining life of the tubes, trend tube degradation, and/or to locate tubes which may fail before the next major planned outage so they can be plugged. Plugging procedures are also addressed to ensure reliable repairs of leaking tubes. Considerations to address when making end-of-life decisions are presented.

There are several contaminants that can result in turbine blade deposits or corrosion. These include iron, sodium, silica, chloride and sulfate. These contaminants can cause performance degradation or turbine blade failure. Recommended best practices include the need to monitor iron with Millipore sampling to establish that the coloration of the sample must be “snow white” meeting the required standards. The parameters that are required to control iron are also discussed. The phase transition zone (PTZ) of the turbine is presented as an especially susceptible area for deposition of sulfates and salts of chloride. The expected appearance is presented to enable quality inspection and sampling. Another part of maintaining a reliable well performing turbine is a well structured, documented turbine sampling process. Guidelines for this are also presented.

Operating a supercritical plant with world-class reliability and efficiency requires structuring the chemical functions of the organization to utilize best practices in the laboratory and chemical analysis. This requires developing an organization structure that optimally allocates all of the necessary functions. These include effective monitoring, sampling, analysis, direction and goals, R&D, and oversight. A structure that divides these tasks between General Chemistry Standards and Control Department (Service Corp), Central Laboratory, and Plant Laboratory is presented in such a way that optimally utilizes the skills residing in each department.

Timely and effective chemical cleaning of a supercritical unit before its heat transfer efficiency is significantly impacted can be the lifeblood of a steam generator. Accurate detection of scale deposition on the tube ID before it significantly impacts heat transfer and tube life, however, can be a very challenging task. This section provides guidance on utilizing best available technology to measure oxide deposits and setting up criteria to enable reliable steam generator operation. The traditional method of determining tube deposits includes physically removing (scraping or bead blasting) a tube sample from the steam generator at a location most likely to have the heaviest deposit and examining it for damage. This can be done during major outages. It was an effective method as long as the only deposits to be removed were the iron transported from the condensate and feedwater systems. As less corrosive water treatments, such as oxygenated treatment (OT), became more prevalent in SC plants, frequent chemical cleaning of the tubes was not needed and as a result the time between cleanings was extended. However, this led to buildup of a thermally insulating tenacious deposit inside the tube surface over time which could not be removed by the traditional scraping or bead blasting methods. SC units operated on OT typically form such deposits which contain three distinct layers. These layers are defined as spinel, hematite and magnetite. This section presents the Scanning Electron Microscope (SEM) as the best method for accurate tube sample analysis and shows how it can be used to evaluate the condition of the tube samples. Thermal conductivity is determined by the porosity of the deposit and by the thermal conductivity of both the structural material (the tube) and the medium which fills the pores.

This chapter provides the building blocks to establish a water chemistry quality control program that is necessary to operate a world-class supercritical power generating facility.

1.4 Boiler Performance Analysis

There are many factors that influence supercritical boiler and combustion performance. Unit design and fuel quality have a major influence on a plant's performance. Plant operations, performance, load response, reliability, and capacity are all inter-related. Therefore, any approach to optimization should be comprehensive in nature, taking into account mechanical adjustments of the firing systems, fuel quality, boiler cleanliness, airflow measurement, furnace oxygen control and many other factors.

In an effort to identify stealth or “hidden” performance issues, a program must be organized with all plant departments fully committed to work together to achieve and preserve plant performance.

With a shortage of domestic coals and newly enacted environmental regulations, Indian power plants must perform well, or deal with the consequences of increased fuel costs, poor reliability and reduced generating capability. During plant operations, thermal energy is lost to the plant's stack, rejected to the cooling tower and/or used by the plant auxiliary equipment. Thus, an effective plant performance program encompasses various program activities that are used to evaluate, sustain, improve or preserve a boiler's performance.

Boiler performance, operational load response, reliability, and capacity are all inter-related. Any approach to manage performance should be comprehensive in nature, taking into account mechanical adjustments of the firing systems, fuel quality, boiler cleanliness, airflow measurement, furnace oxygen and many other factors.

This chapter provides an overview of how to apply proven and “best practices” to comprehensively manage combustion and boiler performance, and to establish a program to clearly define the processes involved with clear divisions of responsibility to ensure program success.

1.5 Turbine Cycle Performance Analysis

Optimizing Turbine cycle performance in a supercritical unit requires implementing best practices of both the turbine and all its associated equipment. The turbine performance is affected not only by its own condition, but by the performance of the condenser, cooling tower, feedwater heaters, valves, etc. All of these are also impacted by water chemistry, and operations and maintenance practices. Accomplishing world-class performance requires learning about and implementing best practices. Many best practices are detailed in the body of this section that can enable the desired world-class performance.

To improve the turbine heat rate requires first understanding the design basis of the turbine cycle and providing a way to know and track the deviations from design performance. Simply tracking the heat rate can be very deceiving, since it is impacted by seasonal conditions and peripheral equipment. This chapter provides means of trending deviations from design heat rate in a way that enables observing unit degradation, and tracking improvements.

Although tracking deviations from design heat rate enables better monitoring of unit performance, understanding the drivers of this performance requires quality monitoring of unit parameters. Modern instrumentation enables continuous monitoring and tracking of temperatures and pressures, and utilizing these parameters to continuously calculate more complex information, such as turbine efficiency, heater Terminal Temperature Difference (TTD), condenser performance, etc. Tracking this information enables continuous improvement to the cycle heat rate.

Condenser performance can be optimized through several strategies. Some of these include monitoring strategies, equipment utilized, maintaining cleanliness through water chemistry and mechanical cleaning and regularly evaluating the condenser performance. The best instrumentation available should be used to detect condenser tube leakage, and thereby protecting the cycle water chemistry. Instrumentation to detect the leaking tube in a timely and effective manner is also recommended.

Optimal design, operation, and monitoring of heaters are presented to provide the means of operating them in a reliable and efficient manner. Means to monitor the heaters and implement practices that minimize cycling of heaters, and maximize performance are also included. A best practice describing a technology to improve heater reliability and extending its life is recommended.

The cooling tower provides the interface of the cooling water with the environment. Degradation in its performance will prevent the condenser and turbine from attaining optimal performance. Ensuring effective performance of a cooling tower requires monitoring the thermal performance of the equipment. The key to achieve consistent cooling tower performance requires developing and maintaining a quality water chemistry program. The biological activity is the initiating mechanism for fouling of high efficiency fills. The parameters for monitoring water quality and the equipment that can provide this type of services is described. Indexes that monitor the biological activity and water quality and the criteria for control are also provided, along with methods that can be used to monitor and inspect tower film fill for fouling. Tests to measure tower performance are also presented.

Operating turbines in a cost effective manner, while maximizing reliability, requires a quality turbine maintenance program. Inefficient turbines can significantly impact the unit heat rate, which will impact the fuel cost. Implementing a quality condition-based maintenance program that regularly evaluates unit operation is essential; it can extend the duration between outages and cost effectively recover those losses. This section presents protocols to accomplish these tasks. Guidelines for both online and outage based assessments are provided. Inspection and sampling are included as part of an integral part of an effective auditing program. Turbine repair practices including processes for both modular repair and individual part repair are described.

1.6 Work Process Management for Improved Availability

Chapter 8 of the full report attempts to communicate one thing: ***People affect the business "Bottom Line" most, not science and technology.*** Applying technology is important, but not to the same degree as getting people to focus on achieving the "Bottom Line" business goals and expectations. Management discipline and training, structure, accountability and human factor “checks and balances” are needed to properly manage all work processes required to achieve the desired business goals.

- Section 8.1 provides reinforcement of the points made above by exposing the reader to and defining what constitutes typical “work processes” in the power production industry.
- Section 8.2 introduces process accountability; how success or need for improvement is measured through Reliability Measures. “Best Practice” process performance measures are introduced, defined and context provided for their proper application.
- Section 8.3 on Work Management and Productivity communicates an understanding of how proper development and application of work processes are related to workforce efficiency and effectiveness. Many “hurdles” that inhibit individuals from being most efficient and effective are described, and “Best Practices” are recommended for their elimination. Added attention is paid to addressing non-routine circumstances that exist during unit turn-down or outage, which is described in Section 8.4. Continuous improvement is a central focus throughout this section.
- In Section 8.4, the central theme is that there is a direct relationship between improvements in outage work processes and the corresponding improvement in outage frequency and duration; and that improvement in unit availability can be achieved.
- Section 8.5 on Human Error Reduction exposes some real-world human factors that inevitably challenge workforce effectiveness and efficiency. Several “Best Practices” from others who have overcome these types of challenges are provided for consideration.
- Another aspect that inhibits workforce effectiveness is detailed in Section 8.6--Root Cause Analysis. A central theme here is the importance of adapting a “randomly timed” work process, often dissociated from other more-routine day-to-day work processes but equally important to consider. The root-cause analysis system or systems help busy people understand the myriad problems they are exposed to on a day-to-day basis, the consequences that result, the true root causes of the problems and thorough resolution of all root-causes to keep them from reoccurring.
- Section 8.7 on Equipment Condition Monitoring is about understanding the condition of plant equipment non-intrusively, using “hard-wired” continuous and portable periodic sensing of condition indicators, to maximize reliability and costs and minimize errors caused by human intervention. Predictive maintenance and condition monitoring has become a cornerstone maintenance strategy, much preferred from a production and cost standpoint over reactive and preventive strategies.

- Section 8.9 includes case studies on "Best Practices" considered by the authors to be useful as reference.
    - Case Study 8.9.1: Root Cause Failure Analysis at Southern Company describes a programmatic approach to Root-Cause Analysis in a large U.S.utility.
    - Case Study 8.9.2: Mean Time to Inspect (MTTI) and Mean Time to Repair (MTTR) expound on reasons why these "leading" metrics are so valuable in measuring the performance of reliability programs.
    - Case Study 8.9.3: Mean Time Between Failure (MTBF)metric expands on 8.9.2 but explains why the "lagging" MTBF metric when implemented and used with MTTI and MTTR can provide a simple way of measuring reliability program performance.

1.7 Addressing Boiler Reliability

Boiler tube failures remain a major issue for the power production industry. In Section 9 of the full report, it will be made apparent that boiler tube failures are an "effect," not a cause. Therefore, discussions in Chapter 9 of the full report (Introduction) and Section 9.2 (Tube Prevention Strategies) will be centered on eliminating the causes of tube and header damage and controlling propagation of that damage to meet or exceed component life expectations. A "Best Practice" approach will be introduced to minimize boiler tube and header failures with Targeted Boiler Management.

It is important to understand the factors (i.e. damage mechanisms) why tube and header failure remains a problem. Toward this end, Section 9.3 (Coal Quality Considerations), Section 9.4 (Water Chemistry Considerations), and Section 9.5 (Metallurgical Considerations) explore the failure mechanisms under each as well as the strategies and techniques in use to defend component failure against these mechanisms.

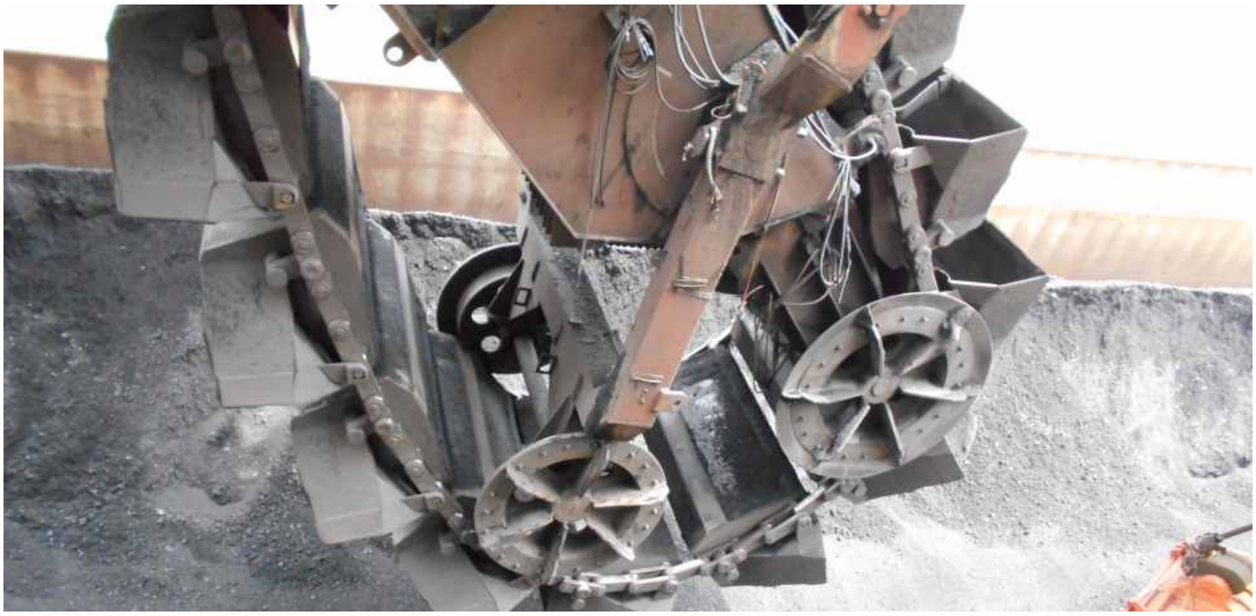
In Section 9.8 (Boiler Condition Monitoring & Diagnostics), an overview of some "Best Practice" technologies (APR and Diagnostic Rules) available in the market, are described and how these may be used for boiler failure control under different operating conditions. In addition, the technologies, tactics and "Best Practice" methods that exist to defend against them via Targeted Boiler Management (TBM) are presented.

TBM was developed based on what has and has not worked historically. It combines and applies the lessons learned and combines them with evolving technology to provide the individuals that are charged with controlling tube and header failure a way to balance the computer automated and manually applied "Best Practice" tools and techniques available to them at low cost for maximum reliability.

1.8 Plant Safety Considerations

Safety is an area that always needs attention and continuous improvement. The consequences of injuries in the workplace is just too great to not give it equal importance as cost, quality, production and all other areas of focus in a power plant. This section provides information on best practices being used in power plants that had vested interests in attempting to reach world-class performance in the area of safety. In this chapter Best Practice, BP-1 is the importance of establishing a vision and mission for safety is emphasized. BP-2 provides a suggested set of safety guiding principles that cover safety comprehensively. BP-3 emphasizes the absolute necessity for holding management fully accountable for effective processes, programs and results. BP-4 speaks to the necessity of having executive management, including the CEO, actively involved in the safety effort. BP-5 addresses the need for effective safety programs and the concern for them becoming stale and perfunctory. BP-6 covers the safety pyramid concept and the importance of including near misses, unsafe acts and unsafe conditions. BP-7 is the key, in that it gives a comprehensive process framework for managing safety. BP-8 encourages the use of a CEO forum for all serious injuries. BP-9 covers the concept of having a site wide Safety Steering Team led by the site head. And finally, BP-10 speaks to recognizing the target audience for the safety message – i.e.,what works for the CEO may not motivate first line employees. Higher management is more strategic and employees on the front line are much more tactical in nature. Therefore different activities and types of information are required.

It is hoped that by implementing these best practices Indian utilities can see fundamental change and achieve continuous improvement in the area of safety.



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USAID PACE-D TA Program Study Tour to U.S. in July 2013: Coal Tripper Deck at OUC Stanton Energy Center.

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9.0 Addressing Boiler Reliability

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