Powering India
Benefits of Digitization in Coal-fired Power Plants
Preface:

Digitization has the potential to save up to 67,000 tons of coal per year and deliver up to $50M in net present value over a remaining 20 year life for a 1GW coal-fired power plant.

According to International Energy Agency (IEA), India will increase electricity production to over 4100 TWh in 2040, making it the third largest power system after China and the United States. Currently, coal based power is the largest contributor in the energy mix and will continue to play a critical role in the future considering the abundant resources of coal in India coupled with low fuel cost and the larger issue of energy independence. However, coal based power has the highest emissions and lowest efficiency compared to other fossil based power generation. Research shows that many of the current coal based assets of about 185GW in India have significantly lower efficiencies with excess fuel use and higher emissions than similar plants operated in other parts of the world, driving the need for viable recommendations that can lead to improvements today and tomorrow.

By looking at the whole power plant at the system level, the authors of this paper explore ways to address the overall plant key performance indicators (KPI's) from the coal yard to stack by using information captured by sensors across the system along with sophisticated analytics to provide real time insights. This will enable better operation of the coal power plants and help to achieve improved performance, reliability and availability leading to reduced emissions and positive outcomes for the utilities. This white paper highlights the challenges and opportunities around coal power generation in India and how digital solutions can drive better outcomes at a system level. Considering the size of the current installed base and additional coal-fired capacity planned for the future, it becomes imperative that even a marginal improvement of 1% in performance and efficiency will have a potential impact of $5B over the life span of 30 years. As India strives to reach the goal of powering everyone, this paper provides key insights and opportunities for various stakeholders in the coal power industry to understand the benefits of digital solutions to improve the existing fleet performance and establish better operating profiles for new plants.

Alain Spohr  
President & CEO  
Steam Power Systems, India  
GE Power

Ashok Ganesan  
President & CEO  
Power Services, India  
GE Power

Mariasundaram Antony  
General Manager  
India Engineering Operations  
GE Power
# Table of Contents

**Powering India: Benefits of Digitization**

1. **Executive Summary** .................................................................................................................. 4

2. **Market Overview** ...................................................................................................................... 5
   2.1 Coal-fired Power Plants in India ................................................................................................. 5
   2.2 Key Challenges .......................................................................................................................... 7
   2.3 Market Opportunities .................................................................................................................. 9
   2.4 Emerging Needs & Solutions ..................................................................................................... 9
   2.5 Path to Digitization ................................................................................................................... 9

3. **Digital Power Plant Architecture — Predix™** ......................................................................... 12

4. **Digital Power Plant — Application Suites** ............................................................................. 14
   4.1 Asset Performance Management (APM) ...................................................................................... 15
      4.1.1 Machine and Equipment Health ......................................................................................... 15
      4.1.2 Reliability Management ...................................................................................................... 15
      4.1.3 Maintenance Optimization .................................................................................................. 16
   4.2 Operations Optimization (OO) .................................................................................................. 16
      4.2.1 Thermal Performance ........................................................................................................... 16
      4.2.2 Boiler Optimization .............................................................................................................. 17
      4.2.3 Emission Monitoring ............................................................................................................ 18
   4.3 Business Optimization (BO) .................................................................................................... 18
      4.3.1 Dispatch Optimizer .............................................................................................................. 18

5. **Enabling Technologies through Digital Twin** ......................................................................... 19
   5.1 Thermodynamics Model ........................................................................................................... 19
   5.2 Artificial Intelligence .................................................................................................................. 19
   5.3 Lifing Models ............................................................................................................................. 20
   5.4 Model Tuning-Dynamic Estimation ........................................................................................... 20
   5.5 Operational Flexibility .............................................................................................................. 21
   5.6 Digital Inspection ...................................................................................................................... 21
   5.7 Next Generation Sensing ......................................................................................................... 21

6. **Conclusion** ............................................................................................................................... 22

7. **Acknowledgements** .................................................................................................................. 23

8. **References** ............................................................................................................................... 23
1. Executive Summary

In order to meet India’s increasing demand for electricity, power generators and utilities will need to transform how they operate their new and existing fleet—leveraging digital technologies to gain more reliability, productivity, and profitability.

India is home to 18% of the world’s population, uses 6% of the world’s primary energy and has the fifth largest power generation capacity of 298 GW as of Mar 2016. Thermal power, the largest component of this capacity, contributes 210.6 GW, followed by hydro 42.8 GW, renewable energy 38.8 GW and nuclear 5.8 GW. Coal is the largest contributor in thermal power with 185.2 GW, representing 62.1% of total installed capacity.

With an intention to reduce carbon footprint, India has set an ambitious plan to add 175 GW of renewable energy generation capacity by 2022. The country aims to have 100 GW of solar power by 2022 along with 260 GW of thermal and nuclear generation and 62 GW of hydro generation capacity.

While renewable energy is fast emerging as a major source of power in India, coal remains the backbone of the Indian power sector with sustainable and affordable cost. Yet more coal-fired power is required to meet demands and is expected to grow at CAGR of 3.6% to reach 438 GW by 2040. India will become the second largest coal fleet in the world after China.

While India is addressing growing demand for electricity today with capacity fueled by coal, it must consider longer term challenges in plant efficiency, environmental impacts, and economic factors.

A study carried out by Centre for Science and Environment (CSE) on 47 selected coal-based thermal power plants across India, found that the average efficiency of the plants having capacity 2000MW or above was 32.8%, one of the lowest among the major power producing countries. The average water consumption was observed 4 m³/MWh as compared to 2.5 m³/MWh that of China. Further new regulations have been introduced in 2015 to limit NOx, SO₂, and mercury in addition to existing particulate matter (PM).

In the current scenario, efficiency with operational flexibility and high reliability become vital. Higher efficiency in the generation of electricity means lower consumption of coal that leads to lower emission. With a 1% improvement in heat rate of coal-fired fleet, India has a potential of $167MM/annum saving in cost. GE Digital Solutions can help plant owners and operators to realize these savings by delivering 1-2% improvement in coal plant efficiency and reliability.

Digital is disrupting and transforming the electricity industry, challenging old models and creating unprecedented opportunities. Over the next decade, there will be ~$1.3 trillion of value to be captured in this transformation. With software and data analytics, combined with advanced hardware, new digitally-enhanced power generation will deliver greater reliability, affordability and sustainability, helping lower costs, improve efficiencies, create growth opportunities and lower carbon output.

At GE, our mission is to be the strategic partner of choice for our customers to derive new value, new insights, new revenue and business models from digital assets. A digital company can’t do this. An industrial company can’t do this. Only a digital industrial company can do this. This white paper helps the coal-fired plant managers and the digital solution providers to better understand the current scenarios, challenges and opportunities of coal-fired power plants in India and explores the benefits of digitization for coal-fired power plants.
2. Market Overview

2.1 Coal-fired Power Plants in India

Installed electricity capacity in India:

India has the fifth largest installed capacity of 298 GW in the world. Coal is the major contributor with 62.1% of the total installed capacity followed by hydro 14.4%, renewable energy sources (RES - solar, wind, small hydro, and bio) 13%, and others as shown in Figure 2.1. The installed coal plant capacity of 185.2GW is distributed among central, state, and private sector entities with a share of 28%, 35% & 37% respectively.

As shown in Figure 2.2, the age profile of installed capacity of thermal plants indicates that 50% of the installed capacity is more than 10 years old and about 25% is more than 20 years old.

Power Generation in India:

With a production of 1296 TWh and consumption of 998 TWh in 2014, India became the third largest producer and consumer of electricity in the world as shown in Figure 2.3.

The total power generation for India in FY 2015–16 is 1162.6 billion units excluding captive power plant. While coal-fired plant contributes 62.1% of the total installation as shown in Figure 2.1, the actual production of electricity due to coal contributes 77.1% of the total generation as shown in Figure 2.3. The Central sector contributes 37%, private sector 32% and state sector 31% (this distribution does include RES as split data was not available).
Per Capita Consumption:

The per capita electricity consumption in 2015–16 is 1075 kWh. The per capita electricity consumption in India is very low when compared to some of the developed countries of the world. India’s per capita consumption is one-third of the world average and is just 33% of China, 10% of Australia and 7.5% of USA. Around 240 million people in the country do not have access to electricity. The per capita electricity is growing at a rate of 6%, indicating increased demand for electricity in future.

Energy deficit:

For 2015–16, the base load energy deficit and peaking shortage was 2.1% and 3.2% respectively. The trend is in declining mode over last eight years as shown in Figure 2.5.

India’s coal power power sector future outlook:

Growth in industrial activities, population, economy, prosperity and urbanization, along with per-capita energy consumption are leading to growth in power demand. This is set to continue in the coming years. The demand for electricity is expected to touch from current level of 1163 TWh to 1900 TWh by 2020 and 3300 TWh by 2040 as shown in Figure 2.6.

To meet the future demand and with a bid to push clean energy projects renewable will grow at 7% to reach from 79 GW to 462GW by 2040. The government has set a target of 175 GW of renewable energy capacity by 2022, which includes 100 GW of solar power, 60 GW of wind power, 10 GW of biomass-fired power and 5 GW of small hydropower.

India is very sensitive to cost and also exhibits an evening peaking system. Despite abundant sunshine, solar photovoltaic displaces conventional sources during the daytime to save fuel costs, but will not help to meet the peak demand needs.
Coal will remain the backbone of the Indian power sector and is expected to grow to 438 GW by 2040 with 41% share in total installed capacity and India will become the second largest in world after China. Today 85% of the coal plants are based on sub-critical technology. By 2040 India will have 50% super-critical coal plants that will boost average coal plant efficiency from 34% to 38% as shown in Figure 2.7.

2.2 Key Challenges

Power generators and utilities that rely on coal-fired power plants faced four key challenges. First, they must improve the operating efficiencies within the installed fleet because it has fallen behind industry standards. Second, they must reduce unplanned downtime and improve reliability. Third, they must address increasing pressures to dramatically reduce emissions. And finally, they must plan for the impact of increasing renewables and become more flexible over time and still remain highly profitable.

Efficiency:

In recent past, various studies have been performed on the efficiencies of coal-fired plants in India.

In a study carried out by CSE on 47 selected coal-based thermal power plants across India, found that the average efficiency of the plants was 32.8%, one of the lowest among the major power producing countries. It has also observed efficiency as low as 16% in few small units.

The study by CEA on 73 coal-fired plants in India reported that the last five year trend of efficiency is increasing as shown in Figure 2.8. However, it is still lower than the design efficiency of 36.75%.

The latest document published by IEA in 2015 on India Energy Outlook reported that the average energy efficiency of India’s coal-fired fleet is just under 35%, below that of China or United States.
Some of the key reasons for lower efficiencies are:

- High gross heat rate due to un-optimized boiler combustion, inefficient soot blowing air pre-heater leakage, low condenser vacuum, and low turbine efficiency
- High auxiliary power consumption
- Low plant load factor (PLF), Figure 2.9
- Poor quality of fuel
- Aging of sub-critical fleet

**Reliability**

Many of the coal-fired power plants in India are facing reliability challenges leading to unscheduled events and uneconomical plant operation. CSE study found that more than 50% of thermal power plants out of 47 selected plants were running inefficiently due to bad operation and maintenance practices. Over 20% of the plants experienced average annual outage of more than 73 days against the desired level of 15 days. Some of reasons are:

- Boiler tube leakages
- Poor performance of ESP
- Poor maintenance practice and spares

**Emission:**

In India, the coal-fired plants contribute approximately 60% of particulate emissions; 45–50% of SO₂ emissions; 30% of NOₓ emissions; and more than 80% of mercury emissions. The CO₂ emission CO₂ emission of coal-fired plants in India was 1.08 kg per kWh, which was 14% higher than China and 7% higher than the global average.

The new emission norms introduced in Dec 2015 necessitates monitoring of NOₓ, SO₂ and mercury in addition to PM, the only pollutant that was regulated prior to Dec 2015.

The various plant optimization solutions were earlier catered towards achieving the best possible efficiency and improved heat rate. The power plant operators would now have to modify their operational parameters that help the plant run efficiently while complying with the stricter regulations for NOₓ, SO₂ and mercury as shown in Table 2.1.

Table 2.1: New emission norms for Thermal Power Plants (TPP) in India, Dec 2015

<table>
<thead>
<tr>
<th>Installation Date</th>
<th>NOₓ (mg/Nm³)</th>
<th>SO₂ (mg/Nm³)</th>
<th>Particulate (mg/Nm³)</th>
<th>Mercury (mg/Nm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TPP’s installed before Dec. 31, 2003</td>
<td>600</td>
<td>600 (units &lt; 500 MW)</td>
<td>100</td>
<td>Nil (units &lt; 500 MW) 0.03 (units ≥ 500 MW)</td>
</tr>
<tr>
<td>TPP’s installed after Dec. 31, 2003 – Dec. 31, 2016</td>
<td>300</td>
<td>200 (units ≥ 500 MW)</td>
<td>50</td>
<td>0.03</td>
</tr>
<tr>
<td>TPP’s installed from Jan. 1, 2017</td>
<td>100</td>
<td>100</td>
<td>30</td>
<td>0.03</td>
</tr>
</tbody>
</table>
Flexibility:

With solar and renewables gaining scale and backed by preferential dispatch, these sources bring in an element of dynamism into the grid due to their variable nature of generation. This puts additional requirement on coal plants which were originally designed for single load point now being asked to operate in cycles. This would mean faster ramp up needs and quicker turndown leading to higher variable costs, i.e., the plant is slipping down the merit order. It also necessitates operation at sustained low load without oil firing.

2.3 Market Opportunities:

To calculate the potential benefits, let us assume the average plant heat rate for a typical 200 MW coal-fired plant of India to be 2400 kcal/kWh. Assuming, the same heat rate for India’s total installed capacity of 185 GW, 1% reduction in heat rate would have multifold impact on savings of the plant as shown in Table 2.2.

Digital solutions can deliver 1-2% improvement in heat rate for typical power plants and even higher values for older, less efficient plants. Improvement in heat rate would result in reduction in production cost due to less emissions and low power consumptions in auxiliary equipment. The environmental impact of the thermal improvement could result in a reduction of CO₂ by 21MT per year.

2.4 Emerging Needs & Solutions:

Given the fact that a coal power generation will significantly continue to dominate India’s energy generation, energy efficiency becomes vital. Further to overcome all the above-mentioned challenges in Section 2.2 in a coal-fired plant, conversion of old plants with super or ultra-supercritical technology and the efficient utilization of existing capacity are the key ways. The government has been taking adequate steps to effectively convert old plants. However, to effectively utilize existing capacity, the plant needs to be operated optimally by trading off multiple objectives such as — improving efficiency, flexibility and reliability, reducing production cost and maintenance cost, meeting stringent emission norms — will be accounted as per Figure 2.10.

2.5 Path to Digitization

Modern coal power plants rely on a complex network of sensors, actuators, digital controllers, and supervisory computers to operate and coordinate each of the plant subsystems. Hundreds of feedback control loops serve to monitor plant processes and perform appropriate control actions, aiming to maintain optimum operating conditions regardless of system disturbances such as changes in coal quality or load demand. However, the highly interrelated nature of power plant parameters means that close control is very challenging, and the plant is often not operated to the limit of its potential capabilities. Steps can be taken now to access valuable data from these complex systems and use digitization and analytics to turn data into actionable knowledge.
As with any innovation, there will be early adopters who will forge the path forward, testing the limits of new technology, proving components that offer benefits and dispensing with those that don’t. Each power organization will be approaching the use of data and analytics from their own point of reference, technology maturity and propensity for change. However, there exists a clear ground swell of sentiment that digital is the way of the future, with a stunning 94% of power generation executives believing that it will transform their industry in the coming year.

For most organizations the introduction of digital starts with attaching and monitoring core assets. In fact, many organizations have been performing asset level monitoring with point solutions, for some time. Taking the next steps to consolidate and manage data across plants and fleets, applying analytics to gain insights, implementing predictive analytics and optimizing performance is where the industry is focused in 2016.

Understanding where to begin, next steps and mapping the course to digital success requires working with a partner, like GE, who shares this vision, can support it with appropriate solutions today and has a roadmap for innovation growth in the future.

*Figure 2.11: Digital Growth Opportunity*

**Connect** — Provides the foundation to leverage analytics by enabling the collection of machine sensor data from assets and processes data, as well as management of that data to derive value.

**Monitor** — Focuses on understanding the performance and health of your assets and processes, and visualization of events.

**Analyze** — Determines the root cause of issues based on historical and real-time data to understand relationships, correlations, and trends, and facilitates effective problem resolution.

**Predict** — Provides foresight into impending problems to avoid issues before they occur and drives greater process consistency and asset uptime.

**Optimize** — Maximizes the performance and profitability potential of assets, plants and fleets to achieve the best possible outcomes. Allows simulation modeling to test “what if” scenarios.
To help utility executives and plant managers operate their coal-fired power plants optimally, GE offers the **Digital Power Plant**. By utilizing machine data, domain knowledge and analytics, our customer reduce the complexity of managing the trade-offs mentioned above. It collects data from sensor, runs on Predix™, an industrial internet platform, and has application suites that deliver key outcome such as improved heat rate, higher reliability, lower emissions, and greater flexibility, as shown in Figure 2.12. The details of the Digital Power Plant architecture and the application suites have been described in section 3 and 4 respectively.

**Figure 2.12: Digital Power Plant**
3. Digital Power Plant Architecture — Predix™

The Digital Power Plant (DPP) architecture is powered by Predix™, the Cloud Platform of the Industrial internet as shown in Figure 3.1.

Figure 3.1: Digital Power Plant Architecture

<table>
<thead>
<tr>
<th>Connectivity</th>
<th>Services</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Industrial Assets</td>
<td>Cloud Foundry</td>
<td>UI / Mobile Applications</td>
</tr>
<tr>
<td>Edge Analytics Engine</td>
<td>Data Infrastructure</td>
<td>End-to-End Security</td>
</tr>
</tbody>
</table>

To address the issues mentioned in Section 2.2 and to enable power leaders with the opportunity to increase profitability from machine data and analytics, GE developed the DPP, delivering capabilities in the following areas:

- **Software Defined Machines:** Unlike traditional machines, where applications for that equipment were built into firmware and notoriously difficult to connect to the Industrial Internet, new breeds of assets autonomously connect to the Industrial Internet, execute native or cloud-based machine applications, analyze collected data and respond to changes in that data.

- **Predix™, the Cloud Platform for the Industrial Internet:** GE’s platform for the Industrial Internet, combines best of breed technologies for massive data ingestion, analytic modeling and execution, asset libraries and a sophisticated User Interface (UI). Predix machine is an on-site gateway for data cleansing and communications and for executing analytics at the edge, required for near real-time response. This environment was industrial built to manage the data and analytics required for power companies to gain operational benefits and action-based recommendations.

  - **Predix Connectivity:** Predix Connectivity provides fast and secure connectivity between industrial asset and Predix cloud using software called as Predix Machine. Predix Machine also runs local applications, like edge analytics.
  
  - **Predix Cloud:** The Predix Cloud is central to enabling the Industrial Internet. It consists of a scalable cloud infrastructure that serves as a basis for Platform-as-a-Service (PaaS), which is what GE and coal power company developers can use to create Industrial Internet applications.
• **Predix Services:** Predix cloud services has following categories:

• **Operational Services:** It enables application developers to manage the lifecycle and commercialization of their applications.

• **Asset Services:** Services to create import and organize asset models and their associated business rules. It has following sub-categories.

• **Data Services:** Services to ingest, clean, merge and ultimately store data in the appropriate storage technology so that it can be made available to applications in the manner most suitable to their use case.

**Digital Twin**: An organized collection of physics-based methods and advanced analytics used to model the present state of every asset in a Digital Power Plant. GE applications use the Digital Twin to model solutions, execute “what if” scenarios and to drive outcomes based on analytic models that mirror and predict the functions of the physical assets.

**Suite of Applications:** Leveraging data from software defined machines and the GE Digital Twin, a complete set of applications designed to improve asset performance and reliability, to increase operation efficiency and to give power business leaders insights that allow them to make more profitable decisions.

**Cyber Security:** GE Predix enforces a multi-layered security layer to protect plant network, assets and data from cyber security threats.

GE has combined security certifications, hardware, software, expertise and sound practices to create an environment of trust for industrial companies.

---

The electricity sector is ripe for realizing value from rapid digital transformation; we estimate that there is $1.3 trillion of value to be captured globally, from 2016 to 2025.
4. Digital Power Plant — Application Suites

With a focus on important outcomes that drive our customer’s KPIs. We have developed a comprehensive set of integrated solutions that meet our customer’s needs where they exist today and help them develop their roadmap for the coming years. These solutions ensure our customers are well prepared to meet their profitability goals with greater reliability, more efficient operations, more profitable dispatch and trading profiles, all operating in a secured and scalable environment.

The Digital Coal Fired Plant has three application suites namely,

- Asset Performance Management (APM).
- Operation Optimization (OO)
- Business Optimization (BO)

The functionality is described below:

**Figure 4.1: Digital Power Plant — Application Suites**

- **BUSINESS OPTIMIZATION**
  - Market Intelligence & Forecasting*
  - Fuel Nominations*
  - Portfolio Optimization*

- **OPERATIONS OPTIMIZATION**
  - Operations Evaluation
  - Plant Optimization
  - Outage Planning*
  - Emissions & Regulatory*

- **ASSET PERFORMANCE MANAGEMENT**
  - Machine & Equipment Health
  - Reliability Management
  - Maintenance Optimization*

- **Predix Platform**
  - Advanced Controls/Edge Computing
  - Cyber Security

* Scheduled for launch in 2016

**Profitability**
- More Profitable Bids/Offers
- Improved Fuel Purchasing Decisions
- Better Schedules Based On: GT MWhrs Life vs. Base Load
- Dynamic Fleet Performance Insights

**Productivity**
- Reduced Fuel Consumption
- Improved CapEx ROI
- Increased MW Capacity
- Lower Operating Costs
- Lower Emissions
- Dynamic Plant Flexibility

**Reliability**
- Reduced Unplanned Downtime
- Proactive Issue Identification
- Improved Outage Planning
- Reduce Maintenance Costs
4.1 Asset Performance Management (APM)

APM is a software application designed to increase asset reliability and availability while reducing maintenance cost. APM has the capability to be connected to the Computerized Maintenance Management System (CMMS) and trigger work orders for Preventative Maintenance (PM) Tasks and Corrective Maintenance (CM) Tasks in the CMMS. Wrench time is tracked in the system. The PM tasks are optimized on a per asset basis depending on the failure mode coverage that the available sensor and tag suite provide. This is accessible through the FMEA module of the APM.

APM also addresses another critical need of coal fired plant on water management. GE’s water management solution covers state-of-the-art chemicals like fireside, coal handling, cooling and boiler feed water treatment, along with water and wastewater treatment membranes and zero-liquid discharge systems (ZLD). This enables better business decisions, eliminate unplanned downtime and lower operating costs.

4.1.1 Machine and Equipment Health

This module provides a unified, complete and accurate view of the asset — its’ state, status and health. The condition of critical assets like the boiler, steam turbine, condenser, primary fans, preheaters, generator etc. can be monitored by collecting the data from the available sensors, applying analytics to track KPIs and associated operational anomalies. A sample snapshot of the asset performance tool is shown below.

4.1.2 Reliability Management

Predicting and accurately diagnosing issues and responding them before they impact asset performance and allowing the operator and maintainer to trigger corrective work orders within the CMMS. This module allows the plant to move events from the forced outage category to the unscheduled and even the planned (concurrent) maintenance category. This has been developed with years of experience in designing, operating and monitoring assets across multiple GE Industrial and Power Generation businesses.

This module enables users to combine various analytic techniques detect, predict condition of asset before it fails. It includes anomaly detection to provide insight that there is something wrong with the asset and then insight when a more accurate prediction of the failure mode can be made as it progresses. This is handled through a case management system that provides transparency to the maintainer and operator regarding the symptoms of the failure mode and allowing them to manage the progressing failure mode to meet business requirements.
4.1.3 Maintenance Optimization

This module uses lifing models to balance reliability, availability, performance and costs against risk maximizing the value of the asset. Capabilities of this module are given below.

- Recommends modifications to preventative maintenance strategies and asset utilization of assets based on budget and reliability risk constraints.
- Allows for synchronization of preventative maintenance activities for many machines on plant level.
- Anticipate failures with longer lead times and adjust life trajectories in near real time.

4.2 Operations Optimization (OO)

Operations Optimization (OO) is a suit that provides Key Performance Indicator (KPI) focused analytics to multiple levels of the customer’s organization.

It provides analytics on both the stable and transitional activities that occur in a power plant, enabling operators to detect and address non-optimal processes. It uses a proprietary set of analytics to analyze power plant efficiency during normal operation and to assess the operational history of the customer’s power plant to determine the average plant start time and current level of plant turndown. It can also monitor the overall capability of a power plant to meet its demand through ramp rate. Operational Optimization will offer the customer Visibility, Insight, & Actions for plant-specific customized KPIs, enabling them to quickly assess their plant assets for operational issues and minimize the cost of addressing any issues that arise.

4.2.1 Thermal Performance

GE’s thermal performance monitoring module enables continuous performance monitoring of plant assets including boiler, steam turbines, feed water heaters, condenser, cooling tower, pumps. It uses thermodynamics models along with analytics to analyze overall power plant performance and individual equipment performance during normal and transient operation.
Thermal Performance has the following capabilities:

- what-if scenario analysis
- compares the actual values of critical parameters with the best achievable in a given operating scenario
- predicts plant output & capacity based on current equipment degradation
- sensor diagnostics

The key outcome of this module is to enhance efficiency of the coal-fired plant by recommending timely corrective actions on the under-performing assets such as ensuring a clean condenser to mitigate losses due to fouling or providing insights to fix the leak in air heater.

### 4.2.2 Plant Optimization

Modern coal power plants rely on a complex network of sensors, actuators, digital controllers, and supervisory computers to operate and coordinate each of the plant subsystems. Hundreds of feedback control loops serve to monitor plant processes and perform appropriate control actions, aiming to maintain optimum operating conditions regardless of system disturbances such as changes in coal quality or load demand. However, the highly interrelated nature of power plant parameters means that close control is highly challenging, and the plant is often not operated to the limit of its potential capabilities.

GE’s boiler optimization module is designed to improve boiler efficiency by working with existing DCS control system.

The air-fuel mix component provides real-time optimization by manipulating controls related to fuel and air mixing to improve heat rate, reduce NOx and better control CO. It uses neural network based optimization and model predictive control (MPC) to extract insights about the combustion process, determines the optimal balance of fuel and air flows in the furnace, and responds to changing conditions in the boiler. It can adjust your control system biases for consistent positioning of dampers, burner tilts, over-fire air and other control parameters to minimize NOx and CO and reduce dry gas heat loss.

The soot-cleaning component provides real-time optimization to determine when each soot-cleaning device should be activated in order to improve heat rate and reduce unnecessary wear and tear on the boiler. This can prevent unplanned downtime by not blowing on already clean surfaces, thus causing tube ruptures.
The typical benefits of boiler optimization are:

- Reduces heat rate 0.75%–1%
- Reduces soot blowing 20%–30%
- Reduces NOx 10%–15%
- Maintains “sweet-spot” for operations engineer

This technology has been deployed at over 100 sites across the globe. Fundamental to the improvement is the ability to build mathematical relationships that model the process behavior. With an accurate predictive model of the boiler processes, fast, optimal adjustments can be made. Plant Optimization provides the inputs and decision making analysis that could improve production, reduce heat rate and increase operating margin.

### 4.2.3 Emission Monitoring

Boiler Optimization as described in section 4.1.2 has the capability to monitor CO and NOx using Model Predictive Control (MPC) technology.

### 4.3 Business Optimization (BO)

Business Optimization is a cloud-based suite designed to help coal power producers to take full advantage of predictive analytics to make improved decisions around power trading, fuel purchases and portfolio management. One of the application dispatch optimizer has been described below.

#### 4.3.1 Dispatch Optimizer

The Dispatch Optimizer helps load dispatch centers to meet short-term and long-term power demands while optimizing overall cost in a grid which has both renewable and non-renewable sources of energy. The dispatch optimizer provides decision-making capabilities suggesting which plants can be shut down while accounting for start-up and shut-down costs, and predictively avails high ramp rates when needed to state load dispatch centers to meet demand surge. It can be used by plant managers to meet daily demand, schedule asset maintenance, and earn bonuses/ avoid penalties by meeting demand surge while continuously optimizing operating margin even at part load conditions.
5. Enabling Technologies through Digital Twin

The application suites like APM and OO that was described in Section 4 cover products those are available as on date and can monitor thermal performance, improve plant operation, reduce NOx and maintenance costs. However, there is a need for enabling technologies to address unique challenges of India as mentioned below.

- Impact of asset life with cyclic load, plant performance and lifing
- Operational flexibility to meet cyclic demand
- Economically viable online coal analysis
- Continuous emission monitoring of NOx, SO₂, PM
- Boiler tube leak detection at incipient level
- Non-availability of sensors on old plants

New enabling technology will also help in enhancing the capability of current application suites of APM and OO. GE is developing these enabling technologies through Digital Twin and/or advanced sensing solutions.

GE Digital Twin is an organized collection of physics-based methods and advanced analytics that is used to model the present state of every asset in a Digital Power Plant. A combination of deep physics insights, engineering design knowledge, new inspection technologies and the latest artificial intelligence and analytics experience delivers a Digital Twin of unprecedented fidelity to solve above challenges. The key digital twin technologies are described below.

5.1 Thermodynamics Model:

Plant Thermodynamic Models predict plant performance under different operating conditions, dispatch modes and grid (or customer) requirements both under steady-state as well as transient operation. The model uses GE coal power plant design knowledge, including Boiler, Steam Turbine, and auxiliaries, with advanced computational methods to accelerate the execution time and enables real-time decision-making based on what-if scenarios.

5.2 Artificial Intelligence

Anomaly detection

- Domain or physics-based models enable anomaly detection within the physical plant through the comparison of calculated parameters with measured values.
- Statistical process control: Univariate and multivariate control chart techniques are used with thresholds set empirically or from domain expertise.
- Machine Learning based anomaly detectors includes multivariate multilevel survival models to baseline asset risk, to classification logistic regression, decision trees, random forest methods, neural networks and clustering methodologies. Models are derived from healthy and fault data using historical database of sensor and configuration data.
- Advanced signal processing techniques are used to detect subtle anomalies in the presence of sensor noise, especially in rotating machinery like steam turbine, boiler feed pumps. A variety of algorithms are used, such as wavelets, kernel regression and multi-sensor data fusion.
- Deep learning based algorithm detects anomalies with constantly updated models during operations.
- Pattern Recognition capabilities contribute to developing the behavioral Digital Twin of an asset by using various sources of measurement data collected over time.
5.3 Lifting Models:

Lifting models are developed by combining empirical data such as operational, part condition, outage and site specific environmental information with robust physics based model and GE’s global fleet data to predict life of assets accurately as shown in Figure 5.1.

Figure 5.1: Lifting Model approach & a typical example for creep deflection

This also enables scenario specific analyses for customer assets and provides prescriptive solutions for optimal value extraction. This allows movement from traditional maintenance manual based scheduling to true reliability based planned maintenance based on specific asset environment and utilization.

5.4 Model Tuning-Dynamic Estimation

The model used for the asset performance need to be tuned as the asset degrades. For example for monitoring thermal performance of boiler, as the boiler tube gets fouled, the baseline model needs to be updated or tuned to incorporate this effect so the correct state of asset health is determined. This is achieved by applying various dynamic estimation modeling techniques like Kalman Filter or unscented Kalman filter through a tracking filter as shown in Figure 5.2.
5.5 Operational Flexibility

The growing capacity of renewable energy plants in India and the insufficient storage capability cause the coal-fired plant to operate at varied load conditions so as to meet the load demand from Grid. When plant loads change pulverizes or mills go off and on, furnace temperature and heat profiles are altered, emission varies and steam and flue gas velocities vary. All of these changes can force the unit to operate away from the design point that means reducing performance.

Further, although these cyclic operations including frequent shutdowns and start-ups as well as rapid load changes are required to compete in today’s market, these operations affect life of high temperature and pressure components such as Boiler and steam turbine parts. The failure mechanism of these hot pressure parts gets shifted from creep for base load design to a combination of creep and fatigue due to cyclic operations. Figure 5.3 shows a reduction in life or increase in damage due to various operating conditions.

Lifing models combined with performance models to characterize low cycle fatigue allow confident operation in this space. This lifing-performance model is integrated with control system to determine optimal ramp rate or turn down rate to enable flexible operation of the plant at minimal damage and costs.

5.6 Digital Inspection

Digital inspection combines inspection techniques with physics models and data analytics to identify potential location of inspection and perform inspection efficiently at lower cost as shown in Figure 5.4.

It uses advanced technologies such as PAUT (phase array ultrasound), RFECT (remote field eddy current testing) and MBN (magnetic barkhausen noise) for inspecting welds, corrosion and creep respectively. This technology can potentially be applied to inspect boiler tubes economically.

5.7 Next Generation Sensing

In anticipation of next generation sensing techniques, GE plans to leverage advanced analytics using existing and emerging sensing technologies like:

- Continuous Emissions Monitoring System (CEMS)
- Acoustic sensing techniques
- Online coal quality analysis techniques
- Virtual sensing techniques

Figure 5.3: Varying load and damage

Figure 5.4: Digital Inspection
6. Conclusion

Coal-fired power plants play a crucial role in India’s power sector and will remain the major contributor in future. The inefficiencies, high emissions, low reliability, low efficiency and low plant load factors are the major challenges. By leveraging new digital solutions and analytics, power generators can make fact-based decisions for operations and maintenance to help increase coal plant efficiency and reduce production cost and maintenance costs. Developing economical solutions that continuously monitor emissions for additional parameters like NOx and SO₂, along with PM to comply with new regulation is the need of the hour. Further, market dynamics impact the operating profiles of coal-plants originally designed for base load that must cycle more as renewables enter the mix over time. Developing new cost effective technologies to predict boiler tube leaks, to analyze coal properties such as moisture, heating value and ash content online, and to optimize asset life for cyclic load fluctuations will enable lower production cost and improve operational margins.
7. Acknowledgements

This position paper has been written by a group of experts from GE Power, Digital, Global Growth Organization and Global Research.

8. References

6. “India’s per capita electricity consumption is 1/3rd of the world average”, newslaundry.com, May 10 2016.
7. “Changing rules of Indian power sector: Empowering the economy”, Confederation of Indian Industry (CII) and PricewaterhouseCoopers Private Limited (PwC), New Delhi, 2015.
8. “CEA Perspective on Energy Efficiency in Coal Fired Power Stations.”
11. Reliability, Maintainability & Availability analysis of a coal fired power plant in eastern region of India. D D Adhikary, G Bose, S Mitra and D Bose
13. Ministry of environment, forest and climate change notification, 7th Dec 2015, the Gazette of India