Building on belief

Towards Sustainable and Clean Thermal Power

Abstract

The need to abate global warming mandates prudent usage of fossil fuels. Coal-powered thermal power plants are under pressure to perform efficiently and reduce emissions. Currently, the power generation sector alone is responsible for nearly 41% of global CO_2 emissions, with coal power being the largest contributor of nitrogen oxides (NOx), Sulphur oxides (SOx), mercury (Hg) and particulate matter . Increased deployment of carbon capture, sequestration and utilization (CCUs) technologies can improve the sustainability quotient but may be insufficient to meet the climate goals set in the Paris agreement. Coal is still expected to provide 22% of global power and account for 68% of carbon dioxide (CO_2) emissions even in 2040[1].

Leveraging the right technology can help thermal power companies reduce up to 2 gigatons of CO_2 emissions[2]. Adoption of the latest digital technologies can help improve thermal plants' performance by reducing the consumption of fuel, auxiliary power, consumables, and greenhouse gas emissions. Existing thermal power plants, therefore, need to be equipped with these technologies to mitigate global warming.

Challenges with Thermal Power Plants

Thermal power plants consist of large and complex equipment for power generation such as pulverizers, boilers, steam turbines and gas turbines. Pollution control equipment like selective catalytic reduction (SCR) converters, flue gas desulphurization (FGD) units, electrostatic precipitators as well as efficiency improvement equipment like air preheaters (APH), condensers and cooling towers make up its landscape.

Even with advanced control systems in place, monitoring, optimizing performance, and periodic maintenance of these equipment becomes challenging due to:

- Complex plant dynamics
- Interconnected equipment with interacting operations
- Variability in coal quality due to diverse sources and inadequate blending
- Flexibility to accommodate transient and sharp variations in power demand
- Gradual degradation and faults of equipment over time
- Tightening and evolving emission standards and safety regulations

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[1] IEA World Energy Outlook 2020
[2] https://www.ge.com/digital/sites/default/files/download_assets/GE-Digital-Power-Plant-Brochure.pdf; Accessed 21 July, 2021.

Figure 1 illustrates the various aspects of power generation, their data sources, and the challenges they pose.

Given the complexities and scale of operations across these plants, it is imperative to take decisions in real-time, as delays lead to huge losses and catastrophic events. There is still considerable dependence on operator expertise for running the plants. Operators take decisions based on heuristics that often result in sub-optimal operation, leading to higher cost of operation and emissions.

Delivering Value through Digital Technologies: An Opportunity

Implementation of the latest digital technologies encompassing the Internet of Things (IoT), artificial intelligence (AI) and advanced analytics play a critical role in improving the performance of thermal power plants. Equipment manufacturers, utility companies and consulting firms have recently launched and deployed digital platforms to address various needs of power utilities.[3,4,5]

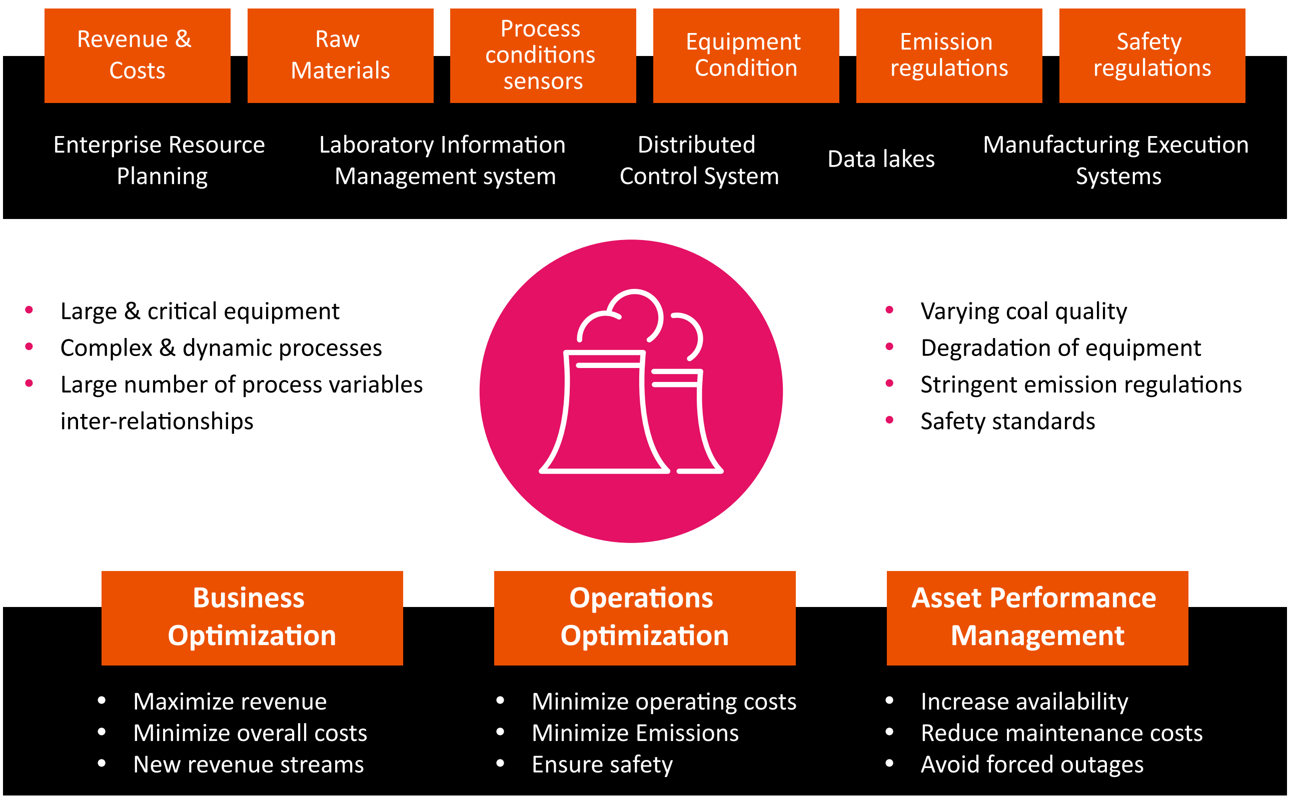

Figure 1: Performance optimization challenges faced by thermal power plants and sources of data in a power plant

Digitalization of power plants has resulted in the generation of huge amounts of operational, enterprise and other data types. This can be effectively leveraged for business operations optimization and asset performance management. Specific examples of creating value while guaranteeing sustainability by leveraging digital technologies are listed in Table 1 below.

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[3] https://www.worldcoal.org/coal-facts/; Accessed 21 July, 2021
[4] https://www.siemens-energy.com/global/en/offerings/services/digital-services/asset-performance-management/whitepaper-download.html; Accessed 21 July, 2021
[5] https://www.arcweb.com/9 August, 2018; blog/digital-technologies-thermal-power-plants-improves-performance-roi

Improve monitoring of process and equipment	Optimize process/operation in real-time	Improve availability and avoid forced outages
• Soft sense furnace conditions in boiler (temperature, cleanliness) • Detect incoming coal quality (change of coal, type of coal) • Predict catalyst degradation in SCR • Soft sense fouling conditions in APH (amount and location of deposition)	• Maximize process efficiency (Boiler-APH efficiency, Turbine efficiency, NOx conversion in SCR, SOx reduction in FGD) • Minimize pollutants and ensure compliance (particulate, NOx, SOx, CO, CO_2, mercury) • Reduce chemical costs (ammonia, limestone) • Ensure safety (furnace temperatures, tube cracks, valves) • Optimize cleaning process (soot-blowing in boilers, cleaning of APH)	• Detect and diagnose failure early in boilers and turbines • Forecast fouling progression in APH • Predict deactivation of catalyst layers in SCR

Table 1: Leveraging digital technologies for sustainable operation of thermal power plants

Digital Twin Solutions for Thermal Power Plants

A digital twin is a cyber-physical system that replicates the behavior of the real-life physical system while maintaining its communication with the actual system in real-time and makes recommendations to improve the plant operations as illustrated in Figure 2. It employs models that are trained using the past plant data, and state-of-the-art algorithms to predict the plant behavior at present and make prescriptive decisions for optimizing plant performance. It uses physics-based predictive models to improve the accuracy of some complex processes.

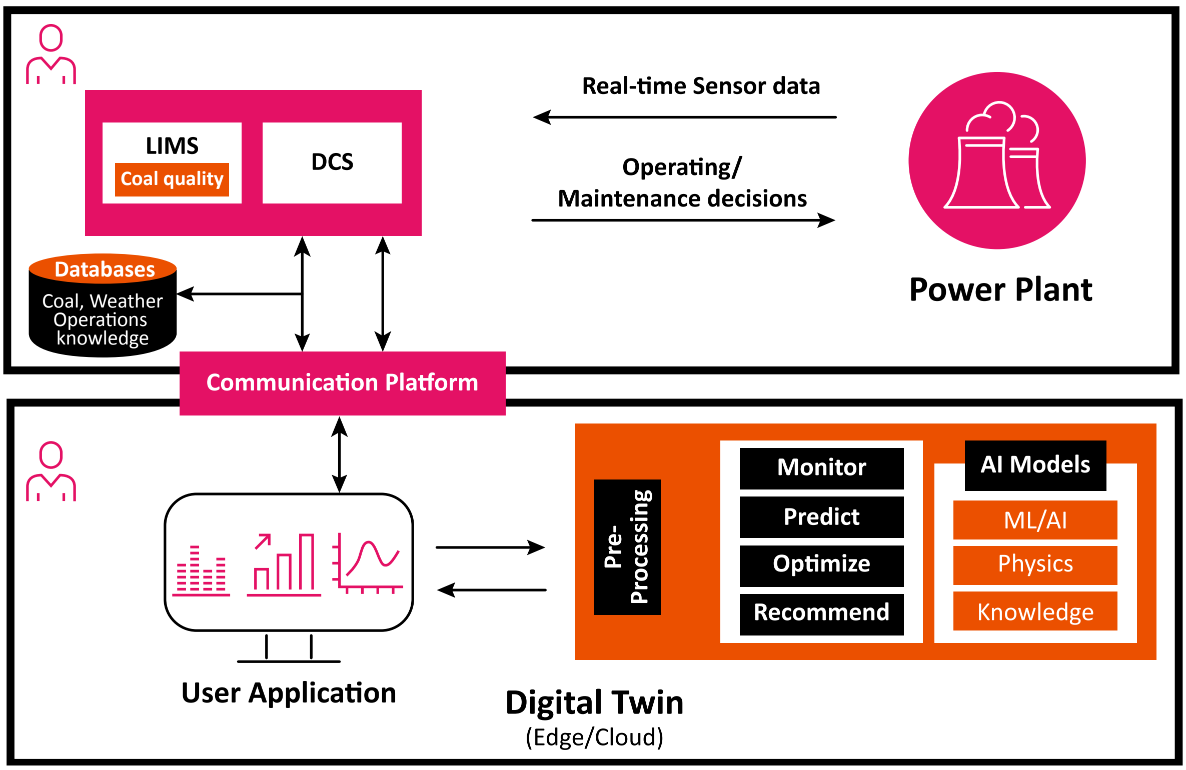

Figure 2 – Schematic of a digital twin system for a power plant

Digital Twin solutions address optimization of key performance indicators (KPI) that have conflicting goals and constraints at the equipment, plant and site levels. Advanced industrial analytics with optimization and control can help solve complex multi-objective decision-making using IoT and the cloud.

Some of the applications where a digital twin can make a difference for improving the plant performance and reducing emissions are described below and summarized in Table 2:

Boiler Digital Twin

A boiler in a 1000 MW unit consumes close to 9000 tons of coal per day and causes nearly 76% of the NOx emissions in the United States[6]. Improving and maintaining the efficiency of boilers and existing thermal power plants can reduce emissions. The challenge is to identify optimum operation settings in real-time, in response to variations in fuel properties and fluctuating power demand.

A digital twin of the boiler can utilize the power of IoT, AI and digital technologies to detect the change of coal[7]. Sensing environmental conditions and power demand, the twin can identify an optimum operation strategy to maximize heat rate and minimize emissions from the boiler. Boiler digital twins can reduce 8-10% of outgoing NOx and cut coal consumption by approximately a million dollars annually. These improvements also result in reduced load on emission control equipment, lower usage of reagents/chemicals, and lower auxiliary power consumption. Digital twins can benefit industrial boilers as well as captive power plants.

Combined Cycle Gas Turbine (CCGT) Digital Twin

Combined cycle power plants are among the cleaner fossil fuel-powered plants. Their fluctuating power demand makes them operate at lower thermal efficiencies and susceptible to process faults. Digital twins of CCGT power plants can learn process dynamics and recommend optimum settings in real-time to improve the thermal efficiency by 0.4-0.6%[8]. Additionally, the predictive maintenance module of the twin can prevent catastrophic failures through early fault detection and dynamic root cause analysis. The CCGT power plants enabled by digital twins ensure substantial benefits in terms of operating costs and emissions.

Flue Gas Desulfurization (FGD) Digital Twin

Coal-fired power constitutes almost 90% of the SO_2 generated from power sources in the United States[6], making it imperative to run the FGD unit optimally. FGD operations are expensive due to the power and chemical requirements. The challenge is to adjust the operation of FGD to reduce the pumping cost and limestone usage without compromising its SOx removal efficiency and maintaining pH levels of limestone slurry in the tank. A digital twin can identify the optimum operating conditions needed to deliver consistent SOx removal efficiency[9]. Such real-time optimization can reduce the overall energy and material costs by up to $30 million annually for a 1,000 MW plant.

APH-SCR Digital Twin

Selective Catalytic Reduction (SCR) units use a series of catalyst beds to facilitate the reduction of incoming NOx from the boiler via chemical reactions with a reagent like ammonia. The catalyst effectiveness gradually decreases due to process conditions, aging, chemical poisoning and deposition of ash from the flue gases. This results in driving up the harmful emissions of mercury, sulfur trioxide and ammonia. The increased ammonia slippage accelerates fouling or clogging of downstream equipment called Air preheater (APH). A clogged APH means reduced boiler thermal

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[6] https://www.eia.gov/todayinenergy/detail.php?id=37752
[7] WO2021033207A2, https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2021033207&tab=PCTBIBLIO
[8] WO2020255173A2, https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2020255173
[9] WO2020261300A2, https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2020261300

efficiency and increased power consumption by fans. Prolonged fouling may result in a forced plant shutdown for APH cleaning and generation of hazardous cleaning effluents. Monitoring the condition of SCR catalyst beds and APH clogging are critical problems.

A digital twin of an SCR-APH system can learn the catalyst degradation and APH clogging patterns from historical data. AI models can be used to identify optimal timelines and schedules for catalyst replacement. The advanced forecasting models for APH fouling can provide an optimum operation strategy to eliminate forced plant shutdowns and reduce the fan power consumption[10].

Equipment	Function	Digital Twin			
		Objectives	Challenges	Recommendations	Benefits
Coal fired Boiler and pulverizer	Burns coal/oil to produce steam (largest emitter of CO_2, NOx, SOx and particulate matter)	• Maximize efficiency • Minimize emissions • Ensure safety	• Fluctuating load • Varying coal quality	• Real-time detection of coal change • Real-time optimization in response to variations	• 8-10% of NOx reduction • Cut annual OPEX by $1M • Reduced reagent usage downstream
Gas Turbine	Burns gas to produce power (cleanest fossil fuel power)	• Maintain efficiency • Detect anomalies	• Fluctuating demand • Environmental variations • Highly dynamic equipment faults	• Real-time optimization in response to variations • Real-time detection, diagnosis of faults	• 0.4-0.6 % increase in thermal efficiency • Avoid forced outages
Flue Gas Desulphurization (FGD)	Reduces SOx from exhaust gases using Limestone (Important for coal as it generates 90% of SO_2 from all power sources in the US6)	• Minimize energy consumption • Minimize limestone usage	• Varying SOx emissions • Varying gas flow from boiler • Expensive Limestone	• Real-time optimization of number of pumps and limestone usage in re-sponse to variations, while maintaining efficiency and pH	• Save up to $30M annually on energy consumption and limestone costs
Selective Catalytic Reduction (SCR)	Reduces NOx using Ammonia and cata-lytic beds (Critical because 76% of power industry emissions in US6)	• Maintain low Ammonia usage and slippage	• Invisible catalyst degradation in SCR • Inaccurate Ammonia slip measurements	• Real-time soft sensing of catalyst degradation and Ammonia slip • Optimized catalyst replacement schedule	• Better environmental compliance by minimization of NOx and Ammonia
Air Preheater (APH)	Enhances efficiency by heat recovery (Saves coal worth $15-20M annually)	• Forecast APH fouling in advance	• Unpredictable fouling of APH	• Advance forecast of APH fouling patterns	• Save $30-40M annually by avoiding forced outages due to Ammonia slip and APH fouling

Table 2: Instances where digital twin technology can make a difference

Towards a Sustainable Future for Thermal Power Plants

In 2019, it was assessed that about 43.1 billion tons of CO_2 was emitted into the atmosphere due to human activities. Drastic actions are necessary to achieve the goals of the Paris agreement to limit the rise of global temperatures to 2°C. While the world increasingly adopts renewable energy, thermal power plants will continue to play a crucial role for a few more decades.

Today, power plants are increasingly embracing digitalization and are primed for reaping its benefits. Unfortunately, many of these solutions have been limited to dashboards, automated reports, and a few isolated digital use cases. Digital twin technology must become ubiquitous across the thermal power industry to ensure reduced carbon footprint and minimal emissions along with improved energy security and availability across the world.

[10] WO2021070201A2, https://patentscope.wipo.int/search/en/detail.jsf?docId=IN322249512&_cid=P20-KS9Z28-29466-1

About the authors

Anirudh Deodhar

Anirudh is a scientist at TCS Research with more than 10 years of experience in process modeling, ML and digital twins. Anirudh and his team have won the Tata group level innovation award at Tata Innovista 2018 and the IT Innovation Award from Express IT awards in 2018, for their work on digital twin technology. Anirudh is a mechanical engineer and holds a Master's degree from University of Cincinnati, USA.

Sri Harsha Nistala

Sri Harsha is a scientist at TCS Research in the areas of process modeling and simulation, optimization, industrial analytics, and digital twins. He holds a Master's degree in chemical engineering from IIT-Bombay. Sri Harsha led the team that won the first place in the US PHM 2018 Data Challenge. His artistic pursuits include painting and creating pencil sketches.

Rajan Kumar

Rajan is a researcher at TCS Research with seven years of experience in industrial process optimization, equipment health diagnostics and prognostics, and digital twins using ML and AI. He holds a Bachelor's degree in chemical engineering from IIT-Kharagpur. Rajan has two granted patents, has filed eight patents, and was part of the APAC regional winning team that won the Tata group level innovation award at Tata Innovista 2019.

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