Optimising Performance: Improving thermal power plant O&M with AI and digital tools

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Thermal power plants (TPPs) are operating in a far more demanding environment than before. Plants are increasingly required to ramp up and down, maintain emissions, performance and reduce unplanned shutdowns, all while preserving asset health. The increased renewable energy (RE) addition results in higher variability in the grid and to manage this variability, the flexible operation of thermal power plant is becoming a necessity. The operations and maintenance (O&M) challenge in thermal generation is now defined by a combination of technical, economic and organisational pressures. Fuel quality variation continues to affect combustion behaviour, boiler performance and heat rate. Stringent environmental norms require tighter control over emissions and operating parameters. At the same time, utilities remain under pressure to reduce costs, avoid unplanned shutdowns and align operations with broader decarbonisation goals.

In this environment, digitalisation is gaining strategic importance, and artificial intelligence (AI) is emerging as a practical O&M tool for improving plant performance, supporting predictive diagnosis and enabling more data-driven interventions.

Key drivers for digital transformation

The shift toward digital transformation in thermal plants is being driven by six broad factors: operational efficiency, cost optimisation, asset reliability, sustainability goals, regulatory compliance and workforce productivity. On the efficiency side, there is growing emphasis on real-time monitoring to optimise plant performance and reduce unplanned outages. The continuous optimisation using APC helps the operators to maintain higher efficiencies for the plants. From a cost perspective, utilities are looking to reduce fuel consumption through and lower maintenance expenditure through condition-based/predictive maintenance. Asset reliability has become a major driver as plants seek real-time asset health monitoring, AI-based failure prediction and lifecycle enhancement. Sustainability objectives are reinforcing the need to improve energy efficiency and reduce carbon footprints, even within conventional generation. Regulatory compliance is increasing the value of better emission control and stronger transparency for audits, while workforce productivity is being supported by digital tools for remote monitoring, operation and skill enhancement.

Within this broader digital transition, AI is becoming relevant because it directly addresses some of the most persistent issues in thermal O&M like part-load operation and its inefficiencies, load cycling and associated life impacts, coal inventory optimisation and blending, combustion stability, auxiliary power reduction, performance improvement, remote asset monitoring, water chemistry fluctuations, and power forecasting. Its value lies in process optimisation, improved operational efficiency, predictive maintenance, data-driven decision-making, O&M cost reduction, and improvements in reliability and asset life.

Specific AI applications in O&M

AI is being applied in TPP O&M to support six broad outcomes: data-driven decision-making, reduction in O&M cost, improved reliability and extended asset life, process optimisation, improved operational efficiency and predictive maintenance benefits.

In thermal plant opex, the primary AI-linked application areas include plant performance improvement solutions, advance process control (APC) solutions, flexible operations solutions, boiler modelling and simulations, performance gap analysis, and digital point solutions based on AI and machine learning. These applications indicate that AI in O&M is being positioned not as a generic digital overlay, but as a set of targeted interventions for improving plant operations and equipment performance. A key part of this approach is the use of digital point solutions across specific plant systems and functions. Together, these applications show that AI is being extended across both core process areas and auxiliary systems.

The AI-based analytics engine supporting these applications combines three layers. The first is a data-driven framework, which performs millions of computations across asset data and supports pattern recognition, prediction and diagnostics. The second is a knowledge base built on design data, historical data and maintenance failure history, allowing plants to leverage and retain team expertise. The third is a physics-based framework, which applies strong domain expertise to specific assets through derived features, failure mode and effects analysis-based fault tree analysis, and process know-how and standard operating procedures. This combination allows digital tools to support diagnosis and decision-making in a more asset-specific and process-oriented manner.

APC is a key solution that helps real time optimisation of plant performance. Among the most important applications is APC, which is a closed-loop solution that works in coordination with the existing distributed control system. It can simultaneously control multiple loops, support the full operable range and enable part-load efficiency optimisation. The system is based on a dynamic mathematical model, model prediction and controller logic, and multivariable control and optimisation, while also influencing proportional-integral-derivative controllers. This makes APC particularly relevant for TPPs that need tighter process control and better operational performance across varying operating conditions.

Boiler modelling and performance optimisation is another major application area. APC's capabilities include predicting boiler performance with different qualities of coal, providing insight into boiler operating conditions, guiding operators towards optimum boiler operation, aiding coal purchase decisions, evaluating and predicting temperature profiles and heat absorption across each heating section of the boiler, and assessing boiler performance under different load conditions. With help of such a tool, significant improvement in boiler efficiency and heat rate improvement is possible. Overall, the AI applications identified for TPP O&M are centred on optimisation, diagnostics, monitoring and performance improvement. Their value lies in combining engineering knowledge with operating data to support more informed intervention across plant processes and equipment.

Case studies

At a 300 MW captive TPP, APC was deployed in response to large fluctuations in power demand caused by process variations, wide variations in coal quality, unoptimised operational parameters, limited response from distributed control system (DCS) control loops tuned for design coal, the use of additional fuels such as blast furnace gas and Corex gas, and deterioration in heat rate performance. The intervention involved the deployment of APC for heat rate improvement and annual maintenance of the application. The implementation required an estimation of heat rate improvement potential from operational data, coordination with the DCS vendor, identification of loops with improvement opportunity, conversion of selected manual loops to automatic control, and optimisation of combustion control under full- and part-load conditions with variable coal quality. The results included better heat rate, better stability, improved ramping capability, lower operating cost and lower carbon footprint, while also helping the TPP cope better with flexible operation requirements.

Boiler modelling and simulation have also been used to address more complex combustion and fuel-related issues. Further, computational fluid dynamics analysis at a thermal power plant with circulating fluidised bed combustion-based TPP in the Philippines shows how digital tools can support detailed operational diagnosis where instrumentation and plant familiarity remain constraints. The study involved a review of existing design and operations, modelling of the primary air system, computational fluid dynamics analysis of the air system and furnace, and recommendations to improve flow distribution and combustion across the full operating range. The exercise highlighted common field challenges such as faulty or unavailable instrumentation for critical parameters and limited familiarity of site personnel with such advanced analysis, but also showed the value of model-based recommendations for correcting flow and improving combustion.

Cooling tower optimisation provides another example of AI-enabled efficiency gains. At a steel plant, performance improvement initiatives for utility cooling towers involved variable frequency drive implementation, replacement of older motors with higher-efficiency motors and automated variable frequency drive operation linked to weather variation through advanced algorithms. At the by-product plant cooling tower, these changes were estimated to reduce energy consumption by 620,000 units annuallyand reduce carbon emissions by 511 tonnes per year. At the cold roll mill cooling tower, the corresponding estimated energy saving was 107,000 units annually and carbon reduction of 88 tonnes per year.

Water chemistry management offers a further use case. At a 1,450 MW TPP in the Philippines, a transition from all volatile treatment oxidising to oxygenated treatment required a review of existing practices, development of a transition plan, implementation support, personnel training, performance monitoring and documentation. The plant faced several constraints, including prolonged operation under the earlier chemistry regime, bottlenecks related to sampling line choke-ups, non-functional analysers and limited site-level skill for oxygenated treatment. Digital monitoring and diagnosis tools were used to support water cycle chemistry optimisation and online monitoring, alongside recommendations and standard operating procedures aimed at ensuring a smoother transition. This highlights how AI and digital tools can strengthen not only performance but also operational discipline and knowledge transfer.

The way forward

AI in the O&M of TPPs is now moving beyond isolated pilot projects toward a more integrated role in plant operations. Its strongest value lies in helping plants cope with a more demanding operating regime marked by variable fuels, flexible despatch, ageing assets, cost pressure and reliability concerns. The most promising applications are in advanced process control, boiler modelling, combustion diagnosis, cooling tower optimisation, water chemistry monitoring and broader performance improvement programmes.

Going forward, AI is likely to become an increasingly important layer in the O&M strategy of TPPs. As plants seek to maintain efficiency, flexibility, compliance and reliability under more complex operating conditions, intelligent systems that can detect deviations early, support root-cause analysis, guide optimisation and preserve domain knowledge will become more valuable.