Realizing the promise of “Big Data” for building the power plants of tomorrow

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Just as smartphones revolutionized everyday life, the prospect of “smart power plants” may hold the same promise for the nation’s energy infrastructure.

During the 2018 Turbomachinery Conference in Oslo, Norway, a paper was presented proposing an innovative approach for assessing near real-time data from power-generating assets with meaningful predictive analytics.

This follow-up article serves as a preview to an in-depth conference paper scheduled for release in the spring of 2021 on the project. Major goals:

- **Prediction**. Characterize remaining equipment life, expended life and determine the “next failure” for critical systems and components.
- **Benchmarks**. Apply characterization of the equipment to establish benchmarks for comparative analysis with future advanced technology offerings.
- **Machine learning**. Develop learning models that can predict time to next failures and forecast failure trends for optimizing plant operation strategies.
- **Operations**. Optimize power plant operation to reduce failures due to cyclic stresses from start-up to shutdown that affect equipment life.

The Oslo presentation, “*Energy Innovation: A Focus on Power Generation Data Capture & Analytics in a Competitive Market*,” raised important issues such as what it takes to rapidly identify and act on a power plant system, components and operation that are disruptive, impact generation, drive up costs and reduce profitability.

Recognizing the potential importance of this concept to electric utility operations and plant designs worldwide, a team of engineers in the United States has been working throughout 2019 and 2020 to develop practical answers to that challenge.

Makeup of research team

The team working to meet that demand consists of Strategic Power Systems Inc. and Turbine Logic (industry) in collaboration with the National Energy Technology Laboratory and Oak Ridge National Laboratory (government).

Their work has been supported by the U.S. Department of Energy *Fossil Energy Program.* through its HPC-4Materials project, which provided access to high-performance computing assets at both laboratories.

Unique engineering and data science disciplines that converged on this project provided the backbone for the unbiased analysis and model building that took place – backed by access to up-to-date sources of plant operating and design data essential tor performing the engineering scope of work.

A key objective was to use predictive data and modeling to characterize remaining life, expended life, and time to “next failure” for critical systems and components.

“The fossil fuel power plant fleet throughout the country is now operating under parameters it was never designed for, switching generation from high to low output, back and forth, rather than at continuous levels as originally intended,” says Briggs White, technology manager for NETL.

“While this may be helpful in lowering greenhouse gas emissions, it takes a toll on the plants themselves. We have to get creative and embrace new technologies to maximize their efficiency and lower their operating costs to keep them running for as long as possible."

HPC4Materials program

Besides providing benchmark data for comparative analysis of advanced technology offerings, this program contributes to the definition of dynamic conditions that could lead to downstream system failure, such as heat recovery steam generator (HRSG) tube failures.

Creating new "wear-and-tear" models can provide operating power plants with predictive capabilities for addressing the expected maintenance required to reduce negative consequences of cyclic duty on the HRSG and balance-of-plant equipment.

Key to the team's work was acess to Strategic Power System's ORAP (Operational Reliability Analysis Program) data set. going back to 1987, which maintains a statistically accurate picture of power plant operation across various duty cycles, applications and technologies.

This, combined with other company assets, provided the time series data with process control data points (e.g. time, load, pressure, temperature, speed, trips, alarms and several others) that allowed for computational analysis and model building.

With these private sector resources, working hand in hand with the national labs, the team took DOE's HPC4Materials from a concept to a working project to provide power plants with real-time decision-making capabilities.

Oak Ridge contributions

Oak Ridge National Laboratory contributions to the project focused on machine learning to predict power plant operating failures.

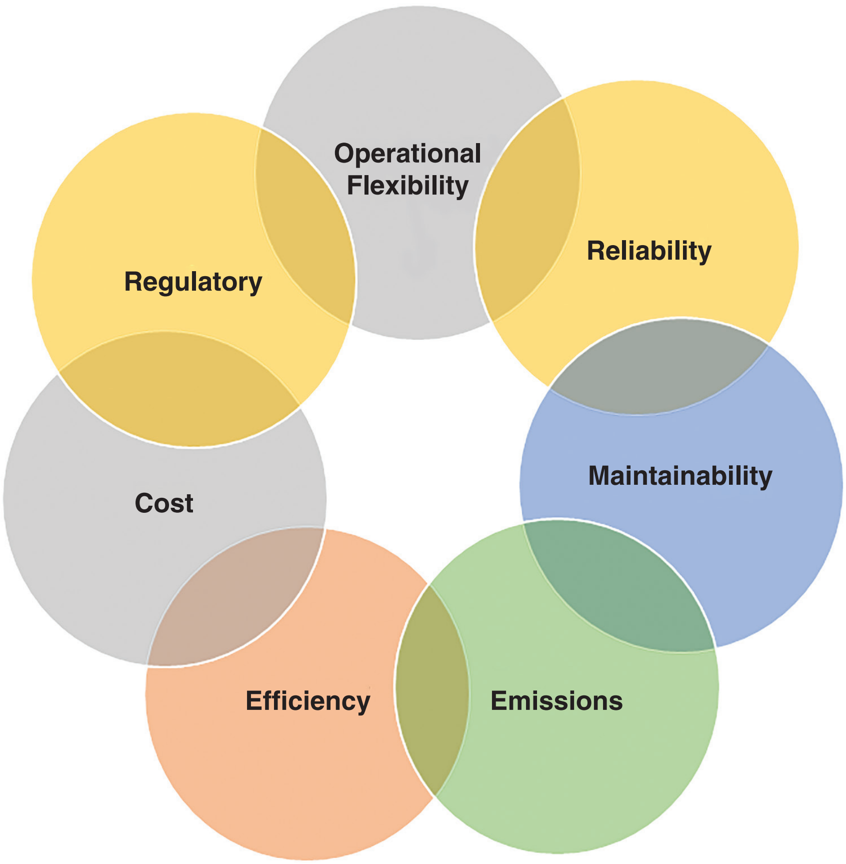
Extensive review of ORAP's Reliability, Availability, and Maintainability (RAM) data guided the team in developing machine learning models for predicting time-to-next failures and forecast failure trends useful for optimizing power plant operation strategies.

Building on this, ORNL developed multiple random models and validated their accuracy against more than a decade's worth of historical data. ORNL also implemented a web-based graphical user interface system for those models to show how they can be used in more intuitive ways.

This proof of concept allowed exploration of models with power plant operators in mind. Machine learning

Big Data has developed technology to predict when power plant components are likely to fail. The information will allow operators to schedule maintenance and take other proactive steps to prevent shutdowns and avoid disruptions in power output.

Power plant operators must juggle a variety of challenges which often overlap or even contribute to one another.



models are being developed that will be helpful for managing risks, planning maintenance and operation -- ultimately reducing downtime and increasing service hours.

Another thrust of this project focused on leveraging real-time data from numerous sensors across the power plants. The goal was to determine the feasibility of forecasting fine-grained detail of power plant operations several minutes in advance to enable an early warning system for plant operators to mitigate issues which otherwise might lead to unexpected failures or other forced downtime.

ORNL leveraged convolutional neural networks to learn from historical sensor data and make predictions about the future state of power systems. ORNL also built a system for visualizing predictions (second by second) from a vast array of sensors to better understand the efficacy of the neural network-making predictions.

National Energy Tech Lab

NETL created physics-based models to optimize power plant operation and reduce failures due to cyclic operation.

To do this, the team used near real-time process data characterizing the operating environment and dynamic conditions, from start-up to shutdown, that affect HRSG tube life.

The lab's supercomputer, together with commercial ANSYS computational fluid dynamics and finite element analysis software, simulated different scenarios for an assortment of modules to solve for combinational effects of fluid dynamics, thermal stress, heat transfer, and structural mechanics of components and materials.

Input data included detailed material properties and realistic operating conditions for predicting local component stresses under frequent cycling. Capturing detailed dynamic stress data involved substantial computational cycles which required access to the lab's JOULE 2.9 supercomputer.

It enabled the team to model component performance at a continuum level and to simulate different operating scenarios to solve for combinational effects of fluid dynamics, thermal stress, heat transfer, and structural mechanics of components and materials.

This work goes to the heart of the NETL and DOE initiative research program (eXtremeMAT) purpose to accelerate development of advanced environment-resistant materials that can withstand extremely high temperatures and pressures.

Further developments needed to realize XMAT goals include new thermal-resistant coatings for power plant components and different combustion patterns to cope with higher stresses due to gas turbines being operated cyclically with more starts, stops, restarts, part loading and rapid loading and unloading.

High-value impacts

"This work goes to show the value of the DOE national labs to the entire country," says Salvatore A. DellaVilla, founder and CEO of Strategic Power Systems.

"They provided full access to resources and talents, including top-tier subject matter expertise in the fields of artificial intelligence and machine learning that are invaluable.

"Collaborating with these labs enabled SPS to perform analysis and investigations that wouldn't have been feasible to pursue on our own."

Going forward, the fruits of this collaboration have the potential to better inform operational decisions, reduce disruptions or forced outages while meeting the needs of changing service demands based on increased needs for operational flexibility.

If these tools and techniques are optimized and commercialized, the benefits will be felt throughout the entire nation. Both large and small independent power producers can continue using existing capital investments in fossil-based energy generation.

The opportunity to extend the project results in a practical way to the equipment owner operators is a critical objective in a changing and complex energy market. Other perks include reduced operational and maintenance costs leading to upgrades of capital equipment, maintaining highly skilled labor, and improving marketplace competitiveness.

As the twenty-first century marches on, the trend of going hi-tech in every facet of life will continue, which means increased energy demands. Meeting this growing demand in a sustainable manner means the nation's energy infrastructure must also go hi-tech with optimized "smart power plants."

Such facilities translate into a better and brighter future everywhere in which the lights stay on, less fuel is used greenhouse gas emissions are reduced, and plant operators save money – all of which ends up as consumer benefits.

About SPS

Expert in data collection, validation, analysis and benchmarking of power plant performance across industry technologies, based on a "Data First" strategy of doing business.

Strategic Power Systems provides key performance metrics following industry standards to power plant owner operators, original equipment manufacturers, and industry stakeholders through its Operational Reliability Analysis Program (ORAP) data services.

This information allows the industry to make informed business decisions relating to the performance and operational readiness of their equipment. There is no system in the world that collects power plant data in such a comprehensive way as ORAP.

About ORNL

Oak Ridge National Laboratory is the largest U.S. Department of Energy science and energy laboratory, conducting basic and applied research to deliver transformative solutions to compelling problems in energy and security.

ORNL's diverse capabilities span a broad range of scientific and engineering disciplines, enabling the Laboratory to explore fundamental science challenges and to carry out the research needed to accelerate the delivery of solutions to the marketplace.

About NETL

The U.S. Department of Energy's National Energy Technology Laboratory develops and commercializes advanced technologies that solve America's energy challenges. NETL's work supports DOE's mission to advance the national, economic, and energy security of the United States.

Project members

This project was supported by the U.S. Department of Energy Office of Fossil Energy, (DOE-FE) High Performance Materials program; Robert Schrecengost, DOE-FE program manager; and Briggs White, NETL technology manager.

The research described was completed by a team of individuals from all four (4) participating entities. Besides the three authors, additional members of the team include:

- **NETL**: Yong Liu, Youhai Wen and Tianle Cheng
- **ORNL**: Dongwon Shin, Matt Lee, Travis Johnston and Maria Mahbub
- **Strategic Power**: Robert Steele
- **Turbine Logic**: Chris Perullo and Scott Sheppard.

Asset Insight data are easily transformed into the unit-specific operating mission, from start-up to a safe shut-down or trip from load, with all of the time series accurately calculated and reported.