ELECTRIC POWER RESEARCH INSTITUTE

Quick Insight Brief: Digital Twin

For more than 50 years, the concept of digital twins has existed in the industrial world. But what exactly is a digital twin, specifically in the context of the power industry? Is it similar to a virtual mirror, digitally reflecting the state of a physical asset for easy visualization and optimization? Or is it an ultra-high-fidelity algorithm that optimizes the design and operation of a device and predicts future faults, so that unplanned outages become a thing of the past? Although the latter may become a reality one day, we are not quite there yet. Today, digital twins operate somewhere in the middle of that spectrum. But the idea of using a computer to simulate the current state of real hardware is not a new one.

Although digital twins are often viewed as emerging technologies for prognostic and diagnostic needs, the concept of detailed asset models has been around for decades. The National Aeronautics and Space Administration (NASA) had an effective digital twin during the Apollo program. When the Apollo 13 capsule became damaged, NASA engineers pulled the flight simulators into duty and recreated the spacecraft conditions. In essence, they created a twin. Digital twins are typically an intelligent integration of many of the underlying tools that already exist. Improvements in materials science, microsensors, computational power, and data analytics techniques have fundamentally changed how complex systems can be modeled and managed. These changes mean that physics-based models and data-driven algorithms that required specialized hardware not long ago can now be run in real time on critical business information technology systems. Physics-based models, data-driven intelligence, and sensing and instrumentation have all existed for a long time but are now accessible and integrated.

The end goal of digital twin integration is to automate complex engineering tasks so that the results are always at your fingertips to improve decision making. It may help to think of the digital twin as a continuum with data and insight flowing from the asset to a processing and analytics platform and then to a person who can react to insights from the data. Those changes in operation or maintenance then feed back to the asset, and the cycle repeats. Digital twins should enable quicker, more insightful decision making by connecting the asset, data processing, and human interaction.

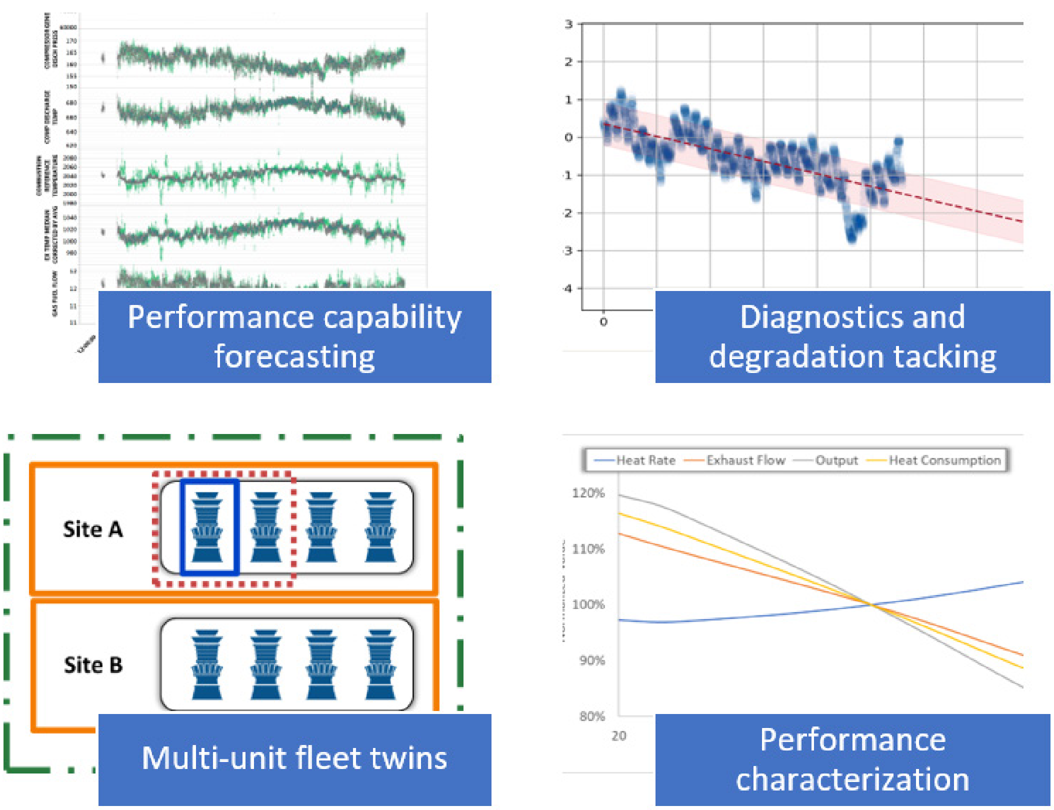
Digital twins are fundamentally about integrating data, knowledge, and analysis capabilities. Extensive data sets are now available thanks to the Internet of Things. These data are processed in large magnitudes by advanced data management tools and machine learning algorithms. This effort contributes to a more informed workforce that is capable of adapting operations quickly to support critical assets. Simultaneously, computer-based modeling techniques have become more accurate and accessible. Digital twins represent the next evolutionary step by incorporating these tools in a real-time analysis of physical system operation.

DIGITAL TWIN RESEARCH AND DEVELOPMENT

The Electric Power Research Institute (EPRI) has been developing gas turbine digital twin models for simple- and combined-cycle gas turbines, a more-than-five-year effort designed to provide owners and operators with improved capabilities that have historically resided in the expert domain of original equipment manufacturers and third-party service providers. The digital twin is a physics-based, digital representation of the actual asset. The thermodynamic model is created with the intent to support the following monitoring and diagnostic (M&D) areas:

- Integration with existing M&D tools, such as advanced pattern recognition
- Power plant performance prediction and trending, such as day-, week-, and month-ahead performance prediction for capacity and generation planning
- Health monitoring and fault diagnostics to support asset management with additional health scores and virtual instrumentation enabled by the digital twin model
- Monitoring and prediction of both base and part-load performance (Many gas turbine tools have been simplified to work only at full-load conditions. To improve utilization of collected data, part-load conditions should also be considered.)
- Outage and repair impacts, including what-if capability to understand and quantify potential root causes of less-than-expected performance improvement or recovery after outage and repairs

Compared to traditional prognostic and health management systems, the digital twin-driven system has significant advantages. On the prognostic side, digital twins can accurately predict future performance. Performance forecasting is especially useful for predicting how much energy to bid for in the power market. Another use is updating the physical model to accurately predict the future performance of the units after performing a large-scale hardware upgrade. This allows an owner to accurately calculate return on investment for the upgrade based on actual data.



These predictions are also helpful for maintenance planning because performance degradation over time will be calculated to see whether operators can postpone specific maintenance until a later outage. Digital twin applications are multi-faceted because they can be applied to a wide range of diagnostics, prognostic, and what-if problems. Examples include using the digital twin to identify causes of post-outage performance issues and expected impact of degradation and fault conditions, to simulate improvements to operation through part repair and upgrades, and eventually to estimate component remaining useful life. There must be an interface that uses the digital twin's predictive analytic capabilities with the physical plant in all these cases.

The EPRI team chose commercially available software for the inner workings of the EPRI digital twin to maximize cost-benefit and enable this effort to focus on the modeling activity. Also considered was flexibility for future use, including modeling the steam turbine and heat recovery steam generator, transient (dynamic) simulation, and modeling large-frame and aero-derivative gas turbines. Gas turbine digital twins have been created and tested for 7FA, 7EA, and 6B frames, though the software can simulate any gas turbine.

EPRI has designed this digital twin to integrate into any industry-standard M&D software. To connect the M&D system, the physical model of the digital twin is encapsulated through a series of closed-form, linear equations that have been tested and shown to provide good accuracy at detecting faults and at predicting day- and week-ahead performance.

One essential feature of a digital twin is its diagnostic and prognostic abilities. Virtual, or soft, sensors of a digital twin, allow deeper analysis on the performance metrics that may or may not be measurable. The analysis from the virtual sensors can provide new insight into the health of the asset. This approach uses historian data and transforms it into virtual sensors capable of more directly detecting faulted operation. Historian data, such as power, heat rate, and thermal measurements, are used as inputs to the digital twin equations. These equations are created from the physical model and are customized to a specific gas turbine. The outputs of these equations are estimates of virtual sensors, which de-noise the historian data and provide a cleaner assessment of individual module performance. The same inputs and outputs can be changed because unit instrumentation availability and reliability are required to meet current M&D needs.

CONCLUSION

New developments in simulation tools and techniques have enabled the creation of digital twin asset models to improve current analytic and prediction capabilities.

The EPRI digital twin brings together existing commercial software, calibration techniques, and model simplification approaches to enable owner-operators to use as-is historian data to create a predictive model of the gas turbine. The digital twin is currently running real time at several EPRI-member sites, inside their advanced pattern recognition tool or historian software. In a monitoring and diagnostics setup, two sets of equations can be used. First, the virtual sensor predictions may be used to estimate unit health directly. Then, future performance predictions can be made with the current estimated values of each virtual sensor. With the first set of equations, the user would directly monitor for shifts in virtual sensors. In the second set, the user would compare future performance estimates against real-time data to detect faults. The turnaround time from data extraction to implementation is as short as one day after the infrastructure is set up for a site. To date these models have been deployed on 25 units of four different types.

To date, the EPRI gas turbine digital twin has been applied to several real-world applications, including forecasting performance capabilities, tracking and trending performance degradation that is caused by compressor fouling, creation of fleet level digital twins for site performance monitoring and prediction, and performance characterization to identify outage and repair impacts to performance.

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Gas Turbine Life Cycle Management

The Electric Power Research Institute, Inc. (EPRI, www.epri.com) conducts research and development relating to the generation, delivery and use of electricity for the benefit of the public. An independent, nonprofit organization, EPRI brings together its scientists and engineers as well as experts from academia and industry to help address challenges in electricity, including reliability, efficiency, affordability, health, safety and the environment. EPRI also provides technology, policy and economic analyses to drive long-range research and development planning, and supports research in emerging technologies. EPRI members represent 90% of the electricity generated and delivered in the United States with international participation extending to nearly 40 countries. EPRI's principal offices and laboratories are located in Palo Alto, Calif.; Charlotte, N.C.; Knoxville, Tenn.; Dallas, Texas; Lenox, Mass.; and Washington, D.C.

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