Evolving Nuclear Power Generation through Optimized Asset Performance Management

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INTRODUCTION

Today's outlook for the future of nuclear power generation is both promising and ominous. Across the world, nuclear technology continues to generate reliable, emission free, high capacity base load energy, and the global footprint for nuclear generation is growing. Advancements in passive safety, modular design, and Generation III+/IV reactor technology signify optimism for utilizing nuclear generation to satisfy electricity demand in the 21st century and beyond. On the other hand, plant sites and generating utilities face substantial economic pressure forcing early retirement and decommissioning in troubled markets. Specifically, the United States commercial nuclear industry is increasingly imperiled due to cost and schedule overrun at the few new sites under construction, as well as lack of coherent vision for energy policy. To encourage sustainable industry growth, Nuclear Power Plants (NPPs) are turning to advanced technologies to optimize people, processes, and assets.

The Industrial Internet of Things

Data and information are more accessible than ever before, and analytics insights more powerful. Information technology across consumer electronics, smart devices, and connected machines creates a data-rich ecosystem known as the Internet of Things (IoT). Industries are adopting IoT principles for improving operational performance using analytical intelligence that harnesses the power of data. In the power generation sector, nuclear is among the industries participating in Digital Industrial transformation, leveraging software and analytics to optimize asset performance management through utility-vendor partnerships.

In the United States and abroad, General Electric (GE) is advancing the adoption of IoT technology for multiple industries using the Predix industrial cloud platform. GE's Asset Performance Management (APM) solution, powered by Predix, is the Digital Industrial flagship which brings enterprise software and advanced data analytics to power generation and other domains[1]. In the nuclear industry, APM incorporates real-time online monitoring with strategy optimization to deliver comprehensive health management. Contemporary data science techniques and domain-based first principles models are orchestrated in an extensible workbench style approach. Analytics provide incipient detection of issues, diagnosis of symptoms, and prognosis of performance impacts in an execution-oriented workflow.

Together in a unified user experience, this integrated approach to health spans the full spectrum of nuclear asset criticality: safety-related, operational critical components, run-to-maintenance, and all in between. Taking advantage of an Asset Performance Management enterprise application on a scalable cloud platform yields substantial opportunity for NPPs to contemporize using information technology. In partnerships with generating utilities, GE has developed and deployed APM capability in the US nuclear fleet to help Deliver the Nuclear Promise through value-driven solutions.

RESULTS

Implementing enterprise software for nuclear power generation exemplifies the bonding of two distinct worlds: power generation assets rooted in the physical domain of operations and maintenance, and digital capabilities made possible by modern information technology. The blending of these two fields represents a technological evolution for the power generation industry that embraces industry operating experience gained over decades of operation, as well as contemporary methods such as Agile development and continuous integration/continuous delivery. In the US power sector, GE is navigating this confluence of domains along with industry partners to provide Digital Industrial solutions designed to deliver tangible business value.

Data Architecture

The process for implementing APM for a power plant considers inputs from a multitude of data sources:

- Operations – Plant process computer, data historian, condition-based monitoring systems, digital I&C, wireless sensors
- Performance – thermal performance, chemistry, heat rate
- Industry – EPRI, NERC, nuclear-specific: INPO/WANO, NRC, NEI, IAEA[2]
- Organizational – performance improvement, industry working groups
- Regulatory – thermal limits, environmental discharge, site security

Data access is established through secure architecture that transfers data using connectivity devices of varying footprints. High density data such as rotating equipment frequency spectrum vibration monitoring typically resides on premise to optimally locate storage and processing power

locally versus in the cloud. The Predix platform enables data integration utilizing modular microservices that ingest a diversity of data inputs, for both cloud and on premise applications. With interfaces established, data is aggregated into a metadata-driven asset model that stores hierarchy and taxonomy metadata associated with equipment instances and system functional locations.

Scalable cloud platform architecture enables data access through connectors and storage stages that are designed for interoperability. Foundational Predix platform components are architected into solutions for power producers on an application-specific basis, including both on premise and cloud installations. The diagram below illustrates the Predix technology stack with microservice level detail:

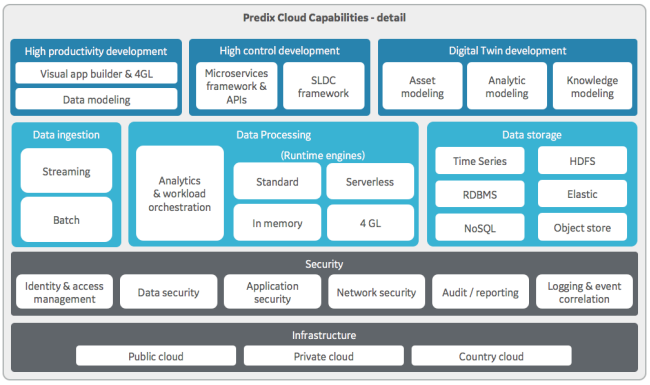

Fig. 1. Predix platform microservices architecture.

At its core, Predix is an enablement platform that brings IoT technology to industrial users. Base level infrastructure tightly couples with security layers (gray) to provision the footprint of computer hardware and system monitoring. The data layer (light blue) connects to, organizes, and stores multiple data types in an object-oriented framework rich in metadata. Development teams use catalogued microservices to deploy capabilities (blue) for application consumption, e.g. in APM. Apps built atop the Predix platform leverage these technology components in modular configurations to deliver diverse use cases, such as data unification and analytical intelligence.

Advanced Analytics

In the application space, analytics traverse asset metadata providing a broad spectrum of insights such as performance analysis, production loss accounting, and anomaly detection. Nuclear power generators benefit from increasing asset reliability, early detection of issues, and diagnosis of symptoms to develop targeted evidence-based response plans. Advanced analytics enable realizing these outcomes by providing incipient failure detection along with directed feedback on insights, based on an extensive library of fleet performance derived correlations. Time series data generated by operating equipment forms the central basis for real-time prognostics & health management when run through online monitoring analytics. Beyond time series, Enterprise Asset Management (EAM) data such as Corrective Action Program (CAP) records, work order & maintenance history, and regulatory compliance forms often contain unstructured text fields, which can be feature engineered to derive powerful attributes and indicators. Methods such as Natural Language Processing (NLP) for decomposing unstructured text fields, Similarity Based Modeling (SBM) for advanced pattern recognition, or Recurrent Neural Networks (RNN) for [un]supervised learning models are orchestrated via an analytics workbench to identify and convey value using the plethora of data generated by NPPs. The integration of contemporary data science techniques with multilayered data streams unique to the nuclear industry represents a watershed of opportunity for power generators to realize analytics-derived outcomes.

Industry Engagement

Using APM as the cornerstone of an enterprise license agreement for Predix applications, Exelon Generation Company has partnered with GE to develop and deploy the full suite of Predix tools across their generation portfolio. Nuclear power comprises the majority share of the Exelon installed base, thus pursuing digital transformation couples closely with the industry's initiative to improve economic performance. Exelon Generation engaged with GE early in platform development as a strong advocate for power use cases in the Predix ecosystem; to date Predix APM has been deployed for several Exelon sites while in parallel co-innovative pilot projects are jointly developed to maximize value opportunities. Central to Exelon Generation's vision in Predix is optimizing the graded approach to asset treatment across the entire asset criticality spectrum. Asset treatment is optimized through several levers, including domain knowledge base, industry operating experience, analytical intelligence, and maintenance strategy. Together these components relate as a Digital Twin, or the software manifestation of a physical asset that can be used for virtual testing, performance prediction, or strategy optimization.

Digital Twin

Key to successful prognostic health management is the definition of an asset model that represents the multiple facets of data pertaining to a piece of physical equipment. Equipment is characterized by manufacturer/make/model, nameplate rating, system classification, functional location, and several other characteristics; the nature of this data is EAM records in nested relational data tables. Operating equipment generates data via sensors/instrumentation and process models; the nature of this data is time series and can be high or low frequency. Status of these assets is observed via rounds, maintenance, and work execution; the nature of

this data is Computerized Maintenance Management System (CMMS) records. Ultimately each of these data types possess value to maintain reliability and maximize asset performance: EAM data the functional state, time series the operating state, and CMMS the task execution state.

In Predix these facets of data converge in a unified model known as the Digital Twin. Multifaceted data is federated to enable more informed asset management and power advanced analytics. Utilizing the diverse data of the Digital Twin, Predix APM optimizes asset performance in four interrelated components: risk, strategy, operations & maintenance, and analytics.

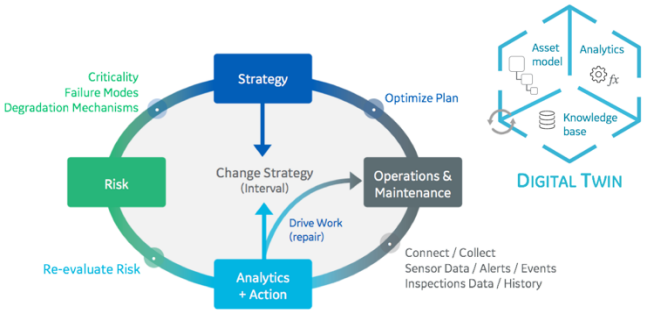

Fig. 2. Digital Twin Optimization workflow.

The workflow in APM begins with assessing risk to define the graded approach to treatment. The spectrum of criticality defines the depth and granularity of asset strategy in place. For nuclear power generators, this process draws influence from 10 CFR 50.69 Risk-Informed Safety Class (RISC) type categorization[3]. Depth of asset strategy is incorporated as the operations and maintenance plan that plant operators execute. Equipment generates data which is run through multiple analytical methods, outcomes of which inform a more intelligent definition of risk. Analysis of task execution correlates actions to operational reliability, further hardening connection of perceived vulnerabilities to actual observed behavior. Through this cyclical process, the Digital Twin is initially defined to represent individual asset context, and subsequently evolves over time to represent actual performance history and optimized scenarios.

CONCLUSIONS

Together in a unified user experience, Predix APM spans a multitude of use cases for power generation: performance monitoring, systems & reliability engineering, and asset strategy optimization. Each use case centers on maximizing business value in support of streamlining nuclear power generation to Deliver the Nuclear Promise. Over decades of operation, the nuclear industry has pursued performance improvement objectives to maximize safety and reliability while also minimizing maintenance burden. Looking at these goals through an innovative lens identifies land rich in opportunity to evolve the industry's technology footprint through big data analytics. Large scale industry initiatives such as knowledge capture & transfer, risk-informed decision making, and value-based maintenance are all facilitated by digital solutions that integrate people and processes efficiently.

Technology development in the nuclear domain has progressed across broadening facets of the industry: advanced controls, autonomous robotics, accident tolerant fuel, and beyond. Recent events such as robotically captured images of the damaged core material at the Fukushima Daiichi NPP demonstrate that significant challenge breeds substantial opportunity. Leveraging modern information technology, GE has pioneered the Digital Industrial vision by developing the Predix industrial cloud platform. Advanced analytics orchestrated upon multidimensional data inform a graded approach to optimize strategy, experienced in the microservice designed APM application. Nuclear power generators have adopted Predix and APM solutions to manage data across enterprise systems, orchestrate targeted analytics, and establish value-based asset treatment practices to drive down O&M cost. The nuclear industry stands poised to evolve into a more profitable and sustainable future by adopting digital technology that powers big data intelligence to better utilize resources across engineering, operations, maintenance, management, and regulatory oversight.

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