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Digital Twin in Integated Power Systems

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An Integrated Power System (IPS) of an advanced marine, transportation or aviation platform consists of an MVDC and an MVAC architecture, which may be comprised of nested and/or zonal power distribution topology in its design with predefined systems and subsystems that may have predetermined interfaces and operational performances. Such electrical architectures tend to adhere to an established interfacing standard for the intended application platform and its expected life cycle. As the systems grow in their complexity, such interfacing standards alone tend to be limited in their scope as to how the system will operate dynamically under various operating conditions. Furthermore, as the platform systems and subsystems are upgraded and retrofitted over its overall operational life cycle, several inter-compatibility issues tend to develop.

One of the key challenges in the design and implementation of the complex multi-megawatt integrated systems is the inter-operational dynamic characteristics of the system. For example, the inter-operational power system dynamic of the aviation platform deals with how different systems and subsystems operate with the host power architecture under all operating conditions, thus covering engineering challenges associated with power generation, distribution & transmission, fault isolation, power conversion, rectification, inversion, regulation, control and monitoring, system simulation and synthesis, interfacing, stability, power continuity, power quality and harmonics, impedance variations, bi-directional energy flow, re-configurability, energy storage (static/ dynamic/hybrid), load management (propulsion, intermittent, pulsed, continuous duty), switchboards and load centers, communication/networking/command/control/monitoring, cyber security, modularity, fault and recovery, redundancy and safety.

Other key the areas of interest in design and development as well as the integration complex application specific power systems development is communication/networking/command/control/monitoring of information network, cyber security, and the assessments of vulnerabilities associated with power system architecture development and system integration. There has been a lot of work done on power system development but very little work is being done on network simulations to study their vulnerabilities and different solutions being implemented to account for network redundancies. The modeling and simulation of computer network systems that control the underlying power systems architecture, has the potential to highlight a broad array of implementation, venality, risk, and operation issues that could exist between the host power system architecture (including its systems and subsystems) and the overarching computer network systems.

Such network simulation focuses on the theories, tools, applications and uses of modeling and simulation in order to effectively optimize networks for:

- Network functional requirements and operational specifications
- Communications/command/control/ computation /data/security (C4DS) protocols used in the network
- Approaches adopted in performance evaluation of the network
- Modeling approaches for networks and system simulation
- Simulation methodologies in network and system synthesis
- Evacuation of network reliability, limitations, latency, stability, recovery and upgradability
- Simulation of system network security and associated viabilities
- Inter-operability of the power architecture and computer network system

The most important method for evaluating the characteristics of networking protocols is by power system control network simulation. Such advanced emulations provide significant benefits, including repeatable scenarios, isolation of parameters, and exploration of a variety of metrics, which when combined with power systems simulation of a given platform can offer a significant insight into the inter-operability of the system well before its construction.

Some of the key integration and design challenges can be addressed by the introduction of digital systems of system design. This is also known as digital twin approach.

A digital twin is a multi-faceted dynamic set of smart digital models of a system or a subsystem along with all its constituents, which accurately represent the design of a product, production process or the performance of a product or production system in operation. The information generated by the digital twin is part of the system design methodology, which can be used to improve future predictive engineering simulations, performance test data and analytics insight. The insight from product and production performance analytics can be used to carry out predictive and condition-based maintenance. The digital twin of a system or a platform is developed meticulously and methodically based on the implementation and integration of detailed multi-physics engineering models of all its subsystem constituents. This approach allows various model updates to be integrated, simulated and analyzed to study any changes that may be introduced to the physical counterpart throughout its lifecycle.

This development approach creates a closed feedback loop in a virtual environment, which offers the best possible design and verification platform for an integrated system development, products lifecycle support, training, production as well as manufacturing processes. The digital twin implementation requires a comprehensive insight into the entire design enterprise to have the ability to create precise digital representations of the product.

For the best results and most accurate performance predictions, the digital twin implementation must be carried out with an acceptable degree of precision and fidelity from its conception. As the digital twin is developed and undergoes different level of maturation and de-risking processes during design, development and production phases, the integrated digital platform can be consistently optimized. This optimization process could be based on updated performance-based information or updated constituents design models as well as other archived functional data.

The constituents of the digital twin are integrated through a digital thread, which inter-connects all the intelligent models and their functional characteristics data. This provided a complete paradigm shift in assisting the stake holders, developers and the platform integrators to fully understand how a complex integrated system can be designed, operated, modified, improved, scaled and optimized in a digital environment well before the physical implementation takes place in the field.

Product based digital twins normally relates to engineering analytics, which is based on advanced multidisciplinary engineering simulations and tests with intelligent reporting on analytical results of the captured functional data. A product digital twin will typically include electronics and software simulations, finite element structural, flow and heat transfer models and motion simulations. Such detailed digital model development result in digital twins, which can provide real-world product/subsystem or systems wide behavior characteristics throughout its lifecycle. As the digital twin model implementation because more mature, predictive engineering opportunities tend to evolve, which includes design tools that manufacturers leverage to expand their traditional design verification and validation processes into a predictive role that supports systems wide-driven product development and support. Different product lifecycle management digital enterprise tools enable the creation of the most accurate, comprehensive digital twin to be developed using both product operational data and detailed engineering models.