Embedded, Edge and Cloud Computing for Gas Turbine Digital Twins

Dr. Vili Panov[1,2], Dr. Samuel Cruz-Manzo[1]
[1] University of Lincoln, School of Engineering, Lincoln, United Kingdom
[2] Siemens Energy, Siemens Industrial Turbomachinery Ltd., Lincoln, United Kingdom

1 Introduction

This study explored development of a *Gas Turbine Digital Twin* based on *Real-Time (Embedded \ Edge)* high speed computing, which can be leveraged with *IOT Cloud Platforms*. Proposed solutions are provided in a form of modular software architecture for a range of platforms *(Embedded \ PLC Based, Edge \ PC Based, Web \ Cloud Based)* and with corresponding functionalities to support model-based control strategies (trip prevention & performance optimization) and advanced gas turbine health management.

2 Cyber-Physical Systems

In today's world of *Next Industrial Revolution* many key industry players are forced to change their conventional process and practices. To join this major transformation, usually referred to us as the *Industry 4.0*, they must pursue extensive R&D efforts in area of developing *Cyber-Physical Systems (CPS).*

The industrial automation already begun with implementation of processes that can accommodate developing *Cyber-Physical Systems* which can offer seamless connectivity with *Internet of Things Platforms* (Fig.1.). A *Digital Twin* concept as a part of *Industry 4.0* strategy can offer answers for these challenges by integrating and deploying different variants of *Digital Twins (Production, Product and Performance)* of the physical assets on various systems such as *Embedded, Edge and Cloud Platforms.*

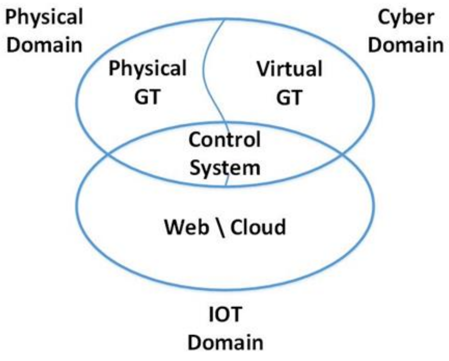

Fig. 1. CPS and IoT domains [1]

3 Digital Twin

This research project aimed to develop innovative automation systems with control and monitoring functionalities to address the requirements of future power plants. This project explored various *Digital Twin* computing architectures and engaged with enabling technologies based on *Physics-Based Models* (performance, estimation and lifing models, model tuning & anomaly detection algorithms) and *Data Driven Models* (pattern recognition, learning models and data analytics). The architectures of closely integrated control and monitoring systems have been developed to support emerging requirements for robustness and autonomy of future digital power plants.

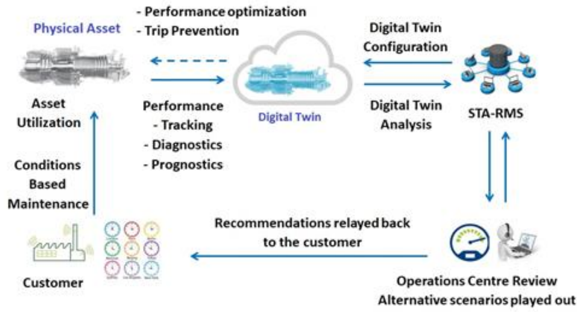

Fig. 2. Digital Twin integration

The developed gas turbine *Performance Digital Twin* is real-time embedded Prognostic and Health Management (PHM) system integrated with Gas Turbine Distributed Control System (DCS). The developed solution offers seamless connectivity with Remote Monitoring Systems and expansion with Cloud based applications and services (Fig. 2.).

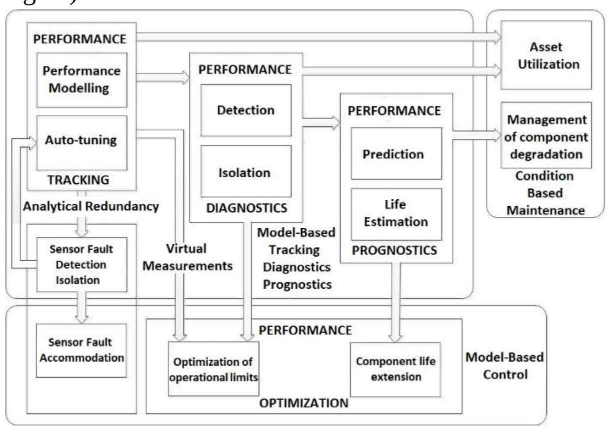

Fig. 3. Performance Digital Twin functionalities [2]

From a functionality perspective the devised solutions focus on three main areas: Model-Based Control (MBC) (virtual and soft sensors), Performance Tracking / Diagnostics / Prognostics, and Condition Based Maintenance (Fig.3.).

4 Integration of MBC & PHM Systems

Traditional gas turbine control and diagnostics techniques are reliable, but they are not optimal. Novel advanced techniques provide the promise to meet the challenging requirements of increased reliability, improved efficiency and extended operational life. The *Digital Twins* based on real-time dynamic engine models has emerged as the most viable approach for solving challenging control and diagnostics requirements. The implementation of *Digital Twin* prediction model can be presented with the generic system of equations:

$$x_k = f_k(x_{k-1}, u_{k-1}, \xi_{k-1}) \quad (1)$$

$$y_{n,k} = g_k(x_k, v_k, \xi_k) \quad (2)$$

where the above discrete model describes system behavior at discrete points in time $k-1$ and k.

These platforms can provide unified frameworks for advanced model-based control and diagnostics technologies (Fig. 4.).

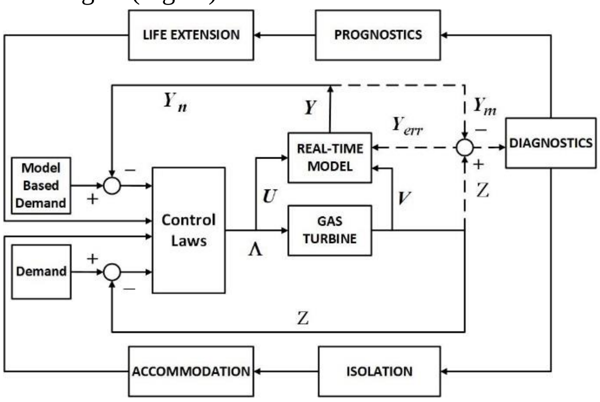

Fig. 4. Integration of MBC and PHM systems [3]

Among developed functionalities of a devised *Digital Twin* is real-time on-line tracking of engine performance based on adjustment of health parameters such as efficiencies and flow capacities of engine gas path components. The synthesized engine health parameters are consequently used for fault detection and accommodation. The developed adaptive model-based control with integrated diagnostics, isolation and accommodation offers the possibility to diagnose and adaptively manage degradation of engine components while taking into account engine-to-engine variation and current operating conditions. The model-based prognostic approach as enhancement of the conventional prognostic technology enables more accurate estimation of remaining useful life, and therefore facilitates increased component life entitlement, improved time in service, better asset utilization and lowered engine maintenance costs.

5 Embedded, Edge and Cloud Platforms

The gas turbine virtual and physical systems within CPS are closely integrated at multiple levels with network computing to provide physical systems with new capabilities (Fig. 5.). This feature enables the generation of new products and services due to ability to exchange vast information generated by *Digital Twins* connected to *IoT* platforms. The information generated by deployed *Digital Twin* consists of the physical engine trackable data objects (such as sensor measurements), and virtual engine smart data objects (such as internal engine states and virtual measurements), are seamlessly integrated into the information network.

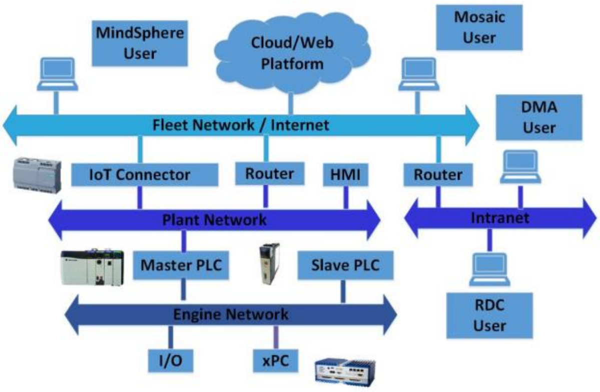

Fig. 5. Embedded, Edge and Cloud platforms

The developed *Digital Twin* functionalities can be distributed across different computational platforms such as *Embedded*, *Edge* and *Cloud* platforms, depending on customer needs related to real-time operation and requirements associated with processing power of available platforms. In this approach system capabilities are expandable with non-real time functionalities which are encapsulated within software solutions deployable on various *IoT* platforms, which support hosting of Agents dedicated to fleet and asset data analytics.

6 Conclusions

The developed real-time on-line *Digital Twin* technology has the ability to enhance current state-of -the-art offerings which are predominantly based on non-real time and off-line solutions. The devised solution highlights the next generation of *Digital Twins* that exploit modular functionalities distributed across the whole *IoT* chain consisting of *Embedded*, *Edge* and *Cloud* computational platforms. The gas turbine *Performance Digital Twin* has been deployed on the operational site and collected field data have been analyzed and presented in this study.

References

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