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Digital Twins for Embedded, Edge and Cloud Platforms

Dr Vili Panov[1,2]
[1]Siemens Energy Industrial Turbomachinery Ltd., UK
[2]University of Lincoln, UK

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Introduction

Cyber-Physical Systems and Digital Twin Technology

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1

Product Digital Twin

Using digital twins for efficient design of new products

2

Production Digital Twin

Using digital twins in manufacturing & production planning

3

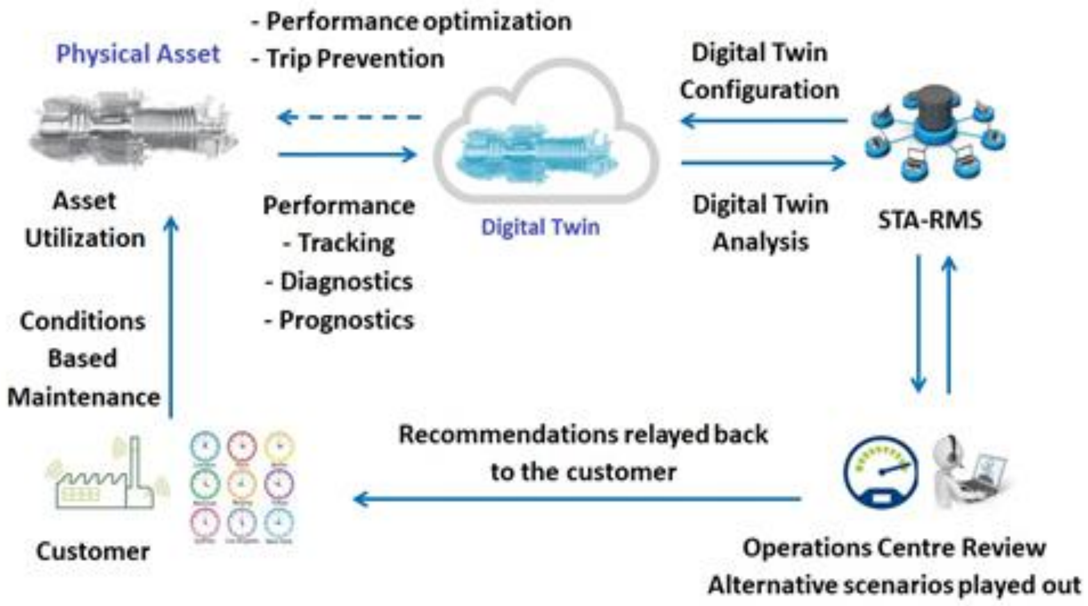
Performance Digital Twin

Using digital twins to capture, analyse, and act on operational data

Gas Turbine Digital Twins

”A Digital Twin is defined as a virtual representation of a physical asset enabled through data and simulators for real-time prediction, monitoring, control and optimization of the asset for improved decision making through the life cycle of the asset and beyond” [*]

Performance Digital Twin



[*] Rasheed, A., San, O., Kvamsdal, T., 2019, “Digital Twin: Values, Challenges and Enablers”, arXiv:1910.01719.

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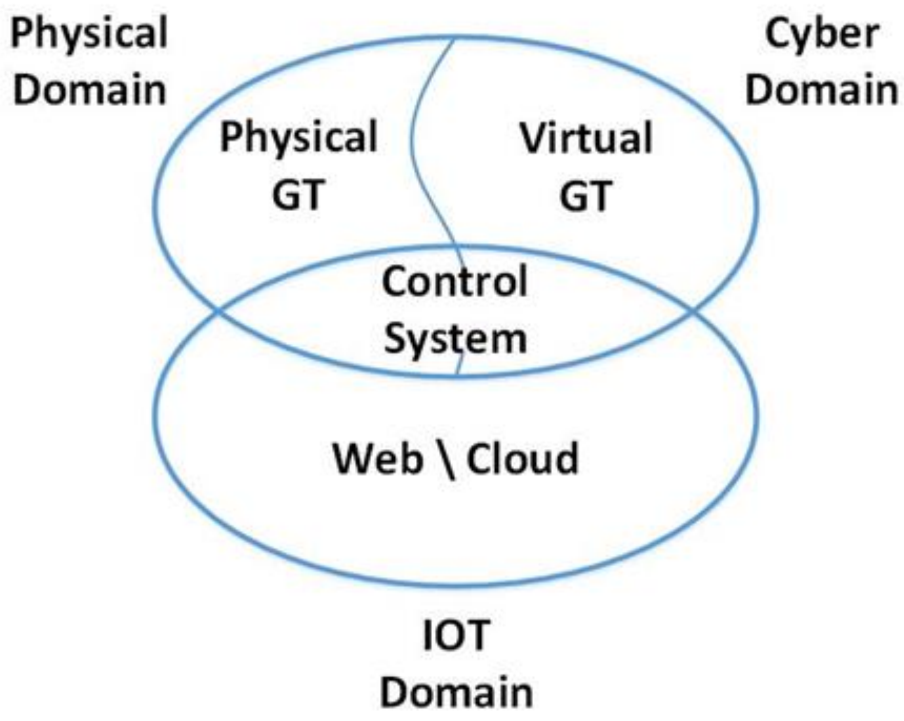
Cyber-Physical System and Internet-of-Things Domains



- Development of **Performance Digital Twin** for industrial **Small Gas Turbine** with objective to improve availability, increase reliability and optimize asset performance
- Digital Twin devised as a operational **Cyber-Physical System** based on **Virtual Gas Turbine** closely integrated with **Control System** of **Physical Gas Turbine** engine
- Extension of Digital Twin functionalities via connectivity of **Distributed Control System** to a **Internet-of-Thing** and **Remote Monitoring System** platforms

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System of Systems

Building Blocks and Network Connectivity

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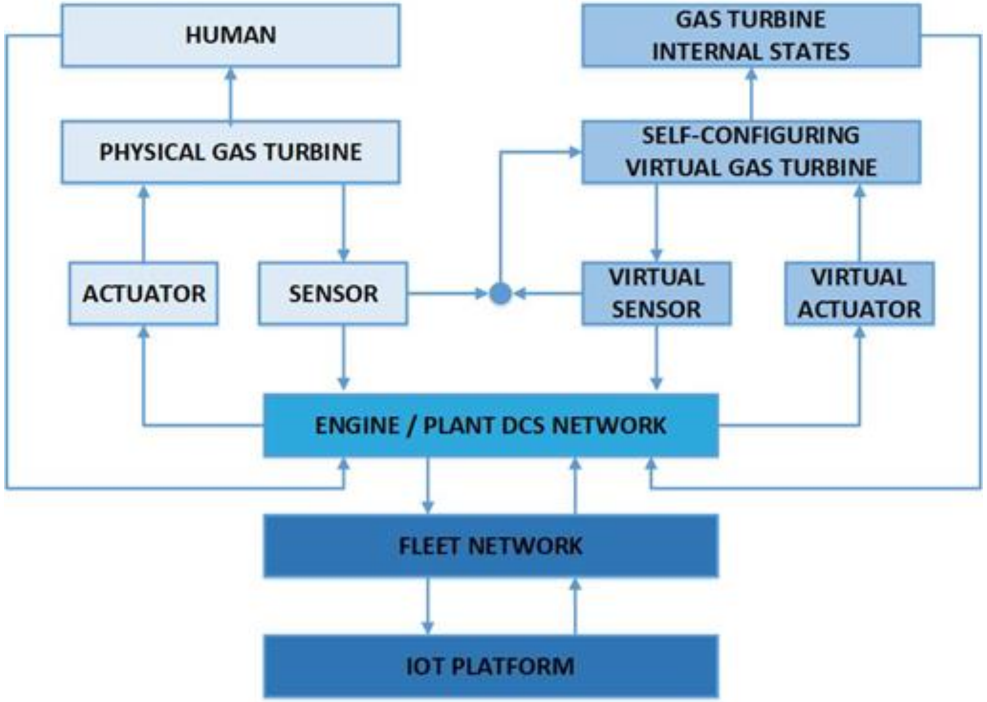
System of Systems Building Blocks



1 **Physical Domain**

The Physical Gas Turbine unit connected to the automation system via multiple sensors and actuators

2 **Cyber Domain**

The self-configuring Virtual Gas Turbine enables GT to be monitored and controlled via adaptation to external and internal health conditions

3 **IoT Domain**

Network technologies based on interoperable communication protocols, offer seamless integration of data objects into the information network (physical engine trackable data and virtual engine smart data)

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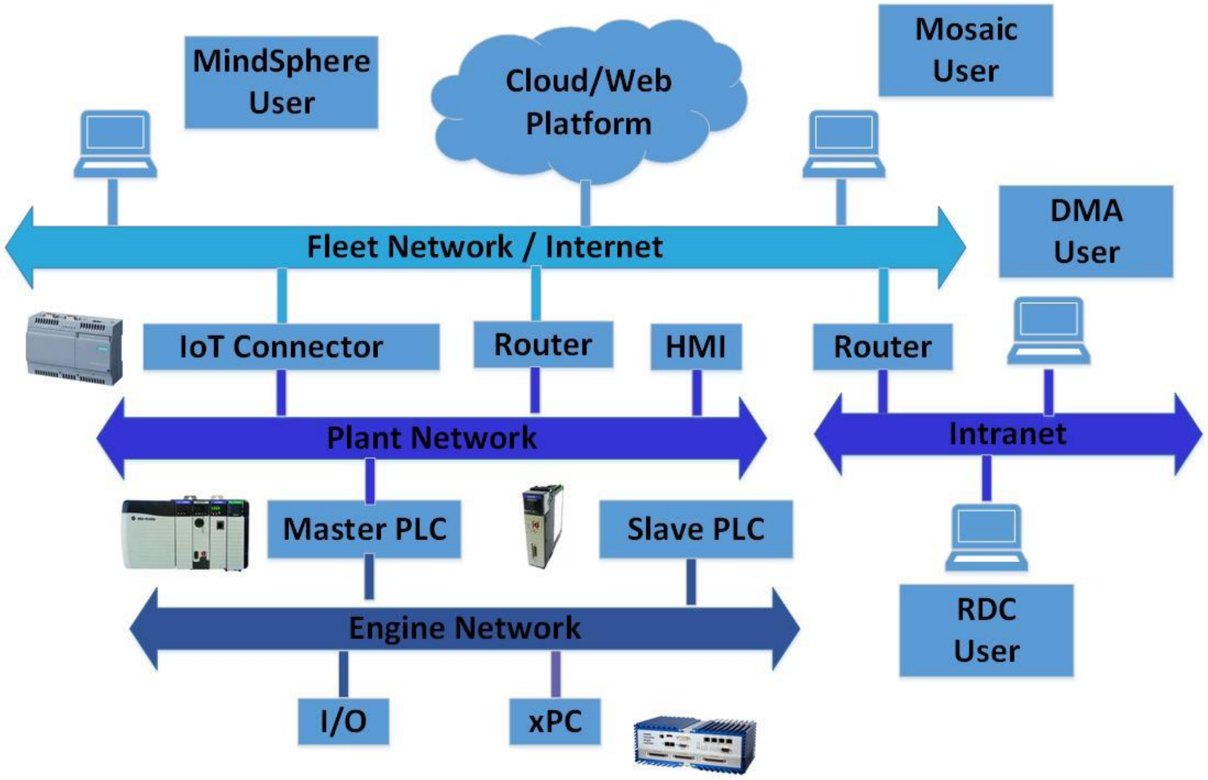
Network Connectivity



- **Engine Network:**
  - Deployment of Digital Twins onto heterogenic platforms (PC and PLC based)
- **Plant Network:**
  - Deployment of Digital Twins using hierarchical architecture – distribution of functionalities onto Slave (Stand-alone) and/or Master (Embedded) PLC platforms
- **Fleet Network:**
  - Connectivity to IoT (Internet-of-Things) platforms via IoT connectors for hosting Cloud Digital Twin Agents
  - Connectivity to RMS (Remote Monitoring System) platforms for deployment of Remote Digital Twin Agents in Enterprise Networks

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Embedded, Edge & Cloud Platforms

Distributed System of Systems

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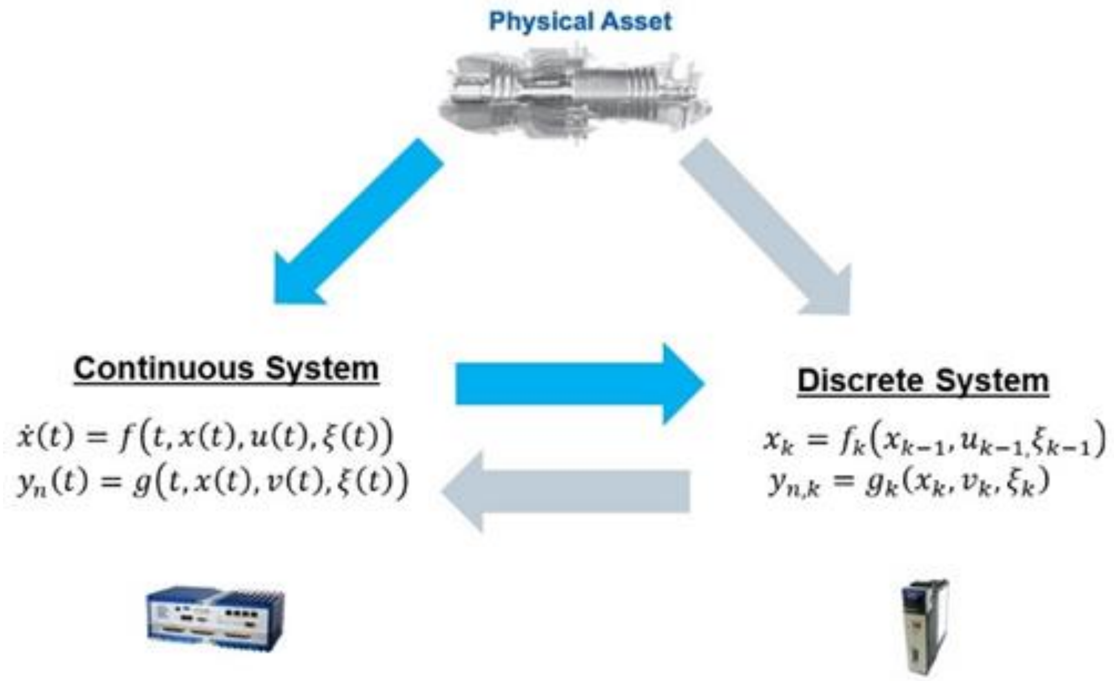
Continuous vs Discrete System



1 **Continuous System**

- Continuous Digital Twin simulation
- Deployment onto PC platform running Real-Time Operating System (RTOS)
- Hybrid integration (Continuous DT – Discrete Controller)
- Networked with discrete PLC platform via Profibus communication protocol

2 **Discrete System**

- Discrete Digital Twin simulation
- Deployment onto Slave PLC
- Homogenic integration (Discrete DT – Discrete Controller)
- Networked with Master PLC platform via Native communication protocols

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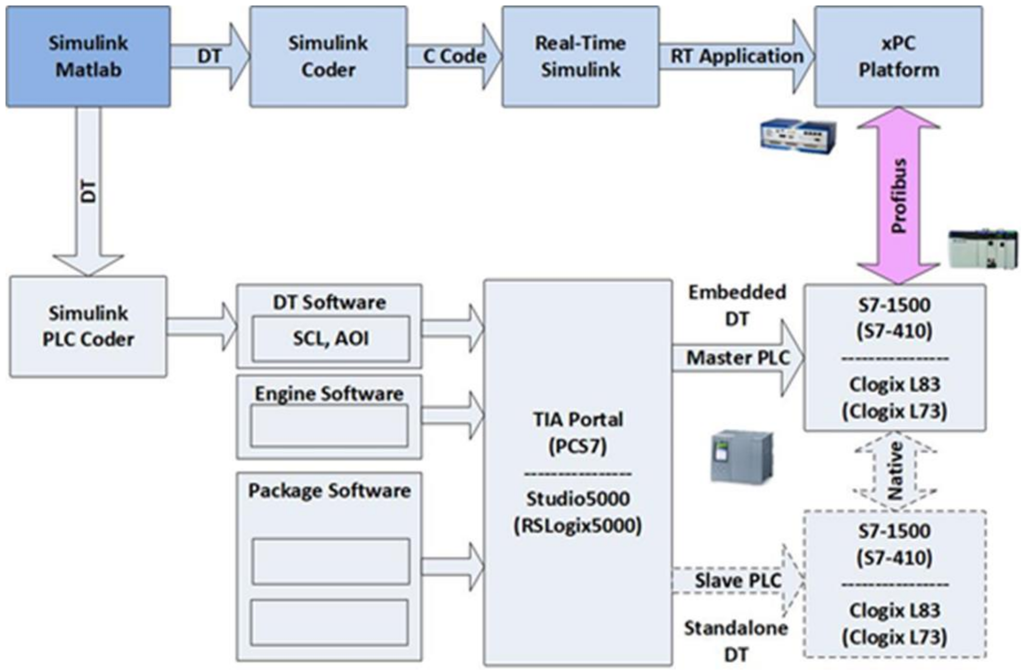
Core Digital Twin Deployment



- **Digital Twin continuous implementation:**
- Simulink continuous Digital Twin solution deployed onto PC by use of Real-Time Simulink tool

- **Digital Twin discrete implementation:**
- Simulink discrete Digital Twin solution deployed onto PLC by use of Simulink PLC Coder tool
- Generated software blocks imported into Integrated Development Environments compatible with Simatic and Allen-Bradley PLC platforms.
- Digital Twin builds deployed in two configurations:
  * Stand-alone solution deployed onto Slave PLC
  * Embedded solution deployed onto Master PLC

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Simulink Real-Time

1 Performance Real-Time Target Machine

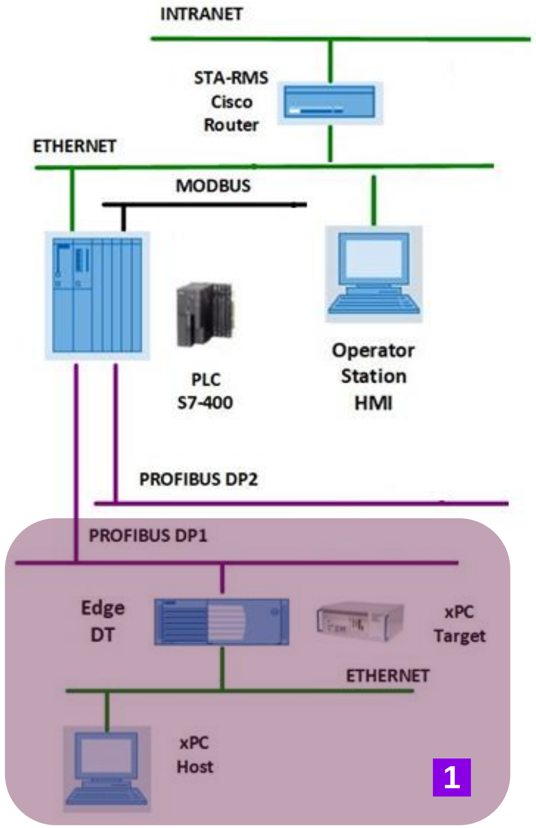
- Test Bed Distributed Control System

2 Mobile Real-Time Target Machine

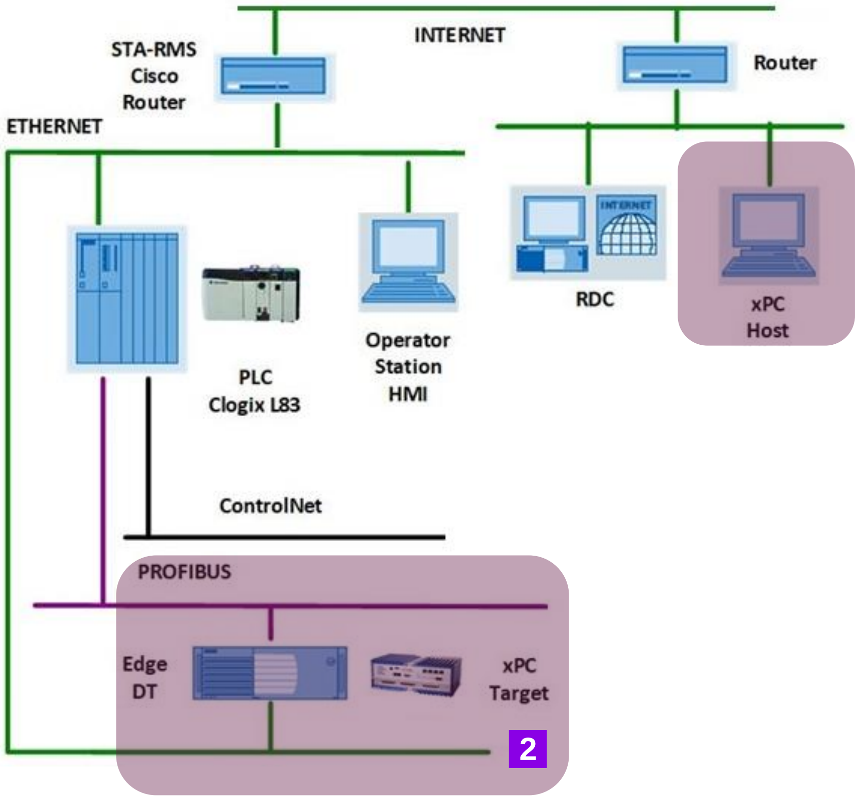
- Gas Turbine Distributed Control System

Build and Deployment of Real-Time Code for Speedgoat Platforms

Test Bed Configuration
Simatic & Speedgoat Platforms



Field Trial Configuration
Allen-Bradley & Speedgoat Platforms



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Simulink PLC Coder

1 Siemens IDE's

- TIA Portal
- PCS7 / Step 7

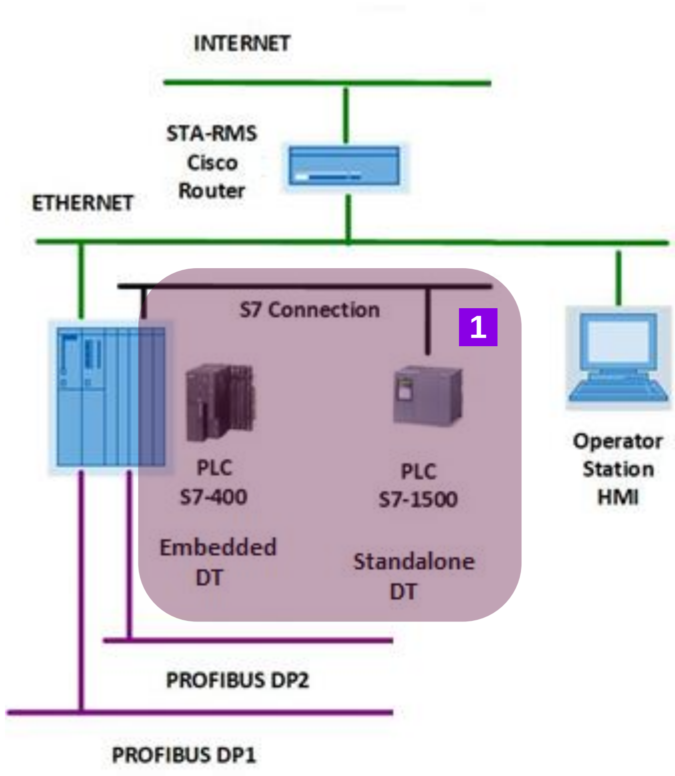
2 Rockwell Automation IDE's

- Studio 5000
- RSLogix 5000

Generation and Deployment of Code for PLC Platforms

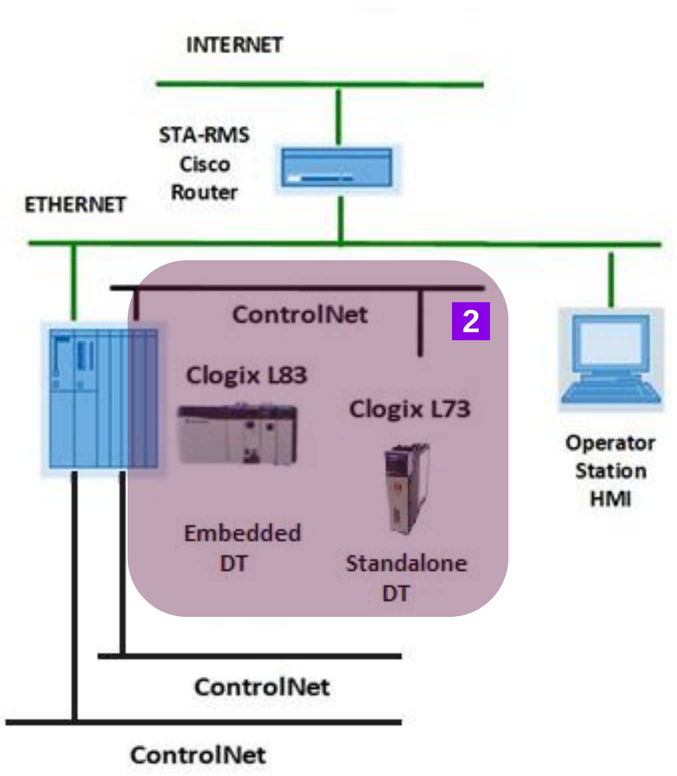
Test Bed Configuration

Simatic Platforms



Field Trial Configuration

Allen-Bradley Platforms



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Generation and Deployment of Code for Cloud and Enterprise Platforms

Matlab Compiler SDK

Matlab Production Server

1 AWS IoT Core

- Mosaic

2 Siemens IoT Core

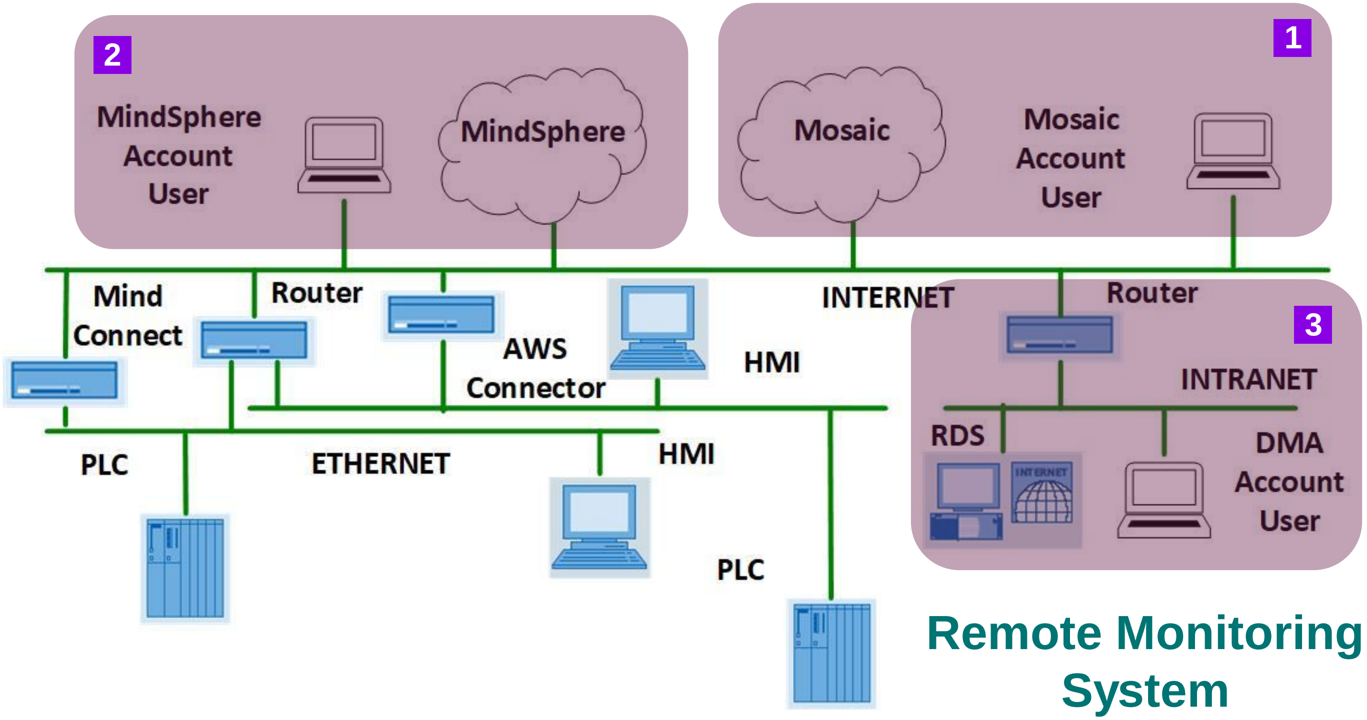
- MindSphere

3 STA-RMS

- DMA Platform

MindSphere Platform
Siemens IoT Core

Mosaic Platform
AWS IoT Core



Remote Monitoring System
DMA Platform

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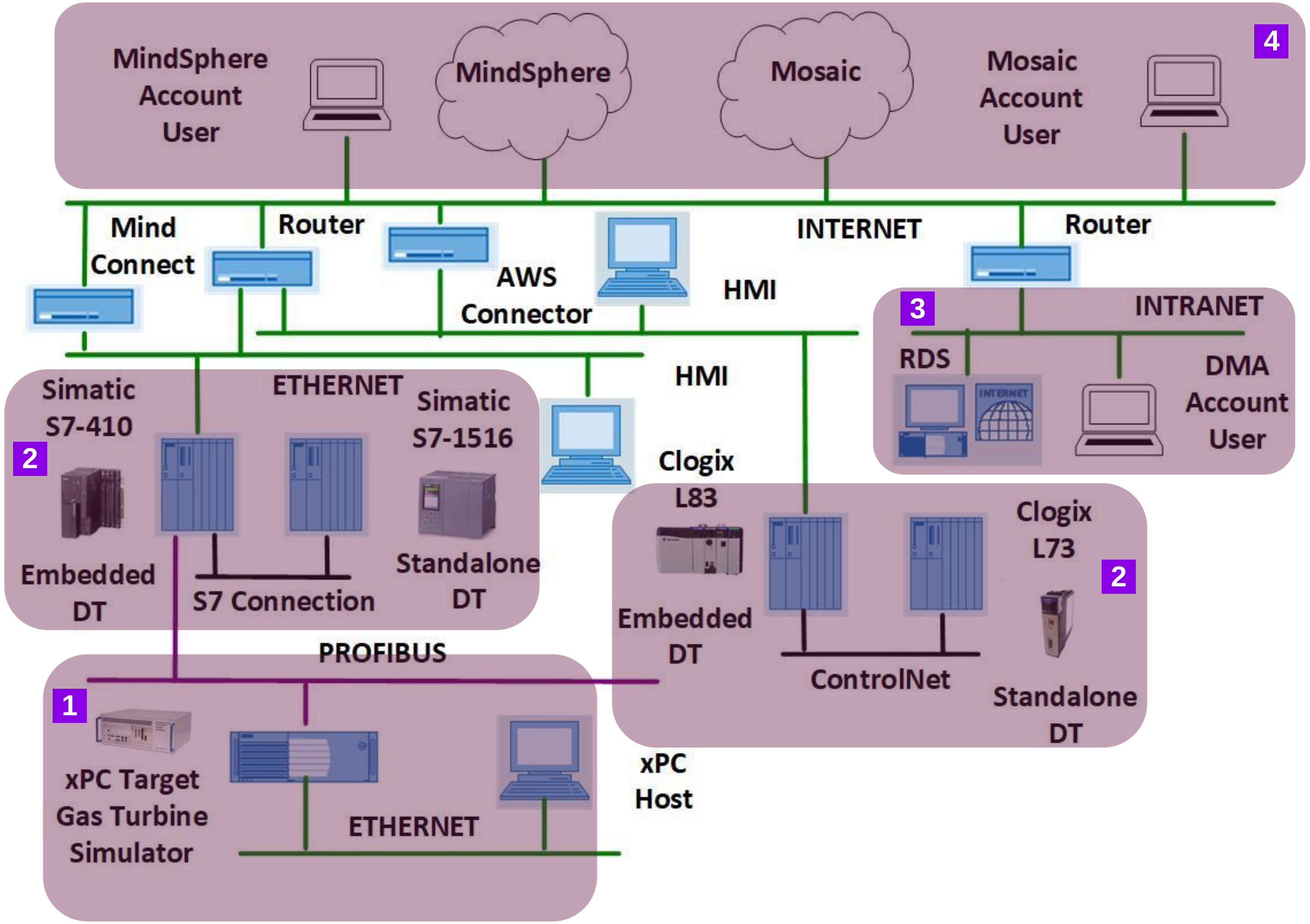
1
Gas Turbine Simulator
- PC Platform \ Speedgoat

2
Embedded Core Digital Twin
- PLC Platforms

3
RMS Digital Twin Agents
- DMA Platform

4
Cloud Digital Twin Agents
- MindSphere \ Mosaic Platforms

Hardware-In-The-Loop Development Facility



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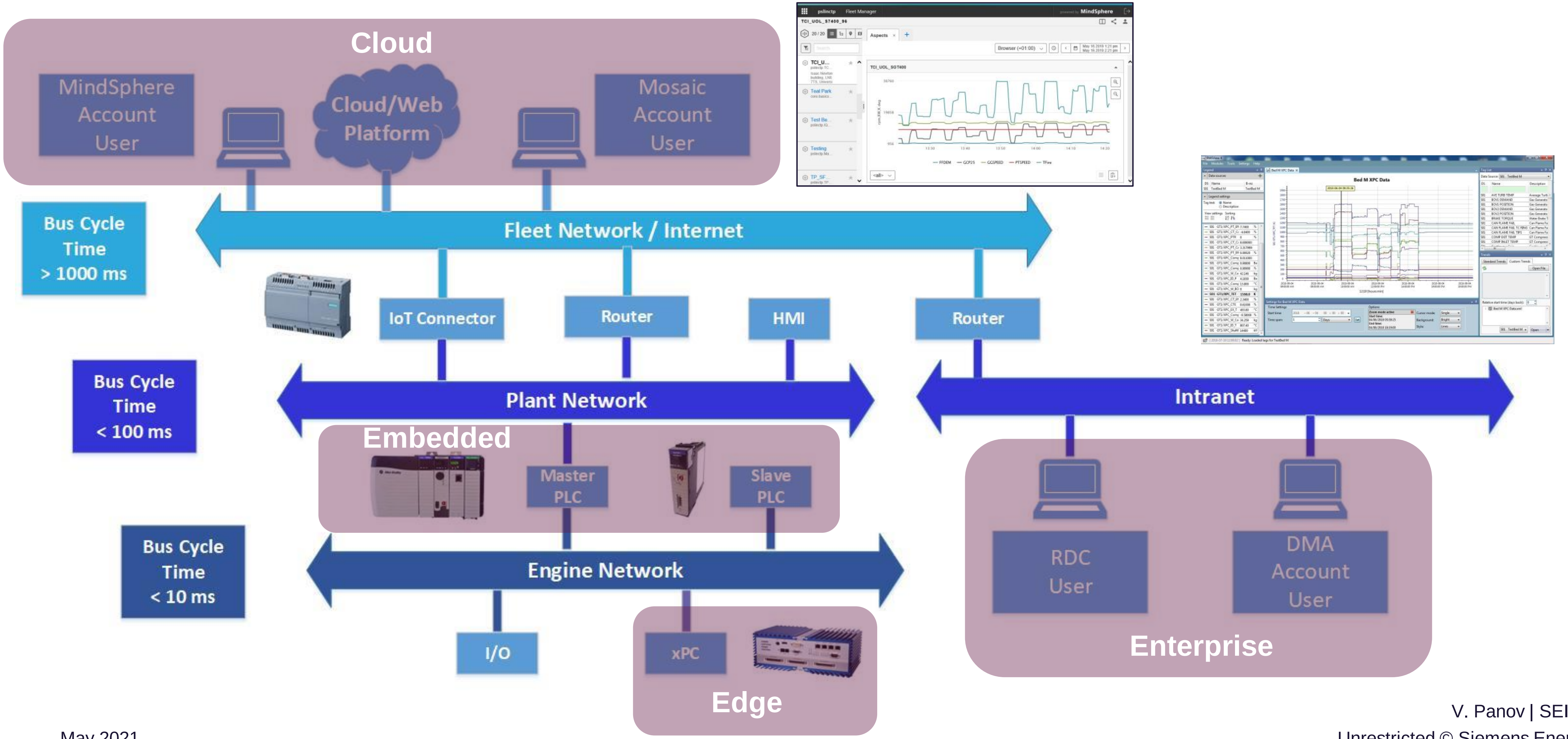
Embedded, Edge, Cloud & Enterprise Platforms



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Performance Digital Twin

DT Core Configuration and Integration

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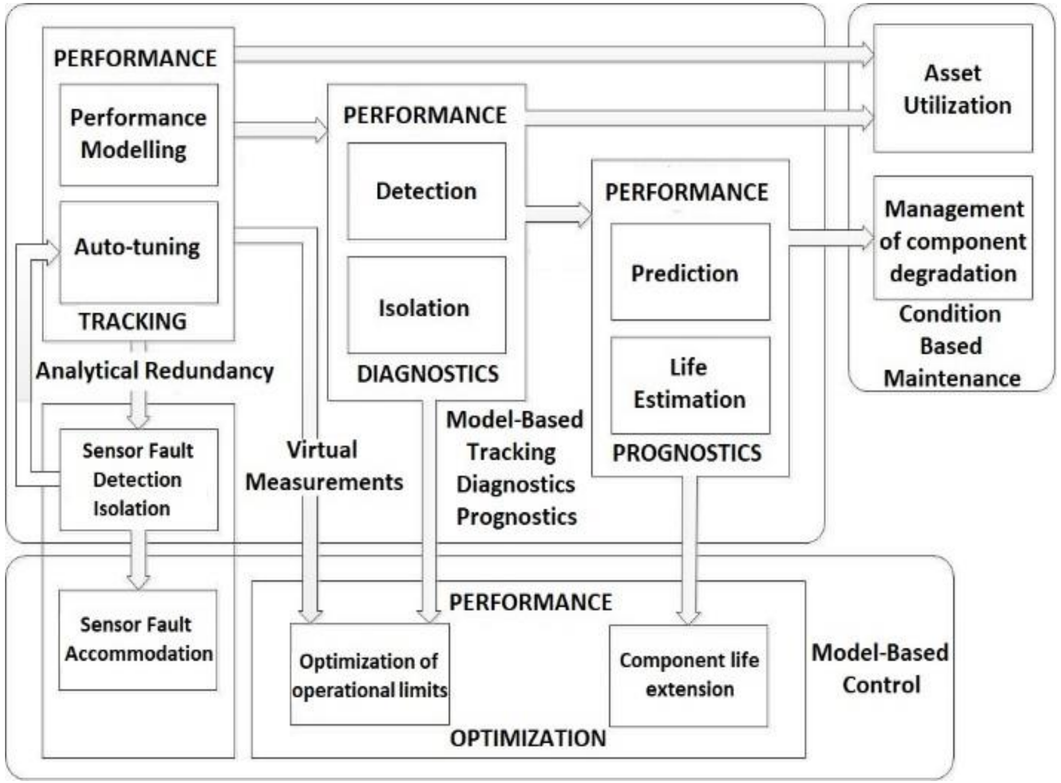
Performance Digital Twin



- **Tracking**
  - Accounting for engine-to-engine variation and engine deterioration based on alignment of DT
- **Diagnostics**
  - Diagnosing typical gas path degradation and fault modes based on health parameters generated by DT
- **Prognostics**
  - Estimation of remaining useful life of gas path components based on regression modelling of health indices deduced by DT
- **Optimization**
  - Performance optimization based on model-based control strategies utilizing DT virtual sensors
- **Analytical Redundancy**
  - Reduction of gas path related trips based on analytical sensor redundancy provided by DT

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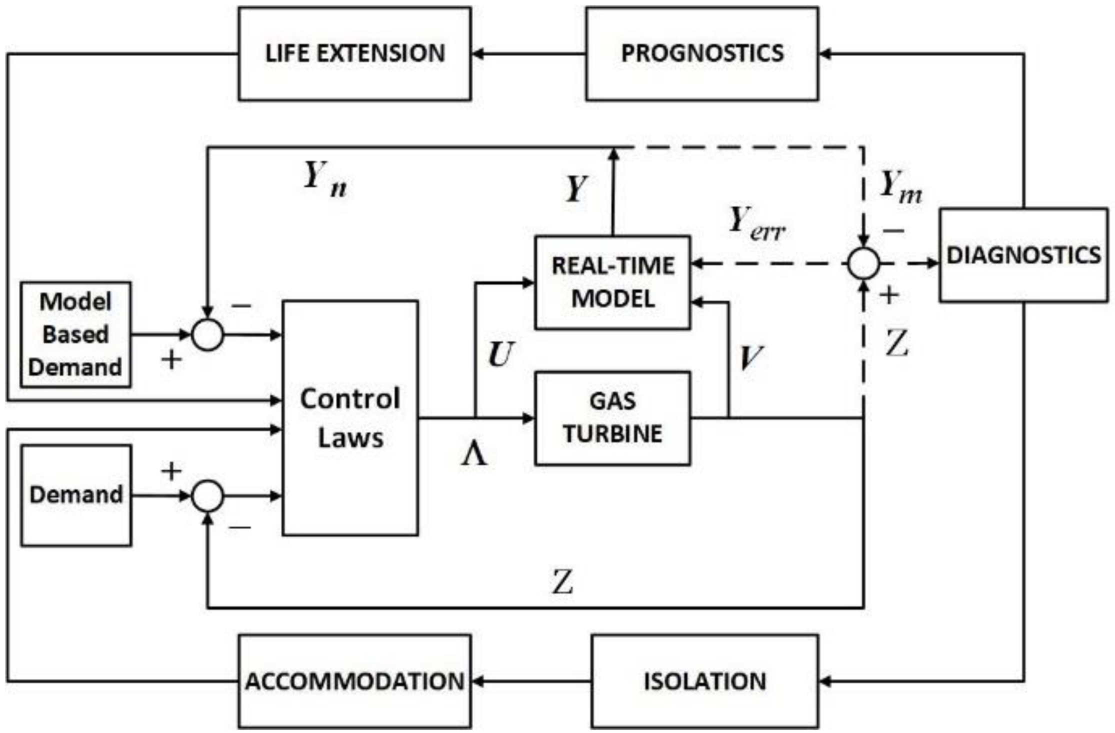
Digital Twin - Platform for Integration of MBC & PHM Systems



1 PHM System

- Tracking while performance deteriorate with time / component degradation
- Monitoring of deviations from expected / nominal conditions
- Detection by comparison of deviations with threshold values
- Isolation of particular fault / degradation modes
- Prediction of remaining useful component life based on actual engine performance

2 MBC System

- Accommodation of fault / degradation modes to regain operability and maintain stability
- Life Extension by reduction of deterioration rates for most life limiting modes
- Virtual measurements of non-measured engine parameters
- Analytical redundancy

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Deployment and Results

Test Bed and Field Trial Results

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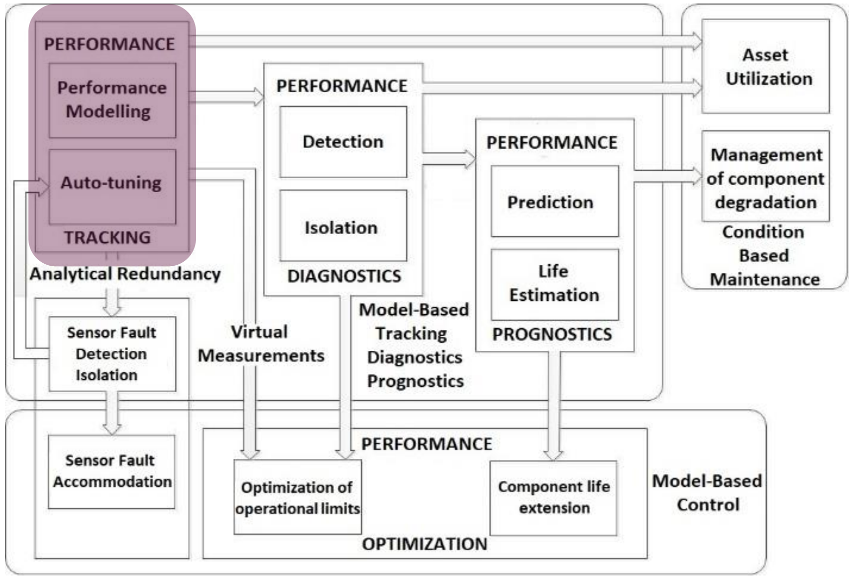
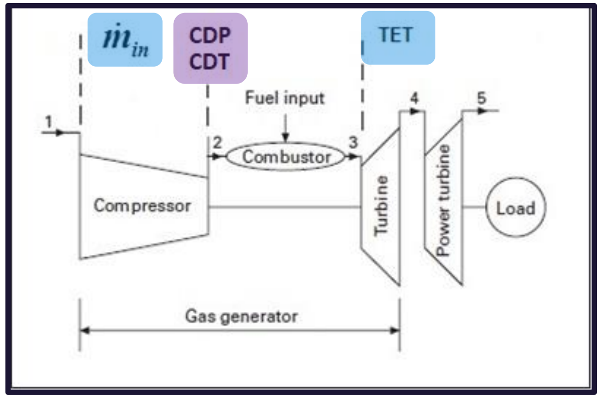
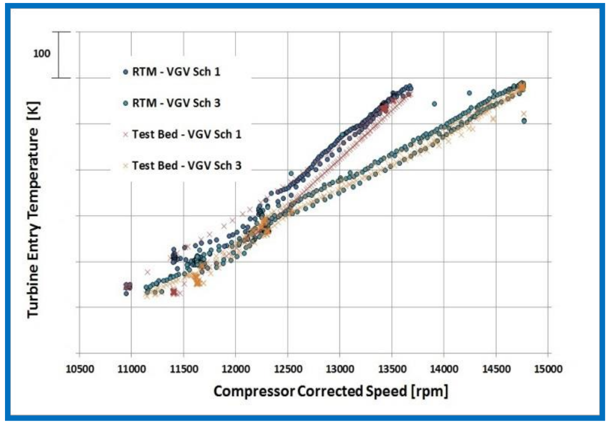
Performance Tracking

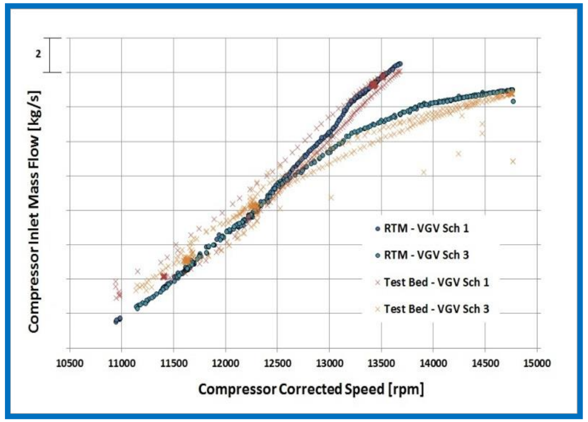




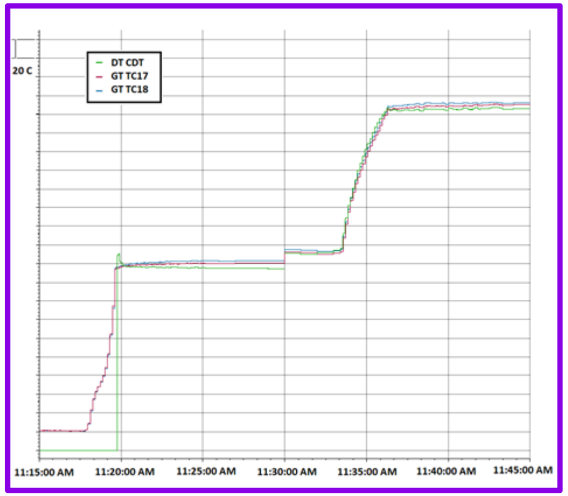
Turbine Entry Temperature



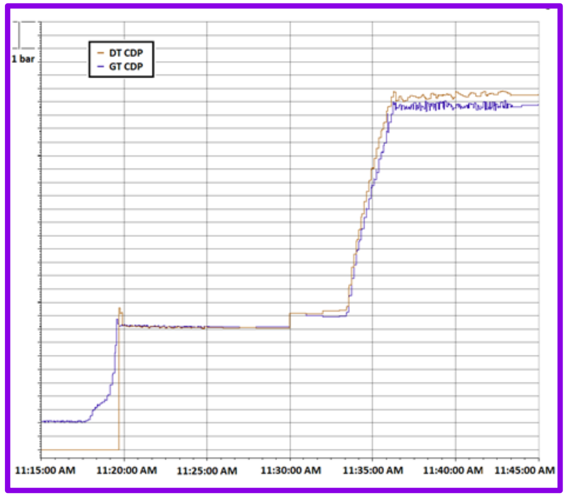
Compressor Inlet Mass Flow



Compressor Delivery Temperature



Compressor Delivery Pressure



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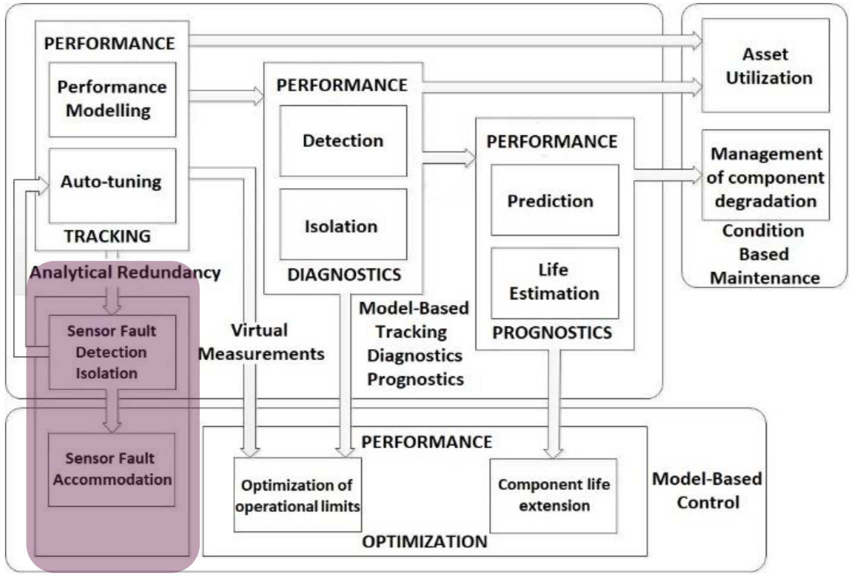
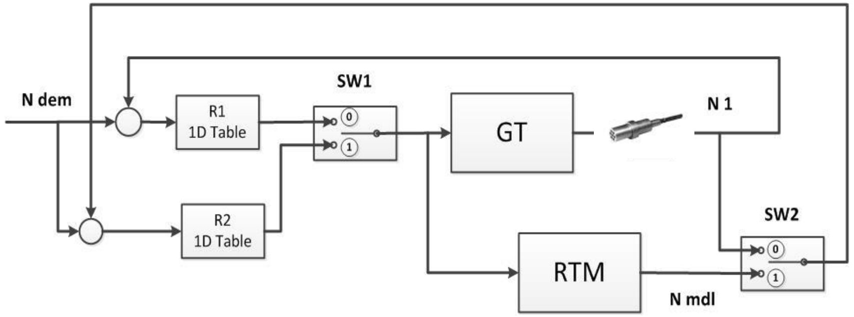
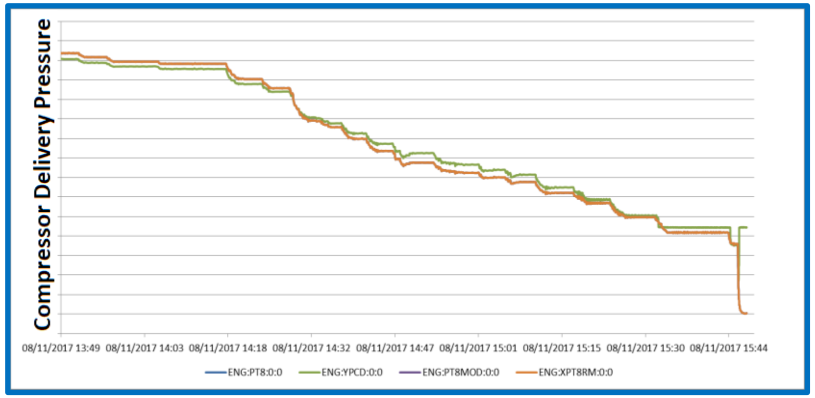
Analytical Redundancy



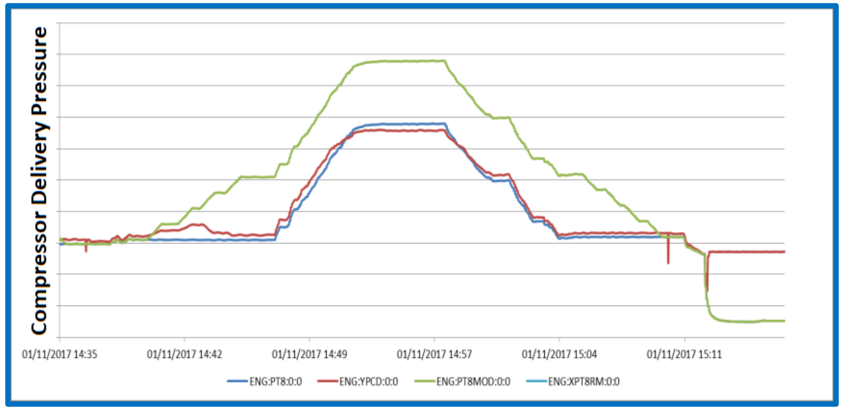
Compressor Delivery Pressure Control Loop



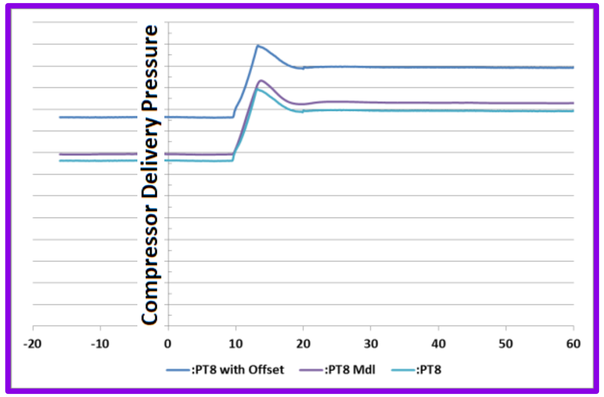
CDP Measurement Tracking – No fault present

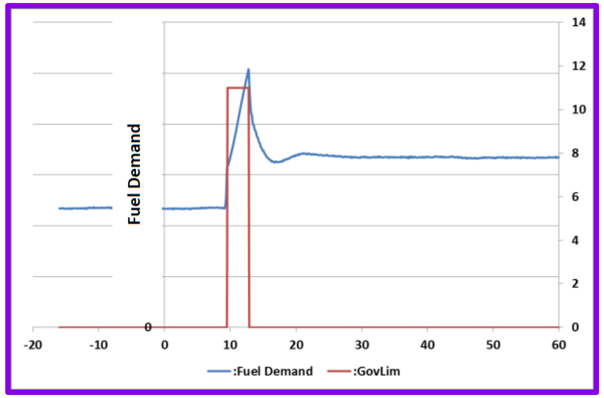


CDP Measurement Tracking – Fault injection



Fast Transient – Governing with CDP Soft Sensor





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Summary

Next Generation of Gas Turbine Digital Twins

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Lessons Learned

Cyber-Physical Systems & Networking

- ***Real-time dynamism and self-configuration - challenges:***
- System and software complexity
- System adaptability
- Ever-evolving system functionalities
- Network interoperability
- Robustness, safety and security
- ***Integration of Physical and Virtual systems within CPS at multiple network levels - benefits:***
- Seamless integration of heterogenic platforms
- Adaptability and scalability of Digital Twin functionalities
- Enhancement of physical Gas Turbine with new capabilities
- Enabler of new products and services for Gas Turbine users

Business / Customer Benefits

- Improved robustness of assets:
- Availability & Reliability
- Increased flexibility of assets:
- Unmanned operation & Operability
- Operational cost reduction:
- Improved efficiency & Extended operational life

Flexible Deployment

- Digital Twin functionalities distributed across different computational platforms: Embedded, Edge, Cloud, and Remote systems platforms
- Connectivity to IoT (Internet of Things) and RMS (Remote Monitoring System) platforms
- Real-Time execution of Core Digital Twin expanded with non-real-time functionalities encapsulated within Agents deployed onto IoT and RMS platforms dedicated to fleet analytics

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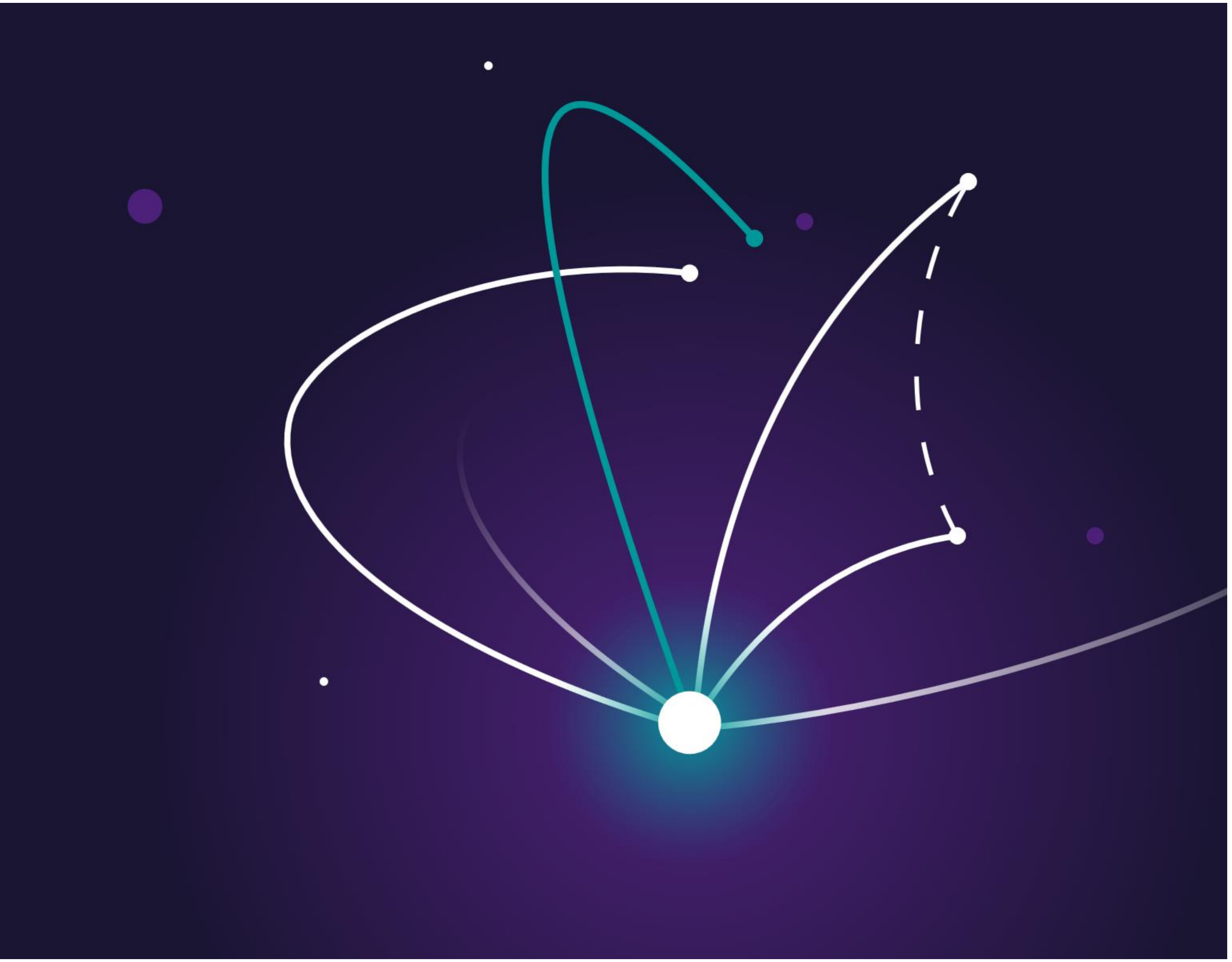

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Dr Vili Panov

Advisory Key Expert

Siemens Energy Industrial Turbomachinery Ltd.

1 Waterside South
LN5 7FD Lincoln
United Kingdom

Phone: +44 1522 584 307

vili.panov@siemens.com vpanov@lincoln.ac.uk

siemens-energy.com **lincoln.ac.uk**

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