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Improving Microgrid Resiliency with Real-Time Simulation

Jean-Nicolas Paquin

Summary

- Definition of a Microgrid
- Microgrid Control System (MGCS) Functions and Hierarchy
- Complexity of the Microgrid and Importance of Testing
- Flexible Test Platforms with Real and Virtual Equipment
- OPAL-RT User Applications
- Looking Forward – The Concept of Digital Twins

Definition of a Microgrid

U.S. DOE Microgrid Exchange Group

- Interconnected loads
- Distributed Energy Resources (DER)
- Clearly defined electrical boundaries
- Acts as a single controllable entity
- Can be connected to a grid or disconnected (isolated/islanded)

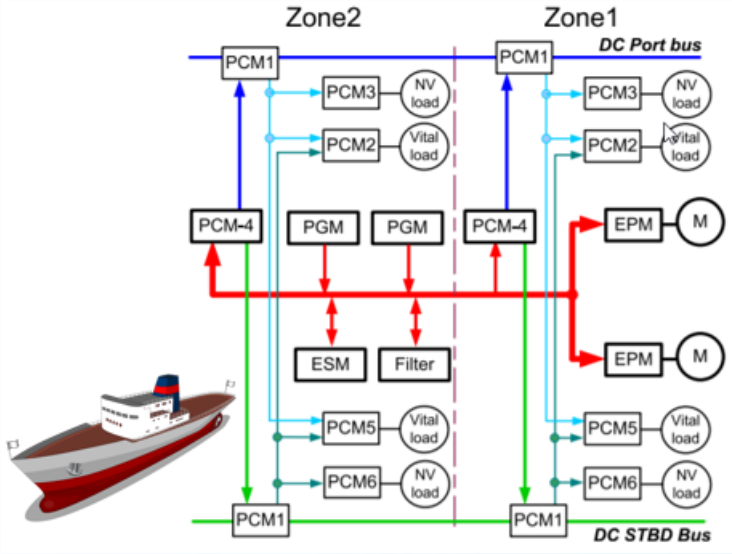
CIGRÉ C6.22 Working Group, Microgrid Evolution Roadmap

- Electricity distribution systems
- Contains loads and DERs
- Operated in a controlled / coordinated way
- Connected to the main power network or islanded

c.f. https://building-microgrid.lbl.gov/microgrid-definitions

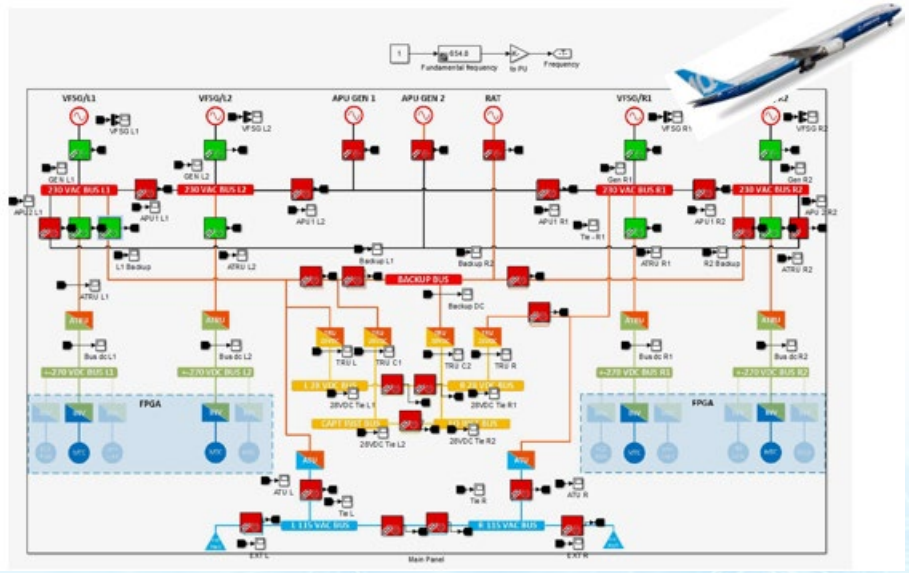
Steady, Floating, Flying

All Electric Ship (AES)



c.f. Y. Xie et al., A PC-Cluster Based Real-Time Simulator for All-Electric Ship Integrated Power Systems Analysis and Optimization, IEEE ESTS Conference, 21-23 May 2007

More Electric Aircraft (MEA)



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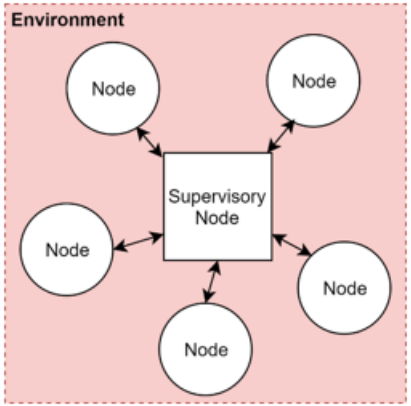
Microgrid Control System (MGCS) Functions and Hierarchy

MGCS Requir. – std. IEEE 2030.7

- **Dispatch:**
  - Grid-connected mode:
    - Import/export of power between the microgrid and the grid
    - Grid support / Frequency response / Voltage support participation
  - Islanded mode:
    - Load / Generation balancing
    - BESS charging optimization
    - Secondary frequency and voltage regulation
- **Transition:**
  - Planned islanding
  - Unplanned islanding
    - Seemless
    - Emergency load shedding
    - Blackstart
  - Reconnection

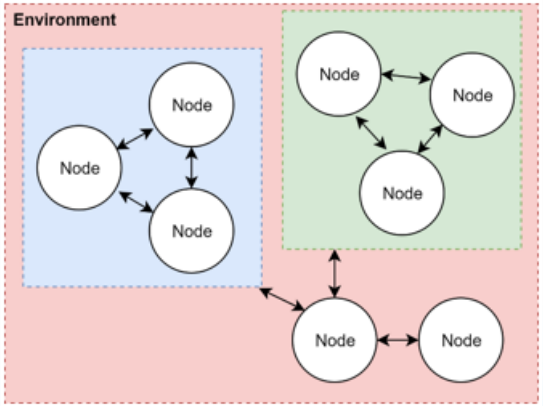
Options for Sec. Controls (MGCS)

Centralized Control System



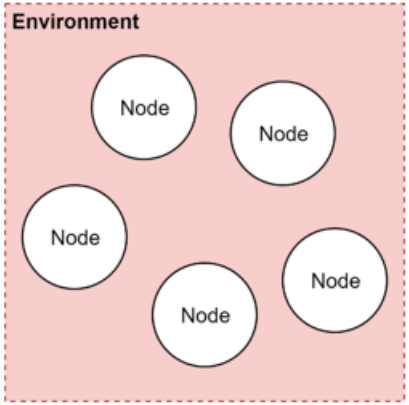
- Central decision making
- Global overview

Distributed Control System



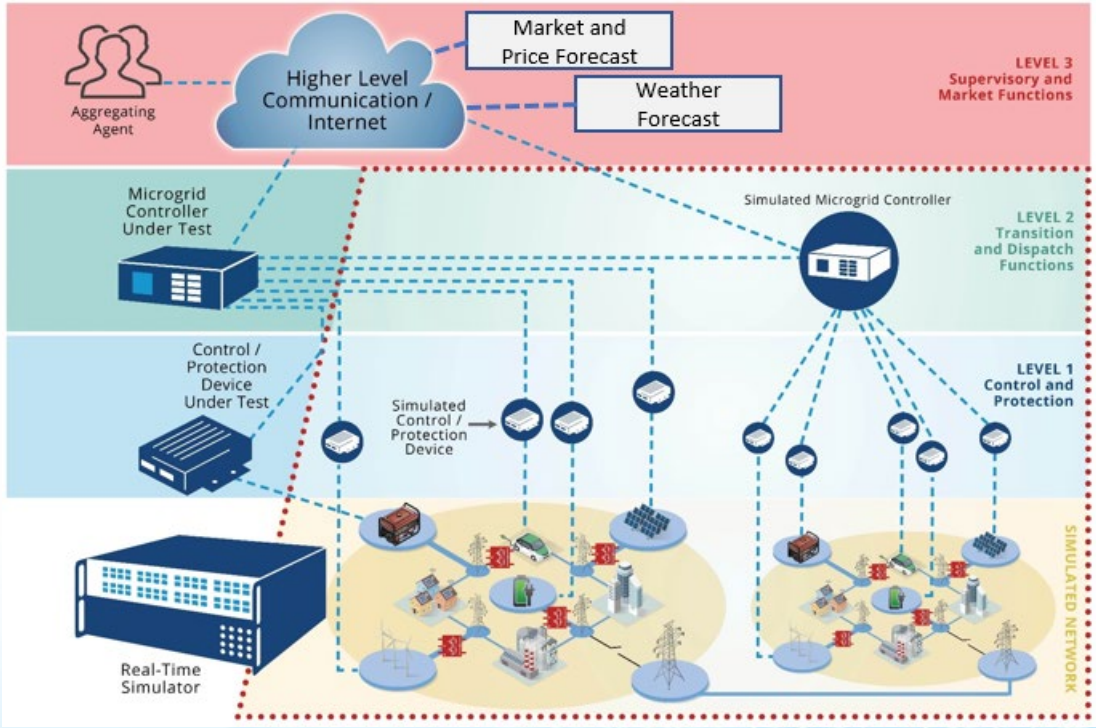
- Distributed decision making
- Knowledge of environment and neighbors

Decentralized Control System



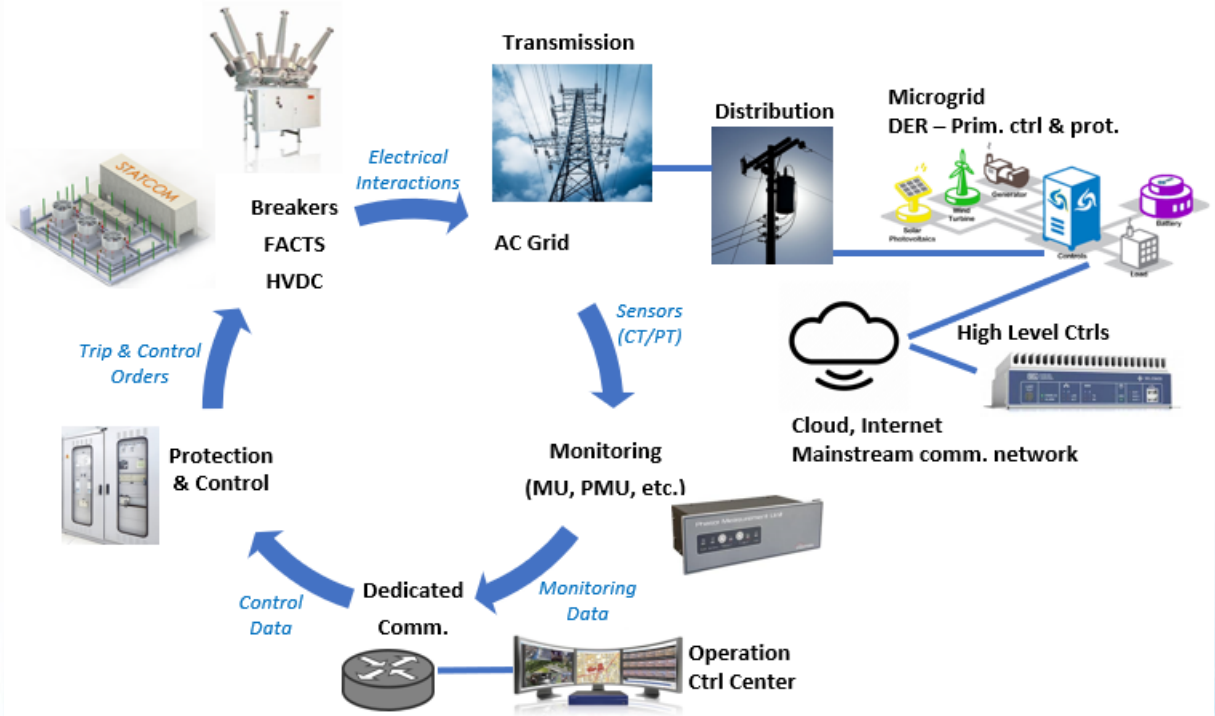
- Decentralized decision making
- Knowledge of environment only

System Hierarchy



Complexity of the Microgrid and Importance of Testing

The Resilience Statement Pa▪ra▪dox



Challenges

- Decentralized controls, active loads and generators
- Ensuring cyber-secure operation
- Prosumers participating in the electricity market / deregulation
- Reliability and security VS low inertia system and potential of interactions between independent controls

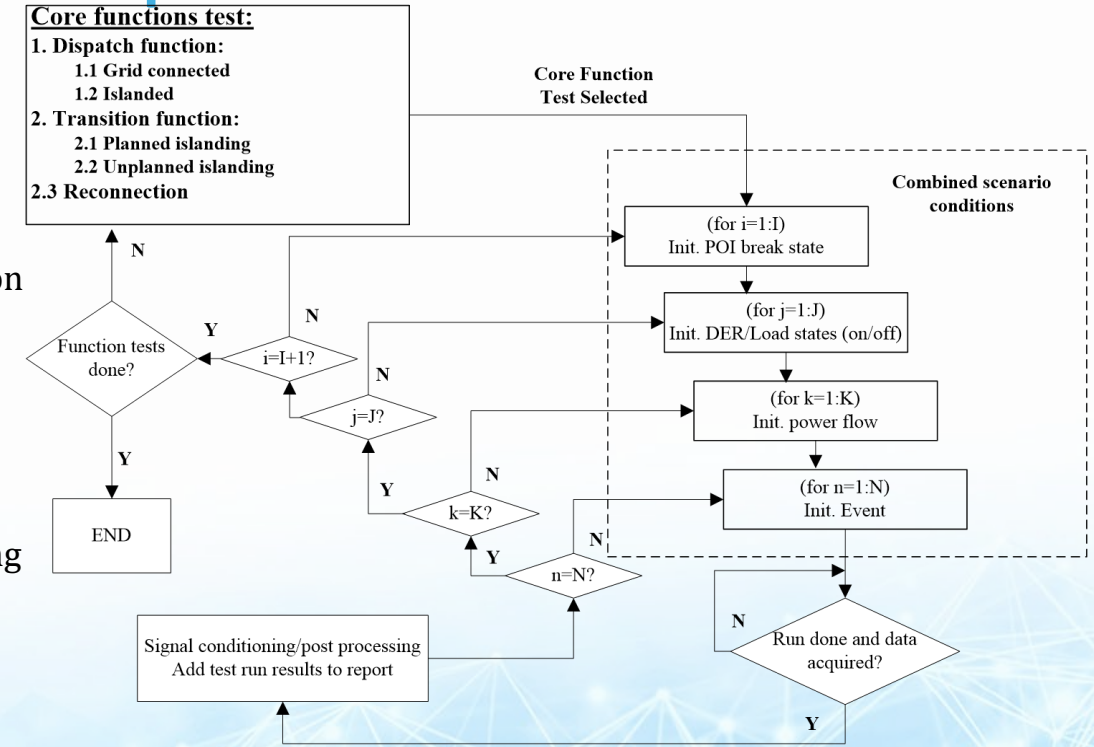
The paradox

- Resilience will be ensured while complexity keeps increasing?
- Perhaps, if the microgrid and its components are designed and tested appropriately…
- Distribution systems now requires the same testing and studies than Transmission systems

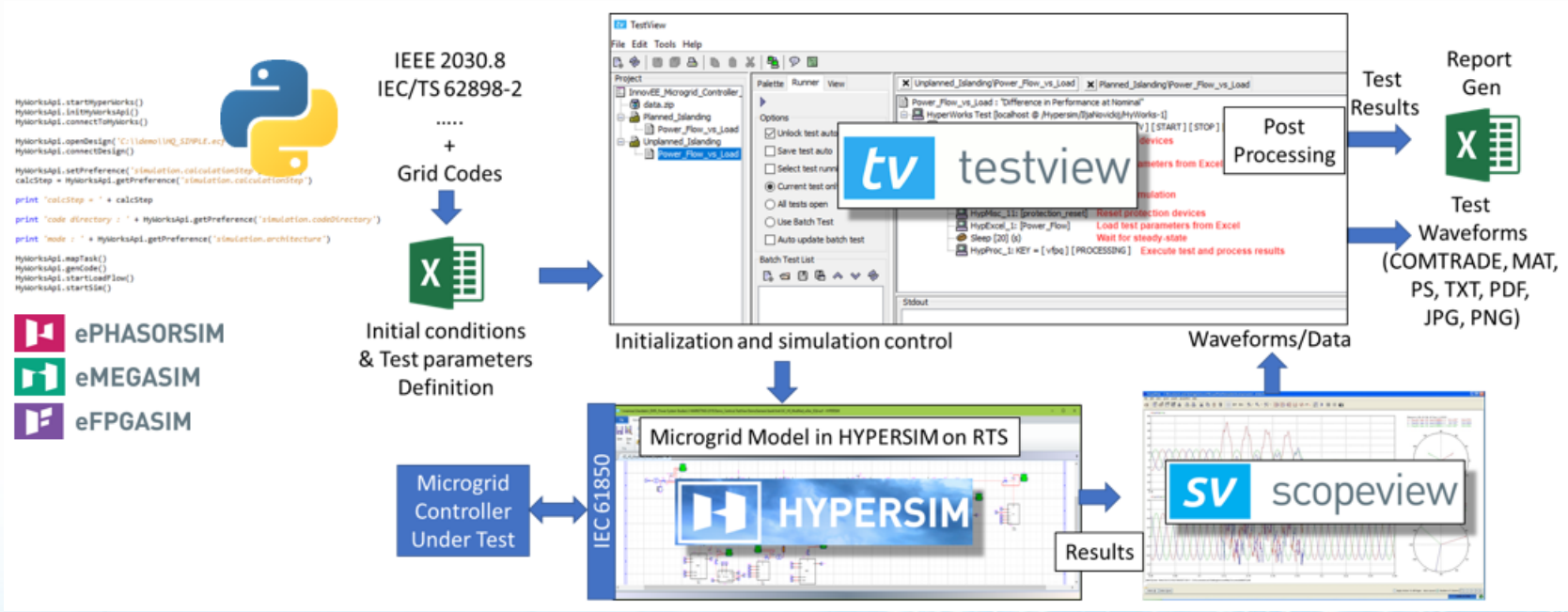
par▪a▪dox *- a statement that is seemingly contradictory or opposed to common sense and yet is perhaps true*
c.f. merriam-webster.com

Test MGCS as per IEEE 2030.8

- **Monitor performance metrics**
  - Voltages and currents
  - Frequency
  - P and Q
  - Power quality indices
  - Energy cost optimization / Fuel consumption reduction
- **Test multiple Scenarios**
  - Power system disturbances
  - Trip of DER / Load
  - Setpoint step change
  - Islanding / connection order received
  - Test MGCS optimization algorithms over long period
  - etc.



Test Automation Tools



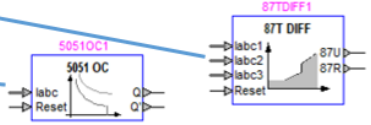
Flexible Test Platforms with Real and Virtual Equipment

Flexible Tests - Real/Virtual equip.

Simulate comm. network

Test feeder protection (HIL)

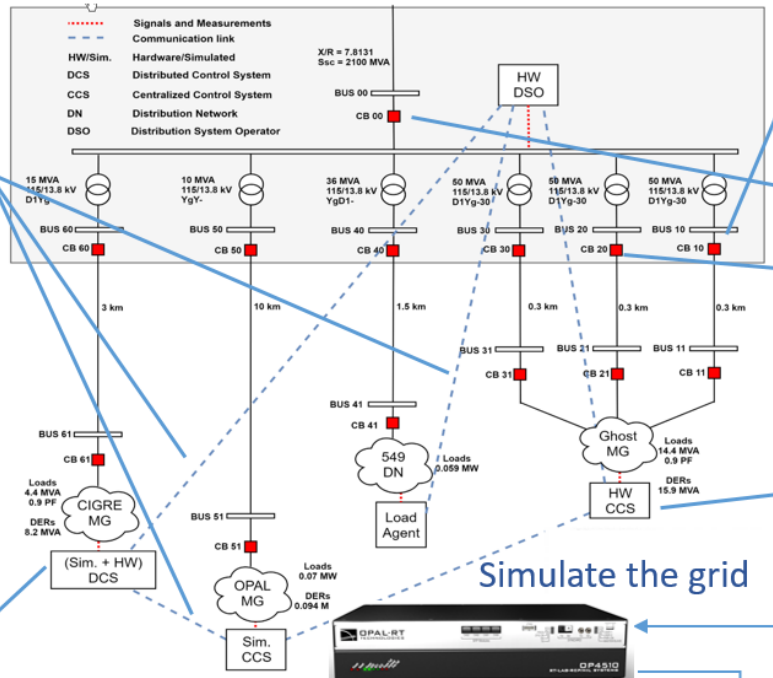
Implement virtual protections



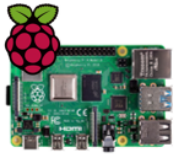
Implement and test MGCS on ruggedized real-time platform (HIL)

RT-LAB

MATLAB & SIMULINK



Implement and test MGCS with low-cost H/W (HIL)

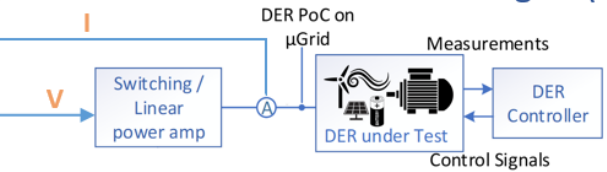


Simulate the grid

HYPERSIM ePHASORSIM

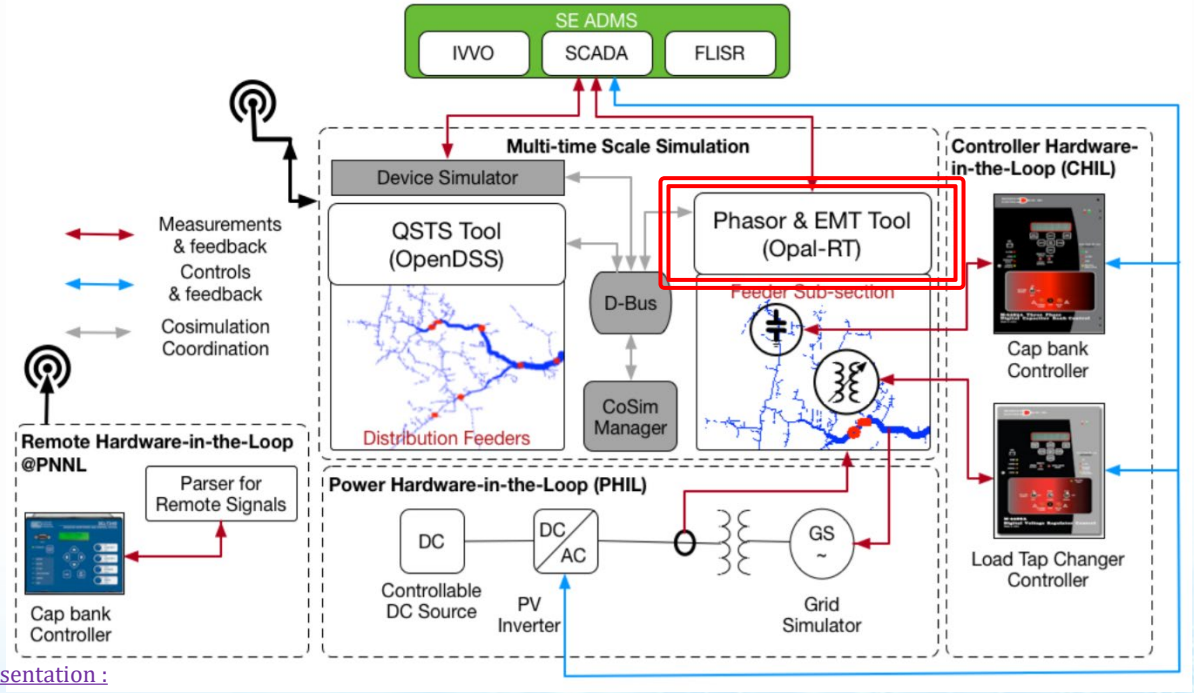
eMEGASIM eFPGASIM

Emulate the grid (PHIL)



OPAL-RT User Applications

ADMS Testbed – 3-Phase Unbal. Phasor RT-Sim.

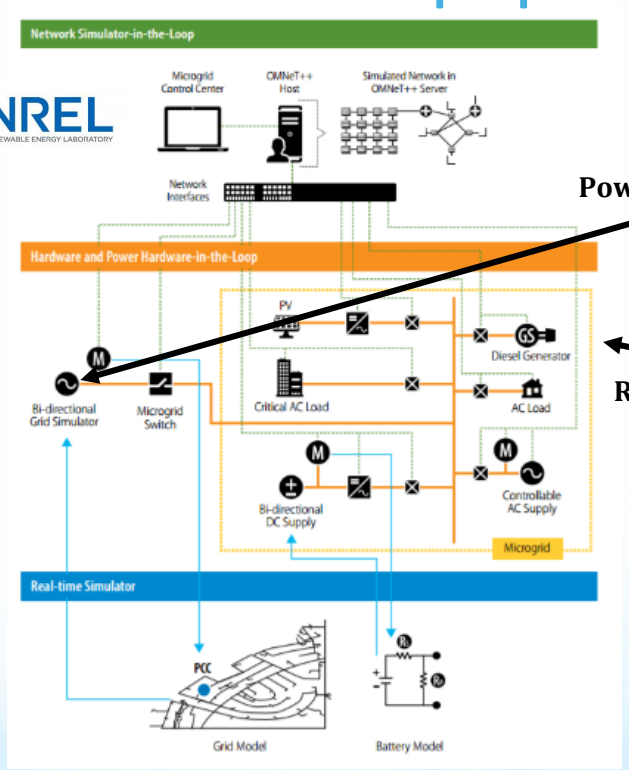


Credit / Multi-author presentation :

M. Baggu, A. Pratt, *Advanced Distribution Management System Testbed Development. [ONLINE 2018-03-12]*

https://www.smartgrid.gov/files/Pratt_Baggu_NREL_ADMS_Testbed.pdf

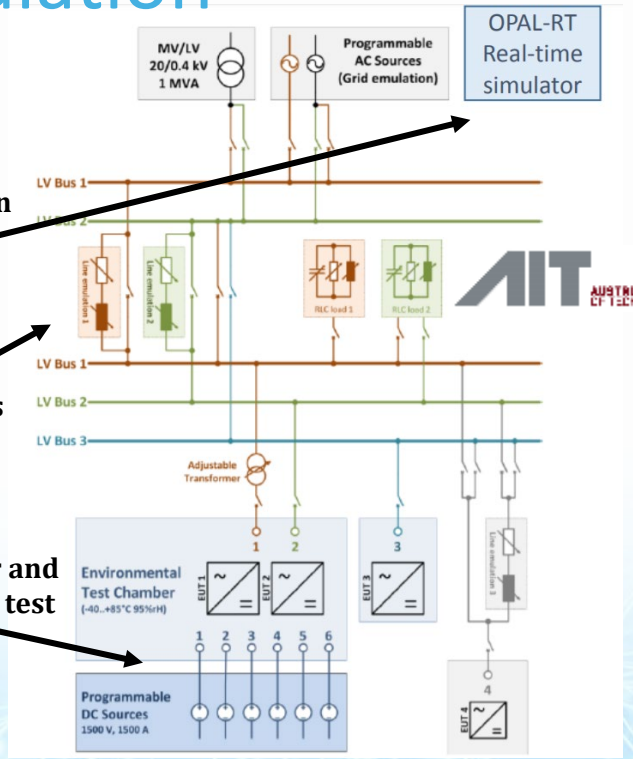
Power Hardware-in-the-Loop – Power Equipment Emulation



Power System emulation using PHIL

Real Loads and assets

Test chamber and device under test

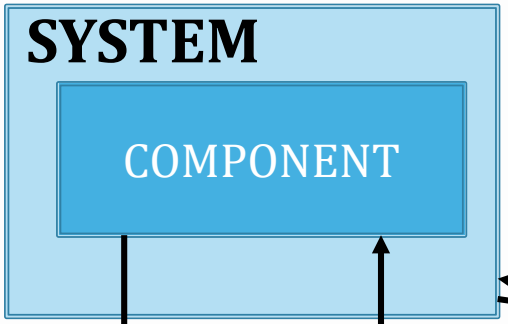


Looking Forward – The Concept of Digital Twins

Looking Forward – Digital Twins

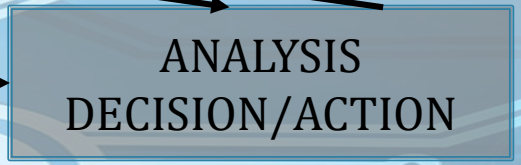
Definition	Authors
"A Digital Twin is an integrated multiphysics, multiscale, probabilistic simulation of an as-built vehicle or system **that uses the best available physical models, sensor updates**, fleet history, etc., **to mirror the life of its corresponding** flying **twin**"	Glaessgen & Stargel, (2012)
"Coupled model of the real machine **that operates in the cloud platform** and simulates the health condition with an integrated **knowledge from both data driven analytical algorithms as well as other available physical knowledge**"	Lee, Lapira, Bagheri & Kao, (2013)
"digital twin is a real mapping of all components in the product life cycle using physical data, virtual data and interaction data between them"	Tao, Sui, Liu, Qi, Zhang, Song, Guo, Lu & Nee, (2018)
"**a dynamic virtual representation of a physical object or system** across its lifecycle, **using real-time data to enable understanding, learning and reasoning**"	Bolton, McColl-Kennedy, Cheung, Gallen, Orsingher, Witell & Zaki, (2018)
"Using a digital copy of the physical system to perform **real-time optimization**"	Söderberg, R., Wärmefjord, K., Carlson, J. S., & Lindkvist, L. (2017)
"A digital twin is a **real time digital replica of a physical device**"	Bacchiega (2017)

Digital Twins – Know your Assets



Digital Twin of specific components (ex. Power plant)

- Model identification
- Preventive maintenance
- Advanced protections and controls



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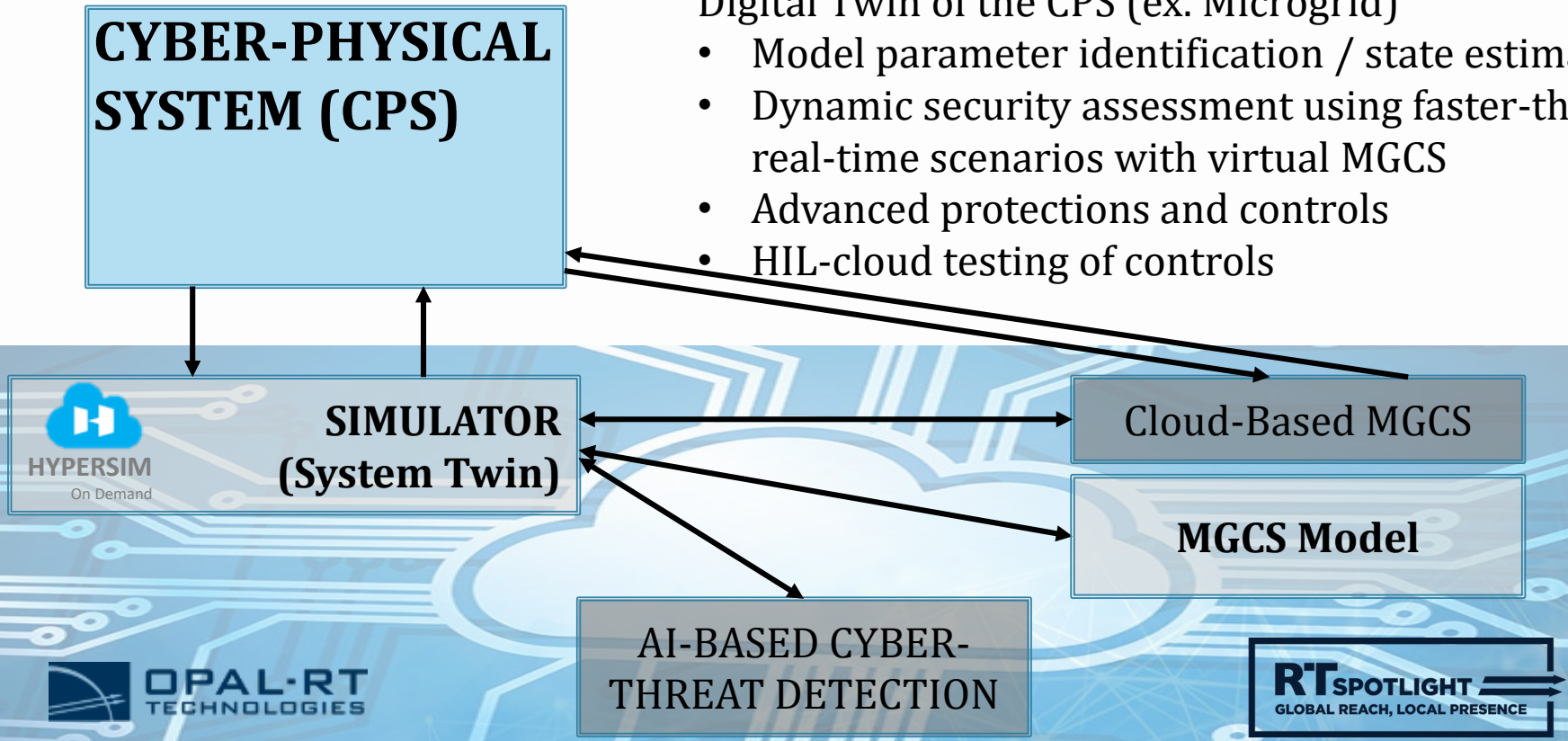
Digital Twins – Plan and Test Actively

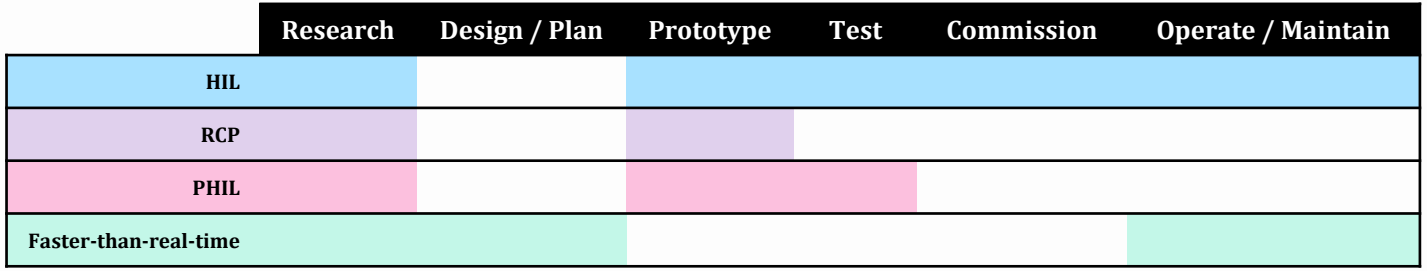
Digital Twin of the CPS (ex. Microgrid)

- Model parameter identification / state estimation
- Dynamic security assessment using faster-than-real-time scenarios with virtual MGCS
- Advanced protections and controls
- HIL-cloud testing of controls



Closing Remarks – Resilience and Security

- Advanced tools and techniques required to ensure resilience and security of the distribution system and microgrids.



- Increasing complexity of the grid will require innovation.
  - Consumers / Producers (Prosumers) and open electricity markets
  - Variability of the load
  - Constraints versus DER hosting capacity
  - Cyber-security / system stability
- Can the distribution system and microgrids be planned ahead 20+ years?
  - "Plug and play" concept in electric grid
    - **Active planning / Improved operation tools / Model-based decision-making**
- Is the concept of Digital Twins an answer to ensure resilience and security of the future **autonomous grid**?

QUESTIONS?

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