Faster Than Real-time Co-Simulation with High Performance Computing

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Idaho National Laboratory

Power and Energy Real-Time Laboratory (PERL)

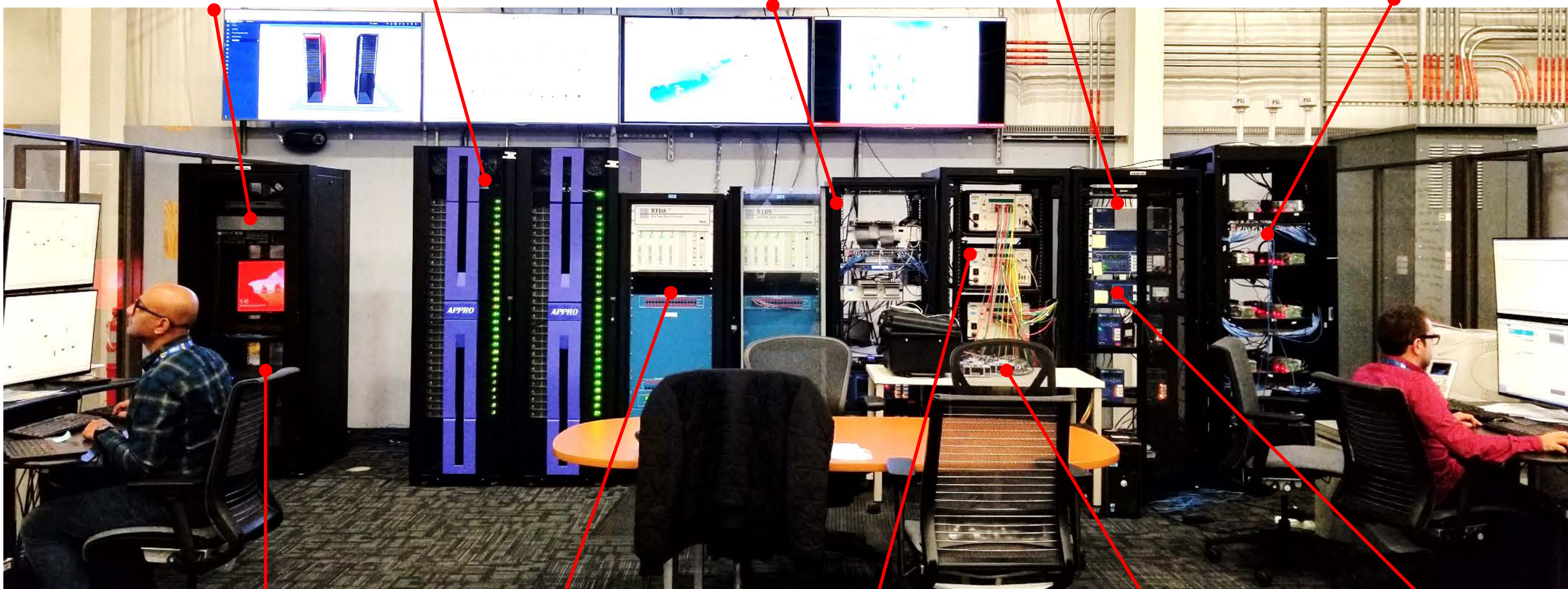
Opal RT, FPGA Development Environment
(IEEE 1394 and MIL 1553)

High Performance Computing
(~1800 compute nodes)

Controllers
(Siemens, SEL RTAC)

100+ RISC-based programmable cards for emulating hardware
Electric Vehicles, Wind Turbines

Typhoon HIL
for Testing Advanced Power Electronics



Linux Servers for communication layer, Real-time Data Analytics

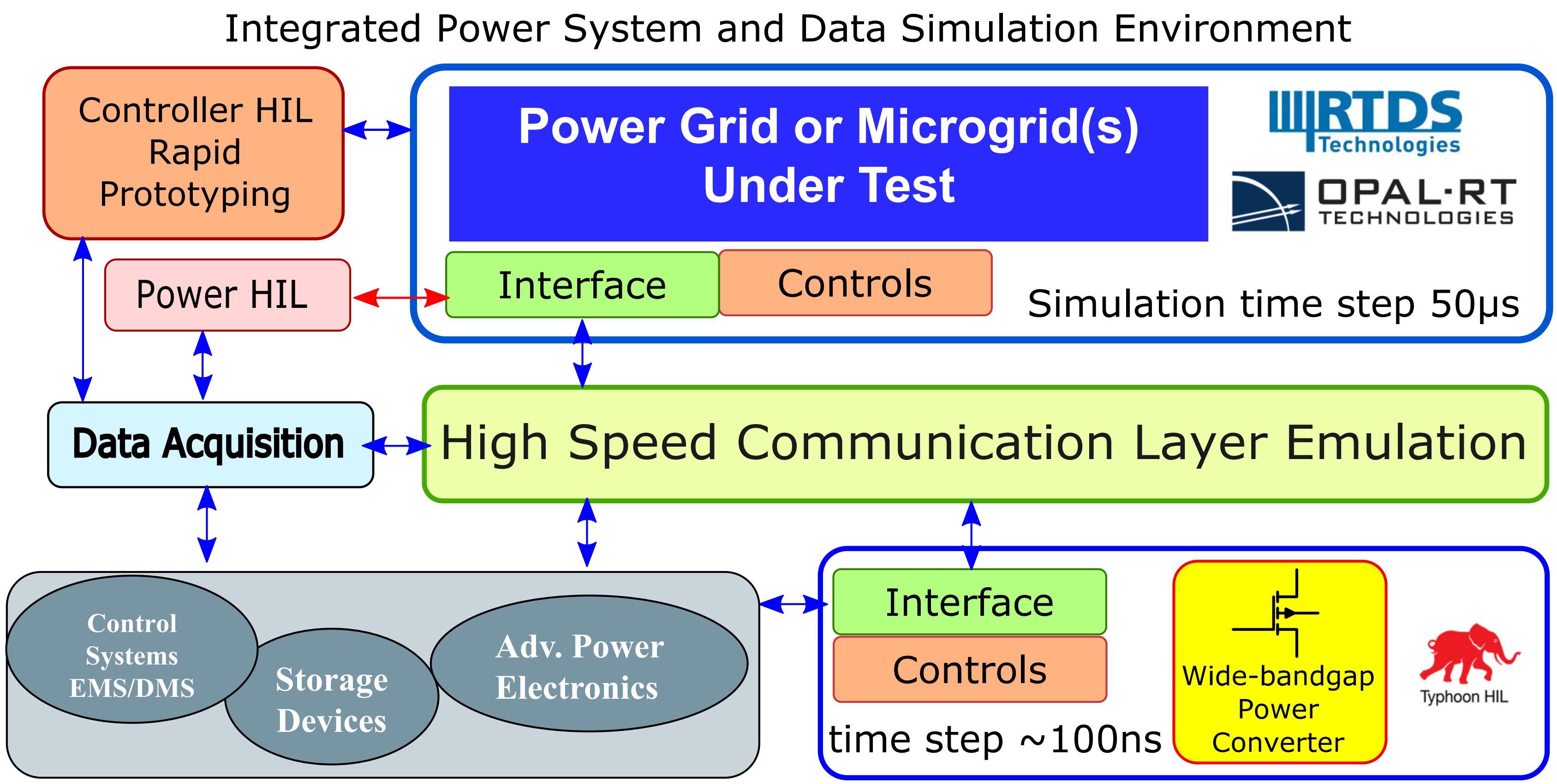
Real-Time Digital Simulator

Programmable V & I-Amplifiers

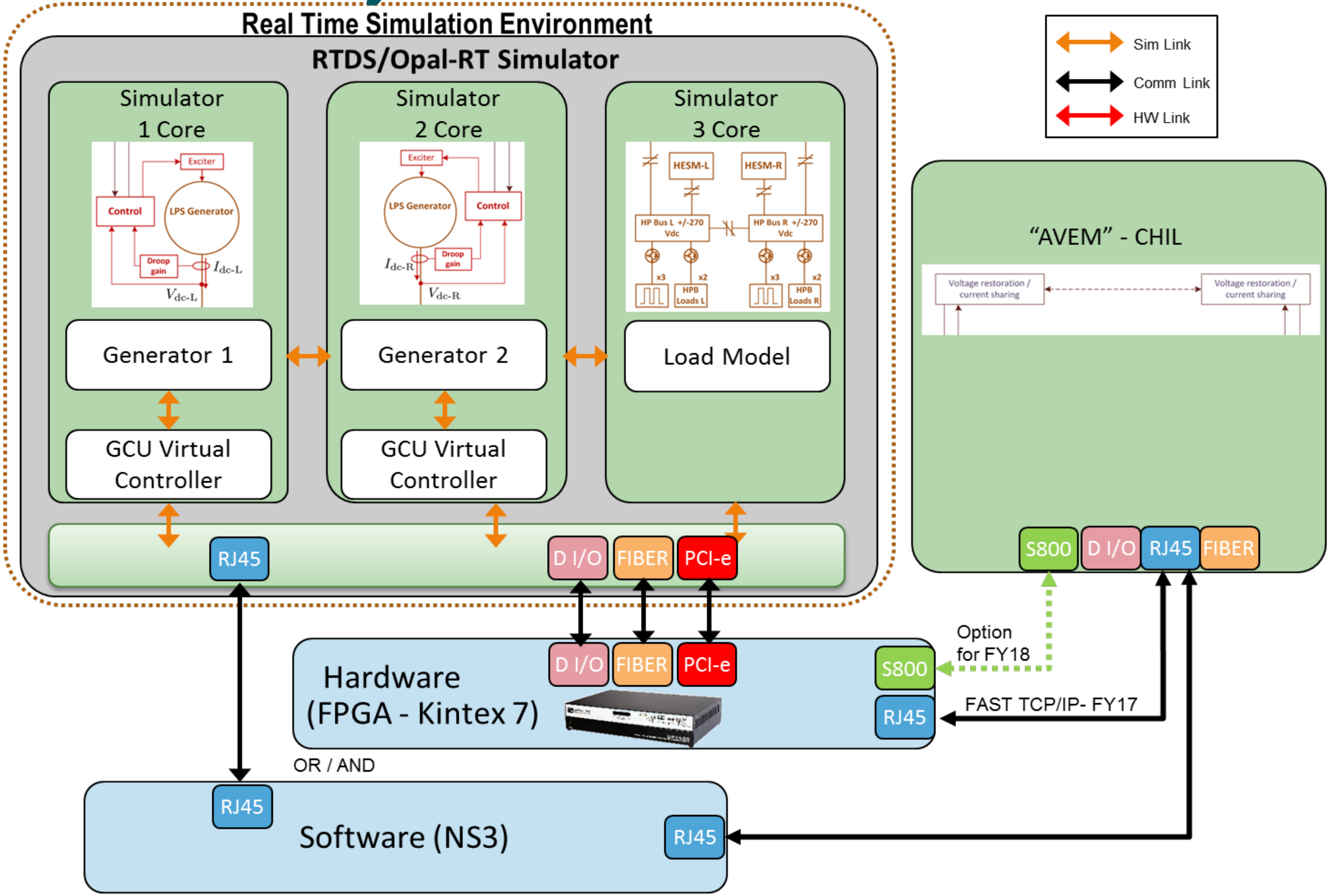
Micro-PMUs

Protection Relays

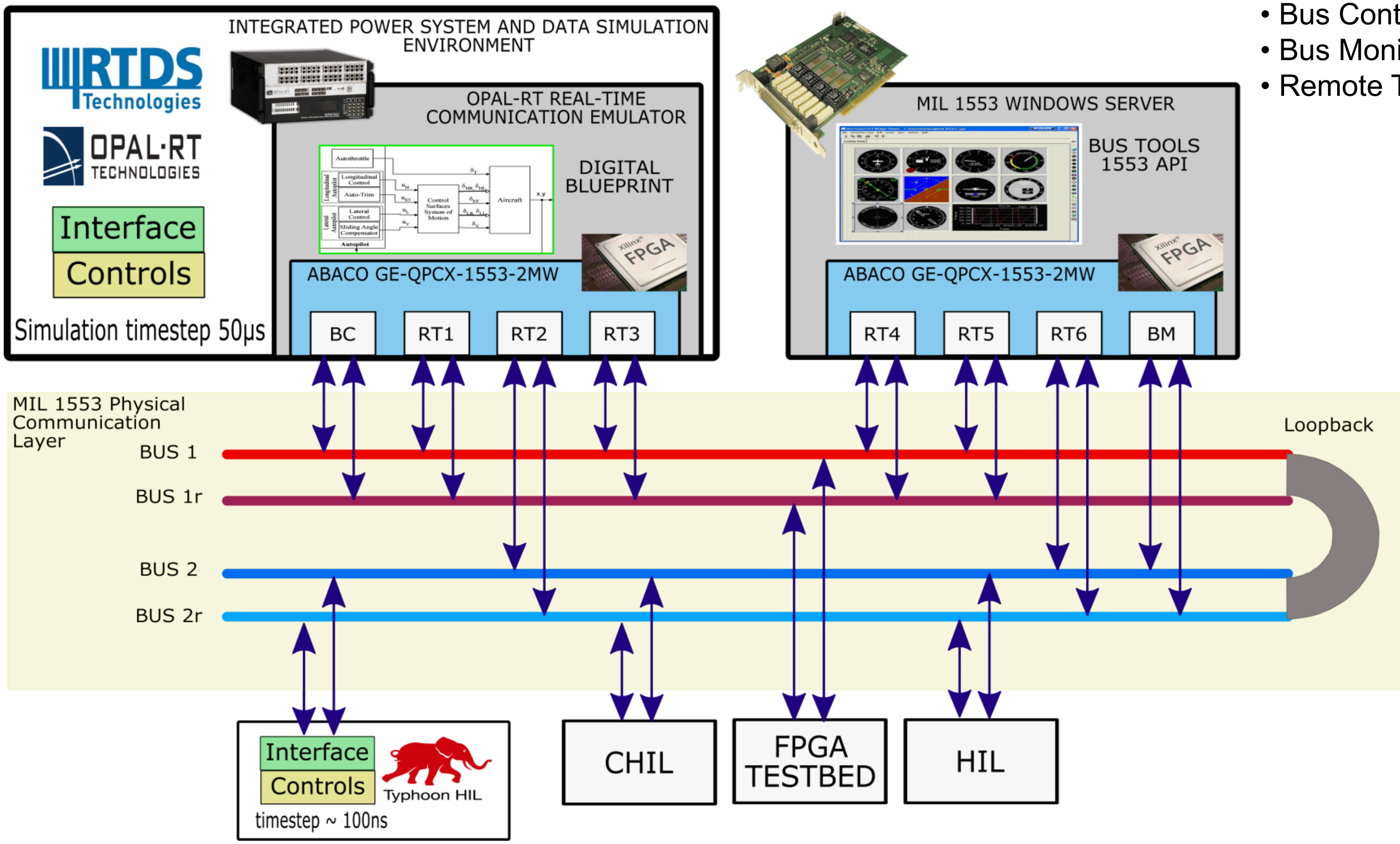
Co-simulation for power systems, power electronics, and communication



1- Real-time Communication Co-Simulation for Aircraft Power Systems



2- Communication Co-simulation Integrated MIL 1553 Data Simulation Environment



- Bus Controller (BC)
- Bus Monitor (BM)
- Remote Terminal (RT)

Each MIL 1553 Card can simulate up to 32 RTs

Multiple 1553 based devices such as CHIL, HIL, and other FPGA test beds can be integrated to study behavior and response using the MIL-STD-1553 protocol.

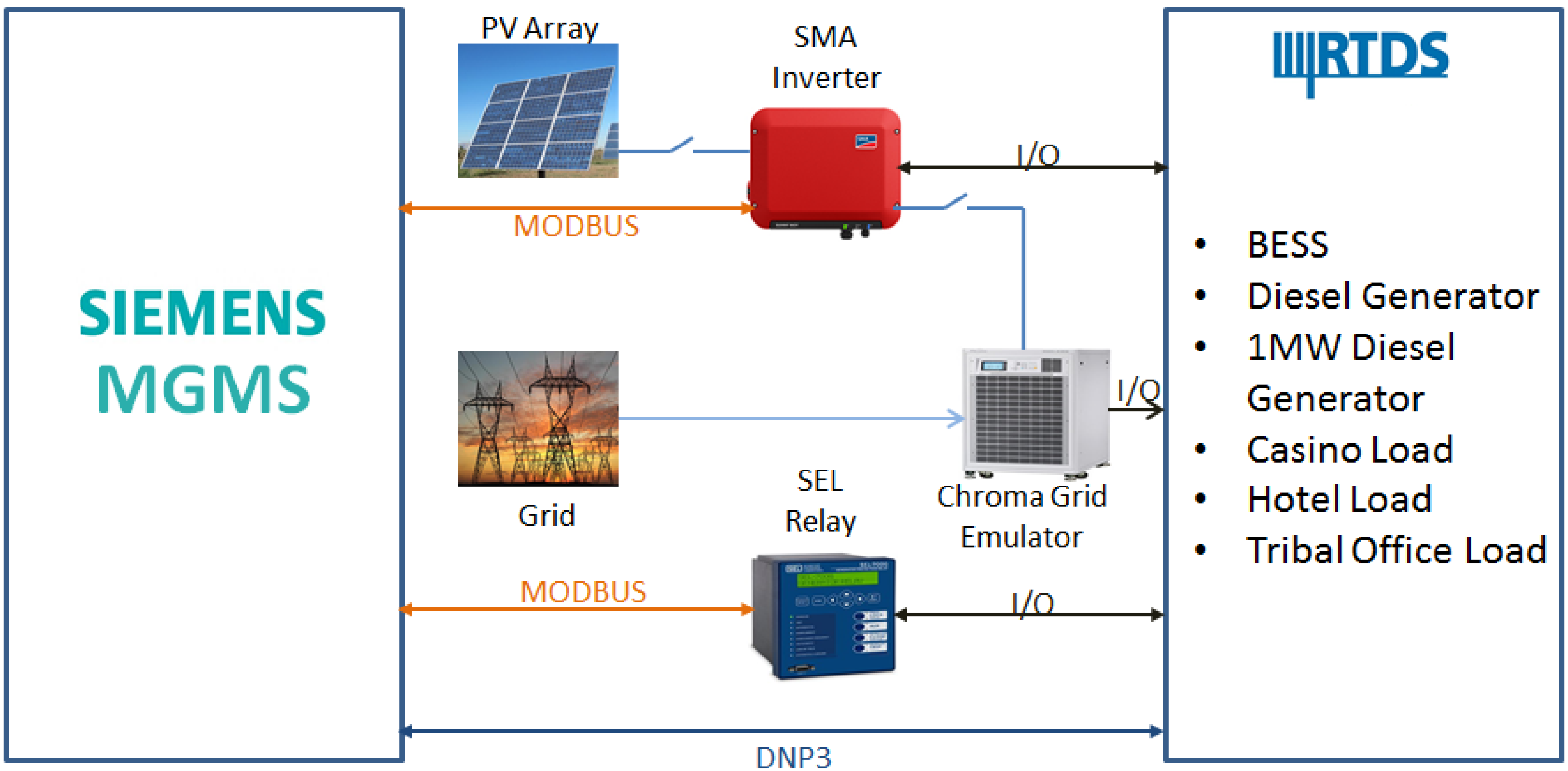
3- CHIL / PHIL Rapid Prototyping - California Energy Commission's Blue Lake Rancheria Microgrid

- First digital blueprint developed and used for HIL testing at INL
- Also a Red Cross Evacuation Route

"2017 FEMA Whole Community Preparedness Award"

"2018 POWERGRID International and DistribuTECH Project of the Year Award"

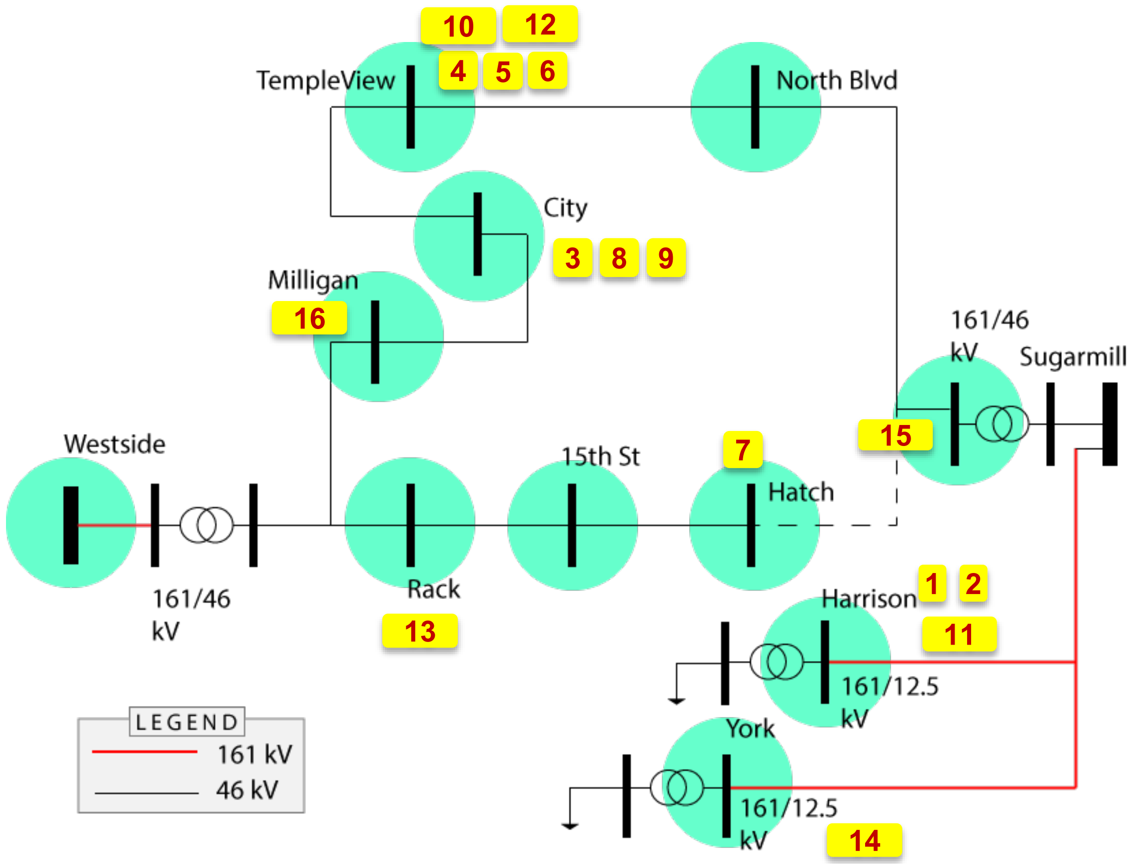
Blue Lake Rancheria Microgrid



Project Report: Real-time Modeling and Testing of Microgrid Management System for the Blue Lake Rancheria-Performance Assurance Report, M Mohanpurkar, Y Luo, R Hovsapian, A Medam, Idaho National Lab. (INL), Idaho Falls, ID (United States) https://www.osti.gov/servlets/purl/1426889

4- Digital Blueprint CHIL- Smart Reconfiguration to Serve Critical Loads

- Critical loads as identified by Idaho Falls Power



Priority	Description
1 – 4	**Very High Priority Loads** (*Examples*: Hospitals, Control/Command center, Emergency Response/Dispatch)
5 – 9	**High Priority Loads** (*Examples*: Airport, Correctional Facilities, Police Department, Fire Station)
10 – 12	**Medium Priority Loads** (*Examples*: Fire Station, State Services)
13 – 16	**Low Priority Loads** (*Examples*: Water Treatment, Community Care)

5- Digital Blueprint CHIL / HIL- Resiliency-driven Microgrid Reconfiguration

- ROR HPP Modeling – dynamic and transient evaluation in real-time simulation
- ROR HPP applications in microgrids/weak distribution grid that provide support / reliability / resiliency

Energy Storage Optimization for
- Multi-timescale (Super-Capacitor, Flywheel, Batteries) response coordination for grid support
- PHIL-based characterization of ESS under dynamic conditions

ROR HPP Modeling – dynamic and transient evaluation in Real-time Simulation

GMLC RADIANCE project outcomes from Run-of-the-river and Pumped Storage Hydro research

a) ROR as a resource for rotational inertia and regulation in coordination with **microgrid controller** and **Energy Storage Optimization** Toolbox (ESOT)
b) Coordinated operation with proximal generation as ROR or **Pumped Storage Hydro (PSH)**

a) Assessing **rotational inertia** from the existing ROR plant – resiliency enhancement
b) Modifications by removing deflector plates for rotational inertia in microgrid for **regulation and frequency support**
c) Upgrading hydraulic governors to **digital electronic** for faster, more efficient operation

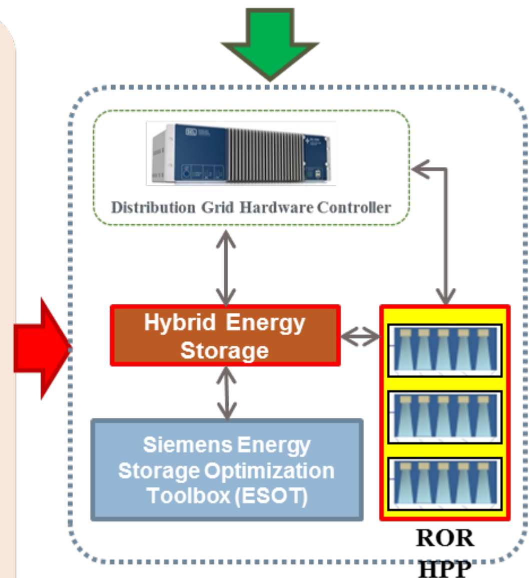
Humpback Creek Run-of-the-river Hydroelectric Plant 1250kW (2 x 500 kW + 1 x 250 kW)

Power Creek Run-of-the-river Hydroelectric Plant 6278kW (2 x 3124 kW)
with Inflatable dams

City of Cordova
1,566 customers, 18MW
One Substation

Orca Power Plant
(10.8MW Diesel) Control Center

Crater Lake Dam Storage
may offset 25% Diesel consumption



a) **Capacity evaluation** for pumped storage hydro (PSH) as energy storage
b) **Evaluation of design configurations** for PSH technologies (multiple vs. single, fixed-speed vs. variable-speed)
c) **Simulation-based testing** of PSH as part of microgrids under dynamic seasonal conditions
d) **Economic analysis** of design configurations and technologies for pumped storage hydro

Idaho National Laboratory

High Performance Computing-based Dynamically Adaptive Protection Schemes for Electric Grid

Project Team

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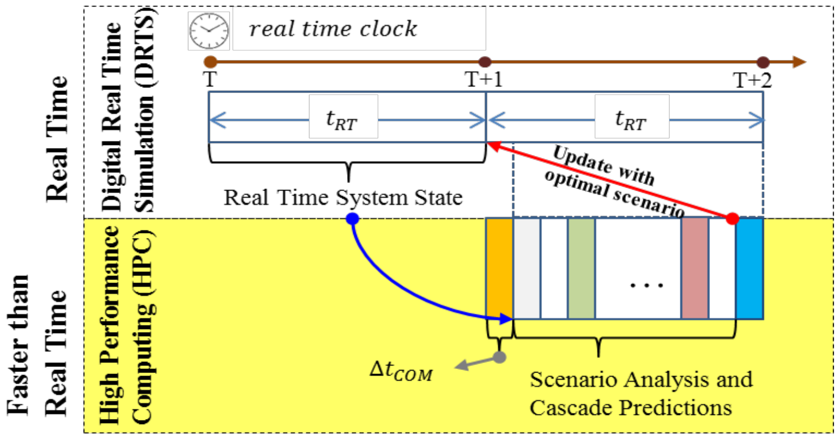
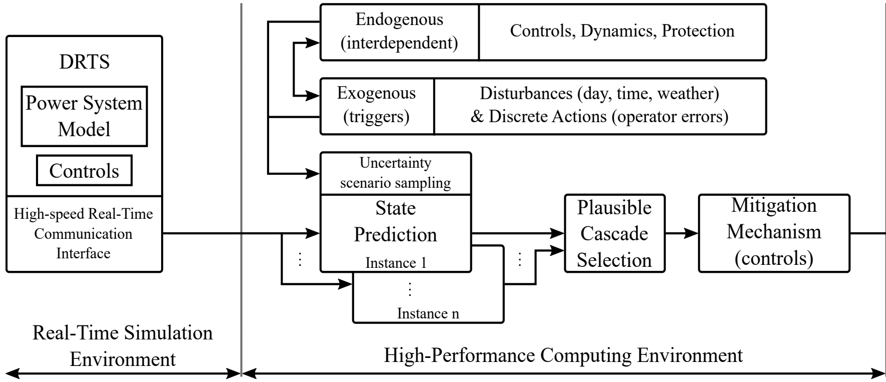
Introduction – DRTS and HPC Integration

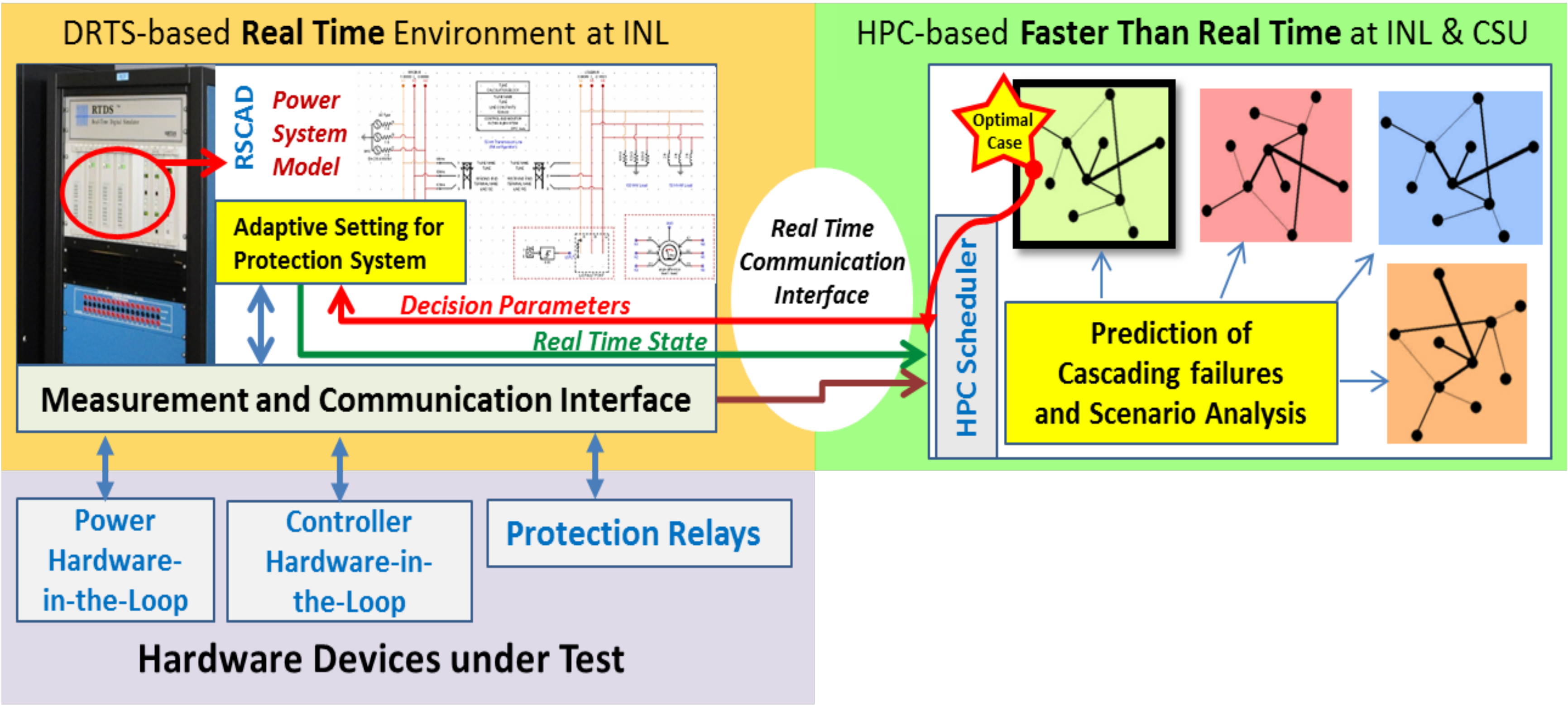
- **Significance**: Electric grid: more complex, dynamic, less predictable, reducing inertia → increased the risk of cascading failures, thereby compromising resiliency.
- **Two major challenges** of the future grid:
  – prediction and mitigation of cascading failures
  – real-time adaptive protection and remedial action schemes
- **Approach**: Digital Real Time Simulator (DRTS) and high-performance computing (HPC) for *faster than real-time prediction* of controls, *dynamically adapting protection* to contain disturbance propagation.
- **Benefit**: An improved and less conservative protection and RAS operation will be obtained by optimizing wide-area protection settings dynamically, and predicting the propagation of cascading failures.

Design Methodology and Approach: Integration of DRTS and HPC





Approach



Conceptual diagram for HPC-based dynamically adaptive protection and remedial action schemes

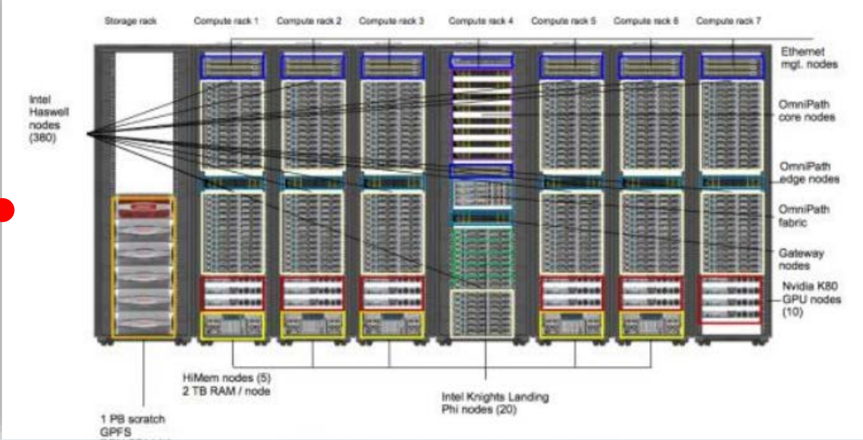
HPC–DRTS Integration Setup at INL

HPC *Fission* racks
56 compute nodes (~1800 cores)

Real-Time Digital Simulator: 2 Racks

HPC–DRTS Integration between INL and CSU

Bi-directional Communication



Real-Time Digital Simulator

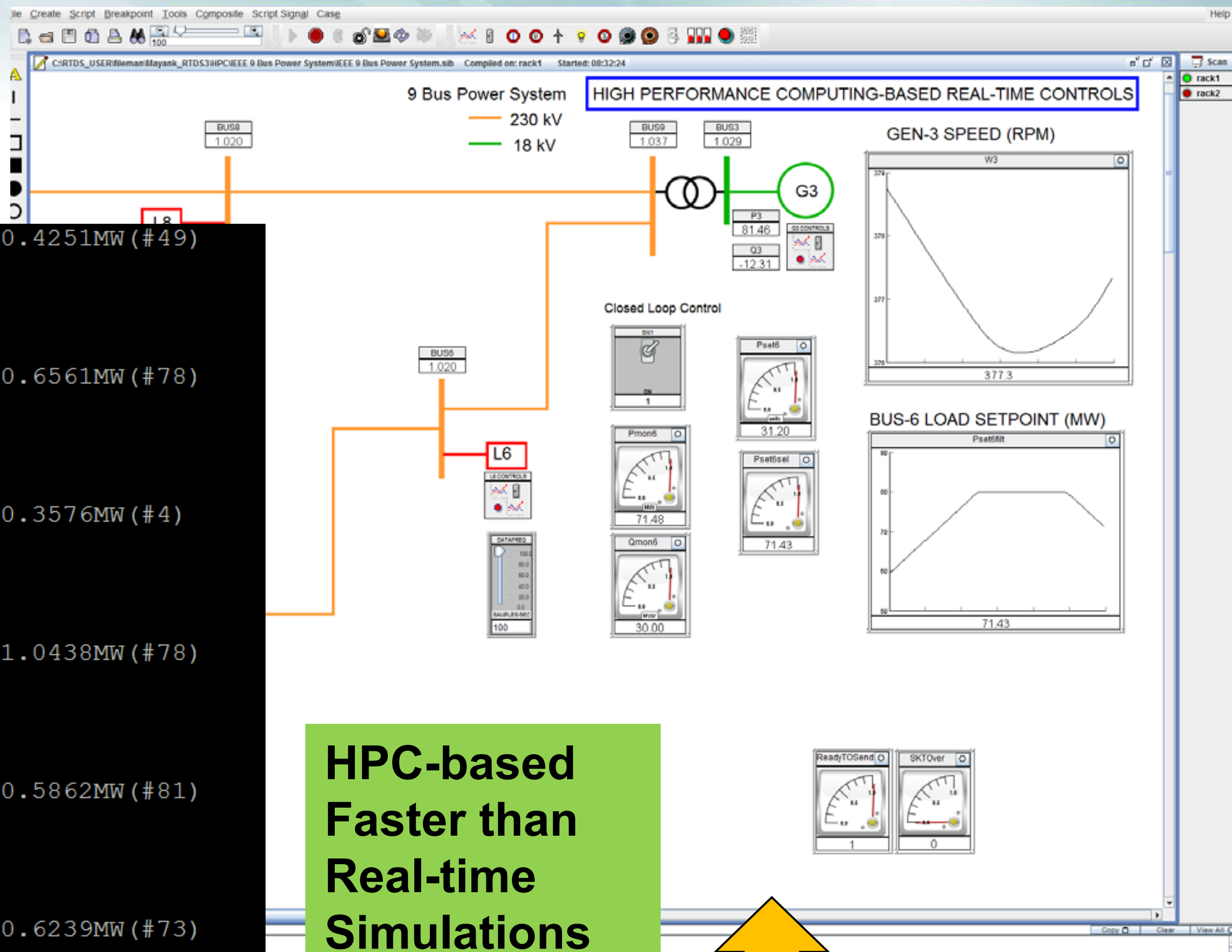
HPC *Fission* racks

HPC *Summit* @CSU

INL HPC Conclave

Co-simulation setup (INL)

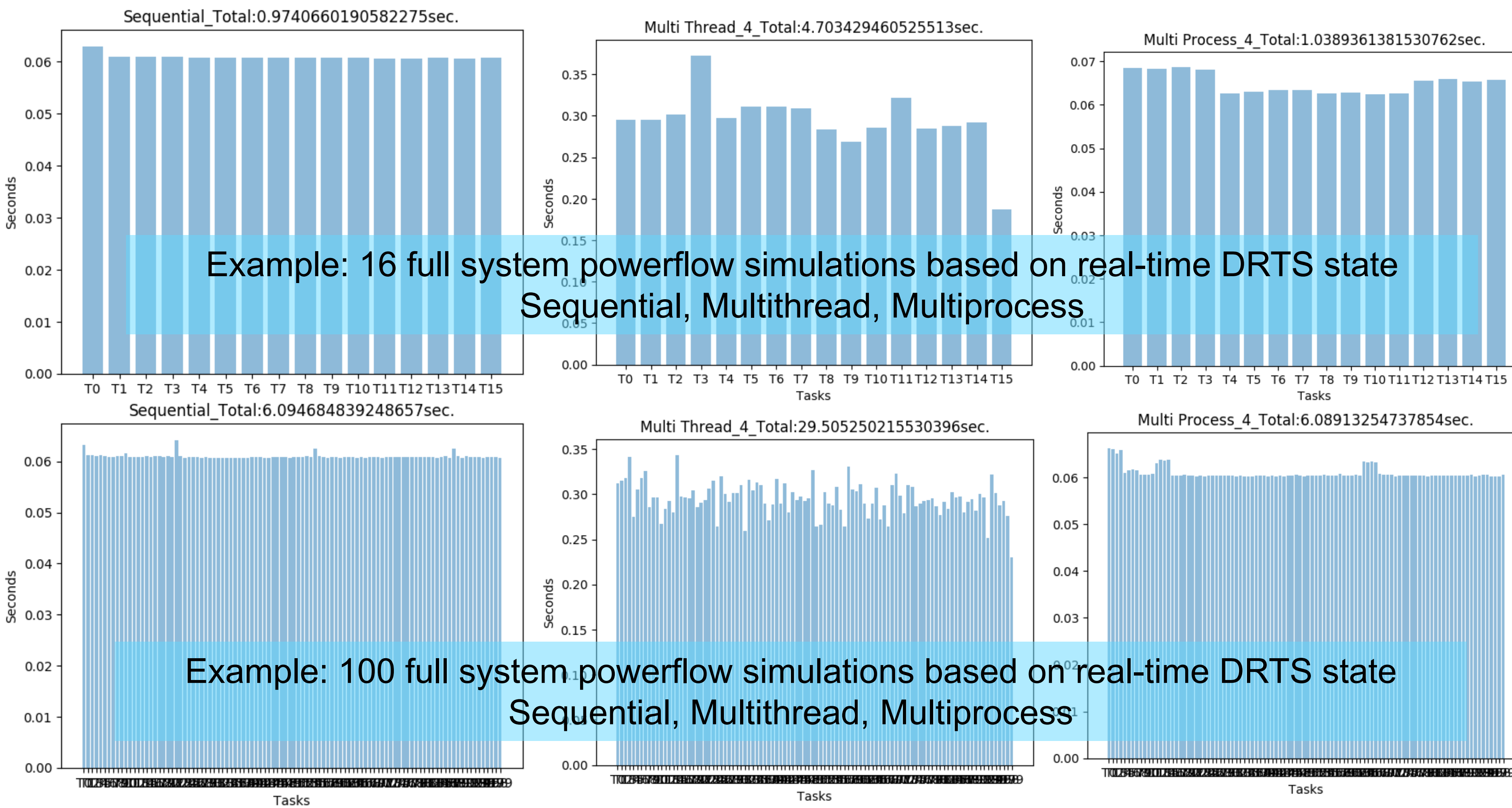
```
Seq: Min. error: 0.0870 found for case:50.4251MW(#49)
Tx:Load to RTDS is 50.4251

Rx:Load from RTDS is 60.5371

Seq: Min. error: 0.0871 found for case:50.6561MW(#78)
Tx:Load to RTDS is 50.6561

Rx:Load from RTDS is 60.2651

Seq: Min. error: 0.0870 found for case:50.3576MW(#4)
Tx:Load to RTDS is 50.3576

Rx:Load from RTDS is 50.9580

Seq: Min. error: 0.0861 found for case:41.0438MW(#78)
Tx:Load to RTDS is 41.0438

Rx:Load from RTDS is 50.4022

Seq: Min. error: 0.0860 found for case:40.5862MW(#81)
Tx:Load to RTDS is 40.5862

Rx:Load from RTDS is 50.4251

Seq: Min. error: 0.0860 found for case:40.6239MW(#73)
Tx:Load to RTDS is 40.6239

Rx:Load from RTDS is 90.0045

Seq: Min. error: 0.0922 found for case:80.0561MW(#53)
Tx:Load to RTDS is 80.0561

Rx:Load from RTDS is 90.0018

Seq: Min. error: 0.0922 found for case:80.0483MW(#45)
Tx:Load to RTDS is 80.0483
```



HPC-based Faster than Real-time Simulations based on Real-time state from DRTS

DRTS simulation in Real-time IEEE 9 Bus System for WECC

Preliminary Results: DRTS – HPC Integration

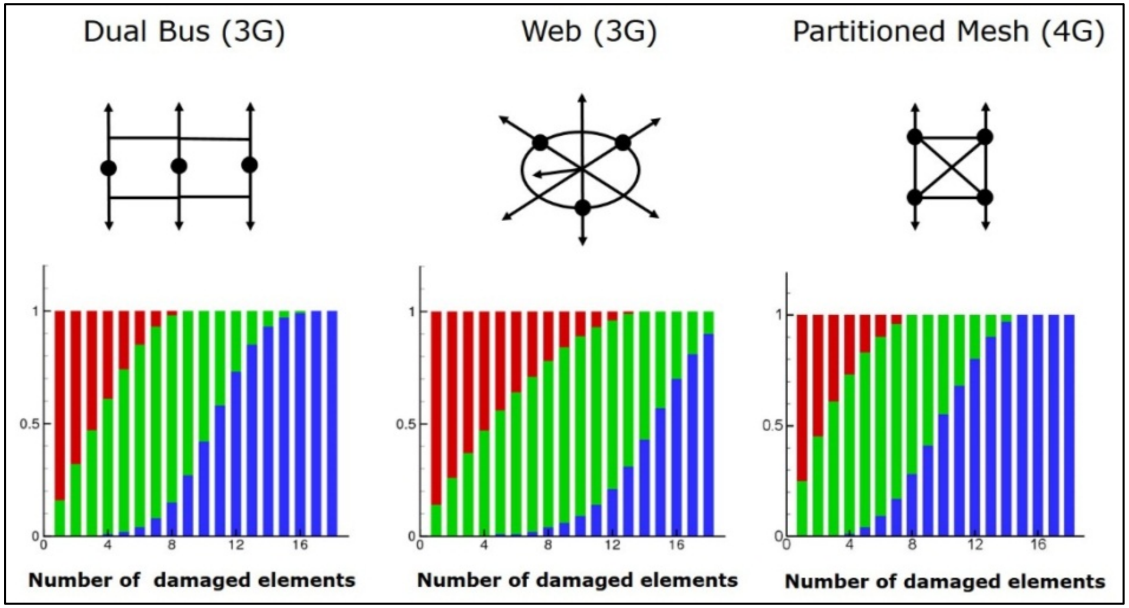


Example: 16 full system powerflow simulations based on real-time DRTS state
Sequential, Multithread, Multiprocess

Example: 100 full system powerflow simulations based on real-time DRTS state
Sequential, Multithread, Multiprocess

Probabilistic Methods for Cascading Failures

- Aim is to describe and quantify in probabilistic terms the grid response to an arbitrary number of simultaneous failures in the grid elements
- Computational cost reduction using deterministic and stochastic analyses tools, and graph theory

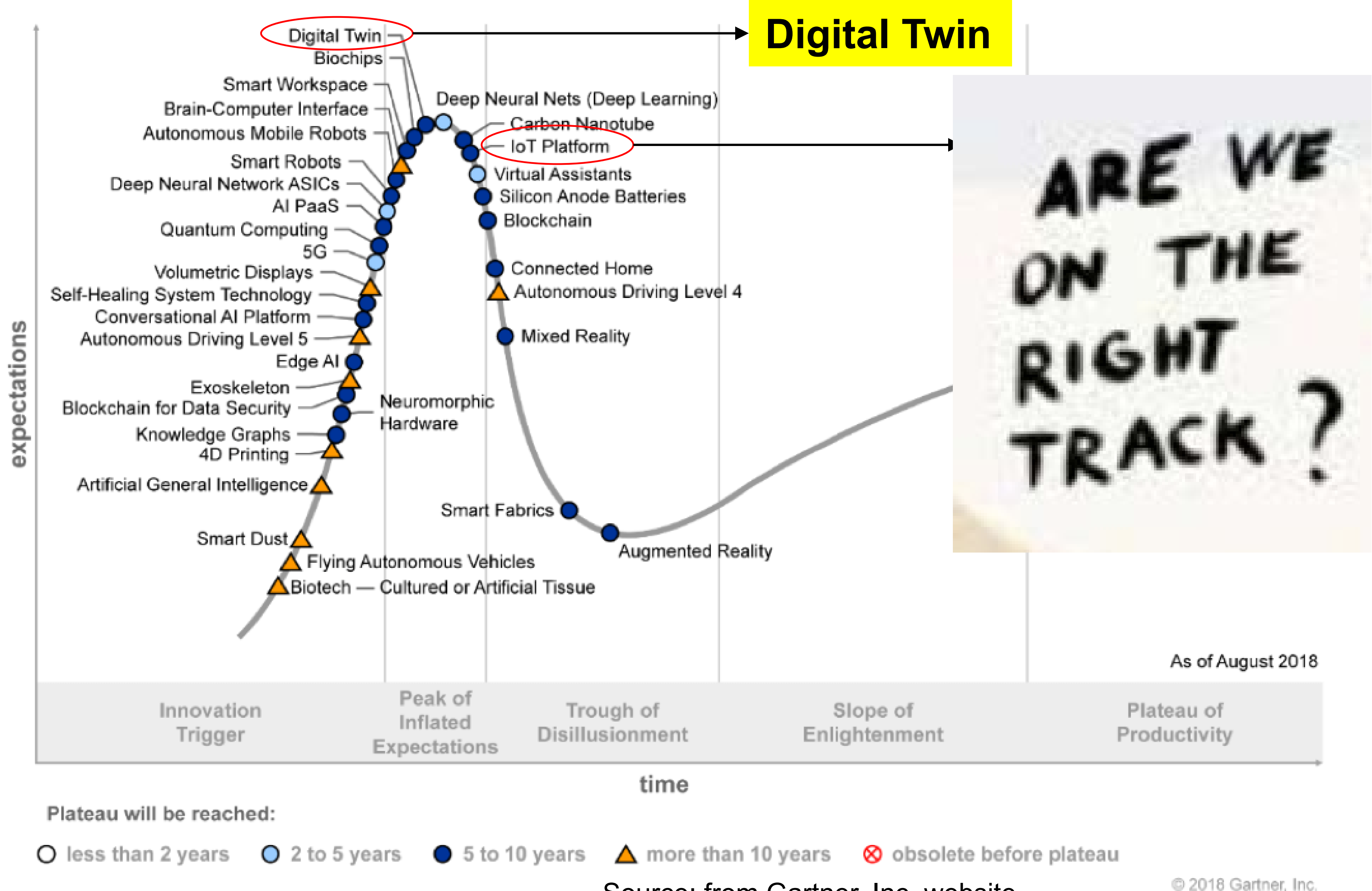


A unique mathematical approach to describe and quantify the grid response to an arbitrary number of simultaneous failures in the grid elements

Concluding Remarks

- Challenges
  - Initialization and synchronization of HPC analysis for each time-step
  - Representation of interface quantities in partitioned network
  - Including partially observability in FTRT analysis
  - Time-efficient solution and representation of analyzed scenarios
    - Machine / deep learning and code optimization opportunities
  - Introducing controls to DRTS and CHIL/CIL for prototyping
  - Adaptive quantities for protection schemes and control
- Interaction between DRTS and HPC
  - acting as a computational platform → controller-in-the-loop for wide area power system problems
- **Other applications**: flow networks including multi-infrastructure interaction (gas pipeline, communication, water supply, or onboard power distribution network), multi-dimensional resiliency analysis and control, electrical-thermal co-simulations.

Emerging Technologies – Timeline of Expectations



Source: from Gartner, Inc. website

Thanks

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