The use of distributed real-time simulation in the validation of systems readiness levels

M. H. Syed, E. Guillo-Sansano and G. M. Burt
Institute for Energy and Environment
University of Strathclyde
Glasgow, Scotland
Laboratory Interconnection: Prospects

• Validation acceleration
  – Integration of specialist skills
  – IP protection

• Comprehensive characterization
  – Integration of specialized equipment

• Effective Demonstration
  – Scalability
Validation Acceleration

Cluster capability
Validation Acceleration

Multi-Disciplinary/Multi-Specialization

- IP Protection, models do not need to be shared.
- In some cases, economically (logistically) efficient
Comprehensive Characterization

- Hybrid Electric Aircraft (HEA)
  - Coupled electrical and mechanical propulsion systems
  - New concepts, technologies and architectures
- Load management in Marine applications
  - Energy storage (prototype) for short term energy supply
- Integrated energy systems

Example distributed laboratories for HEA

Source: The ship is a Microgrid, M. Baker, https://info.typhoon-hil.com/blog/the-ship-is-a-microgrid
Systems Readiness Level

- Technology Readiness Level (TRL) is only valid for appraised functionality of/or a subsystem
- Integration Readiness Level (IRL) grades the integration of technology into a system

\[ SRL = \min\{TRL_1, TRL_2 \ldots TRL_i, IRL_1, IRL_2 \ldots IRL_i\} \]

\[ \frac{TRL}{SRL} \geq 1 \]

Source: NASA TRL
Impact of System Transformation – Great Britain

- Increased RoCoF
- Frequency/Voltage instability
- Controller interaction
- Increased sensitivity to load imbalance and harmonics

- Reduced fault in feed
- Sub-synchronous oscillations and interaction with conventional machines

Sources of UK energy between 12 and 18 April, 2018 (National Grid)
Tackling Grid Transformation

- **Enhanced Frequency Control Capability**
  - RoCoF triggered, regional, 100% active power < 1 second (target 500 ms)

- **Web-of-Cells:**
  - Alternative architecture to support increased decentralization and distributed operation.

**Increased scalability?**
Over thirty institutes from Europe and U.S. performing research related to Smart Grids (SG) integration of Distributed Energy Resources (DER)

- Accredited testing of DER-units and SG-equipment
- Support of SG development and integration of Renewable Energies
- Information and knowledge exchange
- Contribution to standardisation activities

Network of Excellence for Smart Grids
Enabling Distributed Laboratory Experiments

Distance: 21 km

[Diagram showing a map of Europe with nodes labeled RI1 RTDS and RI2 RTDS connected via GTNET, with a distance marker indicating 21 km.]
Distributed RT Challenges

- Analogous challenges to PHIL simulations:
  - Stability: system characteristics and interface
  - Accuracy: time delay
  - Initialization: subsystem inter-dependency
Addressing the Challenges

• Characterization of the delay
  – Contrary to widely deployed fixed deterministic delay, P-HIL delay is variable
  – Accurate compensation requires accurate characterization
  – Impacts stability

Addressing the Challenges

- Advanced time delay compensation technique
  - Not only accuracy but also stability

Addressing the Challenges

• Method for initialization and synchronization for large scale systems.

Milestones in Distributed Laboratory Couplings

01. Concept formulated
02. Fidelity Studies
   - RMS vs phasor
03. Development of interfaces
   - External phasor decomposition
04. Development of frameworks
   - Geographically dispersed PHIL VILLAS
05. Demonstrations
   - Trans-oceanic US-Australia
     Germany, Italy, Netherlands

Limitations of the approach in terms of capturing dynamics?
Applicability for Frequency Control

- Inherent Delay (D1) of the setup:
  - DPSL-PNDC ~8ms
  - PNDC to DPSL ~7.5ms

- Additional delay
  - D2= D1+8ms (each way)
  - D3=D1+16ms (each way)

- Event: Load step (1GW) in LFC 4

- Parameters to observe
  - Average system frequency
  - Average rate of change of frequency of the system
  - Active and reactive power at interface
Applicability for Frequency Control Studies - Fidelity

2-norm error=1.18%
Applicability for Frequency Control- Responsibilising PFC

A decentralized control
• Event detection within 100-150 ms

Applicability for Fault Analysis

- Event: 100 ms three phase fault at bus 4
- Same delays as before, D1, D2 and D3
- Parameters to observe
  - Interface Current
  - Total Fault Current
Resilient Wide-Area Backup Protection

- PMU-based wide-area backup protection
- Scalable through decentralized approach
- Distributed simulation enables comprehensive validation at full scale

Conclusions

• Distributed real-time simulation offers the promise of a number of discrete benefits.
• Complexity of problems being tackled within HIL environment is increasing.
• More rigorous understanding of the errors in distributed simulations is required and mitigating measures are being experimentally investigated.