Holistic Assessment of Cyber-physical Energy Systems Facilitated by Distributed Real-time Coupling of Hardware and Simulators

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Contents

• Holistic testing of CPES + example
• Application of ERIGrid test cases in real time
• Relevant projects @ TU Delft
Holistic testing methodology

- **Test Case**: System under test, Object under Investigation, Functions, Purpose of Investigation, Test Criteria
- **Test Specification**: Test Design, Test System Configuration, Input & Output
- **Experiment Specification**: Experiment Design, Experiment setup

### Test Evaluation

- **Test case**: general system and function specification (why&what)
- **Test specification**: how to test the test case
- **Experiment specification**: how to implement the test specification inside a particular lab
Test description in practice

- **Test case**: conceptual level. (use case, test criteria, relevant functions)
- **Test specification** -- independent of experimental implementation. (relevant KPIs, relevant parameters(factors), stop criterion)
- **Experiment spec.** – implementation design. (hardware, software setup, how many tests, which variations)

KPI: key performance indicator
Case 1: onshore wind park

- Use case: voltage control and fault ride-through
- Physical and control interactions between transmission system and wind park
- Wide time-scale spectrum (us to s)
- Ideal for testing co-simulation and distributed real-time assessment
Case :1 model

FRT controller

Normal operation controls

100MW, type 4, averaged model

FRT: fault ride-through
Case 1: FRT controller

Reactive power injection during faults

Active power recovery after fault clearance

\[ I_{q,\text{add}} \]

\[ U_{1.0 1.2 0.5 0.0} - 1.0 \pm 0.1 0.4 \]

\[ P_{\text{flt}} \]

\[ P_{\text{pre}} \]

\[ 0 \quad t_1 \quad t_2 \quad t \]
Experiment design 1: monolithic simulation

- Variations: fault location, control parameters
- RMS: powerfactory
- EMT: simulink
Experiment design 2: co-simulation
The glue: FMI and Python

Master implemented in Mosaik: https://mosaik.offis.de/

FMI wrapper for Python: FMipp https://pythonhosted.org/fmipp/

FMipp Powerfactory wrapper: https://sourceforge.net/projects/powerfactory-fmu/

FMI: functional mockup interface
CS: co-simulation
ME: model exchange
PF: powerfactoruy\y
Potential for cross-RI simulation: CHiL

Sample time: in 10’s of ms range

*JaNDER: (Joint Test Facility for Smart Energy Networks with Distributed Energy Resources)
The Glue: JaNDER

- Stems from DERri project ([http://www.der-ri.net](http://www.der-ri.net))
- Developed by RSE*
- Connect lab-specific SCADA to
  - a joint SCADA or
  - external users

RSE: Ricerca sul Sistema Energetico
The Glue: JaNDER

- Research infrastructure 1
- Model / Controller from RI2
- Research infrastructure 2

- Real-time DB
  - IEC 61850 interface
  - CIM interface

- JaNDER

Arrows indicate measurements/setpoints flows:
- Level 0
- Level 1
- Level 2
Features of JaNDER

- Sampling rate: ~10-100 per second
- Level 0 (REDIS): variable naming, quality
- Level 1 (IEC 61850): additional (substation & device-specific information)
- Level 2 (CIM): considers grid topology as well
- soft real time: no strict RT constraint
Case 2: Extend RI1 using HW resources of other RIs

Objective: integrate remote HW to testing

RI1: RTDS (TU Delft)
RI2 and RI3: simulators, real components, or grids

RI: research infrastructure, HW: hardware
Case 2: Implementation Steps

1. Successful Remote connection of the Ris (JaNDER L1)

2. Soft-HIL implementation (exchange of data to establish virtual connection independent of any control algorithm)
   - RI1 (network simulator): sending Voltage magnitude + frequency at PCC
   - RI2/3 (microgrids): sending back active and reactive power measurements at PCC.
   - Independent of any control algorithm

3. Use of controllable resources at RI2/3 to connect to CVC instead of microgrid controllers.

4. Use of microgrid controllers to connect to CVC in RI1
Case 2: Challenges

• TCP/IP Accessibility differs per RI, tailored solutions needed
• Speed of the database determines real time capabilities
• linking equipment to REDIS database
• No experimental experience yet: ongoing work
• Part of CIM for JaNDER level 2 not standardised yet
Bus impedance matrix
Superimposed measured current (sending end)
Equation system
Least square method
Sum of Square Residuals (Fault localization)
Measured voltage error
Measured current error
Pre fault System
Post fault System
Superimposed Fault subsystem
Distributed parameter line model (Fault distance)
Positive and negative current comparison (Fault type)
Electrical Sustainable Power Lab

• Reconstruction of existing HV lab
• Multi-disciplinary approach
• Integration: Component, system, SoS
• central role for real time simulation
PowerWeb

• New institute @ TU Delft
• *The* platform for multi-disciplinary research on intelligent, integrated energy systems
• Integrates research on physical, data, and market-driven challenges of CPES
Conclusions

• Holistic testing needed for CPES
• System description methodology supports lab coupling
• Glue: JaNDER
• Interesting use cases:
  – Onshore wind power plant
  – Inter-lab coupling of components with RT simulation
Thank you!

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