Multi-location Virtual Smart Grid Laboratory with Testbed for Analysis of Secure Communication and Remote Co-simulation

Concept and Application to Integration of Berlin, Stockholm, Helsinki

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Agenda

1. Introduction
2. TU Berlin Smart Grid Lab
3. Virtual Lab – Overview
4. Co-simulation
5. Virtual Lab – Performance
6. Conclusion
1. Introduction: Motivation

- Concept of smart grid is closely tied to management, processing, and exchange of comprehensive data
- Distributed energy resources (DER) heavily rely on knowledge about the system's present and future state to offer flexibility
- Requirements:
  - Intelligent data management & controls
  - Fast, secure, and reliable communication
  - Flexible and affordable infrastructure
- Research demand:
  - Techno-economically suitable telecommunication technologies
  - Influence of standards and protocols on smart grid applications
1. Introduction: Co-simulation

- Developing concepts and use cases for smart grids and decentralized energy management systems (EMSs)
- Testing is required to detect and prevent faults that can compromise services or security of supply
- In this process, access to diverse competence and resources is very desirable due to rising complexity of such systems
- An interdisciplinary cooperation of laboratories appears promising
- Capabilities of state-of-the-art (SoA) telecommunication support idea of forming a virtual lab for co-simulation
1. Introduction: Testbed Solution

- **Testbeds are needed** for application-specific validation of smart grid communication
- **Therewith come challenges** including communication performance and data security
- **Presented solution aims** to address these key design challenges of a virtual smart grid laboratory (VSGL)
- **A platform** to provide the framework for quick and convenient set-up of co-simulation of remote laboratory resources
- **Also capable of assessing** the quality of different SoA telecommunication technologies for smart grid application
2. TU Berlin Smart Grid Lab: Overview

- Real-time hardware-software operation laboratory
2. TU Berlin Smart Grid Lab: Power Domain

- LV network infrastructure
  - 100 kVA feeder
  - Islanded or grid-connected operation
- Extension with real-time digital simulation of
  - Transmission grid
  - Neighboring grids
- Integrated DER units:
  - Generation (PV + wind power, HiL)
  - Storage (battery + virtual) + EVs
  - Electric + thermal loads (appliances)
2. TU Berlin Smart Grid Lab: ICT Domain

- SoA ICT infrastructure (modular, extendable, reliable):
  - Data platform based on open source SCADA (CERN)
  - Integration of physical & virtual actors/sensors/systems (IoT)
  - Virtualization of smart grid applications

- Advantages:
  - Highly scalable and adaptable system
  - Flexible time range of data logging, monitoring & control
  - Easy development & testing of novel control algorithms
2. TU Berlin Smart Grid Lab: R&D Example

- Implementing remote control of DER at external site (EUREF Campus)
- Investigating interaction between system operator (SO) and virtual power plant (VPP)

![Diagram showing flow of data and control processes involving DER, SO, VPP, and control algorithm.]

Delay (1 - 4) is mainly caused by step 4.
3. Virtual Lab: Overview

• VSGL:
  – Easy set-up of co-simulations
  – Secured by virtual private network (VPN)
  – Real-time communication

• Three European research labs:
  – TU Berlin (power systems)
    • Design, operation, & control of power systems
    • Integration of renewable and alternative energies
  – KTH Stockholm (control systems)
    • Control of multi-agent and embedded systems
  – VTT Helsinki (self-organizing networks)
    • Intelligent communication technologies
3. Virtual Lab: Communication Platform

- Backbone of platform
  - VPN (star topology)
  - Lightweight protocols
  - Adaptable interfaces
- Connectors at each lab
  - VPN clients
  - Routing entity
  - Network emulation routine
- Emulation of network characteristics for performance testing
  - Bandwidth: traffic limits, delay, variation, correlation
  - Data packets: loss, duplication, corruption, reordering
4. Co-simulation: Use Case Overview

- Residential energy system with several buildings
- Equipment:
  - Shiftable appliances
  - Solar PV & battery storage
  - Heat pumps & heating
  - Shared cogeneration unit
- Implementation:
  - EMS based on Model Predictive Control (MPC) operates entire system to minimize operation costs
  - Virtually connected research labs provide individual components
  - Network performance tested during co-simulation
4. Co-simulation: MPC-based EMS

- EMS provides optimal dispatch for each controllable DER and load using weather and power generation forecasts.
- MPC algorithm calculates the resource setpoints using a floating planning horizon of 24 h in advance.
- Objective is minimization of operation costs subject to energy purchase and sale of electricity.

\[
J(E_{stor}(k)) = \min \sum_{k=0}^{H-1} \sum_{b=1}^{B} \left[ c_{\text{tariff}}(k) P_{b}^{\text{grid}}(k) + c_{\text{stor,b}}(P_{\text{charg,stor,b}}(k) + P_{\text{disch,stor,b}}(k)) \right] + c_{\text{gas}} P_{\text{gas}}(k) \]

- \( B \) is the number of buildings \( b \) and \( H \) is the planning horizon.
- Subject to operational constraints of the controllable DER.
4. Co-simulation: Network Emulation

- Performance testing with 3 scenarios of network conditions
  - **NC1:** Highly restricted bandwidth
  - **NC2:** Reduced cost service (compared with standard 4G)
  - **NC3:** Locally congested connection

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<th>General parameters</th>
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<th>NC2</th>
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<td>RO correlation, %</td>
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5. Virtual Lab: Platform Performance

- Overlayed VPN barely affects platform performance
- Performance affected by:
  - **Distance** between connected labs
    - Helsinki – Berlin (1,100 km): high latency and less throughput
    - Helsinki – Stockholm (400 km): better performance in general
    - Berlin – Stockholm (810 km): unexpectedly high throughput
- **Emulated network conditions**
  - Scenario **NC1**: less throughput and larger latency with respect to scenario **NC2**, but data package losses about the same
  - Scenario **NC3**: largely increased latency and losses, much larger variations between minimum and maximum values
5. Virtual Lab: Comparison of Scenarios

**NC1**
Highly restricted bandwidth

**NC2**
Reduced cost service

**NC3**
Locally congested connection
5. Virtual Lab: EMS Performance Results

- 2 use cases: with and without electric energy storage (EES)
- MPC performance for example building (house 4):
  - With available EES, MPC strongly reduces purchase of electricity
  - 10.5% cost savings

- EES is charged in times of low electricity prices
5. Virtual Lab: Influence of Network

- Conditions of telecommunication network affect performance of MPC-based EMS control
- With highly restricted bandwidth (NC1) and network congestions (NC3), MPC fails to calculate optimum solution in time
- Example detail: House 1, first day

Network scenario NC2: Optimal schedule for exchange with electricity grid is found.

Network scenarios NC1 & NC3: MPC (@KTH) fails to find optimal schedule, due to corrupted data received from house (@VTT).
6. Conclusion

• Successful implementation of a virtual smart grid lab for co-simulation

• Supports testing of communication and control functions for distributed resources

• Communication technologies and ad-hoc network conditions can affect virtual lab performance and co-simulation results

• Impact has been studied by using the virtual lab’s capability of emulating network characteristics during co-simulation

• Further investigations planned, depending on available funding
References


Thank you for your interest!

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