Real-Time Co-Simulation of Transmission and Distribution Networks with Frequency and Voltage Optimal Control

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CONTENT OF PRESENTATION

1. Motivation.
2. Structure of the proposed optimal controller for each area of the grid.
3. Topology of BESSs and their controller at circuit level.
4. Diagrams and scenarios used in the experimental setup.
5. Experimental results (real-time).
6. Conclusions.
MOTIVATION

- Massive integration of renewable power plants.
- High penetration of power electronics-based energy.
- Mismatch between supply and demand.
- The study of the interaction of new generators and loads in an actual power systems can be extremely expensive, unsafe or in some cases impractical to accomplish.
- Real-time simulation (RTS) with power hardware-in-the-loop is a cost-effective and low-risk.

Fig. 1. Overview of different assets interacting in modern power systems.
OVERALL STRUCTURE OF THE PROPOSED CONTROL

- Digital communications and smart measurements.
- Battery-based storage systems.
- ERA modelling algorithm.
- Multi-input, multi-output optimal LQG controllers.
- New aggregator.

Fig. 2. Overall diagram of the proposed control [1].

TOPOLOGY OF THE BESS AND THE CONTROLLER

- Two-level, three branches voltage source converter (VSC).
- It works in four quadrants of the PQ plane.
- Controller in the DQ reference frame with PI linear controllers.
- Synchronization with PLL
- \( P_m^* \) and \( Q_m^* \) are estimated by the aggregator.

Fig. 3. Configuration of the BESSs [2].
(a) Circuit topology and (b) Linear PI controllers.

Fig. 4. Schematic diagram and connections of the proposed setup for the real-time co-simulation.
ACTUAL EXPERIMENTAL SETUP

• Some of the equipment available in the ZHAW Smart Grid Labs.

• Real connections for the experiments of this work.

Fig. 5. Picture of the experimental setup
Test Scenarios

The governor and excitation controllers of all SGs remain active in the following scenarios.

- **Scenario 1:** Load increase at bus 11. Comparison in open-loop and closed-loop.
- **Scenario 2:** Sudden loss of generation of an actual solar plant. Power is amplified 10000 times. Analysis of real noise and harmonic distortion.
- **Scenario 3:** Three-phase-to-ground fault at node 20.
TRANSMISSION NETWORK RESPONSE TO LOAD CHANGE

Fig. 7. Transmission network response to a sudden increase of L3 on bus 11
Fig. 8. Response of distribution feeder to a sudden increase of L3 on bus 11
• Operation near to 50% to extend the life span of the batteries [3].

• The power injection in the transmission network impact the voltage profile in the PCC.

- Three-phase to ground fault on bus 20.
- Duration of 50ms.
- Significant frequency and voltage excursions on all monitored buses.
- The proposed controller reacts to compensate for the frequency and voltage deviations by injecting power from the BESSs in all areas.
- Robustness and reliability are verified under these extreme test conditions.

Fig. 10. Response of the transmission network following a 3-cycle three-phase fault at node 20.
TRANSMISSION NETWORK AFTER SUDDEN LOSS OF GEN.

Fig. 11. Results of transmission network for a sudden loss of generation in the real solar plant
Feedback currents to the real-time emulator without filtering. Noise is coupled to the output voltage of the power amplifier, affecting the operation of all hardware in the loop.

Feedback currents with filter. The stability of the link between the real power hardware and the real-time simulators is improved.

Fig. 12. Actual measurements at the PCC with the solar inverter
CONCLUSIONS

• The proposed controller regulates frequency and voltage with accuracy, even in the presence of real electrical noise, harmonic distortion, and significant changes in the operating conditions of the system.

• The proposed hardware setup is effective for real-time emulation of dynamic behavior of power systems integrated with transmission networks, distribution feeders and renewable energy resources.