HIL Testing for Efficient and Resilient Operation of Inverter-Dominated Microgrids

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▶ ICCS-NTUA

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DELFT, NETHERLANDS

Outline

- Background

- PHIL validation of Virtual Synchronous Generator

- Cyber-security considerations in inverter-based microgrids

- Digital twin for the evaluation of data driven based dynamic security assessment of non-interconnected islands

- Digital twin for optimizing renewable energy utilization in real-world microgrid – ecoMicrogrid

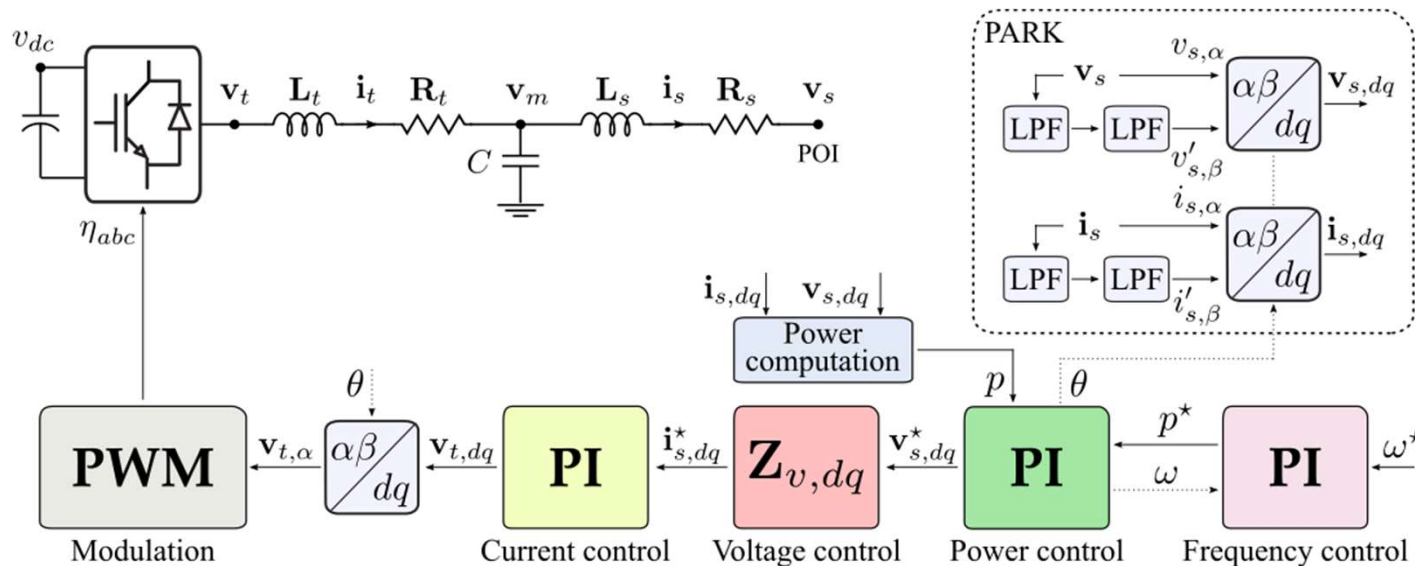- Real-Time Simulation in lab education

- Conclusions

Background

- Why microgrids?
- We utilize real time simulation in wide range of applications → fundamental research up to high TRL solutions

Virtual Synchronous Generator Control Design

Rotating Reference Frame

Matas-Diaz, Francisco & Kontou, Alkistis & Barragán-Villarejo, Manuel & Kotsampopoulos, Panos & Maza-Ortega, J.M. & Hatziargyriou, Nikos. (2023). Assessment of Control Strategies for Single-Phase Grid-Forming Voltage Source Converters. 1-6. 10.1109/SEST57387.2023.10257369.
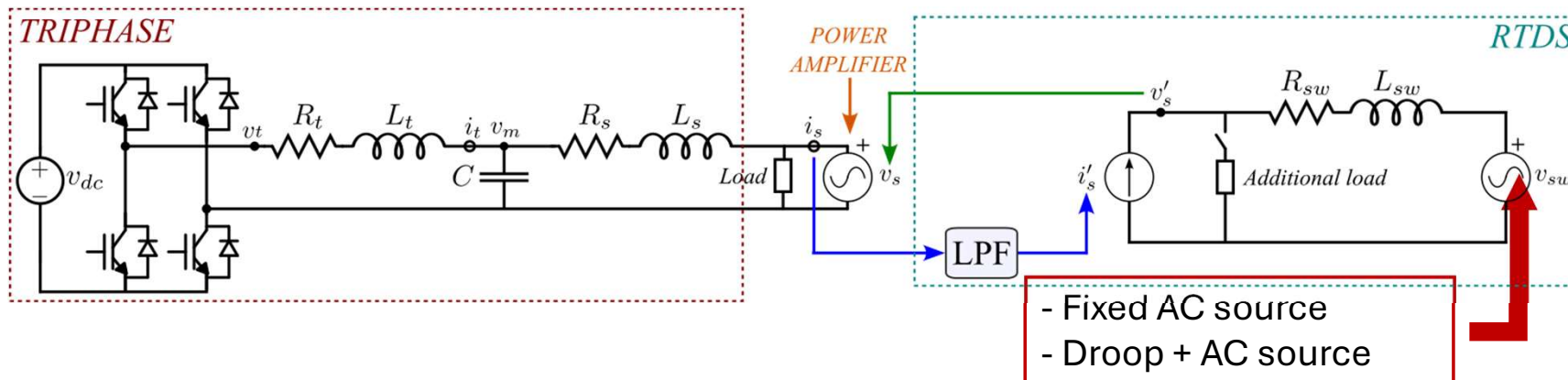
Validation of the VSG operation

- **Full controller**

RoCoF test

Load transient test
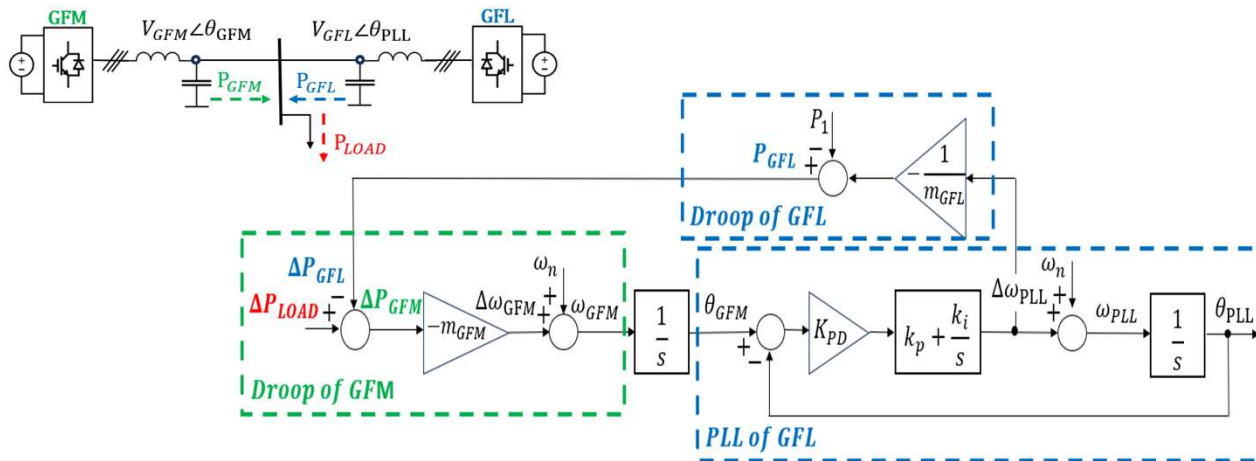
ICCS-NTUA Lab

- Fixed AC source
- Droop + AC source
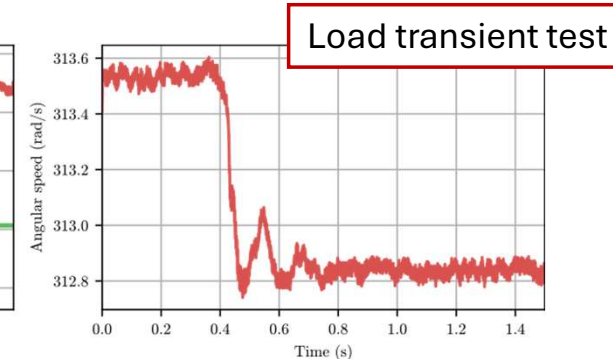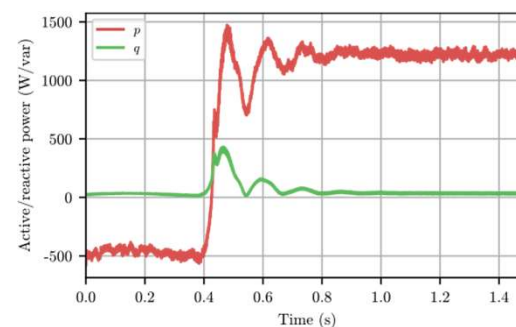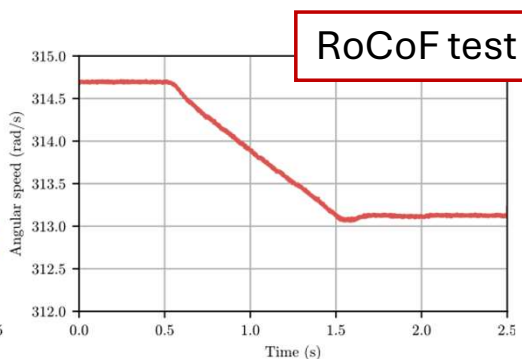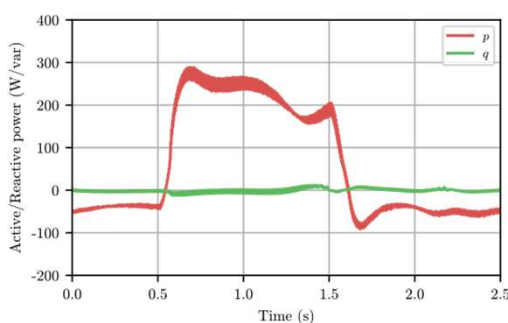
Cyber-security considerations in inverter-based microgrids

- PLL attack in grid-following inverters

- Interaction with power controller of the GFM

- Current limitation can lead to substantial voltage drops and disconnection of units, even black out

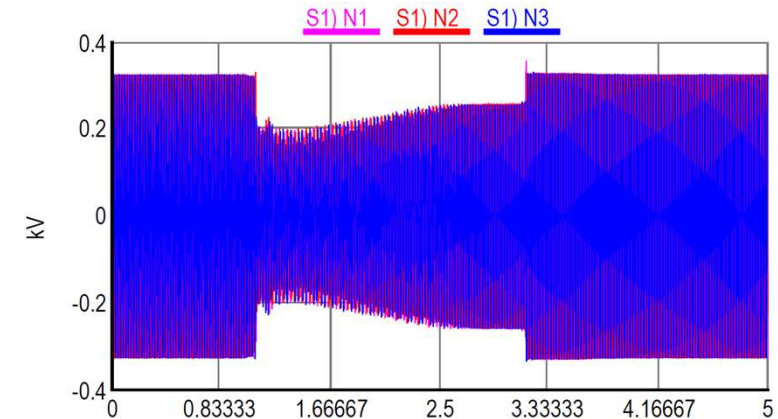- PHIL validation in University of Strathclyde

A. Kontou, M. Syed, A. Paspatis, H. Konstantinou and N. Hatziargyriou, GFM-GFL Power-Frequency Interaction under Compromised PLL in Inverter Based Networks. TechRxiv. September 06, 2024. (under review)
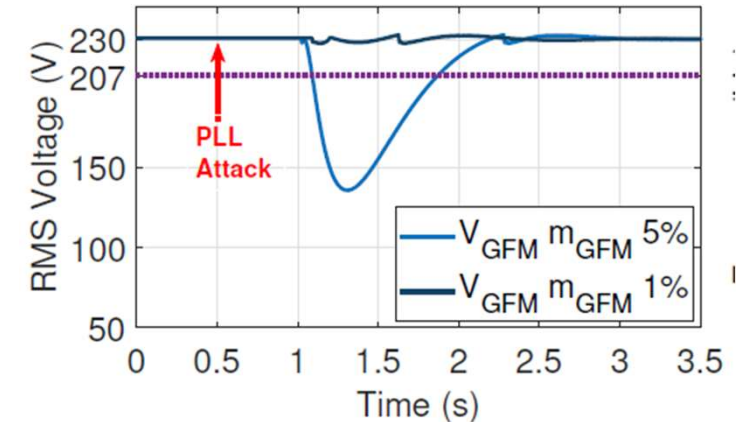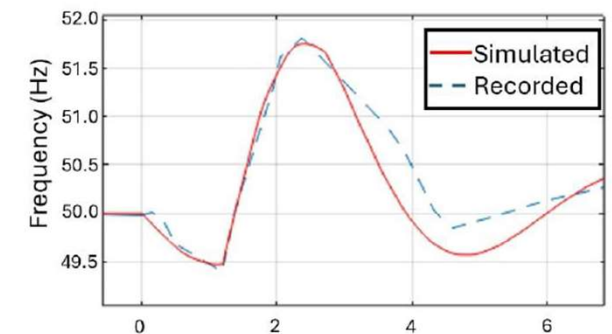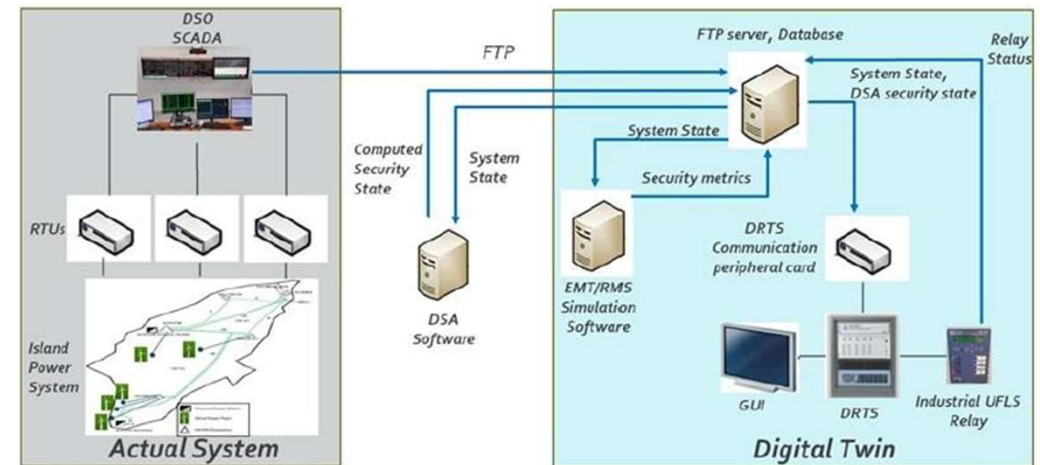
Data driven based dynamic security assessment of non-interconnected islands

- Operating with high-RES penetration can lead to significant frequency transients, due to the limited physical inertia

- Simple rule-based dynamic security function dictates curtailment of five distinct Wind Power Plants (WPP) when necessary, depending on predefined security criteria (dynamic limit, generators' technical minima).

- The conventional approaches may fall short in ensuring dynamic security or may be overly conservative

- Adopting **data-driven approach** can enhance the **accuracy** and **computational speed** of security evaluation

- System operators may be reluctant to embrace these solutions →Digital twin designed for the **realistic testing** of dynamic security assessment applications in the **actual system operating in Rhodes**, a Greek non-interconnected island

Rhodes HV Power System
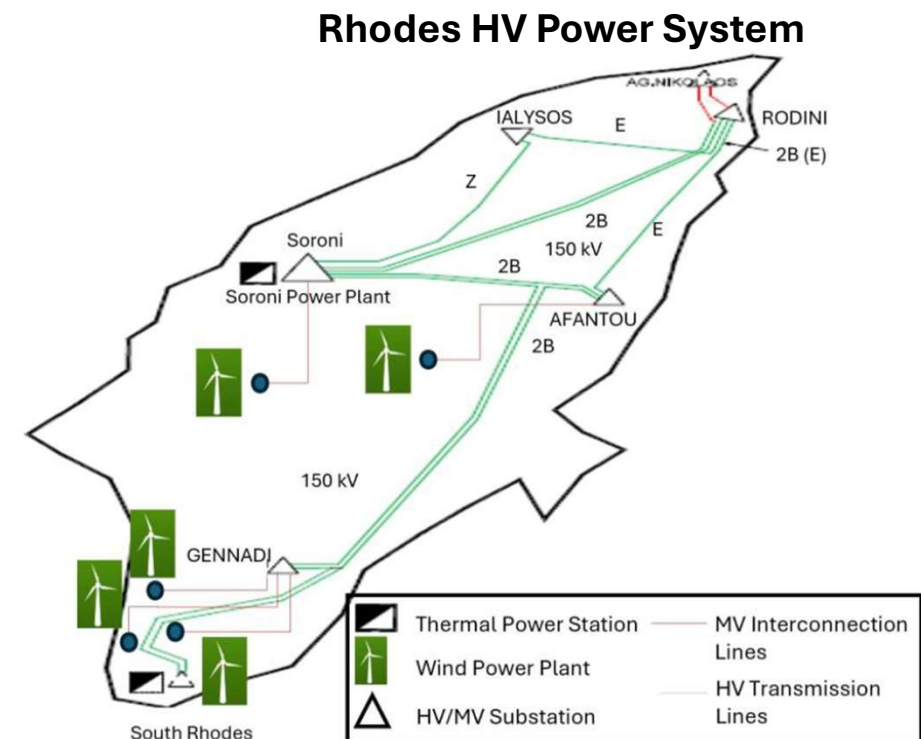
Digital twin for the evaluation of data driven based DSA of non-interconnected islands

- Virtual model of the island in RSCAD with an industrial under frequency load shedding protection equipment.
  - Near real time data obtained from the SCADA of Rhodes island
  - The dynamic security algorithm is executed in real time using the on-line data
  - Testing period of two months

- The developed Dynamic Security Assessment module is trained to identify system states as insecure, if a WPP outage results in frequency dips below the threshold that triggers the activation of UFLS relays
  - Determines the security flag of the current operating state considering probabilistic forecasts for the next hours

- The frequency nadir and RoCoF are collected and used to determine the security status and stored in the database linked to the timestamp of the uploaded system state.

D. Lagos, N. Hatziargyriou, A. Dimeas, G. Sideratos, T. Anastopoulou and T. Patsaka, "Digital Twin for the Evaluation of Data-Driven-Based Dynamic Security Assessment of Noninterconnected Islands: Introducing digital twin on Rhodes Island," in *IEEE Electrification Magazine*, vol. 12, no. 3, pp. 21-30, Sept. 2024, doi: 10.1109/MELE.2024.3423088. keywords: {Renewable energy sources;Heuristic algorithms;Power system dynamics;Integral equations;Market research;Real-time systems;Digital twins},

ecoMicrogrid developed in RE-EMPOWERED project

ecoMicrogrid focus on the **operation and optimization** of Microgrids (for Microgrid operators). Designed **based on the IEEE 2030 standards**.

- **Reduction of energy cost** and **maximum utilization of RES** as well as the reliable and secure operation.

- **Multi vector optimization**. Capable to integrate different scales of microgrids (Electrical and Cooling systems).

- **Predictive control strategies** utilize forecast to pro-actively engage assets and loads to achieve maximum system performance.

- **Data acquisition and archiving** of different energy assets from different vendors.

- **Demand side management and real time pricing**

Joint effort between NTUA and PROTASIS S.A.

- High Technology Readiness Level (TRL) of 8 achieved.
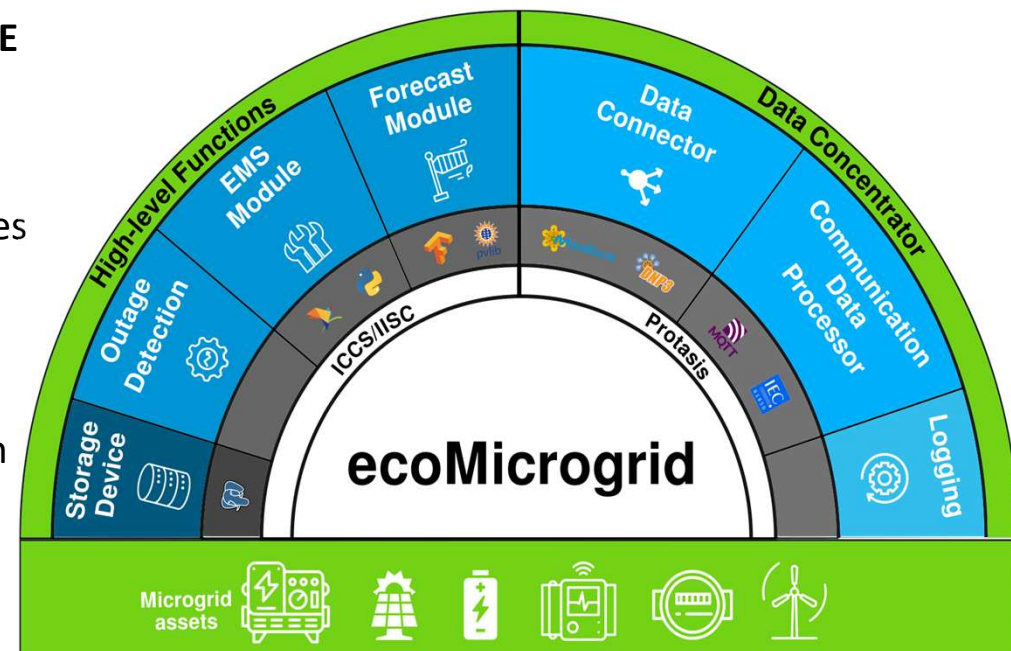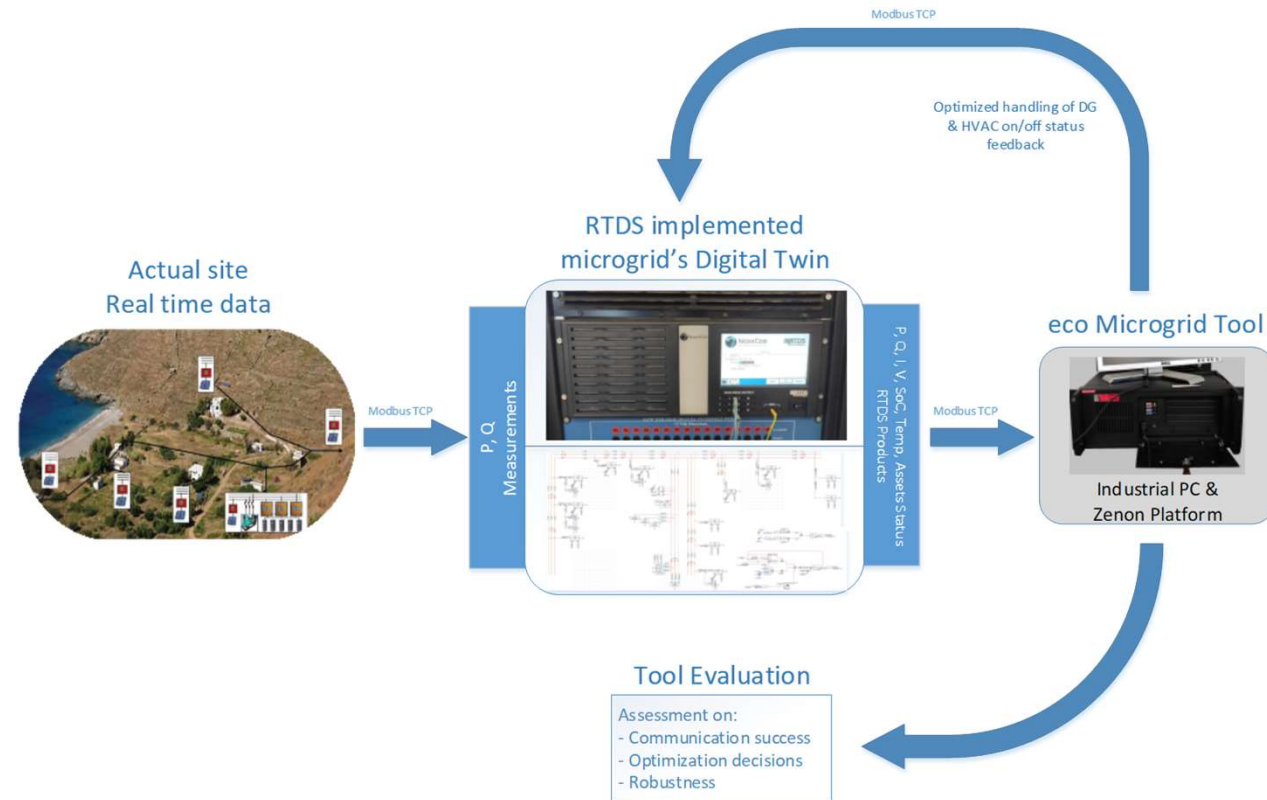
- Commercialization in progress

Fig.: Key system components of the ecoMicrogrid tool.

Development of digital twin for validation of ecoMicrogrid

- 3-ph digital twin model was built of the actual network in RSCAD. (network's distribution lines, house loads, PV productions, DG, Batteries with its SoC modeling, HVAC and control's room thermal model)

- RTDS produces more analytical data (P, Q, I, V, SoC, Temperature, assets status) and feeds the data produced to our tool via Modbus TCP protocol.

- "ecoMicrogrid" tool process in real time the data and following an optimization algorithm makes decision regarding Diesel Generator and HVAC on/off status which feeds back closing the loop to RTDS (via modbus TCP).


Modbus TCP

Optimized handling of DG & HVAC on/off status feedback

RTDS implemented microgrid's Digital Twin

Actual site Real time data

Modbus TCP

P, Q Measurements

P, Q, I, V, SoC, Temp, Assets Status RTDS Products

Modbus TCP

eco Microgrid Tool

Industrial PC & Zenon Platform

Tool Evaluation

Assessment on:
- Communication success
- Optimization decisions
- Robustness

# ecoMicrogrid tool testing – Operational Scenario

Scenario - Pre-cooling System House Control Room

Aim: Assessing the ecoMG EMS ability to regulate the system house temperature & utilize HVAC at high RES penetration hours.

- This scenario represents a **typical summer day** with PV power curtailment, resulting in increased room temperature during the night due to thermal load introduced by the inverters.

- The EMS's desired performance in this test is to utilize the HVAC system during periods of RES curtailment to proactively cool the room before nightfall.
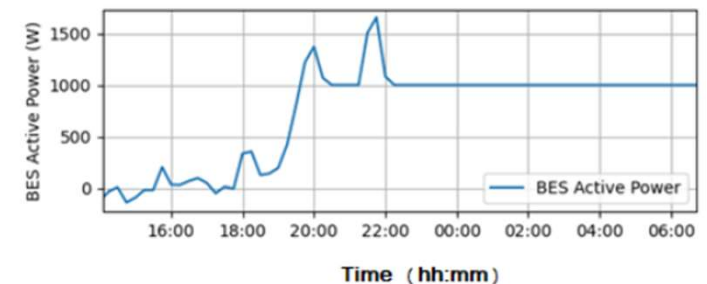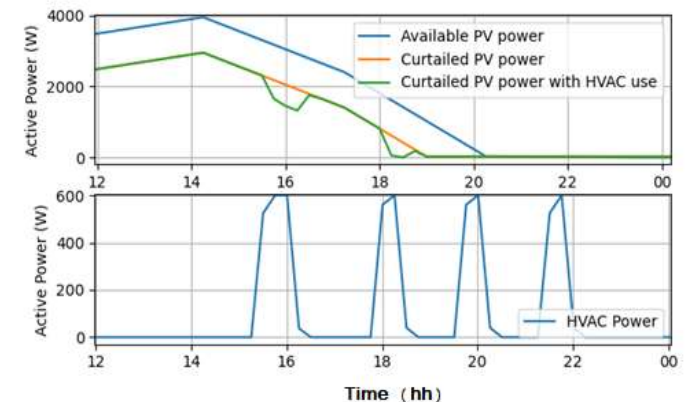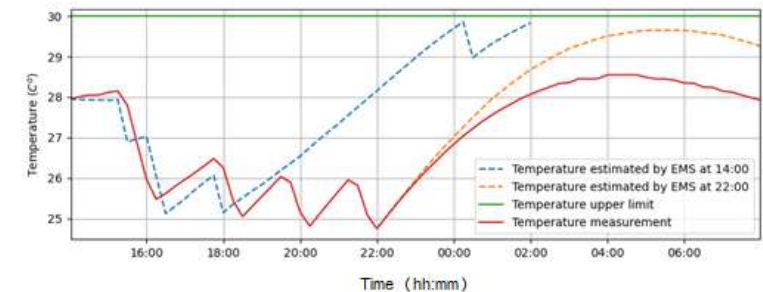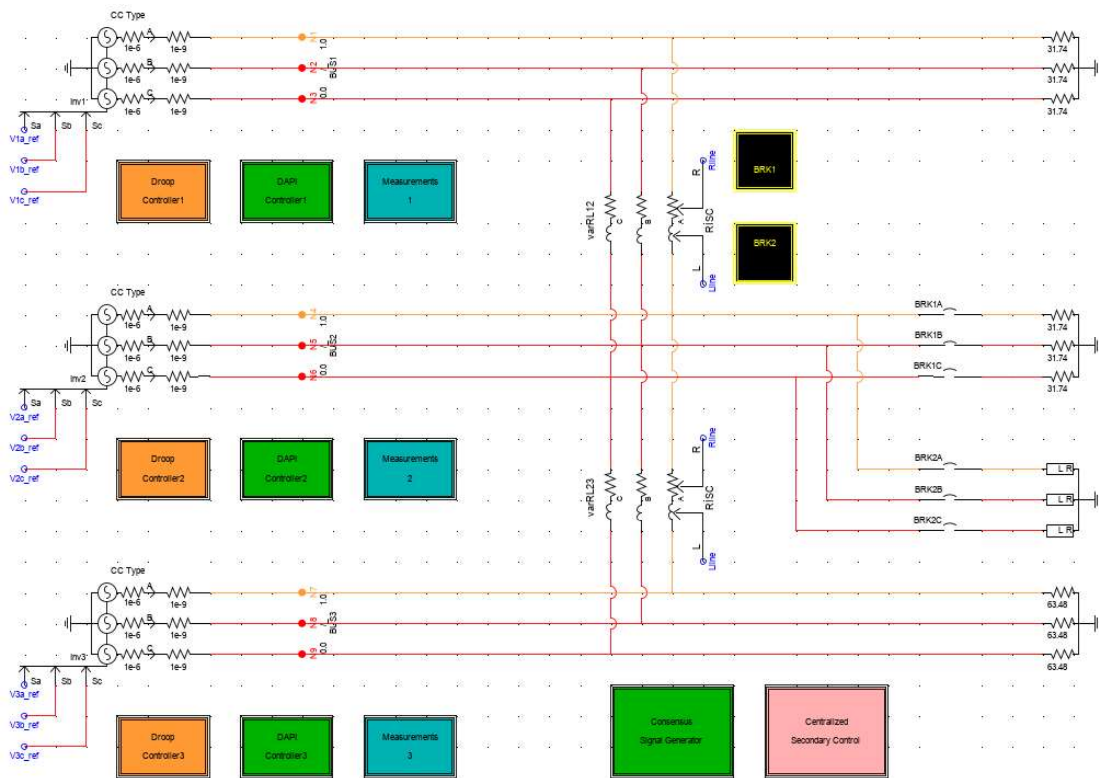
Real-Time Simulation in Lab Education: Hierarchical Control of Microgrids
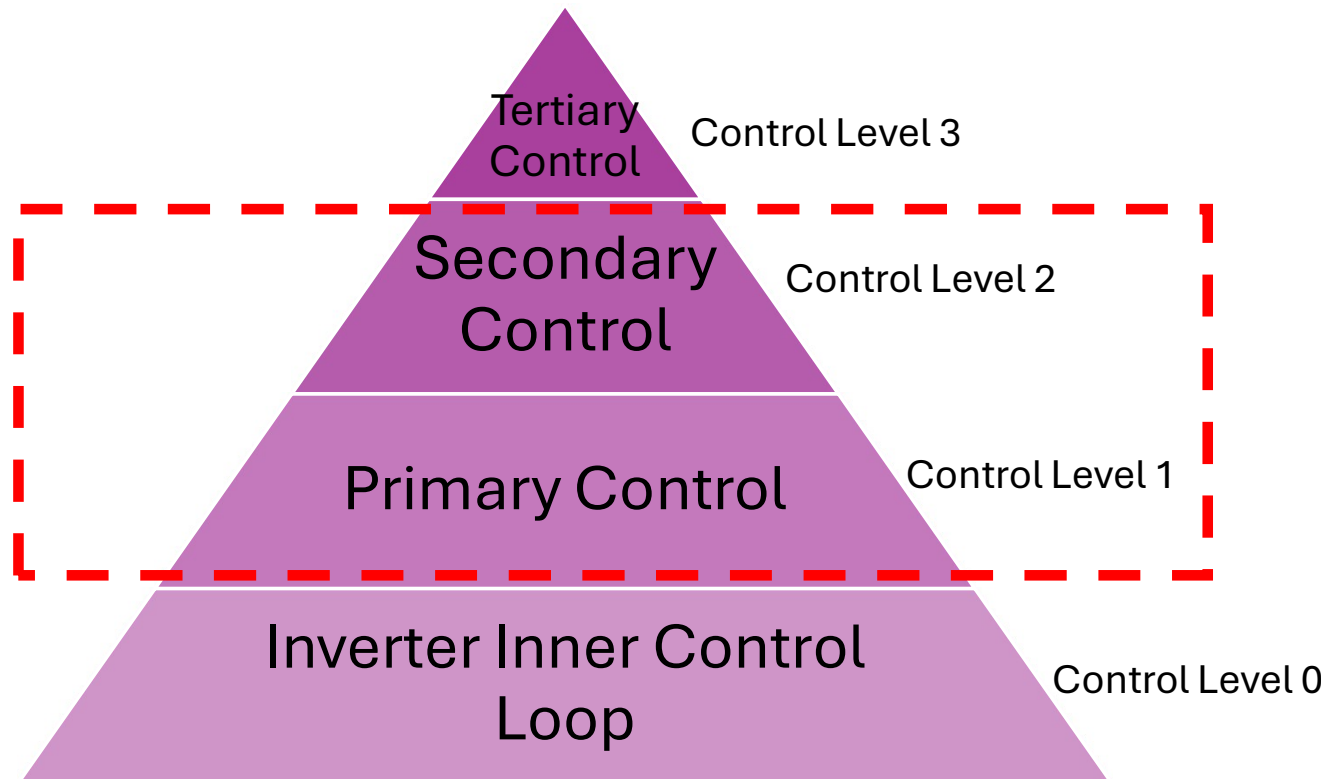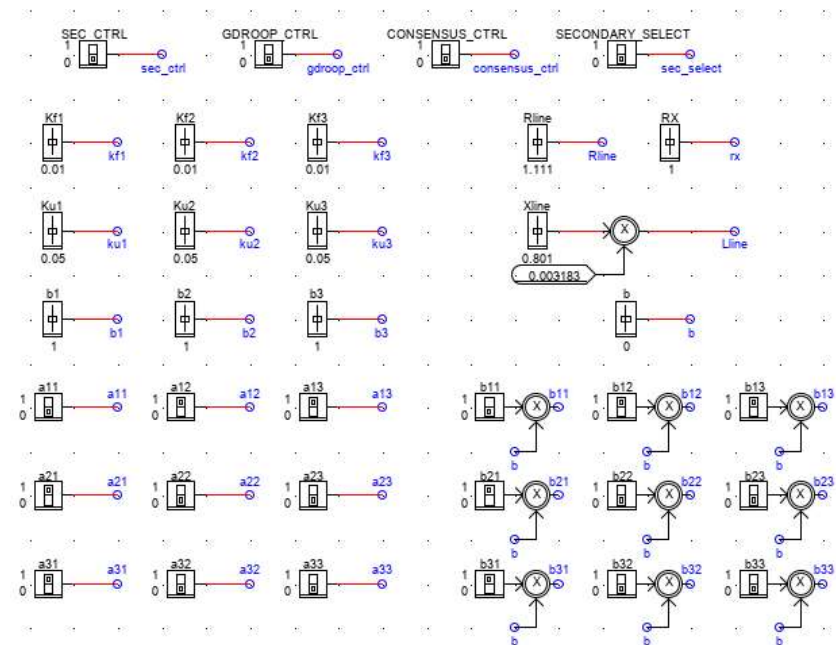

Main objectives of the lab module:

1. Comprehension of primary and secondary control for microgrids
   - Droop, Generalized Droop, Centralized vs Distributed Secondary Control

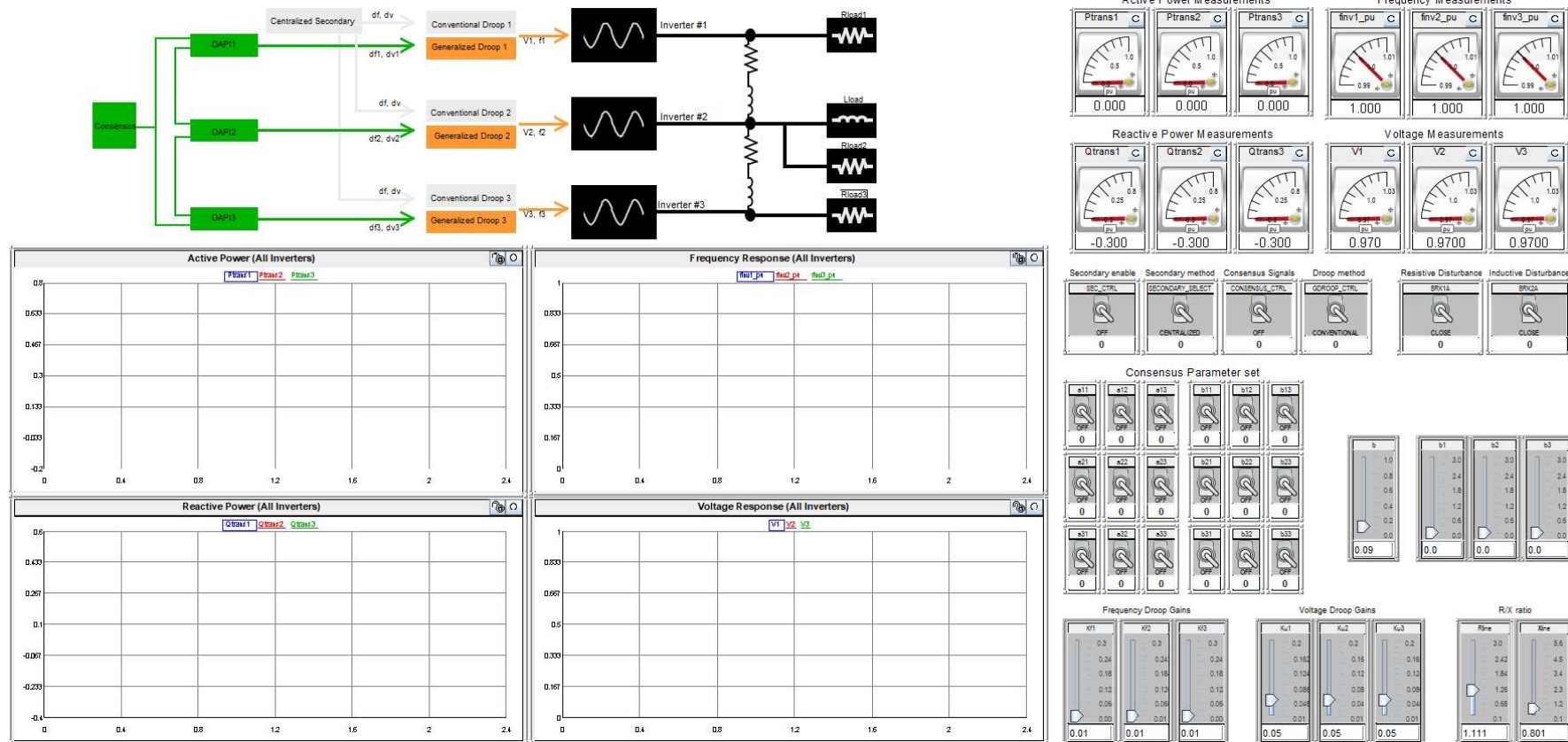2. Familiarization with software design tools

Microgrid design in RSCAD

Microgrid comprising 3 grid forming inverters and loads

Easy-to-use GUI

Conclusions

- PHIL testing of grid forming inverters can reveal unstable modes of operation

- PHIL testing of cyber security scenarios may reveal unstable conditions that cannot be predicted based on linear models

- Digital Twins can act as dynamic living labs that can reinforcing trust towards TNOs and DSOs

- RTS enables hands-on laboratory education and fosters deeper learning reaching higher cognitive levels.

Thank you!

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