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Centre for intelligent electricity distribution
- to empower the future Smart Grid

The CINELDI Testbed for Advanced Distribution Management Systems

CINELDI Webinar

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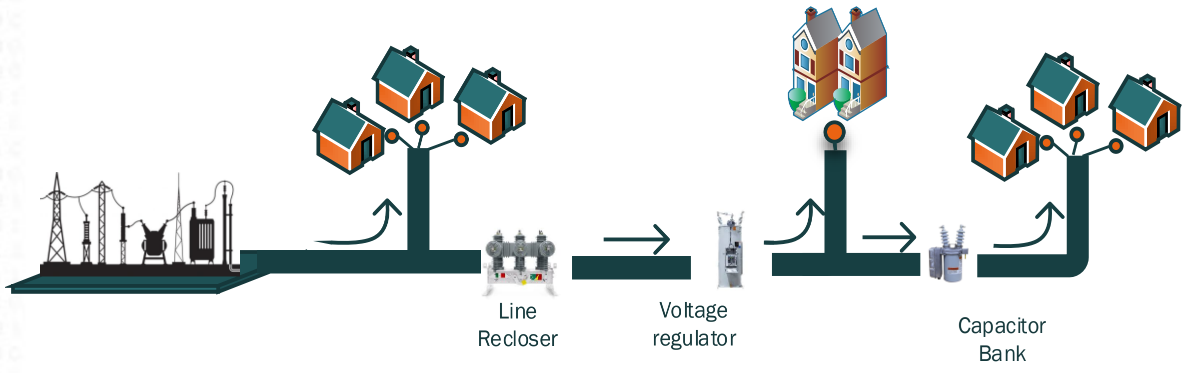
Outline

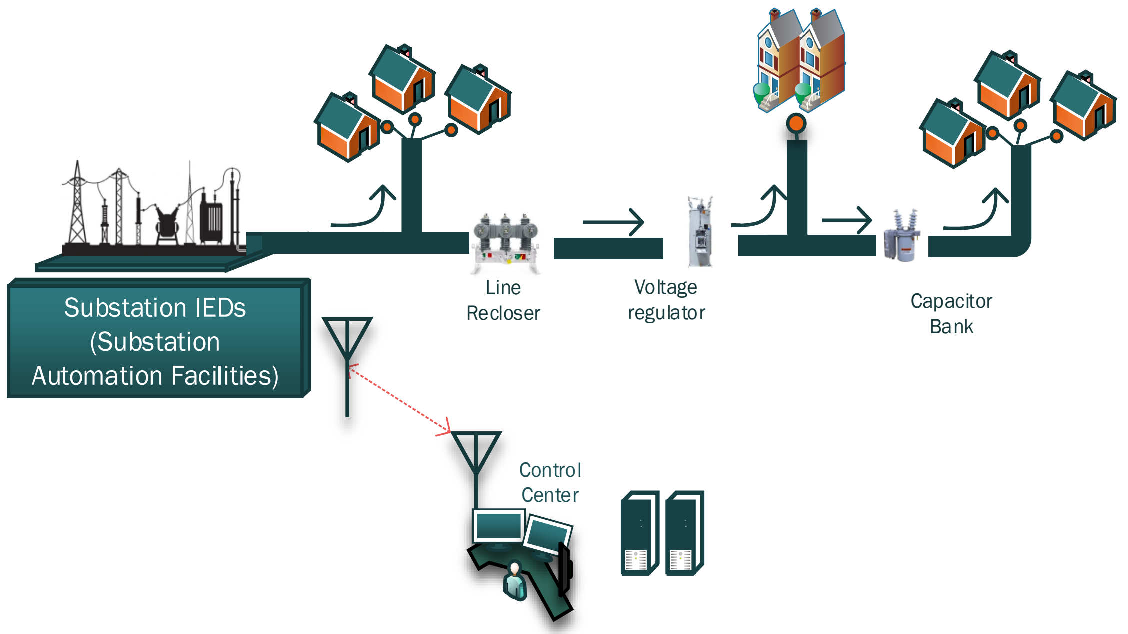
- Grid Modernization Levels
- Distribution Network in Norway
- CINELDI Smart Grid Operation Focus Areas
- ADMS and Testing Needs
- The National Smart Grid Laboratory
- Testbed for ADMS
- Example Test Cases

Grid Modernization Levels



Level 0: Manual control and local automation

Distribution networks today where transformer ratio is modified manually according to the load growth or seasonal changes, typically twice a year.



Level 1: Substation automation and remote control

Substation voltage regulators and substation capacitor bank are controlled with a rule-based volt/VAR optimization. Active voltage regulation is restricted to the substation.

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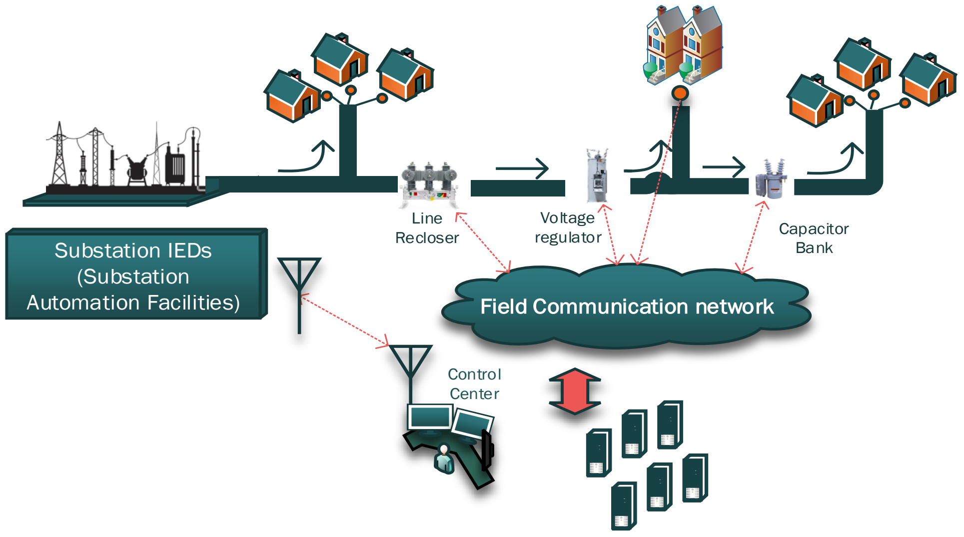
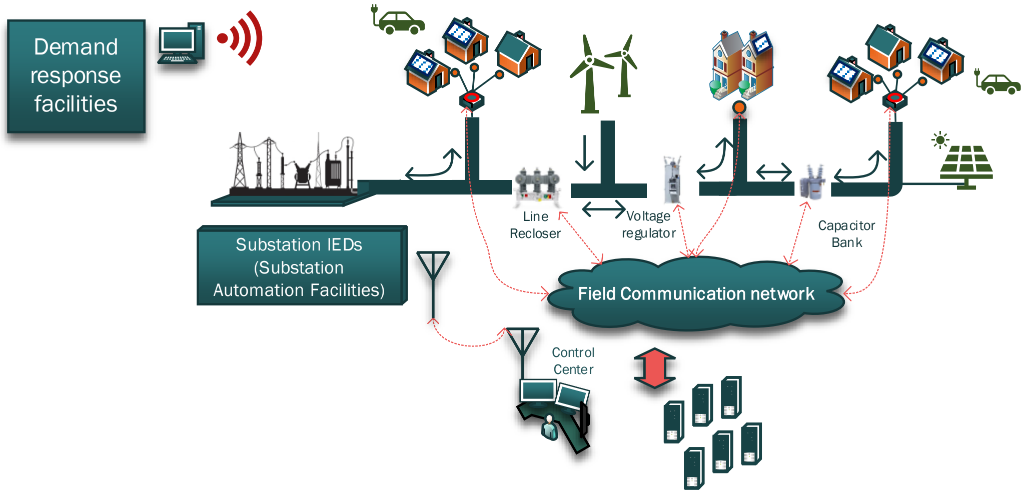
Inspired by: Madrigal, Marcelino; Uluski, Robert; Mensan Gaba, Kwawu. 2017. Practical Guidance for Defining a Smart Grid Modernization Strategy. World Bank Studies;. Washington, DC: World Bank.

Grid Modernization Levels …



Level 2: Feeder automation and remote control

Coordinated Voltage control (CVC) can be implemented including switchable capacitor banks and voltage regulators outside of the substation fence.



Level 3: DER integration and control and demand response

In addition to the traditional voltage regulating devices, all other DER contributors such as smart inverters are incorporated in the CVC.

Inspired by: Madrigal, Marcelino; Uluski, Robert; Mensan Gaba, Kwawu. 2017. Practical Guidance for Defining a Smart Grid Modernization Strategy. World Bank Studies;. Washington, DC: World Bank. © World Bank. https://openknowledge.worldbank.org/handle/10986/26256 License: CC BY 3.0 IGO.

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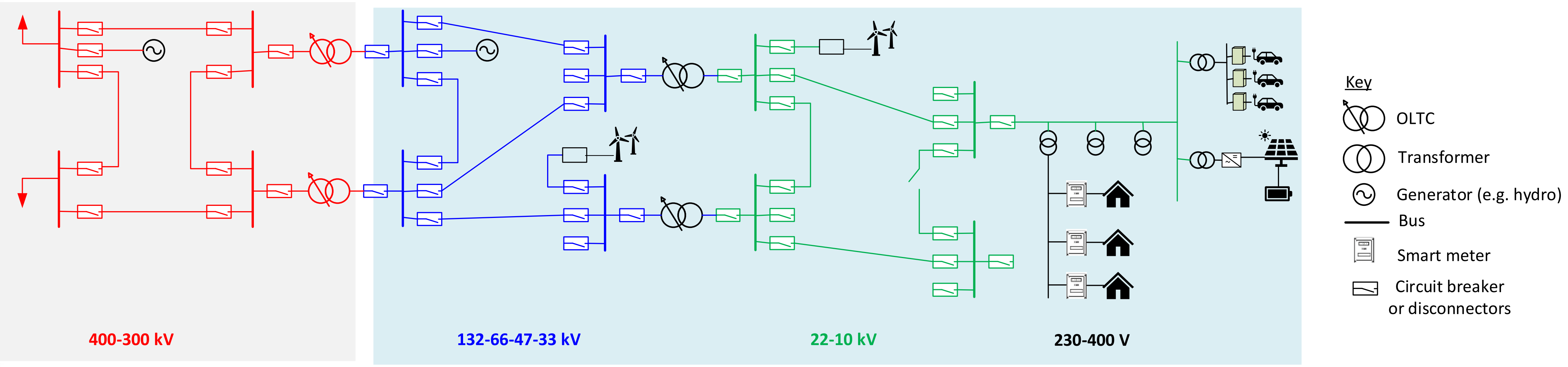
Distribution Network in Norway



- Large demand response potential in the domestic center
- Large availability of hydropower plants with reservoirs which are fast and easy to control.
- Weak grids with approx. 40% of the supply terminals weaker than the standardized EMC reference impedance
- Quickly growing use of purely battery based electric vehicles
- Well-developed broadband communication and electricity markets

Ref. Fosso, O.B., Molinas, M., Sand, K. and Coldevin, G.H., 2014, May. Moving towards the smart grid: The norwegian case. In *2014 International Power Electronics Conference (IPEC-Hiroshima 2014-ECCE ASIA)* (pp. 1861-1867). IEEE.

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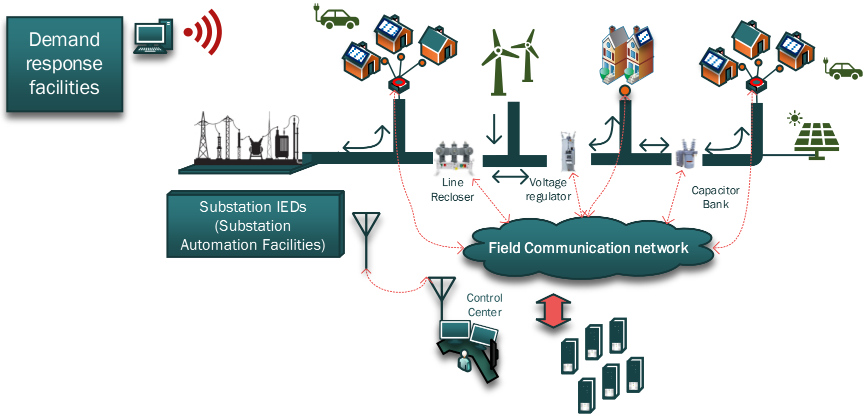
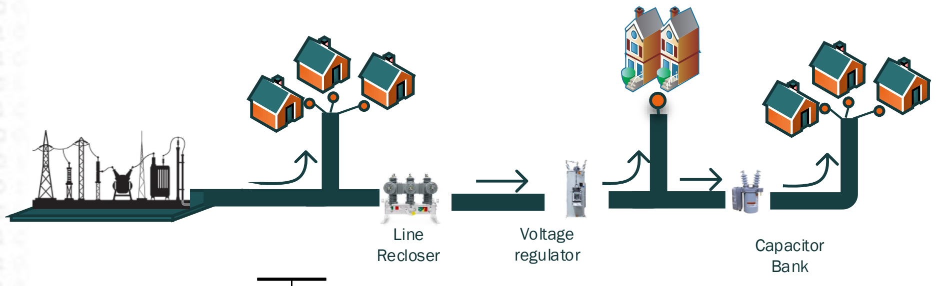
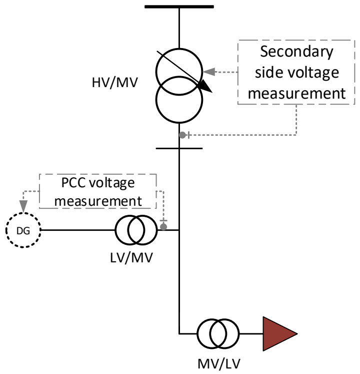
Today's Status – Network Operations



Today's network operation:

- Local measurement/regulation
- A measurement – a purpose
- Reactive – problems are solved as they arise
- Low data availability (silos)





The future network operations:

- Continuous monitoring and optimization of operations
- Data is easily accessible
- Proactive operational planning and Predictive maintenance
- Maximum utilization of the network
  - active measures in the network
  - flexibility with network customers

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Research Areas in CINELDI

Smart Grids Development and Asset Management

Smart Grids Operation

Interaction DSO/TSO

Microgrids/ Local Energy Communities

Flexible Resources in the Power System

Smart Grids Scenarios and Transition Strategies

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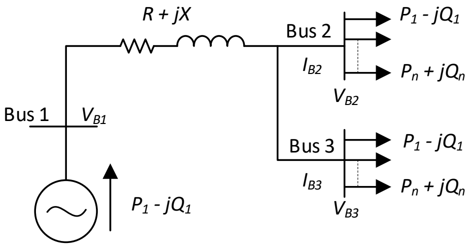
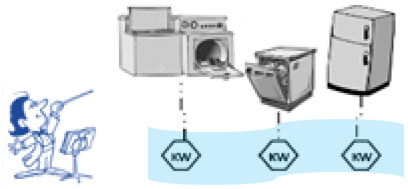
Advanced Distribution Management Systems (ADMS)

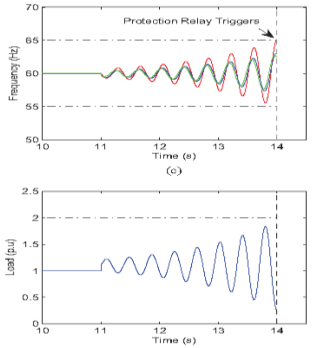
- What is it?
  - It is a control room platform
- What are its characterstics?
  - seamless sharing of models, measurement, database values, and control signals among applications
- What is the objective?
  - comprehensive and optimal monitoring and control of distribution systems

Laboratory Based Testing Needs: Example Use Case

Activation of Flexibility Service







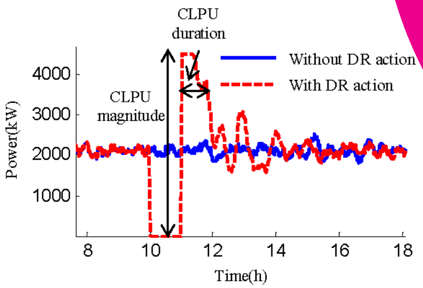
Relationship between DR potential/ activation to voltage level

Vulnerability to dynamic and static load altering attacks

Rebound effect

(e.g. Cold Load Pick-Up (CLPU))

Demand response mismatch



$$\text{DR Mismatch} = \left(\frac{\text{Expected DR} - \text{Achieved DR}}{\text{Achieved DR}} \right) 100\%$$

Intended and unintended consequences of activation of flexibility resources.

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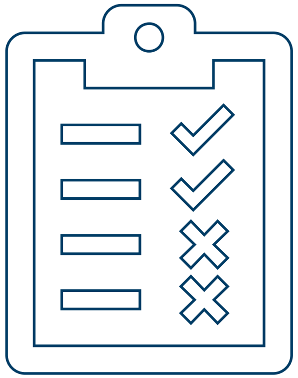
Testbed for New ADMS Functions

- ✓Validation,
- ✓Verification,
- ✓Characterization,
- ✓Integration testing



*A **testbed** is a platform for conducting rigorous, transparent, and replicable testing of scientific theories, computational tools, and new technologies.*

Source: Wikipedia

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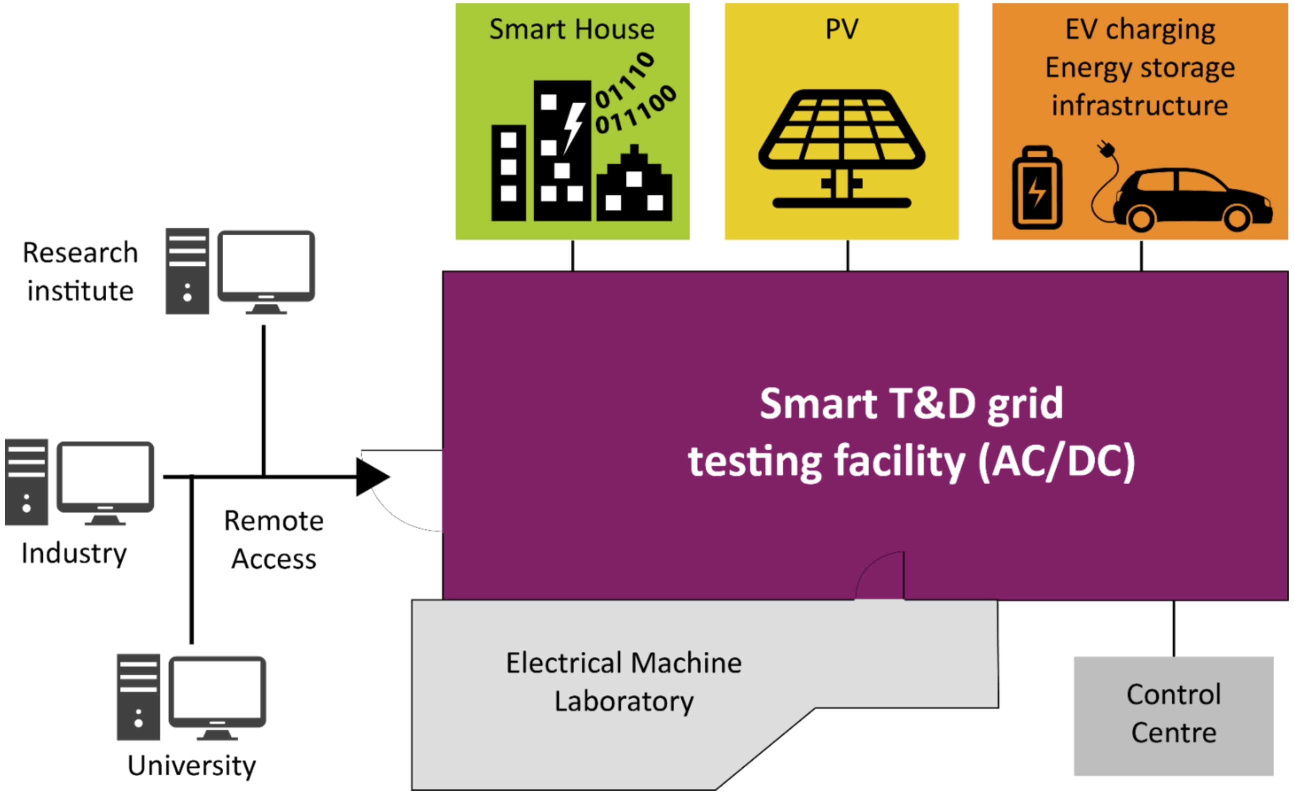
The National Smart Grid Laboratory

- an important asset in CINELDI



https://www.sintef.no/en/all-laboratories/smartgridlaboratory/
https://www.ntnu.edu/smartgrid

National Smart Grids Laboratory (NSGL)

National Smart Grid Laboratory is a 250 m^2 facility located in Trondheim at the campus of the Norwegian University of Science and Technology (NTNU) and jointly operated by SINTEF and NTNU.

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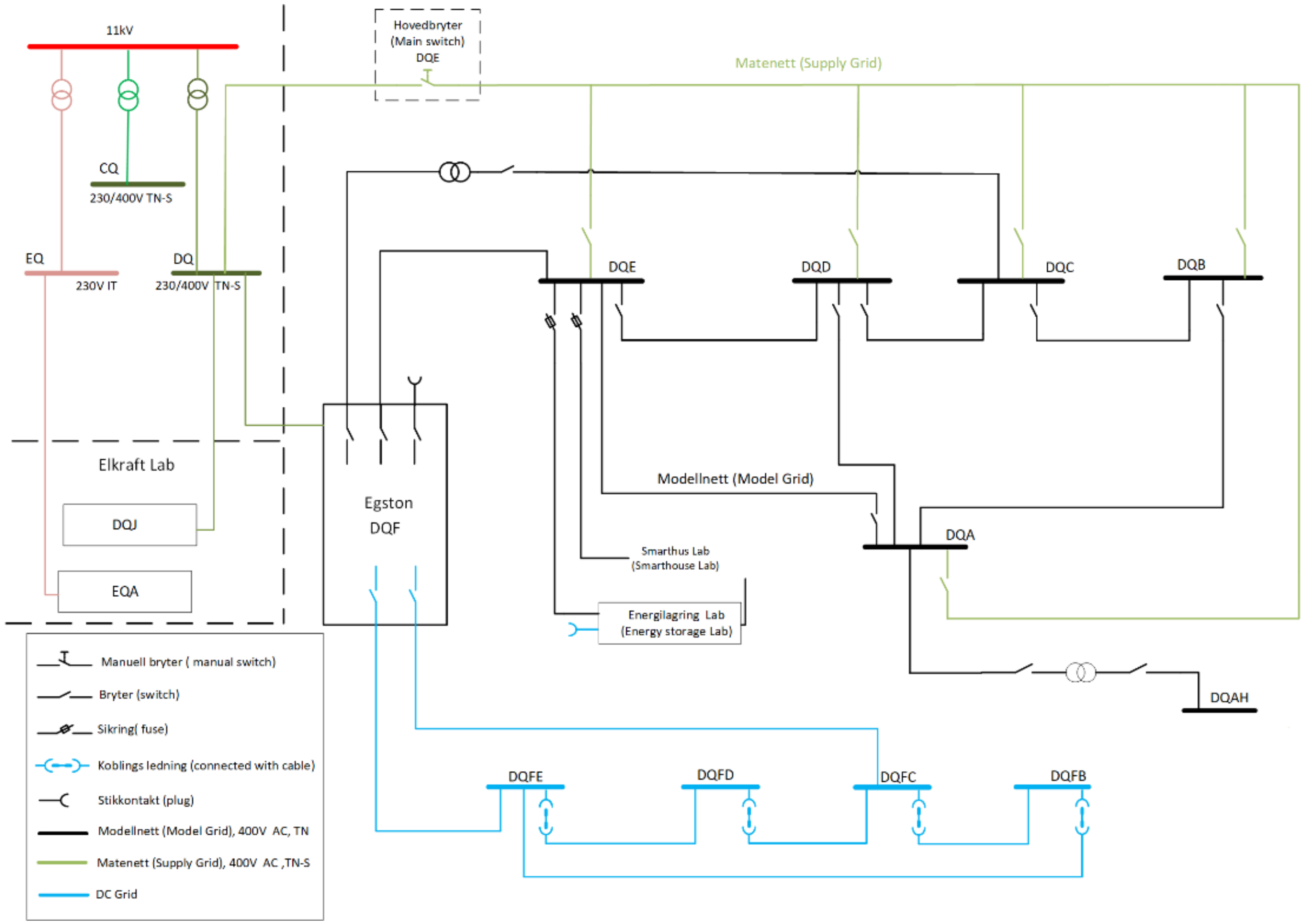
Busbars in the National Smart Grids Laboratory



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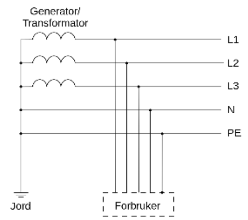

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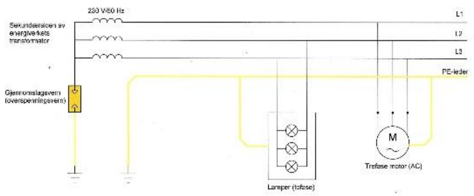


Power electronics converters

- 4x Two Level three-phase converters (60 kW)
- 3x MMC converters (60 kVA)
- 2x back to back two-level converts (100 kVA)
- 2x 20 kVA two- level converters

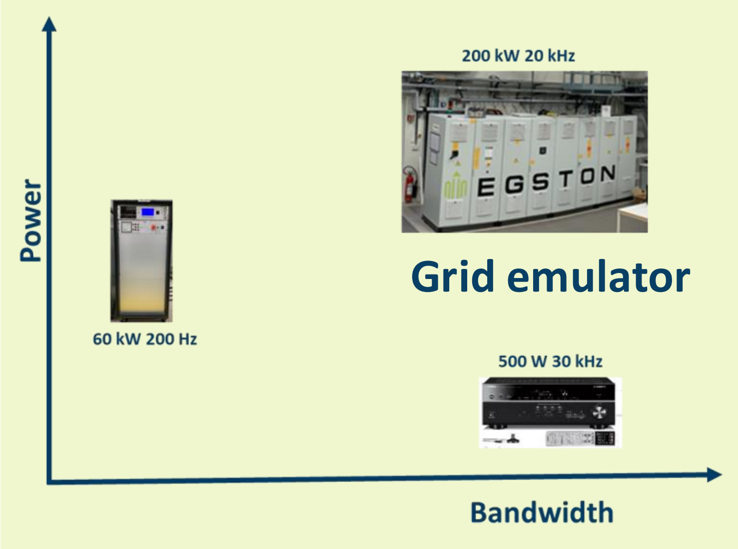
Electrical machines

- 18 kVA synchronous generator
- 55 kVA induction generator.
- 100 kVA, 14 pole generator
- 66 kVA 6 pole generator

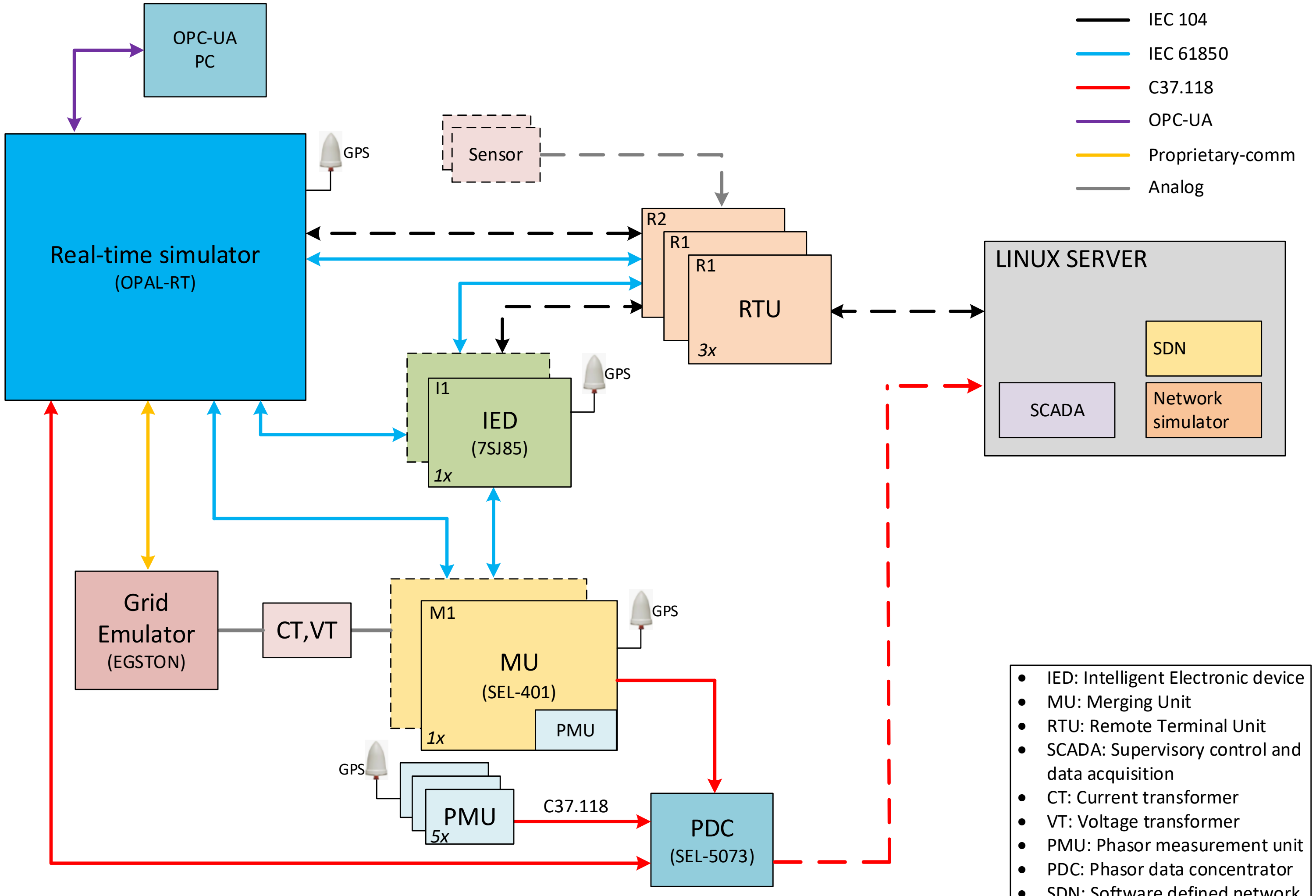
Intelligent Electronic Devices (IED)

- Protection relay: SIEMENS 7SJ85
- Merging Unit: SIEMENS 6MU85
- Merging Unit: SEL 401 MU

Communication routing, RTUs, PMUs



Real-time Simulation and Communication Infrastructure

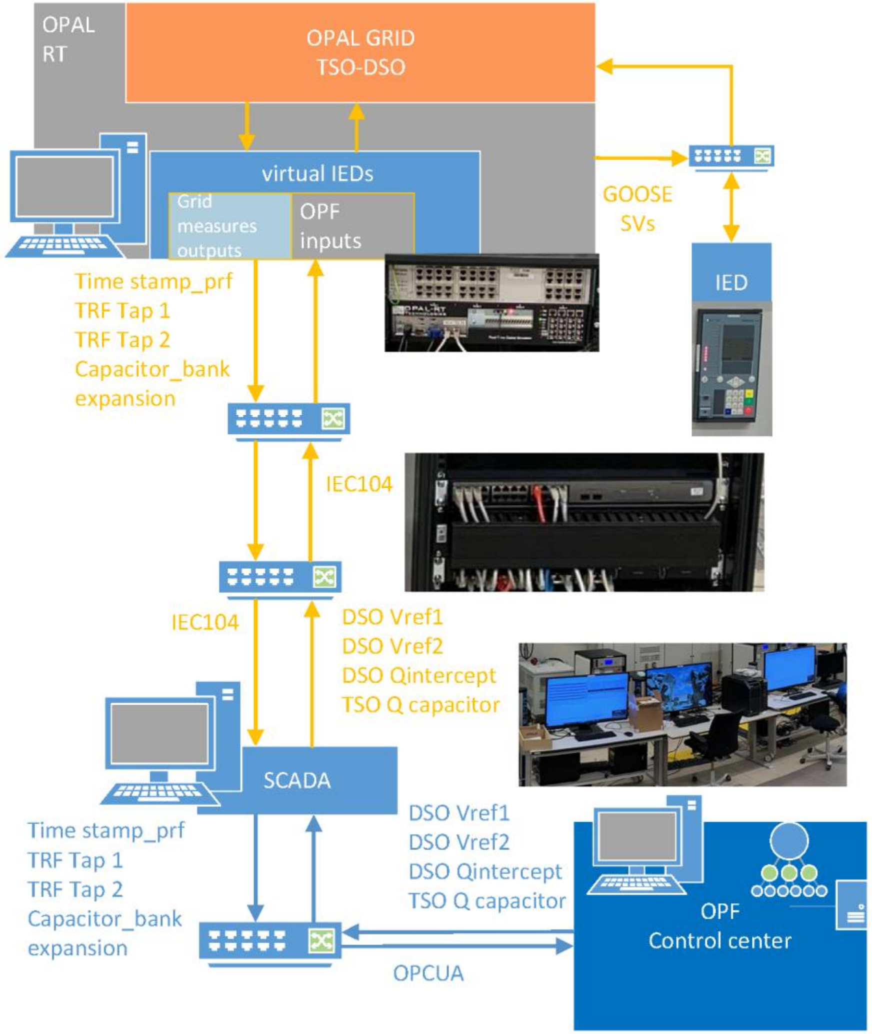


- IED: Intelligent Electronic device
- MU: Merging Unit
- RTU: Remote Terminal Unit
- SCADA: Supervisory control and data acquisition
- CT: Current transformer
- VT: Voltage transformer
- PMU: Phasor measurement unit
- PDC: Phasor data concentrator
- SDN: Software defined network

Examples of Services Offered by the NSGL

- Characterization testing of components such as converters, voltage boosters etc.
- Controller development, fine tuning, and validation
- Testing of smart grid algorithms and architectures
- Energy storage system validation and integration testing
- DER integration standards conformance testing
- Testing of islanded and interconnected operation of microgrids/minigrids
- Evaluation of cyber-physical systems for resilience towards misuses and conformance with network operation standards
- Characterization of integration charging infrastructure in distribution systems for electric transport system
- Testing of transmission systems including FACTS devices and HVDC converters and associated technologies
- Testing of novel functionalities with the smart meter infrastructure.
- Power quality measurements and analysis for conformity with standards.
- Characterization of dependencies of power grid and ICT system and impacts on reliability.
- High fidelity and accuracy testing, such as Power-Hardware-in-the-Loop tests.
- Validation testing of services offered by flexibility resources.
- Grid impact studies of activation of flexibility resources and home automation systems
- Testing of Wide Area Monitoring Systems and PMUs

ADMS Laboratory Testbed *Ver#1*



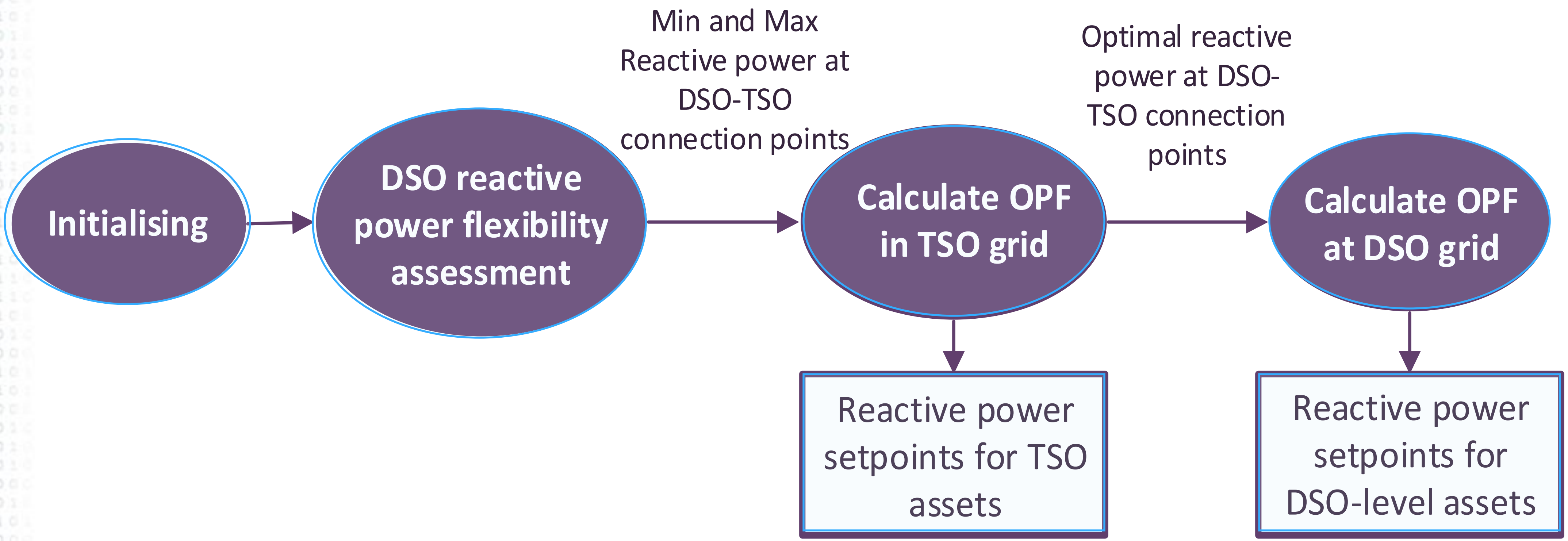
- ✓ Protection relay: SIEMENS 7SJ85
- ✓ AVEVA SCADA
- ✓ OPAL RT (OP5600)

- ❑ IEC 104
- ❑ IEC 61850
- ❑ OPC-UA

Contributions are acknowledged from:
Santiago Sanchez and Ravishankar Borgaonkar

Ref:- Merkebu Z. Degefa, Santiago Sanchez and Ravishankar Borgaonkar, "A Testbed for Advanced Distribution Management Systems: Assessment of Cybersecurity," ISGT-Europe 2021 .

Example Usecase: TSO-DSO volt/var Optimization



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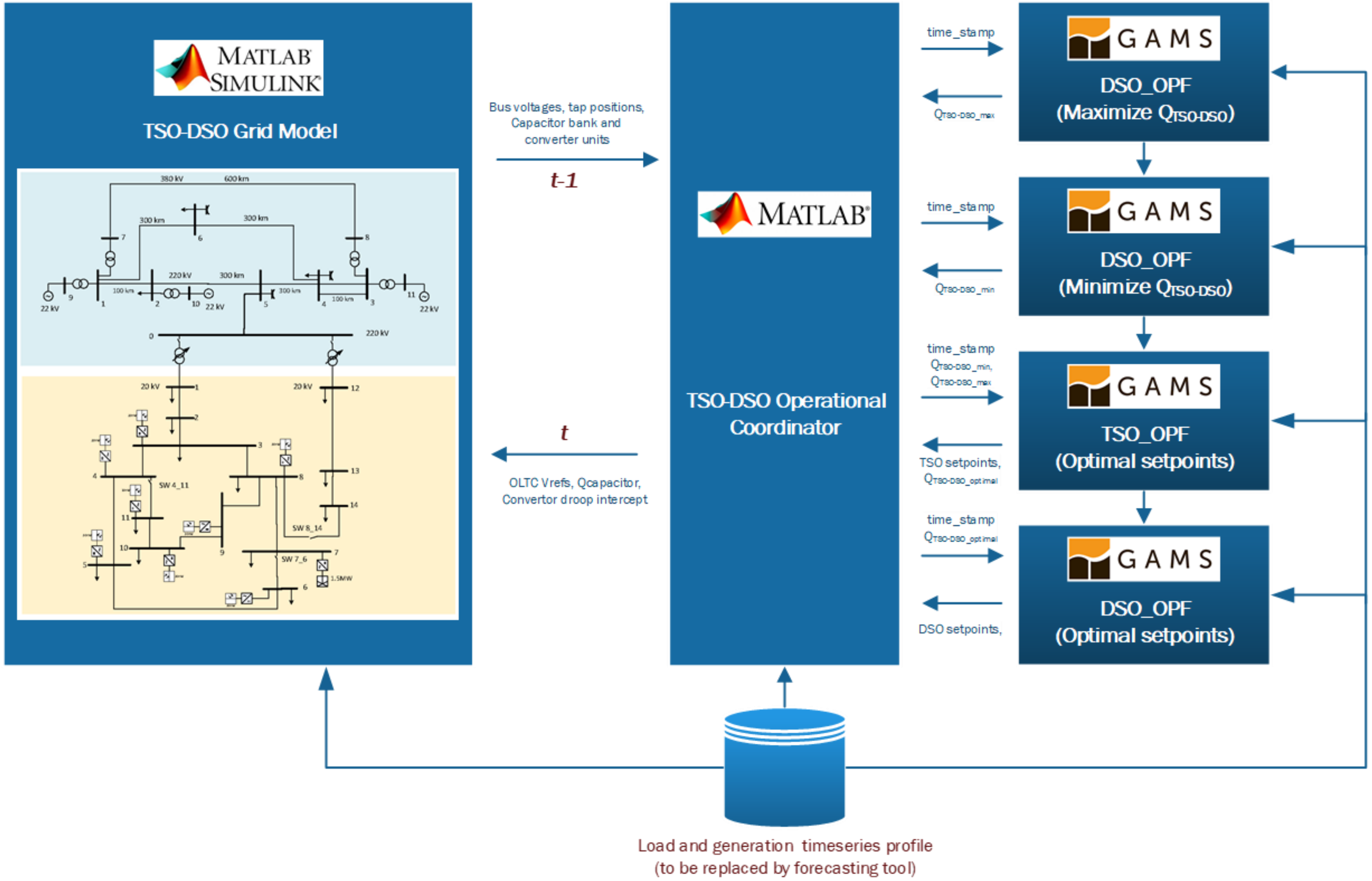
Example Usecase: TSO-DSO Volt/Var Optimization …



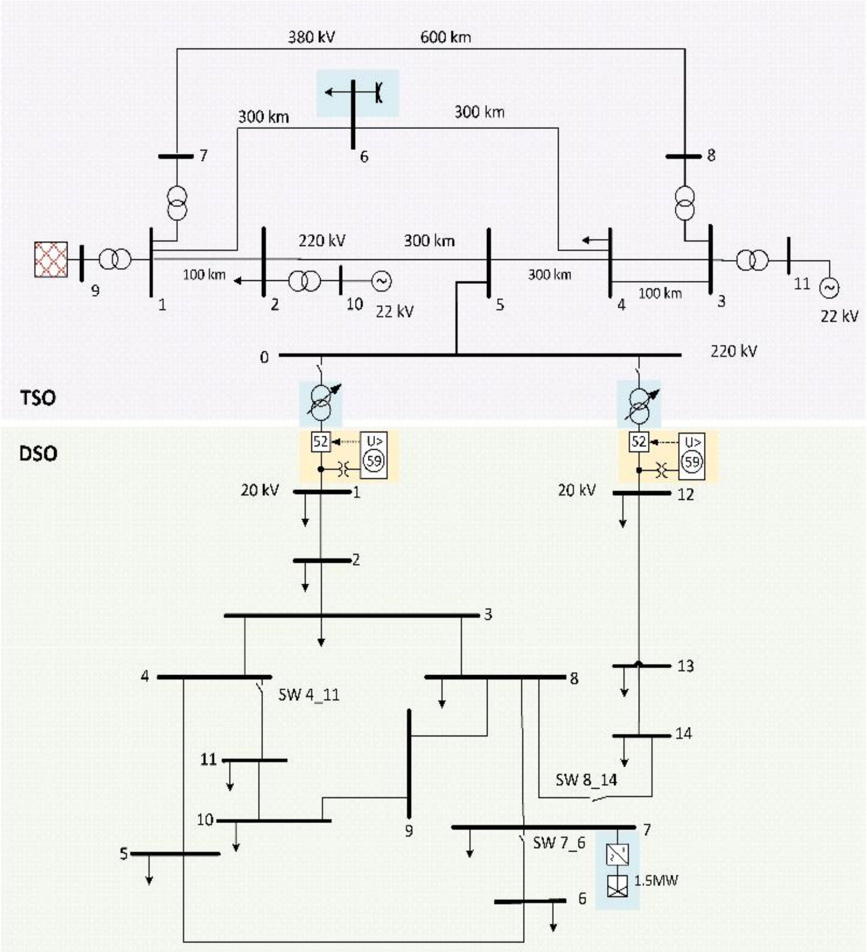
In ver#2

GAMS → pandapower pypower

Example Usecase:
TSO-DSO volt/var Optimization...

Purpose of Investigation:

Characterize the impact of misuse-cases on the operation of distribution network.



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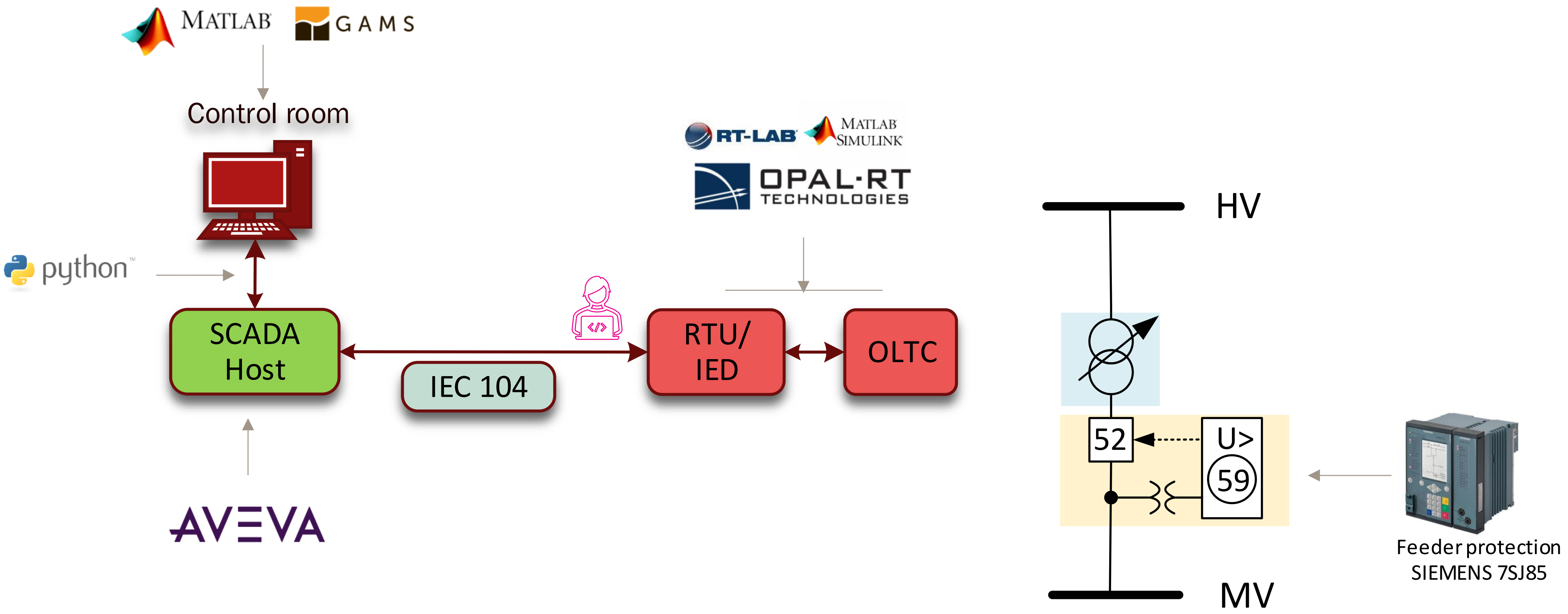
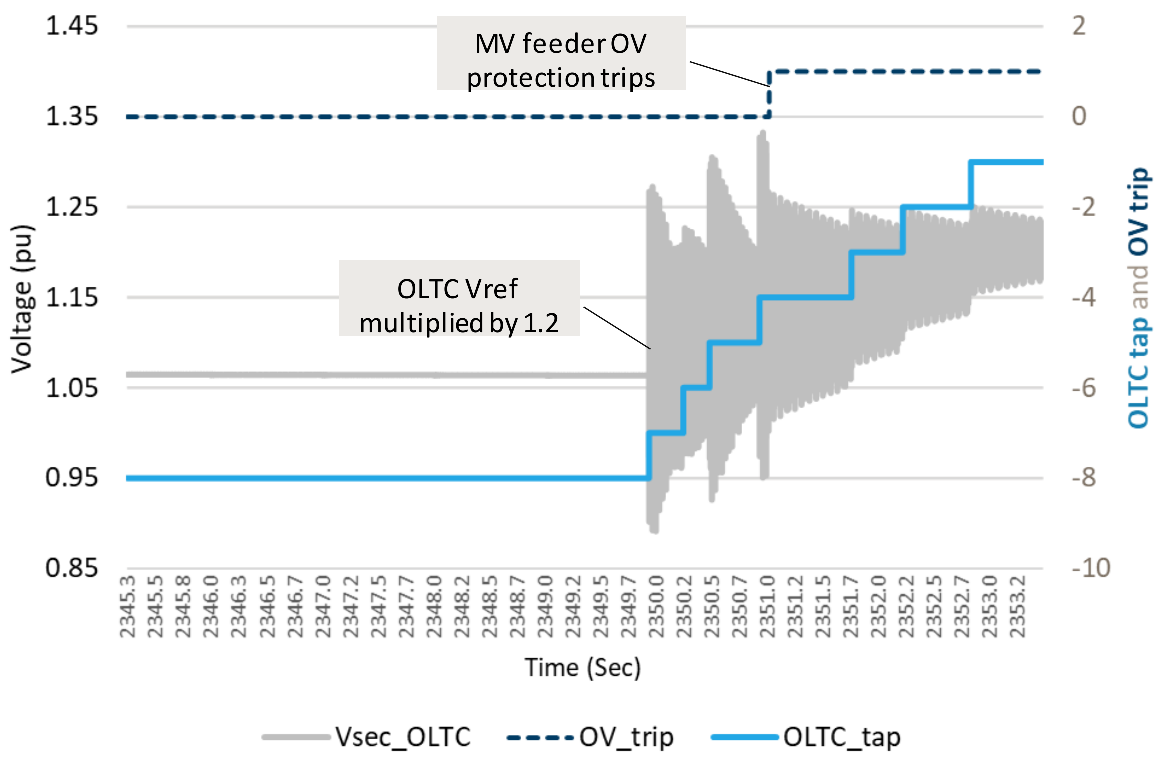
Testing#1: Sequence of Events

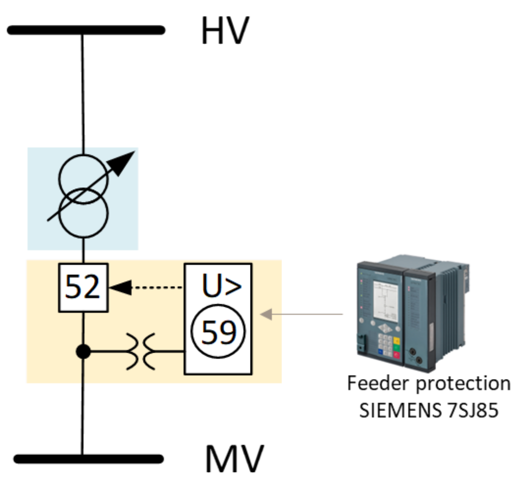


Demonstration of smart operation vulnerabilities.

Testing#1: Evaluation of Impact of Misuse Case

Advanced operational functions shall be tested for their vulnerability.





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TSO-DSO Coordination for Network Operation

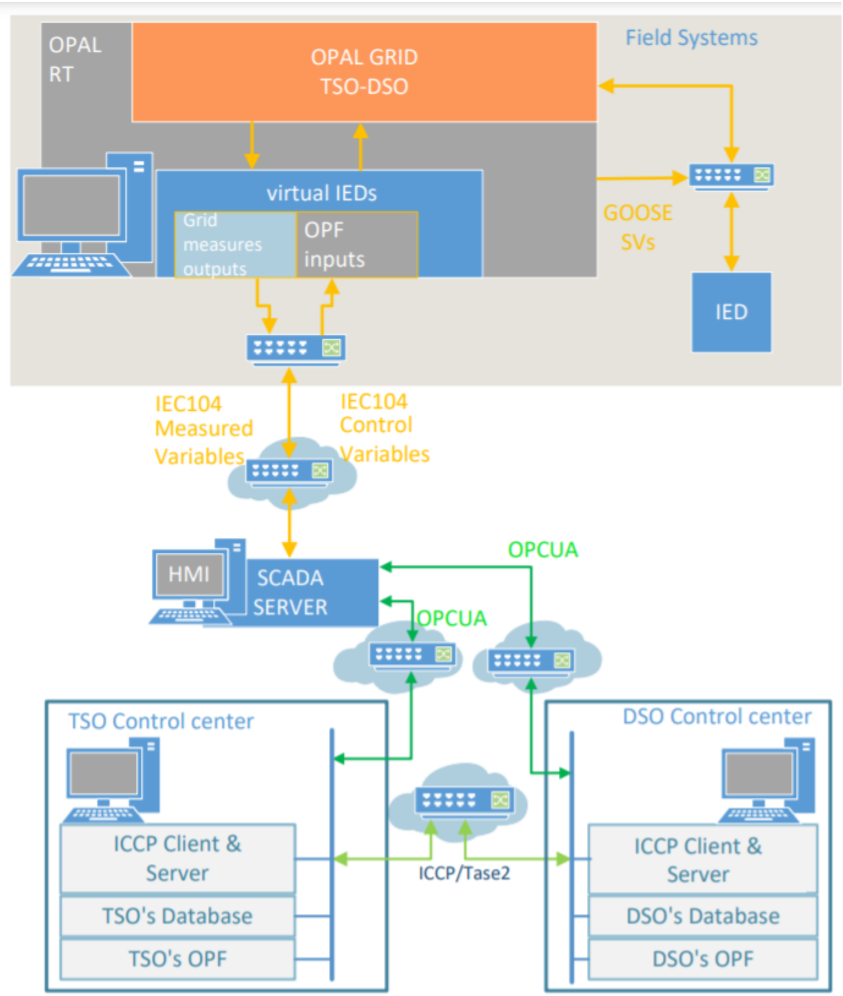
- Operational coordination between TSO and DSO will be characterized by the exchange of large amounts of network and measurement data as well as control signals in near real-time.

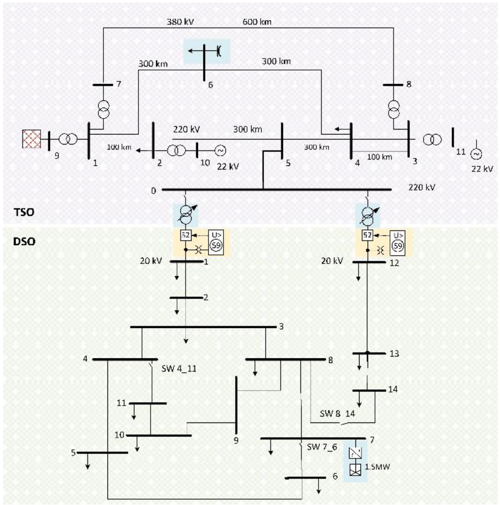
- Some of the research questions are:
  - ❑Study the effects of different levels of equivalent network representations of the DSO network.
  - ❑Study the adequacy of CIM for TSO-DSO operational data exchange.
  - ❑Evaluation of different schemes for controlling components (e.g. converters in the DSO area) for TSO-DSO voltage regulation

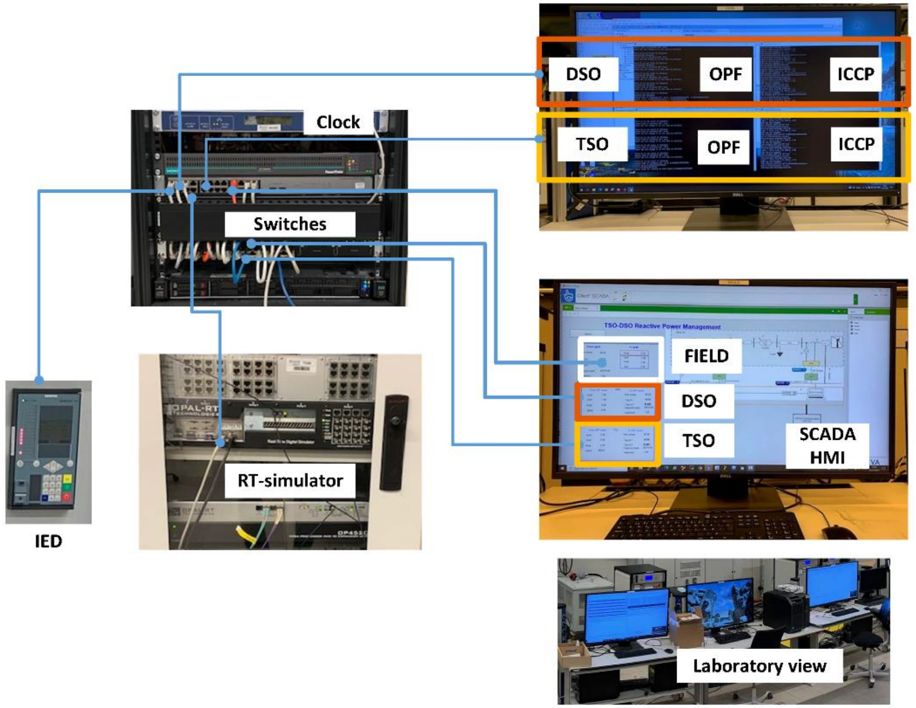
- We expanded the ADMS lab setup to represent the coordination between TSO and DSO Operation Centers.

ADMS Laboratory Testbed *Ver#2 :*

with separate TSO control centre…







Contributions are acknowledged from:
Henrik Lundkvist, Santiago Sanchez-Acevedo, and Kristoffer N. Gregertsen

Ref. Merkebu Z. Degefa, Henrik Lundkvist, Santiago Sanchez-Acevedo, and Kristoffer N. Gregertsen, 'Challenges of TSO-DSO Voltage Regulation Under Real-Time Data Exchange Paradigm, paper in preparation.

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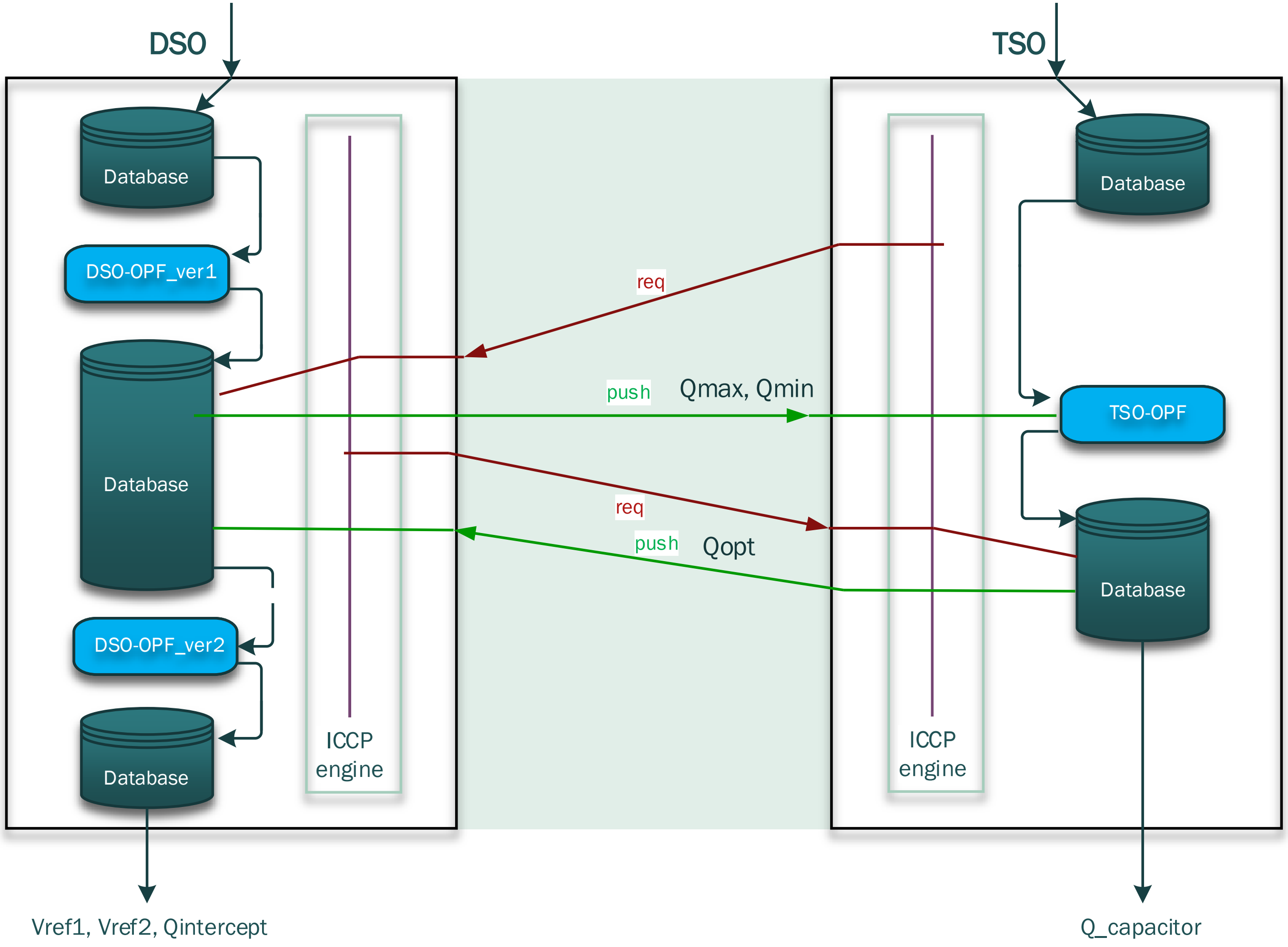
Testing#2: TSO-DSO Operational Coordination

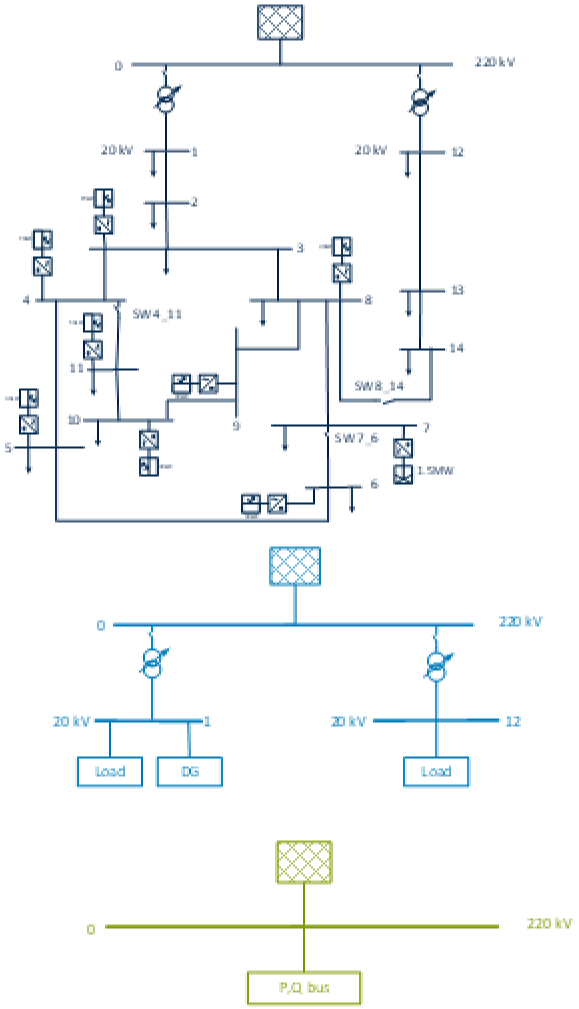


Testing#2: TSO-DSO Operational Coordination …

Purpose of Investigation:

- Characterize the impact of different level of details in distribution network equivalent network in the OPF results of the TSO control center VVO.

- Verify the sufficiency of CIM model for such data exchange.



Testing#2: TSO-DSO Operational Coordination …

- ✓ Full DSO grid knowledge showed lowest loss and highest utilization of the OLTC at the PCC.
- ✓ Equivalent grids can be sufficient as long as simplifications are carried out with a tailored approach for the dynamics considered in specific cases to avoid performance degradation.
- ✓ The use of the CIM/CGMES model for exchanging different levels of DSO equivalent grids has showed its adequacy for such operational coordination.

Operational coordination related data exchange needs between TSO-DSO and DSO-DSO shall be studied. Equivalent network models can be sufficient if done properly.

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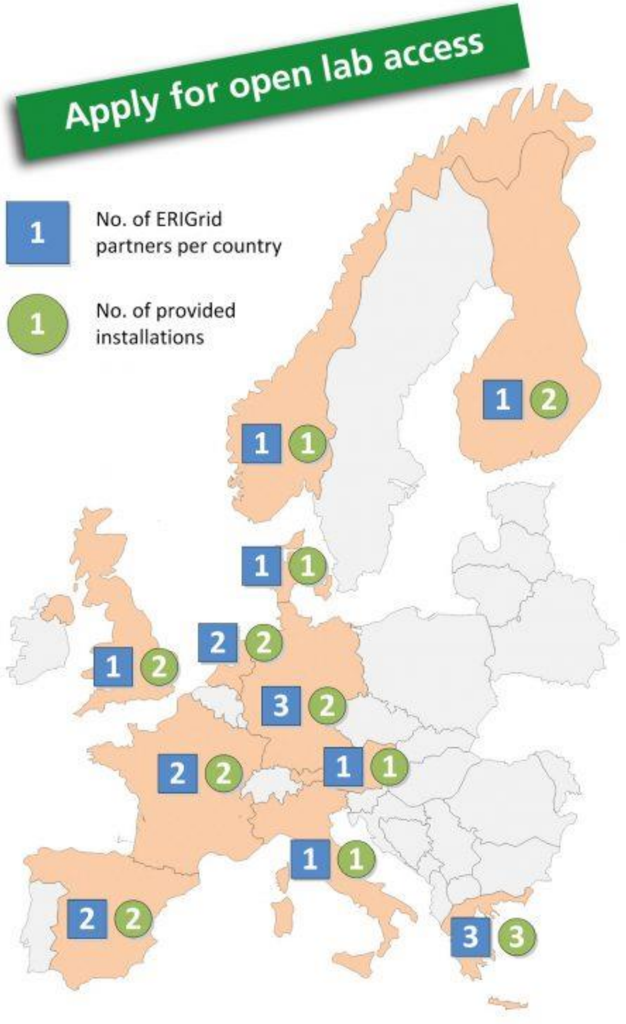
Summary

- First implementation of the ADMS cyber-physical testbed
- Related ongoing activity: *Topology processing and state estimation methods, the use of smart meter data*

  (Raymundo E. Torres-Olguin, Santiago Sanchez Acevedo, Henning Taxt)
- Next activities include:
  - ✓ New functions and use cases (e.g. DERMS)
  - ✓ Scale-up
- Research questions:
  - ✓ Characterization of different control architectures in the distribution system
  - ✓ Formulation of sufficiently accurate OPF for real-time operation
  - ✓ Studying impacts of flexibility activation
  - ✓ Identification and mitigation methods for misuse cases



The Transnational Access programme supported successful applicants by offering the following:

- ❑ travelling
- ❑ accommodation
- ❑ lab access to ERIGrid 2.0 testing and simulation facilities

- ❑ **Apply every 3 months for physical lab access**
- ❑ **Access virtual services anytime no application is required**

https://erigrid2.eu/lab-access/

EU H2020 Programme GA No. 870620

Thank you!

Comments and questions are welcome!

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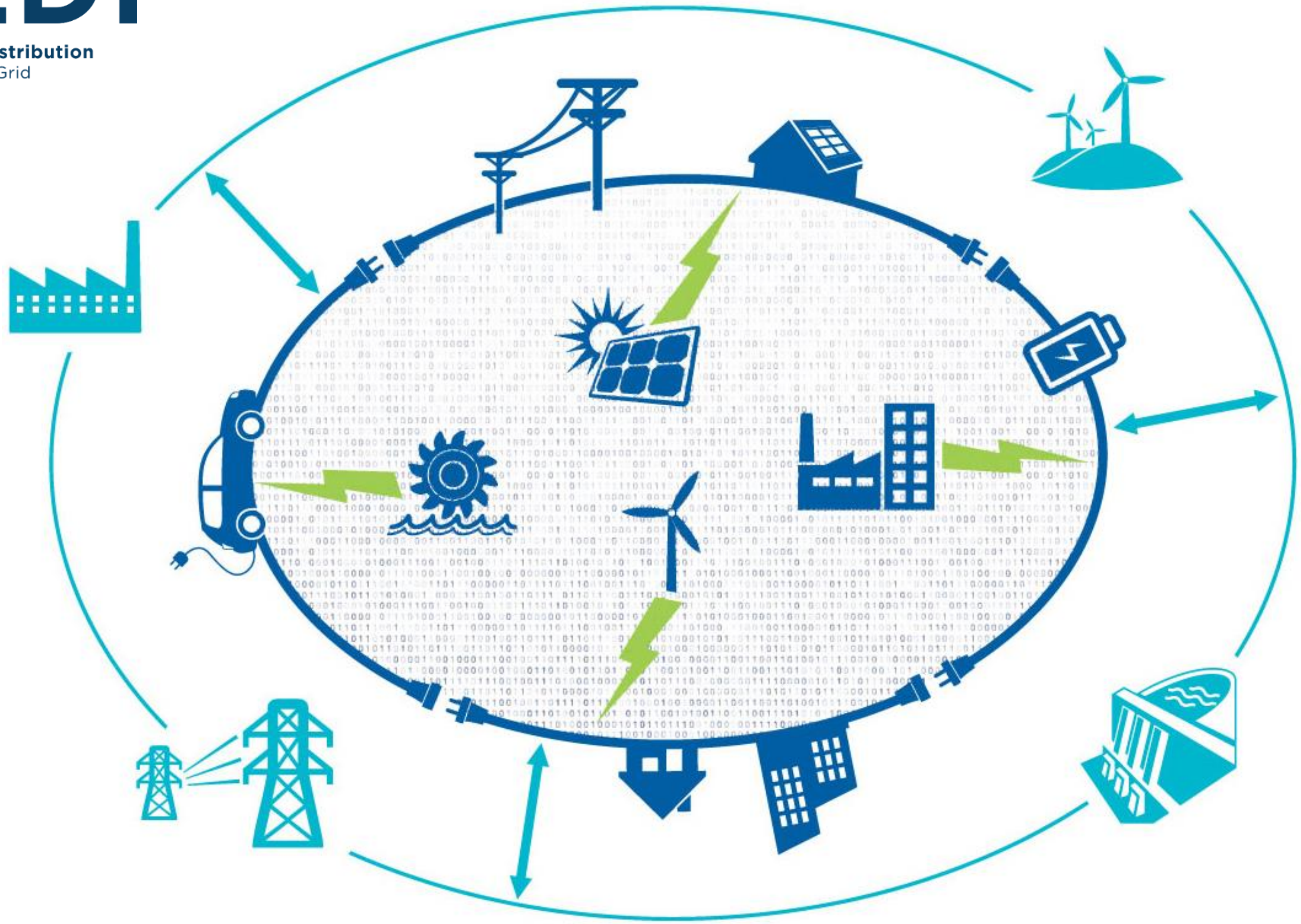

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