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Advanced Laboratory Testing Methods supporting Smart Grids

ERIGrid - European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

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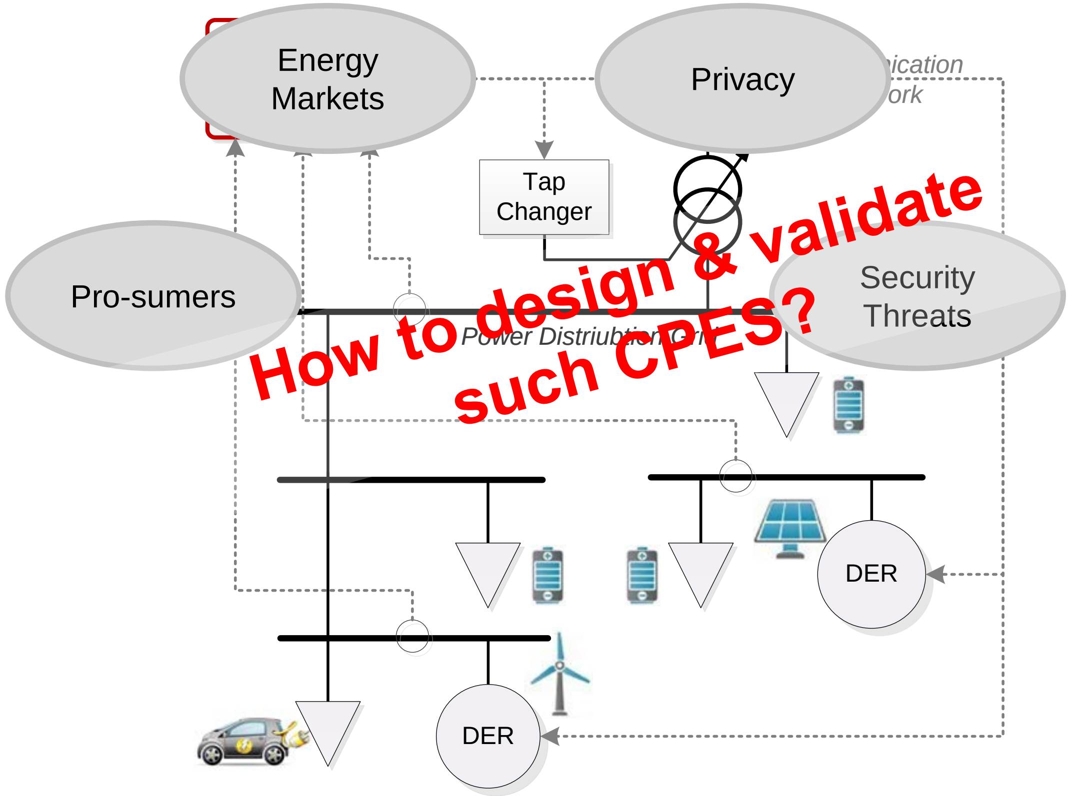
- ERIGrid Trans-National Access

Higher Complexity in Cyber-Physical Energy Systems

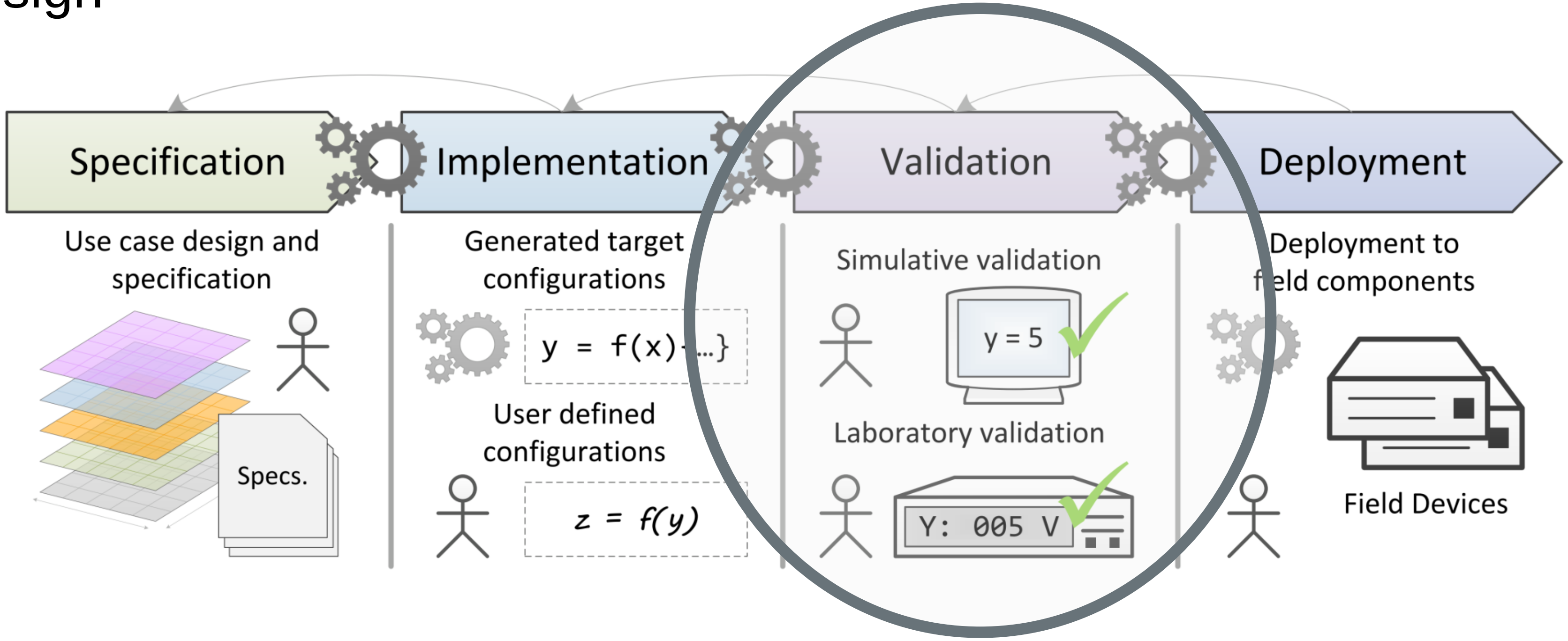
- Planning and operation of the energy infrastructure becomes more complex
  - Large-scale integration of renewable sources (PV, wind, etc.)
  - Controllable loads (batteries, electric vehicles, heat pumps, etc.)
- Trends and future directions
  - Digitalisation of power grids
  - Deeper involvement of consumers and market interaction
  - Linking electricity, gas, and heat grids for higher flexibility and resilience



→ *Cyber-Physical Energy System (CPES)*

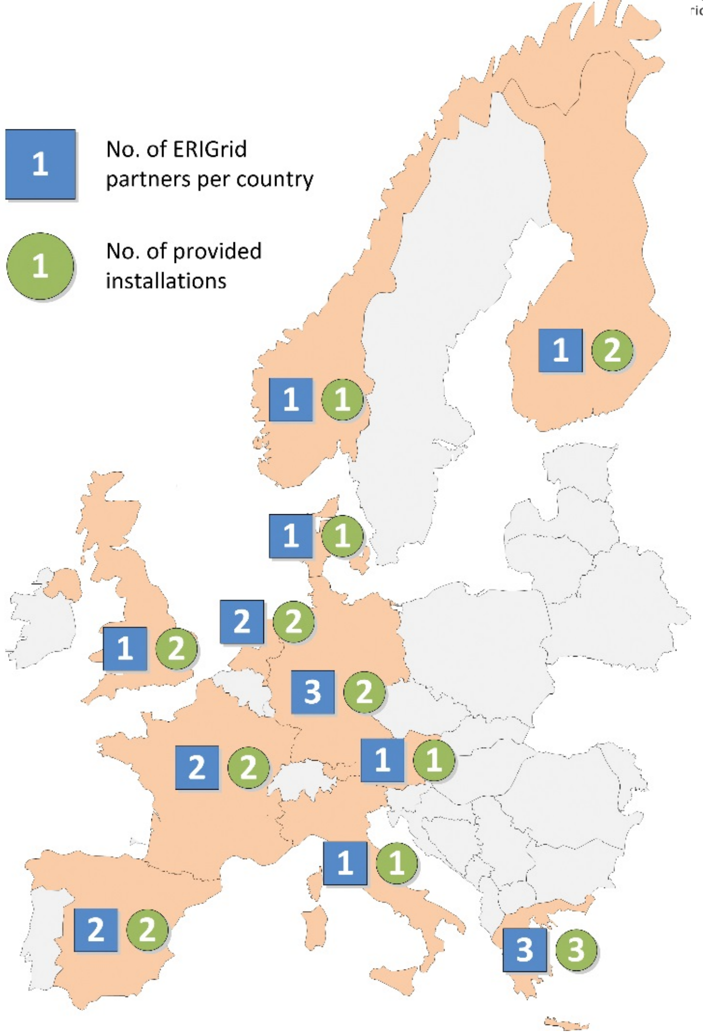
Open Issues and Future Research Needs

- Vision: *"Providing support from design to implementation & installation"*
  - Integrated system design
  - Validation & testing
  - Installation & roll out



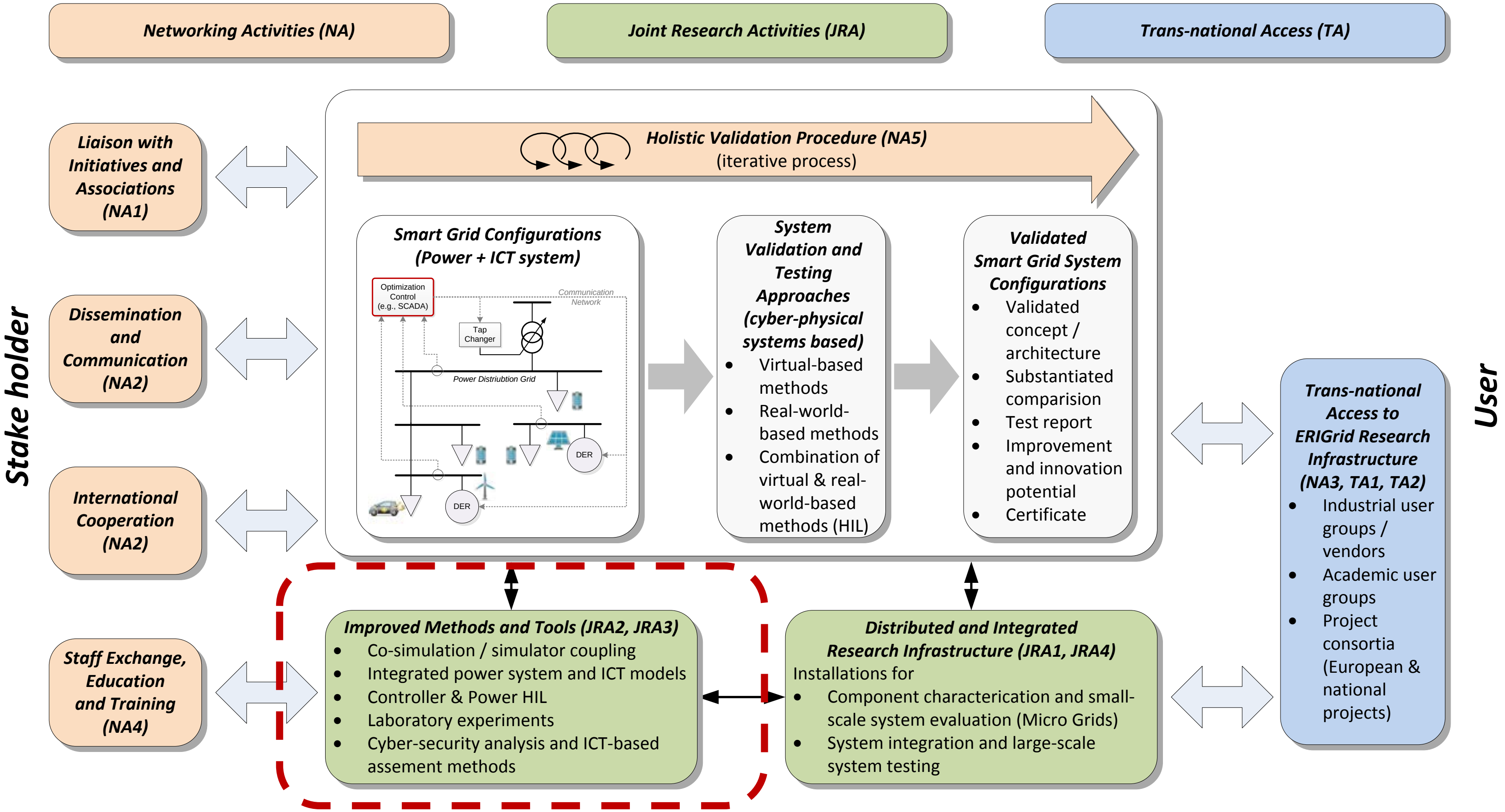
Project Fact Sheet

- H2020 call
  - INFRAIA-1-2014/2015:
    Integrating and opening existing national and regional research infrastructures of European interest
- Funding instrument
  - Research and Innovation Actions (RIA)
    Integrating Activity (IA)
- 18 Partners from 11 European Countries
  + 3 Third Parties involved
- Involvement of 19 first class Smart Grid labs
- 10 Mio Euro Funding from the EC
- ~1000 Person Month



Overview ERIGrid Approach

- Leading research infrastructure in Europe for the domain of Smart Grids



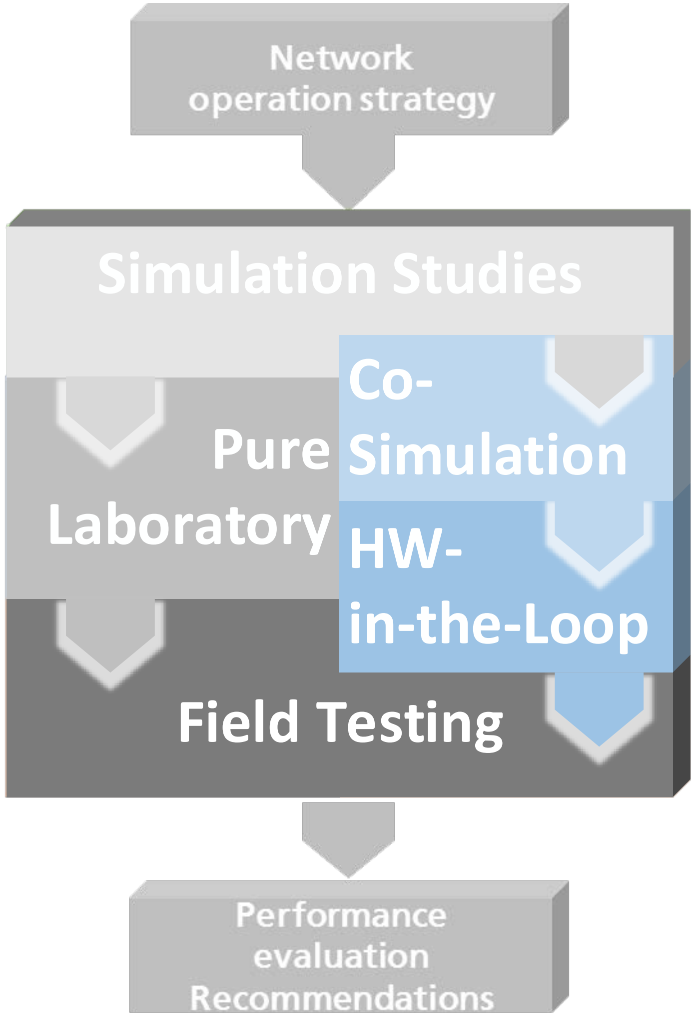
Systematic Testing and Evaluation Approaches

Test Chain

- Idea → Development → Validation

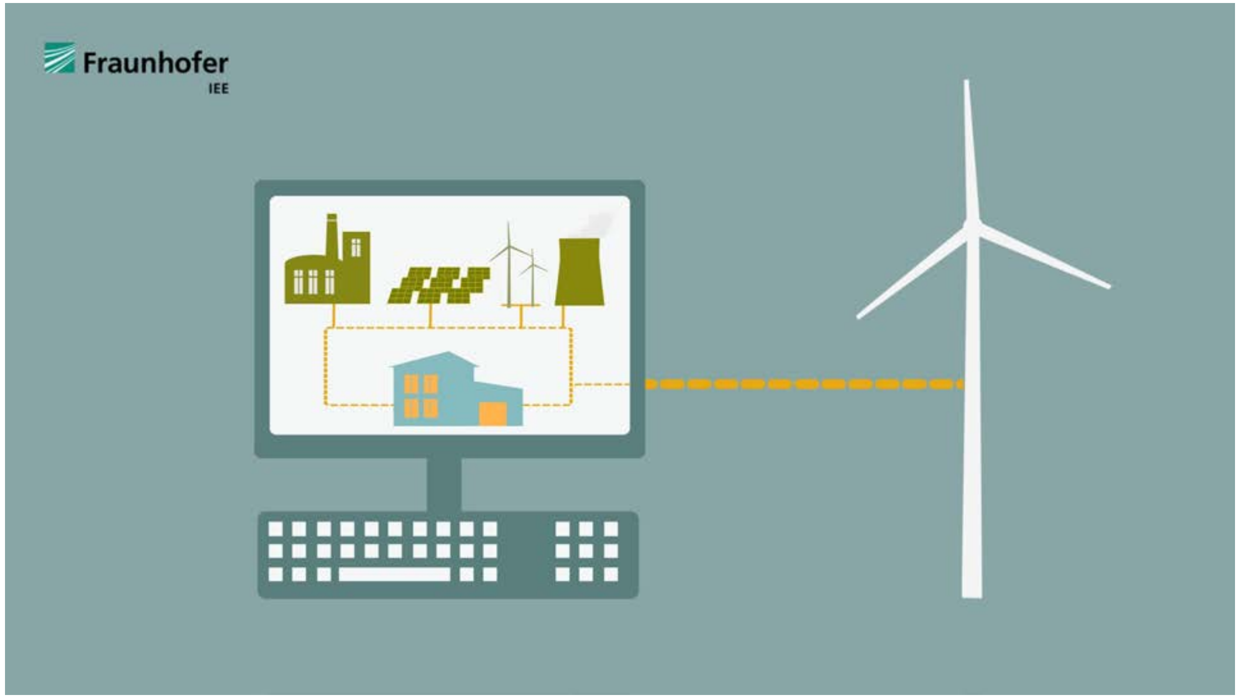
Advantages

- New control algorithms and procedures can be tested in real-time and in realistic environments
- Efficient and low-cost prototyping
- Products' faults or non-conformities can be detected and solved efficiently
- Cost- and time-intensive field tests can be prevented



What is Hardware-in-the-Loop?

1. A simulation model of a system executed on a Digital Real-Time Simulation (DRTS) in real-time mode
2. One or more salient components of that system existing outside of that DRTS
3. The DRTS simulation interacts with the salient component(s) outside the DRTS and vice versa



Background and Motivation

- Rise of complexity of cyber-physical energy systems
  - Large integration of Distributed Energy Resources (DER)
  - Fulfillments of new power quality standards
  - Digitalization of power systems (e.g. Metering)
  - Strong multi-domain grid interconnection (market, heat, gas, electricity)

➔ ***Require holistic validation approach for DER integration***

Background and Motivation

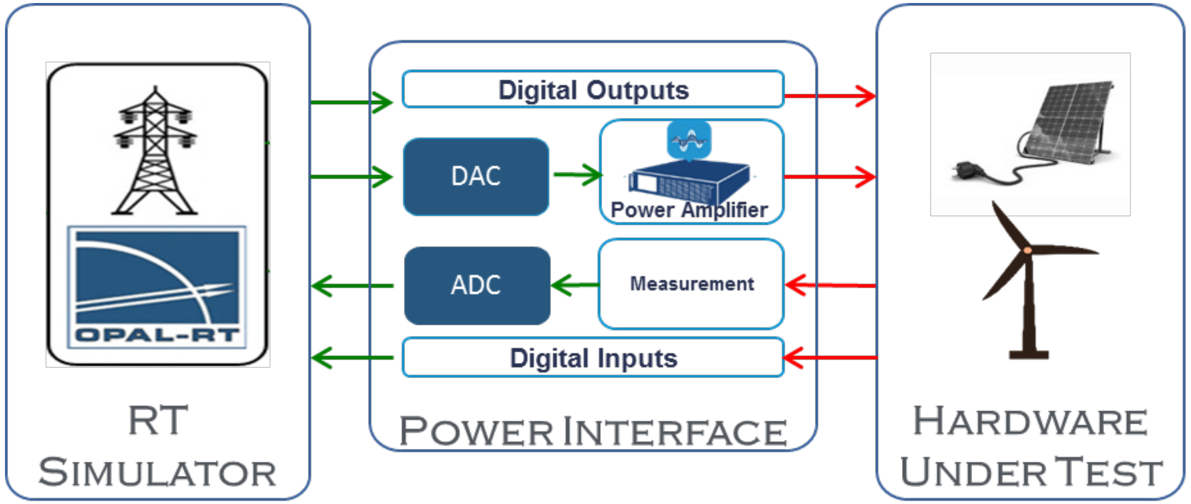
- Advantages of Hardware-in-the-Loop (HIL)
  - Integrating of grid disturbances/extreme conditions
  - Flexibility in changes of grid and component parameter
  - De-risking field testing by controlled testing environment
- Current limitations
  - Integration of the additional CPES domains
  - Consideration of complex systems implementation
  - Remote access to distributed HIL testing environments for joint experiments

➔ ***Generic testing framework needed***

Status Quo of HIL

Power Hardware-in-the-Loop

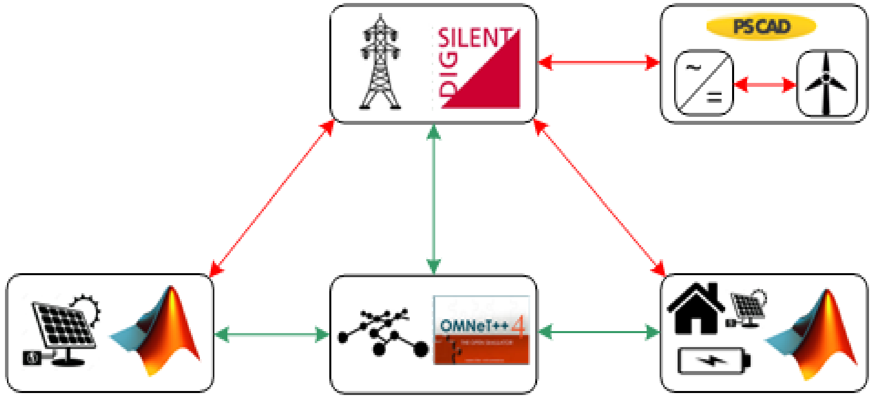
- Coupling DRTS with hardware via a power interface
  - Scalable testing in disturbed/extreme grid conditions without damaging equipment
  - Integrates real hardware behavior and realistic system feed-back
- Require strict considerations on latency and stability

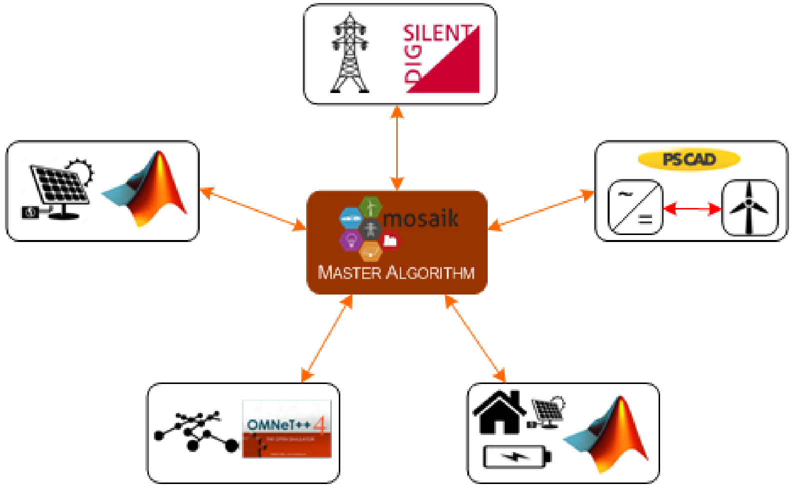


Status Quo of HIL

Co-simulation of Power and ICT systems

- Joint simulation of various simulators in an holistic test-case
  - Detailed and validated models with tailored solvers
  - Shared computational load
  - Model privacy
- Can be done ad-hoc or with Orchestrator





Technical Challenges of HIL

- **Status quo:** Individual domains are designed and validated separately
- **Open issues/activities:** Necessity of integrated system design and validation
  - Integrated tools for CPES validation
  - Scalability and level of detail
  - Interoperability
  - Testing in grid disturbances/extreme conditions

➔ ***Proposal of several techniques in framework of DER validation***

Challenging the Status Quo

HIL and Co-Simulation Integration

- Advantages:
  - Integrated multi-domains using Co-Simulation
  - Realistic behaviors of hardware
  - Collaboration multi-research-infrastructure in a holistic experiment
- Status-quo: Integration of C-HIL to Co-Simulation
  - Integration PHIL to Co-Simulation presents many challenges
- Techniques
  - Offline integration with Functional Mock-up Unit (FMU)
  - Online integration without signal synchronization

Challenging the Status Quo

Improvement of HIL Capability

- Status quo:
  - Increasing stability by reducing accuracy of results
  - Use of filter and high-effort interfacing methods
  - Stability analysis based on frequency domain

- Techniques
  - Analytical approach of stability analyses (required for non-linear models)
  - Time delay / harmonic compensation method

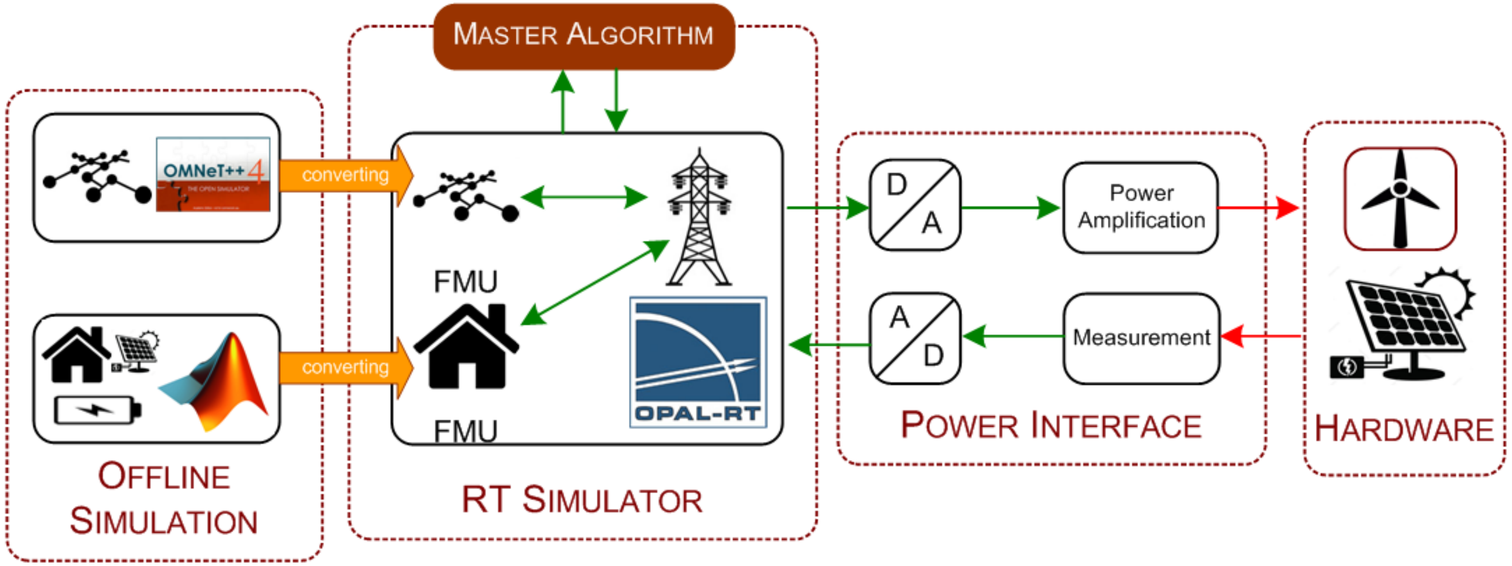
ERIGrid Approaches

Extending HIL Capacity

❖ **3 approaches for integration of HIL to co-simulation framework**

1. « Offline » Co-Simulation Approach

- Offline simulation is converted to FMU and integrated directly to the RT simulator's model -> forced to run at RT simulators time steps.
- Need of compilation verification (some DRTS require to compile the FMU)

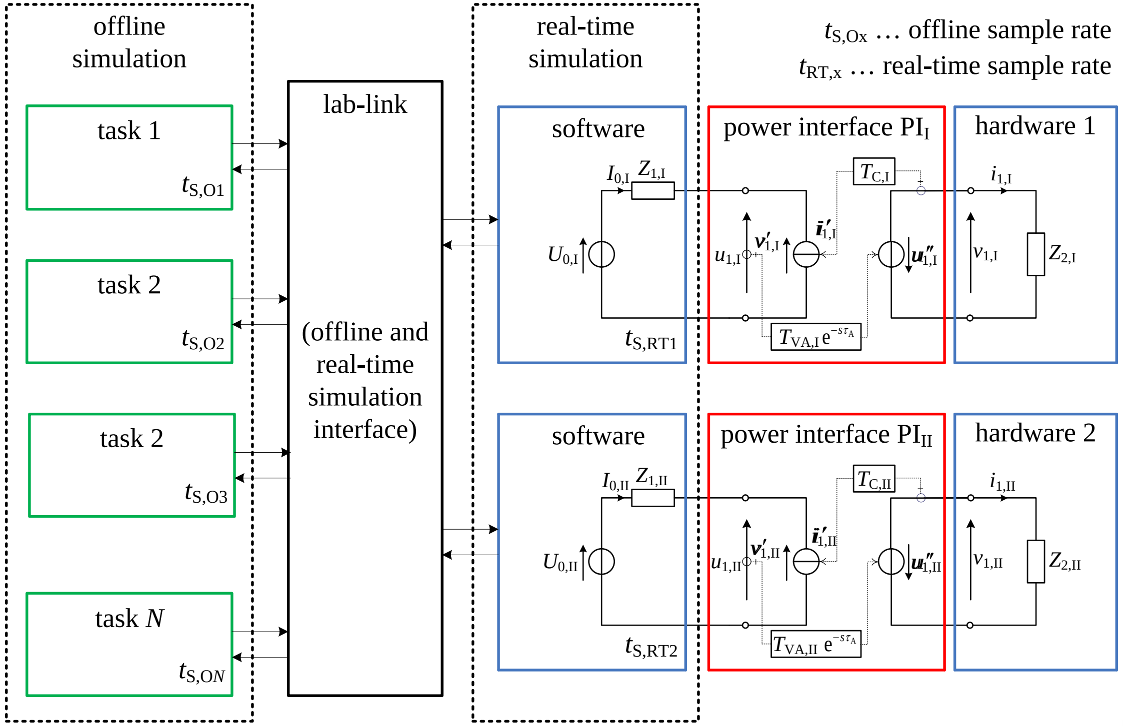


ERIGrid Approaches

Extending HIL Capacity

2. « Online » Co-Simulation Approach – Without Synchronization

- Lab-link Architecture.



Sample rates of subsystems linked via lab-link:

a) offline tasks: $t_{S,O(N\text{-}1)}$ > 100 ms; operating sample rates [100 ms; 2 s]

b) lab link: $t_{S,LL}$ > 1 ms; operating sample rates [100 ms; 2 s]

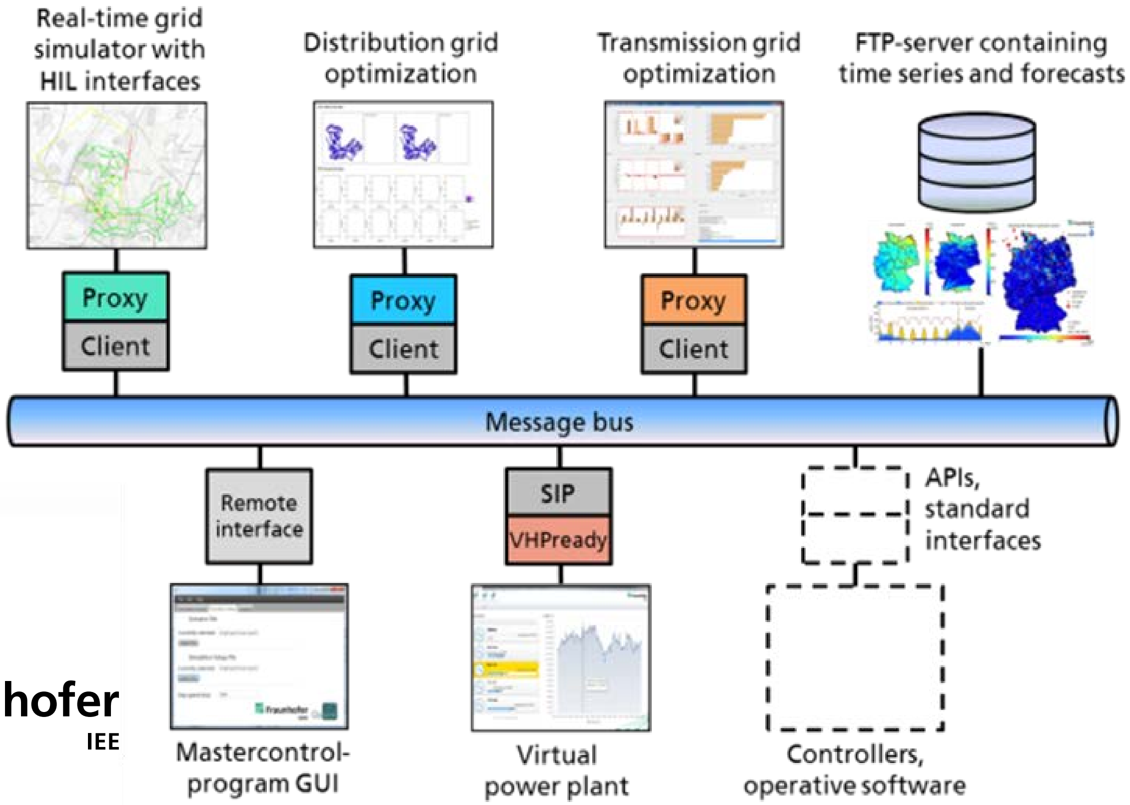
c) real-time simulation: $t_{S,RT}$ < 1ms (up to 100ns); operating sample rates [100 ns; 1 ms]

ERIGrid Approaches

Extending HIL Capacity

3. « Online » Co-Simulation Approach – With Synchronization

- OPSim Solution



- Flexible Co-Simulation environment for modelling multi-actor power systems (e.g. DSO-TSO-grid interactions)
- Real-time mode for controller-in-the-loop (CIL) tests and offline-mode for seasonal simulation time spans
- Opal-RT can be connected to OpSim, which allows us to combine HIL tests with Co-Simulations (asynchronous interface)
- Accessible via various interfaces like IEC 61850, CIM, propriety data models and also via Webservice

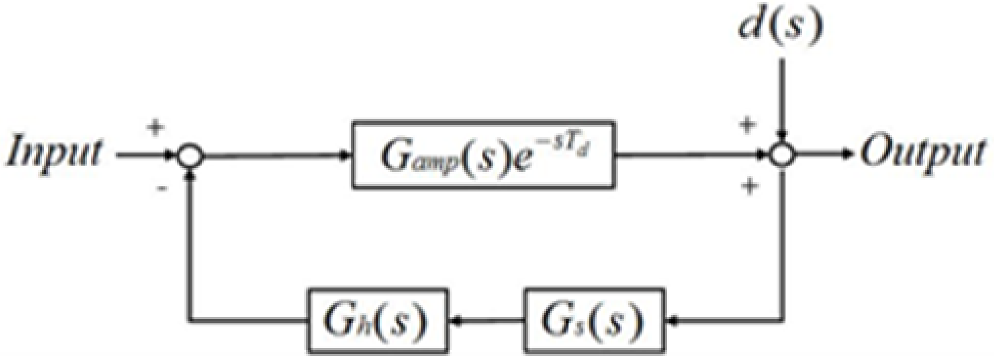
ERIGrid Approaches

Improving PHIL testing Performance

- <u>Determining marginal parameters to achieve stability of PHIL test</u>

Considering Bode stability criterion, for stable PHIL simulation the following conditions should be satisfied:

1. $|G_s(s)G_{amp}(s)e^{-sTd}G_h(s)| \leq 1$
2. $\angle G_s(s) + \angle G_{amp}(s) + \angle G_h(s) - \omega T_d = \pi$



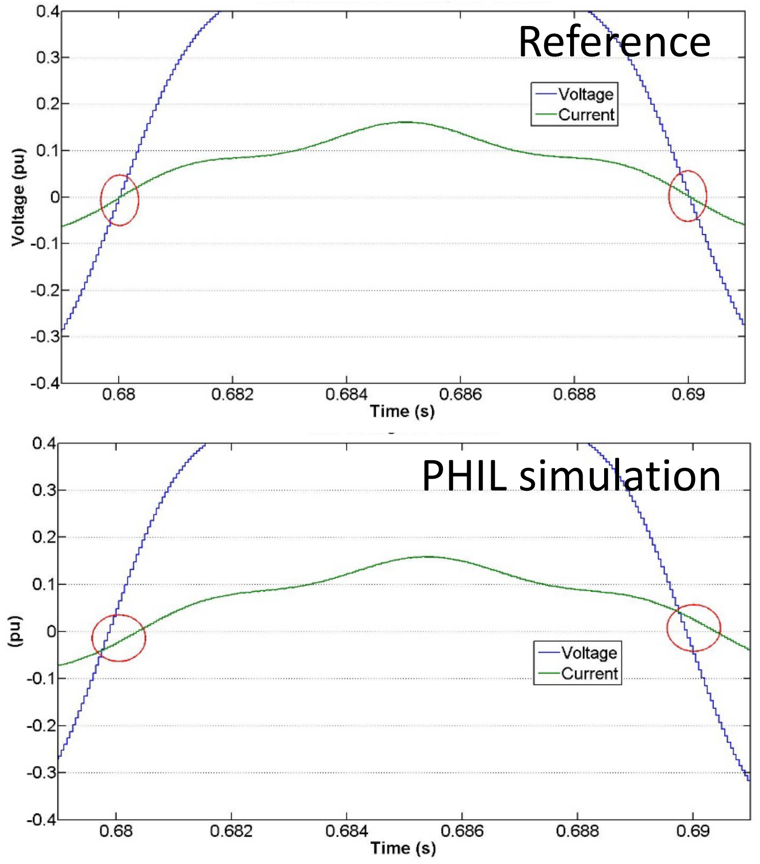
❖ Method successfully applied to the shifting impedance method and feedback filter.

*A. Markou, V. Kleftakis, P. Kotsampopoulos, N. Hatziargyriou, "**Improving existing methods for stable and more accurate Power Hardware-in-the-Loop experiments**", 26th IEEE International Symposium on Industrial Electronics (ISIE), 2017*

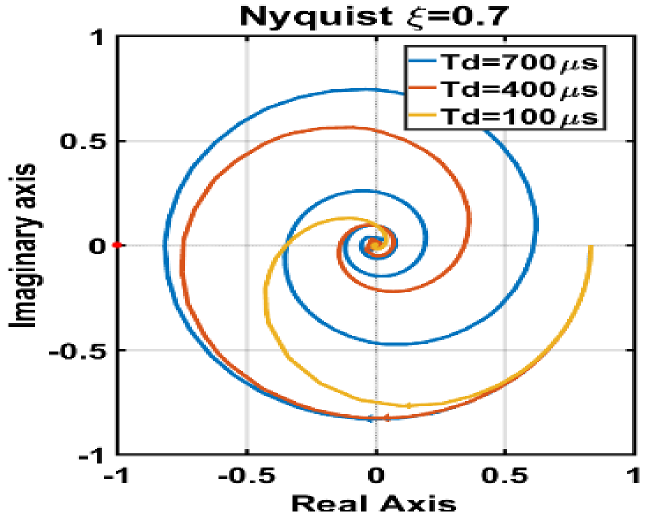
ERIGrid Approaches

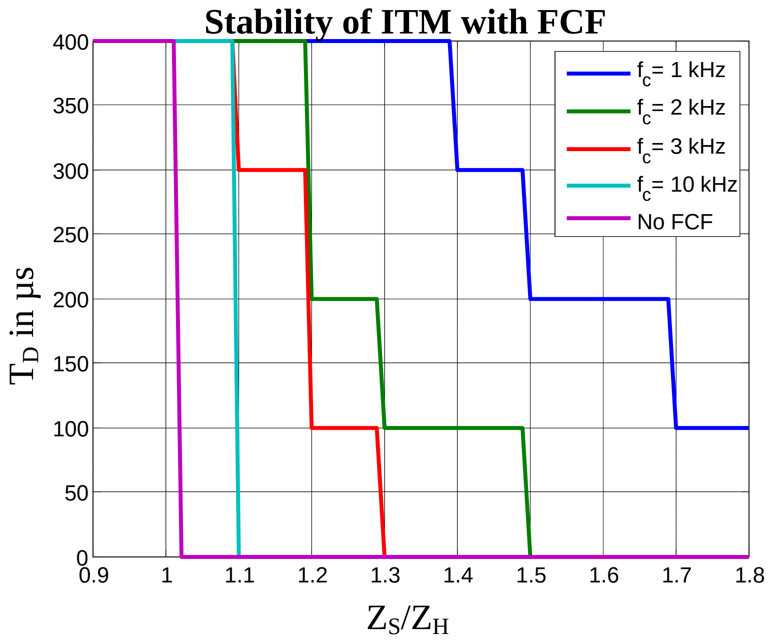
Improving PHIL testing Performance

- Effect on Accuracy



- Effect on Stability



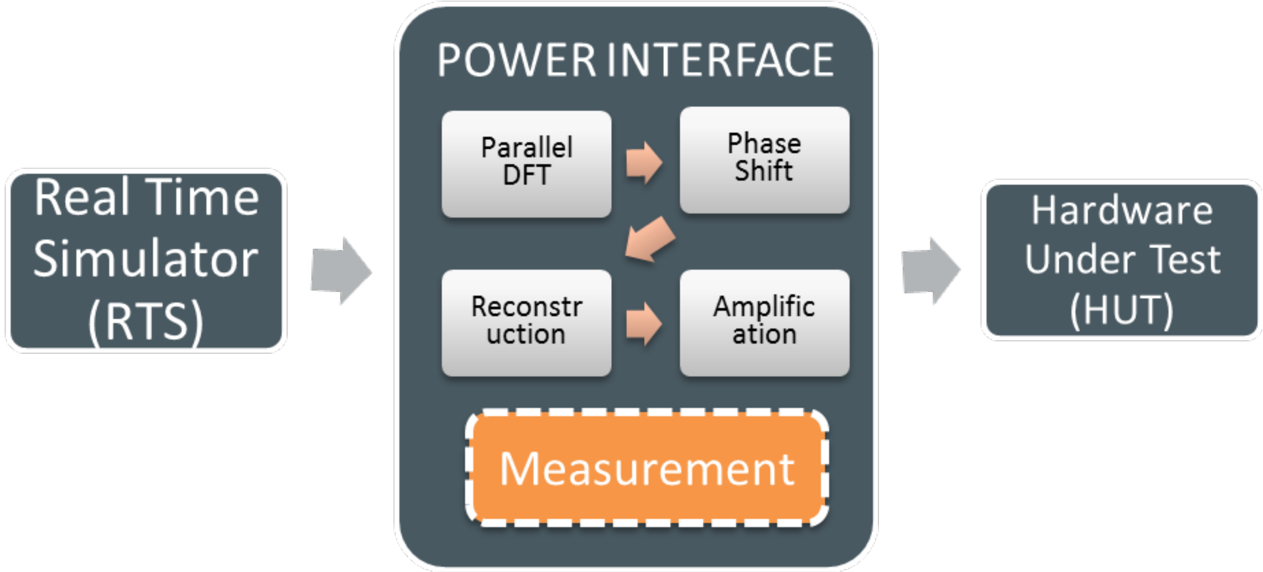


When the time delay is increased, the stability margin is reduced and tends to encircle the instability point (-1,0)

ERIGrid Approaches

Improving PHIL testing Performance

- <u>Time delay compensation in PHIL tests</u>



- Improves stability and accuracy of PHIL.
- Relatively low computation using parallel DFT.
- Compensation of fundamental and harmonics components.

E. Guillo-Sansano, A. J. Roscoe and G. M. Burt, "**Harmonic-by-harmonic time delay compensation method for PHIL simulation of low impedance power systems**," *2015 International Symposium on Smart Electric Distribution Systems and Technologies (EDST).*

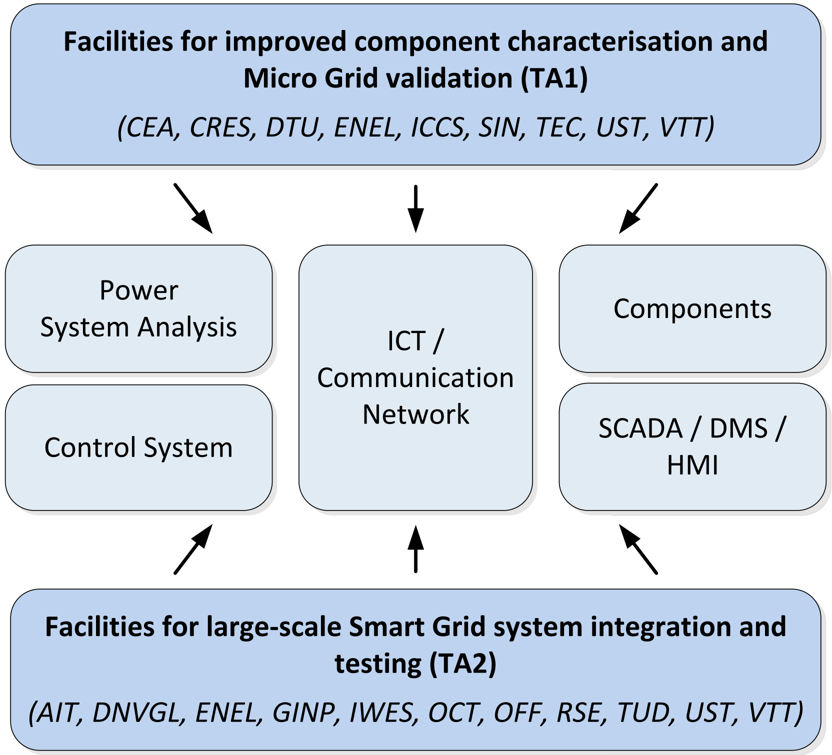
Conclusion

- Status quo of real-time and HIL approaches
  - No inter-domain studies of CPES domains
  - Stability issues of PHIL with non-linear units
- Approaches for challenging the Status-quo
  - Holistic validation of CPES
  - PHIL enhancement

➔ ***Standardized approaches towards these challenges are needed***

Trans-national Access Obj. (TAO)

- TAO1: Provision of user access to research infrastructure of the main players in the Smart Grids European Research Area
- TAO2:Attracting industry-related user projects



R&D topic	Provided services to external users
DER components	• PV-inverter tests (component, integration) • Storage, charging devices test (component, integration) • …
Development of new network components	• Test of new component concepts • Validation of advanced control methods for components • …
Smart Grid ICT / Automation	• Valdiation of controller implementation and integration • Validation of communication protocols • Test of SCADA system developments and integration • Cyber-security assessment • …
Co-simulation	• Co-simulation tests power grid ↔ communication network • Co-simulation tests power grid ↔ components ↔ communication network • …
Real-time simulation and HIL	• Integration tests for inverter-based devices • Validation of new power electronic component topologies • …
…	…

Access to Infrastructures (labs)

- Free of Charge
  - ERIGrid is supported by the H2020 programme of the European Commission under the research infrastructure funding scheme
  - Access to research infrastructures is called Trans-national Access
  - Access and use of the installations (labs) is absolutely free of charge for users (industrial and academic)
  - All expenses, including travel and accommodation are reimbursable, under the conditions agreed with the hosting infrastructure

Access to Infrastructures (labs)

- Start of next call:
  → **15th Aug. 2018**
- For More Information: https://erigrid.eu/transnational-access/

Thank you for your attention!

Fraunhofer IEE

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