## グランド再生可能エネルギー2018 国際会議 AIST-FREA スペシャルセッション

## **GRAND RENEWABLE ENERGY 2018**

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2018/6/20 パシフィコ横浜 会議センターにて





# 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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AIT Energy



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## **Fraunhofer**

## Higher Complexity in Cyber-Physical Energy Systems

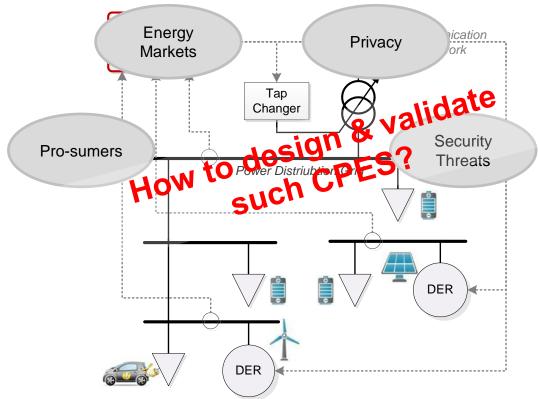


Planning and operation of the energy infrastructure becomes more

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)

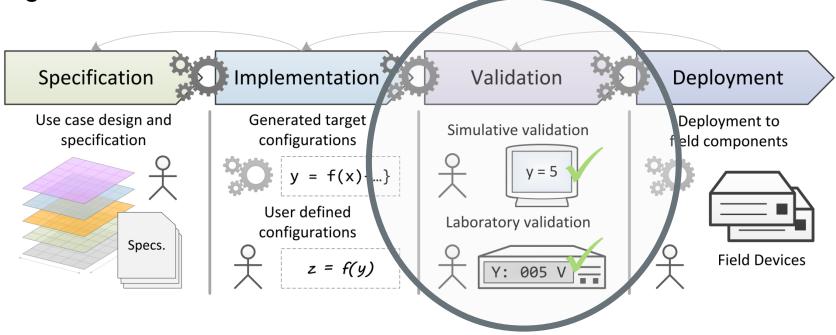






## Open Issues and Future Research Needs

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

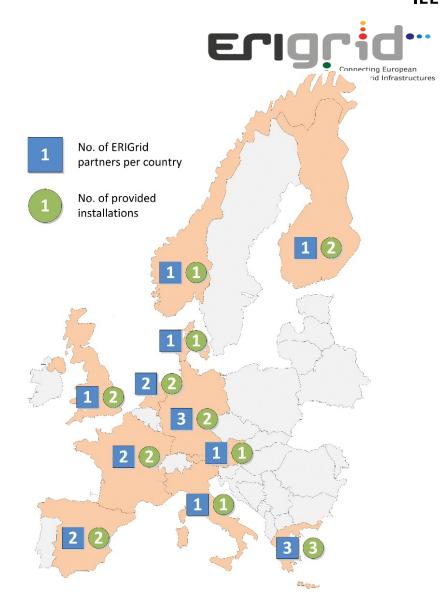






## **Project Fact Sheet**

- 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









Leading research infrastructure in Europe for the domain of Smart

Grids Networking Activities (NA) Joint Research Activities (JRA) Trans-national Access (TA) Holistic Validation Procedure (NA5) Liaison with (iterative process) Initiatives and **Associations** (NA1) System **Smart Grid Configurations** Validated Validation and (Power + ICT system) Smart Grid System Testing **Configurations** Optimization Control (e.g., SCADA) **Approaches** Validated Dissemination (cyber-physical Stake holder Tap Changer concept / and systems based) architecture Communication Virtual-based Substantiated (NA2) methods Trans-national comparision Real-world-Access to Test report based methods ERIGrid Research Improvement Combination of Infrastructure and innovation virtual & real-(NA3, TA1, TA2) potential International world-based Industrial user Certificate Cooperation methods (HIL) groups / (NA2) vendors Academic user groups Project Improved Methods and Tools (JRA2, JRA3) Distributed and Integrated consortia Co-simulation / simulator coupling Research Infrastructure (JRA1, JRA4) Staff Exchange, (European & Integrated power system and ICT models Installations for Education national Controller & Power HIL Component characterication and smalland Trainina projects) Laboratory experiments scale system evaluation (Micro Grids) (NA4)

Cyber-security analysis and ICT-based

assement methods



system testing

System integration and large-scale



## Systematic Testing and Evaluation Approaches

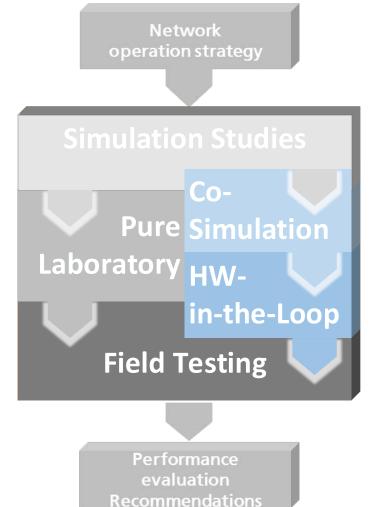


#### **Test Chain**

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



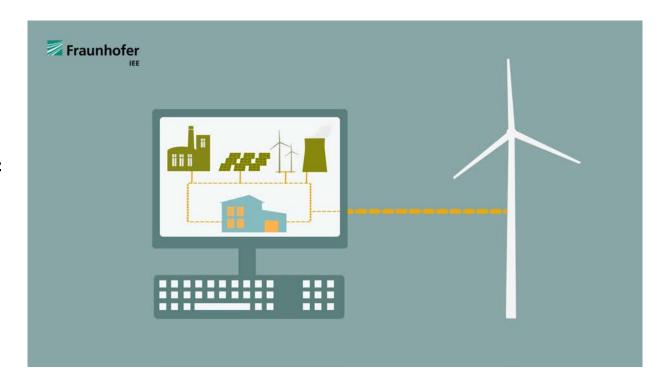
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### What is Hardware-in-the-Loop?



- A simulation model of a system executed on a Digital Real-Time Simulation (DRTS) in real-time mode
- 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



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## **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









- 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

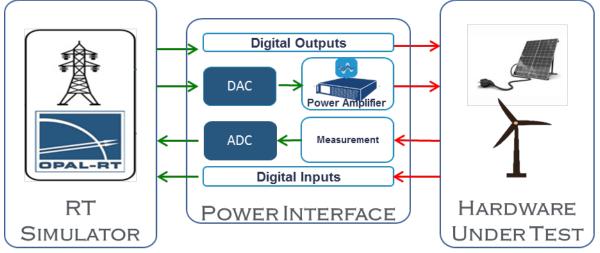
#### Power Hardware-in-the-Loop





- 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





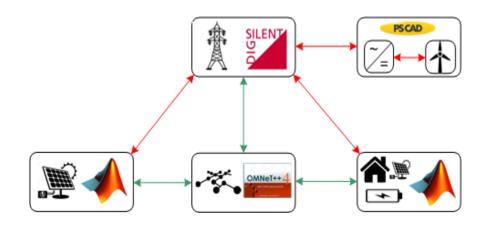


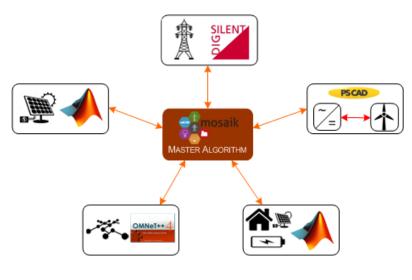
#### Status Quo of HIL

#### 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

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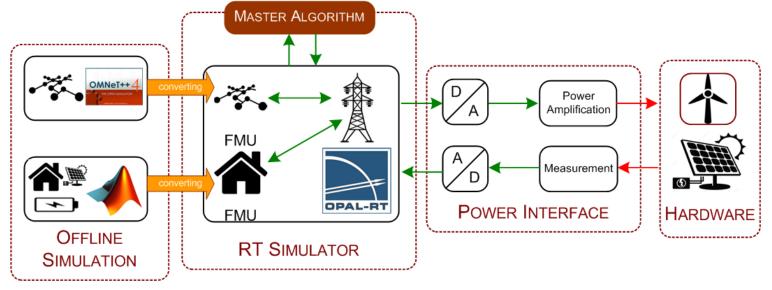
# ERIGrid Approaches Extending HIL Capacity



## ❖ 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**

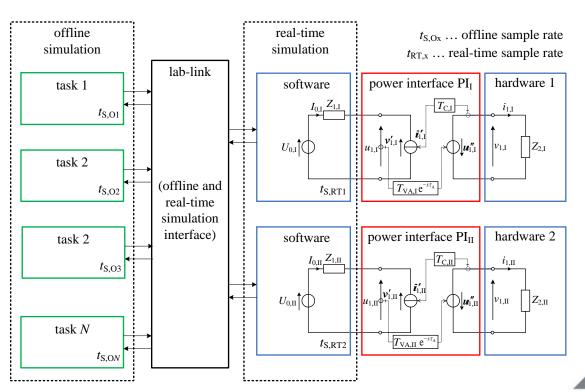
### Extending HIL Capacity





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

Lab-link Architecture.



Sample rates of subsystems linked via lablink:

- a) offline tasks:  $t_{S,O(N-1)} > 100$  ms; operating sample rates [100 ms; 2 s]
- b) lab link:  $t_{S,LL} > 1$  ms; operating sample rates [100 ms; 2 s]
- real-time simulation: t<sub>S,RT</sub> < 1ms (up to 100ns); operating sample rates [100 ns; 1 ms]</li>



## **ERIGrid Approaches**

### Extending HIL Capacity





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

OPSim Solution

Real-time grid simulator with HIL interfaces

Distribution grid optimization

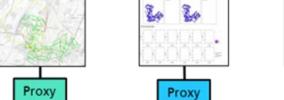
Transmission grid optimization

Transmission grid time series and forecasts

Transmission grid optimization

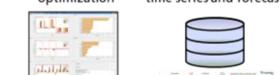
Transmission grid time series and forecasts

Multi-a



Client

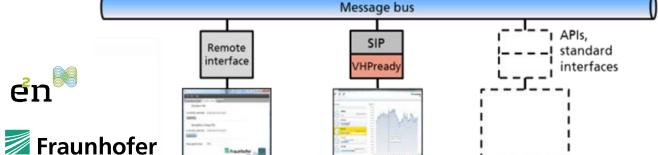
Client



Controllers,

operative software





Virtual

power plant

- 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



Mastercontrol-

program GUI



## **ERIGrid Approaches** Improving PHIL testing Performance

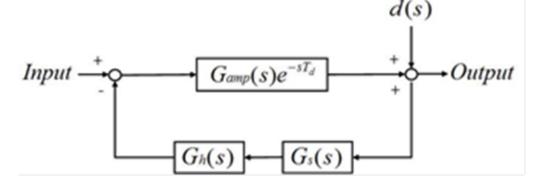


Determining marginal parameters to achieve stability of PHIL test

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

1. 
$$|G_s(s)G_{amp}(s)e^{-sTd}G_h(s)| \le 1$$

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

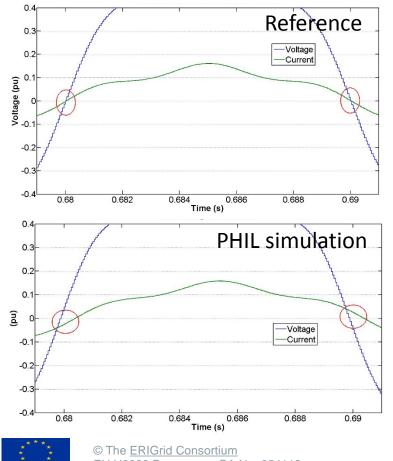


## **Fraunhofer**

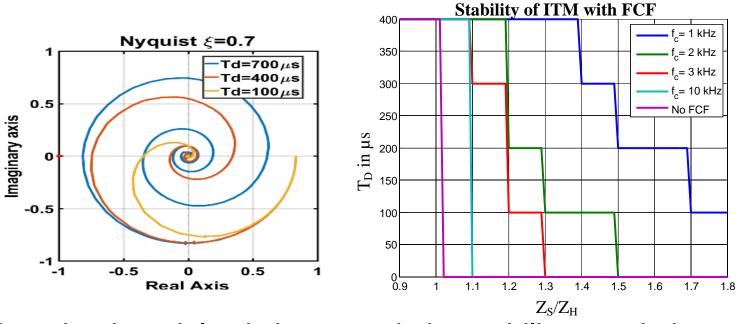
## **ERIGrid Approaches** Improving PHIL testing Performance



#### 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)

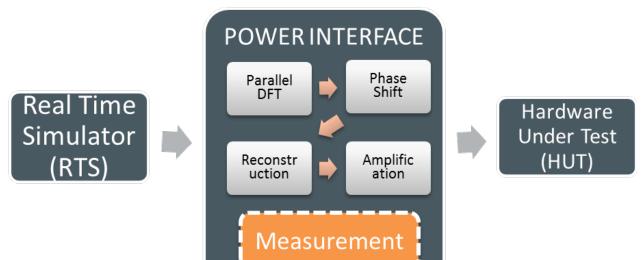
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## **ERIGrid Approaches** Improving PHIL testing Performance





Time delay compensation in PHIL tests



- 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

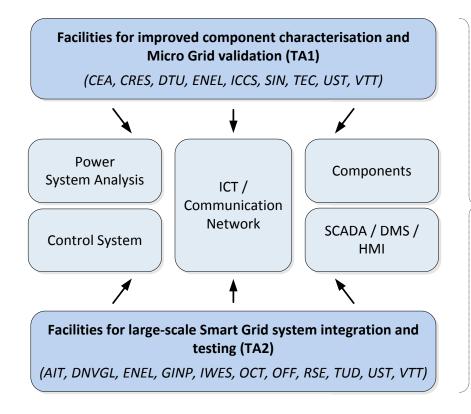








- TAO1: Provision of user access to research infrastructure of the main players in the Smart Grids European Research Area
- TAO2:Attracting industry-related user projects



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





## 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)



ERIGrid calls for free transnational access:

1st call: 15 September - 15 December, 2016 2nd call: 15 March - 15 June, 2017 3rd call: 15 August - 15 November, 2017 4th call: 15 February - 15 May, 2018 5th call: 15 August - 15 November, 2018 6th call: 15 February - 15 May, 2019

erigrid.eu/transnational-access



On the cover: Demonstration and Experimentation Unit of Ormazabal, Distribution Network and Protection Laboratory of University of Strathclyde, Flex Power Grid Laboratory of DNV G

The ERIGrid project provides free access to concentrated know-how and European research infrastructure to scientists and industry involved in the development of smart grid concepts and components.

- 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)
- Involvement of 19 first-class smart grid labs
- . €10M funding from the EC
- Duration: 1 November, 2015 30 April, 2020



































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Applications open every 6 months



Smart Grid Infrastructures





www.erigrid.eu erigrid-mgt@list.ait.ac.at

- Start of next call:
  - → 15<sup>th</sup> Aug. 2018
- For More Information:

https://erigrid.eu/ transnational-access/

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## Thank you for your attention!





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