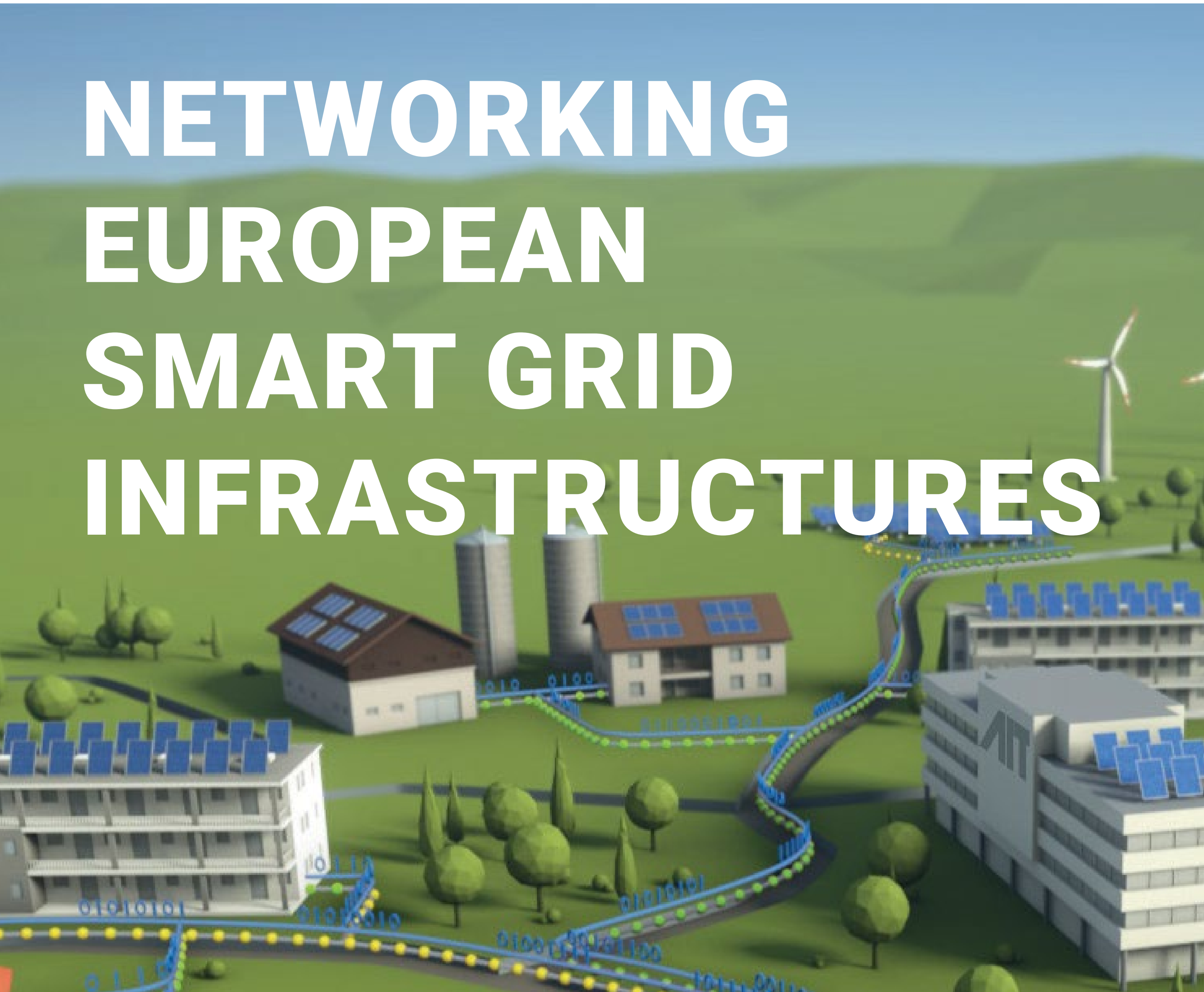
NETWORKING EUROPEAN SMART GRID INFRASTRUCTURES



ERIGRID FINAL PUBLIC PROJECT REPORT
SUMMARY OF ACHIEVEMENTS

November 2015 - April 2020

This project has received funding from the European Union's Horizon 2020
Research and Innovation programme under grant agreement #654113

CONTENT

EDITORIAL

The integration of renewable energy resources - as key enablers for the reduction of greenhouse gas emissions into the power systems - has increased over the past years and led to higher complexity of electric power systems. The increased availability of advanced automation and communication technology, along with novel intelligent solutions for system operation has transformed the traditional power system into a cyber-physical energy system - a smart grid.

Research activities so far have mainly focused on validating certain aspects of the smart grid. However, a holistic and integrated approach for analysing and evaluating such complex system has not been developed yet.

The ERIGrid project aimed to support the technology development and rollout of smart grid approaches, solutions and concepts in Europe by addressing the aspect of system validation for smart grids and developing common methods, concepts and procedures by integrating eighteen European research centres and institutions with outstanding research infrastructures.

We are proud to present hereafter an executive summary of the main developments, achievements, and results of the project.

The ERIGrid Consortium

ABOUT ERIGRID

Flex Power Grid Laboratory of KEMA

- Research infrastructure for validating smart grid systems
- H2020 Call “INFRAIA-1-2014/2015 Integrating and opening existing national and regional RIs of European interest”
- Research and Innovation Actions
- Integrating Activity
- 18 Partners from 11 European Countries
- Involvement of 19 first class European smart grid laboratories
- 10 Mio Euro funding from the European Commission

ERIGrid provided access to concentrated know-how and European research infrastructure to scientists and companies involved in the development of smart grid concepts and components by the following means:

- Supporting technology development, roll-out of smart grid approaches, solutions and concepts with a holistic, cyber-physical systems approach
- Development of a holistic smart grid system validation approach
- Enhancement of Hardware-in-the-Loop methodology and co-simulation tools
- Fostering of multi-lab testing procedures
- Provision of education and training material
- Free access to first-class European laboratories

CONSORTIUM

8 RESEARCH AND TECHNOLOGY ORGANISATIONS

AIT (Coordinator), CEA, CRES, RSE, Fraunhofer IEE, SINTEF, TECNALIA, VTT

6 UNIVERSITIES

DTU, OFFIS, TU Delft, Grenoble INP, ICCS-NTUA, University of Strathclyde

2 TESTING COMPANIES

Ormazabal Corporate Technology, DNVGL/KEMA Labs

1 EUROPEAN ELECTRIC DSO

HEDNO

1 SMART GRID AND DISTRIBUTED ENERGY RESOURCES NETWORK

DERlab

SmartEST Laboratory of AIT

THE INTEGRATED EUROPEAN ERIGRID SMART GRID RESEARCH INFRASTRUCTURE

PRISMES facility of CEA

Power system operation is of vital importance and must be developed far beyond today's practice to meet future needs like the integration of renewable energy resources, battery energy storage systems, electrical vehicle supply equipment and other types of new devices and components. Nearly all European countries are facing an abrupt and very important increase of renewables such as wind and photovoltaic that are intrinsically variable with yields that are up to some extent difficult to predict. Also, an increase of new types of electric loads (air conditioning, heat pumps, electric vehicles, etc.) and a reduction of traditional generation from bulk generation can be observed. Hence, the level of complexity of system operation steadily increases. To avoid dramatic consequences and sustain a reliable power supply system, there is an urgent need for an extended system flexibility.

MOTIVATION AND GOALS

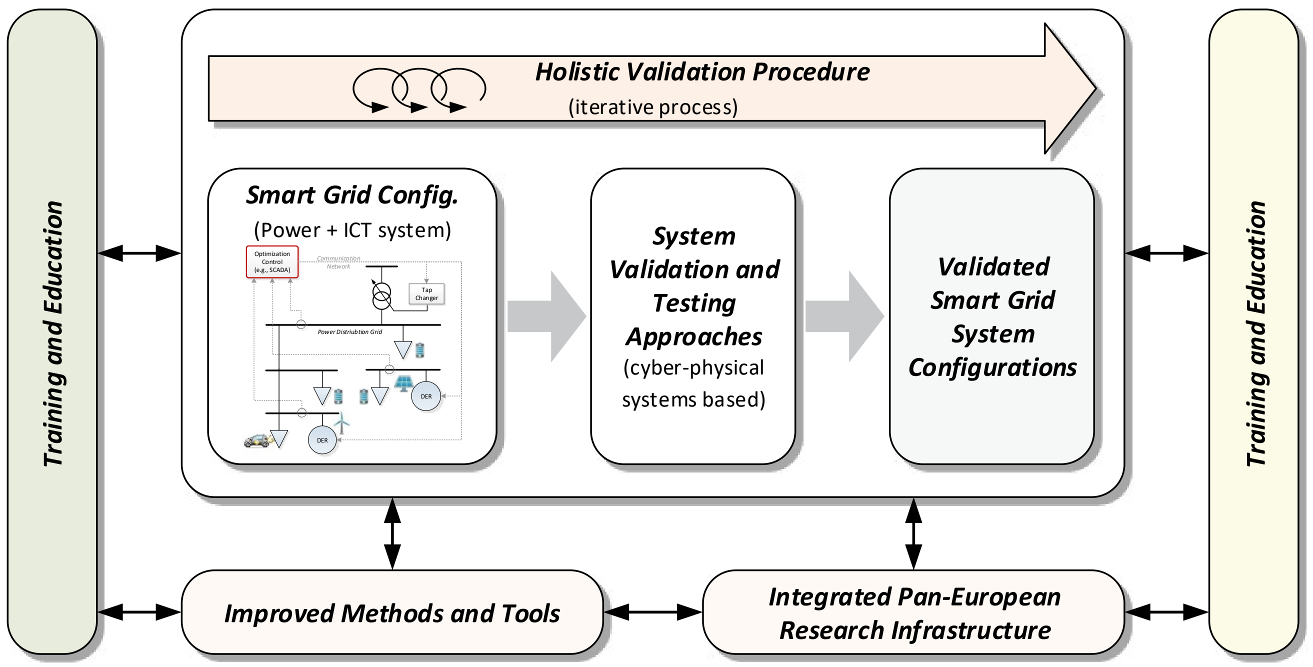
The roll-out of new technology, solutions, and corresponding applications based on recent developments in information and communication technology and power electronics in the power system domain is of importance to realize advanced system functionalities like power/energy management, demand side management, ancillary services provision, and others.

These digitalisation trends and developments are resulting in a transformation of the traditional power system into a so-called smart grid. Previous and ongoing research have tended to focus on how specific aspects of smart grids can be developed and validated, but in the past, an integrated approach for analysing and evaluating complex smart grid configurations was missing.

To tackle the above research and development needs, a pan-European research infrastructure has been realized in ERIGrid supporting the technology development as well as the roll out of smart grid technology and solutions. It provided a holistic, cyber-physical, systems-based approach by integrating European research centres and institutions with outstanding power system and smart grid laboratory infrastructure to jointly develop common methods, concepts, and procedures and provide them for free to researchers, engineers, and students.

The main goals of the ERIGrid project can be summarized as follows:

- The creation of a single point of reference supporting research and technology development on all aspects of smart grid systems validation,
- The development of a coordinated and integrated approach using the partners' expertise and RIs/laboratories more effectively, adding value to research and development projects,
- Facilitating a wider sharing of knowledge, tools, and techniques across fields and between academia and industry, and
- Accelerating pre-normative research and promoting the rapid transfer of research results into industry-related standards to support future smart grids development, validation, and roll out.



Overview of the ERIGrid approach

Experimental setup in SYSLAB, PowerLabDK

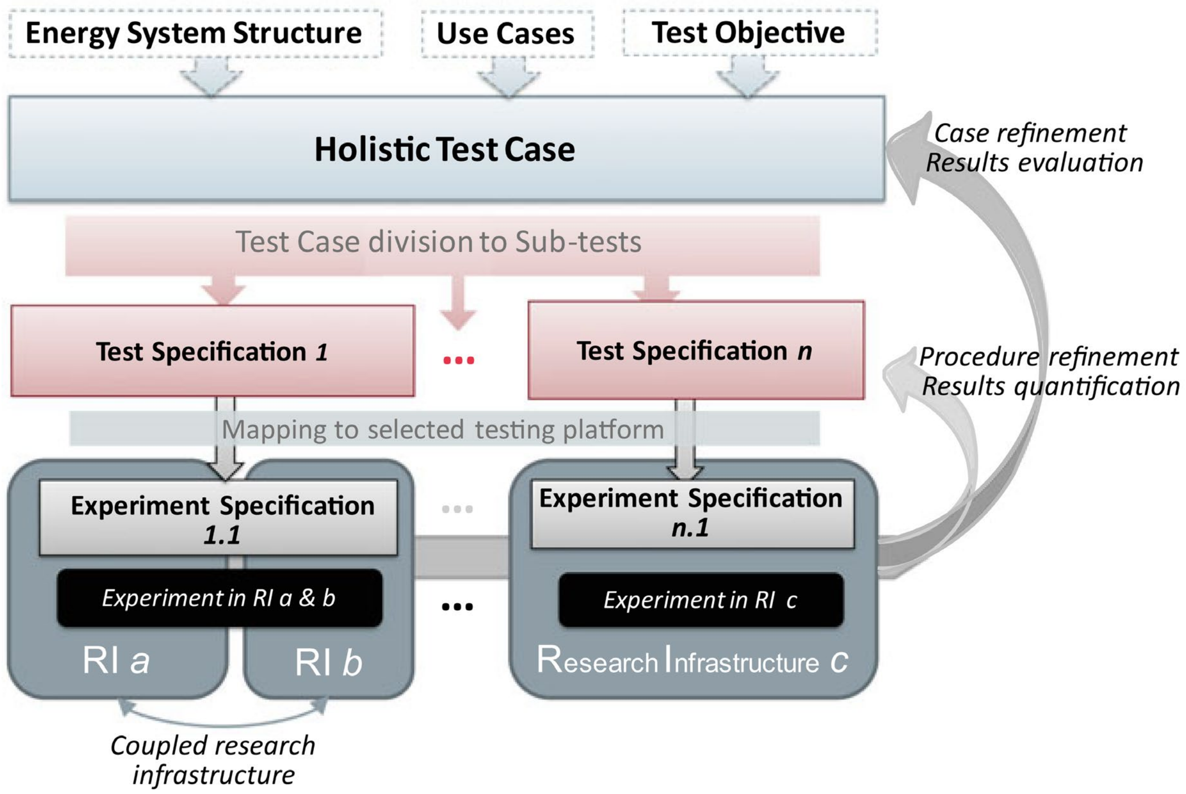
APPROACHES FOR POWER SYSTEM TESTING

SYSLAB, PowerLabDK

System-level validation of smart grid solutions can be a complex effort. A typical smart grid solution, such as a distribution grid centralized demand response control system encompasses multiple disciplines (market, information and communication technology, automation, infrastructure, etc.) and physical infrastructures (electricity, communication networks, etc.). Interactions among automation systems, enabling ICT, and electricity infrastructure are essential for such solutions and make testing of the integrated system a necessity.

DEVELOPED METHODS AND TOOLS

ERIGrid tackled such issues by the provision of proper system-level validation concepts, methods, and corresponding tools. A procedural support can be useful when adopting a complex test platform attempting validation of a complex integrated control solution. A holistic view on testing procedures is one of the core elements of the ERIGrid validation concept. At the outset, a procedure template connects the system definition and use cases with a test objective in a test case. Once this link is fully established, the test specification fully captures the requirements for an experimental setup. The test platform can now be identified and suitably configured, even with a high level of complexity connecting several research infrastructures. The experiment execution in the corresponding infrastructure and the subsequent result evaluation may now lead to judging the test as successful, returning information with reference to the specifications and test case; or it may lead to a re-iteration of the specifications.



Outline of the holistic test procedure

To document the testing needs and requirements as well as to specify the test case the corresponding experiment(s) templates have been developed in the project to support the whole validation chain. The description of the process and the corresponding templates are publicly available.

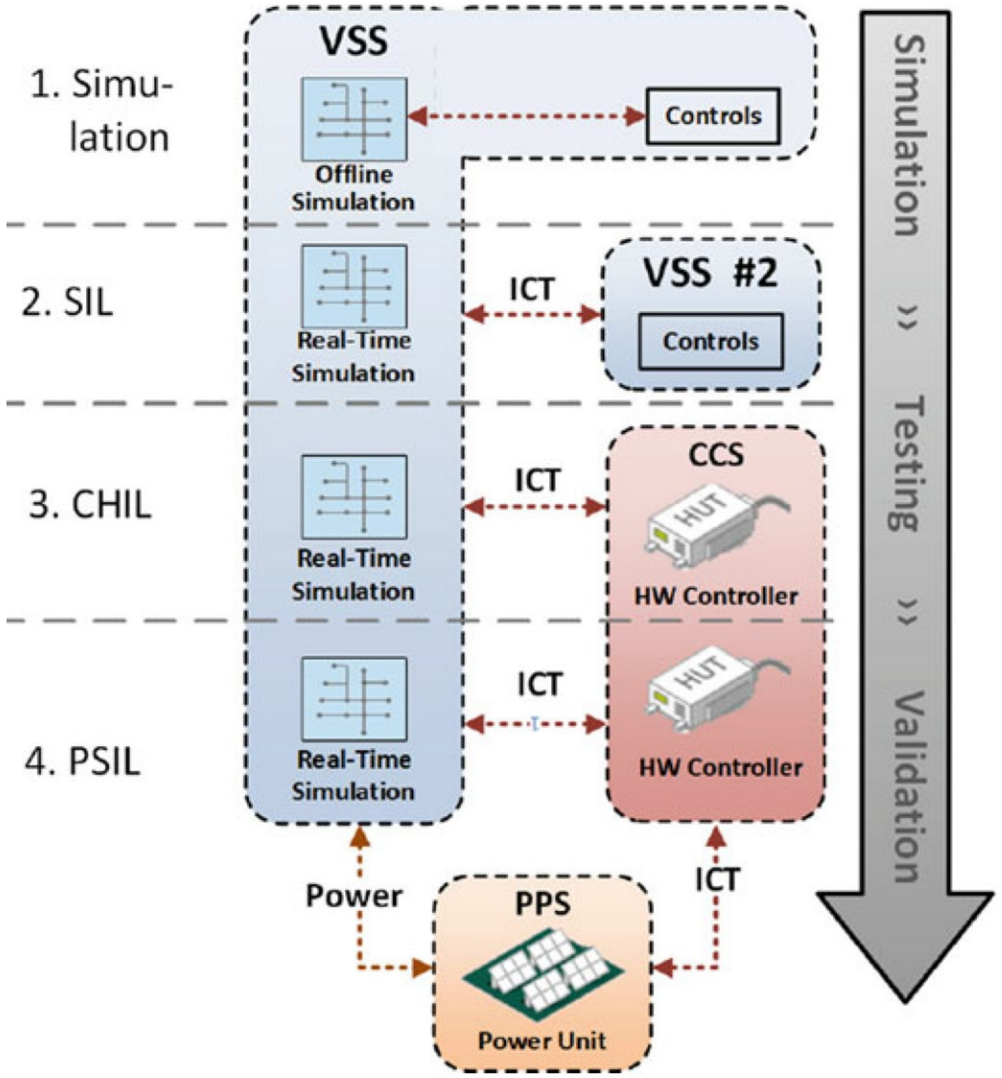
Depending on the types of test purposes, relevant test platforms, devices or systems under test, etc., different procedures and methodologies are applicable. Under the conceptual frame of this holistic test procedure, ERIGrid defined specific approaches within co-simulation, multi-laboratory experiments, and hardware-in-the-loop testing.

Furthermore, a corresponding testing chain concept has been developed as well. In Stage 1 investigations performed in a pure software simulated environment are usually carried out in steady state or transient conditions. This enables the functionality test of the control algorithm but does not represent adequately the interface between power and control systems. Stage 2 of the testing chain proposes the use of two dedicated software tools for executing the power system model and controller separately. This software-in-the-loop simulation or co-simulation technique allows the exchange of information in a closed loop configuration. After verifying the correct behaviour of the control algorithm in Stages 1 and 2, Stage 3 deals especially with the performance validation of the actual hardware controller using a controller-hardware-in-the-loop setup. Such a testing provides significant benefits compared to simulation-only experiments. Using a digital real-time simulator for executing power system models in real time, the actual hardware controller can be tested including all kinds of communication interfaces and potential analogue signal measurements by interfacing it with the real-time simulator.

The final Stage 4, before actual field-testing and implementation, of the proposed testing chain approach is the integration of real physical power hardware controlled by the hardware controller. This combined controller-hardware-in-the-loop and power-hardware-in-the-loop is called power-system-in-the-loop and includes the controller as well as power devices like inverters, motors, etc. This technique is closest to a field test, which can be implemented in a laboratory, since it integrates real-time interactions between the hardware controller, the physical power component and the simulated power system test-case executed on the real-time simulators. Despite the high complexity to ensure stable, safe and accurate experiments, a power-system-in-the-loop setup enables an investigation, not as a single and separate entity, but as a holistic power system. This technique is proven to validate entire functionalities of real hardware controller, interdependencies and interactions between real power components in an entire flexible and repeatable laboratory environment.

<table>
<tr><td colspan="2">Test Objectives
Why is the test needed? What do we expect to find out? A short narrative of context and goals of the test.</td><td colspan="2">Purpose of Investigation (PoI)
The test purposes classified in terms of Characterization, Verification, or Validation.</td></tr>
<tr><td>Object under Investigation (OuI)
"the component(s) (1..n) that are to be qualified by the test"</td><td>Function(s) under Investigation (FuI)
"the referenced specification of a function realized (operationalized) by the object under investigation"</td><td rowspan="2">System under Test (SuT)
Systems, subsystems, components included in the test case or test setup.</td><td rowspan="2">Functions under Test (FuT)
Functions relevant to the operation of the system under test, including FuI and relevant interactions btw. OuI and SuT.</td></tr>
<tr><td colspan="2">Domain under Investigation (DuI):
"the relevant domains or sub-domains of test parameters and connectivity."</td></tr>
<tr><td colspan="4">Test criteria:
Formulation of criteria for each PoI based on properties of SuT; encompasses properties of test signals and output measures.</td></tr>
<tr><td>target metrics
Measures required to quantify each identified test criteria</td><td colspan="2">variability attributes
controllable or uncontrollable factors and the required variability; ref. to PoI.</td><td>quality attributes
threshold levels for test result quality as well as pass/fail criteria.</td></tr>
</table>

Documentation of test cases via canvas

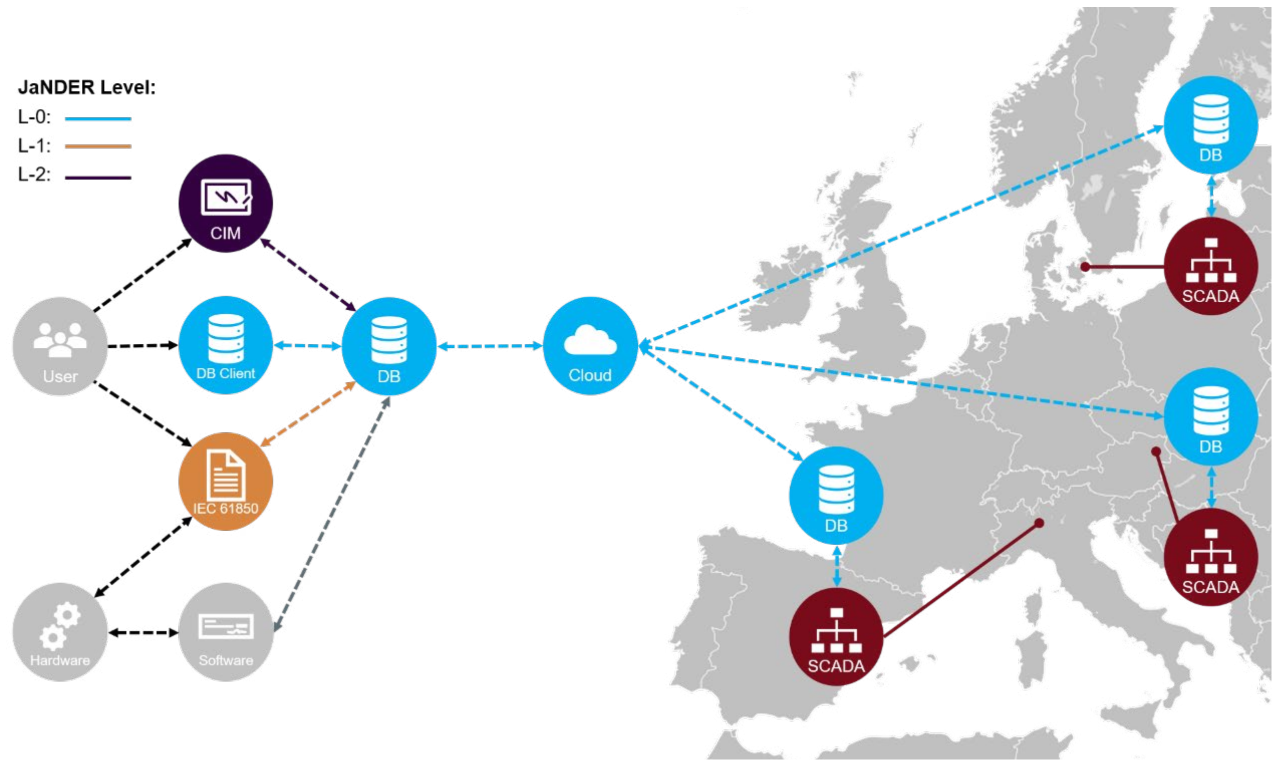


Test chain concept for smart grid systems validation

Overall, three different data sharing services are provided by JaNDER; i.e., (i) Level 1 (basis data sharing), (ii) Level 2 (IEC 61850-based communication, and (iii) Level 3 (CIM-based communication). For the common real time repository of shared data, a naming scheme for the different control commands and measurement signal has been provided as well.

For executing experiments on different stages in the above outlined test chain concept ERIGrid improved and extended several concepts and methods. The main work on simulation-based tools was on the coupling of domain-specific simulators in a co-simulation manner. The functional mock-up interface approach has been used for interfacing different power system and information and communication technology simulators. A further activity was to combine real-time simulation and hardware-in-the-loop for extended experimental possibilities. Also, hardware-in-the-loop based approaches have been improved (time-delay compensation, improved stability assessment, quasi static hardware-in-the-loop, etc.).

For the provision of a Pan-European smart grid research infrastructure ERIGrid developed an approach which allows the online coupling of the different laboratories of the partners called JaNDER. This multi-laboratory integration allows the realization of complex validation needs which probably cannot be implemented in a single laboratory. JaNDER is a cloud platform for the exchange of information (measurements, control signals, laboratory asset descriptions) between geographically distributed laboratories by using a secure internet connection and therefore mainly concepts the automation and supervisory control of the different laboratories.



Overview of the JaNDER architecture

Details about the ERIGrid methods and tools are provided in the corresponding deliverables and the open access ERIGrid guide for power system testing. ERIGrid methods and tools are also provided in an open access manner and can be accessed via the project website: erigrid.eu/dissemination#open-access-tools.

Smart Grid Technologies Laboratory of TECNALIA

EXPERIENCES AND LESSONS LEARNED

The ERIGrid holistic validation approach has been broadly used for different project-internal validation activities, by several user groups to prepare and document the testing and validation work in the used laboratories but also in a couple of other national and European projects.

Overall, it was highlighted by all the users of the holistic validation approach how the methodology promotes clarity and order when planning the experiments and helps also in the standardization of procedures between different laboratories, fostering the collaboration possibilities between different facilities. However, it turned out that there is complexity of the process and difficulty in understanding the involved concepts and definitions. The main steps in the future development of the approach must be oriented to enhance the clarity of the concepts and to simplify the templates and documentation. Furthermore, an adoption of the validation approach to cover broader power and energy systems topics is also a future necessity to cope with future needs.

FREE ACCESS TO POWER SYSTEM AND SMART GRID LABORATORIES

D-NAP laboratory of the University of Strathclyde

One of the core aims of ERIGrid was to provide system level validation methods and tools – which have been integrated into the partners' laboratories – to external researchers, engineers and students. Overall, the project has realized six open calls for the so-called "trans-national access user projects" where 97 submissions have been received. All those proposals have been carefully evaluated by around 55 independent experts from the domain, and finally 73 projects with 175 users have been implemented in the ERIGrid laboratories.

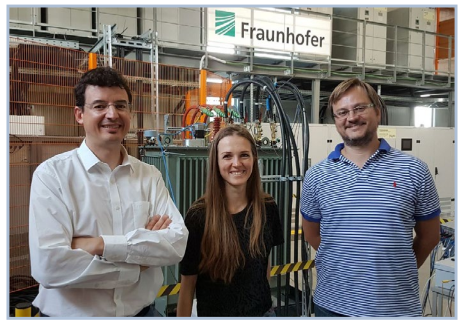
Around 1,000 access days (i.e., days of using the ERIGrid laboratories) have been provided to the users. The covered topics of all the implemented Trans-national Access (TA) user projects had a wide range of activities, which can be summarized as:

- Distributed energy resource and power system components characterization and evaluation,
- Testing of control concepts for power distribution operation,
- Microgrid controller testing,
- Analysis of the interaction of power and ICT systems in a smart grid context,
- Smart grid ICT/automation component validation, and
- Analysis of power electronic-based units covering the power and the controller part.

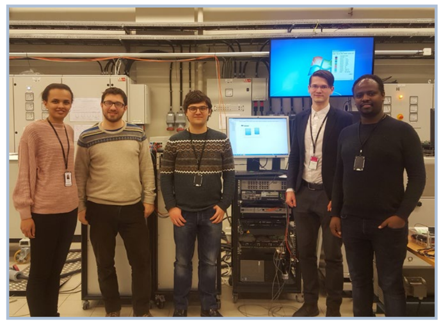
73
user projects from all over the world gained lab access

175
engineers accessed best labs of Europe free of charge

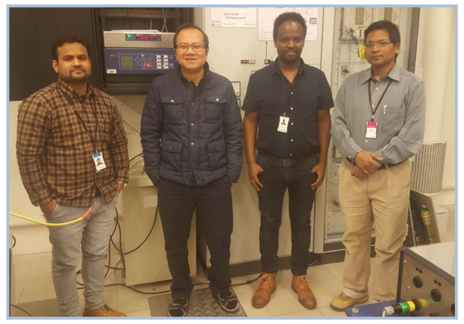
20
had companies involved

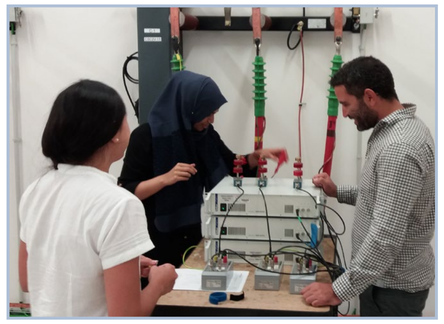


4
multi-side projects (involving more than one laboratory)



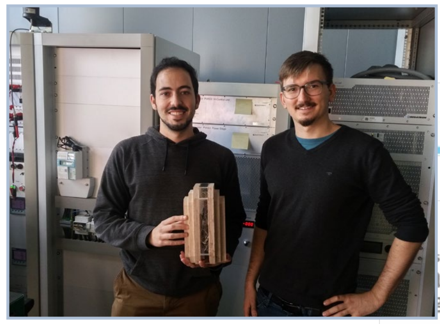
1,000
for over 1,000 days collectively ERIGrid labs were in use



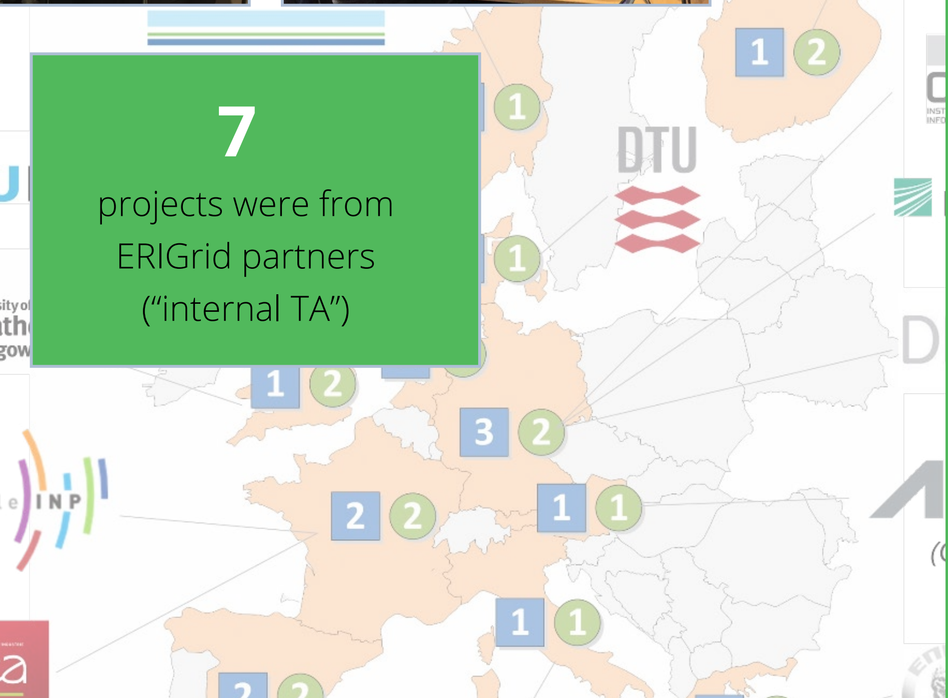


14
projects came from outside Europe

14
projects were led by companies



7
projects were from ERIGrid partners ("internal TA")



IMPACT

The ERIGrid access programme worked very well and supported a lot of different user groups in their research and development work which would have not been possible for them due to missing laboratory infrastructures in their institutions. The usage of the ERIGrid system-level validation concepts and corresponding tools was very helpful for the realization of the user projects. A good preparation of the experiments is crucial for an effective lab work during the access period, optimizing the available budget and lab time: it turned out that the holistic validation procedure, developed by the ERIGrid consortium, was very helpful during the preparation phase of those projects (i.e., for the interaction and discussion of technical details between the user group and the hosting laboratory).

SUCCESS STORIES

The TA programme of ERIGrid has supported numerous research initiatives. The outcomes of TA user projects and success stories listed below are publicly available at the project website: erigrid.eu/ta-success-stories.

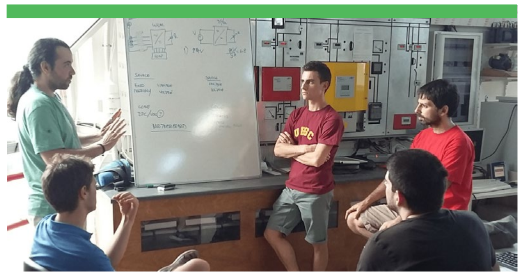
ECONOMIC ASSESSMENT FRAMEWORK FOR MICROGRIDS

Investigating the comparability of microgrids, the ECOSMIC user group worked with comparable set-ups in life-like 24h-loops for experiments in islanded and grid-connected modes at four locations during their TA stays. As a result, they developed a robust case study of residential microgrids, replicated across Europe under life-like conditions.

ENHANCING THE RENEWABLE ENERGY HOSTING CAPACITY OF DISTRIBUTION NETWORKS BY COORDINATED CONTROL

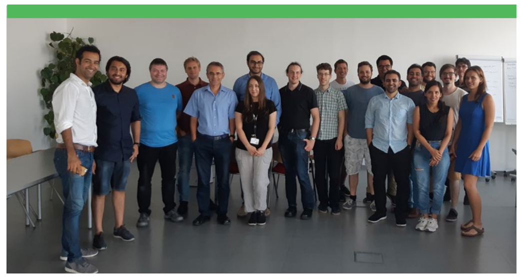
The HOLISTICA project has been the first to physically test an innovative proposal of coordinated transformer tap and reactive control algorithms for the holistic technical management of the LV cell, proposing the MV/LV transformer substation as a control and communication hub for the distribution grid.

ELECTRIFICATION FOR RURAL AREAS AND DEVELOPING COUNTRIES



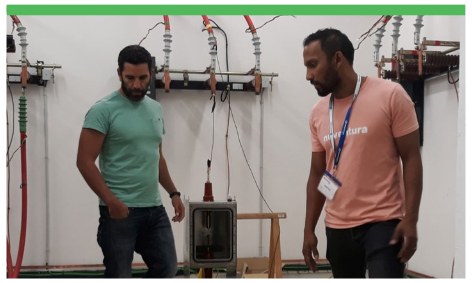
The main obstacle to an affordable and sustainable rural electrification is the lack of power electronics technology compatible with unforeseeable changes in either energy production or load profile. SPEARHEAD's work focused on the use of modular power electronics systems as a means to solve this problem.

OPTIMISING PV INVERTER AND DISTRIBUTION TRANSFORMER OPERATION



As a result of their TA experimental research, the TIPI-GRID team came up with a number of practical recommendations for grid operators underpinning the results from pure simulation studies for the optimised PV inverters Q(U) operation.

ENABLING A CLEANER DIGITAL DISTRIBUTION GRID

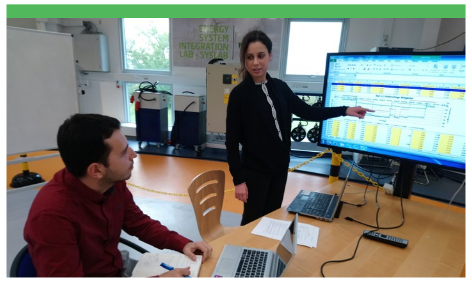


TA project LCA, dedicated to the validation of sensors for smart grid applications in real conditions, horoughly tested the suitability of non-conventional sensor technology for use within their medium voltage gas insulated switchgear.

NETWORKED FEEDBACK CONTROL OF DER FOR REAL-TIME VOLTAGE REGULATION

TA project TEAM-VAR2 experimentally analysed whether networked control approaches, that use the reactive power capabilities of inverters in distribution grids, are practically able to solve these over- and under-voltage problems.

DISTRIBUTION-LEVEL DEMAND RESPONSE USING DOMESTIC APPLIANCES

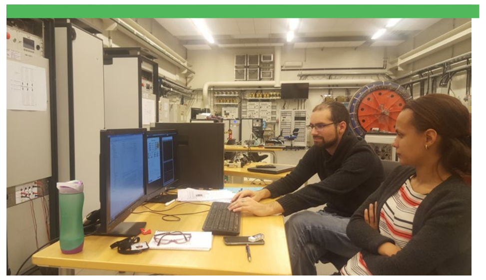


The DiNODR project dealt with developing distribution network centered demand response (DR) approaches, investigating distribution network threatening cases in wholesale market-driven DR applications and designing integrated programs comprising local level and utility level DR solutions.

OPTIMAL CONTROL ALGORITHMS FOR SMART BUILDINGS

The DAMS4IRMA user group tested, validated and analysed the impacts of different control-oriented models of the air-to-water heat pump on the coefficient of performance prediction, especially for the formulation of optimal control problem in presence of variable electricity prices, variable outdoor conditions and variable loads.

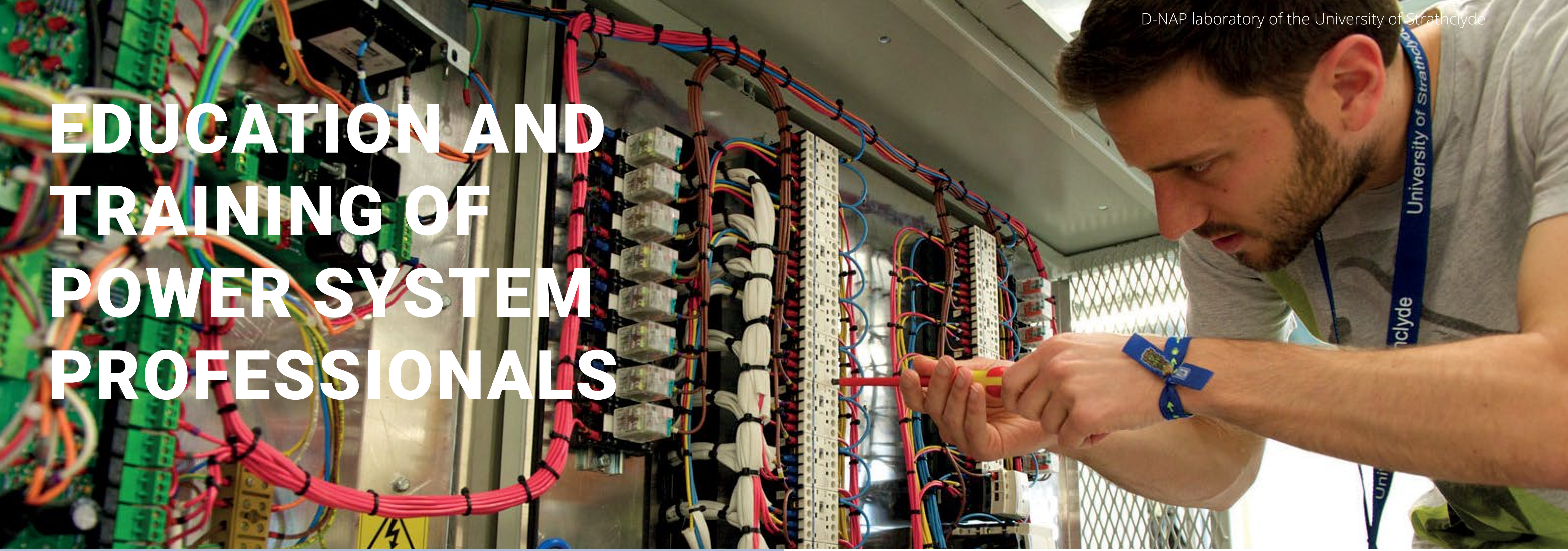
TRANSIENT CONTROL IN MICROGRIDS



The team of the TA user project TCMG developed a new optimisation method for transient control of networks with a large amount of photovoltaics (PV). The method makes it possible to control all inverters for the PV-system simultaneously.

EVALUATION OF DATA LOGGER TECHNOLOGIES FOR SMALL LOCALLY MANUFACTURED WIND TURBINES

The Eval Loggers user group evaluated different data logger technology and data processing techniques for field testing of small locally manufactured wind turbines.



D-NAP laboratory of the University of Strathclyde

EDUCATION AND TRAINING OF POWER SYSTEM PROFESSIONALS

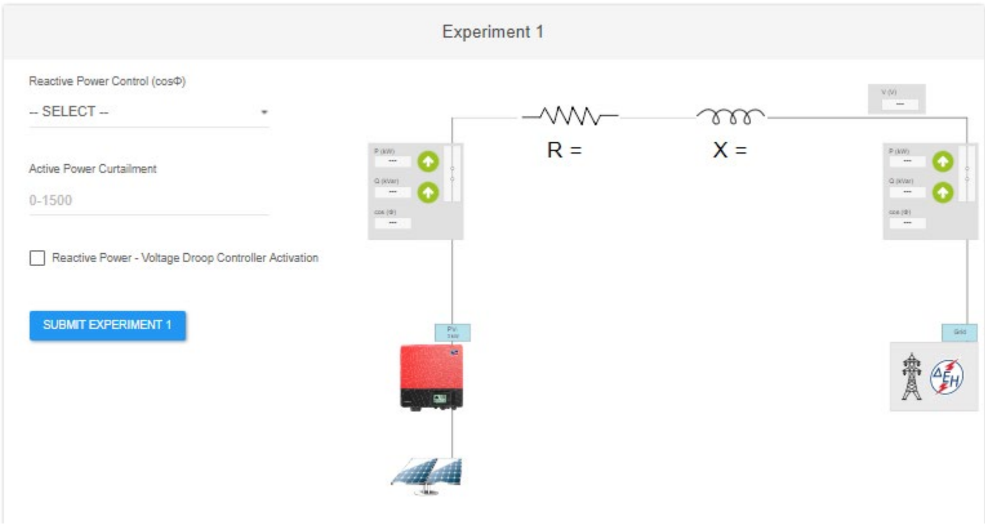
A need for new skills and expertise to foster the energy transition has risen, considering the increased complexity of smart grids. Tackling the contemporary significant challenges requires a skilled workforce and researchers with systemic/holistic thinking and problem-solving skills. At the same time, technological advances can revolutionise education by allowing the use of new technical tools.

Due to the increased complexity of smart grids, current and future engineers and researchers should have a broad understanding of topics of different domains, such as electric power, heat and definitely ICT related topics. Therefore, ERIGrid developed a comprehensive set of training material/activities for high school and university students, (young) researchers, and professionals. In this framework, e-learning tools and hands-on laboratory exercises dealing with important aspects of smart grids and distributed energy resources have been developed. These include the delivery of six webinars (on co-simulation, co-simulation with real-time simulation, hardware-in-the-loop simulation, information and communication technology standards for smart grids, holistic validation approach, multi RI/laboratory-based testing), the development of software tools (on co-simulation, interactive Jupyter notebooks, cyber-resilience tool, etc.), the organization of five training schools, and the creation of several presentations for teaching.

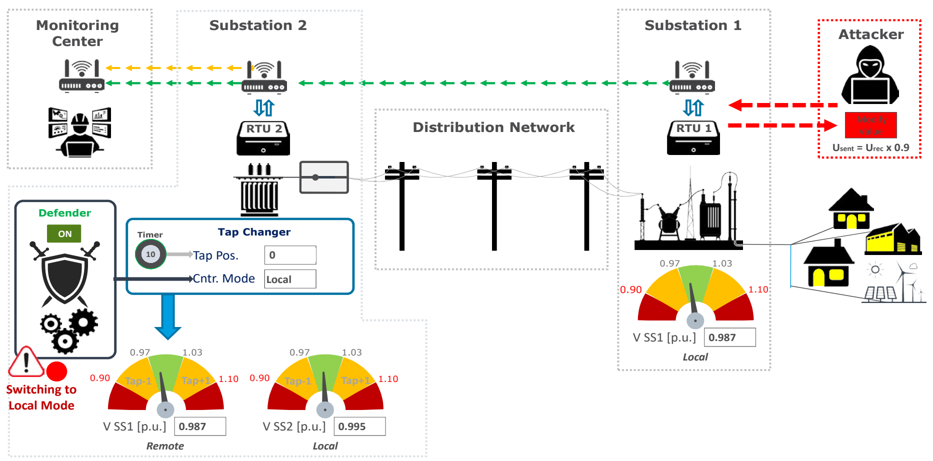
OVERVIEW OF DEVELOPMENTS

The developed education material and corresponding tools are publicly available at the project website to promote their use and replicability.

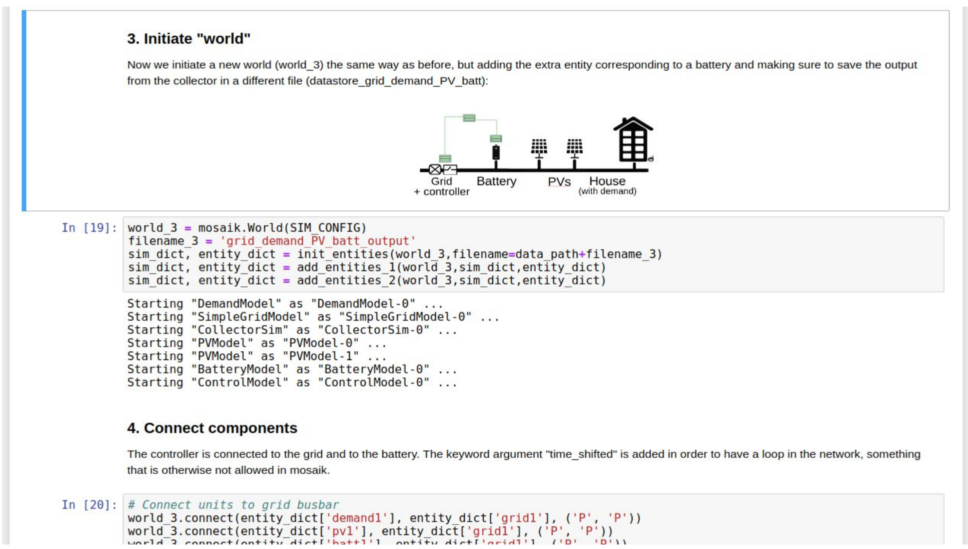
Summarizing, ERIGrid developed over 20 various educational resources, including software and programming tools, remote access to labs, lab exercises, webinars, course materials and other e-learning materials. Over 450 students have already applied ERIGrid exercises, tools, and other resources in their Master or PhD courses and theses. With over 15 educational events, including workshops, tutorials and schools, ERIGrid reached nearly 450 participants who highly appreciated the innovative lab sessions and the impact on their work and/or thesis. Also, around ERIGrid 300 real-time webinar participants have been reached with the above-mentioned webinars. Finally, ERIGrid granted to over 200 researchers, PhD students and young professionals, free access to world-class smart grids laboratories funded through the TA programme.



Remote lab for voltage control experiments



Cyber-resilience tool explaining the impact of cyber attacks



Interactive Jupyter notebooks

ERIGrid Summer School, Athens (GR), June 2019

IMPACT

Most notably, the learners gain remote access to advanced laboratory infrastructures allowing to control equipment and monitor variables (i.e., remote labs). In addition, hands-on laboratory exercises are reported focusing on real-time simulation. Real-time power-hardware-in-the-loop simulation was used for the first time for power engineering education on the important topic of distributed energy resource integration, which was appreciated by the students as shown from questionnaire statistics. Finally, educational activities targeting the younger generations are suitable to disseminate the advantages of the smart grid and can increase the interest in pursuing a distributed energy resource engineering-related career path.

ACHIEVEMENTS AND PROSPECTS

Smart Grid Technologies Laboratory of TECNALIA

The expected large-scale roll out of smart grid products and solutions during the next few years requires a multi-disciplinary understanding of several domains. The validation of such complex solutions gets more important than in the past. There is a clear shift from component-level to system-level testing. An integrated, cyber-physical systems-based, multi-domain approach for a holistic testing of smart grid solutions was missing and is now specifically addressed by ERIGrid.

Four research priorities have been successfully identified and tackled in this Pan-European project to overcome the shortcomings in today's validation and testing of power systems and corresponding components. The research focus was put onto the development of a holistic validation methodology and the improvement of simulation-based methods, hardware-in-the-loop approaches, and lab-based testing, which can be combined in a flexible manner. Furthermore, the integration and online connection of power systems/smart grid laboratories provides additional possibilities for the analysis and evaluation in ERIGrid. All these activities had to be supported by the development of training and education material for researchers and power system professionals.

Summarizing, with all the achievements and results in the ERIGrid project powerful methods, concepts, and corresponding tools have been developed which allow a comprehensive testing of smart grid solutions. However, mainly the domains of power systems and information and communication technology have been addressed by ERIGrid.

The provision of engineering and validation support will be critical for the successful development of future smart grid applications and solutions. Without the proper tool support many of the tasks will require immense manual efforts and engineers educated in multiple domains (energy system physics, information and communication technology, automation and control, cyber-security, etc.).

The ERIGrid results provide a step forwards in the right direction, but more research efforts are still needed in the upcoming years to cope with new trends and corresponding requirements. Especially the integration of the electric power system with other domains (thermal, gas, water/waste water, transportation etc.) into a smart energy system requires additional efforts which are:

- Advanced RIs need to be developed which focus on the integration of different power and energy systems related areas (market issues, thermal topics, electric vehicles, etc.),
- A simplified access and corresponding services (facilitate future access by remote operation and coupling of both virtual and physical laboratories, etc.) to smart grid, smart energy systems, and renewables related RIs addressing challenging user needs is required,
- Domain-specific adaptations of previously developed abstract validation procedures and corresponding concepts, methods, and tools are required to address advanced applications (low-inertia grids, microgrids, hybrid grids, etc.),
- Common and well understood reference scenarios, use cases, and test case profiles for smart energy systems need to be provided to power and energy systems engineers and researchers; also, proper validation benchmark criteria and key performance indicators as well as interoperability measures for validating smart grids and smart energy systems need to be developed, extended, and publicly shared with domain professionals,
- A standardization of multi-domain evaluation and testing procedures is necessary,
- Well-educated professionals, engineers, and researchers understanding smart grid and smart energy systems configurations in a multi-domain and cyber-physical manner addressing the upcoming energy transition need to be educated and trained on a broad scale.

These open research and development issues are tackled by the successor project ERIGrid 2.0 which will be executed during the next years. It is planned to provide additional open access to numerous results of this project for all power and energy systems professionals.

SYSLAB bus bar, PowerLabDK

SELECTED RESULTS

D-NAP laboratory of the University of Strathclyde

non-exhaustive list, please find more at erigrid.eu

PUBLICATIONS

T. Strasser, E.C.W. de Jong, M. Sosnina, M. (Eds), European Guide to Power System Testing: The ERIGrid Holistic Approach for Evaluating Complex Smart Grid Configurations, Springer International Publishing AG: Basel, Switzerland: 2020. doi:10.1007/978-3-030-42274-5.

J. Montoya, R. Brandl, K. Vishwanath, J. Johnson, et. al, Advanced Laboratory Testing Methods Using Real-Time Simulation and Hardware-in-the-Loop Techniques: A Survey of Smart Grid International Research Facility Network Activities, Energies, vol. 13, no. 3267, 2020.

M. Uslar, S. Rohjans, C. Neureiter, F. Pröstl Andrén, et al., Applying the Smart Grid Architecture Model for Designing and Validating System-of-Systems in the Power and Energy Domain: A European Perspective, Energies, vol. 12, no. 1:258, 2019. doi:10.3390/en12020258. doi:10.3390/en13123267.

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C. Steinbrink, A.A. van der Meer, M. Cvetkovic, D. Babazadeh, et al., Smart grid co-simulation with MOSAIK and HLA: a comparison study, Computer Science – Research and Development, pp. 1-9, 2017, doi:10.1007/s00450-017-0379-y.

M. Maniatopoulos, D. Lagos, P. Kotsampopoulos, N. Hatziargyriou, Combined control and power hardware in-the-loop simulation for testing smart grid control algorithms, IET Generation, Transmission & Distribution, vol. 11, no. 12, pp. 3009-3018, Sept. 2017, doi:10.1049/iet-gtd.2016.1341.

DELIVERABLES

Deliverable 4.3: D-NA4.2a Training/education material and organization of webinars

Deliverable 5.1: D-NA5.1 Smart Grid configuration validation scenario description method

Deliverable 5.2: D-NA5.2 Partner profiles

Deliverable 7.1: D-JRA1.1 ERIGrid scenario descriptions

Deliverable 7.2: D-JRA1.2 Focal use case collection

Deliverable 8.1: D-JRA2.1 Simulator coupling and Smart Grid libraries

Deliverable 8.2: D-JRA2.2 Smart Grid ICT assessment method

Deliverable 8.3: D-JRA2.3 Smart Grid simulation environment

OPEN ACCESS TOOLS

Holistic Test Description (HTD): Templates and guidelines relating to the ERIGrid Holistic Test Description (HTD).

Research Infrastructure (RI) database schema: SchemaSpy description of the RI database defined in Deliverable D-NA5.2 Partner profiles.

JaNDER Level 1 access: Small interfacing layer between the openIEC61850 library and Redis database

Local JaNDER database to cloud replication: Small command line program to replicate remotely the commands sent to a local Redis instance

ns-3 FMI Export Module: fmi-export enables the FMI-compliant simulation coupling with ns-3 scripts.

FMI++: The FMI++ library intends to bridge the gap between the basic FMI specifications and the typical requirements of simulation tools (partly extended in ERIGrid)

FMITerminalBlock: Two-way interface between the Functional Mockup Interface (FMI) and IEC 61499-based controllers (partly extended in ERIGrid)

mosaic: Flexible smart grid co-simulation framework (partly extended in ERIGrid)

EDUCATION AND TRAINING MATERIAL

ERIGrid Spring School: Introduction to Real Time Simulation Environment and Application in Sustainable Energy Systems

ERIGrid 1st Winter School: Metrology for Smart Grids and Testing

ERIGrid Workshop: Advanced power system testing using HIL simulation

ERIGrid/CINELDI Workshop Smart Grid Laboratory Developments

ERIGrid Summer School "Advanced operation and control of active distribution networks"

A. Monti, F. Ponci, M. Cupelli, T. Strasser, "Tutorial Methods and Tools for Validating Cyber-Physical Energy Systems", 44th Annual Conference of the IEEE Industrial Electronics Society (IECON), Washington DC, USA, 2018

T. Strasser, "Tutorial Concepts, Methods, and Tools for Validating Cyber-Physical Energy Systems", 2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC), Miyazaki, Japan, 2018

T. Strasser, "Tutorial Methods and Tools for Validating Cyber-Physical Energy Systems", IEEE 16th International Conference on Industrial Informatics (INDIN), Porto, Portugal, 2018

Publication date: June 2020
Cover image: AIT

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