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

Work Package 4

NA4 - Training/Education of Power Systems and ICT Professionals, (Young) Researchers, Students and Staff Exchange

Deliverable D4.4

D-NA4.2b: Training/education material and organization of webinars

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Abbreviations

API	Application Programming Interface
CHIL	Control Hardware-in-the-Loop
CPES	Cyber Physical Energy Systems
CVC	Coordinated Voltage Control
DER	Distributed Energy Resource
DG	Distributed Generation
DRTS	Digital Real-Time Simulator
DT	Digital Twin
EESL	Electric Energy Systems Laboratory
FMI	Functional Mock-up Interface
FMU	Functional Mock-up Unit
GUI	Graphical User Interface
HIL	Hardware-in-the-Loop
HTD	Holistic Test Description
HVDC	High Voltage Direct Current
ICT	Information and Communication Technologies
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
JRA	Joint Research Activity
MPPT	Maximum Power Point Tracking
OLTC	On-Load-Tap-Changer
PHIL	Power Hardware-in-the-Loop
PMU	Phasor Measurement Unit
PV	Photovoltaic
RT	Real Time
RTU	Remote Terminal Unit
STEM	Science, Technology, Engineering and Mathematics
TA	Transnational Access
TCP	Transmission Control Protocol
VPP	Virtual Power Plant
WP	Work Package

Executive Summary

This document gives an overview of the educational and training material developed throughout ERIGrid project and reports on those developed during the current reporting period. Educational and training needs addressing the higher complexity of intelligent energy systems, were identified. The developed material/activities target university students, young researchers, professionals and high school students. In this framework, e-learning tools dealing with important aspects of smart grids and distributed energy resources have been developed. These include the delivery of six webinars in total (e.g., on co-simulation, Hardware-In-the-Loop simulation, holistic testing), the development of software tools (e.g., on co-simulation, cyber resilience, interactive notebooks) and the creation of several presentations.

Most notably, the learners have the chance to understand how co-simulation across various domains is now a necessity due to the complexity of modern power systems. In addition, they familiarize with state-of-the-art approaches and procedures for testing and validation, based on the definition of a generic scenario and the generation of reproducible results. Furthermore, the advantages of the interconnection of different research infrastructures via a communication platform to exchange data in real-time, are highlighted. Special focus is given on cyber security issues, that have risen in recent years, and on their impact on modern power systems. Also, defence actions against cyber-attacks are showcased. For that purpose, an educational tool with a user-friendly Graphical User Interface, was developed. Additional interactive (Jupyter) notebooks were developed on relevant topics. Finally, educational activities targeting the younger generations are presented to disseminate the advantages of the smart grid and increase the interest in pursuing a smart grid engineering-related career path.

The developed material and tools are publicly available at the dedicated section of the ERIGrid website in order to allow efficient use and foster the replicability of the approaches. The material is strongly linked with the JRA 2 (co-simulation) and JRA 3 (real-time simulation) activities of the ERIGrid project. This deliverable is a continuation of the previous deliverable (i.e., D4.3) and reports the educational material developed during the project months 37-54.

1 Introduction

1.1 Purpose of the Document

The rapidly changing landscape in the power and energy sector – aiming to foster the energy transition – rises the need for appropriate education and training of the future and current workforce. Tackling the contemporary significant challenges requires a skilled workforce and students with problem solving skills and out of the box thinking. Technological advances already available today can revolutionise education by making use of e-learning and new technical tools. This affects the education and training of university students, but also young researchers, professionals and school students.

In this context, the work described in this document and the available material at the corresponding section on the ERIGrid website (*https://erigrid.eu/education-training/*) aim to:

- Improve the existing education practices by making use of the tools, procedures and methodologies developed in the ERIGrid project.
- Enrich the academic curriculums with new tools and methods.
- Guide and support early stage researchers on their first research steps.
- Support and enhance the thorough understanding of Distributed Energy Resource (DER) and smart grid related topics by power system and Information and Communication Technology (ICT) professionals.
- Inspire school students to pursue a smart grid related education and career path and to promote environmental awareness at an early stage.
- Promote replicability of the developed tools and methods.

A variety of educational tools and approaches are presented, including state-of the art tools such as Hardware-in-the-Loop (HIL) simulation, co-simulation and Holistic Test Description (HTD) for validation, combined with appropriate educational methods.

1.2 Scope of the Document

Traditional power systems education and training is flanked by the demand for coping with the rising complexity of energy systems, such as the integration of renewable and distributed generation, the need for automation, ICT, cyber security etc [1]. A broad understanding of these topics by current/future researchers and engineers is becoming more and more necessary. In this deliverable education and training possibilities as well as necessary tools are presented, focusing on e-learning approaches. In this context, experiments and experiences of using co-simulation, next-generation notebooks, HIL methods, interconnection of research infrastructures are presented, among others.

1.3 Structure of the Document

An overview of the ERIGrid's impact on transforming the education on power system testing is presented in Section 2. Section 3 explains the value of the used e-learning approaches. Section 4 describes the e-learning material developed in the framework of the project, including statistics from the project's website. Additional educational activities targeting mainly high school students are reported in Section 5. Section 6 provides the main conclusions of this work.

2 ERIGrid Transforming Education on Power System Testing

New smart energy era calls for new approaches in education and training. Addressing the rising complexity of intelligent energy systems [1], the ERIGrid consortium has developed a variety of state-of-the-art materials and tools for students, researchers and other professionals in the ICT and power system domain. All of the resources are open-access, and ERIGrid encourages their use and reproduction.

Right from the start of the project, the ERIGrid consortium was committed to knowledge transfer from within the project, providing open access to the project developments and promoting their extensive application. With the aim to support education in the power system testing domain, the project addressed the rising complexity of the subject with cutting-edge technologies and approaches. For example, it was in the framework of ERIGrid that Power Hardware-In-the-Loop (PHIL) simulation was used for educational purposes in a systematic way for the first time [4]. Another example of utilising modern technologies for education is ERIGrid's remote laboratories applications (voltage control, microgrids and Virtual Power Plants (VPPs) and Microgrid balancing) that allow users to experience real-lab conditions through online access to an actual laboratory.

Presented in an adequate way in the educational section of the website, all the developed resources span over the following topics:

- Co-simulation
- Real-time simulation
- Smart grid validation
- Remote/ICT labs

The resulting materials aim to help students, recent graduates and young professional engineers to bridge the gap between theory and application by working with a variety of state-of-the-art tools. Users were encouraged to share this material with their peers, fellow students, and colleagues, and use the materials in their research and work. In Table 1, a list with the overall numbers of the developed resources and the impacted people, can be found.

Table 1: Impact of ERIGrid educational activities, in numbers

Overview	***No.***	***Description***
Developed Resources	20	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.
Impacted Students	500	ERIGrid educational resources are already successfully used at several universities. Over 500 students have already applied ERIGrid exercises, tools, and other resources in their Master or PhD courses and theses.
Workshop Participants	460	With over 15 educational events, including workshops, tutorials and training schools, ERIGrid reached nearly 460 participants who highly appreciated the innovative lab sessions and the impact on their work and/or thesis.
Webinar Participants	295	Having organised 6 webinars, ERIGrid shared project solutions to nearly 300 real-time webinar participants. The webinars covered a range of topics: OpSim test and simulation environment, Power-Hardware-in-the-Loop simulation, ICT standards, co-simulation, ERIGrid HTD for validating cyber-physical energy systems, and multi-lab integration tests. All webinar recordings are likewise available in the educational section of the website.

Strong focus on practical aspects on top of the underlying theory and applying cutting-edge technologies and tools are key elements of ERIGrid's educational approach. By using modern technological advances and advanced educational methodologies, ERIGrid aims to transform the education of young researchers, professionals, and university students in power system engineering.

3 Value of E-Learning Approaches

3.1 Webinars

The use of webinars (i.e., web seminars) as an e-learning environment is receiving more and more attention [2], [3]. The possibility of addressing large audiences, conducting live exercises/experiments to engage with the audience and interacting with the presenters through questions and answers, render webinars a valuable educational tool. Moreover, the activity presented at the webinar is typically recorded and distributed to the participants and made publicly available through video sharing platforms for later viewings at the learner's own pace. In this way a larger audience than the initial participants are able to benefit from the webinar.

In the contemporary cyber-physical environment, when the learning topics are related to the introduction of complex methods and tools (e.g., advanced testing and simulation), the webinar is an efficient option to achieve the learning objectives. For example, cases in which a webinar was found to be an effective learning environment are:

1. Introduction to a new software tool, where the participants have no previous experience.
2. Performance of live demonstrations of simulations and also laboratory tests.
3. Understanding co-simulation possibilities for cyber-physical systems.

It should be noted that feedback from the webinar participants can be easily obtained and analysed in order to improve the learning process.

3.2 Software Tools and Remote Laboratories

A need for new skills and expertise to foster the energy transition has risen, considering the increased complexity of cyber-physical energy systems. Students and young researchers need to develop critical and problem-solving thinking in combination with practical experience in order to deal with the complex and multi-domain issues of smart grids. This can be achieved with the introduction of software tools and laboratory education in the learning process. At the same time, technological advances can revolutionise education by allowing the use of new technical tools. All these parameters lead to the new era of learning in which software tools, hands-on experience and laboratory education play a fundamental role in the process of teaching and learning [1], [4].

Given the cross-disciplinary nature of intelligent power and energy systems, students should be exposed to a wide range of concepts related to different domains. This can be achieved with the use of software tools, capable of bringing the knowledge of different domains together. Also, software tools and simulations play an important role in the design, analysis and testing process of new solutions, stages of outmost important for the development of new technologies. Furthermore, the use of software tools, equip the learners with technical skills important for their future carrier. Besides the abovementioned, educational software enhances the learning process itself by making it more interesting and interactive while at the same time intrigues the curiosity of the learners and captures their attention. Finally, it allows distant e-learning and reduces the dependency on the lecturer.

On the other hand, laboratory education provides a link between theory and real world offering valuable practical experience to students. For that reason and because many students and young researchers may not have access to state-of-the-art laboratories and facilities, remote labs are gaining significant attention for educational purposes, as they allow the user to connect remotely to actual laboratory infrastructure, obtain measurements and control devices.

4 E-Learning Material

In this section, firstly an overview of the e-learning material developed in the framework of ERIGrid is given, and secondly only the material developed during this reporting period is presented in more detail. The different types of the e-learning material include:

- Webinars
- Software tools
- Remote laboratories
- Presentations

4.1 Overview

A summary of the e-learning material developed in the framework of ERIGrid, is given in the following Tables. More specifically, in Table 2 and Table 3 a list of the organized webinars and their participation statistics, is given. In Table 5 and Table 6, a list with the developed software tools is presented. In Table 7 a list of Remote Laboratories developed during the previous reporting period is given. Finally, in Table 8 and Table 9 presentations with educational/training content from previous and current reporting periods, are listed. A more detailed description of the various e-learning material developed during the current reporting period, is given in the subsequent section.

Table 2: List of Webinars from previous reporting period and participation statistics

No.	***Webinar Name***	***No. Registered Persons***	***No. of Attended Persons***	***Attendance Rate***	***No. of Project External Persons***	***External Attendance Rate****	***Views on YouTube*** *(20/04/2020)*
1	*Co-simulation with real-time simulation using OpSim*	35	32	91%	1	3%	-
2	*PHIL simulation for DER and smart grids: best practices and experiences from the ERIGrid project*	88	59	67%	33	56%	624
3	*ICT standards for smart grids: IEC 61850, CIM and their implementation in the ERIGrid project*	119	76	64%	45	59%	1113

Table 3: List of Webinars for current reporting period and participation statistics

No.	***Webinar Name***	***No. Registered Persons***	***No. of Attended Persons***	***Attendance Rate***	***No. of Project External Persons***	***External Attendance Rate****	***Views on YouTube*** *(20/4/2020)*
4	*Co-Simulation based Assessment Methods*	154	51	33%	41	80%	247
5	*Holistic Test Description for*	87	41	47%	27	66%	161

No.	Webinar Name	No. Registered Persons	No. of Attended Persons	Attendance Rate	No. of Project External Persons	External Attendance Rate*	Views on YouTube (20/4/2020)
	Validating Cyber-Physical Energy Systems						
6	*Demonstration of Multi Research Infrastructure Integration Tests*	79	36	46%	25	69%	55

* (of those attended %)

In Table 4, the summary of the attended persons, project external persons and the total number of views on YouTube, for all the 6 webinars are reported.

Table 4: Summary of participation statistics regarding Webinars (previous and current reporting period)

Webinars	No. of Attended Persons	No. of Project External Persons	Views on YouTube (20/4/2020)
Sum	295	172	2200

Table 5: List of Software Tools developed during previous reporting period

No.	Software Tool	Description	Partner-Developer
1	*Virtual Laboratory for Voltage Control and Microgrid Operation*	The Virtual Lab is an online educational simulation tool that mimics the operation of an actual laboratory microgrid. A mathematical model of the laboratory microgrid has been developed along with a friendly Graphical User Interface (GUI).	ICCS-NTUA
2	*Mosaik-Based Co-simulation*	The mosaik co-simulation framework has been developed to provide researchers with an easy-to-use yet powerful tool for simulation-based testing.	OFFIS
3	*Functional Mock-up Unit (FMU)-as-a-Service Approach*	The Functional Mock-up Interface (FMI) is a standard in co-simulation that allows interoperability among models from different domains, in terms of code. The FMI encloses the dynamic model and generates compiled C code (the Functional Mock-up Unit (FMU)), which can be integrated to other environments as a black box.	GINP, CEA
4	*Jupyter Notebooks (Minimizing the need for programming skills)*	Jupyter notebooks are a merge between a standard text book and what real programming in python looks like.	
	4.1 Home Energy Management System Scenario Build Up	This Jupyter notebook introduces how to build up a Home Energy Management System (HEMS) simulation scenario using mosaik for co-simulation. The notebook introduces gradually more complexity to the simulation.	DTU
	4.2 DoE Exercises	This file contains a series of notebooks showing examples of Design of Experiments (DoE). They use the HEMS simulation in mosaik as a test case and showcase simple and advanced DoE concepts (e.g. meta-modelling using non-parametric methods).	DTU

Table 6: List of Software Tools developed during current reporting period

No.	Software Tool	Description	Partner-Developer
	4.3 Mosaik Jupyter Notebook demos	A set of Jupyter Notebooks that gradually set up a more and more complex power system co-simulation.	OFFIS
5	*Cyber-Resilience Tool*	The Cyber-Resilience Tool is an educational tool to demonstrate how cyber vulnerabilities could affect an electrical distribution grid. It also shows a possible defensive action against cyber-attacks. The tool has a GUI with which the users can perform certain attacks and investigate their impact on the system.	OFFIS

Table 7: List of Remote Laboratories developed during previous reporting period

No.	Remote Laboratory	Accessed-Laboratory
1	*Voltage Control, Microgrids and Virtual Power Plants*	ICCS-NTUA
2	*Microgrid Balancing*	CRES

Table 8: List of Presentations with educational/training content from previous reporting period

No.	Title	Partner-Presenter
	Topic: Metrology for smart grids and testing	
1	The impact of power quality on measurements	UST
2	How accurate is a measurement?	UST
3	An introduction to measurement uncertainty	*NPL*
4	Uncertainties in modelling	*NPL*
5	Adaptive-window PMU algorithms using cascaded boxcar filters to meet and exceed C37.118.1(A) requirements	UST
6	PMU (algorithm) testing to C37.118.1(A) in software	UST
	Topic: Co-simulation for smart grids	
7	FMI – Functional Mock-up Interface. Specification and Applications	AIT
8	Mosaik introduction	OFFIS
	Topic: Holistic Testing	
9	How to Formulate a Test Specification	DTU
10	ERIGrid Test Description Templates	DTU
	Topic: Photovoltaic Systems	
11	Autonomous and Grid-connected Photovoltaic Systems Modelling for Simulation Purposes	CRES
12	Overview of methods for Maximum Power Point Tracking (MPPT) in PVs	CRES
13	Overview of methods for HW Simulation for PVs	CRES

Table 9: List of Presentations with educational/training content for current reporting period

No.	Title	Partner-Presenter
Topic: Advanced power system testing using HIL simulation		
14	CHIL and PHIL simulation: key features and applications	ICCS-NTUA
15	HIL testing of adaptive protection in distribution grids	ICCS-NTUA
16	DER inverter development and testing using HIL simulation	ICCS-NTUA
17	Voltage control in distribution networks with high DER integration: HIL experiences	ICCS-NTUA
18	Islanding detection and seamless transition through operation modes in microgrids: HIL experiences	ICCS-NTUA
19	Distributed control applications using Virtual Power Plants	ICCS-NTUA
Topic: Smart Grid Laboratory Developments		
20	Introducing co-simulation concept and platforms	TUD
21	Integration of HIL to co-simulation	IEE
22	Laboratory demonstrations	SINTEF
23	Development and testing of resilience grid automation using RT sim.	OFFIS

4.2 Webinars

In the framework of the ERIGrid project six webinars have been delivered. In the following paragraphs, a description of each webinar held in this reporting period, is given.

Link to the ERIGrid website: https://erigrid.eu/education-training/#webinars

4.2.1 Co-Simulation based Assessment Methods

The fourth webinar took place on 9th April 2019. It was co-organised by TUD, AIT, DTU, CEA and OCT. The webinar discussed the work done in JRA2 Work Package (WP). It was titled “Co-Simulation based Assessment Methods”. The webinar included presentations from the co-organizers explaining the work done in JRA2 and included two demonstrations to better showcase the working of the various models, couplings and test systems developed.

The webinar started with an introduction on energy transition and how it affects Cyber Physical Energy Systems (CPES). It was stressed how co-simulation across various domains is now a necessity to simulate a modern connected world. Then the motivation behind the co-simulation work done in JRA2 was discussed. The various co-simulation challenges like simulator interfacing, synchronization strategies etc. were discussed and their solutions presented. It was also discussed how the work was divided into three test cases, each addressing a specific co-simulation issue. The co-simulation strategy presentation was followed by presentations on the individual test cases. In Test Case 1, the issue of cyclic dependency between simulators was addressed. The controllers and models developed were presented. It was followed by a demo video of the actual co-simulation. The video was used to showcase the various aspects of a co-simulation and the results generated. In Test Case 2, the issue of software and hardware coupling via co-simulation was presented. After the explanation of co-simulation interaction, a demo video was presented to showcase the co-simulation. Finally, Test Case 3 discussed co-simulation on the context of signal-based synchronization between the simulators. Various communication aspects regarding co-simulation were mainly discussed in this section. The webinar then came to a close and the open source GitHub links to various models and test systems developed were shared. A 15-minute question and answer session followed, where questions from attendees were answered by the presenters.

The webinar received 154 registrations; 51 participants attended the webinar (33% attendance rate). More specific, 41 out of 51 were project external persons (80% external attendance rate). The participation statistics are summarized in Table 3. The webinar was fully recorded (video and audio) and was uploaded in the project website as well as in project's YouTube channel as shown in Figure 1.

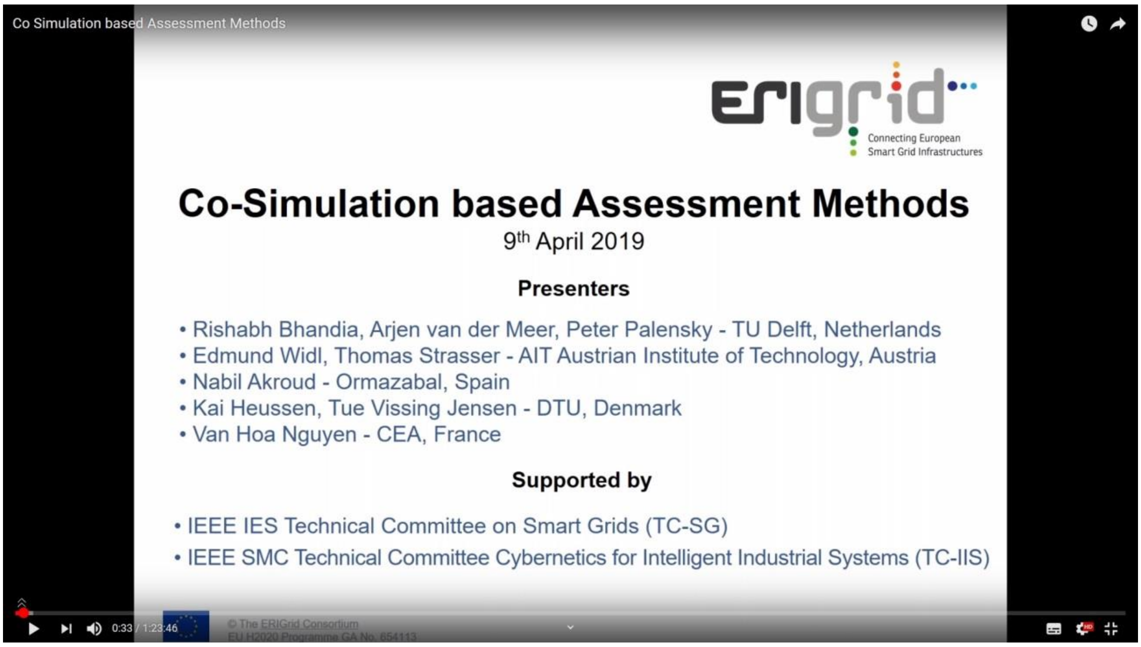

Figure 1: Snapshot of webinar recording on "Co-Simulation based Assessment Methods" available on YouTube

4.2.2 Holistic Test Description for Validating Cyber-Physical Energy Systems

The fifth webinar took place on 21st October 2019. It was co-organised by OFFIS, DTU, SINTEF and AIT. The webinar introduced the outcomes of the NA5 WP and its applications internally in JRA2-4, TA1, TA2 and in collaboration with other projects. The webinar was titled "Holistic Test Description for Validating CPES" and included a tutorial presentation on HTD (NA5 method), a summary of its applications (NA5.5 activity), and a presentation of two sample applications from JRA4.

The first presenter talked about the drivers to use this method and showcased different ways of implementing smart grid validation experiments based on a typical use case, "Coordinated Voltage Control (CVC)". He explained that the component to be validated is the Coordinating Control System and described how the validation will be achieved in two different testbeds. One way is to emulate a physical distribution network in the laboratory and use the control platform to integrate the control system. Another setup is with the help of a Digital Real-Time Simulator (DRTS) and the implementation of a Control Hardware-In-the-Loop (CHIL) and PHIL setup. Next, the HTD was introduced. The main idea and goal of this procedure is the definition of a generic scenario and the generation of reproducible results. The HTD consists of different layers which help the user to map the generic system configuration onto the specific required lab infrastructure and components. For this purpose, various templates were created. In the last part of the first presentation, more details regarding the HTD were given, organized by questions to be answered in such a description, such as "why to test", "what to test", "what to test for" and "how to test".

The next presenter talked about the applications of the HTD method and presented the experience gained. HTD was applied in various projects - some of them in the framework of ERIGrid, like joint research activities, transnational access and exchanges amongst partners - and some other in the framework of other European and national projects. What is more, he explained that depending on the application different types of tests and domains might be needed and that it is important to develop a common procedure for testing and documentation of the results.

In the third section of the tutorial, two example uses of the HTD method were presented. The two testing activities demonstrated the practical use of the templates and the thought process in developing them.

The webinar received 87 registrations; 41 participants attended the webinar (47% attendance rate). More specific, 27 out of 41 were project external persons (66% external attendance rate). The participation statistics are summarized in Table 3. The webinar was fully recorded (video and audio) and was uploaded in the project website as well as in project's YouTube channel as shown in Figure 2.

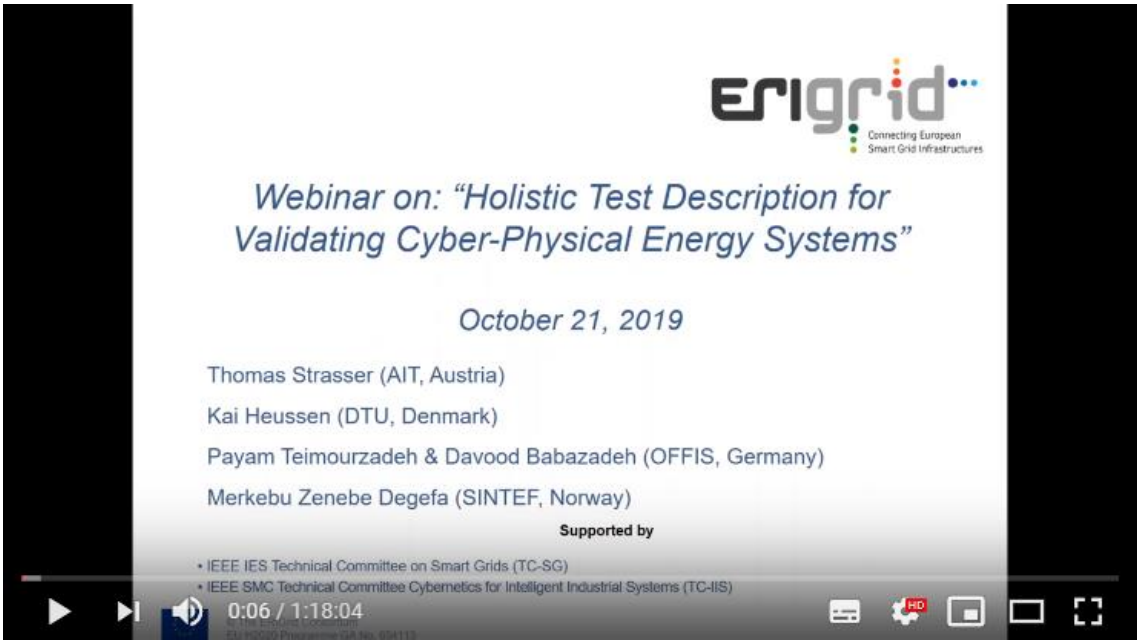

Figure 2: Snapshot of the webinar recording on "Holistic Test Description for Validating Cyber-Physical Energy Systems" available on YouTube

4.2.3 Demonstration of Multi Research Infrastructure Integration Tests

The sixth webinar took place on 26th November 2019. It was co-organised by RSE, ICCS-NTUA, SINTEF, UST and AIT. The webinar introduced the outcomes of the JRA4 WP. The webinar was titled "Demonstration of Multi Research Infrastructure Integration Tests" and included a summary of the methods to integrate research infrastructures and three presentations of the test cases implemented in the JRA4.

The first presenter talked about the motivations that bring ERIGrid partners to integrate their research infrastructures. Different advantages coming from the laboratory coupling have been highlighted. Then, the first presenter introduced the concepts on which are based the test cases presented by the next presenters.

The second presenter talked about the "testing chain" approach. In particular the test case presented was the testing of converter controller through multi-site testing chain with varied testbeds. This presentation showed how the testing chain method can help to develop new components or controllers considering all the smart grid functionalities. Moreover, the presenter highlighted also the usefulness of the HTD provided by NA5 applied to a complex test case.

The third presenter showed an industrial controller validation with state-of-the-art laboratory testing methods. The performance of a centralized voltage control has been tested in realistic conditions, taking into account the time delays and noise in measurements, using the CHIL technique. This method can decrease the time required to validate an advanced smart grid solution before the actual field implementation. Moreover, similar approaches can promote the collaboration of industry and research centers.

In the last presentation the role of geographically separated real-time experiments in the validation of systems readiness levels has been shown. The presenter explains which kind of tests can be performed coupling two research infrastructures via a communication platform to exchange data in real-time. Finally, the results of a centralized voltage control validation test, implemented on a system under test composed of two research infrastructures geographically separated, has been presented.

At the end of the presentations the audience asked 10 questions on different topics. These aspects confirm the good appreciation provided by the audience (4.4 in a range where 1 is poor and 5 is excellent).

The webinar received 79 registrations; 36 participants attended the webinar (46% attendance rate). More specific, 25 out of 36 were project external persons (69% external attendance rate). The participation statistics are summarized in Table 3. The webinar was fully recorded (video and audio) and was uploaded in the project website as well as in project's YouTube channel as shown in Figure 3.

Figure 3: Snapshot of the webinar recording on "Demonstration of Multi Research Infrastructure Integration Tests" available on YouTube

Overall, the webinars had a satisfactory attendance. It should be noted that it was possible to attract several participants outside of the ERIGrid consortium. Moreover, the dissemination of the work performed is progressing well by using the YouTube platform. Table 3 shows that a significantly larger audience has been reached via the YouTube platform and these numbers are expected to increase.

4.3 Software Tools

Given the cross-disciplinary nature of intelligent power and energy systems as outlined above, students should be exposed to a wide set of tools and concepts related to different knowledge domains. Thus, new educational methods and tools must be developed, capable of bringing the different knowledge domains together and allowing the students to understand the coupling and interaction of elements within intelligent solutions.

It is clear that simulations will play an important role in the testing process of new solutions. It is therefore natural that students should learn to use domain-specific simulation tools, both in standalone use cases and in co-simulation setups. Moreover, students should know the limitations of such tools. From an educational perspective, methods that support students to bridge the gap of theory and application are required.

In this section, the software tools developed from the ERIGrid partners during the current reporting period, are presented. The tools are used for e-learning but also in classroom education at the relevant universities.

Link to the ERIGrid website: https://erigrid.eu/education-training/#software

4.3.1 Cyber-Resilience Tool

In future smart grids, more active components and digitization increases the system complexity, which increases the risk of cyber incidents [5]. This, in turn, significantly increases the risk of far-reaching system failures, especially cyber-attacks. This was demonstrated from the 2015 Ukraine blackout, where hackers took control of the control room and caused a blackout. This mandates the need to analyse the impact of cyber events on the interconnected power system. In order to conduct such analysis, a multi-disciplinary lab infrastructure is required; which has components to represents both power and cyber domains.

The *Smart Grid Cyber Resilience Lab* at *OFFIS-Institute for Information Technology* is a test environment for concepts of system integration and management considering uncertainties (or failures) in the cyber domain. It gives the possibility to analyse the integration of ICT and digital technologies in power systems through the use of its real-time components and software so as to not only develop preventive measures, but also investigate reactive measures for the rapid detection and mitigation of physical- and cyber- induced incidents. The Cyber-Resilience Tool is an educational tool developed to demonstrate how cyber vulnerabilities could affect an electrical distribution grid. Furthermore, it also shows how a Digital Twin (DT) of the power grid can aid in detection and defence against such attacks. The open-source tool can be downloaded and used from the ERIGrid website and also from the following link *https://www.offis.de/en/offis/project/cybreslab.html*.

The tool has a GUI (shown in Figure 4) with which the users can perform certain attacks and investigate their impact on the system; both with and without defensive measures. The topology is a medium voltage distribution feeder connecting two substations, namely “Substation 1” and “Substation 2”. There is an On-Load-Tap-Changer (OLTC) transformer equipped with a voltage controller with two control modes: “Remote” and “Local”. The “Remote” mode is set under normal operation and controls the voltage of “Substation 1”, whilst the “Local” mode controls the voltage of the local “Substation 2”. The information of both substations is digitally transmitted to the controller via Remote Terminal Units (RTU), which uses IEC 60870-5-104 and IEC 61850 protocols for remote and local communications respectively.

In this demo, a cyber-attacker exploits the vulnerabilities of the RTU at “Substation 1”. The information sent to “Substation 2” is manipulated, which causes unnecessary tap changes in the transformer. These tap changes eventually cause under/overvoltage at the substations, triggering the respective protection, thus disconnecting the feeder from the electric mains.

The transformer’s controller also has a “Defender”, which consists on a DT of the distribution feeder. The DT is also provided with the data acquired from sensors in “Substation 2”, namely its voltage and current. The “Defender” compares the voltage received from “Substation 1” with the voltage estimated by the DT. A mismatch in these values indicate loss of confidence on the remote voltage value and the “Defender” changes the control mode to “Local”; thereby mitigating the impact of cyber-attack. Only when the threat is resolved, the “Defender” will detect matching voltages, and changes the control Mode back to “Remote”. The defender can be toggled “On” and “Off”, allowing the users to compare its effect on the system.

Since smart grids consists of multiple domains, one of the main challenges is the integration of different tools i.e. co-simulation, so as to analyse different domains. This demo consists of a real-time simulation environment including the following components:

- *ePHASORSIM* from OPAL-RT: Modelling of the power system feeder (e.g. loads, lines, busbars and transformer).
- *eMEGASIM* from OPAL-RT: Modelling of the tap changer controller of the transformer and the defensive mechanism of the system.
- *EXata* from Scalable Network Technologies: Modelling of the communication infrastructure between the substations with IEC 60870-5-104 protocol.
- *Virtual Remote Terminal Unit* (vRTU) from OFFIS: Communication protocol translation and modelling of payload alteration options, i.e., cyber-attacker.

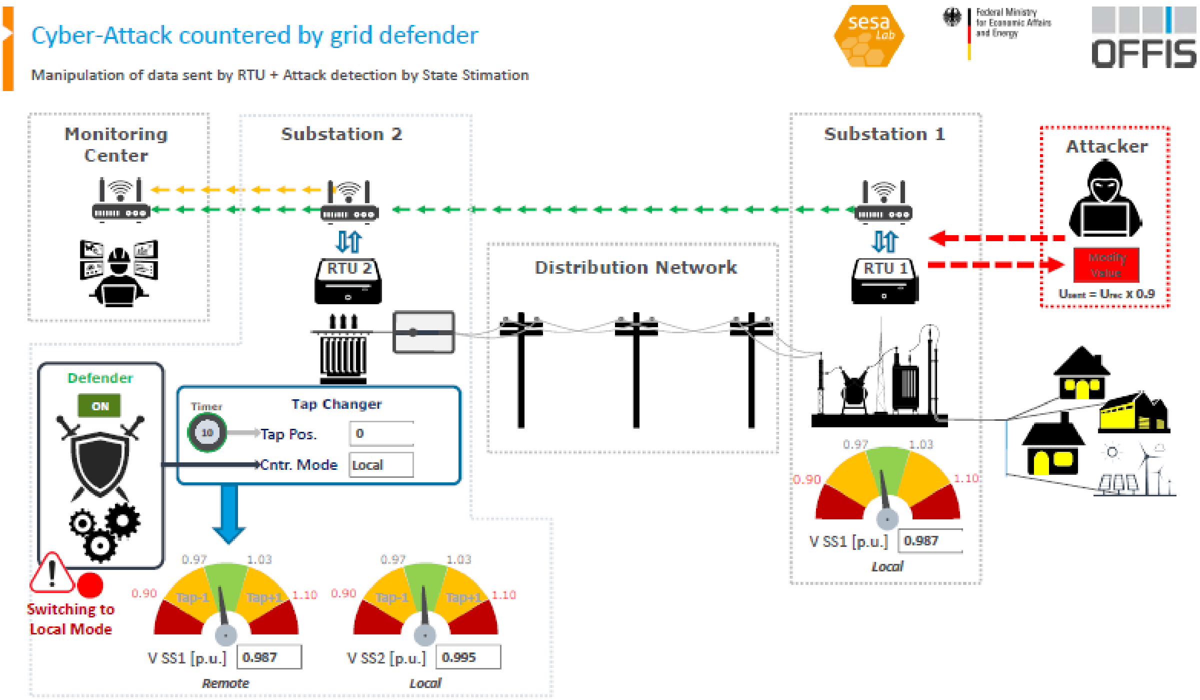

Figure 4: GUI of the Cyber-Resilience Tool

4.3.2 Interactive (Jupyter) Notebooks

Jupyter notebooks are a merge between a standard text book and what real programming in python looks like. The notebooks can contain explanatory text and figures, while running on an IPython [6] kernel allowing the student to execute python code. The use of these notebooks provides a way to narrow the gap between theoretical concepts and application by setting up code examples, where the student is able to directly see real life examples of the theoretical concepts explained in the text. Notebooks of this kind can be developed to cover a wide spectrum of intelligent energy systems concepts.

By constructing a framework where students can focus on a problem to solve, instead of dealing with issues related to programming, the students are able to better absorb and understand the core course concepts. In the case of the notebooks developed for ERIGrid, the learning objectives that the notebooks address are to:

- Design a testing procedure to validate a 'black box' algorithm
- Recognize the importance of statistical Design of Experiments to qualifying tests
- Apply Design of Experiments to evaluate the performance of a black box algorithm

4.3.3 Mosaik Demo Notebooks

Mosaik is an easy-to-use co-simulation framework that allows researchers to couple different simulation model software components to realize dynamic simulation setups of complex systems of systems. The typical application case of mosaik is co-simulation of cyber-physical energy systems. Each integrated simulation tool models one component of the overall system, like the distribution grid, DERs, controllers, or even energy markets. More information on mosaik can be found at the ERIGrid website or the official website *http://mosaik.offis.de/*. Mosaik is an open-source tool.

While the mosaik framework is written in pure Python it can integrate simulators implemented via a variety of technologies. This is possible due to an architecture based on TCP sockets as well as several APIs for simulator integration supporting languages like Java, MATLAB, C#, and even the FMI standard.

Setting up an executable co-simulation setup requires the user to write a Python script following a structure defined by mosaik. This script is typically called a “scenario script” and it specifies which simulators are used and how they are parameterized and connected to one another. The presented set of notebooks provide executable mosaik scenarios that gradually become more complex. In this way, the users/learners can understand step by step the handling of mosaik as well as the general creation of smart energy co-simulation setups for the software-based testing of new approaches.

The notebooks are designed to introduce the usage of mosaik step by step, and for that purpose 4 different notebooks/scenarios were developed. The first notebook/scenario “demo1” introduces a very simple power system (co-)simulation. With every following notebook, further simulation components are added to the system to make it more interesting.

4.4 Presentations

The presentations with educational/training content, uploaded on the ERIGrid website in the current reporting period, are summarized in this section.

Link to the ERIGrid website: https://erigrid.eu/education-training/#presentations

4.4.1 Advanced Power System Testing using HIL Simulation

These presentations created and presented in the framework of the ERIGrid workshop entitled “Advanced power system testing using Hardware in the Loop simulation”, in Athens. The main goal of the presentations is to demonstrate the benefits of HIL simulation for power system testing, especially in today’s shift towards smart grids. Key features of CHIL and PHIL simulation are explained, along with a variety of applications. The corresponding presentations are:

- *“CHIL and PHIL simulation: key features and applications” (ICCS-NTUA):* An introductory presentation into the concept of HIL simulation, in which the features and applications of the two different types – CHIL and PHIL, are explained. In addition, the stability issues related to PHIL simulations and some appropriate methods to deal with them, are presented.
- *“HIL testing of adaptive protection in distribution grids” (ICCS-NTUA):* This presentation explains the protection issues arising in distribution grids with Distributed Generators (DGs), and the importance of adaptive protection systems which can change in real time, depending on the network configuration. In addition, the innovative testbed infrastructure (HIL topology) for adaptive protection schemes, is presented.
- *“DER inverter development and testing using HIL simulation” (ICCS-NTUA):* This presentation describes the stages and techniques for the development of DER inverter and how HIL methods can be used for testing it.
- *“Voltage control in distribution networks with high DER integration: HIL experiences” (ICCS-NTUA):* This presentation describes the emergence of voltage rise issues due to the DG

integration, and the contribution of HIL simulation in validating modern voltage control approaches.
- *"Islanding detection and seamless transition through operation modes in microgrids: HIL experiences" (ICCS-NTUA):* This presentation proposes detection and seamless transition methods through operation modes in microgrids. In addition, HIL experiments for testing these methods are presented.
- *"Distributed control applications using Virtual Power Plants" (ICCS-NTUA):* This presentation describes the advantages of distributed control architecture and its applications in power systems, using the concept of VPP. The paradigm of ICCS's VPP in Meltemi pilot site is showcased, and the way HIL experiments help in the testing of distributed control algorithms is explained.

4.4.2 Smart Grid Laboratory Developments

These presentations were created and presented in the framework of the ERIGrid-CINELDI workshop entitled "Smart Grid Laboratory Developments", in Trondheim. The main goal of the presentations is to share knowledge and experience on smart grid laboratory activities with a special focus on co-simulation and HIL simulation.

- *"Introducing co-simulation concept and platforms" (TUD):* The presentation describes the modern cyber-physical energy systems and the critical need for novel holistic testing and validation approaches. In addition, it introduces the co-simulation concept and presents 2 implemented examples to facilitate the understanding. At the end, some co-simulation platforms are listed and the mosaik, used within ERIGrid, is described in more detail.
- *"Integration of HIL to co-simulation" (IEE):* As an introduction, the background and motivation behind the concept of HIL and co-simulation integration is explained. Following, the 3 developed ERIGrid approaches for integration of HIL to co-simulation framework, taking into consideration the challenges of this method, are presented. At the end, two variations of a test case developed are explained and the results are presented.
- *"Laboratory demonstrations" (SINTEF):* The scope of this presentation is to explain 3 different laboratory HIL test setups, carried out by SINTEF. The first one is about the provision of inertia support to transmission system from High Voltage Direct Current (HVDC) systems. The second one is a testing procedure of a voltage regulation component ("Booster") for distribution grids. The third application is about a real time phasor simulation of a model of the Nordic transmission system.
- *"Development and testing of resilience grid automation using RT simulations" (OFFIS):* At the beginning, the importance of considering ICT in power system planning and operation and using the appropriate testing methods for validation of the resilience grid automation is explained. Next, examples and solutions developed by OFFIS, like ERIGrid vIED platform and HIL set-ups for distributed controllers testing, are showcased.

4.5 Statistics Regarding "Education" Page of ERGrid's Website

In this section, statistical data related to the website of ERIGrid (https://erigrid.eu/education-training/) are presented, since the start of tracking, November 2017 until March 2020. Figure 5 shows the "Education" page views each month in the period mentioned above. The peak of the curve with 400-page views was in April 2019. This can be attributed to a number of facts and events that took place around this period. First of all, on 9th April the well-attended webinar "Co-Simulation based Assessment Methods" was held, the outcomes of which were publicized also in LinkedIn (https://www.linkedin.com/feed/update/urn:li:activity:6521405431464759296/). Second, in the last week of March 2019, a newsletter (https://mailchi.mp/992071003347/free-lab-access-ends-on-15-may-co-simulation-assessment-webinar-open-source-tools?e=355fcc3e3e) was released which advertised past workshops and also contained a section on recent education resources (section "Latest resources"). Lastly, in April there was also the peak of 6th Transnational Access (TA) call promotion.

Under the curve, the aggregated numbers of Unique Views, Users and Page Views regarding the abovementioned period, are given. The meaning of these terms is explained below.

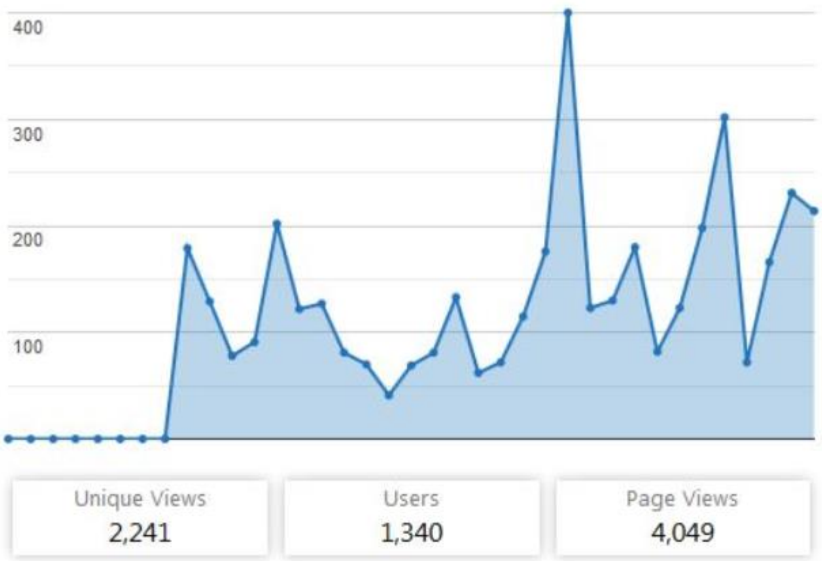

Figure 5: " Education" page visiting data

Legend:

- *Session:* The period of time a user is active on a site [7].
- *Unique Views:* Represents the number of sessions during which a page was viewed one or more times. This metric does not include multiple views of the page within a single session. For example, if a user comes to a web page on a site and in the course of the same session returns to that page 10 times, this would count as 10 Pageviews, but only 1 Unique View [7].
- *Page Views:* is an instance of a page being loaded (or reloaded) in a browser [7].

5 Additional Educational Activities

5.1 European Researcher’s Nights 2019 – Marie Skłodowska-Curie Actions

The European Researchers’ Night takes place every year simultaneously in several hundred cities all over Europe and beyond. The key objective of the event is to increase general public awareness on the diversity of scientific research and also to promote and facilitate greater public participation in the entire scientific process. One of the further goals of the event is to enhance youth’s understanding of science and research and encourage them to pursue a career in Science, Technology, Engineering and Mathematics (STEM).

ERIGrid has contributed to the European Researcher’s night represented by AIT in Vienna, Austria in 2017, 2018, and 2019. Similarly, as the years before, in the 2019 edition (September 27th), ERIGrid contributed to the Viennese event, called Sci4all, sharing knowledge on smart grid research, in particular with topics such as:

- The importance of a higher level of automation in the context of the integration of decentralised and renewable energy sources in the electrical grid,
- The role of information and communication technology in this domain,
- The important role of power system and smart grid research infrastructures in the European context,
- The importance of the development and validation of cross-domain smart grid approaches.

The ERIGrid virtual laboratory tool showing microgrid and distributed energy systems control was demonstrated as well (see figure below).

Figure 6: Snapshots from the European Researcher’s Night 2019 Sci4all event in Vienna

6 Conclusions and Outlook

The emergence of intelligent solutions in the domain of power and energy systems opens new possibilities but poses new challenges, rendering appropriate education and training methods for students and engineers increasingly important. A broad understanding of several domains is necessary to deal with the increased complexity and diversity, such as electric power systems, automation, ICT, thermal systems, cyber security etc.

The ERIGrid project identified educational needs and requirements in the rising complex environment. It is explained that the validation of complex systems is a multi-stage process, while systems-oriented skills and cross-disciplinary learning needs to be cultivated. Programming and system conceptual design competences, together with a pragmatic view, are important. In order to cover the distance between theory and hands-on practice, coding and laboratory education is beneficial. As the required knowledge is too broad, educational methods such as experiential learning and problem-based learning can prove to complement effectively the traditional teaching methods.

In this framework, several tools and methods developed in the ERIGrid project are presented. The delivery of webinars proved to be an efficient way to disseminate the progress and educate researchers on the ERIGrid methodologies. The Cyber-Resilience Tool with its easy-to-use GUI as an educational tool demonstrates how cyber vulnerabilities could affect an electrical distribution grid. It also shows possible defensive actions against cyber-attacks. The use of notebooks can bridge the gap between theory and application, allowing the user to focus on solving a problem, instead of dealing with issues related to programming.

It is clear that the ERIGrid approaches and methodologies, developed mainly in the JRA (e.g. real-time simulation, co-simulation), can be beneficial for education/training purposes. This deliverable firstly summarized the overall e-learning material developed and the impact achieved. A detailed presentation of the material developed in the current reporting period was provided.

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8 Annex

8.1 List of Figures

8.2 List of Tables