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

Work Package 12

TA2 - Facilities for Large-Scale Smart Grid System Integration and Testing

Deliverable D12.1

D-TA2: "Summary Report of TA2 Activities"

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Abbreviations

AI	Artificial Intelligence
API	Application Programming Interface
AS	Ancillary Services
CapEx	Capital Expenditure
CHIL	Controller Hardware-in-the-Loop
DER	Distributed Energy Resources
DG	Distributed Generation
DR	Demand Response
DRES	Distributed Renewable Energy Sources
EMT	Electro-Magnetic Transient
EV	Electric Vehicle
FESS	Fast Energy Storage System
FPGA	Field Programmable Gate Arrays
HEV	Hybrid Electric Vehicles
HFPS	High-Frequency Power Smoothing
HIL	Hardware-in-the-Loop
HTD	Holistic Test Description
HV	High Voltage
HW	Hardware
ICE	Internal Combustion Engines
IRR	Internal Rate of Return
LV	Low Voltage
LVRT	Low Voltage Ride Through
MG	Microgrid
MGCC	Microgrid Central Controller
ML	Machine Learning
MSP	Minimum Selling Price
MV	Medium Voltage
NN	Neural Network
NPV	Net Present Value
OLTC	On Load Tap Changer
OpEx	Operating Expenditure
PBP	Payback Period
PDC	Phasor Data Concentrator
PEV	Plug-in Electric Vehicles
PHIL	Power Hardware-in-the-Loop

PMU	Phasor Measurement Unit
POC	Point-Of-Charging
PV	PhotoVoltaic
RES	Renewable Energy Source
RMS	Root Mean Square
RPW	Reactive Power Window
RT	Real Time
SG	Synchronous Generator
SGCC	Smart Grid Central Controller
SIL	Software-in-the-Loop
SME	Small and Medium Sized Enterprise
TEA	Techno-Economic Analysis
UC	Ultra Capacitor
uPMU	Micro-Phasor Measurement Unit
VI	Virtual Inertia
VSC	Voltage Source Converter
WP	Work Package
WT	Wind Turbine

Executive Summary

This report presents the main outcomes of the ERIGrid TA2 Work Package “Facilities for Large-Scale Smart Grid System Integration and Testing”. Within this WP, thirty-eight (38) Transnational Access (TA) projects have been successfully completed through a collaborative programme of experiments hosted by ten of the ERIGrid consortium’s leading research infrastructures providing free access to EU and international users. The TA projects covered a wide spectrum of smart grid systems and solutions validation and characterisation including but not limited to sensor systems, control systems, machine learning algorithms, micro-grids and market analysis.

This report firstly presents the completed TA2 project in a number of high level clusters to illustrate the technical focus of the experiments. These clusters include the use of real-time simulators, objective testing and proportion of system vs. component testing carried out.

Secondly, the report provides a summary of the main outcomes highlighting the impact of the TA2 activities on the host and user groups including technical and organisational lessons learned. Finally, the report presents a set of recommendations which have been drawn from the learning of the research infrastructures hosting TA projects during ERIGrid TA2, with a view to enhance the TA2 experience and advance systems testing procedures in the ERIGrid 2.0 project.

This report finally presents an overview of exemplary projects, which have been shortlisted from the completed thirty-eight projects, based on host feedback. For each project, a brief overview the scope, the experimental setup which highlights the value of systems testing facilitated by real-time HIL simulation and physical grid infrastructure, and the main outcomes benefiting the user groups are presented. These summaries are presented in the reports annex.

1 Introduction

Transnational Access (TA) activities are at the core of the ERIGrid project where EU and international user groups are granted free access to leading laboratory Research Infrastructure (RI) of the ERIGrid consortium members in order to carry out research and testing projects. Details about the whole TA programme can be found in the deliverables D3.4 [1] and D3.5 [2]. This report, however, focuses on the lessons learned from infrastructure implementation of user projects undertaken as part of the TA2 WP of the ERIGrid project ("Facilities for Large-Scale Smart Grid System Integration and Testing").

1.1 Purpose of the Document

In order to highlight the key role of the RIs used in TA2 to validate solutions of the TA user groups, this document aims to:

- Present an overview of successful TA2 project that are aligned with the ERIGrid scientific objectives through a review of exemplary projects and clustering of the overall TA2 experimental activities.
- Highlight the impact of the TA2 activities to the user groups and ERIGrid community.
- Identify lessons learned from the TA2 activity in general and the experimental implementation and other logistical issues in particular when delivering TA2 activities.
- Recommend concrete improvements to TA2 related procedures and experimental practice where appropriate.

1.2 Scope of the Document

This report focuses on the findings, impact and lessons learned from the TA2 activities. For TA1, a separate report has been published as deliverable D11.1 [3].

1.3 Structure of the Document

This report, firstly presents a summary of completed TA2 projects in Section 2. This is then followed by a high-level clustering of TA2 activities that are aligned with the ERIGrid scientific objectives in Section 3. Furthermore, a number of exemplary TA2 projects are reviewed and their outcomes summarised in the same section. These projects were selected based on a number of criteria with the aim of highlighting the main impact the TA2 projects have had on the user groups in particular and on the ERIGrid community in general. Also, a number reflections and recommendations from the TA2 activities are presented in Section 4 with a view to improve the TA2 project experience and enhance their impact going forward in the ERIGrid 2 project. Finally, the report is concluded with Section 5.

2 Overview of TA User Projects Realised in TA2 Facilities

2.1 Facilities

User projects were hosted in all facilities organised under TA2. Table 1 summarises the utilisation of user projects' host infrastructures. The reported access days of user groups was somewhat balanced according to the expectations. A few partners offering several RIs experienced higher interest in one facility than another. Details on the access projects, user group information and statistics are found in [1] and [2].

Table 1: Overview of user projects per RI

RI Name	***Nº of User Projects***	***Sum of Nº of Users in the Installation***	***Sum of Nº of Access Days***
AIT: SmartEST	12	27	176
DNVGL: FPGLab	3	9	30
GINP: PREDIS	1	1	14
IEE: SysTec	3	7	35
OCT: UDEX	2	5	34
OFF: SESA-Lab	2	3	65
RSE: DER-TF	6	13	58
TUD: ESE-Lab	3	8	58
UST: PNDC	4	5	26
VTT: MP-Espoo	2	4	33
Grand Total	*38*	*82*	*529*

2.2 User Projects

Thirty-eight (38) TA2 user projects have been completed successfully. Table 2 provides a summary of these projects, user group affiliation and the host RI used to implement the associated experiments. Some projects have been carried out using multiple RI between TA1 and TA2 such as VILLAS4ERIGRID. Projects highlighted in gray have been selected and an overview is provided on each in the following section based on host RI feedback on criteria discussed in that section. The detailed results of these user projects have been described in individual reports which are all accessible via the ERIGrid website[1].

Table 2: User projects realised in TA2 (projects reported herein are highlighted)

TA User Project Ref. No.	***TA User Project Acronym***	***Lead Organisation***	***Type***	***Country***	***Host RI***	***Nº of Users in RI***	***Nº of Access Days***
01.002-2016	*INTREPID*	*ORMAZABAL COTRADIS*	*Ind*	*Spain*	*IEE: SysTec*	*4*	*15*
01.003-2016	GaMDER	Istanbul Technical University	HE	Turkey	RSE: DER-TF	2	15
01.008-2016	Smart beats Copper	Ulm University of Applied Sciences	HE	Germany	AIT: SmartEST	5	12

[1] TA user project results, including publications: https://erigrid.eu/transnational-access/selected-projects/

TA User Project Ref. No.	***TA User Project Acronym***	***Lead Organisation***	***Type***	***Country***	***Host RI***	***Nº of Users in RI***	***Nº of Access Days***
01.012-2016	3D-Power	Florida State University (CI2Lab)	HE	USA	AIT: SmartEST	2	20
01.013-2016	AQUA	Universität Passau	HE	Germany	AIT: SmartEST	3	14
02.003-2017	CHROME	Tampere University of Technology	HE	Finland	DNVGL: FPGLab	4	15
02.005-2017	*ECOSMIC*	*University of Antwerp*	*HE*	*Belgium*	*RSE: DER-TF*	*1*	*5*
02.007-2017	HARSH	Aalborg University	HE	Denmark	DNVGL: FPGLab	1	5
02.009-2017	EPB	Ensto Utility Networks, Power Electronic Solutions	Ind	Finland	UST: PNDC	1	10
03.002-2017	DSM-RSAMRE	Batman University	HE	Turkey	TUD: ESE-Lab	4	20
03.004-2017	DISCOVERER	ORMAZABAL COTRADIS	Ind	Spain	IEE: SysTec	2	10
03.007-2017	TIPI-GRID	ZHAW Zurich Uni. of Applied Science	HE	Switzerland	AIT: SmartEST	1	14
03.008-2017	*4D-Power*	*Florida State University (CI2Lab)*	*HE*	*USA*	*AIT: SmartEST*	*5*	*29*
04.003-2018	PVGRIDHIL	Universidad Politécnica de Cartagena	HE	Spain	AIT: SmartEST	1	19
04.005-2018	onPDnet	Haefely Test AG	Ind	Switzerland	OCT: UDEX	2	15
04.007-2018	DEF-HIL*	Fraunhofer IEE	RInst	Germany	AIT: SmartEST	1	9
04.007-2018	DEF-HIL*	AIT	RInst	Austria	IEE: SysTec	1	10
04.008-2018	CESEPS	University of Twente	HE	Netherlands	AIT: SmartEST	1	10
04.010-2018	OptBiEESAgg-NA	Danish Technical University (DTU)	HE	Denmark	RSE: DER-TF	2	10
04.011-2018	*SunHILL*	*University of Vaasa*	*HE*	*Finland*	*OFF: SESA-Lab*	*2*	*25*
04.012-2018	*DEFINIT*	*DEPsys*	*Ind*	*Switzerland*	*UST: PNDC*	*1*	*5*
04.020-2018	Rap-GForce	Aalborg University - Visit1	HE	Denmark	DNVGL: FPGLab	4	10

TA User Project Ref. No.	*TA User Project Acronym*	*Lead Organisation*	*Type*	*Country*	*Host RI*	*Nº of Users in RI*	*Nº of Access Days*
04.021-2018	IISLT	RWTH Aachen University	HE	Germany	AIT: SmartEST	2	15
04.025-2018	ProMeter-Interface*	AGH University of Science and Technology	HE	Poland	RSE: DER-TF	3	9
04.026-2018	iReact-NG	EMTECH SPACE P.C.	Ind (SME)	Greece	AIT: SmartEST	2	9
05.003-2018	VFG-VPP(AS)	Enel Produzione	Ind	Italy	OFF: SESA-Lab	1	40
05.011-2018	*HILT AS-DRES*	*University of Sevilla*	*HE*	*Spain*	*TUD: ESE-Lab*	*2*	*25*
05.014-2018	LFC4IMEVs	Batman University	HE	Turkey	RSE: DER-TF	3	9
05.016-2018	HERDER	Kadir Has University	HE	Turkey	RSE: DER-TF	2	10
05.017-2018	WAHPS	Eindhoven University of Technology	HE	Netherlands	UST: PNDC	1	6
05.018-2018	vIED	OFFIS e.V.	RInst	Germany	VTT: MP-Espoo	2	20
05.020-2018	*EVACC*	*Prince Mohammad Bin Fahd University*	*HE*	*Pakistan*	*VTT: MP-Espoo*	*2*	*13*
05.021-2018	VILLAS4-ERIGrid*	TU Delft	HE	Netherlands	TUD: ESE-Lab	2	13
05.023-2018	CAPS2	Catholic University of Cuenca	HE	Ecuador	GINP: PREDIS	1	14
06.006-2019	CYPRESS	FOSS Research Centre for Sustainable Energy, University of Cyprus	HE	Cyprus	AIT: SmartEST	3	15
06.008	LCA	Nuventura	Ind (SME)	Germany	OCT: UDEX	3	19
06.010-2019	SSM	Soraytec Scandinavia AS	Ind	Norway	UST: PNDC	2	5
06.012-2019	ICVP	Fukushima Renewable Energy Institute, AIST (FREA)	RInst	Japan	AIT: SmartEST	1	10
RI Visits Total	*38*				*sum (avg) | sum*	*82 (2.2)*	*529*

Legend: * - Multi-RI project; HE – Higher Education, RInst – Research Institute, Ind – Industry, SME – Small and Medium Sized Enterprise

3 TA Projects Clusters and Exemplary User Projects

This section presents the completed TA2 project across a number of high level clusters. The clusters have been chosen such that the main technical considerations are reflected. Moreover, exemplary projects are highlighted.

3.1 TA Project Clusters

3.1.1 Utilisation of Single or Multiple RIs

Most projects used a single RI to execute the experiment as can be seen in Figure 1. Some have used multiple RIs, however of those most were not simultaneously connecting multiple RIs.

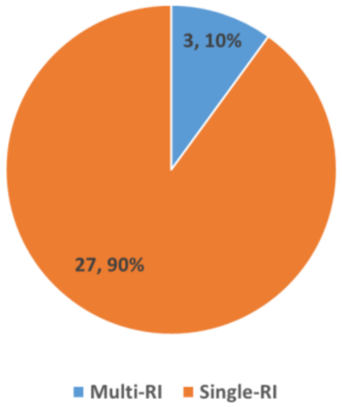

Figure 1: Proportion of projects using single-RIs vs multiple-RIs

3.1.2 Voltage Levels Considered

The split in voltage levels, physical or simulated, considered as part of the system under test are illustrated in Figure 2. The majority of projects focused on Low-Voltage LV network. Tests involving Medium Voltage (MV) networks or components also tend to incorporate an LV networks. This is probably due the prevalence of LV infrastructure in host RIs and the focus on microgrid related research and testing.

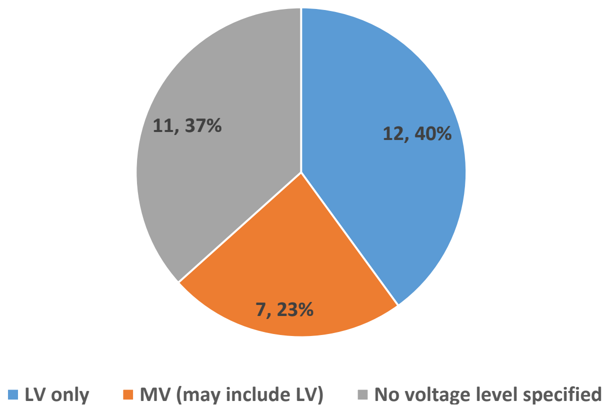

Figure 2: Split of projects based on consider voltage level

3.1.3 Use of Digital Real-Time Simulators

Digital Real-Time Simulators (DRTS) played a key role in realising the majority of the TA2 experiments. The experiments consisted of CHIL, PHIL or a combination of both. Figure 3 shows the most commonly used DRTS, where Opal-RT based setups constituted just under half of those experiments.

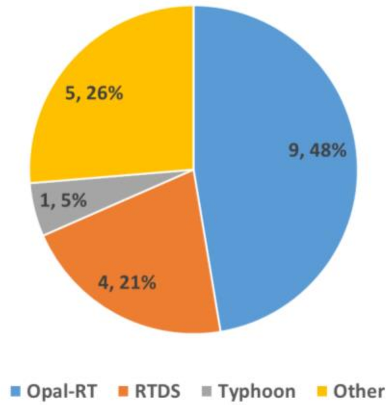

Figure 3: Main DRTS used in TA experiments

3.1.4 Component and System Testing Focus

An almost equal proportion of component and system tests were carried out as can be seen in Figure 4. Where neither component nor system testing are specified as the focus of the experiment, investigations tend to focus on algorithm testing, characterisation of phenomena such as harmonics or partial discharge and evaluation of energy market mechanisms.

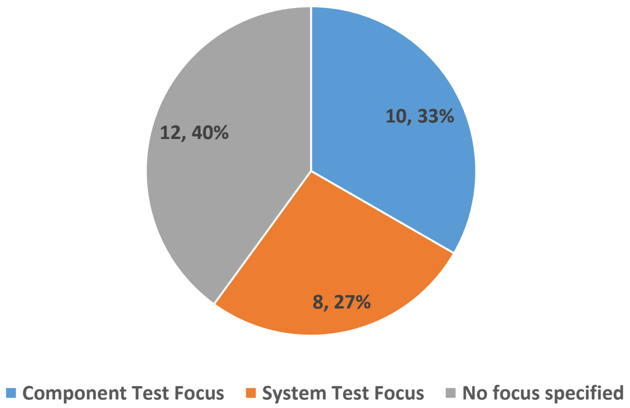

Figure 4: Prevalence of component and system testing in TA2 projects

3.1.5 Characterisation and Validation and Verification Focus

57% of TA2 projects involved validation and verification as the main focus. These include projects considering control algorithms, tests of interoperability, grid code compliance and measurement accuracy. Furthermore, 40% of the projects can be considered to have a characterisation focus such as quantification of controllable resource responses, harmonic content and interactions in a grid and evaluation of PHIL/CHIL/SIL test beds.

33% of all TA2 projects have been reported to involve some level of standard compliance testing or test setups that follow guidelines set by standards.

3.1.6 Algorithms Tested

A large proportion of experiments that incorporated algorithms testing focused on control algorithms, a large number of which involved AC or DC voltage control. Other algorithms tested included measurement algorithms, particularly for event and fault detection, and DER management algorithms pertaining to power flow control.

3.2 Selection of Exemplary Projects

This section summarises the outcomes of seven exemplary projects shortlisted from the TA2 projects presented in Table 2. The host RIs were consulted to produce this list. The following are the main criteria used for the shortlisting. An individual project would not meet all criteria, but the criteria were designed so that the shortlist as a whole would be able to satisfy them.

- Alignment with ERIGrid objectives:
  a. Utilisation of the holistic testing descriptions developed in ERIGrid work package NA5
  b. Use of co-simulation or hardware in the loop experiment realisation
  c. Supporting the ERIGrid education and training objectives set out by the NA4 work package
- Implementation and use of Multi-RI access
- Balance of industry and academic user groups
- Projects that demonstrate value of EU RI to non-EU users
- Projects with publications

The main source of information for this section is the technical reports generated by each of the projects' user groups. These are available on the ERIGrid website[2].

3.2.1 INTREPID

Overview

The proposed solution is based on an electromechanical on load tap changer (OLTC) with vacuum interrupters in MV. OLTC enables voltage regulation by varying the transformer ratio under load without interruption. The OLTC changes the ratio of the transformer by adding or subtracting turns from the MV winding. The transformer is therefore equipped with a tap winding which is connected to the OLTC. Transition impedance bridges adjacent taps for the purpose of transferring load from one tap to the other without interruption or appreciable change in the load current. Besides, they limit the circulating current allowing, in the case of reactors, continuous loading. The new smart distribution transformer, by means of its OLTC, can adjust the transformer substation voltage so that the downstream feeder voltages can be maintained within statutory limits and this can result in an increase in capacity to cope with distributed generation or new loads without the need of new infrastructure. The implemented OLTC is able to carry out a +/-10% regulation in the LV with up to 9 steps of 2.5%.

Motivation

As the European standard EN 50160 [4] defines the voltage requirements in distribution grids and requires that the voltage stays within a band of +/- 10% of the nominal voltage. The compliance with these statutory voltage limits would require a grid extension. As functional testing of new solutions for voltage control is complicated in real networks, the research to assess the operation of the smart distribution transformer must be done in laboratories designed as a platform for the research of new products for the smart grids [5]. Network operators require high reliability products with predictable behaviour to guarantee the correct operation of the grid. Decentralised generation connected to MV or LV networks is developing very quickly in many countries. As renewable energy source (RES) are very volatile, keeping the necessary system stability in the distribution grid will become a more challenging task. New components, products, solutions and concepts try to cope with this new situation.

Set-up and tests

The test centre for smart grids and electromobility SysTec of Fraunhofer IEE provides the infrastructure to realistically develop and test grid components and equipment in view of new system functions, such as controllable transformers for dynamic voltage support. In this case the test facili-

[2] https://erigrid.eu/transnational-access/selected-projects/

ty is connected to the MV network between the equipment under test and the network connection point of the grid operator. It produces voltage dips on the MV side of the equipment under test by means of a mobile test container (LVRT test facility).

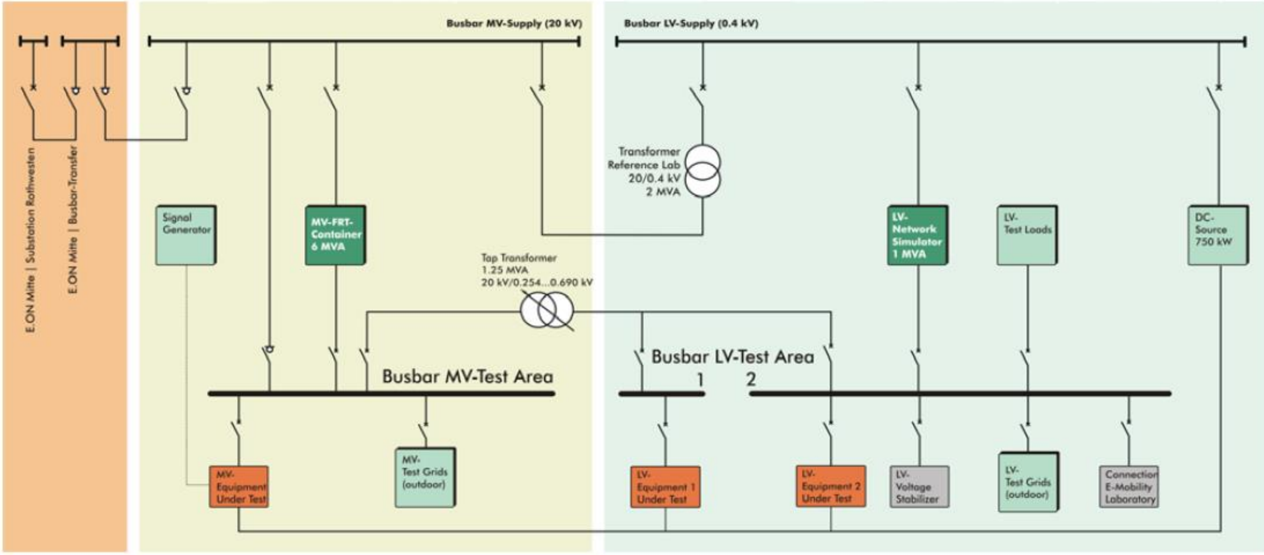

Figure 5: Fraunhofer IEE test facility for testing of the grid interface of DER units and systems

The following test cases were performed:

- Commissioning Tests.
- Voltage Dip. Normal operation. 0.975-0.9 p.u. Using only decoupling.
- Voltage Dip. Quick operation. 0.9-0.8 p.u.
- Voltage Dip. Blocked operation. 0.9-0.8 p.u.
- Advanced algorithm
- Feed-in PV-generation

Main outcomes and lerning

The new smart transformer has been assessed in the SysTec facilities under different voltage dip conditions, according to grid code specifications, proving that the control box was not disconnected after any of the tested dips. Different control algorithms (normal, advanced) have been checked under a set of different operation conditions (normal, quick, blocked). In addition, reverse power flow conditions, in the case that distributed DG excess the LV loads, has been tested along with remote sensors devices.

3.2.2 ECOSMIC

Overview

The objective of the project was to carry out a Techno-Economic analysis (TEA) of the microgrid (MG) set-ups found on four different sites. Four, one-week long visits have been carried out with the motivation to enable comparison between set-ups. The four facilities proposed for visiting were therefore selected so as to be different in both climate and economic/policy conditions.

Table 3: Overview of the configurations used in MG set-ups for the ECOSMIC experiments

	KAПE CRES	RSE	DTU Technical University of Denmark	VTT
Load	4,2 kW	9 kW	25 kW	2,33 kW
PV	4,2 kW	9 kW	10 kW	7,2 kW
Stor-age	Lead-acid 40,2 kWh	Li-Ion 12,5 kWh	Vd-redox/ Tesla W 27 kWh	Lead-acid 58 kWh
Wind	---	---	11 kW	5,5 kW
Grid	Yes	---	Yes	Yes
Diesel	Diesel generator 10 kW	CHP, natural gas 33 kW	---	---

Each visit involved a series of experiments for a residential load profile typical for the location of the respective facility, served by renewable energy sources supported by storage as well as a connection to the main grid and/or a generator based on fossil fuels.

Table 4: Overview of the scenarios carried out at each of the four facilities

KAПE CRES	RSE	DTU Technical University of Denmark	VTT
Grid-connected, heavy load, buy-priority	Summer generation, summer load profile, with base load	Initial SoC at minimum, PV unit connected	Battery first to charge/ discharge; grid next
Grid-connected, heavy load, sell-priority	Summer generation, summer load profile, no base load	Initial SoC at median value, PV unit connected	Discharge primarily during peak hrs, charge first
Grid-connected, light load, buy-priority	Winter generation, winter load profile, with base load	Initial SoC at minimum, PV unit disconnected	Discharge during peak hrs, charge when profitable
Grid-connected, light load, sell-priority	Winter generation, winter load profile, no base load	Initial SoC at median value, PV unit disconnected	Battery first to charge, EV second; battery first to discharge
Island mode, heavy load			
Island mode, light load			

The output of each experiment consisted of the recorded values of electricity production, storage and consumption. Each set of experiments has had its own objective of the experiment set that informed the variations between scenarios. In parallel with the running experiments economic data on the equipment was collected: equipment brands, purchase prices, time of purchase. The data was recorded via HOMER software in that each configuration was separately modelled as a MG and the components were assigned the purchase prices as provided by the respective facility. Based on analysis it is possible to evaluate each system individually and to make comparisons. The data collected is capable of supporting various research questions.

Motivation

The project was developed as part of a PhD research project at the University of Antwerp. The goal is to develop a framework for the economic assessment of MGs by analysing the shortcomings of conventional methods, of which the most popular one is the techno-economic analysis (TEA). The output of a TEA uses CapEx, OpEx and revenues to provide metrics such as: payback period PBP, net present value NPV, internal rate of return IRR, minimum selling price MSP. The probabilistic distribution of these indicators together with the sensitivity analyses provide insight on the impact of variable MG configurations, and they constitute the main rationale of the experiment sets.

This project was designed to enable a series of TEAs on various MG configurations in residential setting. It was hereby aimed at a broad range of technology mixes, MG sizes, operating conditions etc. to derive reliable estimates for the parameters used in the general conceptual framework.The existing knowledge and practice on the TEA of MGs is still limited and does not support reliably the real needs of practitioners: flexibility in the assessment method (i.e. the evaluation of a system that has been built over time, as opposed to being built at once from scratch), as well as enabling comparisons between systems. This project aimed to contribute to this discussion.

Set-up and tests

All the respective scenarios determining each experiment follow the use case given in the diagram.

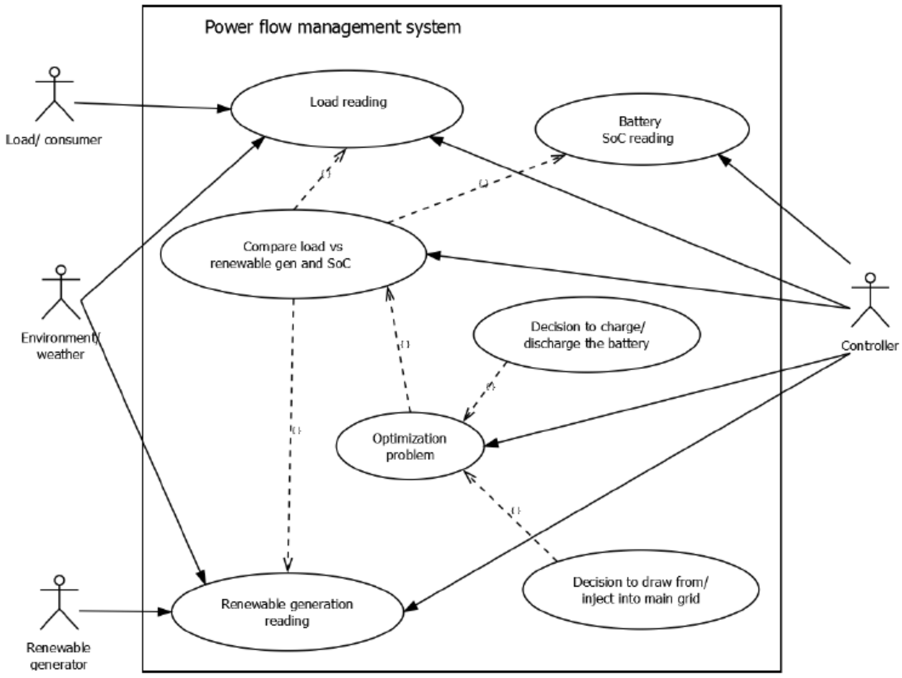

Figure 6: General use case diagram applicable for each of the experiment sets carried out

Results and learnings

The project was a collaboration of the University of Antwerp with CRES, RST, DTU and VTT. In total, two categories of information were collected from each facility. In some of the cases data was incomplete or not provided as of the editing of this report.

For the determination of CapEx:

- Equipment brand and type (e.g. PV cells: number of cells, type, technology, brand)
- Year of acquisition
- Whether the price includes VAT/ discounts
- Installation costs (specialist installer hourly wage, wire lengths, board, etc)

For the determination of OpEx:

- Maintenance schedule, if any
- Maintenance cost
- Downtime associated with maintenance, if applicable
- Purchase price for electricity from the main grid

The analysis software (HOMER) assumes the scenario in which an investment is being planned, so all the purchase prices and associated costs are aligned at the value of current year. In reality, MG set-ups are rarely built from scratch at once; rather, they arrived at their current form through a sequence of expansions, additions and improvements. The economic results indicate that comparison based on TEA between different set-ups is possible and will be informative. On the other hand, the results from the experiment sets suggest how economic efficiency might be improved through an adjustment in the operation scenario of the microgrid.

3.2.3 4D-Power

Overview

The main objective of the Data-Driven Detection of Events in Distribution Power Systems (4D-Power) project is fault detection in power distribution networks using PMU measurements in a Hardware-in-the-Loop (HIL) setup that resemble the real-life communication streaming conditions. A real-time simulated distribution grid, the IEEE 123-nodes test feeder is modelled inside the OPAL-RT multicore target in real-time. The 4D-Power is an extension to the 3D-Power ERIGrid TA project in Summer 2017 by the FSU user group in collaboration with AIT, ARTEMES, OPAL-RT, PSL and Siemens. The 4D-Power will include the generation of 10,000 fault events in order to build a large data repository for Machine Learning algorithms training and validation. 4D-Power is an international team including FSU (USA), AIT (Austria), Opal-RT (Canada), and got support from two PMU manufactures, PSL (USA), and ARTEMES (Austria).

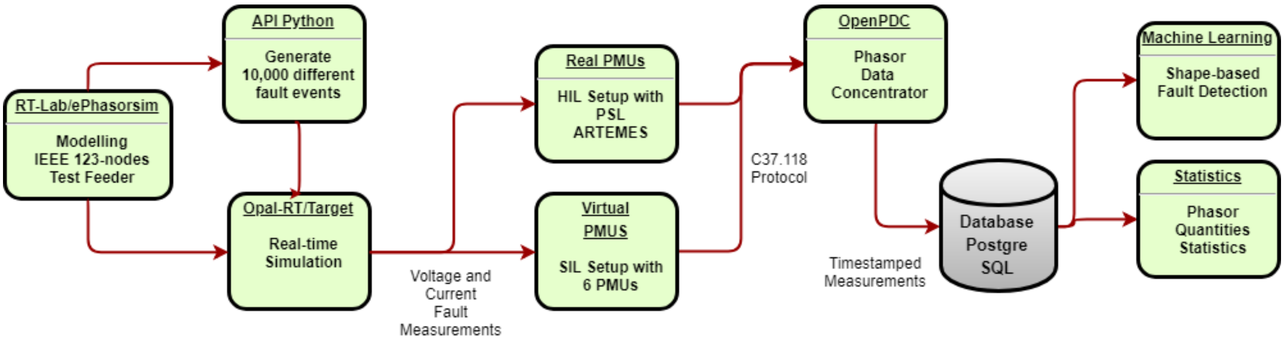

Figure 7: Overall Scheme of 4D-Power Testbed Tasks

The 4D-Power project is divided in the following steps:

- *Objective 1:* Expanding the fault detection scenarios to real world condition using a distribution network model on OPAL-RT HIL and actual PMUs.
- *Objective 2:* develop a large set of fault events that resemble the real-field mining and streaming of measurements obtained in distribution networks for training, testing and subsequent validation of machine learning algorithms. In that sense, 4D-power has created approximately 10,000 fault events that emulate a network's random conditions.
- *Objective 3:* analysing the PMU streams collected data using the advanced machine learning algorithms for event detection developed by the user group.
- *Objective 4:* working closely with industry partners and measurement device manufacturers for analysing impact of multi-vendor PMU desynchronization on event detection.

Motivation

The smart grid revolution is creating a paradigm shift in distribution networks including the dramatic increase in the adoption of distributed energy resources (DER), electric vehicles, energy storage, and controllable loads. This transformation imposes new challenges on existing distribution infrastructure and system operations for stockholders, engineers, operators and customers. Unfortunately, distribution networks historically lag behind transmission networks in terms of observability, measurement accuracy, and data granularity. The changes in the operation of the electric grid dramatically increase the need for tools to monitor and manage distribution networks in a fast, reliable and accurate fashion. The introduction of powerful and accurate measurement devices in the distribution network side such as Phasor Measurement Units (PMU) and the recently introduced Micro-PMU (uPMU), support these tools as a reliable solution.

This project intends to advance towards the applications of high-precision PMUs using an Opal-RT Hardware-In-the-Loop setup combined with the OpenPDC platform to emulate the actual Phasor Data Concentrator (PDC) that collects data from multiple actual PMU made by different vendors, including PSL, and ARTEMES. Furthermore, this work is focused on producing realistic data set of different fault events in distribution networks. Data sets that include the different faults are scarce and often unlabelled. Therefore, it is challenging for new machine learning, signal processing, and statistical methods to be tested and validated for fault detection applications. Hence the proposed experiment paves the way for understanding needs and requirements for PMU data in laboratory setups for future standardization related testing objectives.

Set-up and tests

A real-time simulated distribution grid (e.g. IEEE test feeders) was modelled in the multicore Opal-RT real-time simulator provided by the Smart Electricity Systems and Technologies Laboratory (SmartEST) connected to two PMUs from different vendors. The solver of choice for the real-time simulation is ePhasorsim, an Opal-RT tool that has the advantage of having an Application Programming Interface (API) in Python. This feature allows running a script with different control signals in an automatic manner. In 4D-Power, the user group utilized the API Python to execute a sequence of faults with randomly-generated impedances in order to have a large dataset for event detection algorithms' training and testing purposes. There are several virtual PMUs using PMU model provided by Opal-RT/ePhasorsim. The network of virtual and actual PMUs operates under normal conditions prior to setting different fault types (balanced and unbalanced) to obtain random fault scenarios for detection and classification testing purposes. Communication setup complies with the IEC 61850 and the phasor magnitude, and angle measurements are then streamed under the IEEE standard C37.118. An open-source phasor data concentrator (i.e., OpenPDC) used to retrieve the synchrophasor readings and store them in the database with support for free alternatives such as PostgreSQL. Finally, the machine learning and statistical algorithms in R and Python are executed to determine the fault event locations and classification.

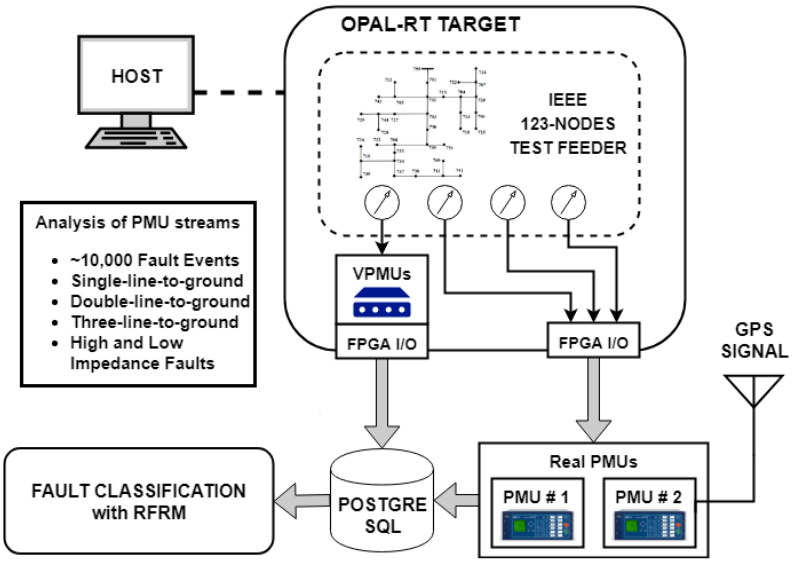

Figure 8: Scheme of the real-time evaluation framework (4D-Power)

Results and learnings

The project took place in AIT: SmartEST laboratory. A data set was created through the measurements of 8 virtual PMUs modelled in Opal-RT. Also, two actual PMUs were connected in HIL setup for monitoring the IEEE 123-nodes test feeder. The user group repeated a similar setup for the five experiments achieved, where each experiment varied the fault location and fault impedances.

The primary objective was providing a testbed for the integration of multi vendors PMU devices that are already used in power distribution networks monitoring. Also integrating virtual PMUs in Opal-RT environment with actual PMUs. Major contributions of the project are:

- The expansion of the testbed to a larger grid, the IEEE 123 test-feeder, which is more realistic given its size and its characteristics.
- the creation of a large dataset of fault events in this model, with approximately 10,000 fault events of line-to-ground faults.
- The inclusion of fault impedances changes when simulating this large number of faults
- Dealing with different sampling rates, configurations, calculation algorithms, and as it was determined, different time synchronization references.

3.2.4 SunHiLL

Overview

The aim of this research was to build a real-time co-simulation platform for a sub-urban area, Sundom Smart Grid (SSG) in Vaasa, Finland. The case studies performed with the developed platform were related to technical Ancillary Services (AS), particularly to reactive power control provided by Distributed Energy Resources (DER), connected to Medium Voltage (MV) and Low Voltage (LV) distribution networks. The developed real time co-simulation platform is based on OPAL-RT's real-time simulation system OP5600, consisting of power system simulations with ePhasorsim (frequency domain/phasor or RMS type), control and communications simulations with eMegasim (time domain/EMT or discrete type).

Earlier developed base scenarios of the power grid were modelled with PowerFactory software, where the load and generation data, as well as the voltage in the HV side were defined based on the results of earlier simulations with Simscape Powersystems. The developed Reactive Power Window (RPW) control algorithm was implemented as a controller for the MV connected 3.6. MW Wind Turbine (WT) converter to control reactive power flow at the HV/MV connection point of the simulated power system. Controller-hardware-in-the-loop (CHIL) tests were performed in several different network scenarios. The tested hardware, were BeagleBoneBlack (BBB) and FPGA. CHIL test results showed, the FPGA was more reliable than the BBB to perform CHIL tests, therefore for further studies, when aiming CHIL tests, FPGA is preferable. The developed test bed offers a flexibility platform to enable the operation of microgrid flexible resources in different technical service markets.

Motivation

The standardization of microgrid controllers is still in its development phase. The majority of IEEE and IEC standards are in development. Therefore, it is essential to build up a comprehensive test platform for microgrid controllers that can perform the simulations (CHIL) and tests of different types of required functionalities of microgrid controllers. In addition, the test platform should be flexible so that it can be transformed into different kinds of microgrids, which can be a MV network, a MV feeder or a LV network located in rural, sub-urban or urban area. Options for ancillary services are one main focus on the development of Smart Grids and microgrids, which is a result but also a possibility due to massive implementation of distributed generation (DG) units. Sundom Smart Grid, Innovation Cell Finland in DeCAS project, enables the development of ancillary service solutions for future grids over traditional boundaries from the high voltage level to the LV level. SSG is a pilot living lab jointly created by ABB, Vaasan Sähköverkko (DSO), Elisa (communications) and University of Vaasa.

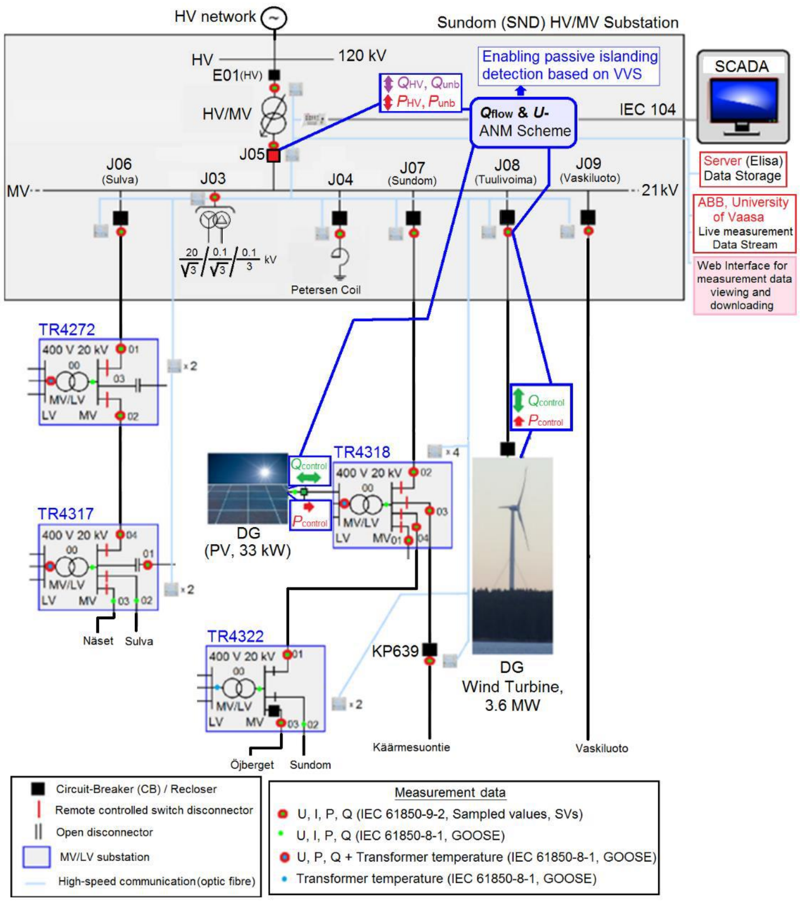

Figure 9: On-line diagram of Sundom Smart Grid living lab

The aim of this research is to study and develop a real-time co-simulation platform integrating real measurement data stream from SSG, a simulated power grid, communications, control functions, CHIL and a communications emulator for the future microgrid studies. The benefit of this developed platform could be realized by different use cases e.g. for demand response (DR) and technical AS actions for the sub-urban area, living lab SSG. The research and development work had the following phases:

- Determination of requirements for the simulation platform based on the developed use cases
- Model development
- SIL simulation cases run
- Platform preparation
- CHIL simulation cases run

Set-up and tests

The offline simulations were performed by Simscape PowerSystems (SPS), as well as by eMegasim + ePhasorsim. The real-time simulations were performed for SIL and CHIL testing by OP5600. The test case study and the automation/control system are modelled using the Simscape PowerSystems (MATLAB/Simulink) Toolbox. Opal-RT has the provision to publish and subscribe to GOOSE messages. Active power *P* and re-active power *Q* was read from the predefined point inside the model and grouped in a dataset to be published by IEC 61850 GOOSE protocol.

The platform consists of RT power system simulator to model the grid, the corresponding controllers and the communication protocols. The simulation platform had the capability to model the grid (in phasor domain) and controllers (in time domain). The system was OPAL OP5600 HW with eMegasim (time domain) and ePhasorsim (phasor domain) environments via Simulink/Matlab and RT-Lab software.

Results and learnings

At OFFIS: SESA-Lab facilities, a comparison was made for SIL and CHIL simulations. The comparison in selected RPW limits TSO was done between BBB (Test 10) and FPGA (Test 7). In Figure 10 is presented the reactive power flow from the WT converter. It can be noticed that there is difference in the operation that might be explained with the processing performance that came out from the very first Q_{set} parameters. The other reason might be that the controller is not predictive i.e. Q_{set} is lagging the measured (Q, P) points.

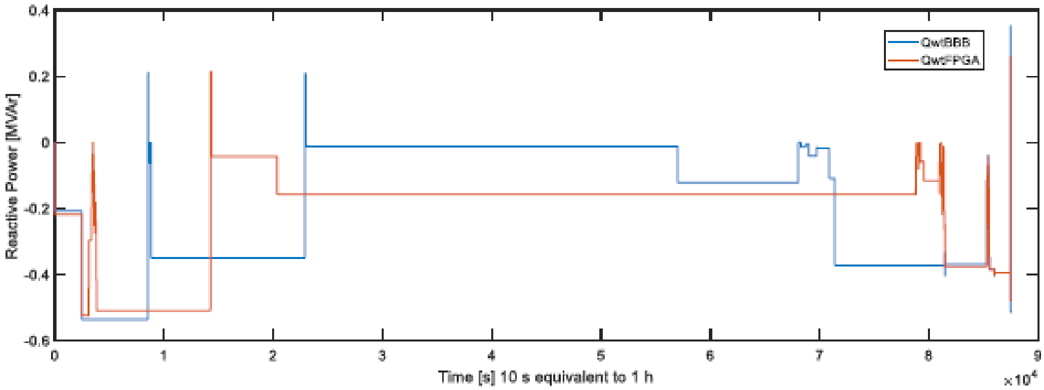

Figure 10: Reactive power of the WT converter in Scenario 2018/2 CHIL BBB and FPGA, when Ts = 0.1 s, input data was interpolated and RPW control was set up according to TSO limits, except QD1 limit to 0

The round-trip GOOSE latency for the BBB and for the FPGA are presented. The average round trip latency calculation was for BBB 4.548406 ms and for FPGA 2.384781 ms. From the achieved results, it is obviously clear that the FPGA is a more promising instrument with less round-trip latency (2.3ms) in which that could better be used for the smart grid/microgrid central controller SGCC/MGCC. Finally, it was concluded that he RPW controller should be predictive in order that (*Q*, *P*) points would stay inside the window reliably. Now the adaptive control followed the measurements and made a decision about a new set point if needed. So, to say the control was all the time “late”. Next, a predictive tool should be implemented to the RPW control.

3.2.5 DEFINIT

Overview

This project tested the capability of the GridEye measurements and algorithms for fault identification in distribution grids. Its realisation allowed testing and improving the performance of fault identification algorithms of the GridEye system. The Power Networks Demonstration Centre (PNDC) of the University of Strathclyde was the host institute providing access to their infrastructure. This infrastructure used includes *i)* the medium and low voltage network with a primary substation and 4 secondary substations, *ii)* fault thrower for throwing different single-phase, two-phase, and three-phase faults, *iii)* single-phase and three-phase loads for providing different operating loading levels, *iv)* switch to modify grid configuration from radial to ring, and *v)* measurement equipment including MV sensors with Beckhoff analogue acquisition cards and LV Fluke power quality measurement devices. Four GridEye cells were installed in the network measuring voltages and currents in MV and LV network.

Motivation

Based on investigations in the literature and patents as well as the current industry practices and products the following challenges have been identified for fault identification in MV grids

- Need for a dedicated device for fault identification with associated infrastructure and installation costs
- Need for MV voltage measurements and voltage measurement transformers
- Using a centralized approach which requires communication infrastructure
- Impact of bidirectional power flows is not taken into consideration
- Noting that the fault identification in LV grids has received very little attention

Based on these findings, algorithms were designed to use GridEye measurements for fault identification in low and medium voltage grids. The particularity of these algorithms is: *i)* only a limited number of measurements, including LV voltages and currents and MV currents are needed, *ii)* removing the hardware and installation costs for MV voltage measurements, *iii)* decentralized approach with minimum use of communication, *iv)* no need for a dedicated device only for fault identification and re-moving its hardware and installation costs.

Set-up and tests

The system under test was the GridEye monitoring system of DEPsys. This is comprised of an MCU100 unit and up to three SUR100 units, daisy chained to the MCU. An SUR provides current monitoring through the attached Rogowski coils. Voltage is measured directly by the MCU. The PNDC MV test network configuration, installation locations, and summarized tests of the GridEye system are illustrated below.

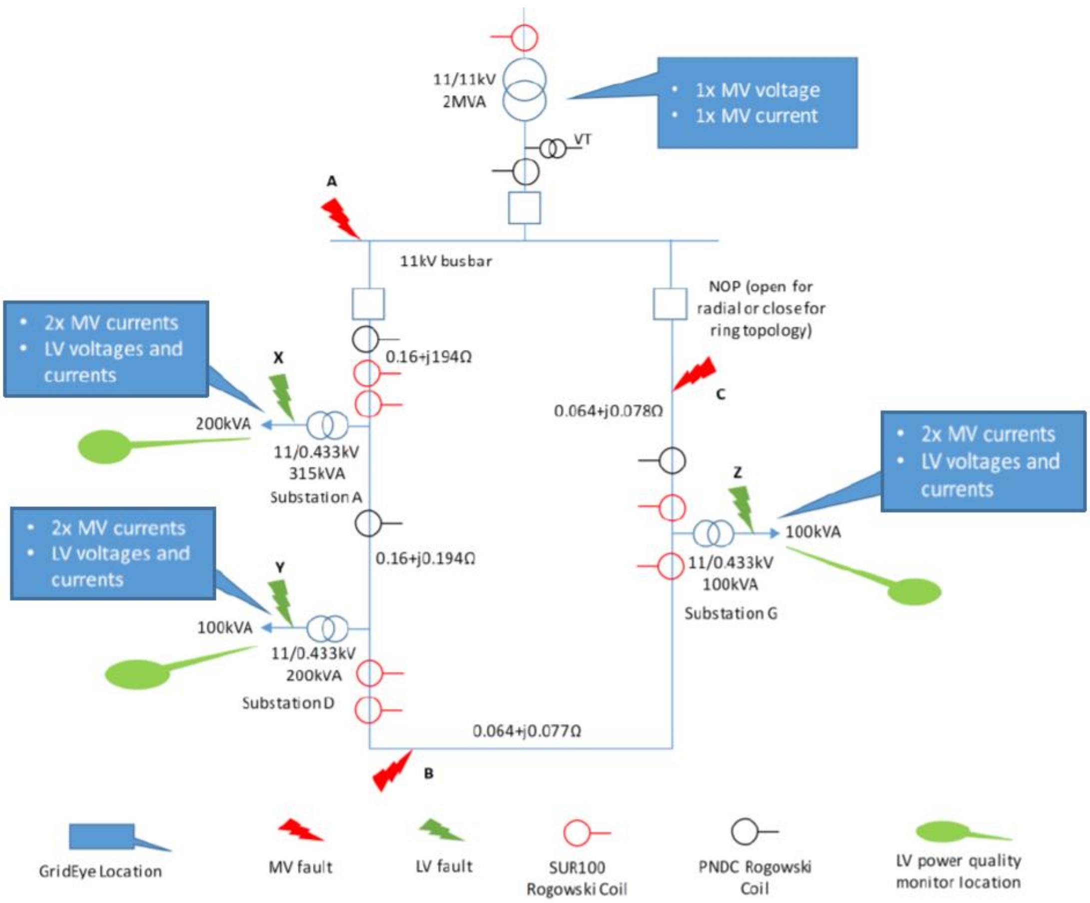

Figure 11: Test network configuration

Table 5: Test schedule

Test category	Tests applied
MV faults	• Fault location: A, B & C. • Fault type: L1-G (R_f = 20 Ω), L1-L2 (R_f = 60 Ω), L1-L2-L3-G ($R_{f1\text{-}3}$ = 150 Ω, R_{fg} = 20 Ω) Each fault type will be repeated three times at each location. The fault scenarios will be applied for radial and ring network configurations.
LV faults	• Fault location: X, Y & Z applied at LV test bays downstream of the substation LV output. • Fault type: L1-G (R_f = 0 Ω), L1-L2 (R_f = 0 Ω), L1-L2-L3-G (R_f = 0 Ω). Each fault type will be repeated three times at each location.
Loading conditions	• Reduction of total load by 20 kW steps to 0 kW. • Increase of total load by 20 kW steps from 0 kW to maximum loading. • Apply a power factor of 0.9 to the total load. The above loading scenarios will be repeated for radial and ring network configurations. • Apply a single-phase load of 30 kW to substation A, while three-phase loads of 80 kW are applied to substations D & G.
Transformer inrush	Close MV circuit breaker at the primary substation to energise the test network while substation transformers A, D & G are connected.

Results and learnings

The performed tests were carried out in PNDC and have allowed to collect measurement data when different types of faults (earth fault, 2-phase fault, 3-phase fault) are applied in MV and LV grids, resembling various real grid operating conditions and configurations. Examples of earth fault measurements are given in below.

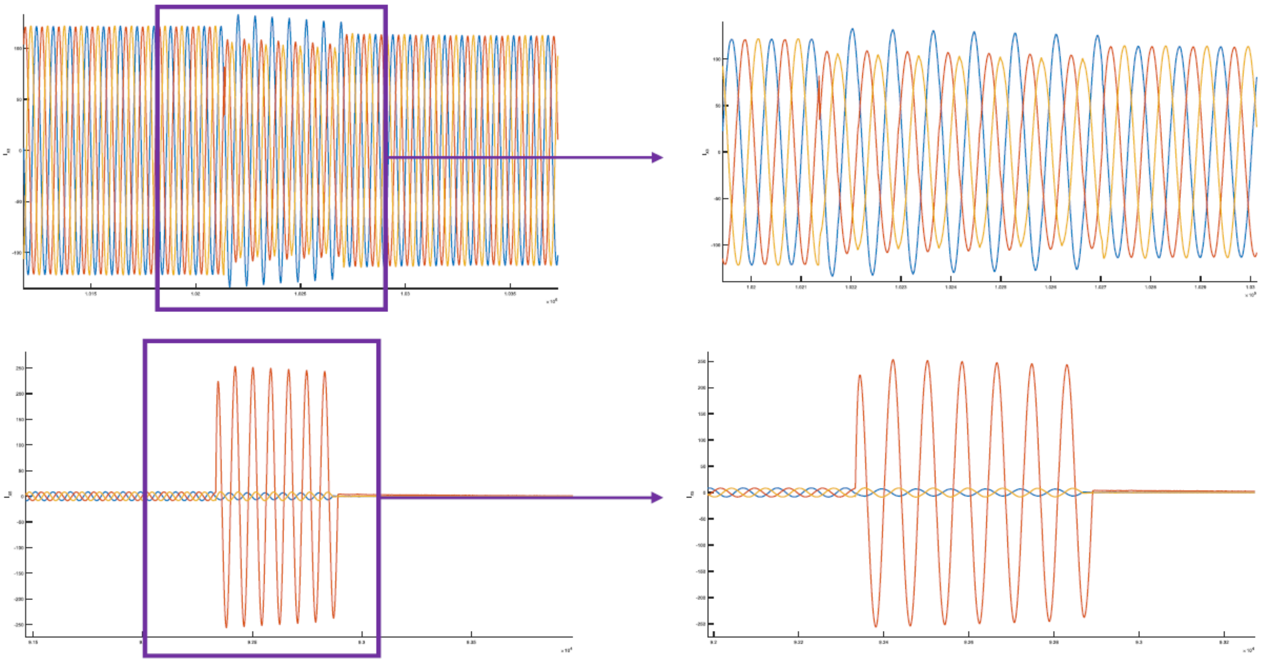

Figure 12: Examples of earth faults measurements

These measurements have allowed the validation of the fault identification algorithms. They have eventually contributed to acceleration of the time-to-market for the fault identification application.

3.2.6 HILT_AS_DRES

Overview

In spite of many AS are proposed in the specialized literature, this proposal focuses exclusively on the provision of Virtual Inertia (VI) and High-Frequency Power Smoothing (HFPS) which are directly related to the minimization of grid frequency variations. On the one hand, VI tries to emulate the behaviour of traditional SG just after a frequency excursion. On the other hand, HFPS tries to smooth the output power of the distributed renewable energy sources (DRES) due to the uncontrollable nature of the energy resource to mitigate frequency variations. For doing so, it is necessary to effectively control the injected active power to the grid being necessary to incorporate energy storage in the traditional DRES interfaces. Therefore, the objective of this proposal is to test in a Power Hardware-in-the-Loop (PHIL) environment a new DRES interface incorporating in its DC bus the required Fast Energy Storage System (FESS) for providing VI and HFPS. To achieve this objective, several devices are used which to be experimentally have validated operating individually and jointly. Therefore, a series of tests is designed to achieve the final objective in a safe and robust way.

Motivation

The replacement of the generation based on fossil origin fuels by the generation of renewable origin not only imply a change of the primary energy source but also of the electrical generation devices and their control which will signify a challenge to operate the electrical system in a stable and efficient way with these new resources. DRESs replace the SGs by electronic-based generation which by itself is not able to provide inertia to the system and the intermittency of renewable generation leads to the impossibility of generating a dispatchable power. This causes two major problems among others. First, a significant decrease in rotational inertia of the power system which may causes large frequency variations in case severe disturbances leading to frequency instability and blackouts due to operation of islanding relays. Second, the undispatchable nature of the primary energy source (PV or WP) produces continuous variations of the injected power to the system which not only may cause frequency fluctuations but also other problems like voltage flicker. The specific objectives of the proposal can be summarized in the following points:

- Experimental validation of the capabilities of the DRES interface for providing VI and HFPS.
- Analysis of the deviations with respect to the simulation results.
- Limitations of the proposed DRES interface
- Validation of the quantification methodology used for measuring the provided ASs.
- Definition of a standardized testing methodology

Set-up and tests

In order to achieve the objectives, set out in the previous subsection, it is necessary to have three devices that are capable of reproducing the integration of a DRES into an electric power system. The main components of the testbed are:

- *PV System Emulation:* The primary energy source is emulated by a controlled DC source. This source is provided by TU Delft and it allows local control or remote control by externally providing setpoints.
- *Specimen under test:* This device consists of a voltage source converter (VSC) capable of transforming the DC current provided by the PV plant in AC current in order to integrate the PV plant into the electrical system. This is provided by the Universidad de Sevilla.
- *Grid Emulation:* The behaviour of the electrical system will be reproduced by a back-to-back (B2B) converter provided by TU Delft.

The electrical connection of the experimental assembly and the signals exchanged between them is shown in Figure 13.

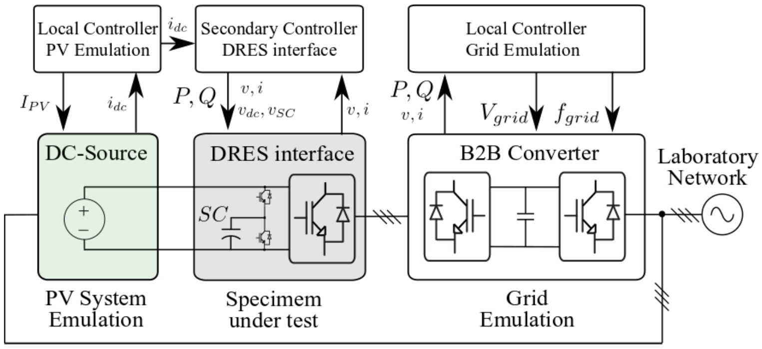

Figure 13: Test setup involving the DRES interface and the PHIL platform

The tests conducted are:

1. Unitary Tests
2. Integration test of the experimental setup
3. Provision of auxiliary services corresponding to Inertia and HFPS

Results and learnings

The laboratory work carried out in the TUDelft: ESE-Lab facilities with the DRES interface developed by the University of Seville has allowed the validation of all control strategies designed for this prototype in a unified way. In addition, a safe and robust test protocol has been designed for the interconnection of the different electronic power equipment involved in the experimental setup. These tests have been carried out in a successful way, allowing progress towards the final objective: provision of auxiliary services HFPS and Inertia in a PHIL system. The tests corresponding to these services demonstrate that the PHIL system can emulate the interconnection of a DRES to a power system and use the UC energy to supply both services. Finally, this work has reinforced the collaboration between both research groups that will lead to new work in the future.

3.2.7 EVACC

Overview

In this project, a machine learning-based communication-free EV charge control strategy is developed to mitigate the issues caused by uncontrolled EV charging. Furthermore, fairness is ensured among the EVs available at different locations in the power distribution system. To do so, a nodal voltage and the voltage-to-load sensitivity, are measured at each load node, which are fed to the EV charge controller. The output of the charge controller is the charging rate of an EV. In fact, an upstream node is generally less sensitive to changes in the load as it is closer to the feeding point. In order to validate the robustness of the proposed controller, light and heavy loading conditions are considered which mimics the daily, monthly, yearly, and seasonal load variations.

This EVACC project presents a new Artificial Intelligence (AI)-based autonomous EV charge controller. Online local measurement is performed for calculating sensitivity, i.e., changes in voltage to the changes in load at a node. And local voltage measurements along with sensitivity are the controller inputs. The ML-inclusion adds robustness in the system regarding possible system changes in loading conditions and system re-configurations. Main contributions are:

- An approach for estimating, in real-time, the sensitivity of point-of-charging (POC) voltage to load power changes using local measurements only in the real-time digital simulator (RTDS).
- A new ML-based communication-free EV charge control strategy that is dependent on the local nodal voltage and sensitivity measurements.

Results prove that the proposed controller effectively improves the voltage profiles while ensuring fairness among the EVs connected at various charging points in the system.

Motivation

Auto industries are urged by fuel price volatility and gowning public interest in renewable fuel-powered transportation to invest in sustainable fuel-based vehicles. Consequently, for internal combustion engines (ICE) the shift from fossil fuels is addressed urgently through the introduction of electric vehicles (EVs). ICE-based cars are replaced by plug-in electric vehicles (PEVs) and Hybrid electric vehicles (HEVs). While EVs offer greater benefits to the society they may pose significant operational problems to the distribution systems if their charging is uncontrolled [6]. Line congestions, low voltage sags, trans-former overloads, and price volatility are more prominent for large-scale EV integrations in the distribution systems. To address the uncontrolled charging of EVs and issues of under-voltages, higher losses, phase unbalance, and demand peaks, we propose an autonomous charge controller, that addresses the problems associated with the EV charging. In this research work, the ML approach is being used on the extensive data generated by the RTDS in the VTT MultiPower lab. Voltage and online sensitivity estimation in RTDS at the nodes of our test system serve as the learning parameters for the MLP network to decide on EV charging rates. Coming up with optimum layers and learning algorithms is an important step in determining the same charging rate for all the EVs available at upstream and downstream nodes of the distribution system. As to keep customers satisfied and distribution system relieved of voltage mitigations fairness is necessary. The neural network (NN)-based learning approach achieves that through training on the generated dataset.

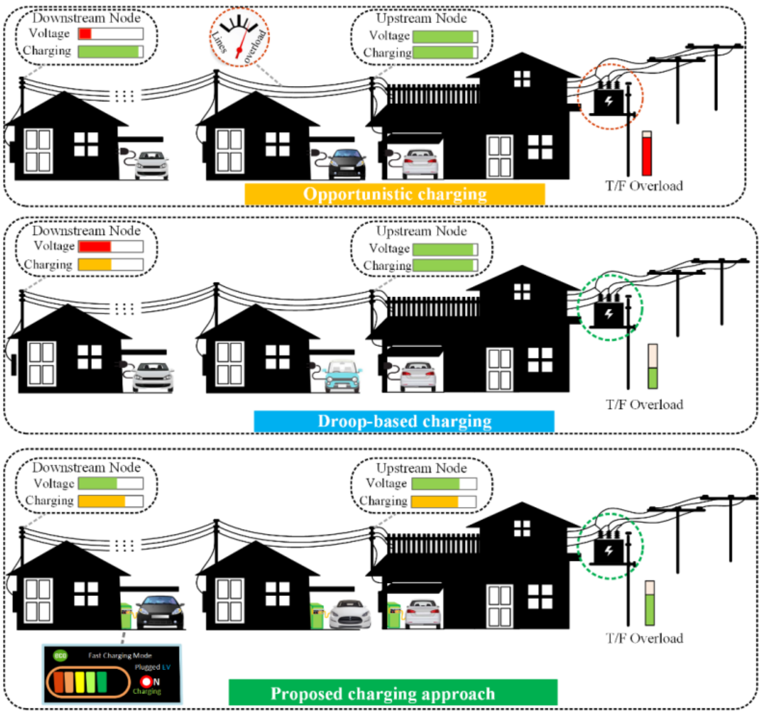

Figure 14: Overview of EV charge control structure

Set-up and tests

The following tests are executed in the project "EVACC":

- Online sensitivity estimation at the nodes in the system. Sensitivity estimated from an online method in RTDS coincides with sensitivities calculated from the direct diagonal entries in DIgSILENT PowerFactory 2019.

- Voltage profile for light loading and heavy loadings in the distribution system are obtained and used together with sensitivities in training NNs.
- A Multi-Layer perceptron network is used to derive the charging reduction factors for voltage violation elimination.
- Training and testing of the neural networks.

The test system described in the previous section is used to assess and validate the proposed EV charge controller. In order to incorporate daily, monthly, and yearly load variations, different loading conditions are considered. Also, the performance of many EV charge controllers such as opportunistic, proportional, nonlinear, and voltage-and-sensitivity-based chargers are compared with the pro-posed EV charge controller.

Results and learnings

The project was conducted in VTT: MP-Espoo facilities. Opportunistic, proportional voltage-based, voltage-based nonlinear, and voltage-and-sensitivity-based controllers have some sort of limitations, such as power quality issues and/or unfair charging patterns. The artificial intelligence based proposed controller solves these issues. After obtaining all the measurement data, the controller is trained using NN with the data. Several retraining, layers variation, and a number of neurons are performed as a hit and trial method since there is no single criterion regarding the best number of layers or the number of neurons in each layer. By employing the proposed charging method, the voltage is always above the minimum allowed voltage during both light and heavy loading. Additionally, the EVs are charged much faster compared to other techniques. Another noteworthy aspect of the proposed controller is fair charging among the EVs available at different locations in the system.

4 Reflection on Results of the TA Programme

Over and above the outcomes and learning presented in this report, a short questionnaire has been developed and circulated among the host RIs to elicit further insights and learnings from the TA activities. The questions posed to the host RIs in the questionnaire are (along with brief explanatory notes):

1. What has the user group learned from the project?
   Guide: learnings that would have otherwise not have been obtained without the TA provisions.
2. What was the value/impact of providing access to the user group?
   Guide: direct impact on the user group's solution or research progress.
3. What was the learning for the RI host and the ERIGrid community?
   Guide: learnings that impact the development of testing procedures and facilities in the RI as well as the ability to conduct HIL, co-simulation and distributed RI experiments.
4. Where the Holistic Testing Description (HTD) has been applied, to what extent did the project demonstrate the value of the HTD and what suggestions do you have to improve it?
   Guide: was the HTD validated? Any shortcomings identified? Any recommendations for improvement?
5. Upon reflecting on the TA project conduct and outcomes, what would the RI host have done differently?
   Guide: this can include technical and non-technical aspects such as method adopted for designing the experiments or logistical planning of the user group's stay.
6. Any things that worked particularly well during the TA provision process (before, during and after the use group access) that should remain and be encouraged during ERIGrid 2.0 TA?
   Guide: this can include technical and non-technical aspects.
7. Any things that did not work particularly well during the TA provision process (before, during and after the use group access) that should be improved during ERIGrid II TA?
   Guide: this can include technical and non-technical aspects.

The responses to this questionnaire have been consolidated in outcomes and recommendations and summarised in the following two sections.

4.1 Summary of Outcomes

The key outcomes and impact of the TA2 activities for users are:

- The TA has provided access to state of the art infrastructure for realistic modelling and testing under close to real-world conditions, which TA users did not have access to
- TA activities enabled the users to develop their solutions and research in a meaningful way based on results and identified shortcomings during testing. This would result in further development or readiness for commercial trials. Furthermore, access to the RI and associated expertise added value to the experience in terms of knowledge exchange and highlighting the importance of systems validation.

The key outcomes and impact of the TA2 activities for host RIs are:

- Based on their TA experience, some host RIs are considering infrastructure improvements, introduction of new testing functions and features and the adoption of new business models
- The running of TA projects had a positive impact on the organisation and management skills of host RIs particularly during the planning and execution phases of the activities
- TA activities were an opportunity for synergistic use of resources and infrastructure between academia and industry. Some of these synergies were realised with co-authored publications that identify key contributions of and next steps for both parties

The key outcomes and learning for ERIGrid are:

- The HTD was not fully developed from the beginning of the TA2 activities. However, where the HTD was used during the planning phase of the user project, it was found that its use positively impacted the success of the project in terms of articulating the project outcomes and achieving the test objectives.
- Splitting of larger user projects into different phases or multiple applications demonstrated to be an efficient way of achieving the project outcomes, accelerating the work and maximising the value of RI use.

4.2 Summary of Recommendations

The following is a summary of the key recommendations to be considered during ERIGrid 2.0:

- Lesson learned should be collected as part of the TA delivery process. It is suggested that at the end of each project, the host RI should collate a list of lessons learned and these are then collected in a common database for all TA projects. This necessarily requires that the host logs these lessons throughout the project from planning through to execution and reporting. The lessons learned pertain to (non-an exhaustive list):
  - Applicability of the designed experiment to meeting the test objectives
  - Documentation related to the description of RI testing facilities, capabilities, configurations
  - Utilisation of the HTD and communication of its value to the user group
  - Utilisation of regular TA2 work package virtual meetings to share learnings, refine the access procedures and adopt best experimental practices
- Accelerate the development and implementation of multi-RI testing techniques in host RIs. It was found that experiments executed over multiple-RI required further development and extension of the underpinning techniques including:
  - Real-time modelling for HIL testing
  - Incorporating multiple-RI testing specification into the HTD
- Prior to conducting the experiments, a period of familiarisation to the laboratory and real-time modelling capabilities should be added to de-risk the research project. This would help in focusing and refining the test objectives taking into account the RI capabilities and reducing risks. It was suggested that a planning visit by the user could be arranged, however this may not be practical due to time and cost constraints. So, an alternative such as remote training and sharing of relevant laboratory documentation is recommended.
- HTD and its incorporation in TA activities should be improved. Based on user and RI feedback the following improvements should be considered:
  - Additional explanatory notes would be helpful in implementing the HTD
  - The HTD should be introduced to the user with a set of example case studies to demonstrate the value of the process and help in adoption
  - It may be required that adopting the HTD is a prerequisite for TA projects in ERIGrid 2.0 where appropriate. This would build the evidence base demonstrating the value of the HTD and help in refining it in light of user and host feedback.
- The planning of each TA should be improved. The importance of the planning phase for each user project cannot be underestimated. Adequate preparations and time invested in this phase increases the likelihood of timely completion and achieving of project objectives. Planning should ensure:
  - Identifying a single point of contact from the RI to ensure timely communication and planning with the user group
  - Well defined timing of user group stay
  - Clearer definition of RI capabilities and limitations
  - Encouraging the use of the HTD, even in a simple form such as the HTD canvas developed in NA5

- TA management could be improved to ensure efficiency of host RI execution of projects and a more streamlined TA user experience. In light of procedures developed within NA3 work package, or equivalent work package in ERIGrid 2.0, the following recommendations are suggested:
  - Reduction of paperwork required for the access where possible
  - In some cases, it may be more straightforward for hosts to arrange travel and accommodation for the use group depending on the complexity of expenses claims procedures
  - More detailed plans that are agreed by the host and user group may be required

5 Summary and Conclusion

The TA2 WP facilitated 38 TA user projects which were diverse in terms of user groups and purpose of their RI visits. The benefits for the user groups through the access projects have been highlighted. The findings from TA2 user projects went beyond the scope originally defined for TA2, and motivated and included extensions of capabilities of some of the participating RI.

Perhaps equally important, the user groups engaged with the hosting RI creating an impact on the ERIGrid community of RI researchers and hosts. Apart from the benefits achieved directly for the user projects, the RI also grew in their capabilities by servicing the advanced user requests. In collaboration with the user groups an impressive number of joint publications could be achieved.

The observations from RI hosts have been summarised, both technical and organisational learnings have been highlighted. Finally, a set of recommendations for future improvement of access have been formulated based on four years of transnational access experience of the ERIGrid RI teams.

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7 Annex

7.1 List of Figures

7.2 List of Tables