# European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out – Second Edition

*Work Package WP5*

## NA4 - Iterative Creation of Scenarios and Test Case Profiles

*Deliverable D5.1*

## D-NA4.1 Functional Scenarios


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| **ACER** | Agency for the Cooperation of Energy Regulators |
| **ADC** | Application Domain Cube |
| **aFCC** | Adaptive Frequency Containment Control |
| **aFRR** | Automatic Frequency Restoration Reserve |
| **AI** | Artificial Intelligence |
| **AMI** | Advanced Metering Infrastructure |
| **ATP** | Automated Trading Platform |
| **BESS** | Battery Energy Storage System |
| **BMS** | Building Management System |
| **BRC** | Balance Restoration Control |
| **BSC** | Balance Steering Control |
| **CACM** | Capacity Allocation and Congestion Management |
| **CHIL** | Control Hardware-in-the-Loop |
| **CHP** | Combined Heat and Power |
| **CT** | Current Transformer |
| **DER** | Distributed Energy Resource |
| **DFA** | Distributed Flexibility Asset |
| **DG** | Distributed Generation |
| **DLFM** | Distribution Level Flexibility Market |
| **DMS** | Distribution Management System |
| **DR** | Demand Response |
| **DSO** | Distribution System Operator |
| **EC** | European Commission |
| **EH** | Energy Hub |
| **EMS** | Energy Management System |
| **EMT** | Electromagnetic Transient |
| **EPC** | Engineering Procurement Construction |
| **EPES** | Electrical Power and Energy System |
| **ESO** | European Standards Organization |
| **ESP** | Energy Storage Partnership |
| **EU** | European Union |
| **EV** | Electric Vehicle |
| **EVSE** | Electric Vehicle Supply Equipment |
| **FLIRS** | Fault Location, Isolation and Restoration System |
| **FLSR** | Fault Location and Service Restoration |
| **FMO** | Flexibility Market Operator |
| **FPGA** | Field-Programmable Gate Array |
| **FRT** | Fault Ride Through |
| **GHG** | Greenhouse Gas |
| **GIS** | Geographic Information System |
| **GSCAM** | Generic Smart Cities Architecture Model |
| **HIL** | Hardware-in-the-Loop |
| **HMI** | Human Machine Interface |
| **HTD** | Holistic Test Description |
| **HV** | High-Voltage |
| **HVAC** | Heating, Ventilation, and Air Conditioning |
| **HVDC** | High-Voltage DC |
| **ICT** | Information and Communication Technology |

| | |
|---|---|
| **IEC** | International Electrotechnical Commission |
| **IED** | Intelligent Electronic Device |
| **IoT** | Internet of Things |
| **IRPC** | Inertia Response Power Control |
| **IT** | Information Technology |
| **JP** | Joint Programmes |
| **JRA** | Joint Research Activity |
| **KPI** | Key Performance Indicator |
| **LEC** | Local Energy Community |
| **LV** | Low-Voltage |
| **MAS** | Multi-Agent System |
| **MV** | Medium-Voltage |
| **MU** | Merging Unit |
| **NA** | Networking Activity |
| **NECP** | National Energy and Climate Plan |
| **OLTC** | On Load Tap Changer |
| **OMP** | Organized Market Place |
| **OPF** | Optimal Power Flow |
| **OT** | Operational Technology |
| **P2H** | Power-to-Heat |
| **P2P** | Peer-to-Peer |
| **PE** | Power Electronics |
| **PHIL** | Power Hardware-in-the-Loop |
| **PMU** | Phasor Measurement Unit |
| **PPC** | Power Plant Controller |
| **PPVC** | Post Primary Voltage Control |
| **PSDPC** | Power System Dynamic Performance Committee |
| **PV** | Photovoltaics |
| **PVC** | Primary Voltage Control |
| **RES** | Renewable Energy Sources |
| **RI** | Research Infrastructure |
| **RTU** | Remote Terminal Unit |
| **SCADA** | Supervisory Control And Data Acquisition |
| **SET Plan** | European Strategic Energy Technology Plan |
| **SGAM** | Smart Grid Architecture Model |
| **TA** | Trans-national Access |
| **TC** | Test Case |
| **TDS** | Time Domain Simulations |
| **THD** | Total Harmonic Distortion |
| **TSO** | Transmission System Operator |
| **UC** | Use Case |
| **V2G** | Vehicle-to-Grid |
| **VA** | Virtual Access |
| **VPP** | Virtual Power Plant |
| **VPS** | Virtual Power System |
| **VT** | Voltage Transformer |
| **WoC** | Web-of-Cells |
| **WT** | Wind Turbine |

# Executive Summary

This deliverable describes the work conducted in ERIGrid 2.0 task NA4.1 'Definition of Functional Scenarios'. The work has been conducted via a survey and a brainstorming workshop. The results are six Functional Scenarios:

1. Ancillary services provided by Distributed Energy Resources (DERs) and active grid assets,
2. Microgrids & energy communities,
3. Sector coupling,
4. Frequency and voltage stability in inverter dominated power systems,
5. Aggregation and flexibility management, and
6. Digitalisation,

which describe the overarching topics within ERIGrid 2.0. The Functional Scenarios will be used as an input in further ERIGrid 2.0 work.

Smart grid and smart energy systems solutions have become complex and multidisciplinary. With the further integration of Information and Communication Technology (ICT) and other energy systems new testing scenarios, profiles, and processes must be defined. In order to achieve this, big trends affecting research, testing, and validation processes have been reviewed, with a special focus on new aspects such as interoperability testing or digitalisation. The scenario descriptions define requirements, actors, etc. on a functional level. ERIGrid 2.0 work package NA4 'Iterative Creation of Scenarios and Test Case Profiles' addresses these needs. This work has been conducted with emphasis on the alignment with the European Green Deal, further support on the technology validation and roll-out phases, and further integration of the research infrastructures.

A Functional Scenario has been defined as an umbrella term comprising of motivation and relevance for ERIGrid 2.0, system descriptions, use case and test case descriptions, and experimental setup descriptions. Each scenario has a single core idea and is formed on the basis of inclusiveness. Functional Scenarios consider several high-level scenarios in other projects and networks as a background forming the overall circumstances in which the Functional Scenario is considered. The high-level scenarios provide a holistic understanding of the current status and development while also highlighting future visions and requirements impacting the Functional Scenarios. The high-level scenarios also address the high-level drivers for the Functional Scenarios, such as needs for digitalisation of the smart energy systems. Furthermore, Functional Scenarios are related to the generic system configurations developed in ERIGrid and consider the work conducted in ERIGrid as a strong background for ERIGrid 2.0.

The necessity for a mutual understanding of scenarios which are of interest to the ERIGrid 2.0 partners and their research infrastructures and in alignment of the project objectives, led to conducting a survey regarding the first actions of the NA4.1 work. The purpose of this survey was to gather inputs on a set of Functional Scenarios that were analysed in more detail to deduce the most relevant approaches for ERIGrid 2.0. Overall, 15 partners participated in the survey and submitted 35 scenarios. The survey results include scenarios on sector coupling, multi-energy systems, ICT and automation, energy communities, microgrids and low-inertia grids, and stability, control and grid code challenges. Detailed descriptions of Functional Scenarios submitted to the survey are presented in Appendix A: Functional Scenario Survey Data of this deliverable.

The formation of the Functional Scenarios was organised in six working groups, each of which focused on a single Functional Scenario. The decision on the six Functional Scenario was taken during the NA4 regular meetings and the brainstorming workshop itself based on the results of the Functional Scenario survey.

The focus of the first working group has been on a component focused scenario developed based on the survey results on DERs and inverters. The resulting Functional Scenario 1 integrates key components, such as DER inverters and controllers with ICT, control and automation architectures to enable new grid services with the development of interfaces between the active components. The second working group has been focused on topics related to microgrids and energy communities forming Functional Scenario 2 to support the local microgrid and energy community development by enabling flexibility services locally with ICT and control including exploitation of grid intelligence. While the third working group has been working on the survey results on sector coupling and multi-energy systems with Functional Scenario 3 anticipating a massive roll-out of power-to-X components in the near future by developing system level understanding of the impacts on the electrical domain. The fourth working group has been focused on grid management and overall the perspectives of Distribution System Operators (DSOs) and Transmission System Operators (TSOs) resulting in Functional Scenario 4 assuring frequency and voltage stability in low inertia systems through capabilities of Renewable Energy Sources (RES), Distributed Generation (DG), controllable loads and storage systems as well as ICT and control systems. The fifth working group has been based on the survey results comprising of aggregation, flexibility, market and reserve topics and defined Functional Scenario 5 to focus on communication functionality for aggregation, service matching, fail-over, configuration, and interoperability addressing scale-related properties of aggregation and control solutions. Lastly, the sixth working group has been focused on digitalisation including wide range of topics such as ICT infrastructure, communication, automation, control and monitoring. Functional Scenario 6 explores the impact of ICT solutions on the physical (electrical power) system covering new applications of data and data processing as well as new paths for exchanging data.

The Functional Scenario templates used during the brainstorming workshop have been included in the Appendix B: Functional Scenario Templates.

The work started in NA4.1 will continue in NA4.2 and NA4.4 with discussions on more detailed definitions of the test cases which will initially provide the inputs for other project activities. The discourse on the Functional Scenarios is also assumed to support ERIGrid 2.0 physical lab and virtual access work and decision-making beyond ERIGrid 2.0.

# 1 Introduction

## 1.1 Purpose and Scope of the Document

Smart grid and smart energy systems solutions have become complex and multidisciplinary. With the further integration of ICT and other energy systems new testing scenarios, profiles, and processes must be defined. In order to achieve this, big trends affecting research, testing, and validation processes will be reviewed, with a special focus on new aspects such as interoperability testing or digitalisation. The scenario descriptions will define requirements, actors, etc. on a functional level. ERIGrid 2.0 work package NA4 'Iterative Creation of Scenarios and Test Case Profiles' addresses these needs. The main objectives of this work package include:

- Providing relevant scenarios, test case profiles, and use cases,
- Investigating major trends affecting research and validation processes,
- Developing functional scenarios towards use cases with a broad domain view,
- Harmonising the development of holistic test case procedures, test reporting methods and extension to simulation cases,
- Defining a process for updating and maintaining the scenario and use case sets continuously, and
- Communicating the scenario, test cases, and use cases work together with project dissemination activities.

The work of NA4 progresses from holistic high-level functional scenarios towards more detailed use cases. This work will continue by planning the implementation of the use cases in the partner research facilities. Following the general alignments of ERIGrid 2.0, the emphasis of the work has been on:

- Alignment with the European Green Deal,
- Further support on the technology validation and roll-out phases, and
- Further integration of the research infrastructures.

NA4 work is closely linked with other ERIGrid 2.0 work packages. NA4 provides input for JRA1 in terms of identified benchmark cases and development of the reference simulation scenarios and for JRA4 in terms of validation approaches, research infrastructures and their integration.

The work in NA4 is conducted in four tasks, each focusing on a specific stage of the development of scenarios and use cases for the project:

- NA4.1 Definition of Functional Scenarios
  - Identifying major trends affecting validation activities,
  - Developing a methodology for assessing developments in a systematic way together with project stakeholders,
  - Processing and ranking the developments according to their relevance to the project,
  - Scanning similar developments in other projects and initiatives to improve specifications and avoid overlapping,

  - Providing functional scenarios to be applied within the project, and
  - Discussing the functional scenarios with project advisory board and stakeholders.
- NA4.2 Common Reference Test Case Profiles
  - Formulating a set of reference test cases to offer reference profile for harmonisation and bench-marking efforts,
  - Defining test case profiles and use cases applicable in all ERIGrid 2.0 work,
  - Gathering and integrating detailed specifications from work in Joint Research Activity (JRA) work packages, and
  - Providing a collection of exemplary test cases and use cases and a small number of generalised test case profiles for major technology areas.
- NA4.3 Harmonisation of Holistic Test Procedure
  - Collecting feedback and experience from a broad range of users to identify needs for the extension or clarification of the original holistic test case procedure,
  - Harmonising the holistic testing procedure to provide a consistent framework for a broad range of tasks, and
  - Compiling a collection of *best practice applications* to serve as a proof-of-concept and a guide for users.
- NA4.4 Continuous Update of Functional Scenarios and Test Case Profiles
  - Developing a continuous process for keeping the defined scenarios, test case profiles and use cases updated throughout the project and implement it during the whole project duration,
  - Iterating the ideas continuously especially with the advisory board and other relevant stakeholders,
  - Maintaining iteration with other work packages, especially JRAs and Trans-national Access (TA) experiences, and
  - Following supporting development work taking place in EU and national projects, and relevant working groups (e.g., ETIP SNET or EERA JPs).

This deliverable summarises the work conducted within task NA4.1.

## 1.2 Structure of the Document

This document is organised as follows: Section 1 provides information about the report content whereas Section 2 explains the approach used and the decisions made during the work. Furthermore, it describes some earlier developments on the area of high-level scenarios. Section 3 introduces the functional scenario work done within the working groups, and Section 4 discusses further use of the functional scenarios developed. The deliverable is concluded in Section 5. Finally, additional information is provided in the appendices.

# 2 Approach and Terminology

The work of ERIGrid 2.0 NA4 has been launched by defining ERIGrid 2.0 Functional Scenarios. These scenarios are meant to be high-level descriptions, which will provide a foundation for the detailed definitions of use cases and test cases.

The term *scenario* often refers to a description of a possible future vision and the sequence of events impacting the aforementioned vision. The purpose of developing scenarios can be either to predict or to survey possible futures and often encompasses several uncertainties. Scenarios can also guide policy development and decision-making. The ERIGrid 2.0 scenario work focuses on visions reaching year 2050.

The development of scenarios in ERIGrid 2.0 is based on the work initiated in ERIGrid, in which generic system configurations were defined rather than traditional high-level scenarios. The work was based on the e-Highway 2050[1] project methodology for qualification of scenarios aiming to develop scenarios from qualitative to quantitative with the potential to include several static system configurations under one high-level scenario. The quantitative generic system configurations were considered more useful as including detailed technical data to the descriptions is allowed leading to a better foundation for developing use cases and test cases.

ERIGrid generic system configurations, especially use case descriptions, were based on the International Electrotechnical Commission (IEC) PAS 62559 in which formal requirements for use cases and formation of use cases has been standardised (IEC 62559-2, 2015). The use case descriptions formatted according to IEC 62559 can be mapped to the SGAM. In ERIGrid 2.0 Functional Scenarios, these detailed descriptions of use cases with the standardised format are out of scope of this deliverable and are to be considered in the future ERIGrid 2.0 tasks.

## 2.1 Functional Scenario Structure

In ERIGrid 2.0, the high-level scenarios are defined as Functional Scenarios, similarly as in ERIGrid. The following structure has been defined in this work:

- Functional Scenario,
- System Description,
- Motivation,
- Use Case,
- Test Case,
- Experiment Setup, and
- Relevance for ERIGrid 2.0.

Functional Scenario is an umbrella term comprising several systems descriptions, which can each include multiple use cases, test cases and experiment setup descriptions. Each Functional Scenario includes only one motivation and relevance for ERIGrid 2.0 as the aim of the Functional Scenario is to collect and harmonise similar topics and use cases under the same

[1] e-Highway 2050 website

umbrella scenario. The structure of a Functional Scenario is presented in Figure 1, with indications about the possibility for the various items to be present as a single or multiple occurrences.

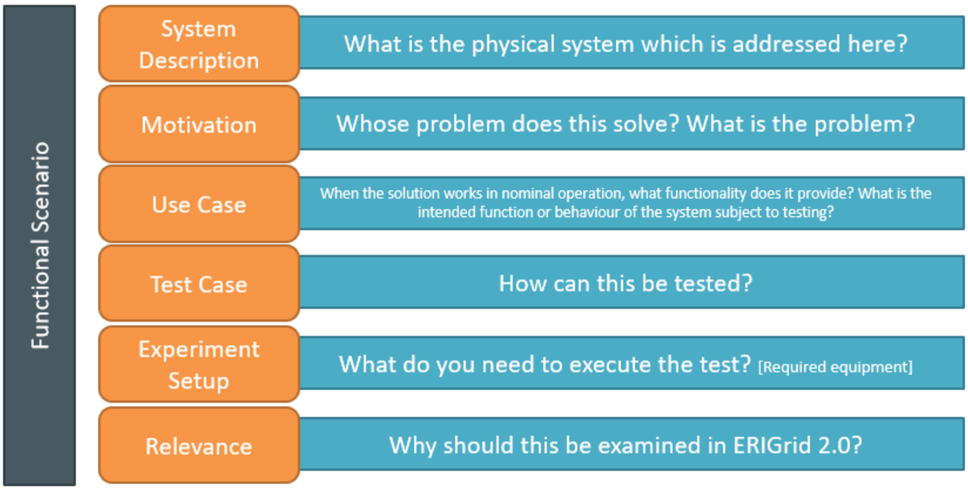


*Figure 1: Functional Scenario structure with 'x1' and 'xN' indicating if each part can be included only once or several times in a single Functional Scenario.*

- *System Description* states the physical system addressed in the Functional Scenario, such as a wind farm connected to a transmission grid. One Functional Scenario can include multiple system descriptions.
- *Motivation* describes the overall purpose of the entire Functional Scenario by explaining the problem that is to be solved and who is impacted by this problem. There is only one motivation per Functional Scenario, thus all the different system descriptions, use cases and test cases under the Functional Scenario converge to the same motivation. The motivation can be either an interesting use case or an interesting testing method, and be valuable due to scientific or business reasons.
- *Use Case* addresses a functionality that the solution provides in nominal operation and the intended function or behaviour of the system subject to testing.
- *Test Case* describes how the solution can be tested.
- *Experimental Setup* describes the equipment required to conduct the testing.
- *Relevance* explains why and how the Functional Scenario is relevant for ERIGrid 2.0. Each Functional Scenario has only one relevance for ERIGrid 2.0, which is shared by all the system descriptions, use cases, test cases and experimental setups included in the Functional Scenario.

Defining the specific relationships between the items is out of the scope of NA4.1 and is to be defined in NA4.2.

In the context of ERIGrid 2.0, the concept of Functional Scenario and its structure, including the use cases and test cases, is to be applied throughout the project. The Functional Scenario work especially aims to support the development work of the research infrastructures and simulation environments by accounting for all the relevant use cases and test cases provided within the project. Therefore, ERIGrid 2.0 Functional Scenarios can also include references to relevant high-level scenarios in related projects.

## 2.2 Background on Existing High-Level Scenarios

### 2.2.1 ERIGrid

In the framework of ERIGrid[2] an approach with similar objectives for specifying high-level scenarios was followed. The specification work was carried out in one of the Joint Research Activities (JRA1) of the project as a collaboration between several work packages. (Mäki et al., 2016) The main objectives of this activity were the following:

- Identifying relevant scenarios and use cases,
- Analysing them in the context of ERIGrid capabilities, and
- Defining needs of extending Research Infrastructure (RI) services or developing new ones,

The approach followed to define the specifications was a top-down analysis which started from high-level generic system configurations and moved towards more practical use cases. The emphasis of this work was to develop an approach that addressed the following aspects:

- Needs of the involved high-level RIs,
- Needs for supporting technology validation and roll-out phases, and
- Potential for integration of the RIs.

Overall, the scenarios defined in this activity aimed to serve as high-level descriptions of the circumstances, providing a basis for more detailed use case and test case definitions (Mäki et al., 2016).

Based on the ERIGrid analysis the term scenario often refers to some visionary descriptions of future development and the factors influencing it. Therefore, in the course of ERIGrid, generic system configurations were considered more useful than traditional high-level scenarios. A system configuration approach allows the inclusion of more detailed and quantitative data in the descriptions and the provision of a better technical basis for the development of use cases and test cases. While high-level scenarios give some qualitative statements about the progress, system configuration uses quantitative data such as number of components, size of the system, etc. The scenarios envisioned in ERIGrid consist of or are interrelated with the following aspects:

- *System Configuration* defined as an assembly of (sub-)systems, components, connections, domains, and attributes relevant to a particular test case.
- *Scenario* defined as a compilation of System configuration, Use Cases, and holistic test cases in a shared context.
- *Use Case* defined as a specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders of the system.
- *Test Case* defined as a set of conditions under which a test can determine whether or how well a system, component or one of its aspects is working given its expected function.
- *System* defined as a set of interrelated elements considered in a defined context as a whole and separated from their environment.

[2] ERIGrid website

Figure 2 provides an overview of the ERIGrid perspective over the scenario definition and configuration as well as the scope of the project within the definition levels.

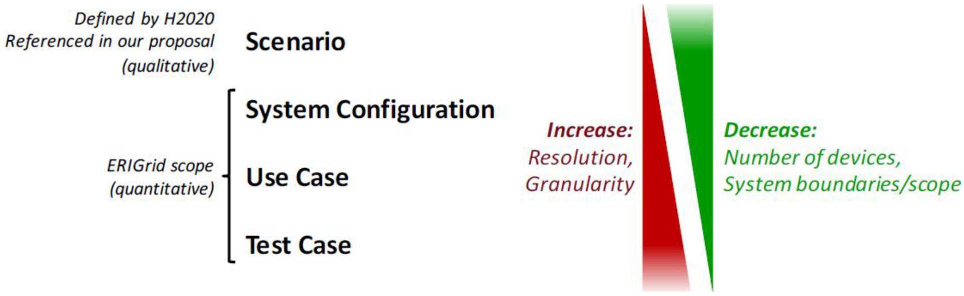


*Figure 2: Scope of ERIGrid within the architecture definition levels (Mäki et al., 2016).*

The analysis of the above-mentioned aspects led to a detailed conceptual structure of a System Configuration summarised in the items below:

- Domains,
- Components,
- Connectivity,
- Constraints,
- Attributes,
- Associated Use Cases, and
- Reference to high-level scenarios.

The work also identified three main system configurations, each addressing a system area. The decision on these three system areas was taken based on a technical workshop discussions, utilising also the outcomes of a scenario survey carried out during the project. The three system configurations were the following:

- Distribution grid,
- Transmission grid and offshore wind, and
- Vertical integration.

Distribution grid considers the electricity distribution system at Medium-Voltage (MV) and Low-Voltage (LV) levels. The area covered by this configuration starts at the connection point with the High-Voltage (HV) level, the HV/MV transformer, where the responsibility area of the DSO also typically starts. On the LV side, the configuration is limited to customer interface (metering point) or at the connection point of each active component or DER unit. However, the configuration also needs to consider components beyond the network connection point to the degree that they impact on the state of the distribution grid. Hence components like control systems for DER units or controllable loads are included in the configuration. (Mäki et al., 2016)

The offshore wind power plant scenario was selected because it is a predominant future scenario with special operation characteristics and impact on transmission grids. Some of the key characteristics of this system configuration are meshed High-Voltage DC (HVDC) network, AC grid parts for the connections of the wind power plants to the HVDC hubs, multiple connections to the shore, interconnection with different control areas, etc. (Mäki et al., 2016)

The vertical integration scenario and system configuration provides a possible background for use cases requiring the coordination and integration of transmission and distribution grid related tasks. In principle, it includes all domains used in the other system configurations; however, abstractions and aggregations of usually included components are employed, as the full detail may overload the testing infrastructures. (Mäki et al., 2016)

### 2.2.2 European Green Deal

The European Green Deal (European Commission, 2019) is the growth strategy that will transform the European Union into a modern, resource-efficient and competitive economy where climate neutrality will be achieved by 2050, and the economic growth will be decoupled from use of resources. Rather than describing potential scenarios, the European Green Deal provides a roadmap with actions by all sectors of the European economy, needed investments and available financing tools. Among the actions, and considering that the production and use of energy across economic sectors account for more than 75% of the European Union (EU)'s greenhouse gas emissions, *decarbonising the energy sector* is critical to reach climate objectives in 2030 and 2050. (European Commission, 2019) Decarbonisation of the energy sector will rely on a set of concepts and actions completely aligned with the functional scenarios proposed in ERIGrid 2.0:

- The *power sector must be based largely on a smart integration of renewable sources*.
- *Transition to climate neutrality requires smart infrastructure:* deployment of innovative technologies and infrastructure, such as smart grids, hydrogen networks or carbon capture, storage and utilisation, energy storage, as well as enabling sector integration.
- *Digital technologies* are a critical enabler for attaining the sustainability goals of the Green Deal in many different sectors. *Digitalisation* presents new opportunities for distant monitoring and optimising how energy and natural resources are used. Accessible and interoperable data combined with digital infrastructure and artificial intelligence solutions, facilitate evidence-based decisions and expand the capacity to understand and tackle environmental challenges.
- The EU's *energy supply must be secure and affordable* for consumers and businesses.
- It is essential to ensure that the *European energy market is fully integrated, interconnected and digitalised*, while respecting technological neutrality.

The European Green Deal sets the scene that frame the functional scenarios specified in ERIGrid 2.0, making them fully relevant to achieve the ambitious goals and placing the electricity system (jointly with a sectoral integration of energy end uses) at the core of the energy transition, away from fossil fuels (European Commission, 2019).

### 2.2.3 Clean Energy for all Europeans Package

In 2019 the EU completed a comprehensive update of its energy policy framework to facilitate the transition away from fossil fuels towards cleaner energy and to deliver on the EU's Paris Agreement commitments for reducing Greenhouse Gas (GHG) emissions. The agreement on this new energy rulebook – called the Clean energy for all Europeans package – marked a significant step towards the implementation of the energy union strategy, published in 2015 (European Commission, 2020).

Based on the commission proposals published in November 2016, the Clean Energy for all Europeans Package consists of eight legislative acts. The rules bring considerable benefits from a consumer perspective, from an environmental perspective, and from an economic perspective. By coordinating these changes at EU level the legislation also underlines EU leadership in tackling global warming and provides an important contribution to the EU's long-term strategy of achieving carbon neutrality by 2050 (European Commission, 2020). The legislative acts consists of:

- *Directive (EU) 2018/844, Energy Performance in Buildings*: Aims to improve energy performance in buildings.
- *Directive (EU) 2018/2001, Renewable Energy*: Sets the binding target of at least 32 % of renewable energy sources in the EU's energy mix by 2030. This Directive also addresses issues regarding renewable energy communities.
- *Directive (EU) 2018/2002, Energy Efficiency*: Sets the binding target of at least 32.5 % energy efficiency by 2030, relative to a "business as usual' scenario.
- *Regulation (EU) 2018/1999, Governance of the Energy Union*: A robust governance system for the energy union, under which each Member State is required to establish integrated 10-year National Energy and Climate Plans (NECPs) for 2021-2030.
- *Regulation (EU) 2019/943, Electricity Regulation*: Aims to upgrade the legal framework governing the Union's internal electricity market, in order to ensure that markets and networks function in an optimal manner, to the benefit of businesses and Union citizens.
- *Directive (EU) 2019/944, Electricity Directive*: Directive for EU electricity market design. The specific Directive also introduces the term citizen energy community and promotes the citizens' engagement in the energy sector.
- *Regulation (EU) 2019/941, Risk Preparedness*: Aims to ensure a common approach to electricity crisis prevention and management, the competent authority of each Member State should draw up a risk-preparedness plan on the basis of the regional and national electricity crisis scenarios.
- *Regulation (EU) 2019/942, ACER*: Regulation outlining a stronger role for the Agency for the Cooperation of Energy Regulators (ACER).

The ERIGrid 2.0 consortium is fully aware of those legislative acts and selected Functional Scenarios that are totally aligned with them in order to promote research that will facilitate and accelerate the implementation of the regulatory frameworks. In other words, the defined Functional Scenarios set the ground to promote research that will increase RES penetration and efficiency, test new electricity market designs, explore the opportunities that flexibility management and energy vectors coupling offer, increase system reliability and stability as well as enable the digital transformation and energy transition. (European Commission, 2020)

### 2.2.4 Projects

**ELECTRA IRP**[3] (European Liaison on Electricity Committed Towards long-term Research Activity – Integrated Research Programme) envisages a future managed in a decentralised fashion, with a high share of renewable resources providing flexibility at all voltage levels and the possibility of local sensing, monitoring, and control. In order to do so, a grid control scheme

[3] ELECTRA IRP website

called Web-of-Cells (WoC) was developed, which splits the power system into control cells. This means that by using the internal flexibility of any type of generators/loads and/or storage systems, a specific section of the power system should maintain an agreed power exchange at its boundaries. Hence, the total amount of internal flexibility in each cell shall be at least enough to compensate for the cell generation and load uncertainties in normal operation. This control scheme was defined under six high-level use cases to maintain frequency (balancing) and voltage control in each cell:

- Balance Restoration Control (BRC),
- Adaptive Frequency Containment Control (aFCC),
- Inertia Response Power Control (IRPC),
- Balance Steering Control (BSC),
- Primary Voltage Control (PVC), and
- Post Primary Voltage Control (PPVC).

Moreover, the *ELECTRA scenarios* are based on the following assumptions:

- Generation will shift from classical dispatchable units to intermittent renewables.
- Generation will substantially shift from central transmission system connected generation to decentralised distribution system connected generation.
- Generation will shift from few large units to many smaller units.
- Electricity consumption will increase significantly.
- Electrical storage will be a cost-effective solution for offering ancillary services.
- Ubiquitous sensors will vastly increase the power system's observability.
- Large amounts of fast reacting distributed resources (can) offer reserves capacity.

**GIFT**[4] (Geographical Islands Flexibility) is a H2020 project which aims to increase the penetration rate of RES in the islands' grid, reducing the need for diesel generation and thus decreasing the GHG emissions directly related to it. This will be achieved through the development of several flexibility solutions, such as:

- Virtual Power System (VPS) for trading flexibility using FlexOffer protocol,
- Energy management systems for harbours, factories, homes,
- Better prediction of supply and demand and visualisation through a Geographic Information System (GIS) platform, and
- Innovative storage systems allowing synergy between electrical, heating and transportation networks.

FlexOffer is a universal format and a trading mechanism to describe, buy and sell energy flexibilities. The concept works bottom-up, managing flexibilities provided by any source: generation plants, households, small and medium-sized industry, office buildings, or electrical vehicle charging stations. GIFT is one of the major players in the FlexOffer community, which aims to promote and standardise this open and scalable protocol.

[4] GIFT website

In order to demonstrate the proposed technologies, two lighthouse islands have been selected, namely Procida, Italy and Grytoya, Norway. For the demonstration, purpose specific functional scenarios and use cases have been analysed. These scenarios focus mainly on concepts of Local Energy Community (LEC) and Congestion Management of Distribution Grid. Figure 3 showcases an overview of the demonstration setup for GIFT.

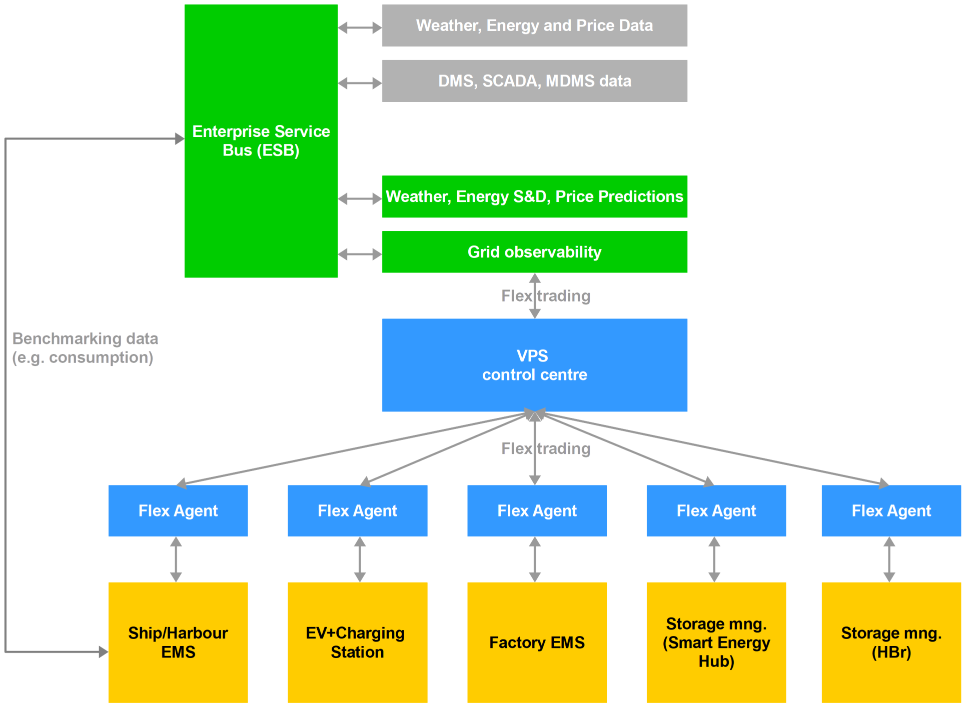


*Figure 3: Overview of the GIFT project implementation.*

**eNeuron**[5] (GreEN Energy HUbs for Local IntegRated Energy COmmunities optimisatioN) H2020 project is addressing the ambitious environmental and energy goals of EU to design a low-carbon energy system by the mid-21st century. The main goal of eNeuron is to develop innovative tools for the optimal design and operation of LECs for facilitating their everyday operation. These tools focus in particular on integrating multiple energy carriers at different scales to identify the potential benefits achievable for the community and its stakeholders. An Energy Hub (EH) facilitates multiple energy carriers conversions, conditioning, storing and using. Moreover, developing an interface between the local community and external energy infrastructures and/or loads for exchanging energy at their interfaces and providing required energy services. The eNeuron tool will consist of two operational layers:

- The upper will deliver the design and daily operation optimisation of multi-carrier local integrated energy systems, through two composing stages.
- The upper based on a centralised optimisation interacts with the lower where decentralised operational optimisation will take place forming a hybrid and necessary approach for LECs and future business models in power grids.

The overview of the eNeuron is presented in Figure 4. The research objectives of eNeuron are:

[5] eNeuron website

- Critical assessment of the current deployment of integrated local multi-vector energy systems (power, storage, transport, and Heating, Ventilation, and Air Conditioning (HVAC)) and corresponding supporting mechanisms, tools and technologies in Europe.
- Identification of the *Integrated Local Energy Community* subject.
- Development of the use cases and new business models for the eNeuron tool.
- Development of multi-objective optimisation framework for the targeted energy hub tool.

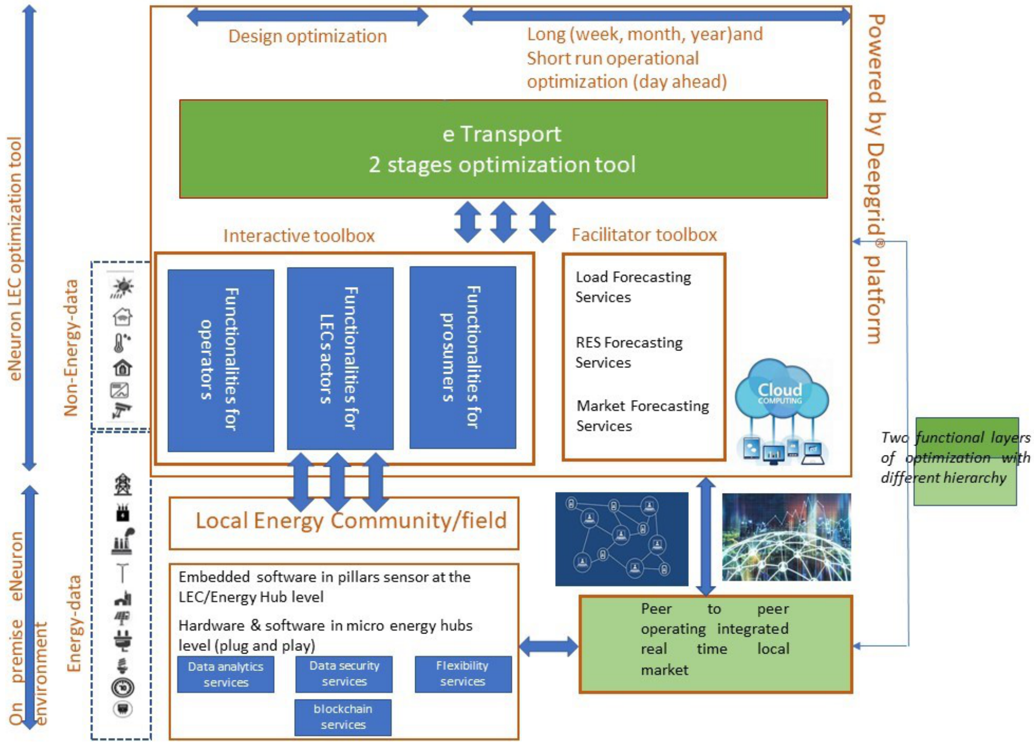


*Figure 4: Overview of eNeuron project.*

**FLEXIGRID**[6] (Building a low-carbon, climate resilient future: Secure, Clean and Efficient Energy) is a H2020 project, which aims to improve the distribution grid operation making it more flexible, reliable and cost-efficient, through the development of four hardware solutions consisting in the secondary substation of the future, new generation of smart meters with improved feeder-mapping capabilities, protection dealing with high RES penetration and a multi-purpose concentrator able to control grid assets, called Energy Box.

Moreover, the project envisages the development of four additional software modules addressing fault location and self-healing, forecasting and grid operation, grid congestion management and thermal energy storage optimisation. Furthermore, a single open source platform will be upgraded to enable the integration of the different hardware and software solutions at the edge by fully exploiting the data provided by local and distributed energy resources. This way, FLEXIGRID solutions will be interoperable with the Information Technology (IT) systems used by the energy stakeholders, increasing its replication potential. Also with the aim of ensuring the project's impact along the EU networks, eight different use cases have been identified addressing most common EU distribution grid problems as follows:

[6] FLEXIGRID website

- Secondary substation upgrading for higher grid automation and control,
- Protections functions operating with large RES share penetration in the distribution grid,
- Holistic energy system optimisation and emulation for commercial and residential customers,
- Microgrid congestion management and peak shaving,
- Coordinating distribution network flexibility assets and protections schemes coordination in urban districts,
- Virtual energy storage for urban buildings,
- Dispatching platform for MV generation, and
- Isolated valley grid operating in islanding mode.

Finally, four demo-sites has been chosen to represent in a complementary way the different use cases of the project and deploy and upgrade FLEXIGRID solutions to reach complete and qualified systems: a rural and peri-urban network in the Spanish grid with a very high RES share; a hotel resort in the Greek Island of Thasos with big limitations to integrate RES; an urban grid in the city of Zagreb, Croatia, accounting congested areas, and an isolated valley in the South-Tyrol region of Italy with a very high share of hydroelectric energy.

**MIGRATE**[7] (Massive InteGRATion of power Electronic devices) aims to find solutions for the technological challenges the grid is faced with currently and especially in the future. By 2020, several areas of the High-Voltage AC (HVAC) pan-European transmission system will be operated with extremely high penetrations of Power Electronics (PE)-interfaced generators, thus becoming the only generating units for some periods of the day or of the year — due to renewable, e.g. wind, solar, electricity. This will result in

- Growing dynamic stability issues for the power system (possibly a new major barrier against future renewable penetration),
- The necessity to upgrade existing protection schemes, and
- Measures to mitigate the resulting degradation of power quality due to harmonics propagation.

European TSOs from Estonia, Finland, France, Germany, Iceland, Ireland, Italy, Netherlands, Slovenia, Spain and UK have joined to address such challenges with manufacturers (GE, Schneider Electric) and universities/research centres. They propose innovative solutions to progressively adjust the HVAC system operations.

**P2P-SmarTest**[8] (Peer to Peer Smart Energy Distribution Networks) is an H2020 project which aims to ensure the integration of demand-side flexibility and the optimum operation of DER and other resources within the power grid by employing Peer-to-Peer (P2P) mechanisms while maintaining real-time power balance and the quality and security of the supply with a special focus on:

- Day-Ahead and real-time energy trading between microgrids.
- Replacement Reserve between a microgrid trader and the Aggregator.

[7] MIGRATE website
[8] P2P-SmarTest website

- Real-time voltage control in a MV distribution network where several microgrids are connected operating according to a P2P scheme.
- Testing of different ICT alternatives for P2P energy trading communication.

**RESERVE**[9] (Renewables in a Stable Electric Grid) future energy systems will use RES to minimise CO2 emissions. Currently large generators powered by fossil fuel turbines maintain the stability and quality of energy supplies through their inertia. The inertia of these generator-turbine groups gives providers a significant time window in which to react to network events. There is an urgent need to find ways to stabilise energy systems with up to 100% RES (where inertia is often lost due to power converter mediated energy transfer) to generate *RESERVEs* so that society can relax in the knowledge that it has a stable and sustainable energy supply. RESERVE will address this challenge by researching new energy system concepts, implemented as new system support services enabling distributed, multi-level control of the energy system using pan-European unified network connection codes.

RESERVE will create a pan-European multi-site simulation test-bed, bringing together the best facilities in Europe. The results include published models of system support services, innovative architectures for the implementation of the services, performance tests on pan-European real-time simulation, and live test-beds, a model for pan-European unified network connection codes and actions to promote results to standardisation organisations, all of which maintain the RESERVE in energy systems. Commercialisation of results will culminate in breakthroughs in the efficient utilisation and use of RES, a spin-off and a wide range of enhanced professional solutions and services.

**SDN microSENSE**[10] (SDN - microgrid reSilient Electrical eNergy SystEm) aims to provide and demonstrate a secure, resilient to cyberattacks, privacy-enabled, and protected against data breaches solution for decentralised Electrical Power and Energy System (EPES). All designed, developed, and tested technologies should consider the latest related research findings and maintain high compliance with current industrial standards, e.g. IEC standards. The project includes six use case demonstrations. The first use case is hosted by the Norwegian Smartgrid Laboratory in Trondheim. This project has received funding from the EU's Horizon 2020.

**INTERPLAN**[11] (INTEgrated opeRation PLAnning tool towards the Pan-European Network) main goal is to provide an integrated operation planning tool for the pan-European electricity network, with a focus also on the TSO-DSO interfaces, to support the EU in reaching the expected low-carbon targets. A methodology for proper representation of a *clustered* model of the pan-European network is provided, with the aim to generate grid equivalents as a growing library able to cover all relevant system connectivity possibilities occurring in the real grid, by addressing operation planning issues at all network levels (transmission, distribution and TSO-DSO interfaces). In this perspective, the chosen top-down approach will actually lead to an *integrated* tool, both in terms of voltage levels, going from high-voltage down to low-voltage up to end user, and in terms of building a bridge between static, long-term planning and considering operational issues by introducing controllers in the operation planning. Proper cluster and interface controllers will be developed to intervene in presence of criticalities, by exploiting the flexibility potentials throughout the grid based on a close cooperation among TSOs and DSOs.

[9] RESERVE website
[10] SDN microSENSE website
[11] INTERPLAN website

Accordingly, the specific, measurable research objectives of INTERPLAN which will be attained within the project duration are as follows:

- Analysis of the European electricity grid, including the main interconnection issues, and criticalities, both within EU countries, and at pan-European level.
- Detailed assessment of the regulatory framework in Europe including existing grid codes. Emphasis will be put on exploitation and analysis of previous projects and work, considering both pan-European level (transmission grid) and also looking down to flexibility present in the distribution grid, paying specific attention to address flexibility possibilities coming from storage, demand response individually or aggregated.
- On the policy front a proposal with all possible amendments to the grid codes will be documented reflecting the work developed in the INTERPLAN. This will be a prime objective of the project as an attempt to deliver an elaborated report to a high degree of detail to make the proposed changes as receptive as possible for adaption by the appropriate authorities. The implications to European regulation will be elaborated and aligned to the recommendations on grid codes.
- Besides, INTERPLAN has developed several use cases within the network operation planning tool, which address future European network challenges. These use cases are consisting of active and reactive power optimisation, congestion management as well as inertia management at both transmission and distribution levels with a focus on TSO-DSO collaboration and obtaining support from renewable-based generation at distribution level and demand-side management.

**IPN ECODIS**[12] is a Norwegian initiative on Engineering and Condition monitoring in Digital Substation (ECoDiS). The project is hosted by Statnett and includes Norwegian DSOs as industry partners and SINTEF Energy Research as main research partner. The access to more accurate data, both real-time and historical, improves monitoring of state and technical condition of components in the substation. Consequently, better operational, maintenance and reinvestment decisions can be made, and costs can be reduced. But, prior to harvesting these benefits of digital substations, there are challenges that need to be investigated, i.e., availability and quality (life expectancy and ability to withstand the Nordic climate) of sensors, cybersecurity, interoperability, ability of IEC 61850 to support new functionalities — and not the least, testing condition models using digital twins. This project investigates these challenges in three pilots and a new test platform in the National Smart Grid Laboratory. The project will expand the existing pilot of Statnett, the Norwegian TSO at Furuset and build two new pilots for the DSOs Skagerak and Hafslund.

**NOBEL GRID**[13] (New Cost Efficient Business Models for Flexible Smart Grids) is developing, deploying and evaluating advanced tools, ICT services and business models for all actors in the smart grid and electricity market, in order to ensure shared benefits from cheaper prices, more secure and stable grids and cleaner electricity. These tools and services are enabling active consumers' involvement and the innovative business models for new actors and facilitate the integration of distributed renewable energy production, in order to improve the quality of life of European citizens.

The main outcomes of the project are ICT tools that offer secure, stable and robust smart grids,

[12] IPN ECODIS website
[13] NOBEL GRID website

allowing DSOs to mitigate management, replacement and maintenance costs of the electricity distribution grid, in presence of large share of distributed renewable energy resources. Also, new services and business models will be provided for all the actors of the distribution grid. The project results are being demonstrated in five different electric cooperatives and non-profit demonstration sites in five EU Member States (Belgium, Greece, Italy, Spain and the UK), with the active involvement of all the energy grid actors, citizens, and based on the new business models defined during the project.

**PV-ANALYTIC**[14] (Advanced photovoltaic system monitoring and analytics solution enhanced with intelligent interoperable data-driven features for efficient big data real-time analysis, failure diagnosis, automated management and integrated microgrid control) is funded by SOLAR-ERA.NET regional research and technology development and innovation programme. The aim is to develop smart grids ensuring high Photovoltaics (PV) plant performance and fully flexible plant operations. The project has been initiated in order to primarily assess PV system big data performance monitoring and control requirements, formulate procedural functions for the acquisition, aggregation and interoperability of new technologies (battery energy storage systems and smart inverters) and develop novel data-driven health-state analytics. The algorithms will be integrated to an edge computing solution with cloud-connectivity, which will be an innovative multi-service interoperable health-state monitor and advanced PV Power Plant Controller (PPC) that is enhanced with user-friendly visualisations and financial components in the cloud.

The project is expected to have significant impact on the value chain of the technology given the reduction of PV electricity costs, by increasing the lifetime output, improving the operational efficiency and optimising system operations. Targeting further enhancement of lifetime, quality and sustainability of PV is in-line with the primary objectives of the European Strategic Energy Technology Plan (SET Plan) for Operation and diagnosis of PV plants and new communicative, automated and interactive developments such as Solar 3.0, Internet of Things (IoT) and Industry 4.0 concepts. This is the first time such a system will be demonstrated with functionalities well beyond the current state-of-the-art, and is well anticipated in the fast growing PV market with continuously narrowing profit margins and intelligent grid supportive operational functionalities.

In addition, the advanced monitoring system can further act as the buffer between PV power plants and the smart grid, contributing with the control algorithms to supportive functions for grid stability especially for the important task and requirement by many DSOs/TSOs for PV power plant flexibility with the utilisation of PV, smart inverters and Battery Energy Storage Systems (BESSs). The proposed system is therefore of prime interest to a large stakeholder target group ranging from policy makers and utilities, plant operators, Engineering Procurement Construction (EPC) contractors, module producers and investors.

**ROAD2DC**[15] (New tools for the design and control of AC/DC hybrid distribution networks) was a project funded by the ELKARTEK 2018 Programme in the Basque Country, Spain. The goal of the project was to develop mathematical tools and control solutions for demonstrating the applicability of AC/DC hybrid networks, taking full advantage of both technologies (AC and DC) for transmission and distribution of electricity. The focus was on MV/LV distribution networks where DC parts were inserted to interconnect AC parts and to integrate DC-based

[14] PV-ANALYTIC project summary report
[15] ROAD2DC website

systems. This concept requires a large penetration of power electronic devices, which can generate severe frequency/voltage deviations, power flow and stability issues, and quality of supply problems. Optimisation of the topology of these AC/DC hybrid networks and advanced grid management systems are needed to reduce the system costs and increase efficiency. After a comprehensive analysis of currently deployed hybrid networks (specially microgrids) three so-called "scenarios" (i.e. networks) were specified for analysing at simulation level the mentioned issues (mainly network stability and resonances) and the developed control solutions:

- *Medium Voltage distribution network*: a DC network section was inserted between two AC sections at MV level; the DC part contained DC loads, PV generation and batteries.
- *Low Voltage residential network*: a DC feeder run in parallel to the AC feeder from the secondary substation to the consumption points (each house received simultaneously AC and DC supplies by two separate lines).
- *Isolated network for marine applications*: this type of AC/DC hybrid electric system can be found in many big ships nowadays.

**SmILES**[16] (Smart Integration of Energy Storages in Local Multi Energy Systems for Maximising the Share of Renewables in Europe's Energy Mix) has aimed at improving the knowledge on the integration of electrical and thermal storages in local multi-energy systems. This was foremost done with the help of simulation studies carried out jointly by the project partners, each using their own models and tool-chains. To facilitate the collaboration among the partners, the so-called PreCISE approach was used, an extension of ERIGrid's Holistic Test Description (HTD) that focuses specifically on defining simulation studies in a tool-independent way. This provided a systematic approach to document and share information about the optimisation studies and therefore facilitated the collaboration among experts using different tool-chains and modelling paradigms.

### 2.2.5 Stakeholder Networks

**CEN-CENELEC-ETSI Smart Grid Coordination Group:**[17] In March 2011, the European Commission (EC) and EFTA issued the Smart Grid Mandate M/490 which was accepted by the three European Standards Organizations (ESOs), CEN, CENELEC and ETSI, in June 2011. M/490 requests CEN, CENELEC and ETSI to develop a framework to enable ESOs to perform continuous standard enhancement and development in the smart grid field. In order to perform the requested work, the ESOs combined their strategic approach and established in July 2011, together with the relevant stakeholders, the CEN-CENELEC-ETSI Smart Grid Coordination Group (SG-CG), being responsible for coordinating the ESOs reply to M/490.

**EERA – Smart Grids, Energy Systems Integration, Smart Cities**[18] (The European Energy Research Alliance) is an association comprising around 250 research institutes in the EU, with the goal to expand and optimise EU energy research capabilities through the sharing of national facilities and the joint realisation of national and European programs. EERA activities contribute to the overall goal to catalyse European energy research, with the objectives defined in the EU's SET Plan and its clean energy transition strategy being the guiding principles. EERA operates 17 joint research programmes, referred to as Joint Programmess (JPs), to organise work within

[16] SmILES website
[17] CEN-CENELEC-ETSI Smart Grid Coordination Group website
[18] EERA website

the association. Within the context of ERIGrid 2.0, the JPs on Smart Grids, Energy Systems Integration and Smart Cities are of most relevance, because their topics overlap with the goals of ERIGrid 2.0.

**ETIP SNET:**[19] The ETIP Smart Networks for Energy Transition (SNET): European Technology & Innovation Platforms (ETIPs) have been created by the EC in the framework of the new SET Plan by bringing together a multitude of stakeholders and experts from the energy sector. The role of ETIP SNET is to guide Research, Development & Innovation (RD&I) to support Europe's energy transition, more specifically, its mission is to:

- Set out a vision for RD&I for Smart Networks for Energy Transition and engage stakeholders in this vision.
- Prepare and update the Strategic Research and Innovation Roadmap.
- Report on the implementation of RD&I activities at European, national/regional and industrial levels.
- Provide input to the SET Plan action 4 which addresses the technical challenges raised by the transformation of the energy system.
- Identify innovation barriers, notably related to regulation and financing.
- Develop enhanced knowledge-sharing mechanisms that help bring RD&I results to deployment.
- Prepare consolidated stakeholder views on Research and Innovation to European Energy Policy initiatives.

ETIP SNET is functioning through 6 Working Groups representing the following specific areas and supported by external experts that are selected through formal applications:

- WG1: Reliable, economic and efficient smart grid system,
- WG2: Storage technologies and sector interfaces,
- WG3: Flexible Generation,
- WG4: Digitisation of the electricity system and Customer participation,
- WG5: Innovation implementation in the business environment, and
- NSCG: National Stakeholders Coordination Group.

**IEEE PES Task Force on Stability definitions and characterisation of dynamic behaviour in systems with high penetration of power electronic interfaced technologies:**[20] A task force set up jointly by IEEE Power System Dynamic Performance Committee (PSDPC) and CIGRE had addressed the issue of stability definition and classification in power systems from a fundamental viewpoint and had closely examined the practical ramifications. The relevant report published in 2004, primarily dealt with fairly slow, electromechanical phenomena, typically present in power systems dominated by synchronous machines and their controls. Since that time, the dynamic behaviour of power systems has gradually changed due to the increasing penetration of converter interfaced generation technologies, loads, and transmission devices and has progressively become more dependent on (complex) fast-response power electronic

[19] ETIP SNET website
[20] IEEE PES Task Force website

devices, thus arising new stability concerns. In recognition of this change, a Task Force was established by IEEE PSDPC in 2016 to re-examine and extend, where appropriate, the classic definitions and classifications of the basic stability terms. The report summarises the results of this work and presents extended definitions, characterisation and classification of power system stability.

**ISGAN-SIRFN**[21] (Smart Grid International Research Facility Network) provides a coordinated network of world-class smart grid research and test-bed facilities to perform controlled simulations, and evaluations of integrated smart grid technologies and protocols across areas such as distributed and renewable energy integration, energy storage systems, advanced distribution management, advanced metering infrastructure, cybersecurity, and similar applications, among countries participating in the International Smart Grid Action Network. All these aspects are focused on the following four key areas:

- Test Protocols for Advanced Interoperability Functions of DER,
- Microgrids Testing,
- Power System Testing, and
- Advanced Laboratory Testing Methods.

Particularly, for the Power System Testing area, a test case collection was defined as follows:

- Coordinated Control Systems,
- Microgrids,
- Distribution Grid Protection and Reconfiguration, and
- Stability of Low-Inertia Transmission interconnections.

**FME CINELDI**[22] is National Centre for Intelligent Electricity Distribution with 29 partners from industry and research. The CINELDI centre works towards digitalising and modernising the electricity distribution grid for higher efficiency, flexibility and resilience, and the main goal is to enable a cost-efficient realisation of the future flexible, and robust electricity distribution grid. The research activity covers six main areas:

- Smart grid development and asset management,
- Smart grid operation,
- Interaction DSO/TSO,
- Microgrids,
- Flexible resources in the power system, and
- Smart grid scenarios and transition strategies.

[21] ISGAN-SIRFN website
[22] CINELDI website

**Smart Otaniemi**[23] is an innovation ecosystem connecting experts, organisations, technologies, and pilot projects with a shared vision of going beyond traditional energy production and distribution towards smart energy technology models and concepts. Smart Otaniemi is funded by the Smart Energy program of Business Finland. The aim is to take research and development ideas on new level by acceleration in the Smart Otaniemi pilot environments and network and develop new business opportunities on topics, such as Artificial Intelligence (AI) and blockchain, aggregator business models, smart Electric Vehicle (EV) charging infrastructure, 5G and IoT services. Smart Otaniemi includes the following focus areas and topics:

- *Local flexibility*: demand response and virtual power plants, maintenance and operations, and storages.
- *Building level intelligence*: smart buildings, energy efficiency, and heating and cooling.
- *Smart mobility*: charging of vehicles, autonomous transportation, and transportation system.
- *Platforms, connectivity and enabling technologies*: data sharing and analytics, connectivity, cybersecurity, AI and blockchain, and modelling and simulation.

## 2.3 ERIGrid 2.0 Functional Scenario Survey

### 2.3.1 Survey Purpose and Process

The necessity for a holistic understanding of scenarios which are interesting to the ERIGrid 2.0 partners and their research infrastructures, led to conducting a survey as the first action of the NA4.1 work. The purpose of this survey was to gather inputs on a set of Functional Scenarios that should be analysed in more detail in order to deduce the most relevant approaches for ERIGrid 2.0.

The survey was taken by means of a simple online form via Microsoft Forms, which enables easy presentation of the results. Overall, 15 partners participated in the survey and submitted 35 different scenarios. The preliminary analysis of NA4.1 showed also the need for defining the concept of Functional Scenario in terms of aspects that should describe it in detail. These aspects were the basis of the survey itself which includes the following items:

- Information provider name and affiliation,
- Functional Scenario title,
- System under Test description,
- Motivation,
- Use Case,
- Test Case,
- Experimental Setup,
- Relevance to ERIGrid 2.0,
- Related projects/networks, etc.,
- Published on, and

[23] Smart Otaniemi website

- General comments and suggestions.

The results of this survey will be used not only to form the Functional Scenarios for ERIGrid 2.0 but also use cases, test cases, and experiment setups for actual demonstrations used throughout the project will be based on these Functional Scenarios.

### 2.3.2 Survey results

According to the contributions of the survey participants it appears that the suggestions are commonly of interest in the research field of smart grids and smart energy systems. Based on the survey results, the majority of them are related to MV/LV distribution grids and their management. The following topics were frequently mentioned:

- DER management system,
- Microgrids, low-inertia grids and LECs,
- Sector coupling and Multi-Energy systems,
- Frequency and Voltage stability in Inverter-Dominated Power Systems,
- Aggregation and Flexibility Management, and
- Digitalisation (ICT and automation).

Overall, regarding the submitted data of the survey, there are plenty of references on use cases compared to actual Functional Scenario types. This may be due to the requirement to include several alternative research approaches but also because a Functional Scenario has a broader meaning in terms of applicability and it may describe a wide range of systems/applications, whereas use cases usually refer to more specific subsystems and processes. This also highlights the complexity and diversity of the topic. Moreover, the potential goal for the partners of the project is to combine all these use cases and built up solid Functional Scenarios. Thus, the survey data provided very useful information such as characteristics and parameters for the system configurations.

The full list of scenarios for which the information was collected is as follows:

- Aggregated DER
- Communication and connectivity enabling smart energy systems
- Coordinated operation of Power-to-Heat units
- Coordination of electricity consumption and production between independent actors in a microgrid or energy community
- Cyber-physical testing of resilient control systems
- DER management system
- Development of a cybersecurity system to protect metering data and personal information of the MV customers
- Digital Substations
- Distributed controls in smart grid
- Distribution Network with increased DER penetration

- DSO/Aggregator coordination in LV grids
- Energy Community
- Energy management in LECs with a high share of DERs
- Fault management system
- Flexibility activation.
- Flexibility market operation and interaction with underlying power system operation using the FLEXGRID Automated Trading Platform (ATP)
- Frequency reserve optimisation
- Local Energy Communities
- Low Inertia Systems
- LV network with high number of EV chargers
- Microgrid
- Multi-energy integration
- Multi-level voltage control
- On Load Tap Changer (OLTC).
- Predicting loads of a Grid of a Non-Interconnected Greek island
- Provision of ancillary services from DGs
- Remote systems testing of wind turbine
- SmartDorf (a fictional village or part of a small town with a structure typical for the rural area of Austria)
- Solar photovoltaic power plant control
- Stability and interactions in converter-dominated microgrids
- Stability of power electronics dominated systems
- Testing of distributed capabilities from grid forming converters

Several responses highlight that the proposed scenarios are aligned with the European Green Deal, while several of the responses address the issue of Multi-RI experiments which is one of the key objectives of ERIGrid 2.0. Last but not least, it was noted in most responses that there is a need for further development of the testing and validation procedures that were originally developed in ERIGrid.

In addition to these recommendations, the survey results showed alignment with one of the following research topics/areas:

- Sector coupling and multi-energy systems,
- ICT and automation,
- LECs,
- Microgrids and low inertia grids, and
- Stability, control and grid code.

Detailed descriptions of Functional Scenarios submitted to the survey are presented in Appendix A: Functional Scenario Survey Data of this deliverable.

### 2.3.3 Survey Analysis

Following the data collection from the survey responses, the next step in the process was the analysis of the responses provided by the partners. It is noteworthy that since the scope of the survey was to gather wide and detailed information from the partners, the submitted scenarios presented notable diversity. Some of the scenarios were more in a generic/abstract level, whereas others, mainly related to other projects, were more detailed and narrower.

The relevance of the proposed scenarios to ERIGrid 2.0 was another aspect well defined in the responses and the majority of the scenarios were clearly suitable and within the ERIGrid 2.0 scope, goals and objectives. The relevance to ERIGrid 2.0 has been found to include aspects such as:

- Needs of high-level research infrastructures,
- Needs of multi-RI testing,
- Development of sector coupling,
- Development of testing methods and procedures,
- Supporting technology validation and roll-out phases,
- Justifying joint use of research infrastructures,
- Need for co-simulation tools and methods,
- Development of remote testing and connections,
- Development of flexible communication structures,
- Need for cyber-physical testing, and
- Need for cybersecurity testing.

Towards a more efficient analysis of the survey results, the submitted data has been categorised according to some commonalities. This categorisation was also used for the needs of the brainstorming workshop in which the consortium discussed the results and agreed on refinements. All in all, the following approach was to consider the actual application area and domains and according to this method, six categories have been identified:

1. Digitisation and ICT / interoperability
    - ICT penetration, smart metering, digital substations, smart building interface, validating ICT solutions, etc.
2. Ancillary services provided by DERs and active grid assets
    - EV integration, RES integration, inverter functionalities
3. Grid management by TSO & DSO
    - Voltage control, frequency control, reserves, EV integration, etc.
    - Microgrids, islanding, automation, etc.
4. Aggregation and flexibility management

  - Aggregator business, validation, trading and optimisation, grid support functions, geographically distributed testing etc.
  - Dispatch functionality
  - DER with sector coupling, distribution grid

5. Microgrid & energy Community
   - Validation, multi-RI testing
   - Co-simulation
   - EV integration, prosumers, end-users
   - TA and Virtual Access (VA) activities

6. Sector coupling & multi-energy
   - Flexibilities in energy systems, multi-energy systems, Control Hardware-in-the-Loop (CHIL), Power Hardware-in-the-Loop (PHIL), Hardware-in-the-Loop (HIL), Cyber-Physical System, etc.

The data can also be categorised in various other ways such as the compliance with the needs of ERIGrid 2.0 consortium and capabilities. These aspects could also be considered as cross-cutting requirements that the above-mentioned categories should meet:

- Alignment with European regulations and legislation.
- Use of co-simulation and real-time HIL, etc.
- Orientation on digitalisation of electrical systems / ICT / reliable energy systems.

The survey outcomes will serve as an input for system configuration development as well as formation of use cases during later phases of the project.

## 2.4 Linking Functional Scenarios with Existing Scenarios

The work conducted considers several high-level scenarios as a background forming the overall environment in which the Functional Scenarios are examined. The high-level scenarios provide a holistic understanding of the current status and development while also highlighting future visions and requirements impacting the Functional Scenarios. The high-level scenarios also address the high-level drivers for the Functional Scenarios, such as needs for digitisation of the smart energy systems.

Functional Scenario can be associated with several high-level scenarios. However, it is not possible to combine all the high-level scenarios with a single Functional Scenario and to avoid contradictions, thus each of the Functional Scenarios is associated with a set of high-level scenarios.

All of the Functional Scenarios are related to the generic system configurations developed in ERIGrid and consider the work conducted in ERIGrid as a strong background on the ERIGrid 2.0 scenarios. The Functional Scenarios are also aligned with the European Green Deal and Clean energy for all Europeans package to contribute in achieving the ambitious goals of the energy transition and accelerate the developments in RES penetration and efficiency, testing of new energy market designs, flexibility management and energy vectors coupling. Similarly several projects and networks have been derived based on the European SET Plan, thus naturally aligning the visions with ERIGrid 2.0.

Several of the existing high-level scenarios and use cases defined in other projects focus on developing distribution grids, e.g., FLEXIGRID, INTERPLAN, IEEE PES, ROAD2DC, and RESERVE, while many highlight ICT scenarios including NOBEL GRID, IPN ECODIS, SDN microSENSE, and PV-ANALYTIC. Many of the high-level scenarios described in the other projects are relevant for different topics within ERIGrid 2.0 including energy communities, aggregation, microgrids and ancillary services, such as GIFT, eNeuron, P2P-Smartest, RESERVE. Secondly, methodology scenarios developed in ERIGrid and extended in SmILES on the HTD are also highly relevant for ERIGrid 2.0.

Within ERIGrid 2.0, the high-level scenarios and visions described by networks constitute relevant drivers while some of them have overlapping goals. These relevant networks highlighting the major drivers include EERA JPs on Smart Grids, Energy Systems Integration and Smart Cities, CEN-CENELEC-ETSI Smart Grid Coordination Group, ETIP SNET, IEEE PES Task Force on Stability definitions and characterisation of dynamic behavior in systems with high penetration of power electronic interfaced technologies, ISGAN-SIRFN, FME CINELDI, and Smart Otaniemi.

# 3 Functional Scenarios

The work of ERIGrid 2.0 Networking Activity (NA)4.1 has been focused on the definition of Functional Scenarios forming the basis for the general themes researched within the project while also providing a foundation for establishing the use cases and test cases to support the development of research infrastructures and simulations environments.

The formation of the Functional Scenarios has been organised in six working groups each focusing on a single Functional Scenario. The decision on the six Functional Scenarios was taken based on the results of the Functional Scenario survey. The six working groups were:

- Ancillary services provided by DERs and active grid assets,
- Microgrid and energy community,
- Sector coupling and multi-energy systems,
- Grid management,
- Aggregation and flexibility management, and
- Digitalisation.

Each working group has developed a Functional Scenario based on their general topic, relevant Functional Scenario survey results and discussions during the brainstorming workshop. The Functional Scenario templates used during the brainstorming workshop have been included in Appendix B: Functional Scenario Templates.

Due to the first survey results presenting different understanding of the various questions and covering many different topics, a general structure was prepared to support the working group leaders. They were also provided with guiding questions to encourage them to focus on the most pressing parts of the Functional Scenario such as the scope, motivation and relevance for ERIGrid 2.0 while maintaining inclusiveness.

It has been highlighted that each of the Functional Scenarios should have a single core idea and be focused on opportunities and not on the detailed implementations. The implementation and further technical details are developed in other tasks within the project.

## 3.1 Functional Scenario 1: Ancillary Services provided by DERs and Active Grid Assets

### Motivation

This Functional Scenario is strongly motivated by the need of efficient system integration of renewable energy and EV charging on various system levels. The increasing amount of distributed resources raises new needs for improved management of a distribution system utilising wide connectivity and active components. The aspects to be considered include, for instance, voltage level control (OLTC and other approaches), stability issues and power quality aspects. As the amount of traditional generation in the system reduces, inertia and controllability reduce as well, leading to increasing needs for the development and integration of inverter functionalities to provide system support. Likewise, the increasing needs for flexibility and controllability will lead to a strong need for utilising distributed resources for ancillary services. While these needs have been raising, the DER units and other components have also developed and include now new functionalities through which they are interoperable and capable of providing such services.

Certain common aspects for the use cases within this Functional Scenario have been identified, including for instance the strong presence of DER, more complex grid control needs, mixed hierarchy for decision making and an active role of distributed units. These are all seen to increase the need for system-level testing approaches.

## Relevance for ERIGrid 2.0

This Functional Scenario has clear relevance to the ERIGrid 2.0 project. At a high level, it clearly contributes to European development and technology roadmaps. The overarching objectives require systematic solutions which further require system testing approaches. This scenario integrates key components such as DER inverters and controllers with ICT, control and automation architectures to enable new grid services. Advances in digitalisation, communication and interoperability have key roles for the development of interfaces between the active components. The need for new ancillary services providers also has strong links to sector integration development and improved profiling and flexibility capabilities for sectors such as transport, industry and heating/cooling, which are expected to be increasingly electrified in the near future.

## System Descriptions

Two system descriptions have been defined within this scenario:

**Decentralised network (including MV/LV distribution networks, microgrids, off-grid solutions, etc.)** includes system-level aspects and new architectures where distributed assets are utilised actively. This description considers various system levels ranging from public networks to local microgrids and their combinations. As a whole, the system consists of an electrical grid and a control infrastructure. The electrical system consists of a LV/MV distribution grid with a number of Electric Vehicle Supply Equipments (EVSEs) or other controllable DERs distributed across multiple feeders.

**Inverter functionalities** includes local-level aspects of providing services through advanced inverters and controllers. This includes also specific details on inverters and their service capabilities. The parallel operation of multiple inverters in electrical systems is also considered.

## Use Cases and Test Cases

Use cases were defined for each of the system descriptions:

**Decentralized network**
Use cases for 'Decentralized network (including MV/LV distribution networks, microgrids, off-grid solutions, etc.)':

- Voltage regulation, including the impacts of RES, EV fast charging and other new components introduced in the grid. This includes also the use of OLTCs at the substations for the purposes of stabilisation and regulation of voltage level as well as different control logics for managing the voltage levels on different network layers. This topic also includes the use of reactive power control and voltage control capabilities offered by storage units, controllable loads and EV Vehicle-to-Grid (V2G) integration.

- Reduction of energy system losses. The energy losses on the distribution grid can be minimised by optimally dispatching the DER units connected to it.
- Active power control and frequency control. The provision of Automatic Frequency Restoration Reserve by utilising the capabilities of DER, storage units and controllable loads.
- Active network management methods. This includes the management of energy consumption or generation of DERs via local DER energy management systems bundled in a Demand Response (DR) program.

Test cases for 'Decentralized network (including MV/LV distribution networks, microgrids, off-grid solutions, etc.)':

- Evaluation of energy loss and cost reduction on distribution grid.
- Control of voltage with an on-load tap changer controller.
- Assessment of ancillary services provision in island grids, weak grids or microgrids.
- Characterisation of communication latencies and synchronisation of various measurements.
- Characterisation of power/energy response to DR signals.
- Characterisation and verification of aggregator portfolio, including management methodology.
- Assessment of parallel operation between DERs and conventional power plants in interconnected grids.

**Inverter functionalities**
Use cases for 'Inverter functionalities':

- Power quality improvement services reducing harmonics, resonances, etc.: includes testing methods for EV chargers or the inverters of storage units to decrease possible Total Harmonic Distortion (THD) as well as resolving some stability issues.
- Specific system services (blackstart, virtual inertia, Fault Ride Through (FRT)). The main scope is to maintain frequency stability in systems with a low share of synchronous generators, hence low classic inherent inertia. The showcase utilizes synthetic inertia, as well as fast frequency response provided by RES, DG, controllable loads and storage systems. The frequency is brought back to nominal values by Optimal Power Flow (OPF)-based frequency restoration.
- Interaction between inverters and other components: interactions with feeders, between inverters, in different operation modes, etc. This includes the investigation of the behaviour of the inverters or converters under voltage and frequency variations as well as faults, phase angle shifts and in assistance to a blackstart.

Test cases for 'Inverter functionalities':

- A simulated distribution network coupled to the hardware converter and DC source through a power amplifier.

- Precise control of PV system operational settings (smart inverter) for reactive power and active power limitation.
- Estimating possible THD caused by EV chargers on a specific network layout.
- Configuration of control systems of power electronics: modification of the control parameters and assessment of the impact.
- Configuration of hardware (multi-level converters, passive and active filters etc).

### Experiment setups

Relevant experiment setups apply various tools and methods. Dynamic simulation studies can be utilised to study system-level impacts as well as phenomena occurring at the equipment level. Real-time simulation (especially CHIL and PHIL) can be used to integrate controllers or actuators into simulated systems. The simulation of connectivity and telecommunication will also be essential in the future. The integration of simulation tools for power system, power electronics and communication will become more important. Laboratory test setups will also be used widely, for instance in MV/LV grids, controllers, power electronics, etc. Multi-RI integration can be used especially when integrating facilities focusing on specific grid layouts with facilities advanced in power electronics or ICT aspects.

## 3.2 Functional Scenario 2: Microgrids & Energy Community

### Motivation

There is a growing trend to settle energy affairs in a local fashion: consumers want to buy their electricity or heat from local sources in a peer-to-peer setting, either individually or aggregated into local energy communities. The same goes for prosumers: fostering self-consumption, offering flexibility services, and facilitating community building have become significant values and services.

The key enablers for these developments reside at all layers of the energy system: The advent of domestic smart energy devices, affordable PV installations and new technology such as DC microgrid installations are indispensable hardware. In terms of ICT and control the prosumer has access to flexibility enabling services running on aggregator services or local microgrid operation platforms. Hardware and software have in their turn to comply to institutional boundaries.

The increased interplay between hardware and software at the *edge* of the electricity system requires careful assessment of the energy services provided to both the local microgrid as well as the transmission system. The requirements for the installed microgrid and domestic assets differ per energy service provided. For instance, power quality support requires a high degree of controllability in the microgrid offered by generation and loads interfaced through power electronics. System-level bidding and flexibility services from aggregators necessitates domestic devices to handle control signals accordingly. The same goes for the invocation of emergency operation by system operators. The impact of such requirements on the local energy system as well as the benefits of the distributed service provision for the overall power system needs to be addressed by simulation studies and lab experiments.

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Institutions, more specifically infrastructure and market regulations, often prohibit experimentation and roll-out of unconventional distribution system-level concepts (e.g. shared neighbourhood battery, behind-the-meter electricity trading, islanded microgrids, generic transactive energy systems). Demonstrators and living labs shall hence interlace strongly with governing bodies to ensure the right playfield for testing the efficacy of energy community based innovations.

## Relevance for ERIGrid 2.0

Relevant local energy services a microgrid can provide:

- Self-balancing,
- Frequency restoration and support,
- Congestion management,
- Black start support,
- Multi-energy resource optimisation, and
- Power quality support.

However, the applicability and efficacy of a particular service depends on the grid configuration. In ERIGrid 2.0, distinction has been made between 1) microgrids connected to a larger overlay grid, 2) islanded microgrids, which can be based either on AC or DC transmission, and 3) multi-carrier systems in which microgrids, heat, and gas component and networks are strongly interlaced.

Islanded microgrids require all reliability, balancing, and emergency controls an ordinary power system has, whereas those synchronised to the transmission system only need to engage those controls that have performance indicators locally (e.g. congestion, power quality, local balancing).

The development of microgrids in general allows excellent exploitation of grid intelligence as assets are strongly coupled to controls. More specifically, microgrids in a multi-carrier network setting enable better utilisation of the integral energy supply as normal over-engineering requirements can be relieved to a certain extent. In any case, components, subsystems, and control become more interdependent on each other. Aspects like stability, reliability, affordability, and usability need to be conserved. This requires careful simulation, testing, and validation of grid configurations by multiple stakeholders.

This is where ERIGrid 2.0 comes in: the unique mix of testing and simulation facilities (such as the co-simulation approaches for multi-energy systems of JRA2, and the geographically distributed testing approaches of JRA3) allows mastering the complexity of (coupled) microgrids and captures the multi-disciplinary aspects that local energy communities introduce to such engineering systems.

## System Descriptions

This functional scenario proposes 3 types of operation modes of local energy systems:

**Islanded microgrid** isolated electricity network, either based on AC or DC, which serves a local energy community.

**Synchronously connected microgrid** local electricity system based on AC, in which the local energy community utilises local services like self-balancing and contingency management.

**Local multi-energy system** a local energy system in which the energy is transported through multiple types of physical carriers (electricity, heat, gas), which have one or more modes to convert between the carriers.

Each of these described systems could co-exist in one particular setup. That is, an electrical microgrid setup having the possibility to switch from island mode to interconnected mode. The microgrid on its turn can interconnect with other energy carriers by components like domestic or neighbourhood-level heat pumps, electrolysers, and electric vehicles. The resulting generic grid configuration will constitute a basis for use cases specific to (future) microgrids and local energy communities.

## Use Cases and Test Cases

For ERIGrid 2.0, microgrids and local energy communities encompass the following use cases. The specific test cases along with their purpose, Key Performance Indicators (KPIs), and test setup will be addressed in the relevant JRAs.

**Distributed power quality support by synchronously connected microgrids**
In both nominal and faulted operation, the microgrid can sustain the power quality of its own network but also the (sub)transmission networks higher up. Power quality can be, but is not limited to: 1) voltage level, 2) voltage flicker, 3) frequency regulation, 4) mitigation of harmonic distortion, 5) phase unbalances, 6) distributed fault ride-through support. The use case revolves around the controls and infrastructure needed to realise this; the roll-out towards ancillary service markets and the detailed implementation on aggregator level is outside of its scope.

**Flexibility invocation by aggregator entities – implementation aspects**
Congestion is one of the main challenges distribution system operators are facing, predominantly in urban environments and rural areas with a sudden (stepwise) increase in PV installations not foreseen in long-term planning cycles. Flexibility is the main–temporary–solution to mitigate overloading; and microgrids and local energy communities can participate in such services, usually through dedicated aggregators. This use case deals with the implementation and system impact aspects of connecting assets like smart energy domestic devices and electric vehicles to such aggregator services. Notable considerations include 1) as to whether to apply standardised or dedicated ICT frameworks to establish the connection between aggregator and prosumer, 2) how to (physically) connect each domestic device in a standardised way, 3) how to limit the social intervention as much as possible, and 4) to invoke flexibility in a reliable, secure, and fair manner, among others.

**Self-consumption, P2P trading, and flexibility in multi-energy systems**
Self-sustainment (consumption, flexibility, trade) is a significant value for local energy communities. Eyeing future developments this is to be extended from electricity to heat networks. This use case will focus on the implementation aspects of such developments. Which hardware is needed? Which assets are compatible and which need more elaborate effort to interoperate (e.g. controls, additional physical utilities)? How can the energy system be optimally utilised in

both collaborative and non-collaborative conditions? And what are the implications for the interconnected energy systems (e.g. district heating, sub-transmission electricity system). Both static and dynamic energy system models are needed for assessing this, assessed in a co-simulation setting due to the level of heterogeneity. Moreover, the interaction between multiple physical assets and the ICT infra can best be holistically addressed in a relevant (real-time) environment. Depending on the phenomena of interest and their properties like time constants such assessment lends itself very well for distributed laboratory coupling treated in JRA3.

## 3.3 Functional Scenario 3: Sector Coupling

### Motivation

The main motivation for this Functional Scenario is the anticipated massive roll-out of power-to-X components in the near future (David, Mathiesen, Averfalk, Werner, & Lund, 2017; Möller et al., 2019). While these technologies are very well understood on the component-level, we still lack a sufficiently good understanding of what that will mean for the electrical domain on the system level.

Furthermore, the following stakeholders will profit from the use cases and test cases defined in this functional scenario:

- *Infrastructure operators*: integrated operation of systems; understand pathways for future investments.
- *Component providers*: understand the potential of integration on the component level.
- *Technology providers*: make services ready for sector coupling (automation, energy management, optimization, data analytics, etc.).

### Relevance for ERIGrid 2.0

Sector coupling is a major trend in energy research. Hence, we anticipate that project partners will be interested in gaining and/or increasing experience by including non-electrical domains in laboratory setups, with a focus on representing non-electrical constraints in the electrical domain.

However, current laboratory infrastructure is not yet mature to work on the topic of sector coupling. Therefore, defining this functional scenario encourages partners to build capability to represent these kind of scenarios (simulation and laboratory). And even though there are currently only few laboratories in Europe with the required lab capabilities, a lot of laboratories have partial capabilities (e.g. for component test stands).

Furthermore, there is potential for a commercial demand for these kind of setups, also in view of follow-ups of lab access projects in ERIGrid 2.0.

### System Descriptions

All considered system configurations are built around electrical systems, due to the expertise of the project partners in the electrical domain.

The most basic extension of an electrical system towards sector coupling is the inclusion of independent power-to-X units. Use cases based on such system are relatively easy to implement and deploy, and thus have a low entry threshold for project partners with little or no experience with this subject. More advanced system configurations include heat networks and/or gas network with X-to-Y units as coupling points.

## Use Cases and Test Cases

**Regulating power provision by power-to-X units**
The aim is to provide regulating power to the electrical transmission network by controlling power-to-X units at distribution level, while respecting heat quality on the thermal side. The goal is the characterisation of power-to-X service availability and its impact on the electrical domain, involving comparison of coordinated vs. uncoordinated schemes under various conditions.

**Thermal network optimisation**
The aim is to coordinate the operations of district heating and electrical power systems with the help of a multi-energy management system, with respect to thermal optimisation of the heat network and increase of local consumption of distributed RES generation. The goal is to verify that self-consumption of renewable energy sources in a coupled heat and power network improves when using distributed power-to-heat appliances compared to a base scenario without power-to-heat.

**Multi-energy system**
During normal operation the system satisfies both the electrical and the heat load in order to reduce the energy bill of the consumer and improve the energy efficiency. Moreover, the heat and gas network can also provide ancillary services to the electrical power system ensuring the functionality of the normal operation. The goal is to verify the fulfilment (in real-time) of a service considering different conditions (winter profile, summer profile, etc.), grid requirements and market rules.

## Experiment Setups

There are 3 possible experiment setups for all variations of this functional scenario with an increasing level of complexity in terms of implementation and deployment:

- pure simulation, including offline co-simulation of electrical and non-electrical models.
- quasi-static PHIL assuming zero inertia conditions:
  - emulation of non-electrical units, i.e. soft real-time integration of non-electrical simulation models into laboratory.
  - non-electrical component testing with emulated electrical domain.
- multi-RI integration, mixing electrical and non-electrical equipment and/or simulation models at different sites.

## 3.4 Functional Scenario 4: Frequency and Voltage Stability in Inverter Dominated Power Systems

### Motivation

Power systems with a low share of synchronous generation and massive integration of DERs pose many challenges for DSOs and TSOs in terms of frequency and voltage stability due to system inertia reduction and lack of reactive power support. A high integration of DERs is reducing the inertia and the frequency stability of the power system. Power systems with low share of synchronous generation, and consequently low total system inertia, are vulnerable to power imbalances. Traditionally, OLTC transformer or shunt capacitor are in charge of voltage support in the distribution system. The high penetration of DERs in distribution systems has significant impacts on the voltage stability and quality at distribution level. Increased stability issues pose problems for DSOs and TSOs. Also, they can jeopardise the safety of producers' and consumers' equipment.

One of the challenges for network operators is the validation and roll-out of reliable and interoperable coordination and control systems. DERs manufacturers and control systems suppliers are required to interoperate and coordinate with traditional components for the frequency and voltage regulation.

This Functional Scenario focuses on demonstrating how frequency and voltage stability in low inertia systems can be assured through capabilities of other power system objects present in the low inertia grids, such as RES, DG, controllable loads and storage systems. Additionally, a holistic manner for the integration of different interoperable layers of the power systems such as ICT, physical network and control systems under different testing scenarios is demonstrated.

### Relevance for ERIGrid 2.0

This Functional Scenario will be implemented and validated at system level which includes transmission system and distribution system combined with ICT domains. Additionally, the test cases will be executed with distributed power hardware in the loop to coordinate different real-time labs using virtual real-time gateways (JaNDER or VILLASnode) that have been developed in ERIGrid. As a result, it is obviously relevant to the main purposes of ERIGrid 2.0 in terms of holistic testing system and the experimental point of view using the ERIGrid developed testing methods.

### System Descriptions

The testing system can be categorised into two different targets:

**Voltage stability:** distribution of sub-transmission system with multiple-voltage levels, e.g., MV/LV, MV/MV, or HV/MV system, including controllable grid equipment, DER and EV:

- Converter-based generation (PVs, winds) connected to different voltage levels (medium 10 kV and low 0.4 kV).
- OLTC transformer (e.g. 110/10 kV or 10 kV/0.4 kV) or Shunt capacitors for voltage support (e.g. at medium voltage level).

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- (Reactive) power controllable equipment at different voltage levels (10 kV and 0.4 kV; e.g. PV, wind, battery, hybrid plants). Voltage levels will cover any two voltage levels of 110 kV $\rightarrow$ 10 kV $\rightarrow$ 0.4 kV.

**Frequency stability:** The power system with high penetration of converter-based generations such as batteries, wind generator, etc. will be investigated. A controller will be implemented to extract the synthetic inertia and fast frequency control from converter-interfaced components. Additionally, ICT system will be also included in this testing system.

## Use cases and test cases

### Voltage stability

**UC1:** Coordinated DER+OLTC services at MV and LV level support mitigation of voltage constraint violations. The addition of an OLTC for voltage control can decrease the voltage violations in the network, however this needs to be considered within the optimisation method applied for the planning of the LV network and it's operation should be coordinated with the other available resources in the network. The following Test Case (TC) falls under Use Case (UC)1.

**TC1:** A single-phase-to-ground fault in medium voltage grid causes an imbalanced supply voltage in the low voltage grid, i.e. dip in 1 phase (e.g. phase A) in low voltage level. Activating OLTC control can cause over-voltage for phase B and C, DERs connected to that phase can participate in voltage control by supplying reactive power.

### Harmonic distortion

**UC2:** Harmonic distortion in the case of DER/EV high penetration. The connection of a large number of electric vehicles EV to the grid, in particular for fast charging, can raise several technical problems or can have significant impacts on power systems like injection of harmonic currents. If there are many electric vehicles in fast charging at the same time, the voltage distortion should exceed the admissible limit. The following TC falls under this UC.

**TC2:** Diverse feeders in a radial distribution system: Two low voltage feeders, the first has a peak load due to high EV loading (possible undervoltage violation at feeder end) and the other feeder appears with off peak load (possible overvoltage at feeder end). Several issues such as the diverse loading on single feeder, high load, high in-feed, low/high transmission supply voltage, voltage step at transmission system shall be examined.

### Frequency stability

**UC3:** Synthetic inertia and fast frequency response/control provided by converter interfaced resources. Supply of synthetic inertia requires energy stored in systems behind power electronic interfaces, such as batteries, rotating masses in wind turbines or even other power systems. Fast frequency response is the controlled contribution of electrical torque from a unit that acts rapidly on a frequency measure. It can react proportionally to the deviation or inject power according to a pre-determined schedule.

**TC3:** Different test cases considering different grid configurations, load changes, changes in the R/X ratio of the grid using a PHIL setup. A reference microgrid can be defined and replicated by interconnecting power electronics converters, loads and rotating machines. A critical aspect is to add sufficient control hardware and communications between the units. Scaling down the microgrid size will allow testing in a laboratory scale.

### Experiment Setups

The possible experiment setup for this functional scenario can be implemented with these facilities and the ERIGrid developed methods as follows:

- Real time simulations and PHIL and MV laboratory setups.
- CHIL experiments for the coordination experiments.
- Coordinated inter-laboratory experiment (VILLASnode type).

## 3.5 Functional Scenario 5: Aggregation and Flexibility Management

### Motivation

Power systems are adapting to the increasing amount of DERs being integrated including EVs, energy storages, PV, wind turbines, and smart building especially on the MV and LV levels. In order to control and monitor the growing amount of distributed resources, aggregation and flexibility management features are being advanced as well, and are becoming critical for the power system operation and integrity. Conventionally, such pure communication and computational functions are validated within the data and communication domains, or in the same way as a conventional power plant (e.g., by pre-qualificition). There is a lack of cyber-physical testing strategies overall. The complexity of validating the combined ICT and physical aspects pose a challenge for today's test setups and established validation approaches. Basic and advanced functionality such as communication functionality for aggregation, service matching, fail-over, configuration, and interoperability are at the core of this development, but are hardly addressed by conventional testing. New aspects of testing should also address the scale-related properties of aggregation and control solutions. The complexity of validating the ICT solutions, which have enormous impact on the grid operation in terms of software, control and communication, remains as the main challenge.

As the aggregation and flexibility management are overarching topics interconnecting several different distributed resources, the stakeholders encompass aggregators, DSOs, TSOs, regulatory authorities, and developers of the aggregation business and the trading platforms. The stakeholders are motivated by different aspects of developing aggregation and flexibility management. The regulation of new flexibility services is negotiated among aggregators, DSOs, TSOs, and regulatory authorities while DSOs and TSOs are concerned with pre-qualifying the aggregator solutions and portfolios. Aggregators and developers further focus on development of new business models and peer-to-peer trading platforms to support LECs.

### Relevance for ERIGrid 2.0

Aggregation and flexibility management are well aligned with the goals of the European Green Deal and support several ERIGrid 2.0 objectives in view of energy sector coupling via distributed energy resources such as electric vehicles and power-to-heat systems. Due to the small individual contributions but their large numbers of such systems, aggregation-related testing capabilities are essential. This Functional Scenario highlights several potential testing demands in this area. The project further will build on the related test cases in respective JRA tasks, which aim at enabling new aspects of sector coupling, communication, and configuration and control in testing. The proposed test cases can be seen as a critical enhancement of the demonstration cases already implemented in ERIGrid, with the aim to offer possibilities for validation of flexible communication structures ranging from fast frequency response to market-based redispatch of flexibility. The distributed nature of aggregation has also potential for enhancing the use of geographically distributed testing as a continuation of ERIGrid demonstrations and research on geographically distributed HIL.

## System Descriptions

In each case under this functional scenario, the systems are cyber-physical, involving three domains: ICT, electrical power system, and the domain of final energy use.

Two scales of the power system and number of DER are considered:

**MV/LV distribution networks** with various loads, renewable generation, demand side flexibility, such as EV charging infrastructure including several aggregators.

**A single LV distribution feeder** with various loads, renewable generation, demand side flexibility, such as EV charging infrastructure.

## Use Cases and Test Cases

The testing challenges in this Functional Scenario have been grouped into four distinct areas, as follows. The differences relate to use cases, affected time scale as well as the associated domains and system under test.

### Flexibility trade and optimal dispatch

Aggregation can serve the representation and coordinated operation with respect to energy markets. Cyber-physical interactions appear especially in congestion management, where aggregators may trade as well as in the facilitation and match-making in local energy communities.

**UC1a:** Aggregators offering congestion management services to a DSO, while creating a price-optimal dispatch of their portfolio's DER.

**UC1b:** A peer-to-peer trading platform for energy community management, leading to an implicit energy dispatch that is traced by the community manager.

**TC1a:** Multiple aggregators offer grid services, congestion management request as an added feature.

**TC1b:** Evaluation of various service definitions and activation patterns.

### Pre-qualification of distributed ancillary service provision

This type of scenario extends the concept of pre-qualification testing from conventional power plants to distributed aggregations forming a virtual power plant.

**UC2:** Continuous service provision under disruptions.

**TC2:** Pre-qualification of service provision including software, communication, and flexibility characterisation aspects, and addition/removal of resources.

**Local impact of fast frequency services**
An aggregator able to provide fast frequency services might disturb operations at a local grid level. Here the level of disruption for a DSO, the power quality and potential congestion within a LV feeder is the main concern.

**UC3:** Frequency-based ancillary services provided from DER in the LV grid

**TC3:** Extrinsic TSO signal triggers flexibility reserves at distribution network level focusing on local control, DER capability and communication aspects.

**Interoperability across Aggregation Infrastructures**
This sub-scenario refers to testing the interoperability of DER among different aggregation infrastructures. For example, it should be possible for a DER to leave an aggregator and join another one in a seamless way as much as possible. The local management system (at building or resource-level) should therefore be tested for interoperability with different aggregator and/or peer-to-peer trading platforms. This test case is related to a problem of transferring DER from one aggregator to another.

**UC4:** Joining of local resource management system in peer-to-peer trading platform:

**TC4:** Test methods for integration/interoperability assessment for building and resource-level management systems in participation with peer-to-peer platform.

### Experiment Setups

Experiment setups for the types of test cases listed above can take many forms, from co-simulation to full hardware realisations. In any case, there are no available standards defining a reference setup for the listed problems. Possible setups include:

- Pure co-simulation of physical elements and communication, interfacing with the real aggregator software in-the-loop.
- Simulation and physical demonstration of LV network with fast/high-fidelity interfacing to a real-time simulation to emulate the scaled up HV/MV system elements.
- Physical DERs with hardware Building Management System (BMS) are integrated with a cloud-based peer-to-peer trading platform, whereas the grid monitoring is implemented on-site.
- Virtualised inter-laboratory setups (e.g., via JanDER or VILLAS) with distributed resources in several laboratories and realistic communication challenges.

## 3.6 Functional Scenario 6: Digitalisation

### Motivation

Power systems tend to use ICT conservatively and often rely on traditional control systems with limited connectivity and a low degree of automation and autonomy in the field. This is a potential barrier to the deployment of smart grid concepts involving advanced monitoring, control and protection. These concepts are commonly based on networked communication in real time between intelligent devices distributed in the field – and they are brought within reach by enabling technologies such as 5G networks and the IoT.

While a wide range of potential benefits has been identified, ranging from more efficient operation to cleaner energy, new business opportunities and improved safety, a roll-out of these new technologies also poses a risk to the economics of energy system operation as well as to the resilience of the integrated cyber-physical system. However, while the physics of electrical power systems are well established, the behaviour of tightly coupled cyber-physical power systems is much less understood, as evidenced by a sparsity of simulation tools and standardised testing methods.

The need to characterise and verify the performance of such integrated systems under realistic conditions, whether through simulation or by physical experiment, implies that a realistic representation of networked control systems has to be used. Such systems are not configured in a static way, they cannot be modelled satisfactorily by a *central control element* substitute and they are subject to permanent and transient communication failure, cyberattacks, race conditions, glitches and other real-world phenomena.

This functional scenario focuses on use cases with a system scope, i.e., where multiple entities interact in the electrical power domain as well as the ICT domain. Relevant test cases explore the impact of ICT solutions on the physical (electrical power) system. In this context, the term 'ICT solutions' covers new applications of data and data processing as well as new paths for exchanging data.

### Relevance for ERIGrid 2.0

The predecessor project ERIGrid has been primarily focused on the testing of electrical power hardware, including control and communication systems at the device level. Supervisory control systems which coordinate between units have mostly been considered as an afterthought. However, these control systems are the primary enablers of smart grids. If ERIGrid 2.0 aims to achieve a more comprehensive capability for testing smart grid concepts, there is a need for a functional scenario which can push these boundaries.

This Functional Scenario aligns well with the work plan of ERIGrid 2.0, including JRA1 on enhanced validation methods, JRA2 on co-simulation- and HIL-based approaches and JRA3 on RI integration and automation.

This Functional Scenario is highly relevant for developing cyber-physical testing capabilities at the individual research infrastructures for the next generation of lab access projects.

### System Descriptions

All system configurations pertinent to this Functional Scenario are **cyber-physical systems** combining an electrical power system (or a section thereof) and an ICT infrastructure enabling the control and/or monitoring of the physical system. The latter consists of a set of networked intelligent devices interconnected through a number of communication links.

The extent and composition of the system configuration in question are highly dependent on the applied use case and test objective. The spatial extent may encompass an entire transmission system, a low-voltage distribution feeder or be limited to the perimeter of a single digital substation. However, the key distinguishing feature of the test system is that in all cases, the electrical system and the ICT infrastructure are functionally interlinked and are considered to be equally important parts of the system.

## Use Cases and Test Cases

The collected use cases fall into the following three main categories:

**Automated grid operation and distributed coordination**
Use cases in the first category are concerned with coordination and automation processes at the scale of one or multiple distribution network feeders. The phenomena of interest are typically characterised by the need to integrate systems under heterogeneous ownership (e.g., DSO, DER owner and aggregator) across multiple communication networks and up to a regional geographical scale, and at time scales from seconds to hours. Use case/test case combinations of interest include the characterisation of the impact of network properties on network monitoring concepts such as multi-source state estimation, the validation of novel grid-level autonomous functions such as fault location and service restoration and the verification of the failover performance of the redundant command and control infrastructure of an aggregator.

**Substation automation and protection**
The second category contains use cases related to the automation of processes in substations and between substation equipment such as protection devices. The phenomena of interest are typically characterised by a small geographical extent, a single organisational entity controlling all involved assets, many devices sharing a single network segment and, in the case of protection, very short time scales and high reliability requirements. Use case/test case combinations of interest include the validation of novel automation and protection concepts, interoperability verification as well as the performance characterisation of equipment from different vendors.

**Cybersecurity**
This category of use cases relates to different aspects of cybersecurity in connection with automated and networked control systems. This includes vulnerability analysis as part of an ICT system design and improvement process, intrusion detection as an operational tool as well as impact analysis in order to measure the attack resilience of a given power system.

## Experiment Setups

Cyber-physical testing has not yet advanced towards a mature discipline with established methods and standardised tools. This is particularly visible in the lack of validated multi-domain simulators allowing for an integrated evaluation of power system and ICT network performance. Therefore, and despite the associated effort, it is expected that the test cases in this functional scenario will at least initially demand single-RI experiment setups involving physical components, either fully physical or in an xHIL configuration. Experiments involving multiple RIs and remote components, as well as pure simulation experiments, are very relevant once the ERIGrid 2.0 consortium establishes the required capabilities, mostly in the JRA2 and JRA3 work packages.

# 4 Harmonized Presentation of Functional Scenarios

Functional Scenarios defined in the Section 3 share common characteristics, but also include differences. The guidance and structure for the Functional Scenarios as well as the definition have been the same for all the working groups, however due to the number of relevant Functional Scenario survey results and the work conducted in the brainstorming workshop there has been a slight variation in the development of the Functional Scenarios.

All of the Functional Scenarios have been defined according to the principles of each Functional Scenario including only one core idea and the aim for inclusive opportunities rather than detailed technical implementation. However, these principles, especially due to a demand for inclusiveness, have led some developed Functional Scenarios to include a wide range of topics and consider a variety of use cases and test cases, while others prove themselves quite narrow in definition and thus able to include further information on the technical aspects of the test cases and experimental setup requirements.

A couple of redundant issues have been recognised during the harmonisation of the Functional Scenarios. Firstly, the background foundation for the Functional Scenario 6 on digitalisation has been considerably vast including wide range of topics from automation to cybersecurity, which has in turn impacted its consolidation. A holistic approach has been used to consolidate this Functional Scenario by formulating a system description as a cyber-physical system and allowing a range of use cases and test cases associated with the scenario. Secondly, it has been considered that the themes and topics of Functional Scenario 2 on microgrids and energy communities and the Functional Scenario 5 on aggregation and flexibility management are closely linked with possibly redundant elements due to the broad concept of energy communities. This challenge has been resolved by continuous discourse between the respective working groups to ensure that each of the Functional Scenarios' scope remains distinct and thus all Functional Scenarios retain their unique usefulness for ERIGrid 2.0 in a harmonious manner.

Functional Scenario 5 on aggregation and flexibility management encompasses cyber-physical system setups in line with the Functional Scenario 6 use cases on automated grid operation and distributed coordination. In relation to Functional Scenario 2, Functional Scenario 5 adopts all aspects virtual (non-localised) on energy communities, including the match-making and coordination elements. The possible overlap between Functional Scenarios 5 and 6 is resolved by focusing on application-oriented testing challenges in the former and rather methodical challenges in the latter.

The Functional Scenarios have been initially mapped on a standard description to clarify the harmonisation process and illustrate the holistic representation of the scenarios. The standard description utilised has been SGAM and its extension GSCAM. GSCAM extends the SGAM to cover several sectors including energy, traffic, and health as Application Domain Cubes (ADCs) by combining SGAM type configurations of different sectors (Uslar et al., 2019). In the mapping of the Functional Scenarios, the different sectors considered have been mainly electricity, heating and cooling, gas and data. Figure 5 and Figure 6 illustrate SGAM and GSCAM utilised in the initial mapping.

Functional Scenario 1 on ancillary services provided by DERs and active grid assets has been mapped to the component layer of the SGAM especially focusing on the DER domain with strong connections to the other domains, zones, and interoperability layers. Functional Scenario 2 on microgrids and energy communities focuses on the domains of distribution, DER, and customer premises locally, thus considering locally zones such as process, field, station, and operation on all the interoperability layers. Functional Scenario 3 on sector coupling ex-

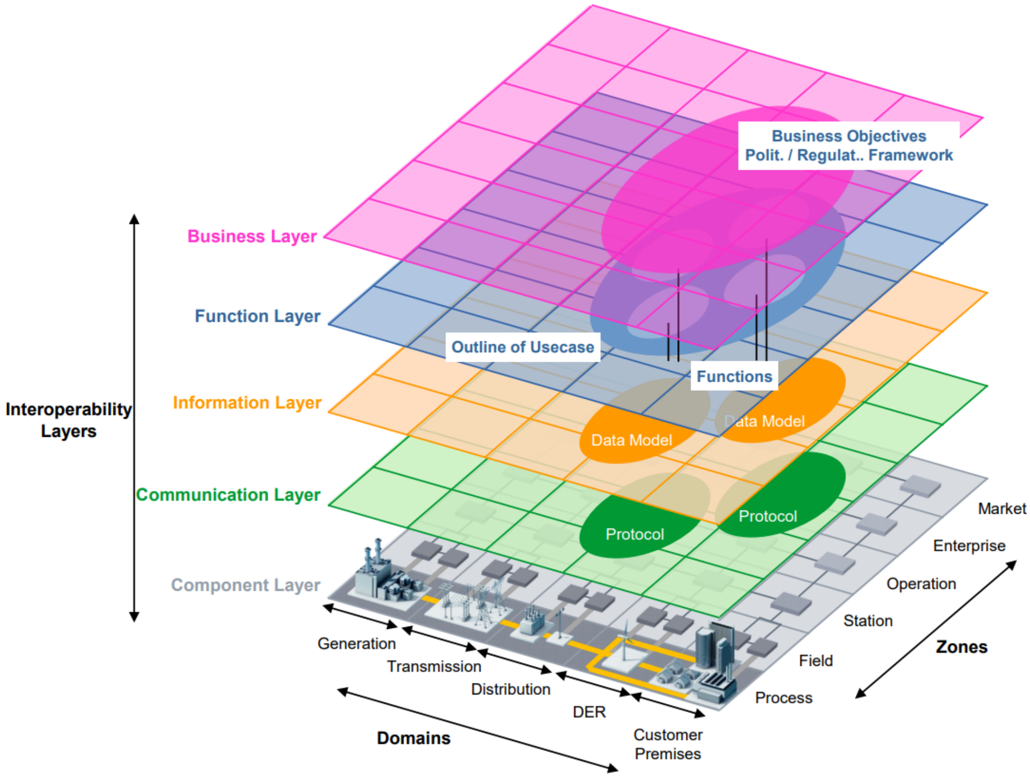


*Figure 5: SGAM the standard description utilised in harmonisation of Functional Scenarios.*

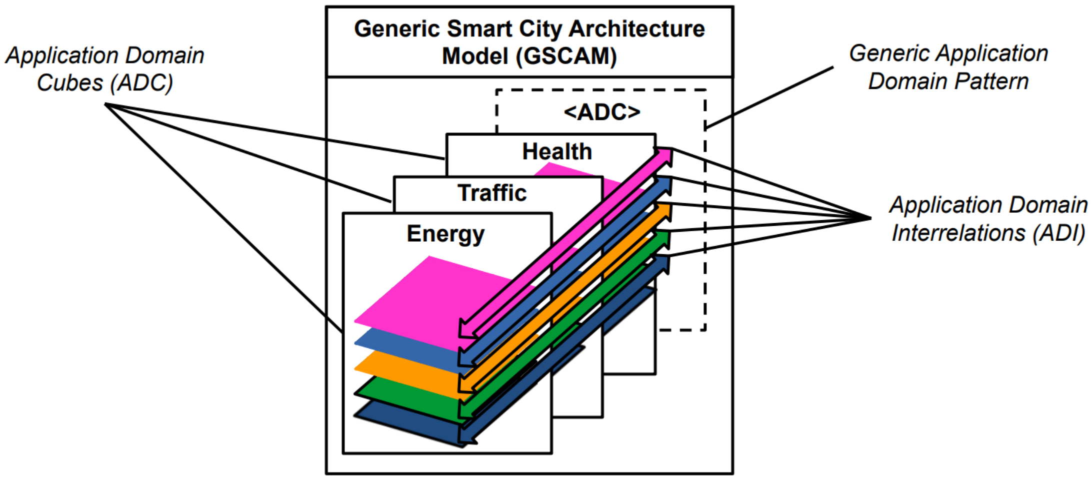


*Figure 6: GSCAM an extension of the SGAM standard descriptions used in harmonisation (Uslar et al., 2019).*

pands beyond power systems on the GSCAM focusing on the interlinks between the power system ADC and the other ADCs interconnected. Functional Scenario 4 on frequency and voltage stability in inverter dominated power systems has been mapped on the transmission and distribution domains covering all the zones and interoperability layers on these domains. Functional Scenario 5 on aggregation and flexibility management focuses on the virtual aspects of distribution, DER, and customer premises domains on all the interoperability layers especially considering the operation, enterprise and market zones. Functional Scenario 6 has been mapped on the SGAM especially on the communication and information layers.

While mapping the redundancies especially amongst Functional Scenarios 2, 5, and 6, the following harmonisation discourse has been considered. Functional Scenarios 2 and 5 will be emphasising the function and business layers from local and virtual perspectives, while Functional Scenario 6 encompasses the communication and information layers with weight on the methodical challenges. The detailed mapping of the Functional Scenarios will be continued in NA4.4.

# 5 Conclusions

NA4.1 defined six Functional Scenarios used within ERIGrid 2.0. Each of the Functional Scenarios has the potential to consist of several System Descriptions, Use Cases, Test Cases, and Experimental Setups, while including only a single motivation and relevance for ERIGrid 2.0. The foundation of a Functional Scenario is a core concept and within NA4.1 and all the scenarios presented have been formed on the basis of inclusiveness. The six Functional Scenarios are the following:

- *Ancillary Services provided by DERs and Active Grid Assets*: Integrates key components, such as DER inverters and controllers with ICT, control and automation architectures to enable new grid services with the development of interfaces between the active components.
- *Microgrid and Energy Community*: Supports the local microgrid and energy community development by enabling flexibility services locally with ICT and control including exploitation of grid intelligence.
- *Sector Coupling*: Anticipates the massive roll-out of power-to-X components in the near future by developing the system level understanding on the impacts on the electrical domain.
- *Frequency and Voltage Stability in Inverter Dominated Power Systems*: Assures frequency and voltage stability in low inertia systems through capabilities of RES, DG, controllable loads and storage systems as well as ICT and control systems.
- *Aggregation and Flexibility Management*: Focuses on communication functionality for aggregation, service matching, fail-over, configuration, and interoperability addressing scale-related properties of aggregation and control solutions.
- *Digitalisation*: Explores the impact of ICT solutions on the physical (electrical power) system covering new applications of data and data processing as well as new paths for exchanging data.

The activities in NA4.1 included a Functional Scenario survey, which resulted in 35 responses by 15 partners. These results varied in the level of detail from high-level descriptions to detailed implementations and were used as the inputs to form the Functional Scenarios. Each Functional Scenario, its scope and description, was formed in the brainstorming workshop by its the respective working group. The work started in NA4.1 will continue in NA4.2 and NA4.4 by discussions on more detailed definitions of the test cases providing the inputs for JRA1 benchmark cases and reference simulations and JRA4 validation approaches, demonstrations, and the integration of the research infrastructures. The discourse on the Functional Scenarios is also assumed to support ERIGrid 2.0 lab and virtual access work and decision-making beyond ERIGrid 2.0.

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# Appendix A: Functional Scenario Survey Data

Functional Scenario title: Aggregated DER

Information provider: CRES

System under Test: Aggregated DER either as technical Virtual Power Plants (VPPs) or are microgrids connected to a distribution grid and controlled by signal generated by the Control Area Operator.

Motivation: The DER units connected to a distribution grid of a control area should provide flexibility in terms of active power in order to support frequency restoration of this area.

Use Case: Automatic Frequency Restoration Reserve from DERs

Test Case:

1) Latency/time delays in the reaction of DER to a signal from the operator and influence on frequency.

2) Capacity availability from EVs in order to provide the requested power/energy

Experiment Setup:

1) Transmission System Supervisory Control And Data Acquisition (SCADA) and Distribution Management System (DMS), Communication Channels, Internal controllers of DERs (control of non electric domains)

2) EV batteries including BMS, EV charging stations, Central Controller of EV charging station, grid connection, communication channel, Transmission System SCADA and Distribution Management System (DMS)

Relevance to ERIGrid 2.0: A number of services currently provided by large-scale power plants in the future will be provided by smaller-scale DER. In particular, DER such as EVs could be a good case of Automatic Frequency Restoration Reserve (aFRR) providers due to their fast response in power set-points. This scenario is highly relevant to ERIGrid 2.0 as part of the Electrification of Transport aspect.

Related project, network, etc.: ERIGrid

Published on: D-JRA1.2 Focal use case collection

General comments and suggestions: -

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Functional Scenario title: Communication and connectivity enabling smart energy systems

Information provider: VTT

System under Test: The communication interconnections and the ICT layer of smart grids.

Motivation: Power systems often rely on old communication technologies and connectivity techniques, which could be hindering the developed monitoring, control and protection possibilities on the smart grids. Communications and connectivity could enable new solutions and business opportunities on the energy systems, for instance increasing flexibility and advancing the development of energy communities, while also accelerating the development and implementation of future clean energy systems. Additionally, modern communication technologies, including 5G and beyond, pose interesting scientific opportunities especially when applied to the critical communications in smart grids, operation and control of massive IoT or distributed synchronous real-time connectivity.

Use Case: Enable improved connectivity on smart energy systems to for instance increase the monitoring and control of the smart grids.

Test Case: By implementing connectivity between different actors and devices and measuring parameters such as latency and reliability.

Experiment Setup: Platform for communications or bilateral connectivity and power system devices capable of communication including controllable loads, generators and energy storage, grid emulators, real-time simulators, protection and control systems.

Relevance to ERIGrid 2.0: Related to the research of ICT, automation and control infrastructure of smart grids and smart energy systems, enabling people to better use the ERIGrid 2.0 infra on TA visits and continue the research from ERIGrid.

Related project, network, etc.: Smart Otaniemi innovation ecosystem, including also Fleximar (local flexibility market), HEILA (integrated business platform for DER), and 5GTNF (5G Test Network Finland).

Published on: Smart Otaniemi website[24], brief summary of Smart Otaniemi[25], Final report of HEILA[26], website of 5GTNF[27].

General comments and suggestions: -

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Functional Scenario title: Coordinated operation of Power-to-Heat units

Information provider: DTU

System under Test: For the purpose of this scenario, we consider urban thermo-electrical systems which come in two variants:

VARIANT 1: Electrically-supported district heating network, using network-integrated Power-to-Heat (P2H) units.

VARIANT 2: Electrical heating on each house of the electrical network, i.e. residential heaters / heat pumps.

Motivation: Heating currently comprises 50 percent of Europe's final energy demand. As part of decarbonisation of the energy sector, a major portion of this sector will have to be supported by coupling to the electrical sector, e.g. using heat pumps. Such a strong dependency will lead to several issues:

1. Operational issues in one system necessarily impacts the other (e.g. loss of electrical connection leads to low heating quality).
2. Electrical demands are co-driven by heating demands, leading to increased peak loads and coincidence factors during cold periods.

At the same time, these open up additional opportunities in both systems:

[24] Smart Otaniemi website
[25] Smart Otaniemi brief summary
[26] HEILA project final report
[27] 5GTNF website

 doi:10.5281/zenodo.3991723 

1. For the electrical system, short-duration dynamics can be absorbed by the large inertia in the heating system.
2. For the heating system, using electrical energy for distributed heat provision allows optimisation to provide the same heat quality at lower heating losses.

Use Case:

UC1 Regulating power provision by Power-to-Heat units (Variants 1 & 2): Provide regulating power to the electrical transmission network by controlling power-to-heat units, while respecting heat quality on thermal side.

UC2 Thermal network optimisation (Variant 1): Coordinate the operations of district heating and electrical power system with respect to thermal optimisation of the heat network.

Test Case: The test case aims to characterise different aspects of the coord. system, e.g:

Characterisation of electrical impact of P2H integration. Focus on changes in electrical system demand under increased P2H unit penetration.

Characterisation of flexibility available (heat and electricity). This may relate to both seasonality (summer/winter), response rate or operational impact of flexibility use.

Validation for units providing uni-sectoral flexibility. That is, how does one certify units which deliver services to one domain with respect to requirements in the other domain.

Characterisation of P2H 'cross-talk' on heating side (VARIANT 1) Due to network congestion in heating side by providing flexibility to electrical network. Provision of electrical services may lead to reduced flexibility and heating quality on the heating side.

Validation test whether control system respects information separation between heating system and electricity system operators.

System quality measures include: First, for the electrical System: Voltage levels in electrical distribution network, Degree of congestion in distribution grid under rapid heat pump deployment. Second, for the heating system (district heating side): total heat losses in district heating network, heating quality (temperature/flow) limits at residential consumer connection or in-residence. Third, on the consumer side of the heating system, the thermal comfort of a building.

There are 2 types of generic system configuration, depending on the variant chosen:

VARIANT 1: With district heating network: decentralised feed-in to network, residential / commercial / industrial consumers connected to network.

VARIANT 2: Without district heating network: residential consumers with per-building power-to-heat unit

Both variants include an electrical grid with 10 kV and 0.4 kV.

Experiment Setup:

At a minimum, a representation of the electrical grid and the heating system corresponding to the variant examined is required, along with at least one power-to-heat unit.

Since communication between domains happens both at the physical interface and at the level of the operating entities, a means of controlling these units via explicit modelling can be added, together with infrastructure to support communication between controllers.

Any of the above can be (partially) implemented in simulation in addition to the lab, which may be particularly relevant if scaling to a large number of units is a desired goal here, especially in VARIANT 2, where, e.g. 100 residential-level heat pumps may be required to characterise system response.

Relevance to ERIGrid 2.0: ERIGrid 2.0 has sector coupling and multi-energy systems as themes. Among project partners, lab facilities with all the relevant kinds of units and networks are found, with different partners having different sections of the system configuration. There are thus many multi-RI experiments possible here. In ERIGrid, we developed methods of interfacing these (also with simulated networks), and would like to perform tests of these units integrating via that interface, or its extended version in ERIGrid 2.0.

Integration with the heating system is an excellent candidate for use of quasi-static PHIL, as fast electrical dynamics are less important, but accurate energy transfers highly relevant.

The scenario could be combined with co-simulation for heating/electrical side, which serves as a useful test of the virtual access platform.

Related project, network, etc.:

H2020 projects: SmILES (Use cases, cross-domain services, system configuration definitions)

Networks: EERA, specifically JPs Energy Systems Integration, Smart Cities, Smart Grids

Non-H2020 projects:

1. DREM [DNK] (Relevance: Cross-domain services)
2. HONOR [SWE/NOR/GER/DNK]
3. CITIES [DNK] (Relevance: Sector coupling for smart grids)
4. Digital Energy Lab [DNK] (Relevance: Key network data available)

Published on:

Leitner et al: "A method for technical assessment of power-to-heat use cases to couple local district heating and electrical distribution grids" [28]

Lund et al: 4th Generation District Heating (4GDH): Integrating smart thermal grids into future sustainable energy systems [29]

European heat roadmap[30]

Gehrke, Richert: Use cases for integrated electrical and thermal energy systems operation and control with a view on simulation tools [31]

[28] Leitner B., Widl, E., Gawlik, W. & Hofmann, R. (2019.) A method for technical assessment of power-to-heat use cases to couple local district heating and electrical distribution grids. Energy, 182, 729-738.

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[30] European heat roadmap website

[31] Gehrke, O. & Richert, T. (2017.) Use cases for integrated electrical and thermal energy systems operation and control with a view on simulation tools. In the Proceedings of 2017 52nd International Universities Power Engineering Conference (UPEC), December, 21st, 2017, Heraklion, Greece.

Cai et al: "Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis" [32]

General comments and suggestions: -

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Functional Scenario title: Coordination of electricity consumption and production between independent actors in a microgrid or energy community

Information provider: SINTEF

System under Test: The locally coordinated control (e.g microgrid controller) of a low-voltage distribution grid with several actors. The grid can either be a *normal* distribution grid, defined as an energy community, or a microgrid.

Motivation: For a microgrid with one connection point to the distribution grid, there might be cost savings in coordination between the different customers in the microgrid, hence lowering the electricity cost from the grid. The same goes for an energy community, if they are allowed to have one connection point to the distribution grid. The sharing of electricity between customers is however not straight-forward, often based on optimisation, forecasting, and communication and control systems are needed.

Use Case: Provide technically and economically robust and efficient operation of a microgrid / energy community in interaction with the power system. The system coordinates the electricity consumption in the microgrid/energy community, by monitoring the electricity consumption/production of each customer, optimising the exchange with the distribution grid, and controlling local units.

Test Case: Optimally control power production/consumption/storage in a microgrid/energy community, responding to stochastic variation/uncertainties in load or production, or responding to external signals (explicit or implicit) from system operator or flexibility market.

Experiment Setup:

1. Control system (e.g microgrid controller)
2. Load, generation and storage (physical or modelled)
3. Utility grid connection (physical or modelled, e.g. PHIL)
4. External signals and environmental factors (price/control signal, isolation, weather forecast etc.)

This functional scenario has overlapping infrastructure requirements with 'Stability and interactions in converter-dominated microgrids'.

Relevance to ERIGrid 2.0:

1. Energy communities are part of EU legislation/directive and is a tool to increase renewable share.
2. This scenario could be a good entry point to multi-energy topics that ERIGrid 2.0 sets out to accommodate.

Related project, network, etc.: -

[32] Cai, H., You, S., Wang, J., Bindner, H. W. & Klyapovskiy, S. (2018.) Technical assessment of electric heat boosters in low-temperature district heating based on combined heat and power analysis. Energy, 150, 938-949.

Published on: -

General comments and suggestions: -

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Functional Scenario title: Cyber-physical testing of resilient control systems

Information provider: DTU

System under Test: The test system consists of an electrical grid and a control infrastructure. The electrical system consists of a LV/MV distribution grid (e.g. 0.4 kV and 10 kV) with a number of EVSE or other controllable DERs distributed across multiple feeders. An aggregator operates a control infrastructure on the grid section, consisting of one or several aggregator master servers, one or several data concentrators and one Intelligent Electronic Device (IED) per EVSE (or other DER), acting as a control front end to one or several charging EVs.

Motivation: As advanced and networked control systems proliferate in smart grid/smart energy systems, a need arises to ensure the resilience of the the integrated cyber-physical system, i.e. to characterise and verify the performance of such integrated systems under adverse conditions. Such adverse conditions may not only be created by an electrical event such as e.g. a short circuit, but also by events in the ICT domain such as network interruptions or cyberattacks.

In order to perform meaningful testing on the matter of resilience, realistic control systems have to be used. Such systems are not configured in a static way, they cannot be modelled sufficiently by a *control blob abstraction* and they are subject to permanent and transient communication failure, cyberattacks, race conditions, glitches and other real-world phenomena.

First and foremost, this functional scenario will be useful for aggregators, fleet operators, DSOs and other entities seeking to deploy or improve control infrastructure for harvesting services from DERs.

Use Case:

UC1: Dynamic client portfolios

An aggregator delivers a service to the grid (e.g. following a specified load profile). DER units (EVs) can request to subscribe to an aggregator, in order to deliver grid services as a part of its portfolio. They subsequently receive control signals according to the aggregator's dispatch strategy until they unsubscribe. Not all units have the same set of control capabilities and feedback signals. The aggregator adjusts its service offer and delivery according to the portfolio of subscribed units at any time.

UC2: Failover

An aggregator delivers a service to the grid (e.g. following a specified load profile). One of the data concentrators (in the communication chain between the aggregator master server and the DER units) fails. The master server assigns the concentrator's clients to another concentrator and operation resumes, i.e. the aggregator continues to deliver the service as before.

Test Case:

UC1-TC1: Characterisation of portfolio management algorithm

The test objective is to measure the performance of an aggregator algorithm managing a dynamic portfolio of connecting and disconnecting EVs for the purpose of delivering a grid service.

Metrics may include the optimisation or fairness of dispatch or e.g. the fraction of available flexibility used for delivering a grid service in a reliable way.

UC2-TC1: Verification of service compliance in a failover situation

The test objective is to verify that the aggregator does not violate the service definition of a grid service it is delivering, during and after the occurrence of a failover situation. The primary metrics depend on the service, but would typically include maximum setpoint deviation, minimum ramp rate and minimum step response time. Time to restoration of normal operation could be considered as a secondary metric.

Experiment Setup: The test setup requires a grid section which can represent a congested distribution feeder, multiple controllable loads, an communication network and multiple networked devices on which the functions of aggregator, data concentrator and IED can be implemented.

As the focus of the scenario is on cyber-physical testing, all tests require a cyber-physical setup; however, one or multiple components could be simulated. For example, the following variants could be imagined:

1. Fully physical setup: Physical grid, physical loads, physical communication network and physical networked devices.
2. Hybrid setup, PHIL: Virtualised networked devices and communication network simulator, exchanging load setpoints and status with a physical grid and physical loads.
3. Hybrid setup, CHIL: Real-time simulation of electrical grid and loads, exchanging load setpoints and status with physical networked devices which are interconnected via a physical communication network.
4. Fully simulated setup: Cosimulation/multi-domain simulation involving an electrical grid simulator, simulated loads, a communication network simulator and virtual representations of networked devices (e.g. virtual machines or simulator processes).
5. Multi-RI setup: An experiment could be split between multiple RIs in several ways, e.g. splitting the physical system into multiple feeders or having the physical system being tested in one RI and the control system in another.

Relevance to ERIGrid 2.0: ERIGrid-1 has primarily focused on the testing of (real or simulated) electrical power hardware. The inter-unit control systems (i.e. the controllers beyond the unit controller which are needed to coordinate the operation of multiple power assets) have mostly been considered as an afterthought. However, these control systems are the primary enablers of smart grids. If ERIGrid 2.0 aims to achieve a more comprehensive capability for testing smart grid concepts, there is a need for a functional scenario which can push the boundaries of the consortium's capabilities in this area.

Control systems tested in ERIGrid-1 have been characterised by the following points:

1. The control topology is static, hard-wired and known beforehand. For example, a control system designed for one master and three slaves will always have one master and three slaves, and none of these roles can change.
2. The type of information exchanged between entities is known beforehand. For example, a slave will always report voltage and current measurements through pre-assigned channels.

3. Only numerical information is exchanged between entities. This does not include, for example, requests, commands or other types of protocol.
4. Controller processes and communication links are considered completely reliable and fault-free.

These restrictions does not well represent even current control systems. For exploring future, advanced control concepts, they are inadequate. It is important to ensure that the joint tools developed in ERIGrid 2.0 don't restrict advanced controls by design, even if not all capabilities can be developed within the project.

Related project, network, etc.: Parker[33], Nikola[34], and ACES Bornholm[35].

Published on:

Bondy DEM, Heussen K, Gehrke O, Thavlov A. A Functional Reference Architecture for Aggregators. In Proceedings of the 20th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA 2015). IEEE. 2015.

Bondy DEM, Gehrke O, Thavlov A, Heussen K, Kosek AM, Bindner HW. Procedure for Validation of Aggregators Providing Demand Response. In Proceedings of 2016 Power Systems Computation Conference (PSCC). IEEE. 2016 [36]

General comments and suggestions: -

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Functional Scenario title: DER management system

Information provider: CRES

System under Test: Centralised control system for the organisation and operation of DER

Motivation: It performs supervision and maintenance of the components and provides information to the operators and field crew personnel and interacts with the DER Energy Management System (EMS)/VPP system for the control of the generation.

Use Case:

1. Monitoring electrical flows
2. Managing energy consumption or generation of DERs via local DER energy management system bundled in a DR program

Test Case:

1. Characterisation of communication latency and synchronisation of the various measurements
2. Characterisation of power/energy response to DR signals

Experiment Setup: Prosumers, RES, distributed storage, distribution grid, Advanced Metering Infrastructure (AMI) (smart meters, Phasor Measurement Units (PMUs)), SCADA.

[33] PARKER project website
[34] NIKOLA project website
[35] ACES Bornholm website
[36] Bondy, D.E.M., Gehrke, O., Thavlov, A., Heussen, K., Kosek, A.M., Bindner, H.W. (2016.) Procedure for Validation of Aggregators Providing Demand Response. In Proceedings of 2016 Power Systems Computation Conference (PSCC), August 11th, 2016, Genoa, Italy.

Relevance to ERIGrid 2.0: DER management systems are indispensable parts of smart grids that encompass flexibility from prosumers of various energy domains. Especially in DR the role of prosumers that include EV charging, thermal storage etc. could be very relevant. Therefore, this scenario is also worth investigating in ERIGrid 2.0.

Related project, network, etc.: Smart Grid Coordination Group

Published on: CEN-CENELEC-ETSI Smart Grid Coordination Group First Set of Standards, November 2012

General comments and suggestions: This document provides an exhaustive list of UCs that we might find relevant for the definition of our scenarios.

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Functional Scenario title: Development of a cybersecurity system to protect metering data and personal information of the MV customers

Information provider: HEDNO

System under Test: Smart meters, Automatic remote reading system, network communication (5G)

Motivation: DSOs, Sources of vulnerabilities include firmware, hardware architecture, system applications, as well as a network interface, communication problems (low signal) to very unapproachable districts of the Hellenic Grid (islands, underground installations), other communication attacks include wireless scrambling increase in the phenomenon of the electricity theft.

Use Case: In this scenario an information management application (algorithm) to detect various cyberthreats for the consumers data (metering & personal) and evaluate them.

Test Case: The algorithm will protect the bidirectional communication link between the metering unit (smart meter) and the main gateway (server and portal site of consumers metering data)

Experiment Setup: Simulation software, smart meters, communication equipment, servers, data bases

Relevance to ERIGrid 2.0: This scenario is relevant to ERIGrid 2.0 goals and the benefits are:

1. The decrease in technological risks thanks to the development of complete information systems
2. The conclusion of information systems and the adoption of common standards that will contribute towards reducing the duration of digital transformation
3. The decrease in the maintenance and operation cost of the information systems
4. The possibility of future application of Big Data Analytics in metering data

Related project, network, etc.: -

Published on: -

General comments and suggestions: -

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Functional Scenario title: Digital Substations

Information provider: TUD

System under Test:

1. The physical system being addressed here is digital substation. A typical digital substation includes substation bays, merging units, Ethernet switches, Human Machine Interfaces (HMIs), time servers, IEDs, centralised protection and control units, station control systems, etc. A substation bay comprises busbars, disconnectors, circuit breakers, Current Transformers (CTs) and Voltage Transformers (VTs), etc.
2. Communication within the substation is realised by local operating networks (process bus) at the bay level using communication protocols, e.g. IEC 61850, for power system protection and automation applications. Furthermore, LAN at the station level enables communication with control centre through a dedicated communication gateway using protocols such as IEC 104 and DNP3.

Motivation:

1. Target audience of this scenario includes: system operators, equipment manufacturers (vendors) and researchers.
2. The energy transition towards renewable energy resources and related developments such as intelligent demand response, deployment and usage of storage devices, etc. call for a greater deal of flexibility in protection and control applications. This is to ensure security of supply. With rapid developments in ICT and computing, industrial processes and systems are transitioning to Industry 4.0 & IoT based systems. This is also taking place in the electrical power grid as integration of digital technologies allows for increased inter-connectivity between different components and layers of the grid. This has motivated newer automation and protection standards, such as IEC 61850. The increased interdependence between cyber and physical layers in the power grid, coupled with advanced power system automation and communication standards has given rise to digital substations. These digital substations allow for improved flexibility of protection and control applications. Consequently, they are an integral part of the smart grid, aiding in the energy transition. Hence, there is a growing industrial push for widespread adoption of IEC 61850 and digitalization of substations that requires thorough testing and validation.
3. In a digital substation, analogue hard wiring is replaced with optical communication fibre based on Ethernet. This provides increased information availability and a reduced footprint. Further, increased digitalization also offers benefits such as improved safety, performance, reliability, etc.
4. While providing the above-mentioned benefits, digitalization raises some important questions:
    (a) How do protection and control schemes differ in a digital substation in comparison to conventional electrical substations?
    (b) How can latest automation and protection functions/schemes be tested and validated?
    (c) Is centralised substation protection and control superior than distributed substation protection and control?
    (d) How to address cybersecurity concerns while ensuring system performance?

   (e) How to defend and mitigate against cyberintrusions in digital substations?
   (f) How resilient and reliable are digital substations?

Thus, there is strong case to study, analyse and validate various facets of digitalization of substations.

Use Case:

1. Interoperability (UC1)
   (a) Analysis of substation operation with components from multiple vendors.
   (b) Performance testing of different manufacturer devices under similar conditions.
2. Novel protection and automation functionality (UC2)
   (a) Real-time system-based testing and validation of special protection and automation schemes.
3. Cyberresilience (UC3)
   (a) Impact analysis of cyberattacks on digital substations
      - CPS tool and method for cybersecurity investigations.
      - Analyse effect of cyberattacks/incidents on grid stability and operation.
   (b) Defence of digital substations
      - Improve cyberresilience of digital substations.

Test Case:

1. Distributed co-simulation of digital substations across multiple RIs involving relevant protocols.
2. Geographically Distributed Power Hardware in Loop (GD-PHIL) configuration to emulate digital substations and grid connection.
3. Simulate/emulate interaction between control centre and substation.
4. Modelling and simulation of cyberevents through dedicated network simulators in a distributed co-simulation setting.

Experiment Setup:

1. Power System Modelling and Simulation:
   (a) RTDS (Electromagnetic Transient (EMT))
   (b) OPAL-RT (EMT)
   (c) DIgSILENT PowerFactory (Time Domain Simulations (TDS) / online power flow)
2. Communication network simulators/emulators:
   (a) Mininet
   (b) CORE
   (c) SCADA and other Operational Technology (OT) (partner RIs)
3. Hardware requirements:

   (a) Substation network elements: Ethernet switches, IEDs, Remote Terminal Units (RTUs), Merging Units (MUs), HIL devices, etc.

4. Software requirements:
   (a) Open source libraries for IEC 61850:
      - libIEC61850[37]
      - OpenIEC61850[38]
   (b) Commercial relay configuration software, e.g. SIPROTEC configurator, etc.

Relevance to ERIGrid 2.0:

1. This functional scenario aligns well with planned ERIGrid 2.0 JRA on co-simulation-based approaches. Further, the proposed use cases from this scenario can also be tested and demonstrated in JRA3 and JRA4 respectively, using the improved and extended services developed within their scope.
2. The functional scenario of a digital substation addresses an industrially and academically relevant topic that matches the broad project theme of digitalization. This is particularly interesting for grid operators, in order to evaluate substation protection and control architectures with different design principles, e.g. digital vs traditional substations.
3. Digital substations, automation and protection standards are crucial to the energy transition as outlined earlier.

Related project, network, etc.: Flexigrid (H2020)[39], SPARKS (H2020)[40]

Published on:

S. Kumar, N. Das, S. Islam and A. Abu-Siada, "Verification of Latency and Delays Related to a Digital Topology based on IEC 61850," 2019 29th Australasian Universities Power Engineering Conference (AUPEC), Nadi, Fiji, 2019, pp. 1-6, doi: 10.1109/AUPEC48547.2019.211964.

O. A. Tobar Rosero, R. J. Santamaría Isaza, G. Darío Zapata Madrigal and J. C. Olaya, "Relevant Aspects for Interoperability in Electrical Substations under Implementation of Process Bus IEC 61850-9-2 with Multi-Vendor Devices," 2019 FISE-IEEE/CIGRE Conference - Living the energy Transition (FISE/CIGRE), Medellin, Colombia, 2019, pp. 1-6, doi: 10.1109/FISECIGRE48012.2019.8984957.

H. Vardhan, R. Ramlachan, W. Szela and E. Gdowik, "Deploying digital substations: Experience with a digital substation pilot in North America," 2018 71st Annual Conference for Protective Relay Engineers (CPRE), College Station, TX, 2018, pp. 1-9, doi: 10.1109/CPRE.2018.8349795.

ABB. Digital substations[41].

General comments and suggestions: -

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Functional Scenario title: Distributed controls in smart grid

[37] libIEC61850 website
[38] OpenIEC61850 website
[39] Flexigrid website
[40] SPARKS website
[41] ABB Digital substations website

Information provider: SINTEF

System under Test: The scenario is on automated operation of the grid with distributed control. The system under test consists:

1. Measurement devices such as MUs, PMUs, etc.
2. Intelligent Control units such as Control and Protection IEDs
3. 'Intelligent' actuators that can be controlled by IEDs such as switches, breakers, reclosers, etc.
4. Controller (e.g. at the DSO level)
5. Communication infrastructure (ICT support system)

Motivation: Due to the large-scale introduction new components such as DERs, the operation of the distribution grid is changing significantly. To support this new transformation of the grid and handle the new uncertainties and challenges arising from the introduction of new components and technologies, ICT has been used extensively. However, little is known about its impact on the performance of the grid's normal operation. Besides, to increase the reliability, performance and robustness of the grid, there has been some efforts to make the grid more autonomous. In this regard, a number of distributed control approaches such as Multi-Agent System (MAS) approaches, self-healing with the coordination of IEDs etc. were proposed by researchers for different smart grid applications. Hence, it will be interesting to investigate different use cases of autonomous operation of the grid, and specifically to look into the role of ICT, its interdependency with the power system in such autonomous operation of the grid.

Use Case: The following use cases can be considered (non-exhaustive list):

1. Fault Location and Service Restoration (FLSR), Self-healing: the ability to quickly recognise and isolate faulted components and restore power to unaffected customers with little or no human intervention.
2. A real-time state-estimation to Support applications like Coordinated Voltage-Control.

Test Case: A power grid network set-up consisting a power system component such as micro-PMUs, MUs and IEDs connected through a state of art communication network is needed. Tests such as protection coordination between IEDs, tests on reconfiguration of the network to reconnect deenergized parts of the network etc. can be studied.

Another test case is to look into real time state estimation using micro-PMUs and/or MUs, with an emphasis on investigating the performance and type of communication architecture / technology used to connect these devices to the controllers. It is an interest to study the impact of the communication system on the real time state estimation as well as the impact on the actions of the controllers.

Experiment Setup: The experiment requires a Hardware-in-the-loop setup in the laboratories and some parts can be modelled with simulation. Hardware devices such as IEDs, MUs. Micro-PMUs are required for the power system. Devices such as routers, switches, modems for wireless communication etc. may also be required for the communication/ICT support system.

Relevance to ERIGrid 2.0: At the core of the scenario/use cases is ICT, control and automation. They focus on studying the impact of the communication system on the automated operation of the grid.

Related project, network, etc.: IPN ECODIS (Research and demo project with Norwegian Systems Operators), EU H2020 SDN microsense, SaintGrid Project (Norwegian Research Project), CINELDI[42]

Published on: -

General comments and suggestions: -

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Functional Scenario title: Distribution Network with increased DER penetration

Information provider: CRES

System under Test: Distribution Network with increased DER penetration. The DER are flexible and dispatchable in order to allow optimal operation of the grid.

Motivation: Energy losses on the distribution grid can be minimised by optimally dispatching the DER units connected to it.

Use Case: Optimal Distribution Network Control for the Reduction of System Energy Losses.

Test Case: Evaluation of energy loss and cost reduction on distribution grid.

Experiment Setup: Distribution network in meshed form, prosumers, RES, distributed storage, various levels of controllers (local, central etc.) including forecasting, SCADA, and EMS.

Relevance to ERIGrid 2.0: This scenario allows for multiple domains of energy to participate in. Usually the optimisation of the grid operation is a slow procedure based on scheduling and dispatching of units. Other energy networks such as gas and heat could play the role of flexible prosumers (or storage) allowing thus an interesting set experiments, highly relevant to our project.

Related project, network, etc.: ERIGrid

Published on: D-JRA1.2 Focal use case collection

General comments and suggestions: -

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Functional Scenario title: “DSO/Aggregator coordination in LV grids”

Information provider: TEC

System under Test: Coordinated control framework for DSOs and Aggregators with a high penetration level of EVs and PVs power generation in low-voltage networks. (Physical system: low-voltage networks, photovoltaic power systems, electric vehicles, loads).

Motivation:

1. Significant voltage variations, excessive overloading- and-power losses levels on lines and distribution transformers due to a large scale of EVs and PVs penetration into LV networks.
2. Lack of coordinated power control schemes between the DSO and the Aggregators that help to smooth the load profiles and decrease renewable power generation curtailment.

[42] CINELDI website

Use Case: Coordinated charging operations for EVs aggregation according to the available PV power generation.

Test Case: Testing of a centralised power control algorithm that modifies the load base program of the DSO at the distribution transformer level in a low-voltage network model due to the effect of the PVs and EVs.

Experiment Setup: Representative environment using off-line simulations, PHIL platform, and real resources in a microgrid:

1. Control signals from the DSO to the Aggregator
2. PVs
3. EVs
4. Flexible loads (domestic)
5. Measuring and monitoring devices

Relevance to ERIGrid 2.0:

1. Multi-domain (electrical/control/ICT)
2. Digitisation of electrical systems
3. Simulation-based validation (HIL)
4. System-level approach
5. Alignment with European regulations (Clean Energy Package)

Related project, network, etc.: -

Published on:

Z. Xu, Z. Hu, Y. Song, W. Zhao, and Y. Zhang, "Coordination of PEVs charging across multiple aggregators," Appl. Energy, vol. 136, pp. 582–589, Dec. 2014.

J. Quirós-Tortós, L. F. Ochoa, S. W. Alnaser, and T. Butler, "Control of EV Charging Points for Thermal and Voltage Management of LV Networks," IEEE Trans. Power Syst., vol. 31, no. 4, pp. 3028–3039, 2016.

J. Hu, Y. Li, and H. Zhou, "Energy Management Strategy for a Society of Prosumers Under the IOT Environment Considering the Network Constraints," IEEE Access, vol. 7, pp. 57760–57768, 2019.

General comments and suggestions: -

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Functional Scenario title: Energy community

Information provider: RSE

System under Test: Local loads, renewable generators and storage systems aggregated under a common controller/management system.

Motivation: The aggregation of local resources facilitates the local optimisation of power flows reducing the energy losses, but their long-term success will depend on their ability to operate energy networks in a cost-efficient way ensuring benefits for all customers and the whole energy system.

Use Case: In nominal operation, the local management system has to aggregate several local resources (under the same primary or secondary substation) to reduce the energy bill increasing the self-consumption of the whole aggregate and satisfying technical constraints. Furthermore, it could provide flexibility services.

Test Case: System configuration must include non-controllable renewable generators, aggregated loads, flexible resource (energy storage, controllable generator or the grid), the aggregation platform and the management system. The aim of the test is to verify the fulfilment (in real-time) of the scheduled power profile in presence of error (forecast, measurement) and fault (communication, component) even in case of grid-service provision.

Experiment Setup: The controller can be tested following the testing chain approach: Simulation, CHIL and finally through a single RI (with electrical and thermal components) and/or multi RIs.

Relevance to ERIGrid 2.0: Creation of a low-carbon and cost efficient system. Furthermore, this Functional Scenario needs a detailed description of the test procedure due to the complexity of the system and the experiment setup could be implemented combining different RIs.

Related project, network, etc.: -

Published on: JRC Energy communities report[43], Rescoop.eu[44]

General comments and suggestions: -

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Functional Scenario title: Energy management in LECs with a high share of DERs

Information provider: TEC

System under Test: Multi-agent P2P platform, distribution system (lines, transformers, etc. ), local energy community (DERs/loads), controllers, communication systems, measuring and monitoring devices.

Motivation:

1. Massive integration of distributed energy resources has settled a change in paradigm of energy markets.
2. Change from a centralised unidirectional energy model towards a more collaborative, multidirectional, distributed and networked model that brings technical and economic benefits to the users.
3. Greater autonomy and involvement of end-users needed.

Use Case: Peer to peer energy trading within a LECs

Test Case: Implementation of a multi-agent P2P platform (energy sharing coordinator + DERs)

Experiment Setup: Small-scale prototype of the local energy community

1. Energy sharing coordinator (control system)
2. PVs
3. Batteries/EVs

[43] Caramizaru, A. & Uihlein, A. (2020.) Energy communities: an overview of energy and social innovation. JRC science for policy report.
[44] Rescoop.eu website

4. Flexible loads (domestic)
5. Inflexible loads (e.g. ships)
6. Measuring and monitoring devices

Relevance to ERIGrid 2.0:

1. Multi-domain (electrical/control/ICT)
2. Development of local energy markets/local energy community approaches
3. Digitisation of electrical systems
4. Simulation-based validation (HIL)
5. Alignment with European regulations (Clean Energy Package)

Related project, network, etc.:

1. eNeuron (H2020 – about to start)
2. INTERRFACE (H2020)
3. P2P-Smartest (H2020)
4. Renaissance (H2020)
5. Prospect (H2020)
6. Datasim (FP7)

Published on:

Global Observatory on Peer-to-peer, Community self-consumption and Transactive Energy Models[45]

Jogunola, O., Ikpehai, A., Anoh, K., Adebisi, B., Hammoudeh, M., Son, S. Y., & Harris, G. (2017). State-of-the-art and prospects for peer-to-peer transaction-based energy system. Energies, 10(12), 2106.

Baez-Gonzalez, P., Rodriguez-Diaz, E., Vasquez, J. C., & Guerrero, J. M. (2018). Peer-to-peer energy market for community microgrids [technology leaders]. IEEE Electrification Magazine, 6(4), 102-107.

General comments and suggestions: This functional scenario has been proposed by TECNALIA as is very aligned with the objectives of ERIGrid 2.0. and cover a wide spectra of objectives in the project: it is a clear example of a multi-domain, multi-energy carrier case that also is intended to combine a physical testbed (small-scale prototype) with simulations.

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Functional Scenario title: Fault management system

Information provider: CEA

System under Test: Fault management system for active distribution networks

Motivation:

1. DSOs/customers

[45] Peer-to-peer trading models website

2. High energy interruption costs
3. Quality of service

Use Case: -

Test Case: Multi-Agent System-based Fault Location, Isolation and Restoration System (FLIRS)

Experiment Setup:

1. Cluster of Raspberry PI
2. Real-time simulator
3. Digital relays (IEDs) with IEC 61850 communication
4. Ethernet Switch

Relevance to ERIGrid 2.0: Digitisation/Reliable energy system

Related project, network, etc.: -

Published on: -

General comments and suggestions: -

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Functional Scenario title: Flexibility activation

Information provider: SINTEF

System under Test: Distribution network utilising flexibility resources from multiple energy vectors.

Motivation: Testing is required for the intended impacts and unintended consequences of activation of flexibility. Before rolling out a demand response program one has to validate if the methods

1. Will deliver the required capacity
2. Will have acceptable level of consequence on the power quality
3. Will have limited rebound effect
4. Will not open new vulnerabilities for misuses such as Load Altering Attacks

Use Case: Once pre-qualification and validation strategies are in place, it will clear the path for multiple actors to offer their flexibility potentials and also aggregators to design innovative methods.

Test Case: Activation of aggregated flexibility from EV batteries, PV-battery systems and hot water tankers to reduce peak load in distribution system.

Experiment Setup: A fully simulated distribution network; partly simulated partly physical flexibility resources located at different buses of the distribution network. Communication between central dispatch of aggregator and the flexibility resources.

Relevance to ERIGrid 2.0:

1. This is part of testing procedure development for prequalification and activation of flexibility

2. It encompasses multienergy system based flexibility pool where communication plays significant role.

Related project, network, etc.: -

Published on: -

General comments and suggestions: -

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Functional Scenario title: Flexibility market operation and interaction with underlying power system operation using the FLEXGRID ATP

Information provider: AIT

System under Test: Flexibility market with transmission and distribution system

Motivation: The Flexibility Market Operator (FMO) is responsible for the operation of the proposed Distribution Level Flexibility Market (DLFM). The aim of the DLFM is to fill a gap in the current wholesale electricity market design. This gap results from the way that grid constraints are represented in the European target model for wholesale electricity markets as regulated by the guideline on Capacity Allocation and Congestion Management (CACM). This model assumes that grid constraints only exist between (mostly politically determined) bidding zones, while power flows within bidding zones are unrestricted (basically assuming a copper plate on bidding zone level). This model increasingly leads to infeasible market outcomes (i.e. the higher the RES penetration levels are, the bigger the problem becomes), because it neglects the existence of grid constraints within bidding zones.

Use Case: The FLEXGRID project will develop services that address these issues and offer them, via its ATP, to the newly established role of FMO. The aim is to provide grid-aware services for use case scenarios that are currently not being addressed through market-based mechanisms. The ATP can thus be seen as an enabler for Art. 32 of the e-Directive. The ultimate goal is to align market outcomes with technical restrictions of the electricity grid in the most efficient way. One of the key requirements to the ATP for being able to solve grid-related problems is a higher spatial resolution than currently available at Organized Market Places (OMPs) along with parametrisation of offers to provide additional information to ATP users. Due to the potential large number of flexibility providers (i.e. Energy Storage Partnerships (ESPs) and grid locations, a high degree of automation is required for the efficient and robust operation of the DLFM. In addition, advanced automated market clearing algorithms that go beyond current pay-as-bid models is required for efficient matching of many small Distributed Flexibility Asset (DFA).

Test Case: Using simulations of both market and the power system, coupled with the FLEXGRID ATP.

Experiment Setup: Co-Simulation setup with market simulator, power system simulator and the FLEXGRID ATP (CHIL setup where the FLEXGRID ATP acts as the controller).

Relevance to ERIGrid 2.0: This scenario takes full account of new market solutions and their integration, not only with the TSO, but also with the DSO and the distribution system. Furthermore, there are a number of challenges related to the execution of such tests that are of interest for the further development of validation and testing procedures in ERIGrid 2.0. This scenario is also interesting for RI coupling, especially because it come from the FLEXGRID project where more than one ERIGrid 2.0 partner is involved.

Related project, network, etc.: Former ERIGrid project.

Published on: The scenario is based on High Level Use Case (HLUC) 1 in D2.1[46].

General comments and suggestions: The FLEXGRID project also contains other interesting use cases that could be of interest for ERIGrid 2.0. These can all be found in D2.1[47].

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Functional Scenario title: Frequency reserve optimisation

Information provider: DERlab

System under Test: Distribution network, aggregated flexibility from generation and load.

Motivation: High integration of DER and electrification, which is expected for the future European network, can affect negatively the frequency stability of the power system. In order to ensure the frequency stability in such systems, contribution of DER and demand (demand response) is significant.

Use Case: Participation of DER and demand response in providing frequency tertiary reserve by optimising the active power distribution in medium and low voltage network.

Test Case: Solving the multi-objective optimisation problem (minimisation of network losses, congestion management and maximising the share of RES)

Experiment Setup: Network simulation tools (PowerFactory, Python)

Relevance to ERIGrid 2.0: Reliable energy system

Related project, network, etc.: H2020 INTERPLAN

Published on: INTERPLAN D5.3 Control system logics cluster and interface controllers [48]

General comments and suggestions: -

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Functional Scenario title: Local energy community

Information provider: CRES

System under Test: An aggregation of prosumers organised in order to pursuit a common goal such as self consumption.

Motivation: Prosumers are aggregated in an organisational scheme (essentially a technical VPP or a microgrid) which allows them to pursuit common goals such as increase self-consumption of RES, reduce CO2 emissions etc.

Use Case:

1. Increase self-consumption from RES
2. Congestion management of interconnection line

Test Case:

1. Validation of self-consuming capability

[46] Flexigrid D2.1 deliverable
[47] Flexigrid D2.1 deliverable
[48] INTERPLAN D5.3 deliverable

2. Capability of levelling the load through the interconnection line

Experiment Setup: Prosumers which include flexible and inflexible loads, RES (mainly PVs), distributed storage, EVs. various levels of controllers (local, central etc.) including forecasting, SCADA, and EMS (multi-agent distributed system that manages flexibility of prosumers).

Relevance to ERIGrid 2.0: Energy Communities is a rapidly growing solution towards fostering Distributed Generation and Consumption. They allow for a wide range of energy domains to come into play, including EVs, heat networks etc. From a technical point of view Energy Communities do not differ much from VPPs and microgrids and therefore are an ideal scenario for our project since it addresses the main aspects of ERIGrid 2.0 while it allows a large number of partners to implement tests on their RIs.

Related project, network, etc.: Geographical Islands Flexibility[49]

Published on: D2.1 : Use-cases, architecture definition and KPIs definition[50]

General comments and suggestions: -

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Functional Scenario title: Low inertia power system stability

Information provider: TEC

System under Test: Electrical system stability in presence or low inertia synchronous machines and power converters working as grid following, grid supporting and as grid forming.

Motivation:

1. Massive integration of distributed energy resources is reducing the inertia and the frequency stability of the power system.
2. Different behaviours of the converters are proposed to help to maintain the stability of the system. the real effect of those behaviours should be tested to check their influence on the overall stability.
3. More research is needed to influence future grid codes to enhance the stability of the power system.

Use Case: Stability analysis of and island formed by a synchronous generator and power converters with different behaviour.

Test Case: Different test cases considering different grid configuration, load changes, changes in the R/X ratio of the grid.

Experiment Setup:

1. PHIL model of the grid and the synchronous generator.
2. Real converters implementing different behaviours (grid following, grid supporting, grid forming).

Relevance to ERIGrid 2.0:

1. Multi-domain (electrical/control)
2. Simulation-based validation (PHIL)

[49] GIFT website
[50] GIFT D2.1 deliverable

3. System-level problem
4. Alignment with European regulations (Clean Energy Package)

Related project, network, etc.: -

Published on:

Z. Xu, Z. Hu, Y. Song, W. Zhao, and Y. Zhang, "Coordination of PEVs charging across multiple aggregators," Appl. Energy, vol. 136, pp. 582–589, Dec. 2014.

J. Quirós-Tortós, L. F. Ochoa, S. W. Alnaser, and T. Butler, "Control of EV Charging Points for Thermal and Voltage Management of LV Networks," IEEE Trans. Power Syst., vol. 31, no. 4, pp. 3028–3039, 2016.

J. Hu, Y. Li, and H. Zhou, "Energy Management Strategy for a Society of Prosumers Under the IOT Environment Considering the Network Constraints," IEEE Access, vol. 7, pp. 57760–57768, 2019.

General comments and suggestions: -

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Functional Scenario title: Low Inertia Systems

Information provider: AIT

System under Test: Power system with a low share of synchronous generators.

Motivation: Power systems with low share of synchronous generation, and consequently low total system inertia, are vulnerable to power imbalances. Such systems can experience frequency stability problems, such as high frequency excursions and higher rates of change of frequency. Therefore, the main focus of this showcase is to demonstrate how frequency stability in low inertia systems can be assured through capabilities of other power system objects present in the low inertia grids, such as RES, DG, controllable loads and storage systems.

Use Case: The main scope is to maintain frequency stability in systems with low share of synchronous generators, hence low classic inherent inertia. The showcase utilises synthetic inertia, as well as fast frequency response provided by RES, DG, controllable loads and storage systems. Frequency is brought back to nominal values by OPF-based frequency restoration.

Test Case: The validation of this showcase should consist in the simulation of the network according to 24-hours day-ahead operational planning data pre-calculated by the sequence of actions process. A part of the RES generator models must be equipped with real-time droop controllers which were configured according to the previously calculated setpoints. Another part of the models must be equipped with configurable synthetic inertia provision. The validation test case should define an event which disturbs the frequency in order to calculate a frequency step response. Such event should be defined for at least one time step at the simulated day. The validation does not necessarily need to cover the complete 24 hour period since frequency stabilisation should actually take place within seconds.

Experiment Setup: A combination of large-scale power system models (e.g. PowerFactory or Simulink) and real-time models for power electronics controllers (e.g. Field-Programmable Gate Array (FPGA) models or controllers) are needed. Therefore, tools are also needed that can combine these kinds of models in both real-time and non-real-time.

Relevance to ERIGrid 2.0: The studies of how low inertia systems can be controlled and handled are of high interest in order to allow a higher integration of more renewable energies into the power system. As such, the ERIGrid 2.0 project should allow and facilitate such studies. At the moment, the laboratory tools available, both for simulation and hardware tests, are not well suited to capture all the affects that can be seen in low inertia systems. The combination of power electronics controllers running on FPGAs with a very small time-step, together with large-scale power system models, is a very challenging in terms of infrastructure and testing-procedures. Here, ERIGrid 2.0 could make a big improvement. This scenario is also interesting for RI coupling, especially because it come from the Interplan project where more than one ERIGrid 2.0 partner is involved.

Related project, network, etc.: This functional scenario is taken from the InterPlan project[51] where AIT is also participating. The algorithms and models needed for implementing this test case can be shared with the ERIGrid 2.0 project.

Published on: See Showcase 1 in D6.1[52]

General comments and suggestions: The combined studies of large-scale power systems together with power electronics needed to handle low-inertia systems is a topic of internal interest for AIT. First tools and methods for such studies have already been investigated. The InterPlan project also contains other interesting showcases that could be of interest for ERIGrid 2.0, for example to further the integration of RIs.

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Functional Scenario title: LV network with high number of EV chargers

Information provider: HEDNO

System under Test: EV hosting capacity of a LV network.

Motivation: The smart charging strategies for maximising the EV hosting capacity may result to power quality issues, as the EV inverters will not operate at their nominal load (optimal THD). Aggregating many smaller EV load, due to smart charging, may result in non-acceptable THD.

Use Case: Evaluate the EV hosting capacity of a LV network or test methods to decrease possible THD.

Test Case: On a specific network layout of the an LV network with various EV chargers. Estimate possible THD.

Experiment Setup: Simulation software will be needed, maybe hardware components.

Relevance to ERIGrid 2.0: Could use some setup that needs more than one laboratory or HIL.

Related project, network, etc.: -

Published on: -

General comments and suggestions: -

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Functional Scenario title: Microgrid

[51] Interplan website
[52] Interplan D6.1 deliverable

Information provider: CRES

System under Test: Microgrid balancing

Motivation: Islanded operation of microgrid. Physical separation from the mains.

Use Case:

1. Management of Flexible DERs for the Balancing of Microgrids in Islanded-Mode
2. Uninterruptible Power Supply
3. Black start

Test Case:

1. Capability of Microgrid Central Controller to ensure short and long-term active/reactive power balance
2. Capability of microgrid to provide seamless transition from a grid-connected to islanded mode
3. Capability of microgrid to electrify local Distribution Network after a blackout

Experiment Setup: Minimum requirement components: Small-scale distribution grid, flexible and inflexible consumers, RES units, storage units, local controllers, Microgrid Central Controller.

Relevance to ERIGrid 2.0: The microgrid scenario is relevant to ERIGrid 2.0 because it is a topology that could encompass various target users, e.g. prosumers, residential buildings, Combined Heat and Power (CHP) units etc. Also it incorporates various levels of ICT and control infrastructure and is mature enough technologically speaking. This maturity may provide a significant number of TCs for the consortium given that several partners' RIs include microgrids.

Related project, network, etc.: ERIGrid

Published on: D-JRA1.2 Focal use case collection

General comments and suggestions: It would be nice to check all the UCs from this deliverable. Several of these UCs were not used in ERIGrid at all and may still be relevant for ERIGrid 2.0.

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Functional Scenario title: Multi-energy integration

Information provider: RSE

System under Test: Electric power grid interconnected with heat and gas networks, with their own loads and generators.

Motivation: Heat and gas network can improve the flexibility of the power system providing grid-services through coupling technologies. However, the regulatory framework is not well-designed to fully exploit this flexibility.

Use Case: Multi-energy system: during normal operation the system satisfy both the electrical and the heat load in order to reduce the energy bill of the consumer and improve the energy efficiency. Moreover, the heat and gas network can also provide ancillary services to the electrical power system ensuring the functionality of the normal operation.

Test Case: System configuration must include the electric power grid, almost one carrier energy network and the components that allows power-to-X functionalities (coupling technologies). The aim of the test is to verify the fulfilment (in real-time) of a service considering different condition (winter profile, summer profile, etc), grid requirements and market rules.

Experiment Setup: The system can be tested through a single RI (with electrical and thermal components) and/or multi RIs coupled both on the electrical and heat point of view. 1) Single RI: at least one thermal generator, one thermal storage, heat network, one coupling technology, one electrical load, main grid, not controllable renewable resource, one electrical storage and the energy management system. 2) Multi RI: same components listed above on different RIs. The coupling among the RIs has to be established through a suitable communication platform and hardware/software interfaces able to emulate the components in the other RIs.

Relevance to ERIGrid 2.0: Creation of a low-carbon and market-based integrated energy system.

Furthermore, this Functional Scenario needs a detailed description of the test procedure due to the complexity of the system, the experiment setup could be implemented combining different RIs and the system is strongly influenced by grid requirements, market rules and weather conditions.

Related project, network, etc.: EU project MAGNITUDE

Published on: MAGNITUDE[53]

General comments and suggestions: -

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Functional Scenario title: Multi-level voltage control

Information provider: DTU

System under Test: Distribution of sub-transmission system with multiple-voltage levels, e.g. MV/LV, MV/MV, or HV/MV system, including controllable grid equipment and distributed energy resources:

1. Converter-based generation (PVs, winds) connected to different voltage levels (medium 10 kV and low 0.4 kV)
2. OLTC transformer (e.g. 110/10 kV or 33 kV/0.4 kV) or Shunt capacitors for voltage support (e.g. at medium voltage level)
3. (reactive) power controllable equipment at different voltage levels (10 kV and 0.4 kV; e.g. PV, wind, battery, hybrid plants)

Voltage levels: Covers any two of 110 kV $\rightarrow$ 10 kV $\rightarrow$ 0.4 kV

Motivation: Traditionally, OLTC transformer or shunt capacitor is in charge of voltage support in the distribution system. The high penetration of DERs in distribution systems has significant impacts on the voltage stability and quality at distribution level. Increasingly, the sub-transmission OLTC transformers are limited in compensating for the diversity of voltage deviations occurring in demand- and production-dominated feeders. At the same time, DERs are able to support voltage due to their characteristics and coordinating control schemes. The nature of reactive power support is not transferred far away, so local voltage support is more efficient than centralised equipment. Coordinating control systems can be employed to optimise injection

[53] MAGNITUDE project website


doi:10.5281/zenodo.3991723

of reactive power to avoid excessive current losses associated with long transport of reactive power. Related to TSO/DSO coordination respectively.

One challenge for network operators is the validation and roll-out of reliable and interoperable coordination and control systems. DERs manufacturers and control systems suppliers are required to interoperate, and coordinate with traditional voltage support components for the voltage regulation. Active monitoring at LV levels is often problematic, as is the coordination of voltage control and reactive power flows at several voltage levels.

Use Case: Coordinated multi-level voltage control of DERs (PVs, winds) with OLTC or reactive power compensators to minimise voltage deviation.

Three main UCs:

UC1 Coordinated DER+OLTC services at MV and MV level support mitigation of voltage constraint violations at 0.4 kV level

UC2 MV-level OLTC is aims to support operation at 0.4 kV level based on active monitoring of voltage limits at LV level including autonomous DER services at 0.4 kV level

UC3 OLTC and DER reactive power injections (MV) coordinated to limit/control reactive power exchange at MV/HV levels

Specific voltage levels and service requirements are location and case-specific. Variants of these use cases can include existing coordinated and distributed control schemes. The main concern is here to transcend the voltage levels.

Test Case: The performance of voltage control solutions is quantified by:

Voltage quality for each potential problem area - Time response of controller to event - Under the scope of the above system configuration, use cases and motivation, several test objectives appear relevant:

1. Does the overall control system operate as required? (system validation; also performance characterisation)
2. What is the suitability of the coordinated scheme suitably account for phase-imbalanced operation? (char./val.)
3. What is the sensitivity of the solution to communication disruption? (bandwidth, lag, packet loss) (characterisation of communication-dependency)
4. To what extent are individual DER suited by their capability to interoperate in a coordinated control scheme?

For the above 4 test objectives a few test scenarios are outlined below:

1. System Performance criteria: Voltage limit violations; resistive losses; violation of reactive power limits at transmission-substation (UCs3); quantity of DER activation; number of OLTC tap-changes; Time-delay of voltage recovery; Feeder-level voltage control Test Scenarios: Diverse feeders: In radial distribution system: Two low voltage feeders; one has a peak load (possible undervoltage violation at feeder end) and the other feeders with off peak load (possible overvoltage at feeder end); diverse loading on single feeder; high load; high in-feed; low/high transmission supply voltage; voltage step at transmission system
2. In relation to the phase imbalance cases, the following test scenarios may be relevant:

(a) Lack of phase rotation in a legacy low-voltage system causes a voltage dip in a single phase due to high penetration of single-phase EV chargers. Activating OLTC control can cause over-voltage for the other 2 phases, DERs connected to that phase can participate in voltage control by supplying reactive power.

(b) A single-phase-to-ground fault in medium voltage grid causes an imbalanced supply voltage in the low voltage grid, i.e. dip in 1 phase (e.g. phase A) in low voltage level. Activating OLTC control can cause over-voltage for phase B and C, DERs connected to that phase can participate in voltage control by supplying reactive power.

(c) A single-phase-to-ground fault in the low-voltage grid causes an imbalanced voltage that propagates into the medium-voltage grid. Activating OLTC control can cause over-voltage for phase B and C, DERs connected to that phase can participate in voltage control by supplying reactive power. (?)

3. Communication aspects: same system performance metrics as above. Test scenarios include:
   (a) Remote measurement drops out, is delayed...
   (b) Signals available in either direction
4. Interoperability aspects: here the test system configuration may be reduced as compared to the overall performance assessments above; test cases focus on information exchange btw. central control and DER control system and DER response (details tbd)

Experiment Setup:

1. A DRTS (RTDS, OPAL-RT) or lower-fidelity tool for simulation of MV/LV power system target(s) for Control system deployment
2. For PHIL test: DER units with associated control systems (PVs, Wind Turbine (WT), Batt., etc.)
3. Communication channel for control domain within and between labs

   optional:
4. RI with physical distribution network for GD-PHIL / GD-RTS – VILLAS or JANDER for data exchange
5. RI with single-phase controllable loads

Relevance to ERIGrid 2.0: Two main aspects appear in this test case that are relevant to the ERIGrid 2.0 objectives:

1. The need for 'communication side channels' between different control elements: higher- and lower level controllers, remote measurements, remote actuators.
2. Multiple voltage levels are hard to test in a single laboratory setup unless the power system in-the-loop is fully simulated. Especially the closed-loop interaction with multiple physical DER and control systems motivate also geographically distributed HIL.

A secondary motivation for voltage coordination use cases is that time-scale requirements are less tight, allowing for the application of quasi-static HIL.

Practically speaking, this Functional Scenario:

1. existing voltage control schemes can be adapted to this use case.

2. in a GD-PHIL setup, different RI each can represent sections of the system configuration.
3. motivates to benchmark and extend existing interfacing approaches like JANDER and VILLAS.
4. Use of Quasi-static GD PHIL.

Related project, network, etc.: Relates to ERIGrid-1 TAs: HOLISTICA, TEAM-VAR2, VILLAS4ERIGrid, etc.

Case relevant for ISGAN-SIRFN Power System Testing

H2020 projects on TSO/DSO coordination (tbd)

Published on: Technical reports of above named TAs

Example paper for the use case: Huachun Han, Qiang Li, Zhenhua Lv, Multi-level Voltage Interaction Control in Active Distribution Network Based on MPC[54]

General comments and suggestions: This Functional Scenario is academically motivated by the complex experiment setup, as highlighted in 'relevance'. Modifications and merging of the description may lead to different aspects getting lost, so the most important thing would be to preserve the aspects named under 'Relevance for ERIGrid 2.0'.

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Functional Scenario title: OLTC

Information provider: OCT

System under Test: Network Voltage

Motivation: Problems of voltage regulation, sometimes affected by RES integration or EV fast charging.

Use Case: Stabilisation of the voltage level

Test Case: By stabilising the voltage with OLTC controller

Experiment Setup: OLTC controller, transformer and network simulator (or experimental controllable network - UDEX)

Relevance to ERIGrid 2.0: Increasing RES and EV impact on the current electrical networks affecting seriously the performance and safety on them.

Related project, network, etc.: ERIGrid

Published on: Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499[55]

Remote Laboratory Testing Demonstration[56]

[54] Han, H., Li, Q. & Lv, Z. (2019.) Multi-level Voltage Interaction Control in Active Distribution Network Based on MPC. In the Proceedings of 2019 Chinese Automation Congress (CAC), February 13th, 2020, Hangzhou, China.

[55] Spiegel, M. H., Wild, E., Heinzl, B., Kastner, W. & Akroub, N. (2020.) Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499. App. Sci. 2020, 10(5), 1611.

[56] Pellegrino, L., Sandroni, C., Bionda, E., Pala, D., Lagos, D. T., Hatziargyriou, N. & Akroub, N. (2020.) Remote Laboratory Testing Demonstration. Energies, 13(9), 2283.

A New Smart Distribution Transformer With OLTC for Low Carbon Technologies Integration[57]

Cyber-physical energy systems modelling, test specification, and co-simulation based testing[58]

General comments and suggestions: -

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Functional Scenario title: On load tap changer

Information provider: OCT

System under Test: Grid voltage

Motivation: Voltage regulation within network standards stabilisation of voltage.

Use Case: Stabilisation and regulation of network voltage.

Test Case: Control of voltage with a tap change controller.

Experiment Setup: Transformer with tap changer and tap change controller distribution network or network simulator.

Relevance to ERIGrid 2.0: Grid code compliance. Increasing instability of grid voltage due to intermittent renewable sources.

Related project, network, etc.: -

Published on: Remote Laboratory Testing Demonstration[59]

Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499[60]

General comments and suggestions: -

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Functional Scenario title: OLTC

Information provider: OCT

System under Test: LV output

Motivation: Increase the ability of low voltage networks to accommodate higher number RES.

Use Case: Maintain the voltage level within the normal limits.

Test Case: Applying voltage anomalies on the input/output of the OLTC.

Experiment Setup: Flexible MV generation, LV load and OLTC +Transformer

[57] Del Río Etayo, L., Cirujano, P., Lauzevis, P., Perez de Nanclares, G., Soto, A. & Ulasenka, A. (2017.) A New Smart Distribution Transformer With OLTC for Low Carbon Technologies Integration. In the Proceedings of 24th International Conference on Electricity Distribution, June 12-15th, 2017, Glasgow, the UK.

[58] van der Meer, A., Palensky, P., Heussen, K., Morales Bondy, D. E., Gehrke, O., Steinbrinki, C., Blanki, M., Lehnhoff, S., Widl, E., Moyo, C., Strasser, T.I., Nguyen, V.H., Akroub, N., Syed, M. H., Emhemed, A., Rohjans, S., Brandl, R. & Khavari, A. M. (2017.) Cyber-physical energy systems modelling, test specification, and co-simulation based testing. In the Proceedigns of 2017 Workshop on Modelling and Simulation of Cyber-Physical Energy Systems, October 12th, 2017. Pittsburgh, PA, USA.

[59] Pellegrino, L., Sandroni, C., Bionda, E., Pala, D., Lagos, D. T., Hatziargyriou, N. & Akroub, N. (2020.) Remote Laboratory Testing Demonstration. Energies, 13(9), 2283.

[60] Spiegel, M. H., Wild, E., Heinzl, B., Kastner, W. & Akroub, N. (2020.) Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499. App. Sci. 2020, 10(5), 1611.

Relevance to ERIGrid 2.0: Increase the ability of low voltage networks to accommodate higher number RES.

Related project, network, etc.: former ERIGrid project.

Published on: Remote Laboratory Testing Demonstration[61]

Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499[62]

Cyber-physical energy systems modelling, test specification, and co-simulation based testing[63]

General comments and suggestions: -

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Functional Scenario title: Predicting loads of a Grid of a Non-Interconnected Greek island.

Information provider: HEDNO

System under Test: Prediction algorithm of RES penetration loads in order to ensure sufficiency and stability operation of a Hybrid Network.

Motivation: DSOs, energy loss, lack of several alternative load forecasting methods for different and complicated Electricity Systems.

Use Case: In this scenario a distribution management system application, such as an algorithm which is implemented to a non-interconnected network (Greek island Samos, Kalymnos or Kos), as a forecasting calculator tool for the loads of the RES penetration and more particularly, e.g. prediction of the wind dynamic loads daily per hour.

Test Case: The algorithm will be receiving inputs (meteorological, previous days loads) to evaluate and define the optimum RES penetration load

Experiment Setup: Simulation software, controller, power components

Relevance to ERIGrid 2.0: This scenario is relevant to ERIGrid 2.0 goals since it combines power components (wind turbines) and the network and also the control of the network (load penetration from RES).

Hardware in-the-Loop testing can be used for this scenario, for both power components (PHIL with hardware PVs or wind turbines) and control elements (CHIL with hardware controller / algorithm)

Related project, network, etc.: -

Published on: -

General comments and suggestions: -

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[61] Pellegrino, L., Sandroni, C., Bionda, E., Pala, D., Lagos, D. T., Hatziargyriou, N. & Akroub, N. (2020.) Remote Laboratory Testing Demonstration. Energies, 13(9), 2283.

[62] Spiegel, M. H., Wild, E., Heinzl, B., Kastner, W. & Akroub, N. (2020.) Model-Based Virtual Components in Event-Based Controls: Linking the FMI and IEC 61499. App. Sci. 2020, 10(5), 1611.

[63] van der Meer, A., Palensky, P., Heussen, K., Morales Bondy, D. E., Gehrke, O., Steinbrinki, C., Blanki, M., Lehnhoff, S., Widl, E., Moyo, C., Strasser, T.I., Nguyen, V.H., Akroub, N., Syed, M. H., Emhemed, A., Rohjans, S., Brandl, R. & Khavari, A. M. (2017.) Cyber-physical energy systems modelling, test specification, and co-simulation based testing. In the Proceedigns of 2017 Workshop on Modelling and Simulation of Cyber-Physical Energy Systems, October 12th, 2017. Pittsburgh, PA, USA.

Functional Scenario title: Provision of ancillary services from DGs

Information provider: ICCS

System under Test: Different types of grid (interconnected, weak, islanded etc) with DGs.

Motivation:

1. Reduced inertia of power systems and weather-dependent energy production due to increased renewable generation may lead to unreliable and low quality power supply (consumers are affected).
2. Recent years, because of the increased penetration of DGs, TSOs and DSOs is required to cooperate in order to secure reliable operation of power systems. (Responsible for the reliability of the electrical systems).

Use Case:

1. Various ancillary services, reactive power and voltage control, active power and frequency control (primary response, secondary response), virtual inertia, fault-ride through, black start, reserves, etc.
2. Smooth and reliable operation of power systems.
3. Reconsideration of standards for ancillary services.

Test Case:

1. Implement changes in reactive power and active power and assess the behaviour of the system and the DG when it provides the above mentioned ancillary services.
2. Assessment of the parallel operation between DGs and conventional power plants or diesel generators in interconnected grids.
3. Assessment of ancillary services provision in island grids.
4. Assessment of ancillary services provision in weak grids.

Experiment Setup: Simulation tools, Control and Power hardware-in-the-loop testbed, Power Electronic devices, controllers, grid emulator, PV emulator.

Relevance to ERIGrid 2.0:

1. Transition towards smart grids in a reliable and secure way.
2. Increased penetration of renewable energy sources and alignment with the European Green Deal for the transition towards CO2 free energy production.

Related project, network, etc.:

1. RESERVE H2020: To reduce CO2 emissions, consumers and utilities increasingly use renewable power sources, such as solar, wind, and biomass. But utilities face the challenge of maintaining stability of supply from weather-dependent and diverse generation sources. In the RESERVE project will develop and field test new techniques that can enable a stable supply of purely renewable resources.
2. Nobel Grid: provides advanced tools and ICT services to all actors in the Smart Grid and retail electricity market in order to ensure benefits from cheaper prices, more secure and stable grids and clean electricity.
3. ERIGrid

Published on:

M. Maniatopoulos, D. Lagos, P. Kotsampopoulos and N. Hatziargyriou, "Combined control and power hardware in-the-loop simulation for testing smart grid control algorithms," in IET Generation, Transmission & Distribution, vol. 11, no. 12, pp. 3009-3018, 24 8 2017, doi: 10.1049/iet-gtd.2016.1341.

Plethora of papers and projects related to ancillary services.

General comments and suggestions: -

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Functional Scenario title: Remote systems testing of wind turbine

Information provider: UoS

System under Test: Wind turbine in a systems environment.

Motivation: To evaluate ancillary service provision from wind turbine in a systems environment through remote PHIL.

Use Case: Ancillary service provision

Test Case: A real wind turbine will be connected remotely to a systems testing facility through remote PHIL.

Experiment Setup: Wind turbine + power amplifier at one end. DRTS + power amplifier + distribution system at the other end.

Relevance to ERIGrid 2.0: This scenario is highly relevant for ERIGrid 2.0 as it can showcase the applicability of testing remote hardware. Furthermore, interfaces and methods developed within ERIGrid can be directly applied and evaluated.

Related project, network, etc.: Project planned but not yet delivered.

Published on: -

General comments and suggestions: -

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Functional Scenario title: SmartDorf

Information provider: AIT

System under Test: SmartDorf[64] is a fictional village or part of a small town with a structure typical for the rural area of Austria. It is hosting a small number of residential homes, offices and workshops. A high share of the building stock is connected to a district heating network that is supplied by a central gas-fired boiler. Generation from rooftop photovoltaic power plants covers a significant part of the annual electric energy demand. Electric boilers are installed in the district heating network with the aim to further increase the self-consumption of photovoltaic generation at a network scale.

Motivation: The aim is to demonstrate self-consumption of renewable energy sources in a coupled heat and power network using distributed power-to-heat appliances.

Use Case: This use case deals with M-EMSs for hybrid thermal-electrical distribution networks. The electrical distribution system is connected to the district heating network at one or multiple

[64] SmartDorf website

points where electricity can be converted to thermal energy via power-to-heat appliances. The operational goal is to efficiently use energy generation from DERs connected to the electrical energy distribution system. To this end, the M-EMS operates the available power-to-heat and storage appliances with the goal to directly convert or store surplus energy from DERs with respect to future/predicted energy demands.[65]

Test Case: This test case is used to verify that self-consumption of renewable energy sources in a coupled heat and power network improved using distributed power-to-heat appliances compared to a base scenario without power-to-heat. This means that energy flows flowing out of the network are reduced. At the same time energy imports should not increase. Relevant effort variables of both networks, i.e. bus voltages, supply temperatures and differential pressures, must stay within the allowable range. Also, the loading of the transformer is not allowed to reach critical levels. Otherwise the test fails.[66]

Experiment Setup: One way to execute this test is via simulation.[67]

Relevance to ERIGrid 2.0: There are 2 relevant points for ERIGrid 2.0:

1. This is a concrete example of a multi-energy system, combining an electrical distribution system, a district heating system and decentralised power-to-heat units.
2. Extending the HTD for better support of simulation-based experiments is a potential goal of NA4. There has been done some work in this direction with the 'PreCISE approach' from the SmILES project.[68]

Related project, network, etc.: The SmILES project has worked on an extension of the HTD specifically for simulation-based experiements, called the 'PreCISE approach'.[69]

Published on: Most data related to the work done in SmILES is available on the 'Shared Data and Information Platform'.[70]

Results from this specific functional scenario have been included into the following publications: Combined Optimal Design and Control of Hybrid Thermal-Electrical Distribution Grids Using Co-Simulation (DOI: 10.3390/en13081945) A method for technical assessment of power-to-heat use cases to couple local district heating and electrical distribution grids (DOI: 10.1016/j.energy.2019.06.016)

General comments and suggestions: -

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Functional Scenario title: Solar photovoltaic power plant control

Information provider: UCY

System under Test: Photovoltaic system

Motivation: PV plant owners and distribution system operators. reliable grid integration of PV systems at high shares at distribution feeders.

Use Case:

[65] UC4 network optimised use of DER website
[66] Increased RESself consumption website
[67] Electric boiler use excess power implementation website
[68] SmILES data and methodology website
[69] SmILES project website
[70] SmILES data and methodology website

UC1: Voltage control at grid connection point

UC2: Active power curtailment

Test Case: Precise control of PV system operational settings (smart inverter) for reactive power and active power limitation.

Experiment Setup: Smart PV PPC with programmable automation control, PV system with smart inverters and interoperable communication interfaces (Modbus TCP).

Relevance to ERIGrid 2.0: Reliable energy system at high renewable shares. Grid code compliance.

Related project, network, etc.:

ELECTRA, “Modernising the distribution grid for enabling high penetration of photovoltaic electricity through advanced data analytic operational observability and management” Funded by the RESTART 2016 – 2020 Fund through the RPF Cyprus.

PV-ANALYTIC, “Advanced photovoltaic system data-analytic monitoring solution enhanced with intelligent interoperable features for efficient solar big data real-time analysis, failure diagnosis, automated management and integrated control” Funded by the European Regional Development Fund through the Solar Eranet.

Network: Austrian Institute of Technology, Technical University of Denmark, Electricity Authority of Cyprus, Ministry of Energy, Cyprus Energy Agency, Cyprus Regulatory Authority, Gantner Instruments Test & Measurement GmbH.

Published on: FOSS UCY website[71]

General comments and suggestions: The described Functional Scenario is a flexible programmable automation control system for PV systems that is scalable and fully-integrated with all required data acquisition, analytical and control logic functionalities to demonstrate advanced and reliable PV system operations. The system is capable of further demonstrating Solar 3.0 digital concepts that further consider PV-plus-storage operational functionalities and advanced ancillary services.

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Functional Scenario title: Stability and interactions in converter-dominated microgrids

Information provider: SINTEF

System under Test: The scenario will address a converter dominated AC microgrid as physical system under test. The microgrid configuration may include also rotating machines and generators. A characterising feature of the microgrid is the relatively low value of physical inertia. The microgrid could be also an hybrid DC/AC configuration with DC distribution and loads added.

Motivation: The scenario is relevant in the context of smart grids and electrification of rural areas with renewables. A converted dominated microgrids exacerbates the requirements for energy management, frequency and voltage control. Moreover, interactions between converters and resonances are in general more difficult to predict and mitigate.

Use Case: The main functionalities are to supply local loads and integrate distributed energy resources. The microgrid can be operated as connected to an external power system or dis-

[71] FOSS UCY website

tribution grid or operated as an electrical island. The function subject to testing are linked to the continuity of supply for the users connected and to the quality of the voltage and frequency regulation.

Test Case: A reference microgrid can be defined and replicated by interconnecting power electronics converters, loads and rotating machines. A critical aspect is to add sufficient control hardware and communications between the units. Scaling down the microgrid size will allow testing in a laboratory scale.

Experiment Setup: The setup will require availability of converters with their related controllers, loads and electrical machines. Ideally a platform for PHIL would be beneficial to be able to recreate an external grid or to extend the size and complexity of the microgrid.

Relevance to ERIGrid 2.0: The use case scenario is very relevant in light of the present development trends for microgrid and for integration of distributed resources from renewables. This encompass also room for scientific development on testing methods and laboratory best practices that would fit in the scope of the project. Finally, being a technical area of wide interest would extend the possibilities for laboratory networking.

Related project, network, etc.: The use case is closely connected to activities carried out in the FME CINELDI[72] in the WP4 (microgrids).

Published on: -

General comments and suggestions: -

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Functional Scenario title: Stability of power electronic dominated systems

Information provider: ICCS

System under Test: Parallel operation of multiple inverters in electrical systems.

Motivation:

1. Change in time scales of power system dynamic phenomena (faster/high frequency dynamics, encompassing wave and electromagnetic phenomena).
2. Need to extend the bandwidth of the phenomena to be examined.
3. It is of major importance to understand and analyse the impact of the increased use of power electronic devices.
4. Increased harmonics and stability issues pose problems for DSOs and TSOs. Also, they can jeopardise the safety of producers' and consumers' equipment.

Use Case:

1. Converter-driven stability studies.
2. Reduce harmonic distortion and resolve stability issues.
3. Consider new approaches for system modelling and analysis. Use methods which incorporate dynamic phenomena neglected before.

Test Case:

[72] CINELDI website

1. Configuration of control systems of power electronics: modification of the control parameters and assessment of the impact.
2. Configuration of hardware (multi-level converters, passive and active filters etc).

Experiment Setup: Simulation tools, control and power hardware-in-the-loop testbed, Power Electronic devices, controllers, grid emulator.

Relevance to ERIGrid 2.0: It is of paramount importance for the transition towards inverter dominated power systems and the increased building and operation of microgrids. This in turn, is essential for the transition towards CO2 free energy production and ultimately for the alignment with the European Green Deal.

Related project, network, etc.:

The MIGRATE Project, AN EU-FUNDED PROJECT UNDER THE FRAMEWORK OF EUROPEAN UNION'S HORIZON 2020

MIGRATE stands for Massive InteGRATion of power Electronic devices and is an EU-funded project under the framework of Horizon 2020. The aim of MIGRATE is to find solutions for the technological challenges the grid is currently and especially in future faced with.

IEEE PES Task Force on Stability definitions and characterisation of dynamic behaviour in systems with high penetration of power electronic interfaced technologies.

Published on: Stability definitions and characterisation of dynamic behaviour in systems with high penetration of power electronic interfaced technologies. Primary Committee: Power System Dynamic Performance Committee (PSDP). IEEE PES Task Force: Authors: Nikos Hatziargyriou, FIEEE (chair), J. V. Milanovi, FIEEE (co-chair), C. Rahmann, SMIEEE (secretary), V. Ajjarapu, FIEEE, C. Caizares, FIEEE, I. Erlich, SMIEEE, D. Hill, FIEEE, I. Hiskens, FIEEE, I. Kamwa, FIEEE, B. Pal, FIEEE, P. Pourbeik, FIEEE, J. J. Sanchez- Gasca, FIEEE, A. Stankovi, FIEEE, T. Van Cutsem, FIEEE, V. Vittal, FIEEE, C. Vournas, FIEEE.

General comments and suggestions: -

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Functional Scenario title: Testing of distributed capabilities from grid forming converters

Information provider: UoS

System under Test: Distribution system with Power converter and DC source.

Motivation: To evaluate the behaviour of novel controls implemented on the power converter.

Use Case: The behaviour of the converter under voltage and frequency variations as well as faults, phase angle shifts and blackstart capability is investigated.

Test Case: A simulated distribution network will be coupled to the hardware converter and DC source through a power amplifier.

Experiment Setup: All the equipment typically required for PHIL.

Relevance to ERIGrid 2.0: This is a simple PHIL experiment, however the grid forming capabilities has potential for the evaluation of novel distributed controls for blackstart or other grid resiliency aspects. This could then be performed in a distributed laboratory manner aligned with ERIGrid 2.0. Related project, network, etc.: Not yet public

Published on: Not yet public

# Appendix B: Functional Scenario Templates

## Appendix B.1: Functional Scenario 1

**Functional Scenario**: Ancillary services provided by DERs and active grid assets

### Motivation

- Need of efficient system integration of renewable energy and EV charging
- Need for improved management of distribution system with presence of new components
    - Voltage level control (for instance OLTC)
    - Stability issues
    - Power quality
- Reduced traditional generation in the system -> reduced inertia and controllability -> need to develop and integrate inverter functionalities
- Increasing need for flexibility and controllability will lead to strong need of utilizing distributed resources for ancillary services
- New functionalities from DER units are interoperable and available for providing services

### Relevance for ERIGrid 2.0

- Contribution to European development and Green Deal etc.
- Systemic solutions requiring system testing approaches
- Relevant components (inverters, controllers) strongly related to smart grids
- ICT, control, automation and optimization in the core
- Digitalization, communication, interoperability etc. Interfacing aspects in a key role for this scenario
- Ancillary services enabling electrification of transport and other sectors, as well as flexibility provided by them

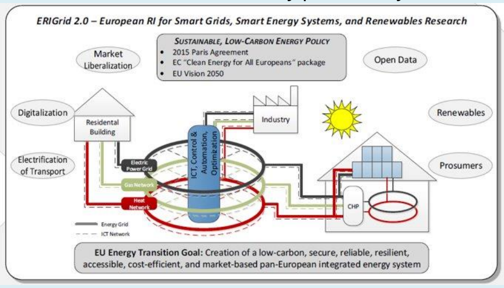


*Figure 7: Brainstorming workshop template of Functional Scenario 1.*

## Appendix B.2: Functional Scenario 2

**Functional Scenario**: microgrids and energy communities

### Motivation

- Main focus: provision of energy community services for local energy systems (can be islanded and/or a local abstraction)
- Ongoing connection of massive distributed energy resources in the grid
- Local energy systems need services for the local community (self-balancing, frequency restoration, black start, voltage control, multi-energy resource optimisation)
- Technical focus: implementation of and connection between overarching ICT/controls and assets in the local energy system
- Need for optimisation of synergies between different energy domains (multi-carrier, commodity)

- Note: Synergy with aggregation and flexibility
- Note: in most situations, microgrids are not in islanded mode

### Relevance for ERIGrid 2.0

- Optimise synergies of different energy domains (multi-carrier, commodity)
- Testing and validation of intelligent energy devices on component and system level
- Fosters integration of EVs, prosumers, and engagement of end-users
- Multi-RI testing:
    - (discrete) operation of local energy system controllers, its ICT infra, and the connected assets can be tested in a distributed way.
    - (continuous) Virtual physical coupling. Multi-energy system modelling, testing, and simulation.
- Cosimulation: multi-energy systems need a heterogenous modelling approach, co-simulation can help as a tool
- TA and VA: real-time lab coupling, microgrids, IEDs, *plug-and-play* controllers --> local energy system workbench

*Figure 8: Brainstorming workshop template of Functional Scenario 2.*


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## Appendix B.3: Functional Scenario 3

**Functional Scenario**: sector coupling and multi-energy

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| massive roll-out of power-to-X components<br><br>we do not have a good understanding of what that will mean for the electrical domain, especially on the system level<br><br>the following stakeholders will profit from the use cases and test cases defined in this functional scenario:<br>• infrastructure operators: integrated operation of systems; understand pathways for future investments<br>• component providers: understand the potential of integration on the component level<br>• technology provides: make services ready for sector coupling (automation, energy management, optimization, data analytics, etc.) | sector-coupling is a major trend in energy research → see European heat roadmap (https://heatroadmap.eu/)<br><br>partners might be interested in gaining experience with including non-electrical domains → focus on representing non-electrical constraints in the electrical domain<br><br>current laboratory infrastructure is not yet mature to work on this topic:<br>• defining the functional scenario encourages partners to build capability to represent these kind of scenarios (simulation & laboratory)<br>• there is currently only one (?) laboratory in Europe with the required lab capabilities, but a lot of labs with partial capabilities (e.g., component test stands)<br><br>potential for commercial demand for these kind of setups (also in view of TNA and follow-ups) |

*Figure 9: Brainstorming workshop template of Functional Scenario 3.*

## Appendix B.4: Functional Scenario 4

**Functional Scenario: Frequency and Voltage stability in Inverter Dominated Power Systems**

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| • Massive integration of distributed energy resources is Reducing the inertia and the frequency stability of the power system. Power systems with low share of synchronous generation, and consequently low total system inertia, are vulnerable to power imbalances. Traditionally, OLTC transformer or Shunt capacitor are in charge of voltage support in the distribution system. The high penetration of DERs in distribution systems has significant impacts on the voltage stability and quality at distribution level. Increased stability issues pose problems for DSOs and TSOs. Also, they can jeopardize the safety of producers' and consumers' equipment.<br>• One of the focuses is to demonstrate how frequency stability in low inertia systems can be assured through capabilities of other power system objects present in the low inertia grids, such as RES, DG, controllable loads and storage systems.<br>• One challenge for network operators is the validation and roll-out of reliable and interoperable coordination and control systems. DERs manufacturers and control systems suppliers are required to interoperate and coordinate with traditional voltage support components for the voltage regulation. | • Holistic: the validation must be done at System Level<br><br>The proposed Functional scenario is by definition Holistic<br><br>• Must be relevant from the experimental point of view: CHII, PHIL, HIL,<br><br>In order to execute the test cases it is needed to use the ERIGRID developed testing methods<br><br>• Multi domain: Cyber Physical System<br><br>The Functional scenarios is a multi-domain one from the perspective of Electrical Energy and ICT domains |

*Figure 10: Brainstorming workshop template of Functional Scenario 4.*

# Appendix B.5: Functional Scenario 5

**Functional Scenario**: Aggregation & Flexibility management
**In-Scope:** *what are the aspects of relevance?*
- Stakeholder coordination aspects: validation of service delivery qualifications, for e.g. reserves; local energy trading; Congestion management; service conflicts
- Communication-functionality required for aggregation, service matching, fail-over, configuration; interoperability
- Control: aggregation control, dispatch functionality, (monitoring?)
- Physical: DER with sector coupling (EV, storage, PV, WT, Buildings, …); Distribution Grid (MV+LV)

**Out-of Scope:** *what is excluded?* TSO/DSO coordination; Market simulation; Low-inertia system-effects; microgrids services focussed on PCC-level services; Industrial facilities offering flexibility

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| • Whose problem does this solve? What is the problem?<br>Who?/Why?<br>• Aggregators that want to act in present and developing flexibility markets<br>• System operators that want to be able to pre-qualify aggregator solutions and portfolios<br>• Aggregators, Operators and regulators that negotiate the terms of regulation for new flexibility services<br>• Business developers that need to quantify the potential impact of aggregator operations (from all related stakeholders)<br>• Developers of Peer-to-peer trading platforms that need to anticipate the requirements - and energy communities that will adopt peer-to-peer trading solutions<br>What problem?<br>• Complexity of validating ICT solutions with heavy impact on grid operation –software / control / communication | • Why should this be examined in ERIGrid 2.0?<br><br>• In line with EG2.0 objectives<br>  • Multi-sector (e.g. JRA2.1)<br>  • Communication & configuration (e.g. JRA2.2 & 2.3)<br>  • Flexibility management and control<br>• Critical enhancements required for several of the testing needs.<br>  • Representation of flexible communication structures in test system Varied fidelity requirements in terms of testing time scales (from fast frequency response to market-based redispatch of flexibility)<br>  • Interaction of<br>  • Opportunities for geographically distributed testing<br>• Policy relevance |

*Figure 11: Brainstorming workshop template of Functional Scenario 5.*

# Appendix B.6: Functional Scenario 6

**Functional Scenario**: 6:DER management system

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| • It performs supervision and maintenance of the components and provides information to the operators and field crew personnel and interacts with the DER EMS/VPP system for the control of the generation.<br>•<br>• Who will benefit? DER owner or AGG<br>• Who are the stakeholders? AGG, DER | • DER management systems are indispensable parts of smart grids that encompass flexibility from prosumers of various energy domains. Especially in DR the role of prosumers that include EV charging, thermal storage etc. could be very relevant. Therefore, this scenario is also worth investigating in ERIGrid2.0.<br>•<br>• How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?<br>• Possibility for multi-RI<br>• Lab-as-a-service<br>• Characterization of communication infrastructure |

*Figure 12: The first part of the brainstorming workshop templates of Functional Scenario 6 on the DER management system.*

**Functional Scenario**: 11: Fault management system

**Motivation**

•- DSOs/customers;
•- High energy interruption costs
•- Quality of service

•Who will benefit? DSO
•Who are the stakeholders? DSO

**Relevance for ERIGrid 2.0**

- Digitalization/Reliable energy system
-
- How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?
- multi-RI (driven by upscaling)
- Characterization of communication infrastructure

*Figure 13: Second part of the brainstorming workshop templates of Functional Scenario 6 on fault management system.*

**Functional Scenario**: 14: Energy community

**Motivation**

- The aggregation of local resources facilitates the local optimization of power flows reducing the energy losses, but their long-term success will depend on their ability to operate energy networks in a cost-efficient way ensuring benefits for all customers and the whole energy system.

- Who will benefit? Energy Community
- Who are the stakeholders? Energy Community, DSO

**Relevance for ERIGrid 2.0**

- Creation of a low-carbon and cost efficient system
- Furthermore, this Functional Scenario needs a detailed description of the test procedure due to the complexity of the system and the experiment setup could be implemented combining different RIs.
-
- How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?

- Integrated test of ICT infrastructure and power grid

*Figure 14: Third part of the brainstorming workshop templates of Functional Scenario 6 on energy community.*

**Functional Scenario**: 19: Communication and connectivity enabling smart energy systems

**Motivation**

- Power systems often rely on old communication technologies and connectivity techniques, which could be hindering the developed monitoring, control and protection possibilities on the smart grids. Communications and connectivity could enable new solutions and business opportunities on the energy systems, for instance increasing flexibility and advancing the development of energy communities, while also accelerating the development and implementation of future clean energy systems. Additionally, modern communication technologies, including 5G and beyond, pose interesting scientific opportunities especially when applied to the critical communications in smart grids, operation and control of massive IoT or distributed synchronous real-time connectivity.
-
- Who will benefit? all users of ICT equipment and services
- Who are the stakeholders? Vendors, all users of ICT equipment and services

**Relevance for ERIGrid 2.0**

- Related to the research of ICT, automation and control infrastructure of smart grids and smart energy systems, enabling people to better use the ERIGrid 2.0 infra on TA visits and continue the research from ERIGrid.

- How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?
- Integrated test of ICT infrastructure and power grid

*Figure 15: Fourth part of the brainstorming workshop templates of Functional Scenario 6 on communication and connectivity enabling smart energy systems.*

**Functional Scenario**: 20: Digital substations

**Motivation**

- 1.Target audience of this scenario includes: system operators, equipment manufacturers (vendors) and researchers.
- 2.The energy transition towards renewable energy resources and related developments such as intelligent demand response, deployment and usage of storage devices, etc. call for a greater deal of flexibility in protection and control applications. This is to ensure security of supply. With rapid developments in Information and Communication Technology (ICT) and computing, industrial processes and systems are transitioning to Industry 4.0 & IoT based systems. This is also taking place in the electrical power grid as integration of digital technologies allows for increased inter-connectivity between different components and layers of the grid. This has motivated newer automation and protection standards, such as IEC 61850. The increased interdependence between cyber and physical layers in the power grid, coupled with advanced power system automation and communication standards has given rise to digital substations. These digital substations allow for improved flexibility of protection and control applications. Consequently, they are an integral part of the smart grid, aiding in the energy transition. Hence, there is a growing industrial push for widespread adoption of IEC 61850 and digitalization of substations that requires thorough testing and validation.
- 3.In a digital substation, analogue hard wiring is replaced with optical communication fiber based on Ethernet. This provides increased information availability and a reduced footprint. Further, increased digitalization also offers benefits such as improved safety, performance, reliability, etc.
- 4.While providing the above-mentioned benefits, digitalization raises some important questions:
- a.How do protection and control schemes differ in a digital substation in comparison to conventional electrical substations?
- b.How can latest automation and protection functions/schemes be tested and validated?
- c.Is centralised substation protection and control superior than distributed substation protection and control?
- d.How to address cyber security concerns while ensuring system performance?
- e.How to defend and mitigate against cyber intrusions in digital substations?
- f.How resilient and reliable are digital substations?
- Thus, there is strong case to study, analyse and validate various facets of digitalization of substations.
-
- Who will benefit? Utilities (TSO,DSO)
- Who are the stakeholders? Utilities (TSO,DSO), vendors

**Relevance for ERIGrid 2.0**

- 1.This functional scenario aligns well with planned ERIGrid 2 JRA on co-simulation-based approaches. Further, the proposed use cases from this scenario can also be tested and demonstrated in JRAs 3 and 4 respectively, using the improved and extended services developed within their scope.
-
- 2.The functional scenario of a digital substation addresses an industrially and academically relevant topic that matches the broad project theme of digitalization. This is particularly interesting for grid operators, in order to evaluate substation protection and control architectures with different design principles, e.g. digital vs traditional substations.
-
- 3.Digital substations, automation and protection standards are crucial to the energy transition as outlined earlier.
-
- How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?
- multi-RI (complexity)
- Integrated test of ICT infrastructure and power grid
- Integrated simulation of ICT infrastructure and power grid
- Cybersecurity testing

*Figure 16: 5th part of the brainstorming workshop templates of Functional Scenario 6 on digital substations.*

**Functional Scenario**: 26: Cyber-physical testing of resilient control systems

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| • As advanced and networked control systems proliferate in smart grid/smart energy systems, a need arises to ensure the resilience of the the integrated cyber-physical system, i.e. to characterize and verify the performance of such integrated systems under adverse conditions. Such adverse conditions may not only be created by an electrical event such as e.g. a short circuit, but also by events in the ICT domain such as network interruptions or cyberattacks.<br>•<br>• In order to perform meaningful testing on the matter of resilience, realistic control systems have to be used. Such systems are not configured in a static way, they cannot be modeled sufficiently by a "control blob abstraction" and they are subject to permanent and transient communication failure, cyberattacks, race conditions, glitches and other real-world phenomena.<br>•<br>• First and foremost, this functional scenario will be useful for aggregators, fleet operators, DSOs and other entities seeking to deploy or improve control infrastructure for harvesting services from DERs.<br>•<br>• Who will benefit? Operators of ICT infrastructure<br>• Who are the stakeholders? Operators of ICT infrastructure | • ERIGrid-1 has primarily focused on the testing of (real or simulated) electrical power hardware. The inter-unit control systems (i.e. the controllers beyond the unit controller which are needed to coordinate the operation of multiple power assets) have mostly been considered as an afterthought. However, these control systems are the primary enablers of smart grids. If ERIGrid-2 aims to achieve a more comprehensive capability for testing smart grid concepts, there is a need for a functional scenario which can push the boundaries of the consortium's capabilities in this area.<br>•<br>• Control systems tested in ERIGrid-1 have been characterized by the following characteristics:<br>•<br>• * The control topology is static, hard-wired and known beforehand. For example, a control system designed for one master and three slaves will always have one master and three slaves, and none of these roles can change.<br>• * The type of information exchanged between entities is known beforehand. For example, a slave will always report voltage and current measurements through pre-assigned channels.<br>• * Only numerical information is exchanged between entities. This does not include, for example, requests, commands or other types of protocol.<br>• * Controller processes and communication links are considered completely reliable and fault-free.<br>•<br>• These restrictions does not well represent even current control systems. For exploring future, advanced control concepts, they are inadequate. It is important to ensure that the joint tools developed in ERIGrid-2 don't restrict advanced controls by design, even if not all capabilities can be developed within the project.<br>• How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?<br>• Integrated test of ICT infrastructure and power grid<br>• Integrated simulation of ICT infrastructure and power grid |

*Figure 17: 6th part of the brainstorming workshop templates of Functional Scenario 6 on cyber-physical testing of resilient control systems.*

**Functional Scenario**: 29: Distributed controls in smart grid

| Motivation | Relevance for ERIGrid 2.0 |
|---|---|
| • Due to the large-scale introduction new components such as distributed energy resources (DERs), the operation of the distribution grid is changing significantly. To support this new transformation of the grid and handle the new uncertainties and challenges arising from the introduction of new components and technologies, ICT has been used extensively. However, little is known about its impact on the performance of the grid's normal operation. Besides, to increase the reliability, performance and robustness of the grid, there has been some efforts to make the grid more autonomous. In this regard, a number of distributed control approaches such as multi-agent systems (MAS) approaches, self-healing with the coordination of IEDs etc. were proposed by researchers for different smart grid applications. Hence, it will be interesting to investigate different use cases of autonomous operation of the grid, and specifically to look into the role of ICT, its interdependency with the power system in such autonomous operation of the grid.<br>• Who will benefit? DSO<br>• Who are the stakeholders? DSO, ICT Vendors | • At the core of the scenario/use cases is ICT, control and automation. They focus on studying the impact of the communication system on the automated operation of the grid.<br>•<br>• How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?<br>• Characterization of communication infrastructure<br>• PHIL |

*Figure 18: 7th part of the brainstorming workshop templates of Functional Scenario 6 on distributed controls in smart grid.*


doi:10.5281/zenodo.3991723

| **Functional Scenario**: 31: Predicting loads of a Grid of a Non-Interconnected Greek island | |
|---|---|
| **Motivation** | **Relevance for ERIGrid 2.0** |
| • DSOs, energy loss, lack of several alternative load forecasting methods for different and complicated Electricity Systems.<br>•<br>• Who will benefit? DSO<br>• Who are the stakeholders? DSO | • This scenario is relevant to ERIGrid's 2.0 goals since it combines power components (wind turbines) and the network and also the control of the network (load penetration from RES).<br>• ·Hardware in-the-Loop testing can be used for this scenario, for both power components (PHIL with hardware PVs or wind turbines) and control elements (CHIL with hardware controller / algorithm)<br>•<br>• How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?<br>• Integrated test of ICT infrastructure and power grid<br>• Integrated simulation of ICT infrastructure and power grid |

*Figure 19: 8th part of the brainstorming workshop templates of Functional Scenario 6 on predicting loads of a grid of a non-interconnected Greek island.*

| **Functional Scenario**: 32: Development of a cyber-security system to protect metering data and personal information of the MV customers | |
|---|---|
| **Motivation** | **Relevance for ERIGrid 2.0** |
| • DSOs, Sources of vulnerabilities include firmware, hardware architecture, system applications, as well as a network interface, communication problems (low signal) to very unapproachable districts of the Hellenic Grid (islands, underground installations), other communication attacks include wireless scrambling increase in the phenomenon of the electricity theft.<br>•<br>• Who will benefit? DSO<br>• Who are the stakeholders? DSO | • This scenario is relevant to ERIGrid's 2.0 goals and the benefits are:<br>•<br>• •the decrease in technological risks thanks to the development of complete information systems<br>• •the conclusion of information systems and the adoption of common standards that will contribute towards reducing the duration of digital transformation<br>• •the decrease in the maintenance and operation cost of the information systems<br>• •the possibility of future application of Big Data Analytics in metering data<br>•<br>• How could it expand the consortium's abilities in terms of testing procedures, validation methods, application areas etc.?<br>• Cybersecurity testing |

*Figure 20: 9th part of the brainstorming workshop templates of Functional Scenario 6 on development of a cyber-security system to protect metering data and personal information of the MV customers.*

## Consortium

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