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Flexible Platform for the Study and Testing of Smart Energy Systems Enabling-Technologies

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***Abstract*—the road between the conventional energy grids and smart energy systems involves, among other things, the validation of smart energy systems enabling-technologies. Such validation is not always possible on-site, so it must be performed in laboratory conditions. In fact, when large electrical grids are targeted together with their information management system the development and testing of smart grid enabling-technologies are possible, in most cases, only in the laboratory. This paper presents a flexible laboratory platform developed for the study, testing and validation of smart grids and smart energy systems enabling-technologies, including Power Hardware-In-the-Loop and Information and Communications Technology.**

Keywords—smart grid observability and control, Information and Communications Technology, Smart Grid Architecture Model

I. INTRODUCTION

In recent years, the concept of smart grid has been at the center of various research projects and publications and in attention of many political actors. The European Commission (EC) defines the smart grid as "an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety" [1]. In the EC vision, the smart grid employs intelligent monitoring, control and communication technologies. The US Department of Energy (DOE) defines the smart grid as "an electricity grid that uses Information and Communications Technology (ICT) to gather and act on information, such as information about the behaviors of suppliers and consumers, in an automated fashion to improve the efficiency, reliability, economics and sustainability of the production and distribution of electricity" [1]. Even though there are some discrepancies between these two definitions, both EC and DOE consider the smart grid as a technological evolution of the traditional electric grid in terms of integrating electricity producers and consumers, obtained using ICT. The need for smart grids is often justified by the desire to facilitate the integration of the renewable Distributed Energy Resources (DER) into the electric network and to enhance the transition from electricity consumers to electricity prosumers [2]. The active participation of consumers in the power balance, the ability of the grid to self-regulate locally and the improved maintenance and services of the electricity supply are used as well to argue for the development of smart grids [2], [3]. The literature presents many other motivations of the smart grid, but a complete review of them does not fall within the scope of this paper.

Most scholars discuss the concept of smart grid only in relation to the electricity sector, but some scholars prefer a holistic approach by including complementary sectors, such as heating, cooling, gas and transportation in a more generic concept of smart energy systems. There are researchers that even suggest that the vision of smart grids is complete only in the context of smart energy systems, arguing that the future smart grid will also include, for example, the electric vehicle infrastructure, residential cogeneration (heat and power) and energy storage solutions [2]. Accordingly, the studies on smart grids should be extended to smart energy systems.

Operation and control of large electric networks coupled to various data systems, such as Supervisory Control and Data Acquisition (SCADA) and Advanced Metering Infrastructure (AMI), and taking into account communication technologies, data traffic and cybersecurity poses challenges for validation activities, especially at high technology readiness levels. Any solution targeting the improvement in operation and control of such grids needs to be tested thoroughly in the laboratory prior to site testing. Typically, open-loop testing is performed in the early stages of the site tests to avoid a negative impact on the electric grid and not all features are fully tested due to the rare occurrence of the grid events that will activate them. By using real-time co-simulation of physical domains, data systems and cloud-based applications can be tested in a variety of scenarios without risking damaging the electric grid. Also, validation of these data systems and cloud-based applications on verified and validated real-time models of the power system can give to Distribution System Operators (DSOs) and Transmission System Operators (TSOs) the necessary confidence before site testing. Manufacturers of electrical equipment such as power converters can also test their product in conditions similar to real operation by using Power-Hardware-In-the-Loop (PHIL) approaches. In this case, the electrical equipment is typically interfaced with a grid simulator that hosts a real-time model of the actual electric network.

This paper presents a laboratory platform for the study and testing of smart energy systems enabling-technologies. The platform has been developed in the Smart Energy Systems laboratory at Aalborg University, Denmark, with the vision to enhance the research on observability, diagnosis and control of the electric networks at all levels, from High Voltage (HV) to Low Voltage (LV). The motivation is that such research is important for the development of smart grids and smart energy systems, but for practical reasons difficult to conduct in public installations. Although grid observability, online diagnosis and automatic control are virtually non-existent in today's LV networks, they will be essential in future smart grids [4], hence the importance of their research. The developed platform is, by design, fully compatible with the Smart Grid Architecture Model (SGAM) and flexible, as it allows the study and testing of technologies at any of the SGAM framework levels. The development of this laboratory platform started in 2014 and since then the platform has continued to be upgraded with new equipment, reaching the structure presented in this article at the end of 2019. Due to this platform, the Smart Energy Systems laboratory of Aalborg University is included in the "Smart Grid Laboratories Inventory 2018" report of the Joint Research Centre, EC, as the only facility of its kind in Denmark [5].

The rest of this paper is structured as follows. Section II makes a brief introduction to the SGAM framework. Section III describes the architecture and the main equipment of the developed laboratory platform for the study and testing of smart energy systems enabling-technologies. This section also presents an application example on smart grid observability, diagnosis and control, and how the developed platform can be used for studies within this field. Section IV briefly presents some of the research projects that have used or are using the introduced laboratory platform, and Section V concludes this paper.

II. SGAM FRAMEWORK

The SGAM provides a unified description of the system architectures for smart grids and aims to identify gaps in existing and future European standardization [6]. The SGAM framework, illustrated in Fig. 1, acts as a reference designation system and consists of three dimensions [6], [7]:

(i) *Domains*, representing the complete energy conversion chain (bulk Generation, Transmission, Distribution, DER and Customer Premises)

(ii) *Zones*, representing the hierarchical levels of the energy conversion chain information management (Process, Field, Station, Operation, Enterprise and Market)

(iii) *Interoperability* dimension, representing the abstract interoperability layers (Component, Communication, Information, Function and Business)

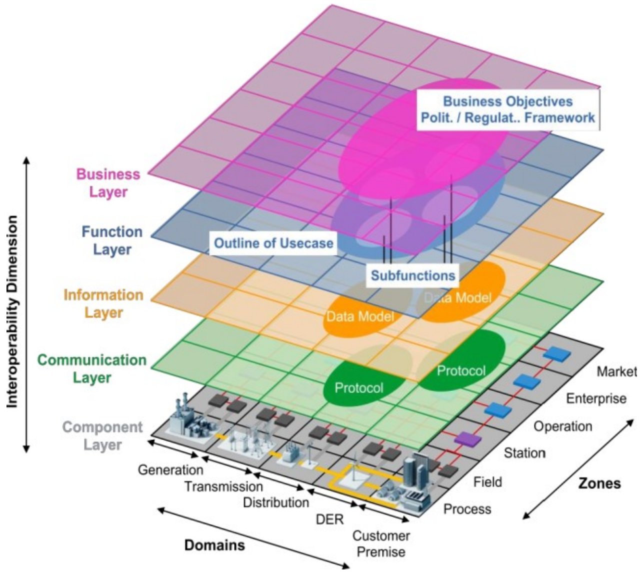

Fig. 1. SGAM framework [6]

Table I provides a brief description of the Domains, Zones, and Interoperability layers of the SGAM framework, while a complete description of them and more details about SGAM is given in [7].

The Component layer corresponds to the so-called smart grid plane, which is spanned by Domains and Zones, while the other layers of the Interoperability dimension overlap with this plane [7]. The smart grid plane enables the representation on which Zones the interactions between Domains take place, and the Interoperability dimension enables the representation of the nature or type of these interactions. Using the SGAM framework, any entity of the electric network can be described from an architectural point of view, including its relation to other entities, by placing it in the appropriate location in the smart grid plane and layer respectively [7].

The popularity of the SGAM has grown steadily in recent years, as it offers a standardized way of approaching research

TABLE I. STRUCTURE OF THE SGAM DOMAINS, ZONES AND INTEROPERABILITY DIMENSIONS [7]

Dimension		**Description**
Domains	Customer Premise	industrial, commercial and residential consumers and prosumers
	DER	small-scale generation units connected to the distribution network, typically between 3 kW-10 MW
	Distribution	infrastructure that distributes electricity to customers, e.g. LV distribution networks
	Transmission	infrastructure that transports electricity over long distances, e.g. HV transmission lines
	Generation	generation of electricity in bulk quantities, connected typically to the transmission system
Zones	Process	the physical equipment directly involved in energy conversion chain, e.g. generators, cables, loads
	Field	the equipment to protect, control and monitor a process, e.g. bay controllers, protection relays, IEDs
	Station	the areal aggregation level for field level, e.g. substation automation, plant supervision, local SCADA
	Operation	power system control operation in the respective domain, e.g. Distribution Management Systems (DMS)
	Enterprise	commercial and organizational processes, services and infrastructures for enterprises
	Market	reflects the market operations possible along the energy conversion chain, e.g. energy market
Interoperability layers	Component	physical distribution of all participating components, including power system and ICT equipment
	Communication	protocols and mechanisms for the interoperable exchange of information between components
	Information	information objects exchanged and the underlying canonical data models
	Function	functions and services, and their relationship from an architectural point of view
	Business	provides a business view on the information exchange, including regulatory and economic structures

and development projects on smart grids. Especially for ICT, such standardization is highly important for future integration and compatibility of smart grid components and smart energy systems. Therefore, a laboratory platform that is compatible with the SGAM is valuable for the development, testing and validation of applications and technologies within smart grids and smart energy systems.

III. Developed Laboratory Platform – Architecture

The architecture of the laboratory platform developed to study and test the smart energy systems enabling-technologies is presented in Fig. 2. The equipment of this platform can be grouped into two categories: electrical network equipment and ICT equipment.

A. Electrical network equipment

Electrical network equipment of the developed laboratory platform consists of the following:

(i) *DER setup*, comprising a grid-connected converter and a DC power supply, controlled by a dSpace system and used to emulate DERs up to 20 kW

(ii) *PVES setup*, comprising a 3 kW grid-connected solar converter, a 3 kWp Photovoltaic (PV) emulator and a 6.4 kWh Li-ion Energy Storage (ES)

(iii) *Load setup*, comprising three programmable single-phase loads of 2.8 kW, used either standalone or in combination with PVES setup to emulate residential prosumers, and a programmable single-phase load of 4.5 kW, used to emulate other types of consumers, e.g. heat pumps or charging stations

(iv) *Monitoring setup*, accommodating smart meters and other industrial devices for electrical monitoring

(v) *Opal-RT Real Time Digital Simulator (RTDS)*, capable of simulating extensive electric networks and smart energy systems, including their monitoring equipment, such as sensors and metering devices

(vi) *4-quadrant Grid Simulator*, with a rated power of 50 kVA, used to interface the Opal-RT RTDS with the aforementioned laboratory setups, thus allowing PHIL studies and tests

(vii) *Configurable electrical wiring*, comprising cables and switches that allow to any laboratory setup to connect either to the main grid or to the grid simulator; it also allows a wide range of possible configurations for the laboratory platform

The presented electrical equipment can also be used to emulate smart energy systems, such as heat pumps, biofuel based DERs, energy storage solutions, etc. Also, additional electrical equipment may be added to the existing equipment due to the flexible architecture of the developed laboratory platform. More details on the characteristics of the existing electrical equipment of this platform are given in Table II.

B. ICT equipment

The ICT equipment of the developed laboratory platform consists of the following:

(i) *Network Emulator Server*, built to support state-of-the-art network emulation and simulation tools, such as DummyNet, KauNet, OMNeT++ and NS3

(ii) *Traffic Generation Server*, built with the capabilities to support platforms such as Scapy and TCPRelay for stochastic network traffic modelling and trace-based network traffic generation

(iii) *Network Control and Visualization Server*, built to support mapping of Geographical Information System (GIS) data to the communication network and online or offline reconfiguration of the communication network

(iv) *Computers and other assets*, used to hosts the various actors of the information management system of the electrical network equipment

(v) *Gigabit Ethernet/Local Area Network switch*, used for to interconnect all computers and laboratory hardware, providing high flexibility and the possibility of future expansion

The ICT equipment of this laboratory platform can be grouped into two subcategories, according to their role, as follows. The first subcategory comprises the ICT equipment directly involved in the information management of the electric network and which, within the SGAM framework, are located in the smart grid plane. The second subcategory comprises the ICT equipment used to manipulate for research or testing purposes ICT equipment directly involved in the information management of the electric network. The first subcategory of ICT equipment includes (iv) and (v), while the secondary subcategory includes (i), (ii) and (iii). In Fig. 2 the ICT equipment of the two subcategories are illustrated with different colors.

The ICT equipment of the developed platform and its ICT layers aim to emulate different technologies and topologies for

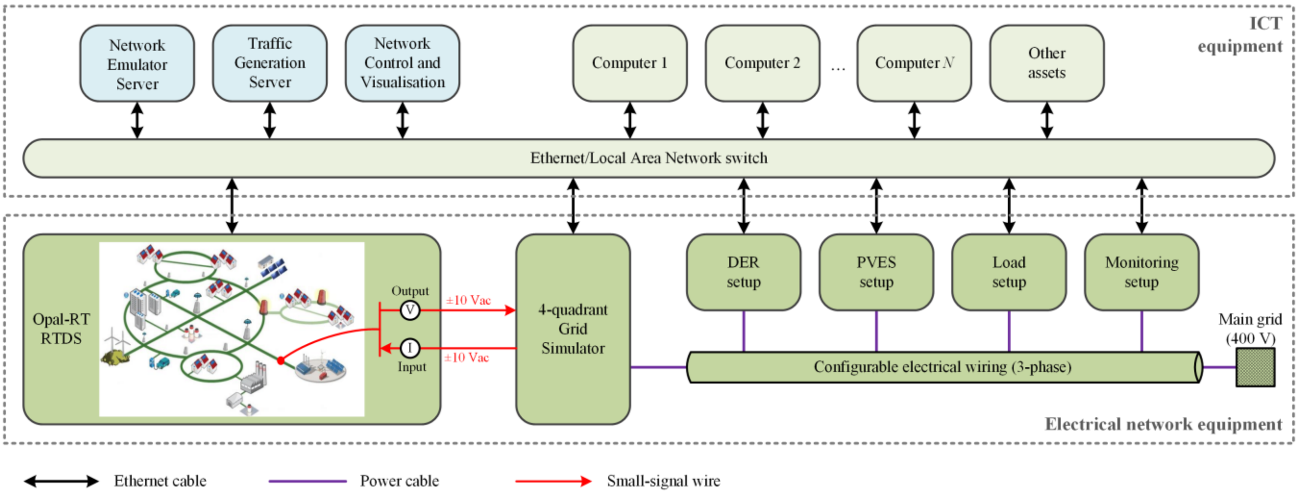

Fig. 2. Architecture of the laboratory platform for the study and testing of smart energy systems enabling-technologies

TABLE II. MAIN ELECTRICAL EQUIPMENT OF THE DEVELOPED LABORATORY PLATFORM

Laboratory setup	Equipment	Description and main characteristics
Opal-RT RTDS	RTDS	OP5640I, 4x Eight-Core Intel® Xeon® processor, OP5340K1 analog input card, OP5330K1 analog output card, OP5353K2 digital input card, OP5354K2 digital output card, Ethernet communication
	host PC	host computer for Opal-RT RTDS, multiple-processors computer for high computational tasks
4-quadrant Grid Simulator	grid simulator	Regatron TopCon TC.ACS.50.528.4WR.S.LC, 4-quadrant, 0…50 kVA, 0…305 V (L-N), 3L+N+PE, 0…1000 Hz, -10…+10 V control signals, individual phase control
DER setup	grid-connected converter	Danfoss VLT5027, -27…+27 kVA, 400 V (L-L), 3L+PE, FS21148-48-99 sine wave filter (LC type, L=1.1mH, C=14.7μF)
	DC power supply/sink	Regatron TopCon TC.GSS.20.600.4WR.S, -20…+20 kW, 0…650 V, -40…+40 A
	dSpace system	dSpace DS1103 PPC, 1 GHz processor, hosts the Simulink-based converter control
PVES setup	grid-connected solar converter	Fronius Symo Hybrid 3.0-3-S, 3 kW AC, 400 V (L-L), 3L+N+PE, 5 kW maximum DC input, 150…1000 V DC input, 2x DC inputs, 1x battery input, Ethernet communication
	PV emulator	ITECH IT6527C DC power supply, 0…3 kW, 0…1000 V, 0…10 A, I-V characteristic emulation, Ethernet communication
	Li-ion ES	BYD H6.4 battery pack, 6.4 kWh, 200…282 V operating voltage range, 256 V rated voltage, 0…1 C rated charging/discharging rates, fully compatible with Fronius inverter
Load setup	programmable single-phase loads	3x H&H ZSAC 2826 electronic loads, 0…2.8 kW, 6…260 V, 0…20 A, RS-232 remote interface, each load connected to a different phase to emulate a three-phase load
	programmable single-phase load	1x Chroma 63804 electronic load, 0…4.5 kW, 50…350 V, 0…45 A, 45…440 Hz & DC, RS-232 remote interface
	host PC	computer with a B&B QSCLP-100 PCI serial card with 4 port RS-232 for real-time communication with the programmable loads hosting the load profiles
Monitoring setup	three-phase smart meters	2x Kamstrup Omnipower meters, 230 V (L-N), 3L+N, 50/60 Hz, Ethernet communication 2x Kamstrup 351Cx2 meters, 230 V (L-N), 3L+N, 50/60 Hz, Ethernet communication
	single-phase smart meters	2x Efacec M Box I100 meters, 230 V (L-N), 1L+N, 50/60 Hz, Ethernet communication
	industrial monitoring system	Bachmann MC210 controller + GMP grid monitoring module, 3x AC voltage inputs, 3x AC current inputs, 0…400 V (L-N), 0…50 A, Ethernet communication
	industrial monitoring system	Bachmann MX213 controller + AIO288 + DIO216 modules, 3x AC voltage inputs, 3x AC current inputs, 0…275 V (L-N), 0…25 A, Ethernet communication

the communication networks involved in the information management of the electric network. As identified by SGAM, ICT layers consist not only of communication protocols for the data exchange between various components, but also of the information that is used and exchanged between these components, as well as between applications or services. A given use-case, application or service can be mapped to ICT layers in several different ways to address specific functional and non-functional requirements. For example, the exchange of information between control centers and substations can be done with IEC 61850 over Internet Protocol (IP) networks or with IEC 60870 over Synchronous Digital Hierarchy (SDH) communication networks. The Network Emulator Server in coordination with Traffic Generation Server and Network Control and Visualization Server can be used to characterize different types of communication network, such as 2G, 3G, LTE, xDSL, etc. It is also possible to generate stochastic or trace-based background traffic patterns to emulate realistic cross traffic based on traffic models and traces of real network traffic. Thus, the ICT layer allows the manipulation of data access strategies and communication conditions between different entities in order to test the potential problems that may arise and affect the quality-of-service.

Different computers or other assets, such as industrial controllers host the functionalities of different grid actors, e.g. DSOs, TSOs, aggregator control centers, renewable or hybrid power plants, residential prosumers, etc. In this way, the laboratory platform gives the possibility to implement and verify new control and operational strategies for actors placed at all levels of the power system, from LV to HV, including voltage control, loss minimization and data aggregation. In addition, new actors and/or functionalities can easily be added to the existing platform.

C. *Application example*

The flexible architecture of the developed platform allows the study and testing in laboratory conditions of smart grid and smart energy systems enabling-technologies at any level of the SGAM framework. This subsection gives an example on how the laboratory platform is used for PHIL studies and tests on grid observability, diagnosis and control.

Fig. 3 presents the SGAM's Component, Communication and Function layers of a LV distribution network with grid observability, diagnosis and control capabilities, and which is implemented in the laboratory. The Process and Field zones are emulated using Opal-RT RTDS, with one specific DER and customer emulated by the DER setup, respectively PVES and Load setups. The LV network is voltage-controlled as follows. A Remote Terminal Unit (RTU), simulated in RTDS, acquires the voltage on the secondary side of the feeding transformer and sends it to the Distributed Management System (DMS) computer, which based on a volt/var control

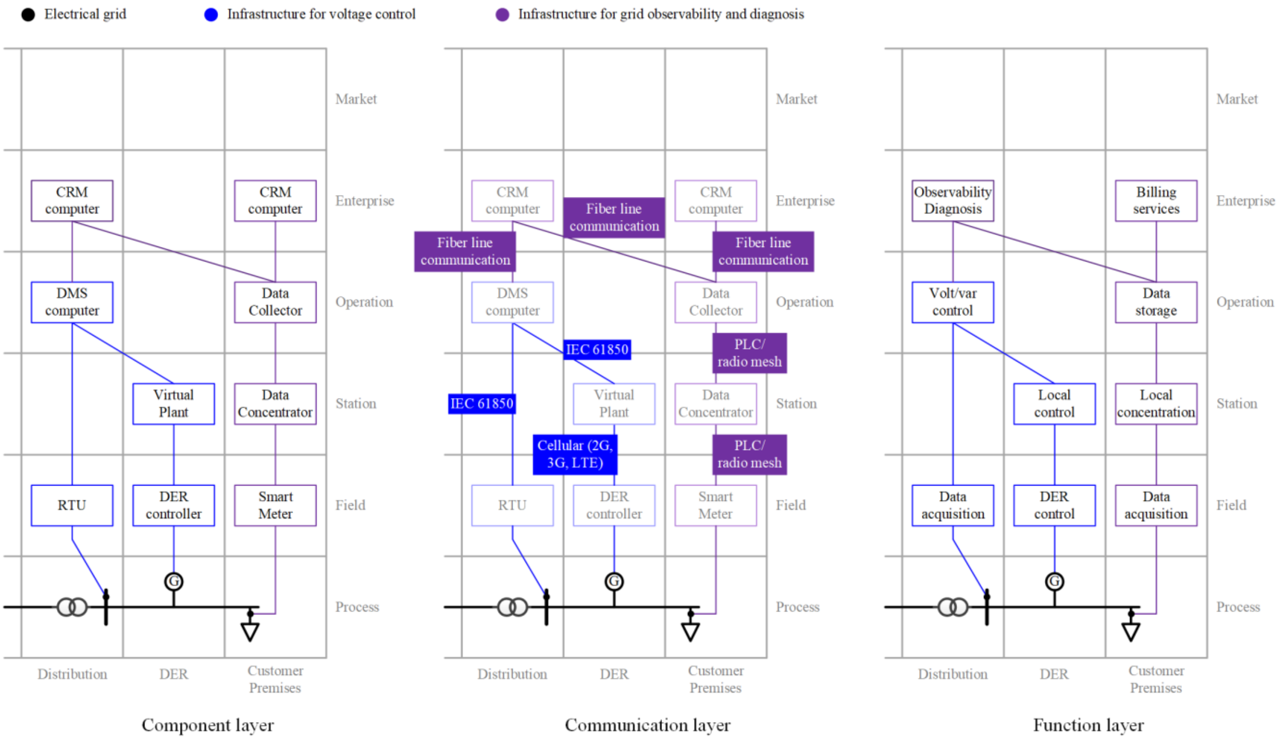

Fig. 3. SGAM layers for grid observability, diagnosis and control of the exemplified LV distribution network

algorithm computes a reactive power set-point reference. The reference set-point is then sent to DERs via the Virtual Plant aggregating them. Each DER controls the reactive power at its own point of coupling according to the set-point received, resulting in this way a coordinated control of the grid voltage on the secondary side of the feeding transformer. The DMS computer and the Virtual Plant controller are emulated using two of the computers shown in Fig. 2.

In addition to voltage control capabilities, the LV network also has grid observability and diagnosis capabilities based on data provided by customers' smart meters. Smart meter data as power consumed/produced and measured voltage/current is collected through Data Concentrators by the Data Collector, which store it. A Customer Relationship Management (CRM) computer, located on Customer Premises domain, Enterprise zone is then used to access it for billing services. Another CRM computer, located this time on Distribution domain, Enterprise zone accesses both the Data Collector and DMS computer and the available data is used for increased grid observability and diagnosis services, such as real-time power outage detection. The CRM computers, Data Collector and Data Concentrator are emulated by four of the computers shown in Fig. 2.

The various communication channels between the actors involved in grid observability, diagnosis and control, shown by the Communication layer in Fig. 3, are emulated by the Network Emulator Server and Traffic Generation Server. In this way, the ICT associated with the LV distribution network is emulated/simulated realistically and flexible, as the type of communication between any two grid actors can be changed any time, if this is desired.

IV. Ongoing Studies

Laboratory testing gives confidence and opportunities to solve integration and implementation challenges prior to field trials. Currently, the developed laboratory platform is used in several research projects that involve proof-of-concept and PHIL testing in a controlled environment prior to field trials. Some on-going activities that involve this platform and are worth to mention are the following.

Net2DG (European public funding [8]) is focused in the development of a proof-of-concept solution based on off-the-shelf computing hardware that uses available communication technologies to leverage measurement data from smart meters and power converters in LV networks. The Net2DG solution correlates these data with information from existing DSO subsystems in order to enable and develop novel grid observability applications for voltage quality, increased efficiency and grid outage detection. The obtained grid observability will be used subsequently by new specially developed control coordination, which will utilize the existing grid actuation capabilities of the converters in conjunction with the existing actuation capabilities of DSOs for voltage quality enhancement and power loss minimization in LV distribution networks.

In context of Net2DG, exemplary distribution networks related to the field tests have been implemented in Opal-RT RTDS and the existing virtual smart meter server has been modified to accommodate the actual smart meter systems that are used on site. Data concentrators and Head End Systems (HES) connect to the ICT layer, while the necessary adapters for supporting specific communication protocols have been developed. Among these communication protocols, there are: IEC 61850 SV/GSE, IEC 60870 104, IEC 61850 MMS and a specific DSO SCADA system. Different types of data traffic will be set up using the Traffic Generation Server, according to defined applications and scenarios for grid observability. Applications and services for grid observability, control and coordination delivered are hosted on top of the ICT gateway and then tested using the laboratory platform.

RemoteGRID (Danish public funding [9]) studies new ways for increasing visibility of LV distribution networks into DSO control center by using AMI infrastructure. The project focuses on developing a management system for DSOs in order to collect, visualize and use the data from smart meters of LV networks to improve the overall operation of the power system. The proposed management system is evaluated in a testbed that focuses on cyber-attacks and LV network asset management, using the developed laboratory platform and in a field test that focuses on the visualization and operational use of smart meter data.

RemoteGRID project considers a virtual AMI subsystem ranging from individual smart meters to the HES. On top of that, databases and data processing that ultimately leads to a GIS visualization tool are developed and successfully used in the laboratory platform for demonstration of cyberattack and grid failure response scenarios. In the field tests, similar tools are used, but with integration to the real HES and challenges that have been related to legal and security aspects, as well as humongous amounts of data, whose correct handling is critical in such applications.

Besides the ongoing research projects mentioned above, the laboratory platform presented in this paper has also been used in projects that have already been completed. Such projects include **SmartC2Net** [10], a project that investigated the use of IP-based off-the-shelf communication technologies for grid monitoring and control, and **RePlan** [11], a project that contributed to the integration of renewable energy into the Danish power system by developing and verifying technical solutions to enhance ancillary services for renewable and hybrid power plants.

It is outside of the scope of this paper to present results of the completed or ongoing research projects that involve the laboratory platform presented in this paper. Such results have been published in other publications and a list of them can be found on [12].

V. CONCLUSION

Smart grids and smart energy systems represent the next evolutionary step of the electric network and of other energy infrastructures. However, the realization of the smart grid vision requires the development and integration of various technologies, especially regarding the ICT, and whose study and testing are not practical in public installations. Realistic laboratory studies and tests are required before field tests for proper validation of smart grid and smart energy systems enabling-technologies.

This paper presented a flexible laboratory platform for the study, testing and validation of smart grids and smart energy systems enabling-technologies. The introduced platform has been developed over the last six years in the Smart Energy Systems laboratory at Aalborg University and is, according to a 2018 report of the EC, the only one of its kind in Denmark. The platform is fully compatible with the SGAM framework and an example has been shown in this sense, consisting of laboratory emulation/simulation of a LV distribution network and its associated ICT actors with role in grid observability, diagnosis and voltage control. The SGAM framework was also briefly introduced, and finally, the paper presented some of the research activities and projects in which the developed laboratory platform was used, even if in a different structure than the one in which it exists today.

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References

[1] H. Lund, "Renewable energy systems: a smart energy systems approach to the choice and modeling of 100% renewable solutions, Second Edition," Waltham, MA, USA, Academic Press Elsevier, 2014, p. 133.

[2] H. Lund, P. A. Østergaard, D. Connolly and B. V. Mathiesen, "Smart energy and smart energy systems," *Elsevier Energy,* vol. 137, pp. 556-565, 2017.

[3] J. Y. Choi and J.-H. Kim, "An integrated simulation framework of a virtual test-bed for smart grid," in *The 40th International Conference on Computers & Industrial Engineering*, Awaju, Japan, 2010.

[4] B. Brinkmann and M. Negnevitsky, "A probabilistic approach to observability of distribution networks," *IEEE Transactions on power systems,* vol. 32, no. 2, pp. 1169 - 1178, 2017.

[5] N. Andreadou, L. Jansen, A. Marinopoulos and I. Papaioannou, "Smart Grid Laboratories Inventory 2018," Publications Office of the European Union, Luxembourg, 2018.

[6] M. Uslar and e. al., "Applying the smart grid architecture model for designing and validating system-of-systems in the power and energy domain: a European perspective," *MDPI Energies,* vol. 12, no. 2, 2019.

[7] CEN-CENELEC-ETSI Smart Grid Coordination Group, "Smart Grid Reference Architecture," CEN-CENELEC-ETSI, Brussels, Belgium, 2012.

[8] "Net2DG," [Online]. Available: http://www.net2dg.eu/. [Accessed 10 02 2020].

[9] "Remotegrid," [Online]. Available: https://www.remotegrid.dk/. [Accessed 25 02 2020].

[10] "Smartc2net," [Online]. Available: http://www.smartc2net.eu/. [Accessed 25 02 2020].

[11] "RePlan project," [Online]. Available: https://www.replanproject.dk/. [Accessed 25 02 2020].

[12] "Smart Energy Systems Laboratory," Aalborg University, [Online]. Available: https://www.et.aau.dk/laboratories/power-systems-laboratories/smart-energy-systems/. [Accessed 22 05 2020].