MULTI-LABORATORY COOPERATION FOR VALIDATING MICROGRID AND SMART DISTRIBUTION SYSTEM APPROACHES

Marcel OTTE, Sebastian ROHJANS
Hamburg University of Applied Sciences, Germany
[marcel.otte; sebastian.rohjans]@haw-hamburg.de

Daniele PALA, Carlo SANDRONI
Ricerca sul Sistema Energetico (RSE), Italy
[daniele.pala; carlo.sandroni]@rse-web.it

Thomas I. STRASSER
AIT Austrian Institute of Technology, Austria
thomas.strasser@ait.ac.at

ABSTRACT

Distributed, renewable energy resources are one of the main driving forces for the realization of a sustainable energy supply in Europe. Their stochastic generation behaviour provides a lot of challenges which have to be managed by energy utilities and network operators. Due to the help of advanced operational concepts and intelligent automation the existing power systems are currently turned into an intelligent entity, a so-called smart grid which can cope with the dynamic behaviour of such renewables. While reaping the benefits that come along with those intelligent behaviours, it is expected that the system-level testing – besides component-level characterisation – will play a more dominant role in the whole engineering process than today. Corresponding validation and testing approaches including a suitable research infrastructure covering power and automation systems equally, are partly missing. This work tackles these issues by introducing an approach for the multi-laboratory cooperation which is currently implemented in the framework of the European ERIGrid project to form a pan-European and integrated smart grid research infrastructure.

INTRODUCTION

Future power systems must integrate a higher amount of distributed, renewable energy resources in order to cope with a growing electricity demand, while at the same time trying to reduce the emission of greenhouse gases [1], [2]. In addition, power system operators in local energy communities are nowadays confronted with further challenges due to the highly stochastic behaviour of renewable generators (solar, wind, small hydro, etc.) and the need to integrate controllable loads (electric vehicles, smart buildings, energy storage systems, etc.). Furthermore, due to ongoing changes to framework conditions and regulatory rules, technology developments (development of new grid components and services) and the liberalization of energy markets, the resulting design and operation of the future electric energy system must be altered.

Sophisticated (systems and component) design approaches, intelligent information and communication architectures, and distributed automation concepts provide ways to cope with the above-mentioned challenges and to turn the existing power system into an intelligent entity, that is, a smart grid [3]. Nowadays, a huge amount of such smart grid related research and technology development but also demonstration projects and field trials are being realized [4], [5].

Usually, before deploying such intelligent solutions and technologies to the field, corresponding products and services need to be validated. Today, such evaluations range from pure device and interoperability checks to factory acceptance tests. However, system-level oriented tests which would be required are difficult to realize; from the testing infrastructure’s but also from a methodological point of view. A holistic validation approach and corresponding methods and tools addressing system level questions are partly missing today [6].

This work is tackling the above outlined validation issues by introducing an approach for coupling geographically distributed smart grid laboratories which is currently realized within the European ERIGrid project. The provided partner labs are extending their portfolio of validation and testing services for complex microgrids and smart distribution grid applications by forming a virtual research infrastructure which provides methods and services for system-level validation.

THE ERIGRID INTEGRATED RESEARCH INFRASTRUCTURE

The lack of system validation approaches for smart grid systems research and development is especially addressed by the European project called ERIGrid. Eighteen research institutions with outstanding smart grid lab facilities from eleven European countries are joining their forces and providing a pan-European and integrated research infrastructure [7].

The target of this integrating activity is to realize the systematic validation and testing of smart grid and microgrid configurations from a holistic, cyber-physical systems point of view. It follows a multi-domain approach and covers power system, Information and Communication Technology (ICT), and cyber-security topics in a multi-domain cyber-physical manner. Education for industrial and academic researchers is provided as well to foster future innovations.

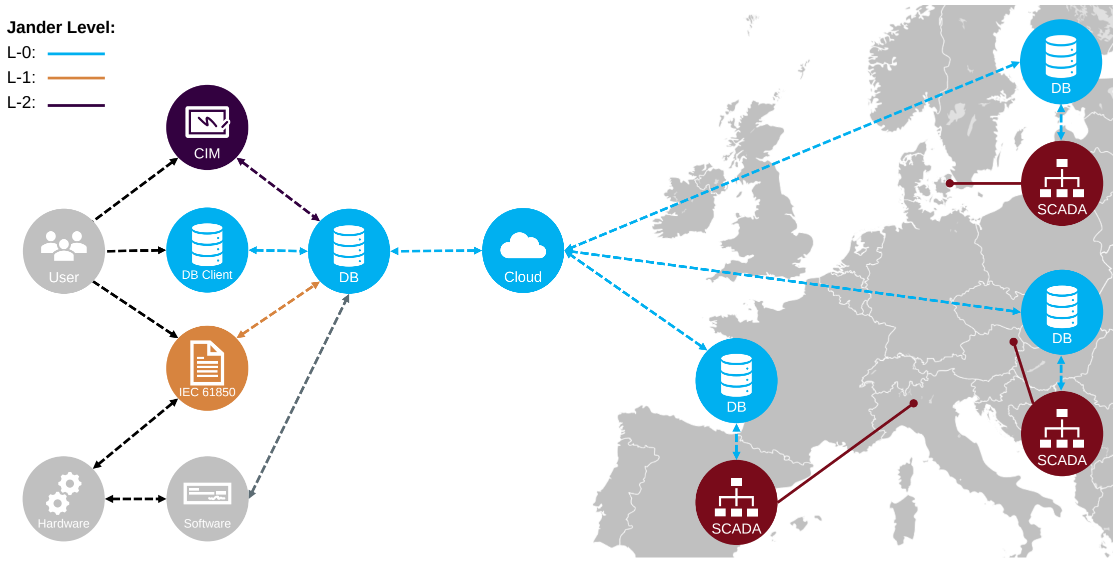

Figure 1: Multi-laboratory coupling using the JaNDER approach

DISTRIBUTED LAB VALIDATION

The above-mentioned integration of various, regional smart grid laboratories leads to the approach of a Joint Research Facility for Smart Energy Networks with Distributed Energy Resources (JaNDER). Its main purpose is to integrate the infrastructures of all ERIGrid partners with secure and interoperable online signal exchange and high-level service provision (e.g., state estimation), providing more opportunities for joint validation of smart distribution systems and microgrid use cases and corresponding applications. To facilitate the validation for all partners and customers, an access from a device interface up to an user interface is needed. The safety and security topics are as well important as the flexible data exchange.

As outlined in Figure 1 the key of the JaNDER approach is the use of databases which are installed local at partners laboratories. They have a signal exchange access with remote devices through a cloud based solution. For an external access and for integrating the distributed research infrastructures of ERIGrid into one virtual facility, the database provides interface solutions for up to 40 different programming languages. The following JaNDER Levels for validating smart grid applications and microgrid solutions are already implemented and tested.

Cloud-based Solution

Providing a flexible infrastructure and considering the safety and security topics of each involved research institution, a cloud-based architecture is able to address these requirements. To obtain the access a safety certificate is needed, which is only distributed by partner RSE which is serving as an administrator of the distributed validation network. Within these certificates the acquisition is feasible, but each device is only controllable with an active connection to the associated research institution, which is delivered by an active cloud and device connection. This leads to a further benefit of the cloud-based solution, the parent control of each device is in the power of each research institution to obtain the best technical support for these components.

As described in Figure 2 the example of a possible configuration outlines the mentioned flexibility. The extern user intends to connect hardware or software components to the infrastructure. The research infrastructure with the devices D and E is due to the offline state not involved. The first laboratory automation system (often a kind of a laboratory SCADA[1]) has access to the cloud and protect the controllability of device B through local configuration settings.

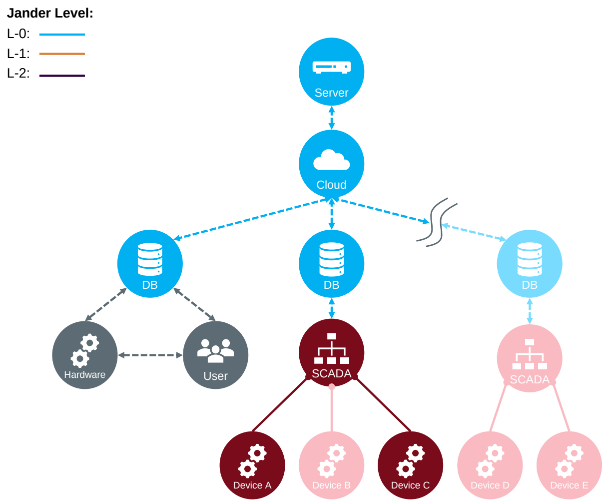

Figure 2: Example of a cloud-based configuration

JaNDER Level 0: Base Level Compatibility

Within the first JaNDER level a database client with a high similarity to the standard command line provides a fast signal exchange through SET and GET commands

[1] Supervisory Control and Data Acquisition

by the user. Considering the multiplicity of all research infrastructures and the extern access of customers, a naming convention is needed to realize the same standard and to avoid the misunderstanding of signal names.
Involving all partners and considering the corresponding laboratory infrastructures, unique signal names for different domains and signal types are required as well.
As described in Figure 3 the ERIGrid naming convention is composed out of IEC 61850 elements with consideration of a human usability [8]. Firstly, the signal types need to be defined, where the domain follows, to obtain the specific units and attributes the IEC 61850 designations are attached. The described signal name (i.e., `M_EA_W.phsA.instMag` in the example from Figure 3) for an instantaneous magnitude of electrical power on phase A will also be referred to JaNDER Level 2.

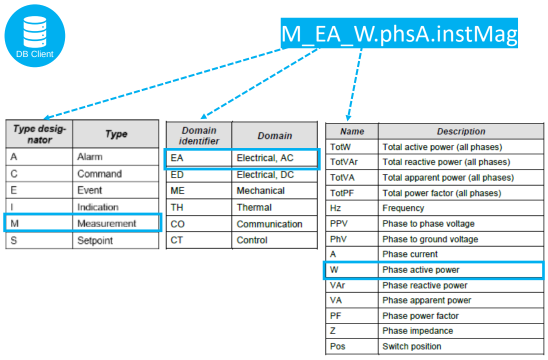

Figure 3: Example of the ERIGrid naming convention

JaNDER Level 1: IEC 61850 Compatibility

Interfacing microgrid and smart distribution system approaches on device level the International Electrotechnical Commission provides an interoperability approach called IEC 61850. This standard provides a common smart grid interface for power system components. This is also a suitable choice for a standardized JaNDER interface. With the use of the OpenMUC open source IEC 61850 framework [8] in ERIGrid, the JaNDER Level 1 provides an implemented signal exchange between the IEC 61850 server and the local database, whereby different clients have access to the integrated ERIGrid research infrastructure.

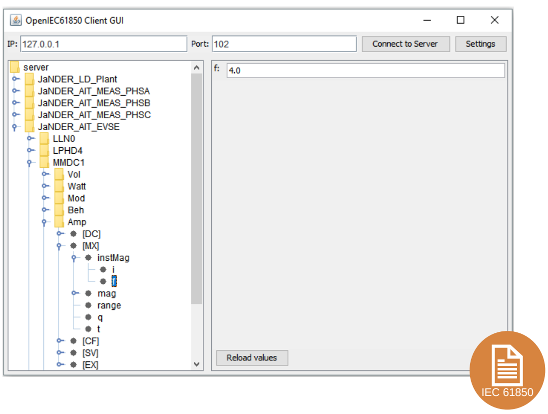

Figure 4: IEC 61850 client user interface

Figure 4 outlines one example IEC 61850 graphical user interface client. Within this client the IEC 61850 structure is represented and the corresponding values of each datapoint is visualized. Contemplating the ERIGrid signal naming convention, a mapping file for defining new data points is available where no software implementation is needed.

JaNDER Level 2: CIM Compatibility

The JaNDER Level 2 provides the most human usability interface. Based on the IEC Common Information Model (CIM) [10] a user interface delivers a signal overview and a circuit diagram.
Figure 5 represents the so called CIM-draw in a web browser environment. The in the cloud available signals are able to assign to hardware components (i.e., signal `M_EA_W.phsA.instMag` for the power measurement of a power meter on phase A). Within this user interface a flexible validation overview represents possible test cases. In addition, signal changes respectively current values and states are visualized as well.

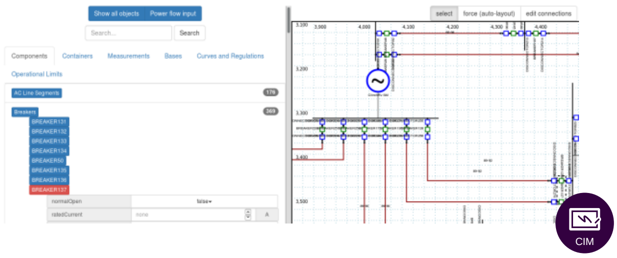

Figure 5: CIM-draw user interface

IMPLEMENTED EXAMPLE

Within the integrated ERIGrid validation environment using the JaNDER approach, smart distributed system or microgrid test approaches can be easily realized. How this is being done, is outlined with the following implemented example

Test Case

As a first test case and proof of concept, the AIT Austrian Institute of Technology implemented a signal access between the local JaNDER database and the open source based SCADA software of the Electric Vehicle Supply Equipment (EVSE) test bed which is part of the AIT SmartEST lab [11].
As outlined in Figure 6, the EVSE test bed as a common smart grid or microgrid component is controllable with a corresponding lab SCADA system. The bidirectional signal exchange between the SCADA and the local database of the SmartEST research infrastructure is implemented, whereby only the signal names needs to be defined in a configuration file to map the different naming convention names (i.e., `Set Charging Current (PWM)` as the SCADA datapoint needs to be mapped with `S_ED_ChargingCurrent.setVal` and the corresponding IEC 61850 naming). After defining

the configuration files, the cloud-based approach is able to be set-up in various manner. As mentioned before the online access of each component is optional, in this case the control of the EVSE is desired in a local test environment as well as the consideration of remote changes. Furthermore, the use of each JaNDER level interface is an important part of the test case and has to be considered in the configuration.

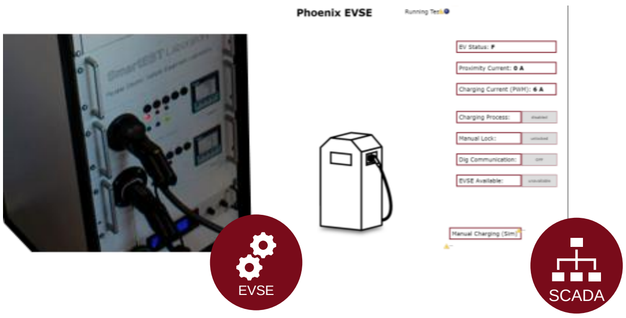

Figure 6: AIT EVSE test stand with web-based SCADA system

Achievements and Results

The test case shows that the signal access to the hardware under investigation is able from each JaNDER level. Due to the bidirectional signal communication, local changes are published in the cloud as well as remote changes are able to control the device. Each JaNDER level was able to write or read the published values. According to different signal types (i.e., `double` or `boolean`) the validation environment differs between states and values; whereby erroneous signal allocation is avoided.

DISCUSSION

With the above introduced JaNDER approach an effective coupling of different European smart grid laboratories becomes possible. Various advantages are based on the cloud approach, which are already outlined. Within the opportunity to define more signal information's (i.e., timestamps and quality of a new datapoint), the validation quality raises. Occasional new interfaces can be implemented and more than 40 different programming languages underlines the flexibility. Moreover, validating microgrids and smart distributions system approaches in a new manner as an interoperable online signal exchange, has the advantage that components can be combined which are in different and remote research institutions. Hereby the know-how of the European smart grid laboratories supports the validation without leaving the place. Considering the trans-national access of external user groups to the ERIGrid laboratories which is provided for free in the project, offers the same advantages. This reduces the effort of transport costs and working time.

CONCLUSIONS

Connecting research infrastructures to a distributed validation environment as the main purpose of this work, leads to the described advantages of flexibility and security through a cloud-based solution. This kind of a distributed and virtual research infrastructure is expandable in the number of connected partners, shared components as well as in the interfacing approaches. Regarding to the discussed aspects, microgrids and smart distribution system approaches require a validation environment with a large amount of information exchange and access to various research infrastructures, which is provided by the ERIGrid project with the multi-lab solution.
The future work will focus on the improvement of the corresponding software solution as well as the involvement of several laboratories for a joint test configuration.

Acknowledgments

This work is supported by the European Community's Horizon 2020 Program (H2020/2014-220) under the project "ERIGrid" (Grant Agreement No. 654113).

REFERENCES

[1] H. Farhangi, "The path of the smart grid," *IEEE Power and Energy Magazine*, vol. 8, no. 1, pp. 18-28, 2010.
[2] "Technology roadmap: Smart Grids," International Energy Agency (IEA), Tech. Rep., Paris, France, 2011.
[3] V. Gungor, D. Sahin, T. Kocak, S. Ergut *et al.*, "Smart Grid Technologies: Communication Technologies and Standards," *IEEE Transactions on Industrial Informatics*, vol. 7, no. 4, pp. 529-539, 2011.
[4] L. Ardito, G. Procaccianti, G. Menga, M. Morisio, "Smart Grid Technologies in Europe: An Overview," *Energies*, vol. 6, no. 1, pp. 251-281, 2013.
[5] F. C. Catalin, A. Miicea, V. Julija, M. Anna *et al.*, "Smart Grid Projects Outlook 2014," *European Commission – Joint Research Centre (JRC), JRC Science and Policy Reports*, Brussels, Belgium, 2014.
[6] T. Strasser *et al.*, "Towards holistic power distribution system validation and testing—an overview and discussion of different possibilities," *e & i Elektrotechnik und Informationstechnik*, Dec. 2016.
[7] T. Strasser *et al.*, "An Integrated Research Infrastructure for Validating Cyber-Physical Energy Systems;" *8th International Conference on Industrial Applications of Holonic and Multi-Agent Systems*, Lyon, France, 2017.
[8] Communication Networks and Systems for Power Utility Automation, Std. IEC 61850, *International Electrotechnical Commission*, Geneva, Switzerland, 2010.
[9] Software Solutions for Monitoring and Control Systems (OpenMUC). [Online] Available: http://www.openmuc.org
[10] Energy management system application program interface (EMS-API) – Part 301: Common information model (CIM), Std. IEC 61970, *International Electrotechnical Commission*, Geneva, Switzerland, 2016.
[11] F. Andrén *et al.*, "Smart Grid Laboratory Automation Approach Using IEC 61499," *Distributed Control Applications: Guidelines, Design Patterns, and Application Examples with the IEC 6149*, CRC Press / Taylor & Francis Group, USA, 2016.