Evaluation of trial results with regard to system applicability, basic requirements and interaction strategies

Version 1.0

Deliverable D4.3

Alberto Dognini

20 December 2019

ERA-Net Smart Grids Plus | From local trials towards a European Knowledge Community

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme.

INTERNAL REFERENCE

• **Deliverable No.:**	D 4.3
• **Deliverable Name:**	Evaluation of trial results with regard to system applicability, basic requirements and interaction strategies
• **Lead Partner:**	FEN
• **Work Package No.:**	4
• **Task No. & Name:**	Field Test Germany
• **Document (File):**	FISMEP – D4.3 – Evaluation of trial results
• **Issue (Save) Date:**	20-Dec-19

DOCUMENT SENSITIVITY

☐	**Not Sensitive**	Contains only factual or background information; contains no new or additional analysis, recommendations or policy-relevant statements
■	**Moderately Sensitive**	Contains some analysis or interpretation of results; contains no recommendations or policy-relevant statements
☐	**Sensitive**	Contains analysis or interpretation of results with policy-relevance and/or recommendations or policy-relevant statements
☐	**Highly Sensitive Confidential**	Contains significant analysis or interpretation of results with major policy-relevance or implications, contains extensive recommendations or policy-relevant statements, and/or contain policy-prescriptive statements. This sensitivity requires SB decision.

DOCUMENT STATUS

	Date	Person(s)	Organisation
Author(s)	20 Dec 2019	Alberto Dognini	FEN / RWTH
Verification by			
Approval by			

This project has received funding in the framework of the joint programming initiative ERA-Net Smart Grids Plus, with support from the European Union's Horizon 2020 research and innovation programme.

CONTENTS

1 INTRODUCTION 5

2 MEDIUM VOLTAGE DC RESEARCH GRID 6

2.1 AUTOMATION FUNCTIONALITIES 6

2.2 FISMEP PLATFORM ARCHITECTURE 7

2.3 EVALUATION AND NEXT DEVELOPMENTS 9

3 SERVICE RESTORATION FOR DISTRIBUTION GRIDS 10

3.1 APPLICATION OF MCDA TECHNIQUE 10

3.2 INTEGRATION WITH PROTECTIVE RELAYS 11

3.3 EVALUATION AND NEXT DEVELOPMENTS 12

4 CONCLUSION 14

5 REFERENCES 15

About ERA-Net Smart Grids Plus

ERA-Net Smart Grids Plus is an initiative of 21 European countries and regions. The vision for Smart Grids in Europe is to create an electric power system that integrates renewable energies and enables flexible consumer and production technologies. This can help to shape an electricity grid with a high security of supply, coupled with low greenhouse gas emissions, at an affordable price. Our aim is to support the development of the technologies, market designs and customer adoptions that are necessary to reach this goal. The initiative is providing a hub for the collaboration of European member-states. It supports the coordination of funding partners, enabling joint funding of RDD projects. Beyond that ERA-Net SG+ builds up a knowledge community, involving key demo projects and experts from all over Europe, to organise the learning between projects and programs from the local level up to the European level.

www.eranet-smartgridsplus.eu

1 Introduction

The energy system has maintained for several decades its structure unvaried: the power flow remained unidirectional from more predictable, controllable and centralized generation plants to consumers located in the distribution grid, over long distances via transmission networks. Nowadays, Europe's energy landscape is experiencing profound change as increasing amounts of renewable energy sources (RES) displace conventional forms of generation. This development has gone hand-in-hand with an expanding share of power production taking place at the distribution level. The aforementioned transformation in the energy system resulted in the development of microgrids, electricity distribution systems containing loads and distributed energy resources (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way. The described transformation coincides with a transition from distribution grids entirely based on the well-established Alternated Current (AC) technology to those that involve the use of Direct Current (DC) technology, to which most of the RES are related.

The main goal of the Work Package 4 of the FISMEP project, Field Test Germany, is the virtualization in the cloud platform of the automation architecture for distribution grids that implements DC technology. In particular, electrical networks in which pure DC and Hybrid AC-DC solutions are implemented.

Following the activities and results presented in the previous deliverables of the same Work Package 4, [1] and [2], this document contains additional information related to the applicability of the implemented solutions, the interaction with the other systems components and the next developments.

2 Medium Voltage DC research grid

The first use case of the German trial test is related to the automation of the Medium Voltage Research Grid in DC technology that RWTH, FEN GmbH and a group of key industry partners have realized in the RWTH campus according to the Forschungscampus P4 project.

The research grid is located at the RWTH-Aachen Campus Melaten in Germany and consist of 5 km Medium-Voltage Direct Current (MVDC) cables connecting different locations in the campus; moreover, it offers possibilities for additional extensions of the grid.

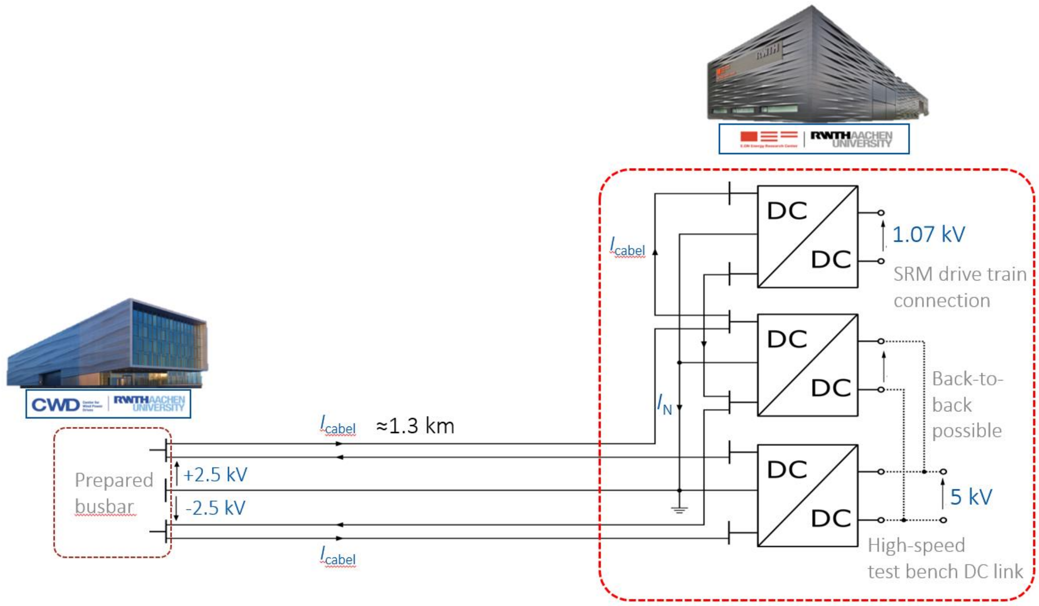


Fig. 1 Scheme of the MVDC research grid.

The Fig. 1 shows the main components that constitute the system: three DC-DC power converters, which implement the Dual-Active Bridge (DAB) topology with galvanic isolation and voltage transformation, are installed in the laboratory of RWTH Aachen University. They are contained in an unique switchgear that includes measurement devices (MV transducers, protective and switching components).

The switchgear is connected via underground electrical cables (bipolar, positive and negative, with two cables per phase and a neutral conductor) to a prepared busbar, located in the Center for Wind power Drives (CWD) of RWTH Aachen University, related to the high-speed drive of a wind turbine test bench.

which can link the high-speed drive test bench to the a prepared busbar, which can link the high-speed drive test bench to the Center for Wind power Drives (CWD) of RWTH Aachen University, where a wind turbine test bench is located. Additional technical information about the MVDC Research grid are reported in [1]

2.1 Automation Functionalities

The main scope of the automation architecture realized within the FISMEP project is the virtualization of the monitoring system that is necessary for the correct operation of the energy system. In particular, the correct voltage level in the different locations of the system needs to be maintained within specified limits, as well as overcurrent situations must be avoided through the continuous monitoring of current magnitudes flowing in the conductors. Additionally, the control of the power flow for each converter permits to deploy the correct energy management strategy, together with the consequent switching operations.

To realize these functionalities, the data measured from the field devices are collected, concentrated and provided to the monitoring system, which is deployed in the FISMEP platform. The measurements for the monitoring of the network are provided by current and voltage sensors (transducers) installed on the cables of the MVDC grid.

2.2 FISMEP platform architecture

The FISMEP platform is realized to accomplish the monitoring functionality of the MVDC grid and to allow the user to directly control the ongoing condition in real time. Hence, several software components have been implemented to accomplish this result. In particular, these components are related to the FIWARE framework, which provides open source components to be implemented and re-used in different domains applications.

Fig. 2 shows the realized architecture, underlying the interactions among the several blocks.

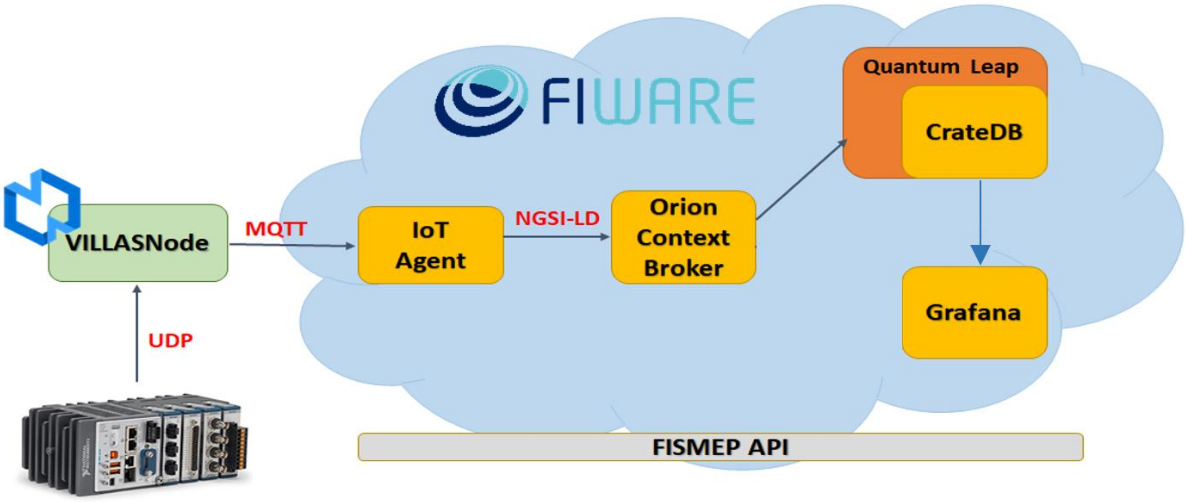


Fig. 2 Architecture of the FISMEP platform

The measurement from the transducers in the field are provided to the Intelligent Electronic Device (IED) constituted by the CompactRIO controller from National Instruments.

The data, received in the form of socket UDP protocol, are mapped according to MQTT (MQ Telemetry Transport) data protocol, completely suitable for the integration with the FIWARE components of the FISMEP platform. This mapping is carried out via the VILLASNode gateway component.

VILLASNode, developed at the Institute for Automation of Complex Power Systems of RWTH Aachen, constitutes the gateway component used for the mapping of the measurements to the MQTT protocol. VILLASnode is a flexible gateway for co-simulation interface data. It converts protocols, (de-)multiplexes signals to and from multiple sources and destinations [3].

The data stream of voltage and current measurements are interfaced in the FISMEP platform using the FIWARE IoT Agent software component. An IoT Agent is a component that lets a group of devices send their data to and be managed from a Context Broker using their own native protocols. IoT Agents should also be able to deal with security aspects of the FIWARE platform (authentication and authorization of the channel) and provide other common services to the device programmer [4].

The Orion Context Broker manages context information and its availability. It is possible to create context elements and manage them through updates and queries. In addition, notification are provided when context elements are modified [5].

Other components that are used for the storage and visualization of data are CrateDB and Grafana. Crate-DB is a time series database, based on QuantumLeap for the integration of NGSI-LD [6]. Using Grafana for visualization purposes, specific alerts can be deployed (e.g., in case a measurement quantity overcomes the assigned limit) or a better understanding of the system with respect of the time evolution [7].

With respect to the earlier implementations, in the initial phase of the FISMEP project, the data stream among the Orion Context Broker, Crate DB and Grafana has been revised: all the data are collected and saved in the time series database, which allows the development of further functionalities and more sophisticated energy management algorithms, and then these data can be visualized using the dedicated component, Grafana. In this way, the visualization is not only limited to the instantaneous measurement but also comparison with previous data or in different time frames.

In the Fig. 5, initial values of data collected and virtualized in the FISMEP platform are reported; the example shows how the visualization of voltage and power flow in the converters is deployed.

Fig. 3 Visualization example of collected data

Moreover, the FISMEP API allows the access to the architecture components from external users, in coordination with the deployments related to the other field tests of the FISMEP project: Swedish (WP2) and Romanian (WP3).

2.3 Evaluation and next developments

The main effort in deploying the presented architecture for the monitoring of the MVDC electrical grid is associated to the interface with the data collected from the field.

In particular, the correct understanding of the implemented protocol and the mapping to the suitable data model have been the essential point for the replicability of the implemented solution. Using the gateway VILLASNode component, the standard MQTT protocol constitutes a valid interface for the FIWARE IoT Agent.

The presented architecture constitutes a valid reference for the replicability of the monitoring solutions in the energy domain. The application is not limited to the DC grids, but can be extended to the general distribution system, with an adaptation of data model that requires a minimum amount of work.

In the upcoming last phase of the project, additional tests will be performed in different grid operating conditions. Moreover, the collected data can constitute the input for more sophisticated algorithms for advanced energy control of the grid.

3 Service Restoration for Distribution Grids

The occurrences of natural disasters and targeted attacks on the distribution grids have caused large scale outages. The electrical networks have to be made resilient, so that they can withstand and recover from these High Impact Low Probability (HILP) events and ensure continuous supply of power to all the end customers. The distribution grids need to be designed resilient not only against regular single faults but also against multiple faults. This can be achieved by grid hardening methods and by efficient and fast Service Restoration (SR).

The goal of the Service Restoration (SR) is to select the tie switches (normally open switches, generally connecting different feeders or segments of the same feeder) to be closed and to re-energize the feeders that had been disconnected due to fault clearance.

The service restoration algorithm developed in the FISMEP project has been presented in [1] and [2]; the present document discussed the achievements and the evaluation about the replicability of its extension.

3.1 Application of MCDA technique

With respect to the FISMEP algorithm for the service restoration already described, effort has been focused on the enhancing of the criteria to select the most suitable reconfiguration path to re-energize the selected load. In doing this, the Multi-Criteria Decision Analysis (MCDA) theory has been applied.

The criteria considered by the algorithm are

1. The total power losses in the grid, P^a considering the reconfiguration from electrical substation *a*.

2. The utilization of electrical lines, which indicates the current that can still flow in a line related to its maximum value, as:

$$\theta_{x,y} = \frac{I_{x,y}^{max} - \left|\overline{I_{x,y}}\right|}{I_{x,y}^{max}}$$

   For each network topology that is analyzed, the three minimum values of $\theta_{x,y}$ are recorded in descending order, indicated as θ_1^a, θ_2^a and θ_3^a, for which θ_1^a is related to the electrical line having the current most close to its specific ampacity.

The selection of the optimal solution requires the combination of these two aspects, summarized in the four quantities P^a, θ_1^a, θ_2^a and θ_3^a involving the use of MCDA techniques.

Initially, the Analytical Hierarchy Process (AHP) [8] is implemented: pair-wise comparisons between each element allow to compute the comparison matrix Γ

$$\Gamma = \begin{bmatrix} 1 & w_{P\theta_1} & w_{P\theta_2} & w_{P\theta_3} \\ \frac{1}{w_{P\theta_1}} & 1 & w_{\theta_1\theta_2} & w_{\theta_1\theta_3} \\ \frac{1}{w_{P\theta_2}} & \frac{1}{w_{\theta_1\theta_2}} & 1 & w_{\theta_2\theta_3} \\ \frac{1}{w_{P\theta_3}} & \frac{1}{w_{\theta_1\theta_3}} & \frac{1}{w_{\theta_2\theta_3}} & 1 \end{bmatrix}$$

In which *w* is the comparison value between the attributes indicated by the subscripts, which ranges from 1/9 (attribute of second subscript is extremely important with respect to the first one) to 9 (attribute of first subscript is extremely important with respect to second one) according to the AHP scale and pre-assigned by the grid operator. The sub-scripts p, θ_1, θ_2 and θ_3 represent the power losses and the line utilization of the three most consumed lines, respectively. The priority vector is obtained, which ranks the four criteria and shows relative weights among them. Then these relative weights are combined with the power losses and line utilizations of each feasible solutions, indicated by the different values of *a* as reference substation, according to the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [9]. This process allows to compute the closeness of each candidate solution to the ideal one, which is composed by the minimum power loss P^a, and maximum θ_1^a, θ_2^a and θ_3^a.

Among the possible solutions, indicated by the different values of *a* as reference substation, the one having the highest closeness C_a^+ is designated as the optimal solution to reconnect the load *b*. Then a closing signal is sent to the open tie switch related to this configuration. The selected optimal solution is, then, a trade-off between the minimization of power losses in the line and the avoidance of lines having the current close to its limit.

3.2 Integration with protective relays

In order to integrate the use of standard communication protocols in the tests setup, the test setup has been expanded with industrial devices to carry out Hardware-In-the-Loop (HIL) simulations. In particular, the devices that have been included are the protective relays used in the Medium Voltage substations of industrial of distribution grid utilities. The relay model REF 615 from the ABB manufacturer have been used.

Goal of the test is the integration of the substation automation protocol IEC-61850 to exchange the notification of the fault occurrence and the command of circuit breakers opening/closing or the status of the switching devices. For this purpose, the commands between the devices implements the Generic Object Oriented Substation Events (GOOSE); moreover, the electrical quantities monitored to detect a fault occurrence, current and voltage (for overcurrent and undervoltage protection, respectively), are provided according to the Sampled Values (SV) technical specification.

Starting from the initial integration with the FISMEP platform as reported in Fig. 4, the protective relays have been included in the test setup as schematized in Fig. 5.

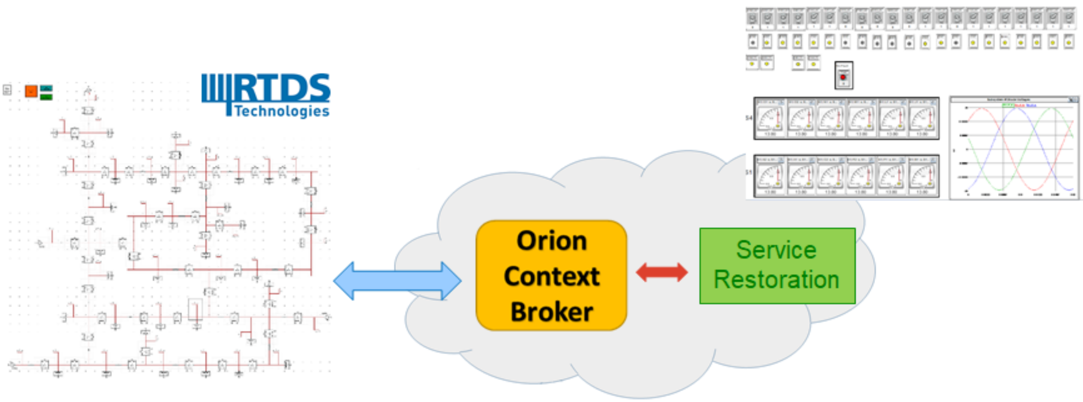


Fig. 4 Integration of Service Restoration with RTDS tool

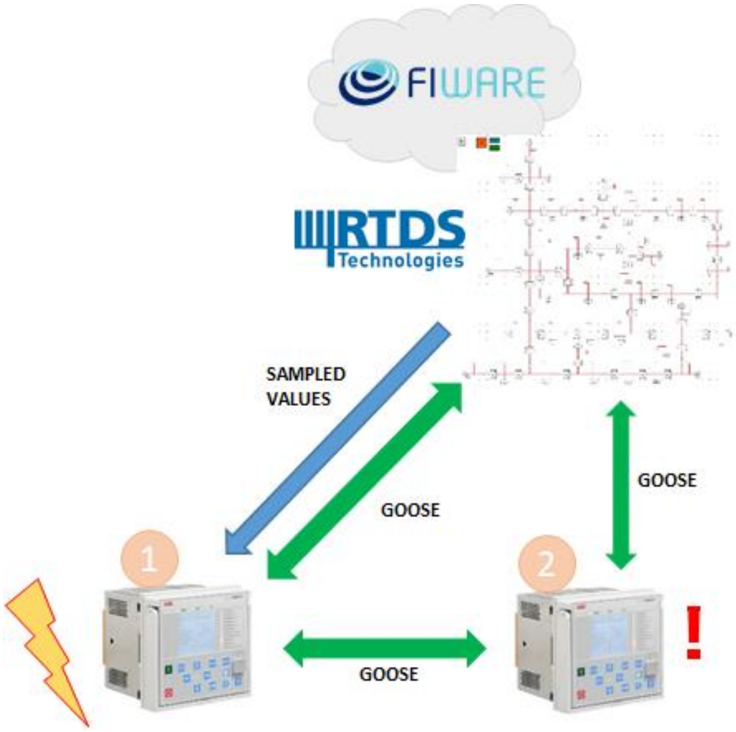


Fig. 5 Protective relays and communication schemes

The proposed test setup consider the connection of Current Transformers (CT) and Voltage Transformers (VT) in the RTDS model with the protective relays installed in the laboratory of RWTH Aachen. The measurement data are provided according to SV protocol and the relays are configured with specific overcurrent thresholds to detect the fault (overload or short-circuit) occurrence. In case of fault detected by the relay, the device publishes a GOOSE message to which the other relays and RTDS are subscribed. The circuit breaker, whose model is present in RTDS, related to the relay that detected the fault trips; moreover, the relay downstream the fault location (on the same feeder) receives the fault occurrence messages and issues an opening command to isolate the fault area (as cascade effect); consequently, RTDS collects the GOOSE message to open the downstream breaker. According to the example reported in Fig. 5, the relay indicated with number 1 detects the fault by monitoring the SV data, issues the tripping GOOSE message that is collected by relay number 2, which opens as cascade effect).

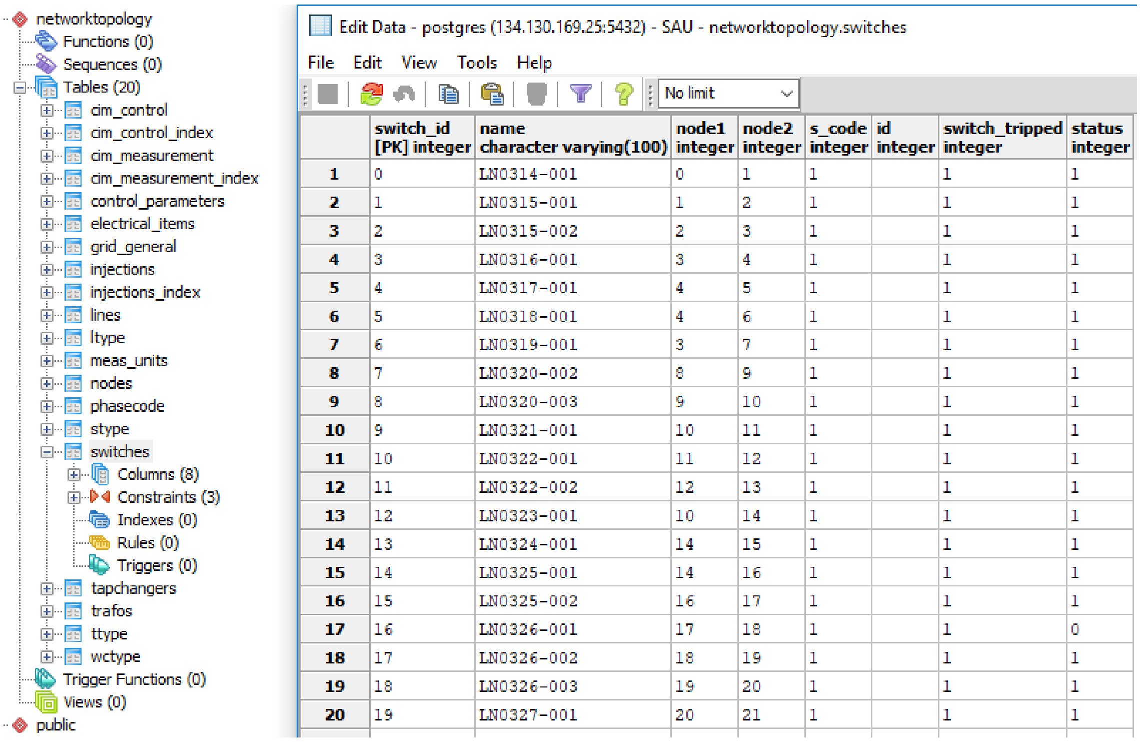
The conducted test proved the suitability of the FISMEP platform and, in particular, the standard automation protocols and devices to be integrated and perform the necessary grid functionalities. Additionally, the GOOSE communication among the relays improves the features of the protection system, guaranteeing a fast and reliable method to isolate the fault area.

3.3 Evaluation and next developments

The evaluation of the described service as middleware considers the expandability of the proposed algorithm, the interoperability with other solutions and the replicability on different platform.

The main goal in developing the described platform is the ability to interface a generic distribution grid (without requiring specific constraints and an excessively high quantity of input data). The proposed algorithm is suitable for nonexclusive grid topology for which the radiality is respected; as input data, it uniquely needs the status (open, close, tripped) of the circuit breakers, the line parameters and the voltage measurements in the grid nodes. In case different measurements are present (active/reactive power generated or injected) they are integrated in the state estimation approach that is easily adaptable to whichever electrical measurement.

The input data are collected in tables, as SQL structures, as reported in the Fig. 6; the same structures are replicated in the FIWARE components of the FISMEP platforms (Orion Context Broker and CrateDB).



	switch_id [PK] integer	name character varying(100)	node1 integer	node2 integer	s_code integer	id integer	switch_tripped integer	status integer
1	0	LN0314-001	0	1	1		1	1
2	1	LN0315-001	1	2	1		1	1
3	2	LN0315-002	2	3	1		1	1
4	3	LN0316-001	3	4	1		1	1
5	4	LN0317-001	4	5	1		1	1
6	5	LN0318-001	4	6	1		1	1
7	6	LN0319-001	3	7	1		1	1
8	7	LN0320-002	8	9	1		1	1
9	8	LN0320-003	9	10	1		1	1
10	9	LN0321-001	10	11	1		1	1
11	10	LN0322-001	11	12	1		1	1
12	11	LN0322-002	12	13	1		1	1
13	12	LN0323-001	10	14	1		1	1
14	13	LN0324-001	14	15	1		1	1
15	14	LN0325-001	14	16	1		1	1
16	15	LN0325-002	16	17	1		1	1
17	16	LN0326-001	17	18	1		1	0
18	17	LN0326-002	18	19	1		1	1
19	18	LN0326-003	19	20	1		1	1
20	19	LN0327-001	20	21	1		1	1

Fig. 6 Integration of Service Restoration with RTDS tool

In case that a different algorithm is needed, rather than service restoration (e.g. the network reconfiguration for the energy management improvement), the structure of the platform and the implemented software components easily allow this adaptation. In fact, the data are collected from the electrical system using a standard approach and, successively, they are managed in the specific middleware component, which is completely interchangeable. Additional information are included in the activities related to the Work Package 5 of the FISMEP project, in which also the FISMEP API features are presented and discussed.

In the coming months, the network reconfiguration algorithm based on state estimation approach for Hybrid AC-DC distribution grids will be implemented as middleware, contributing as an additional service for the energy management. Moreover, the enrichment of standard automation protocols includes the use of Extensible Messaging and Presence Protocol (XMPP) for the communication between platform and power system devices.

4 Conclusion

In this field trial user experience document, related to the work package 4 (Field Test Germany) of the FISMEP project, the achieved developments and their evaluation is conducted.

The automation of the DC Medium Voltage grid of the RWTH Research Campus is achieved with continuous adjustment regarding the software architecture and the monitoring functionalities. Regarding the automation of Hybrid AC-DC distribution grids, additional improvements are introduced to the service restoration algorithm; additionally, the test setup has included different industrial devices for the expansion of the supported automation protocols.

The evaluation of the deployed energy services demonstrates the suitability of the presented components to carry out the selected functionalities using the FIWARE components and the adaptability of the platform architecture to integrate different energy services (with different algorithms) or different data structures from the electrical grid.

5 References

[1] Trial and service design document on FISMEP infrastructure, FISMEP - D4.1, A. Dognini

[2] Field trial user experience including visualization systems, FISMEP - D4.2, A. Dognini

[3] VILLASnode, FEIN Aachen, https://www.fein-aachen.org/projects/villas-node/

[4] FIWARE IoT Agent, https://fiware-tutorials.readthedocs.io/en/latest/iot-agent/index.html

[5] FIWARE Orion, https://fiware-orion.readthedocs.io/en/master/

[6] CrateDB – Cosmos, FIWARE Catalogue, https://catalogue-server.fiware.org/enablers/bigdata-analysis-cosmos

[7] Grafana, Grafana Labs, https://grafana.com/

[8] Thomas L. Saaty, ”How to make a decision: The analytic hierarchy process,” 48(1):9 – 26, 1990.

[9] G. H. Tzeng and J.J. Huang, ”Multiple Attribute Decision Making: Methods and Applications” A. Chapman Hall book, Taylor Francis.