Field trial user experience including visualization systems

Version 1.0

Deliverable D4.2

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07 June 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 4.2
- **Deliverable Name:** Field trial user experience including visualization systems
- **Lead Partner:** FEN
- **Work Package No.:** 4
- **Task No. & Name:** Field Test Germany
- **Document (File):** FISMEP – D4.2 – Field trial user experience
- **Issue (Save) Date:** 07-Jun-19

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Approval by			

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1 Introduction

The main goal of the Work Package 4 of the FISMEP project, Field Test Germany, is the virtualization of the automation architecture for distribution grids in the cloud platform.

In particular, the DC grid to which the developed automation architecture is applied is the Medium Voltage Research Grid in DC technology that RWTH, FEN GmbH and a group of key industry partners are realizing in the RWTH campus according to the Forschungscampus P4 project.

Due to the increasing role of Distributed Energy Resources (DERs) that implement DC technology, DC portions of the grid constitute a valid possibility with great resonance in the scientific community. These DC sub-grids are integrated in the traditional AC networks forming hybrid AC/DC solutions.

For the FISMEP project, the hybrid AC/DC distribution grid in Medium Voltage is realized in the RWTH laboratory using the Real Time Digital Simulator.

The FISMEP platform is connected to the grid via Intelligent Electronic Devices (IEDs) that provide measurements and implement the computed commands. The FIWARE software components, on which the platform is constituted, are perfectly integrated with the developed energy services that perform the management in steady state and/or faulty conditions.

2 Medium Voltage DC research grid

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.

The grid is operated by the Institute for Power Generation and Storage Systems (RWTH-PGS) together with other partners of the Research Campus Flexible Electrical Networks. Unlike conventional alternating current (AC) grids, the commissioned grid operates with direct current (DC) – thus, less components are required and higher efficiencies can be achieved.

Particularly, with the integration of fluctuating renewable energy sources such as wind or solar energy, these advantages come to fruition, since these systems operate with DC and hence the conversion to AC is omitted. In addition, the key components for DC distribution grids use far less material than conventional 50 Hz systems. The novel DC grid can cope with such fluctuations much better and balance them. Furthermore, it requires less material and can efficiently feed in more electric power.

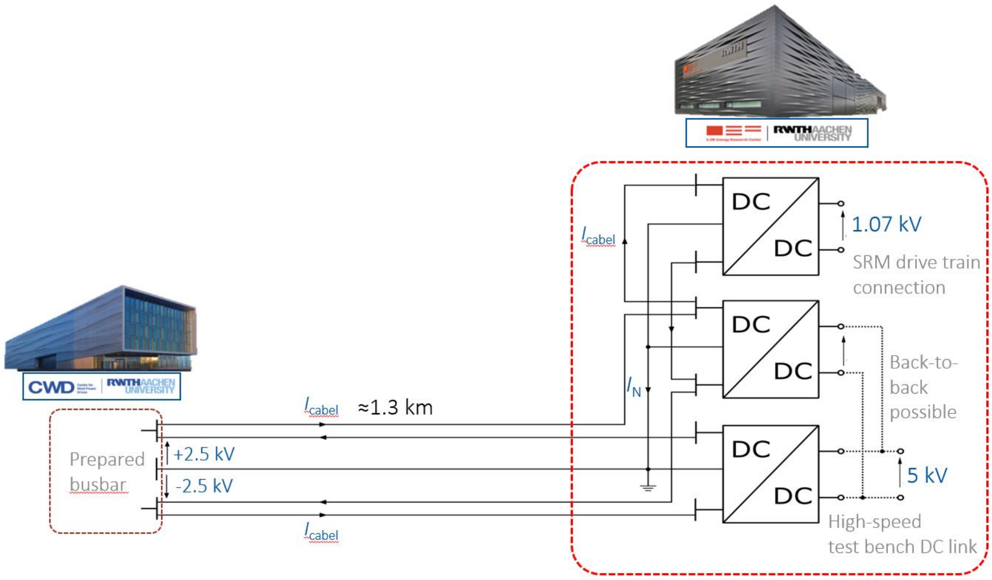


Fig. 1 Scheme of the MVDC research grid.

The MVDC research grid is based on available infrastructure and converter technologies developed WITHIN the project “Design, Construction and Testing of Campus FEN Research Grid”. The research grid offers a modular design, easily reconfigurable to test different network architectures.

The multi-terminal grid is constituted by three DC-DC converters: Dual-Active Bridge (DAB) topology with galvanic isolation and voltage transformation, as reported in Fig. 1. The converters, with a power up to 5 MW, are located in a unique switchgear, which also hosts devices for protection, switching and measuring purposes.

The switchgear is connected via electrical underground cables (bipolar, positive and negative, with two cables per phase and a neutral conductor. The cables (each one with a length of 1.3 km) connects 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 Communication architecture

The measurements for the monitoring of the network are provided by current and voltage sensors (transducers) installed on the cables of the MVDC grid.

The measurements that are collected from the sensors are:

- Voltage between positive and neutral conductors
- Voltage between negative and neutral conductors
- Current in the positive conductor for pole 1
- Current in the positive conductor for pole 2
- Current in the negative conductor for pole 1
- Current in the negative conductor for pole 2
- Current (positive and negative) in the switchgear

Measurements of corresponding quantities are provided by the transducers present in the busbars compartment, at the opposite location of the grid.

Since the protection against overcurrent and short-circuits is performed by the converters themselves, the measurements are used to develop a supervisory control and data acquisition (SCADA) system.

The data are collected in Intelligent Electronic Devices (IEDs) and mapped according to IEC-61850, as described in [1].

2.2 Integration of FISMEP platform

The integration to the FISMEP platform is realized by acquiring the data from the IED, constituted in this setup by the CompactRIO, which are normally provided to the SCADA system of the MVDC Research Grid.

Since the data are normally transmitted according to the IEC 61850 – MMS protocol, it is necessary to translate this communication protocol, to be provided to the FISMEP platform. In fact, the measurements collected by the transducers, installed in the grid, are mapped according to a socket UDP protocol.

The use of a gateway component allows the mapping of the received data according to an MQTT (MQ Telemetry Transport) data protocol, completely suitable for the integration with the FIWARE components of the FISMEP platform.

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 [2].

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 [3].

The Fig. 4 shows the communication architecture between CompactRIO and the FISMEP platform; moreover, the FIWARE components that constitute the platform are represented.

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 [4].

The data can be visualized using the open software Grafana, which interacts with the Orion Conext Broker. 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 [5].

Since data are continuously provided for the monitoring of the grid and their analysis is not necessarily in real time, the measurements are stored according to a time-series database. In this case, the FIWARE component QuantumLeap is used for the integration of NGSI-LD, specifically implemented by the Orion Context Broker, with the time series database Crate-DB (as SQL database) [6].

Fig. 2 illustrate the components used for the acquisition of data from CompactRIO.

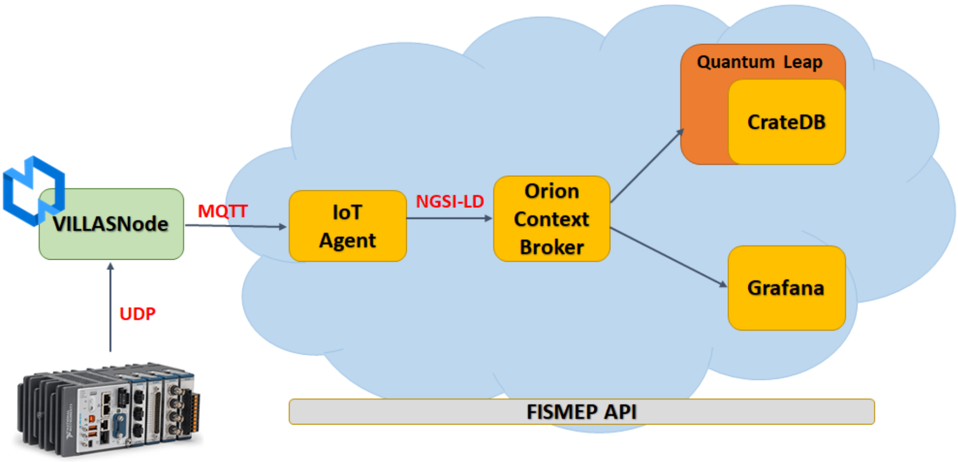


Fig. 2 Acquisition of CompactRIO data in the FISMEP platform

2.3 Features of the FISMEP platform

As anticipated in the previous paragraph, the main goal of data collection from the FEN MVDC grid is the use of a SCADA system: it allows the visualization, monitoring and control of the grid in real time.

Parallely, in the FIMSEP platform the data are acquired in the cloud and available for the visualization purposes through Grafana component. Moreover, the use of FISMEP API allows the availability of data also to external users (third parties), enhancing the realibility of the automation architecture and opening new possibilities for the energy use-cases.

Additionally, the use of time-series database allows the deployment of analysis about the transitory events that occur on the grid. These data can constitute the basis for further energy services, which could be added in the FISMEP platform, regarding the management of the MVDC research grid.

3 Service Restoration for Distribution Grids

The occurrence of outages in electrical networks causes several economic and social impacts. Currently, most of the utilities are not fully automated and the operations related to fault management are manually implemented by human technicians; anyway, the consequences of faults can be reduced by equipping the grids with automation solutions. In case of fault occurrence in a distribution network, after the opening of the corresponding circuit breaker.

The goal of the Service Restoration (SR) is to re-energize the customers that are disconnected after the fault clearance but are outside the fault zone. These customers can be reconnected by performing the power delivery with an alternative path and closing the normally open tie switches, which connect two different feeders and are installed in the distribution grids to increase its resiliency.

To enhance the self-healing capability of distribution grids in case of fault occurrence, a SR solution has been developed and implemented in the FISMEP platform. The SR is based on an innovative Rule-Based Optimization (RBO) algorithm, specifically developed as the first countermeasure in critical conditions, as High Impact Low Probability (HILP) events.

3.1 Service Restoration in the FISMEP Platform

The SR has been developed as middleware, hence it is independent of grid structure or specific electrical parameters. Moreover, it is integrated into the FISMEP platform with the FIWARE components, to deploy an automated cloud-based SR: it retrieves the data from the CB and provides the computed solution according to a defined data model.

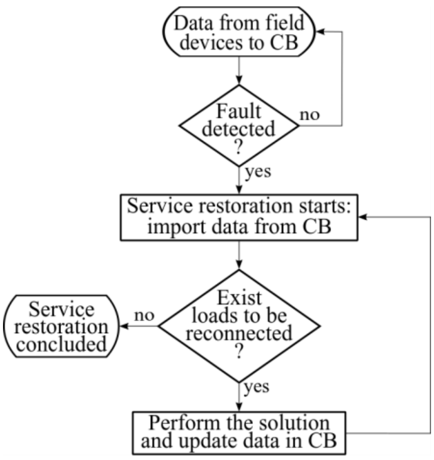


Fig. 3 Flowchart of the Service Restoration

Fig. 3 shows the overall control flow of SR: detecting the fault via Context Broker (CB), performing the service restoration process and sending the command to actuate the computed solution. In this setup, both the CB and the SR service run in the same network. Data are provided from the smart devices in the electrical network to the platform via HTTP and are formulated based on the data structure of CB. The CB is capable of receiving data and notifying an event, in case of correspondence of the acquired value to a specific entity. In this specific implementation, the condition of tripped circuit breakers due to a fault in the grid is monitored to activate the SR. If network data that indicate the presence of a fault are updated in CB, these values satisfy the notification condition: the CB sends a message to SR service, which starts to process the information and sends a message back to the CB to retrieve the data related to the network. The SR algorithm continuously iterates to re-energize each disconnected load, until all possible loads are reconnected or the safety electrical constraints are violated, and provide the solution to the CB. Then, the CB issues the network reconfiguration commands, i.e. closing of specific switches, to the devices in the grid network. Once the closing operation is successfully performed, data are updated in the CB.

To test the SR, the distribution grid is emulated in the Real-Time Digital Simulator (RTDS) with the software RSCAD. Through the Gigabit Transceiver Network (GTNET) card of RTDS the grid data could be sent/published into a communication network via its ethernet port thus emulating the protection and metering IEDs. The test is carried out on different grids and fault conditions; additionally, the recorded communication network latency and the SR computation time are in line with standard values of automated systems, confirming the suitability of the proposed setup.

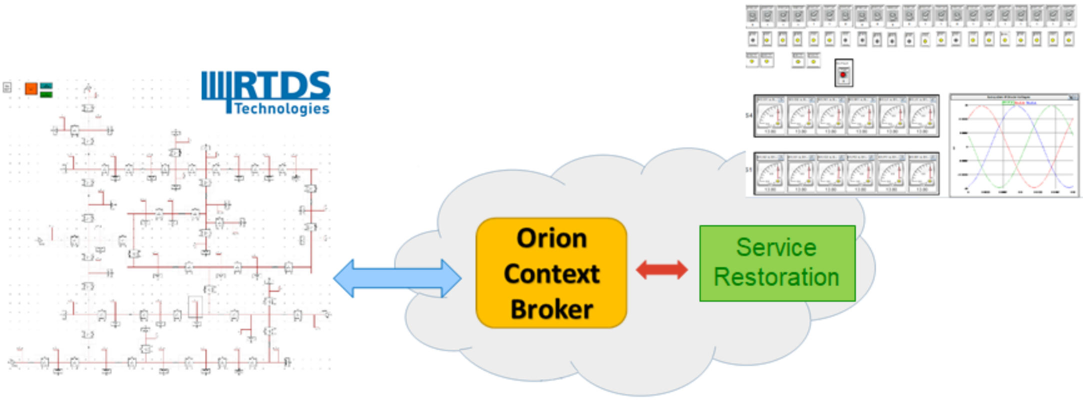


Fig. 4 Integration of Service Restoration with RTDS tool

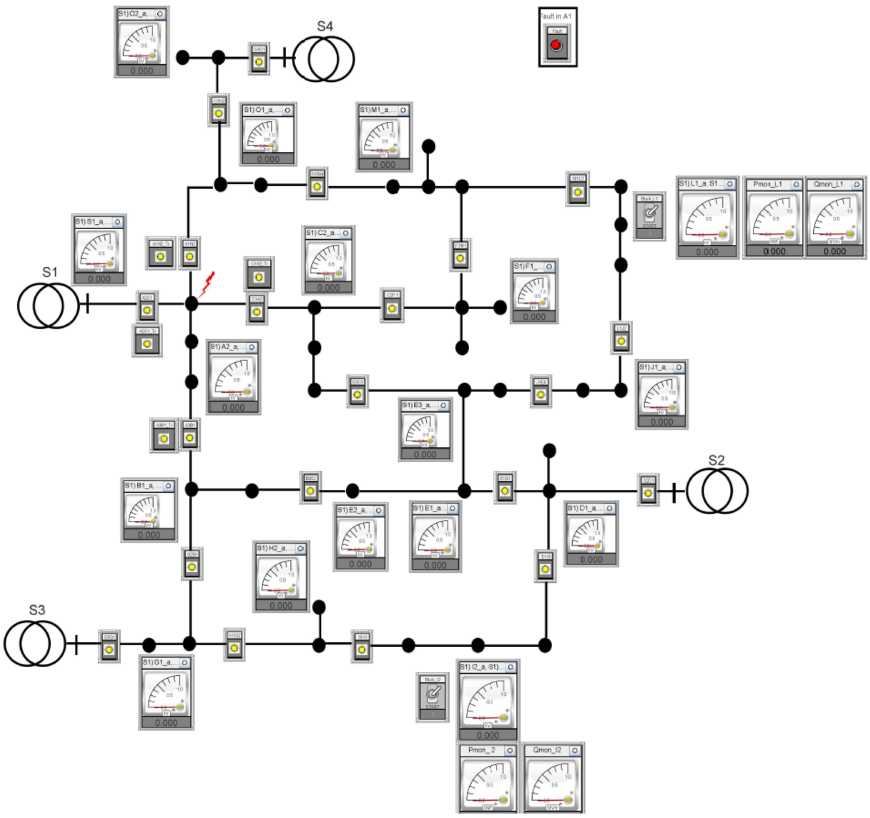


Fig. 5 Distribution grid modelled in RTDS

The AC grid modelled in RTDS and used for the deployment of the service restoration is represented in Fig. 5. It represents a medium voltage distribution grid at 13.8 kV, with four primary substations whose feeders are connected by normally open tie units. Each node hosts a load, in the range from 100 kW to 1 MW, with the exception of two nodes, to which DERs of 200 W and 250 W, respectively, are connected. The overall data of the network are mapped according to the contextual information model of the CB.

4 Hybrid AC-DC Distribution Grids

In order to deploy additional energy services for the management of distribution grids, the inclusion of portions of the network that deploy DC technology has been considered. These DC subgrids are included in the overall AC distribution network and interfaced via AC/DC converters.

In order to integrate these solutions with the FISMEP cloud platform, and perform additional analysis, the hybrid AC-DC grid has been realized in RTDS.

4.1 Grid Model in RTDS

The grid model in RTDS is derived from the AC network model used for the Service Restoration use case, described in the previous paragraph. The AC portion of the grid is still managed in radial configuration, or which the 4 substations (which act as source of power) are electrically disconnected via open tie-units. The DC portion of the grid is linked to the AC one via three AC/DC converters: it consists of a multiterminal DC grid in which a load is present, controlled with constant power. The model is represented in Fig. 6.

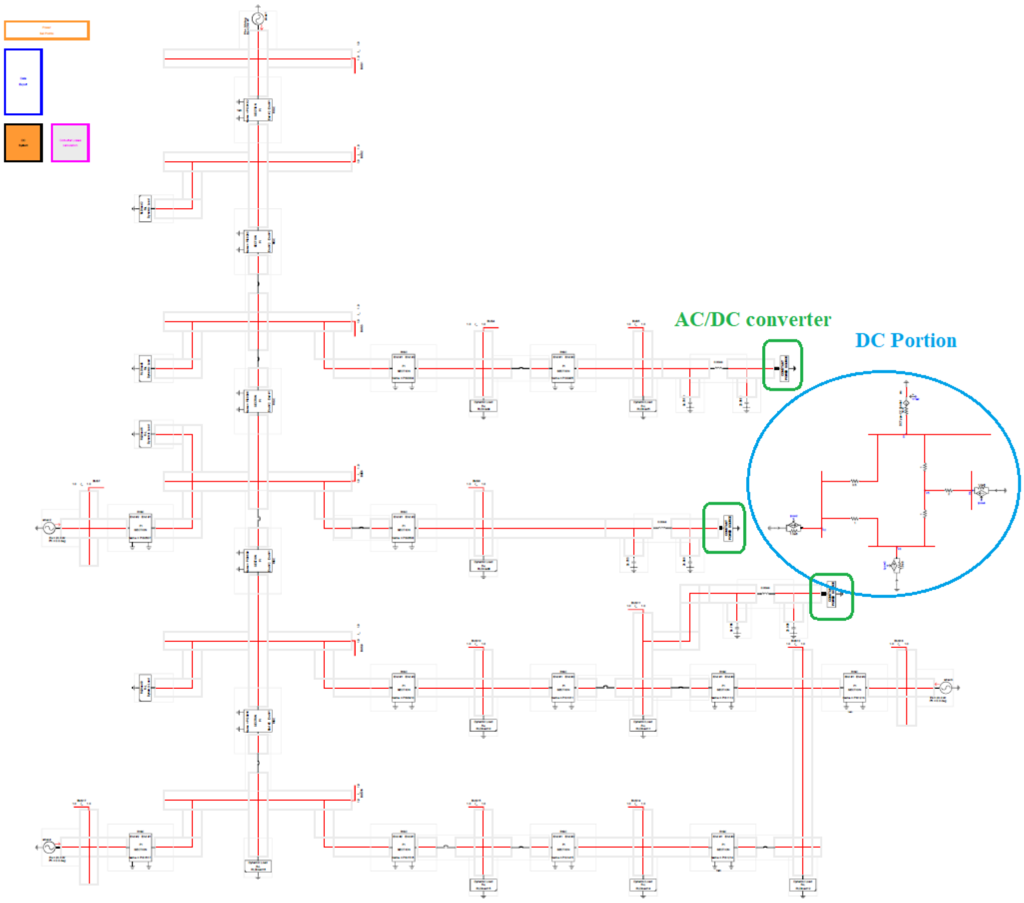


Fig.6 Hybrid AC/DC grid model in RTDS

Since the DC load is modelled using the current generator component, in order to obtain a constant power (given as setpoint), a control block is necessary, as shown in Fig. 7.

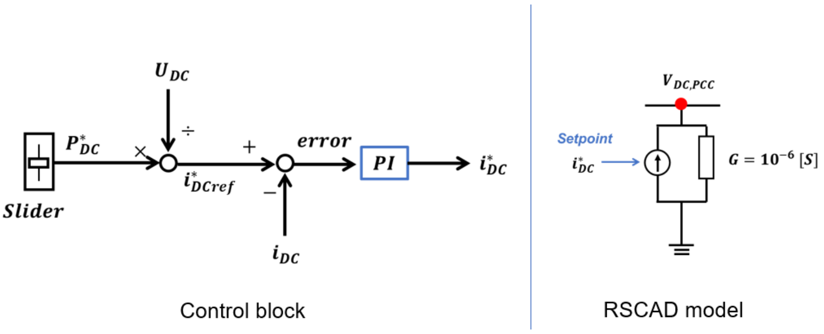


Fig.7 Control Block for the DC load

An important aspect is the system control, necessary to regulate the power flow among the three AC/DC converters and guarantee the stability of the network. In this case, the droop control is applied. In the case of dc voltage droop control, two or more terminals participate in dc voltage control, thereby sharing the duty of instantaneous (primary) power balancing among them. Considering together the errors between the measured and the nominal values, for power and voltage level, a Proportional-Integral (PI) controller allows to obtain the current reference to be used for the energy injection (or absorption, in case of negative value) in the DC grid.

The control block for the current generator, emulating the DC side of the AC/DC converters, is represented in Fig. 8.

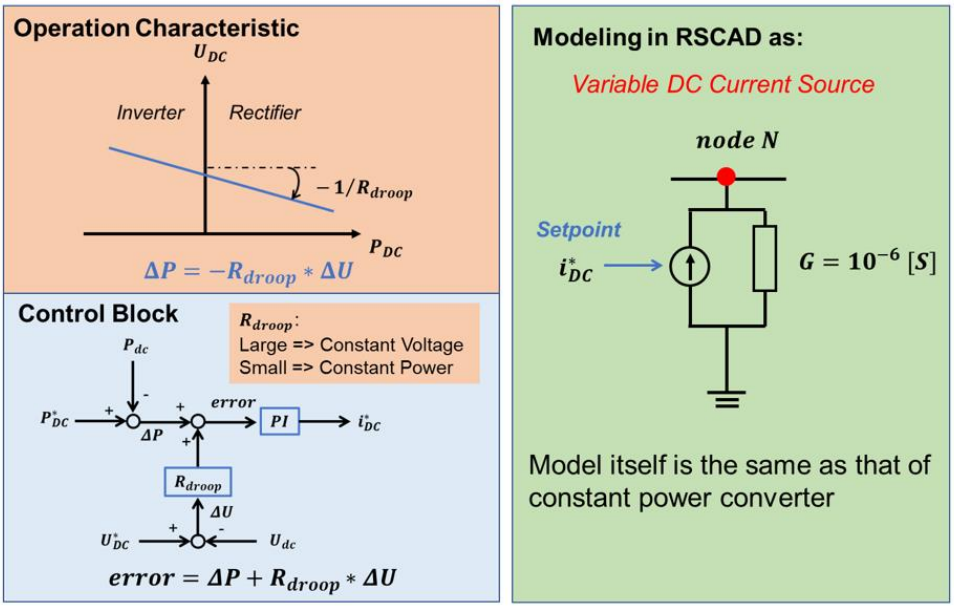


Fig.8 Droop control block for current source

Since RTDS model requires for the DC grid stability a voltage source, one of three converters is modelled with a voltage generator and a specific control block, represented in Fig. 9.

The converter model considers also the power losses modelling, for a real correspondence with the field conditions. In particular, the inner conduction and switching losses are given by the following formula:

$$P_{loss} = a + b * I_c + c * I_c^2$$

In which *a, b* and *c* are factors that considers the different components of the power losses P_{loss} and are related to the converter current I_c. The factor *a* considers the offset of the converter loss and is calculated to reduce the efficiency of converter by 3-5%.

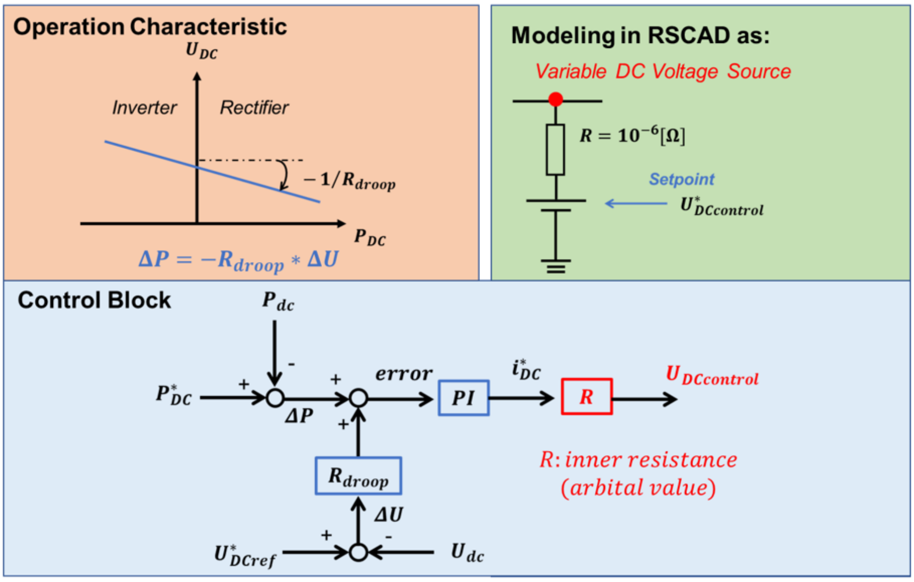


Fig.9 Droop control block for voltage source

Additional losses to be considered are related to the components installed in the field, for the normal operation of the converter; in particular: the filter, the reactor and the transformer (used to regulate the voltage level), as shown in Fig. 10.

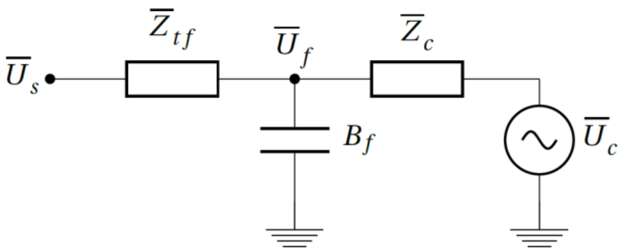


Fig.10 AC/DC converter model

These components are modelled as impedance, whose values are obtained in the literature according to the following table [7]:

Converter parameters	
X_{tr} (p.u.)	0.1121
R_{tr} (p.u.)	0.0015
B_f (p.u.)	0.0887[a]
X_c (p.u.)	0.16428
R_c (p.u.)	0.0001

Using these parameters, the results show a voltage stability of ±2.5% (0.5 kV)

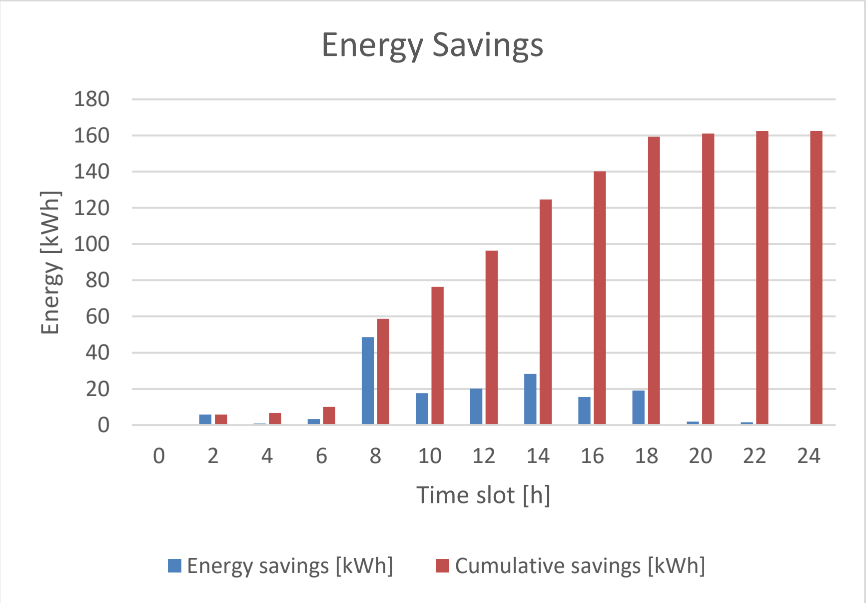
4.2 Network Reconfiguration

The Hybrid AC/DC grid model can be used for multiple use cases and analysis. Similarly to the AC grid, the connection to the FISMEP platform allows the deployment of advanced energy services in the cloud, implemented as middleware software components, for the control of the grid.

The network reconfiguration algorithm is implemented with the hybrid AC/DC grid: it continuously acquires in real time the data from the grid (power consumption/generation at the loads, voltage measurements at the nodes) and calculates the best topology that optimizes the minimum power losses, by operating the switches that are installed along the feeders of the network. Essential requirement is to maintain the radiality of the network: hence open tie units must be present, to avoid the electrically connection between two different substations in the distribution network.

The algorithm is performed once per hour (but different scheduled frequency are possible) and evaluates the variation of the loads consumptions, to determine the best solution in that periods. Multiple analysis have been conducted, considering the repeated variability of the loads during the day (between the day and night the power flows change considerably) and in different seasons of the year, affecting the generation from Distributed Energy Resources (DERs).

Results from the standard scenario regarding the energy savings, obtained by appling the Network Reconfiguration, during the day are reported in Fig. 11.



5 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 progress of activities are presented.

Considering the two aspects of the work package, the development of automation for DC and hybrid AC-DC Medium Voltage grids, the trial test refers to the MVDC research grid of FEN Forschungscampus P4 project and the hybrid AC-DC grid model that is realized in the RWTH laboratory.

The integration with the FISMEP platform is carried out by adopting the appropriate data model and protocols for the integration with the FISMEP platform based on FIWARE components. Data measurements from the field are provided to the platform and constitute the basis for the developed automation architecture.

Energy services as grid restoration after fault (service restoration) and network reconfiguration (to improve the energy distribution in steady state condition) are realized and integrated, providing successful results. IN the future, additional services can be easily implemented in the FISMEP, whose versatile properties constitutes one of the major advantages.

6 References

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