FROM SIMULATION TO REALITY - TESTING TODAY A DECENTRALISED GRID OPERATION OF THE FUTURE

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ABSTRACT

New ideas to operate and optimise the distribution grid of the future are regularly proposed by scientists. These new ideas are required as answer to the massive transformations that are currently happening in the distribution grid. One promising path is to move from the classic central to a more decentralised and distributed control. The work in this paper highlights the main solutions developed to realise a new decentralised grid operation concept that is compatible with a classic operation scheme. The field test was one of the main demonstrators in the EU-funded project DREAM.

INTRODUCTION

Distributed and volatile energy resources like renewable energies have a growing impact on the operations and the protection schemes of the distribution grid. Also a new type of controllable loads, like charging stations for electric vehicles, are getting connected to the power distribution system at an increasing rate, leading to completely new demand patterns. Additionally, the increasing digitalisation is impacting the power system field and must be properly addressed. Therefore, the distribution system operators (DSOs) require new concepts, technologies and smart features for their grid operation. To be able to interact with the enormous number of components that are and will continue to be connected to the distribution grid, the trend goes from using a sole central supervisory control and data acquisition (SCADA) towards a more decentralised control architecture [1], [2]. These functionalities have been developed and tested in simulation [3], [4]. This article describes solutions a consortium of researchers, a manufacturer and a DSO realised to achieve such a decentralised grid operation of the future “smart grid”. This is done using the existing environment, integrating the new infrastructure and running it in parallel to the classic centralised SCADA system. The article is structured as follows: The next section gives an overview about the field test and the architecture of the decentralised grid operation. After that, the realisation of the intelligent components is described. This is followed by an overview over the extended functionalities provided by the new grid operation. The article ends with the lessons learned.

FIELD TEST ENVIRONMENT

The field test took place in the premises of the DSO Électricité de Strasbourg Réseaux. It is the second largest DSO in France, and operates the grid that covers roughly 80 % of the towns and villages of the department Bas-Rhin, including the city of Strasbourg, supplying around 510 000 customers. The area that was chosen for the field test consists of 4 primary substations and 8 feeders from those substations. This part of the grid is partially meshable but operated in a radial way. Each of the primary substations consists of two 63 kV to 20 kV transformers. The grid is equipped with remotely controllable switches (RCS), named “IPT” for the French name of it. In contrast to manual switches, only RCSs are of importance for the automated grid operation, as only those can be operated via a control signal. They are normally installed in combination with a remote terminal unit (RTU). A RTU is an electronic device containing a processor unit that builds the interface between sensors and actuators and a control system (typically the SCADA). For this purpose RTUs can communicate with the control system to send and receive data. The field test included also two remotely operable customers, also called prosumers. Prosumers provide flexibility to the DSO and allow the optimisation of the grid operation. Here, one was a controllable generator, in the form of a PV system. The second was a group of two charging stations for electric vehicles as controllable loads; both of them connected to one of the feeders of one of the primary substations.

Architecture of the Grid Operation

The architecture of the grid operation follows closely the physical devices present in the grid, see Figure 1. The main players were the substation DSOs, responsible for the grid operation in the whole grid area supplied by the corresponding primary substations. Additionally 5 of the existing standard RTUs were replaced by advanced RTUs, prototypes of the new Easergy T300 of Schneider Electric. They provide the possibility to host additional software and together with a measurement infrastructure, they provide an increased monitoring of the grid.
For the two prosumers, two actors were developed, one
for the PV system (PV prosumer) and one for the
charging stations (charging station prosumer).
An aggregator builds the interface between the
prosumers and the substation DSOs.
Furthermore, to allow the supervision of the testing
process a user interface called DREAM Interface was set
up. The communication between the actors was realised
with the “extensible messaging and presence protocol”
(XMPP). XMPP is an open protocol acknowledged to be
very suitable for machine-to-machine-communication
and especially considered together with IEC 61850 for
power utility automation [5]. One of the main drawbacks
is that XMPP requires a central communication server.
To also decentralise the communication as much as
possible, local XMPP servers for each of the substations
were used. This means, most of the actors were
connected to two communication servers, which are
represented in Figure 1 above, by the dotted purple and
dashed violet lines, corresponding to the two
communication pathways. The specific development of
these actors is described in the following section.

INTELLIGENT COMPONENTS

The main task of the field test itself was to combine the
existing centralised environment of the SCADA with the
decentralised new infrastructure of the new grid
operation. This required sometimes trade-offs with
regards to the strict decentralised structure. Main
guideline for design decisions was to preserve the
distributed way in which decisions are taken, also if this
sometimes required central communication paths.

Graphic User Interface (GUI)

An important feature for the testing was a suitable
interface that allowed the proper monitoring and control
of the tests. This was hosted as the main feature within
the DREAM Interface. During the test period, this
interface was running in parallel to the classic SCADA
system in the dispatching centre, see Figure 2.

The main features of this GUI are:

**Visualisation of measurements and grid status:** All
available measurements as well as switch positions are
displayed and periodically updated.

**Management of running actors:** The code for all actors
was started in their particular virtual machine or on their
particular device. This made them run in “standby” mode.
They then could be activated for the grid operation
directly from the GUI.

**Validation and display of possible solutions:** After an
optimisation, the solution, providing new set points, is
not automatically implemented to the prosumers, but is
displayed in a dedicated area within the GUI. The user
can then validate or not this suggested solution. For the
reconfiguration this output is the only official solution in
the field test, as a direct interaction with the RCS is too
risky especially for the first runs. The solution (that
means a suggestion of which switches to open and which
ones to close) can then be followed by the operator, see
Figure 8 at the end of document.

**Log of actions:** To keep track of the actors’ behaviour,
they inform the interface about all the actions they take.
These logs are collected and displayed for verification
and future analyses.

**Advanced Remote Terminal Units**

State-of-the-art RTUs can process measurements of the
grid state available through connected sensors. They also
“know” about the state of e.g. switches and fault passage
indicators (FPI) and can command them. This information is stored in the local data base of the RTU, here called “coreDB”. The RTU can transmit these measurements or receive control signals, e.g. for open / close commands via communication protocols like IEC 104 or HNZ, the conventional French protocol for electric distribution SCADA. On the advanced RTUs an additional layer hosting the Java virtual machine has been integrated, see Figure 3.

Controller-in-the-loop tests
RTUs installed in the power system constitute key devices from a functional point of view. Therefore, the installation of the Java layer on the RTUs in the field was preceded and accompanied by extensive tests in a laboratory environment. Thus, several advanced RTUs were connected with a lab server. This lab server allowed the loading of Java code into the RTUs and the supervision of the RTU behaviour during the execution of the code. Additionally, all types of measurements and switch states could be written into the coreDB of the RTUs, pretending to be the actual environment of the RTU. This allowed the realistic validation of the new functions under all sorts of different grid states.

Field tests
The RTUs installed in the field were used to read from coreDB, firstly to take measurements (voltage and current) via sensors installed specifically for this purpose and to get the status of switches and FPIs. This information can be treated, analysed and provided to other actors like the substation DSO.

Substation DSO
From a functionality standpoint, the substation DSO is the main player in the particular grid area of the primary substation. It is running quite complex algorithms required for the extended functionalities proposed by the grid operation like load flow calculations and optimisations. These core functionalities stayed the same and could be extensively tested in simulation before introducing them into a field test environment. However, methods like the collection of measurements, required to be developed specifically in correspondence with the field conditions. To systemise the required software development, an abstract super class containing the core functionalities was developed, that was implemented either for the simulation or for the field test.

In a perfect decentralised grid operation, the device running the code for the substation DSO would be placed directly at the premises of the primary substation, or at least have direct access (via remote communication or locally) to the measurements and control parameters available at the substation equipment. But in the environment where the field test had to take place the sealed SCADA system made it impossible to access the measurements directly at the primary substation, at least without tremendous investment in new material. With modern IT-components they were only accessible from the SCADA databases. The following structure was therefore developed, trying to keep the highest level of decentralised decision, although relying on a central server for the provision of the measurements due to field technological constraints. For each of the primary substations a workstation computer was set up. On this workstation the substation DSO runs in a particular virtual machine. The measurements of the primary substation provided to the data base of the SCADA were transferred to a web service. From this web service the substation DSO could fetch the dedicated measurements and status information, see Figure 4 for a schematic visualisation.

PV prosumer
The PV installation chosen for the PV prosumer consisted of a 224 kW installation on an agricultural building. This
installation consisted of 19 inverters manufactured by Fronius. The PV system had its own secondary substation that connected it directly to the medium voltage grid. The monitoring and control of this installation from the PV prosumer was realised by an intermediate https-web-service developed in cooperation with REQUEA\(^1\). This web-service translated the requests coming from the PV prosumer into something the inverters could handle. This information was received by a local PC installed on the premises of the PV installation. This computer could communicate with the inverters via Modbus. Measurements from the PV installation took the same way back at the PV prosumer, see Figure 5.

![Figure 5 Interaction between the PV prosumer and the PV installation via an intermediate web-service](image)

The flexibility this prosumer was able to offer to the DSO for the optimised operation of the grid was limited to the reactive power provision for the field test.

### Charging Stations for Electric Vehicles

Two fast charging stations manufactured by Hager were installed in the same village as the PV-system at the premises of a secondary substation. Each of the charging stations contained two charging points with maximal 22 kW power per plugged car. For the tests up to four Renault Zoe were connected to the charging stations, see Figure 6, for a maximum charging power of 88 kW.

![Figure 6 Charging stations with four charging cars, Source: M. Gabel, ESR](image)

These charging stations were used as flexible loads. Together with Hager and the company Freshmile\(^2\) the possibility to modulate the charging power between a maximal and minimal power was developed. The first step to allow this power modulation was the development of a customised firmware based on the field test requirements for the charging stations that was achieved by Hager. Based on this and by using the Open Charge Point Protocol, Freshmile set up a web service that built the interface between the charging station prosumer and the physical device.

### EXTENDED FUNCTIONALITIES

The components described in the section before are the components required to realise the new and extended functionalities of the grid operation. Their core ideas and how they were realised is described in the following sections.

#### Analysis and Classification of Grid State

In the future an increasing amount of measurement data will be available from the distribution grid. Inspired by the power system traffic light concept proposed in [6] these measurements are automatically analysed and classified. For the operator at the dispatching centre this results in a coloured scheme, showing at a glance the state of the grid. For the automatic grid operation, this defines the behaviour and admissible methods, especially with regard to the interactions of market and grid driven operation, as described in [3].

#### Optimisation of the Grid Operation

The real-time optimisation of the grid state is an important functionality for the distribution grid in the future, where grid reinforcements are not done to cover all possible loading situations and where distribution grids have an increased responsibility for e.g. voltage stability. This can result in situations where the production of generators or the consumption of loads must be reduced.

The challenge for the field test was that the considered grid area did not actually have any problems with regard to voltage and load profiles. Nevertheless to test the optimisation, the admissible margins of voltage profile violations and admissible operating threshold of lines were considerably reduced. Figure 7 shows the effect an optimisation can have on the charging stations in situations where the line loading is too high and the grid optimisation reduces the charging power. The optimisation itself is performed according to [4].

![Figure 7 Optimisation results in the reduction of the charging power of the electric vehicles](image)

#### Reconfiguration for Self-Healing after Fault

The automatic reconfiguration as a response to a permanent fault is an important feature for the grid automation. As in a radial distribution grid, in the case of a fault the tripping circuit breaker leaves the whole feeder...

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\(^1\) [www.requea.com](http://www.requea.com)

\(^2\) [www.freshmile.com](http://www.freshmile.com)
unsupplied, reconfiguration is a method to resupply clients. Thus, it increases the service quality for the clients and decreases the System Average Interruption Duration Index (SAIDI) for the DSO.

The testing of the reconfiguration following a permanent fault in the network was subject to several restrictions. Failures that are followed by a service interruption for clients must not be created voluntarily and cannot be performed for testing purposes. So another way was chosen: to have a higher probability for a permanent fault in the grid area of the field test, the system supervised it for several months, ready to trigger at the occurrence of a fault. Unluckily for the tests, there was no permanent fault during this time. Nevertheless, to test the approach in the field, the signals that would normally be generated by a true in-the-field fault were manually injected into the grid operation. This was done in two ways.

The first and simpler way was to disconnect the web service that provided the interface between the SCADA and the grid operation from the automatic updates that represent the “real” grid state. Then the data base was modified so that it would represent a fault at a certain position. The second, a more complex and exhaustive way, was done by using the testing equipment that is normally used when installing new devices in the grid and to test their communication capabilities with the dispatching centre. The signals were created locally, at the affected substation (by “overwriting” the signals send to the dispatching centre) and at the FPIs (they have a “test” button where they can be activated manually). This required two technicians locally at the primary and secondary substations, one injecting the signal causing the circuit breaker operation, the other activating the FPIs.

The result of the reconfiguration is a new configuration of the grid that isolates the faulty section and resupplies as many healthy sections as possible. This is done by activating the remotely controllable switches. Naturally this switch activation is not allowed for the grid operation from the first test on. The result in this case is a text output that describes to the operator at the dispatching centre what to do (which switches to open and which ones to close). This test is displayed in the output field of the GUI, as can be seen in Figure 8.

![Figure 8 Text output of the reconfiguration](image)

That the operation of the switches via the advanced RTUs could be possible was shown separately as can be found in Section describing the advanced RTU.

LESSONS LEARNED

The control centre was operating the classic SCADA system for its normal operations, while the project team was testing and adding the new functionalities, with the intent to make the two systems to work in parallel. This configuration required creative and unconventional solutions to be implemented. Indeed this could be the starting point for most of the equipment renewals for DSOs, as it is unrealistic for them to replace all of their aging equipment in a short timeframe. Consequently it is critical to be able to maintain the aging and newer infrastructure in perfect and parallel working conditions. We believe some important experiences could be gained on this field.

Even though the new optimisation could not fully be exploited mainly due to the good grid conditions, the benefits in terms of improved and easier monitoring of the MV grid were appreciated by the dispatch centre. The self-healing features are also considered to be very helpful. Further analyses are currently being performed to consider the progressive expansion of these features over the entire DSO grid territory.

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