Test and evaluate an automated low voltage grid management system through utilization of CLS-Gateways to control a decentralized energy resource

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Abstract: The implementation of a Smart Metering Infrastructure (SMI) in Germany offers the opportunity to gather grid measurements in the low voltage grid and enable small scale systems like Photovoltaic- (PV-) systems for grid friendly control. The practical control of Decentralized Energy Resources (DER) can be realized via the CLS (Controllable-Local-System)-Gateway, which is implemented as a complementary device to Smart Meters Gateway. Advanced grid management systems can use the CLS-Gateways for low voltage grid optimization to prevent grid asset overloading and voltage band violation. This contribution presents the results from laboratory testing utilizing the Software-/Controller-in-the-Loop methodology.

Keywords: Distribution Networks, Renewable Energy Systems, Smart Grid, Tele-control, Controllable Local System, IEC 61850, Validation, Software-in-the-Loop Testing, OPC UA

1. INTRODUCTION

Due to the ongoing energy transition, a significant increase of distributed energy resource (DER) based on renewable generation as well as controllable loads can be observed in the German energy legislation and grid planning scenarios (Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit [BMU], 2016) , (50Hertz Transmission GmbH - Amprion GmbH - TenneT TSO GmbH - TransnetBW GmbH, 2019), (Deutsche Energie-Agentur GmbH [dena], 2012). Therefore, distribution system operators (DSOs) are confronted with new challenges, particularly concerning the planning and operation of the electrical low voltage grid. Because of the rapid increase of DER, it is necessary to obtain measurements and eventually tele-control the involved systems in order to avoid overloading of grid assets and operate the grid for meeting the technical and legal requirements. What is a common operation concept for (extra-) high voltage grids today will be implemented in distribution grids in the future.

Moreover, the German government has adopted the "Act on digitalization of the energy transition" which describes the transformation of energy metering through the deployment of smart meters for specific consumer and prosumer systems (Bogensperger et al., 2018). This provides a solid basis for a digitalized energy infrastructure, whereas the investigation and testing of bidirectional communication as well as various smart grid control strategies must be further studied. In this context, the implementation of a CLS-Gateway into the SMI is being explored by different research projects for the purpose of realizing direct communication and tele-control of DER. The goal is to enable a reliable, cost efficient and secure access to small scale DER for different stakeholders and participants.

Thoroughly testing and evaluation of such a smart grid control system is relevant for the entire system architecture. This includes small applications like volt/var-functions of PV-inverters for the voltage band management as well as large scale applications such as the coordinated reduction of generation of reactive power (Wang et al., 2017) or, respectively, load due to a global/national/transmission grid over- or under-frequency problem (Wellssow et al., 2018 - 2018). A common methodology used in this context is Hardware-in-the-Loop (HIL) testing.

This contribution describes the implementation of a Software-in-the-Loop (SIL)-based test environment, which enables the investigation of the capability and respectively, the suitability of a grid management system utilizing automated grid operation processes. The introduced grid automation processes aim at facilitating DSO support functions in order to realize a basic smart grid control strategy for low voltage grids containing a high amount of DERs. In this dynamic environment, a fast, reliable and appropriate response to different events, which are difficult to predict, is crucial for efficient grid operation. Targeted operation processes are firstly the automated prevention of grid asset overload, through the integration of a cyclic state estimation, and secondly the automated handling of action requests from an overlaid system operator. Another aspect of the introduced setup is the communication to DERs through CLS-Gateway via the IEC 61850 standard protocol. It describes a commonly used protocol for substation automation, which not only defines different ways to transmit data but also provides a huge repository for structured data models of equipment of the energy domain. Hence, the IEC 61850 standard is applied to this setup on account of its comprehensive range of data models for power systems.

Fig. 1 presents the system architecture for smart grid communication proposed in the research project C/sells for the example of an automated low voltage grid control. Besides existing smart grid components (supervisory control and data acquisition (SCADA) system and PV-inverters), two new hardware components - Smart Meter Gateway (SMGW) and CLS-Gateway (administrated by SMGW-Admin and CLS-Management, respectively) - are developed and applied to the data acquisition and control execution for DER devices. Via the bidirectional communication channel, initialized by SMGW, grid measurements and control commands, are transmitted, secured and encrypted between the DER devices and the SCADA system(Heilscher et al., 2018).

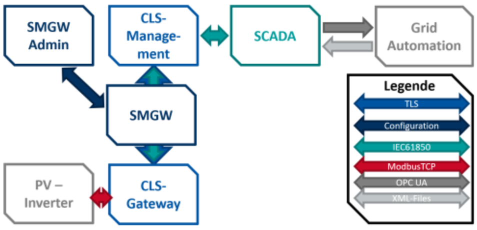

Fig. 1: System design of the automated low voltage grid control system.

The collected grid measurements can be forwarded further to the grid automation module. There the grid topology is reflected and state estimation runs periodically based on power flow calculations. Corresponding to different estimated grid states, necessary control instructions are generated and transmitted as set points backwards to the DER devices. These actions shall ensure that the grid state remains stable considering its operational limits. For distribution grids these limits are primarily the operation within the voltage band defined by the EN50160 as well as below the rated power the grid assets. To realize these actions, available options are limited to adaption of active or reactive power of the connected load or generation units.

This paper is organized into four sections including this introduction. In section 2, the used setup and the test methodology are presented. Results for the tests can be found in section 3. The contribution ends with its conclusion and outlook in section 4.

2. METHODOLOGY

2.1 Systems used in the evaluation

For the examinations presented in this contribution, the implemented algorithms are applied to commonly used systems in the energy industry. The System under Test (SuT) is the combination of utility grade SCADA and an additionally implemented grid automation algorithm (GAA). The tested system is operated at the University of Applied Sciences in Ulm as the Experimental Distribution Control Center (EDCC) (Ebe et al., 2018). **Fehler! Verweisquelle konnte nicht gefunden werden.** shows the architecture of the implemented SuT including its communication paths. The DERs are connected to the SCADA system via IEC 61850 Server-Client-MMS communication compliant to the standard IEC 61850-8-1 (IEC, 2011). The implementation of the GAA in form of a python script is based on the capabilities provided by the Power System Analysis Framework (PSAF) PowerFactory 2019 of DIgSILENT, including load flow calculation, state estimation and python interface for data transmission. The used data models are utilised also setup the IEC 61850 inverter models (International Electrotechnical Commission [IEC], 2009). In contrast to many other conventional protocols utilized in grid operation, IEC 61850 data models are self-described and thus have an object-oriented hierarchical structure, which can be easily integrated in grid automation processes.

The authors used the Open Platform Communications Unified Architecture (OPC UA) protocol to collect and forward the measurements from the SCADA system to GAA. OPC is an open and cross-platform machine-to-machine communication protocol, which originated from the industrial automation sector. The latest iteration of this protocol is Unified Architecture (UA), (Lehnhoff, Rohjans, Uslar, & Mahnke, 2012 - 2012). In the current implementation of IEC 61850 communication used in this contribution, the selected parameters are limited to phase-to-phase voltage at Point of Common Coupling (PCC) as well as active and reactive power. The GAA transmits its determined control action to a shared directory of the SCADA system in the form of an XML-file, which specifies the target DER and the controlled parameter by referring to the same data object by Global Unique Identifier (GUID) as assigned in SCADA data base. This shared directory is under constant monitoring by the SCADA system to fetch newly transferred XML-instructions. If the (execution) time constraint of a file is reached, the new set point is transferred to the respective DER via the IEC 61850 connection.

The implemented and tested GAA is based on an iterative process to reduce asset overloading and voltage band violations. A reduced sequence diagram of the GAA workflow and the adjacent system is shown in Fig. 2. The algorithm starts with acquiring measurement data from the SCADA system via the OPC UA connection, the measurements are then assigned to the measurement device model in PSAF. In step two, the standard state estimation module of PSAF is activated to calculate power flow regarding the examined grid area and check for grid problems such as voltage band violations and asset over loading likewise. These violations are denominated as off-limit conditions. In case a threshold is reached, a suitable counter measure is determined by iteratively altering the active power limitation of the modelled DER in the affected feeder. For each alteration, a load flow calculation is carried out in the simulation and the determined measure is subsequently evaluated. If the executed measure can successfully regulate the voltages at the PCC and keep the asset loading below the threshold, new set point will be transmitted to the SCADA system. Otherwise, the algorithm examines the remaining DERs in an iterative manner. The further optimization of the algorithm will be considered in future contributions, but it is not the focus of this contribution. The GAA transmits the counter measure in individual files one for each change of a set point of a DER. The information is contained in an XML files and references the control variable of the SCADA system via a GUID along with the reference a start and end date as well as the new set point. For the further development, such as the integration of redispatch of medium DER, a label for the invoking process is added.

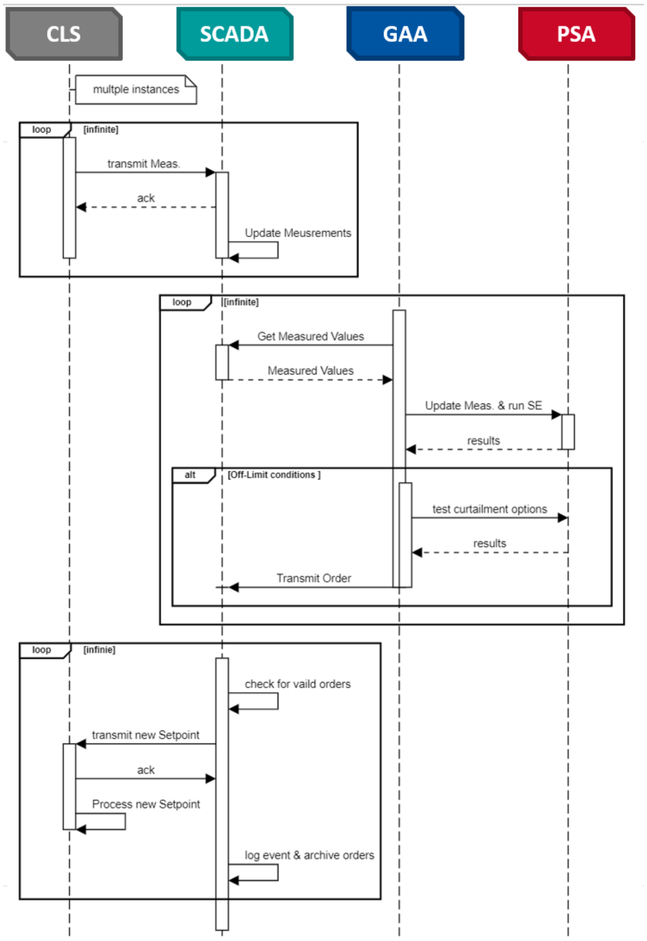

Fig. 2: Sequence diagram of the implemented Grid Automation Algorithm with the following abbreviations Meas. (Measurement), ack (acknowledge), SE (state estimation)

The main part of the transmission process is implemented on the SCADA system as a continuous loop which check for transmitted files, checks if the order is due to execution, write the set point to the control variable which is then transmitted to the individual CLS instance via IEC 61850. As a last step of this process the events are then logged to the journal and the file is archived.

2.2 Testing Methodology

A two-stage approach is used to test the implemented system. The first stage uses a setup, which utilizes the Software-in-the-Loop (SIL) methodology. In the second stage, the implemented system will be demonstrated by a field trial. The SIL setup is depicted in Fig. 3, it consists of the previously described SuT as well as the simulation system. The interface between simulation system und SUT is the IEC 61850 based communication. A set of test scenarios is modelled in the PSAF. The framework calculates relevant grid parameters for each simulation time step. These parameters are collected by the IEC 61850 server of the SIL setup and are then transmitted to the communication front end of the SCADA system. The other way round, the SCADA system can write the active power set points to the modelled PV System via the IEC 61850 communication. These control actions interfere with the upper active power limit of the models to represent the proposed German regulation for the curtailment of decentralized PV systems.

In the field trial stage, the communication path will be rerouted and the SuT is connected to physical DER in field via remote connection, where a SMI infrastructure is used in accordance to German regulation. A comparison of used setups for the two test stages is shown in Fig. 4. Obviously, the SuT remains the same in both test stages, which means the communication between SCADA and GAA will not be affected severely by the different network conditions in field.

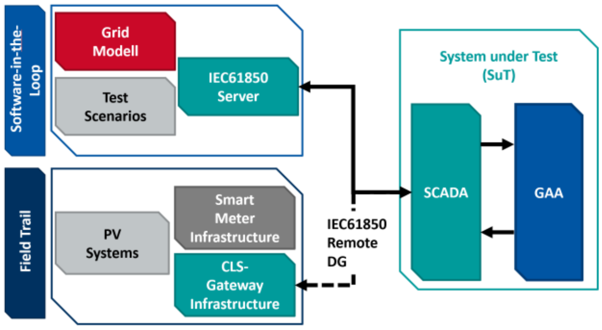

Fig. 3: Comparison of the Software-in-the-Loop setup and the field-trial setup for the system testing

3. RESULTS

The results of the carried-out experiment for the validation of functionally are shown in figure 4. Limitations of this tests are the use of clear sky conditions, the use of a speed up test with a factor of 1:20 as well as the optimal prediction for the loads within the state estimator part of the system. This test case evaluates the correct connection of the individual parts of the system. The graph shows the measurements as well as the controlled set point (curtailment) for a fleet of DERs. The GAA was parametrized to limit the line loading to 90 % and the voltage to 1.05 p.u.. This results in a gradual limitation of infeed in the morning respectively a rise in the afternoon. Due to the accelerated test the transition of the new set points to the emulated DERs is not completed until the next iteration of the state estimation. This can be seen by the difference between the mean and the minimal value of the active power limit.

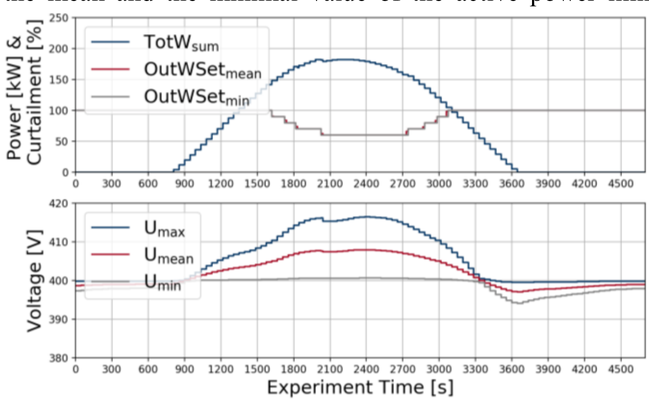

Fig. 5: Results for the fleet of examined DER system. Power curtailment at clear sky day with at accelerated simulation time. TotW (IEC 61850 abr. for total active power) & OutWSet (IEC 61850 abr. active power limitation of inverters)

4. CONCLUSIONS & OUTLOOK

This contribution presents a concept for Software-in-the-Loop setup and subsequent field trial for evaluating a tertiary control mechanise implemented in utility grade SCADA systems. To sum up this contribution it can be stated that the implemented control algorithm passes the information through the different instances of the system.

The presented results cover a portion of the necessary tests for a robust evaluation. Hence the next steps are the further testing of the system in the laboratory environment and the setup of system in a field trail with a limited number of real customers as described in section 2.2. Further improvements in the algorithm will be added till the start of the field trail phase.

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