OPERATION OF EXTENSIVE GRID AUTOMATION: CHALLENGES ON THE EXAMPLE OF VOLTAGE CONTROL

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ABSTRACT

Ongoing grid integration of flexible and decentralized generation and load produces various challenges, such as problems concerning the allowed voltage bandwidth. [1] Grid automation functions are developed to handle these challenges using intelligent methods. These functions can be realized centrally, locally or distributed. To operate the resulting multitude of different solutions, it is necessary to document these including the corresponding requirements and dependencies. Using the example of the wide area voltage control (WAVC), existing description options are explained and their deficits are named. In order to avoid additional expenses due to a lack of documentation, a uniform format and procedure for documentation is proposed.

INTRODUCTION

Driven by the energy transition in Germany and increasing use of IT-based operator support and automation (digitization) the grid operation is changing. An example for this change is the additional effort for voltage regulation. System operators are obliged to operate the grids with a voltage within a permitted band. Due to the significant increase in decentralized generation and changed consumer behaviour, especially in the distribution grids, there are new demands for voltage regulation. The specification of one or more fixed set-points is no longer possible. This is why automation and control technology are increasingly used for this specific purpose and also in general grid operation.

Therefore, more and more different new solutions are developed to solve the various challenges. Most of them are individual solutions. These solutions usually work only for a specific problem, e.g. voltage regulation or bottleneck elimination, and only in certain grid areas with, for example a lot of PV feed-in, Wind feed-in or urban regions. [2] These individual solutions optimally work in the designated areas. In the contrary general solutions cannot be optimally adapted. This is due to the fact that each solution is based on simplified models of the real grid, in which the physical relationships cannot be fully taken into account.

However, a new solution should not be developed for every new problem. Therefore, it is necessary that the existing solutions can be tested quickly and easily adapted for broader usability. Also the comparability between solutions should be possible.

This paper focuses on reviewing description options for automation solutions and evaluating their applicability. In particular, in the valuation the effort involved in producing the documentation, the planning and operating effort with the description and the comparability are taken into account.

The validation is based on the wide range voltage control (WAVC). This is briefly explained below in order to clarify the documentation requirements.

<u>Example : Wide Area Voltage Control</u>

The WAVC uses a decentralized control algorithm in order to implement a flexible adaptation of the voltage set point. The algorithm considers different measuring points in the connected grid branches. Changes in grid topology and thus in the supplied branches must be taken into account. The existing voltage regulation of the transformer is integrated in this control loop. This means that two different control systems (WAVC and traditional voltage regulation) and two controlled components (transformer and connected grid circuits) are interacting with each other (see Figure 1). This is referred to 'cascade control' in control engineering. [3]

In order to realize a flexible adaptation of the set point of the voltage regulator at the substation, the voltages at the most critical points of the grid must be known. For this reason measuring points in the supplied grid circuits are used. In the decentralized variant, therefore, it must first be checked on the basis of the measured values whether the grid section is still supplied via the controlled transformer or whether there was a network switchover. It is assumed that the measured voltage at the local grid feeders increases in the feed-in case.

According to the explanation of the WAVC it becomes clear, that for the operation of grid automation functions different aspects like control engineering characteristics must be considered and documented. In the example, this is especially the dependence between the WAVC and the existing voltage controller of the transformer. Therefore, it is necessary to make a complete and holistic description of the grid automation and used sub functions. This must be as simple as possible in order to be able to operate a variety of different functions easier.

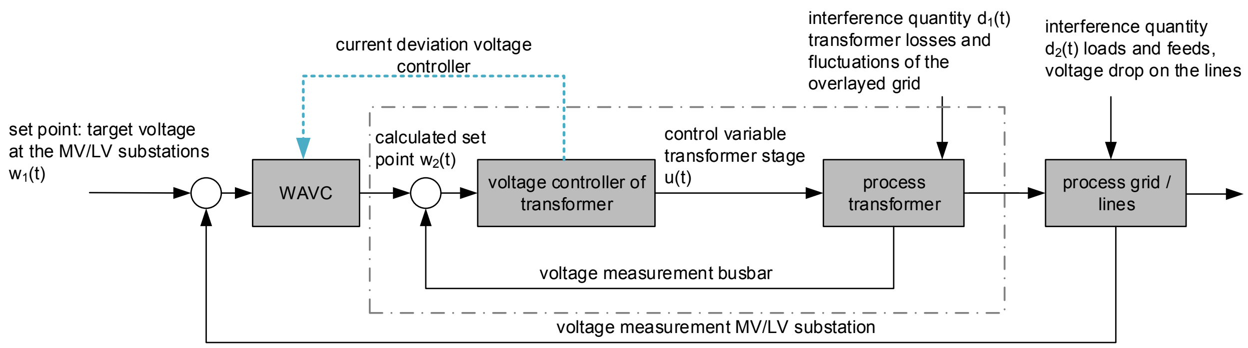

Figure 1: block diagram of wide area voltage control

In the evaluation of the different documentation variants in Chapter 3, it is considered which of the aspects below can be documented;

- (partial) functions, objectives and limits of grid automation
- control parameters such as running times, disturbance variables, controlled systems and dynamic behaviour
- external input parameters such as tap changer stage and warnings
- static parameters such as set points and permissible deviations
- considered measured values
- error behaviour e.g. resulting from missing values

STATE OF THE ART

Currently, there are different standards and frameworks applicable for the documentation of grid automation in parts is possible. In the following, these options are presented with reference to the description of operation-relevant or planning-relevant information of grid automation.

System Description and Operating Concept

The system description documents the system in detail and the boundaries are named. It does not contain any information about the specific use case and operational use. The operating concept does not contain all technical system details. It contains information on general operation.

If these documents are regarded purely as written works, i.e. without the use of other forms of description such as use cases or SGAM, a comprehensive description is usual. Depending on the complexity of the grid automation function, this can also cover a large number of pages (often up to 100 pages).

Furthermore, there are no uniform specifications for these descriptions, so content and presentation can be very different.

For that reason, it is very time consuming to get an overview of the grid automation function based on these documents.

SGAM and Use Cases

A shorter uniform concept for the description of the energy and information systems is the smart grid architecture model (SGAM). The aim of the SGAM is to create interoperability between different systems and levels of observation in the energy industry. [4]

The main objective of the SGAM is to represent a use case across the different layers of the model. By means of different layers, in addition to the components and communications, further specifications and functional descriptions are carried out.

The SGAM divides each layer into domains and zones. The zones are defined from the process to the market (Figure 2). [5]

It is intended to create a framework for the documentation of functional requirements, ICT architectures and used standards. In addition, the framework can be used to identify the actors in the system and describe their goals. [6]

The SGAM is based on a use case description according to IEC 62559. The use case template is used to record and describe the use cases. This is to allow the completeness, quality assurance and the comparability and connection to other systems. However, neither the graphical SGAM framework nor the underlying use case template provides the level of detail with which is needed to describe the systems. The quality and level of detail of the description is therefore not unequivocal and therefore usually not comparable. Examples of the application and the possible level of detail are shown in [7] and [8].

Common Information Model

The common information model (CIM) and the specification common grid model exchange specification (CGMES) are described in the IEC 61970, IEC 61968 and IEC 62325.

The aim of these standards is the description of technical capabilities in distribution grid management, especially with regard to the interface architecture. The standard provides a description of the semantics of system interfaces and syntax. The data exchange can also be specified.

The CGMES was originally defined for grid management systems. Latest extensions make it possible to use it for distribution grids and markets, too. The description uses classes that are based on real objects.
Figure 2 shows the description area covered by CIM or CGMES. It can be seen that grid functions that also act in the field of substations and device level cannot be fully described.

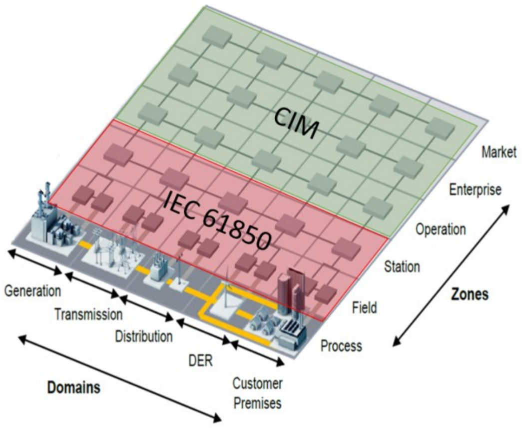

Figure 2: classification of the description area from IEC 61850 and CIM in SGAM [9]

The IEC 61850

IEC 61850 describes separately different communication protocols and the data modelling. As a result of this separation, the data model can also be used to document objects that do not or do not communicate exclusively using IEC 61850. The standard focuses on the description of elements at the process, field and station levels, as illustrated in Figure 2 by the SGAM layer classification.

Within IEC 61850-7-4 different logical nodes are defined. For each logical node it is defined, which attributes, status information, measured values, settings, control blocks and services are to be processed. A detailing of how the records, control blocks and services are defined is made in the -7-2. These logical nodes describe components and capabilities in detail.
Due to the lack of description options at the operation level, no general functions can be modelled and detailed.

Control Engineering Methods

Within control engineering, a modelling is carried out before the detailed description and development of the control. The first step is to determine which target the model should pursue. It is clarified what should happen and how exactly this goal should be achieved. Subsequently, model assumptions are defined, which describe under which boundary conditions the model is valid. Among other things, interactions with other systems and subsystems that are considered or not fully considered are named. This is followed by a verbal description of how and on what basis the control should work.

Based on these three steps, the block diagram is created. Subsystems, disturbance variables and other known elements and divisions are graphically displayed and linked in this. In the next step, the model equations for each subsystem are then set up. These equations describe the behaviour of input and output variables and take into account physical laws.
All information required for the function is described here. However, the modelling for use in different grid areas is quite complex. In addition, only few pieces of information about the actual use in grid operation are documented.

DOCUMENTATION OF WAVC

The WAVC described in the introduction is now used to check whether the properties of the function can be documented with the presented formats. The evaluation is shown in Table 1. It is distinguished whether the characteristics completely, only partly or not at all can be documented. In the category not complete there are either no uniform specifications or complete documentation is not possible.

Table 1: properties of documentation

y = yes nc = not complete / = no	System description	SGAM & Use-Cas	CIM	IEC 61850	control enginer.
function, objectives, limits	y	y	y	nc	nc
control parameters	y	nc	/	/	y
external input parameters	y	nc	/	/	y
static parameters	y	nc	/	/	y
measured values	y	y	/	y	y
error behaviour	y	nc	nc	nc	nc

All necessary information can be described within the system description and the operating concept. But this is not practical because the effort for creating and working with the document is too high.

In the context of a research project the WAVC was described with the SGAM. [10] It is clear that a quick and easy overview is given but no technical details and not all boundary conditions are documented. Within the framework of the SGAM and the Use Case template there are documentation possibilities and expectations regarding the function, objectives, limits and measured values taken into account. In particular, the SGAM cannot document control-related details and dependencies that originate from the physical grid. [7] [8] [11] Information about a controller's parameters therefore are not available in a uniform form or are not fully documented.

The classification of the properties of CIM and IEC 61850 is given by the standards. Figure 2 shows that none of these variants can describe a complete automation function.

The control description does not include extensive explanations. The function, objectives and limits as well as the error states can be read from the description conditionally. A textual description would be helpful.
This description does not describe the actual use in grid operation.

PROPOSED ADAPTED DOCUMENTATION

The SGAM was developed primarily for business consideration. As a basis for the future technical description of grid automation functions, the SGAM should be adapted, extended and detailed. For instance, the domains in the SGAM should be adapted. DER, for example, are also generation. To ensure the technical comparability a level of detail for the description should be established.

In particular, the SGAM and use case presentation should be extended with a control engineering description. The modelling, the block diagram and also the control parameters should be taken into account. In addition, interference variables and influence variables should be named in order to be able to recognize effects on or through other functions. It should be noted, however, that even more complex regulatory structures must be documented. This need is explained in more detail below.

Distributed energy resources (DER), for example, usually support voltage regulation with methods such as Q/U-control or cos(φ)- control. This is illustrated using different examples in [3], [12] and [13]. Therefore, the extended framework should allow a quick and detailed comparison of the various function for the application purpose.

In distribution grids, not only controls for the same objective, e.g. voltage control, are used. Rather than that, a multitude of objectives will be pursued and optimized, including power losses and the reactive power balance. This situation can also be described by a more complex control structure, such as the multi-objective control. [14] In this structure, it is possible that a controller may consider more than one objective or more than one controller with different objectives control the same technical unit. As an example, the first action objective is the concern of the unit operator and the second one is the concern of the aggregator or grid operator. [15] The same structure applies to compliance with limit values and the optimization of different physical values within the grid. This is i.e. concerning compliance with the voltage set point and a reactive power value. [16]

Even more complex relationships, which are not generated by a specific function, but by the use of different functions, must be documented in the future. The use of the SGAM description in combination with the control-engineering description makes this possible by defining the subsystem's behaviour.

A modelling framework for this description will be developed in subsequent research projects.

CONCLUSIONS AND OUTLOOK

With increasing grid automation, complex control structures are emerging within electrical distribution grids - such as cascade controls and multi-criteria control systems. The currently available frameworks allow only a limited documentation of these systems. Especially if more complex cascade controls [13] and multi-criteria controls have to be documented under consideration of dominant and non-dominant objectives. This makes the operation of network automation increasingly difficult.

The planning and the operation of these dependent functions require special knowledge of control engineering. There exist physical dependencies in the electrical grid across voltage levels. Consequently large geographical areas and control systems have to be considered.

There are already different methods of description. The verification with the WAVC showed that none of them is optimal for the technical documentation of grid automation functions. A new approach for a description pattern that considers the existing frameworks and extends it with methods of control engineering has therefore been sketched. In addition to the use of block diagrams, functional rules and dependencies are documented in this approach.

By application of a complete and standardized description, the use and operation of grid automation, such as the WAVC, in the existing system is easier. Without a description, functions can have functional dependencies that can lead to errors during operation. A modelling framework for this description will be developed in subsequent research projects.

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