ON FOSTERING SMART GRID SYSTEMS DEVELOPMENT AND VALIDATION WITH A MODEL-BASED ENGINEERING AND SUPPORT FRAMEWORK

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ABSTRACT

Microgrids and local energy communities are prominent examples of future solutions that will have a tremendous impact on distribution system development. To effectively implement these new and complex control solutions, new and advanced engineering methods are needed as well. This paper presents an automated and model-based engineering and validation method, which supports the engineer during the implementation of these new applications. The proposed approach is expected to be able to reduce the amount of manual effort and in the end, lower the total engineering cost.

INTRODUCTION

The technology development and rollout of smart grid solutions has already started. The massive deployment of Distributed Energy Sources (DERs) in recent years has led to a paradigm change in terms of planning and operation of the distribution system [1]. Automation and control systems, using advanced Information and Communication Technology (ICT), are key elements to handle these new challenges [2]. Beyond purely technical solutions, changes in regulations and grid codes will also be indispensable.

It can also be expected that the total complexity of these systems will increase even more in the future. Microgrids and energy communities are only two examples. Other prominent examples are hybrid grid approaches, where the electric energy system is coupled with other systems, such as gas or water [3]. Another example is smart cities, where smart grids are only one component of a large sustainable system [4]. As a consequence, the electric energy system is moving towards a complex cyber-physical energy system [2].

However, with new approaches and concepts also new challenges emerge. The implementation of complex systems solutions is associated with increasing development complexity resulting in increased engineering costs. The traditional engineering methods used for power system automation were not intended to be used for applications of this scale and complexity [5], [6]. However, the usage of proper methods, automation architectures, and corresponding tools holds huge optimization potential for the engineering process [7].

One methodology that can be used to reduce the engineering effort is to start with detailed use case and requirements engineering. Recent smart grid projects are also utilizing this approach for the development of different applications [8]. Currently, the two most common methods for use cases and requirements engineering are the Smart Grid Architecture Model (SGAM) and the IEC 62559 approach (also known as the IntelliGrid method). These methods complement each other and the main aim is to provide clear and structured documentation of the use case (e.g., voltage control application, energy management solution, demand-response use case) and requirements.

When these use case methodologies are used properly, the results are structured use case descriptions and diagrams. Since one of the main ideas is to identify problems early in the development phase, these descriptions often contain a lot of information. However, a disadvantage with existing approaches is that this information is only provided in a non-formal representation. Thus, it cannot be adequately used in a computerized and automated approach. Furthermore, these existing use case and design methods do not allow the reuse of other already existing input specifications that are typically provided as an input to the engineering process, such as IEC 61850 specifications or power system models.

Consequently, current engineering approaches require a significant amount of avoidable manual work. Since information that has already been provided by the engineer during the use case design is not machine-readable, it cannot be used in an automated fashion in the following engineering phases (implementation, validation, and deployment). Thus, the same information needs to be "redefined" by the engineering in the other phases. This is a very time-consuming and error-prone approach to engineering smart grid applications.

This paper addresses these issues with a concept for an automated and model-based engineering and validation framework which is currently being developed in the Austrian MESSE project. It covers the whole development process of smart grid automation applications and provides development support for specification and design, engineering, validation, and finally deployment and operation.
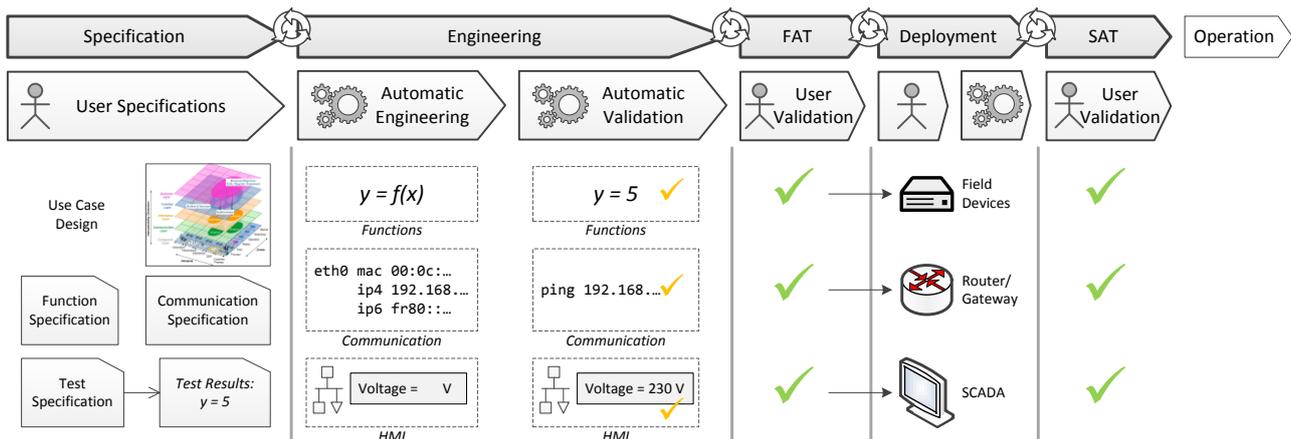
Figure 1: Concept of the model-driven approach for engineering and validation support

MODEL-BASED SUPPORT SYSTEM FOR ENGINEERING AND VALIDATION

This paper proposes a concept for a model-based engineering and validation support system, covering the overall engineering process for smart grid applications—from use case design to validation, and finally deployment and commissioning. Based on a model-driven development approach, the methodology consists of three main parts: *(i)* specification and use case design, *(ii)* automated engineering, and *(iii)* validation as well as deployment. The overall concept is depicted in Figure 1.

Formal Approach for Design and Specification of Use Cases and Applications

As already mentioned above, the current state of practice provides limited support for formal and structured specifications of applications for smart grids. Until now, the need for such descriptions was not very high since the number of complex applications was rather limited. However, with introduction of advanced ICT-based automation systems, such as microgrids and energy communities, this will change in the future.

Starting with the use case description methods defined in SGAM and IEC 62559, a structured description and visualization of use cases can be defined. This will allow an informal exchange of use case descriptions between different business units and between different operators. But, to fully take advantage of the high amount of information in the modelled use cases these description methods must be transformed into machine-readable and formal formats. Similar approaches are currently being proposed, such as [7].

Based on SGAM, IEC 62559, and current formal specification approaches a formal specification and use case analysis method should be defined. The methodology must support several different specifications with various levels of detail. On the one hand, high-level use case descriptions, like SGAM, must be possible. On the other hand, more detailed specifications of functionality, communication, as well as information models must be enabled. These specifications together with the high-level use case description act as the main input and thus form the basis for the automatic generation of target configurations and functions.

The methodology must also allow extensive specification of validation scenarios and expected test results. Current state-of-the art in automatic software testing as well as Design of Experiments (DOE) will be used as a basis [6]. However, since not only software is involved in the development of smart grid applications pure software testing will not be enough. In order to support the automatic testing and validation, it must be possible to define test results as well.

The final specification methodology should also be capable of being integrated into different software tools. The first phase in Figure 1 shows the idea of the *specification* process for this work. From a user perspective this is the phase of the engineering process that contains the most manual work. Therefore, it is important that the specification methodology guides the user. This is also vital to ensure the quality of the automatic generation phase. The automatic generation uses the specification as input, which means the quality of the automatic generation will only be as good as the quality of the specifications. During the specification phase several descriptions for different domains (e.g., functionality, communication) will be available. These must be combined into a semantic-based holistic model.

Automatic generation of target configurations and functions

Based on the specifications from the first phase, different types of configurations are generated. This can be executable code for field devices, communication configurations as well as Human-Machine Interface (HMI) configurations. The executable code is a platform-specific code which can be executed on a certain computing platform. For validation purposes this could also be a simulation platform, in which case the corresponding simulation model would be generated. The communication configurations are used to configure the ICT setup needed for the use case. This includes configuration of the information sent between actors, but can also

be a low-level configuration of the network. HMI configurations are used to define the layout of visualizations, but also to configure how user actions should be interpreted and executed.

By using model-based approaches from software engineering, a concept is provided for the automatic generation. First, by using automatic model transformations, it is possible to keep the information unambiguous (i.e., changes in one input specification are also reflected in the others). Through model transformations it is also possible to automatically generate executable code or simulation models based on the semantic-based model. Another possibility is to use template based approaches. For example, using a certain template, the user can define the layout of the HMI.

The automatic generation of target configurations is very much related to the automatic validation. This means that it must be possible to validate the resulting output configurations. From an engineering perspective, this is an important phase, since it saves the engineer a lot of manual work—translating the designed use case into an actual realization. The automatic engineering process together with the automatic validation is shown as the *engineering* phase in Figure 1.

Automatic validation and testing

Automated testing for software development is a topic that already exists since several years. However, similar approaches for smart grid systems are currently missing. Nevertheless, validation and testing have always played an important role also for electric energy systems. In fact, before components can be connected to the grid, validation and audits are always needed. However, until now these tests have focused mainly on the single components. It is only recently that integrated approaches for the analysis of smart grid system aspects are emerging. Apart from power system aspects, these methods also address information, communication and automation/control topics as well [6]. The integration of cyber-security and privacy issues is also not sufficiently addressed by existing solutions.

In this work a methodology for the automatic testing of cyber-physical energy systems will be developed. The basis for these tests will be validation scenarios and test specifications from the engineer. For an automatic validation, the specifications must be accompanied by expected test results as well. Based on the validation scenarios and specifications appropriate tests are generated. This can be a pure software test, but it can also be a combination of software, hardware, and simulations. If hardware is involved manual setup may be needed. In such cases the methodology should also create setup guidelines for the user.

Once all tests have been generated and configured, the configurations are the input for the following tests. For example, if a control algorithm has been generated one possible test is to load the algorithm to a controller device and validate against a simulated system model (i.e., using a hardware-in-the-loop simulation).

ENGINEERING FOR MICROGRIDS AND ENERGY COMMUNITIES

Microgrids and energy communities are two domains where the proposed methodology will decrease the engineering effort. In order to show this, an illustrating example from the ELECTRA IRP project is shown. The main outcome of this project is a control concept called the "Web-of-Cells" (WoC). The idea is to divide the whole power system over all voltage levels in so-called cell-based control areas. Local problems in a cell are usually solved locally using the available flexibility of generators and loads in the corresponding cell itself [9]. Although the WoC approach is not explicitly a microgrid approach, they are both related with each other.

Illustrating Example

Among the control schemes that have been developed within the WoC approach is a so-called Post-Primary Voltage Control (PPVC). The PPVC is running locally in a cell and handles voltage instabilities using two modes: *(i)* a "proactive" mode, using a look-ahead planning, and *(ii)* a "corrective" mode, which is triggered upon disturbances. For both modes, voltage setpoints are calculated using an Optimal Power Flow (OPF) and then forwarded to the control nodes in the cell, such as DERs, tap-changing transformers, and controllable loads banks [10].

In Figure 2 the process from Figure 1 is applied for the development of the PPVC. In the first phase, a design and specification is made by the engineer. This includes design of the two modes, the OPF, as well as network and communication configurations needed to connect to the control nodes. Next, these specifications are automatically enhanced with information needed for the validation, such as generated tests or simulation inputs.

Based on the detailed—but still generic—configurations from the specification phase, platform and vendor specific configurations are created. For the cell controller, two main parts are configured: communication interfaces and functionality. The communication interfaces are configured to allow access to the ICT network, for example with network addresses and protocols (e.g., IEC 61850, Modbus/SunSpec). To configure the functionality, implementations of the OPF and the two modes are generated as platform-specific code for the cell controller. Similarly, the details of the ICT network, such as VLAN identifiers or priority, are configured.

To test the generated configurations manual tests are combined with the generated tests from the specification phase. When possible, the test results are also automatically validated but in the end, it is the engineer who has the main responsibility. In Figure 2, this step is illustrated as part of the Factory Acceptance Test (FAT), but it can of course equally be part of the Site Acceptance Test (SAT). After the validation phase the developed cell controller is ready for deployment.
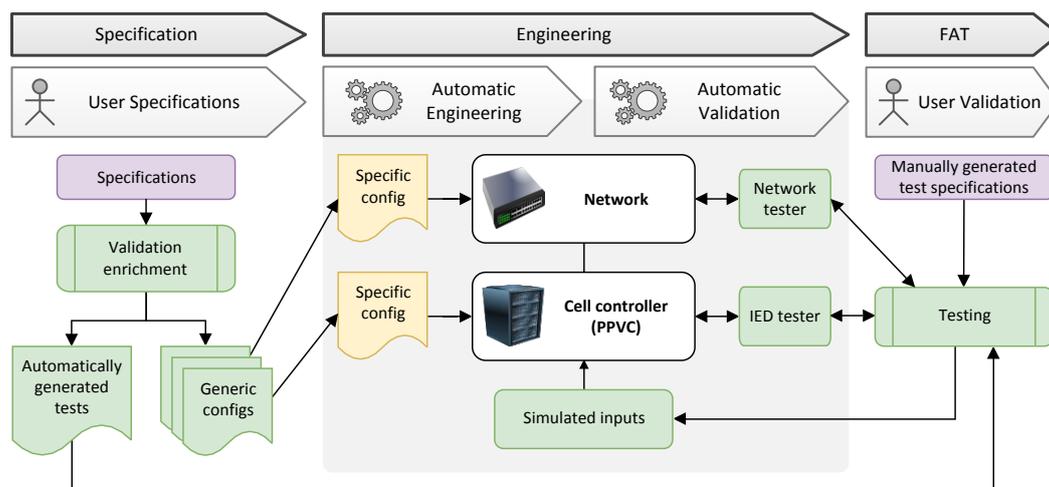
Figure 2: The model-based engineering approach applied to the development of the cell controller

CONCLUSIONS

The concept presented within this work will be well applicable to architecture and system development for microgrids and local energy communities. The model-based engineering concept provides a solid foundation that fosters the formalized and systematic comparison of different development options. Based on a single set of test specifications and validation scenarios provided by the user in the initial specification phase, the test and validation framework generates test cases for each development option under investigation. Therefore, the model comparison is not restricted to architectural design decisions and its implications on the implementation but instead also comprises the results of the test executions.

As seen from the provided example, the model-based engineering concept can automate many steps that are traditionally carried out manually. Therefore, it is expected that the proposed approach will reduce the manual effort of developing smart grid applications and in the end, reduce engineering complexity and costs.

Acknowledgments

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