Towards a Model-Driven-Architecture Process for Smart Grid Projects

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Abstract. The complexity in electrical power systems is continuously increasing due to its advancing distribution. This affects the topology of the grid infrastructure as well as the IT-infrastructure, leading to various heterogeneous systems, data models, protocols, and interfaces. This in turn raises the need for appropriate processes and tools that facilitate the management of the systems architecture on different levels and from different stakeholders' view points. In order to achieve this goal, a common understanding of architecture elements and means of classification shall be gained. The Smart Grid Architecture Model (SGAM) proposed in context of the European standardization mandate M/490 provides a promising basis for domain-specific architecture models. The idea of following a Model-Driven-Architecture (MDA)-approach to create such models, including requirements specification based on Smart Grid use cases, is detailed in this contribution. The SGAM-Toolbox is introduced as tool-support for the approach and its utility is demonstrated by two real-world case studies.

1 Introduction

One of the key challenges resulting from the Smart Grid vision is to handle complexity in distributed systems [3]. The first step to address this challenge is to structure the overall domain. In this context, the results of the European Standardization Mandate M/490 currently gain momentum, especially the Smart Grid Architecture Model (SGAM) [12]. The SGAM has been developed by members from CEN,

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CENELEC and ETSI and considers established domain models (e.g., from NIST and IEC) as well as domain-independent architecture frameworks such as TOGAF. Furthermore, in terms of interoperability dimensions the GridWise Interoperability Context Setting Framework was adopted. As shown in Figure 1, it provides the means to express domain-specific viewpoints on architecture models by the concepts of *Domains*, *Zones* and *Interoperability Layers*, which shall be briefly introduced in the following.

The *Domains* regard the energy conversion chain and include: *generation* (both conventional and renewable bulk generation capacities), *transmission* (infrastructure and organization for the transport of electricity across long distances), *distribution* (infrastructure and organization for the distribution of electricity to the customers), *DERs* (distributed energy resources connected to the distribution grid) and *customer premises* (both end users and producers of electricity, including industrial, commercial, and home facilities as well as generation in form of, e.g., PV generation, electric vehicles storage, batteries, and micro turbines).

The hierarchy of power system management is reflected within the SGAM by the following *Zones*: *process* (physical, chemical or spatial transformations of energy and the physical equipment directly involved), *field* (equipment to protect, control and monitor the process of the power system), *station* (areal aggregation level for field level), *operation* (power system control operation in the respective domain), *enterprise* (commercial and organizational processes, services and infrastructures for enterprises), and *market* (market operations possible along the energy conversion chain).

Finally, as it constitutes a major requirements towards distributed systems the SGAM defines *Interoperability Layers*. These cover entities ranging from business objectives to physical components to express the respective architecture viewpoint. Like proposed by TOGAF, interrelations between concepts from different layers shall ensure traceability between architecture properties.

Furthermore, the Mandate M/490 proposes a methodology for use case management also including a template for use case descriptions [13]. It is suggested by the original reports to combine this methodology with the SGAM in order to create architecture models addressing the requirements elicited in context of appropriate use cases. However, the original purpose of the SGAM is to identify standardization gaps. Therefore, it has to be adopted to be suitable for a genuine model-driven architecture process. In [1] and [14] gaps for applying the SGAM beyond its original purpose have been identified. One issue that has been pointed out by both is its missing formalization. This gap will be addressed in this contribution by proposing Unified Modeling Language (UML) meta-models in order to formally describe SGAM-based architectures.

The remainder of this contribution is structured as follows: The overall approach is presented in Section 2. Two case studies conducted in this context are afterwards outlined in Section 3 and provide further details on possible application contexts and design decisions. The contribution is concluded in Section 4, which also outlines future work.

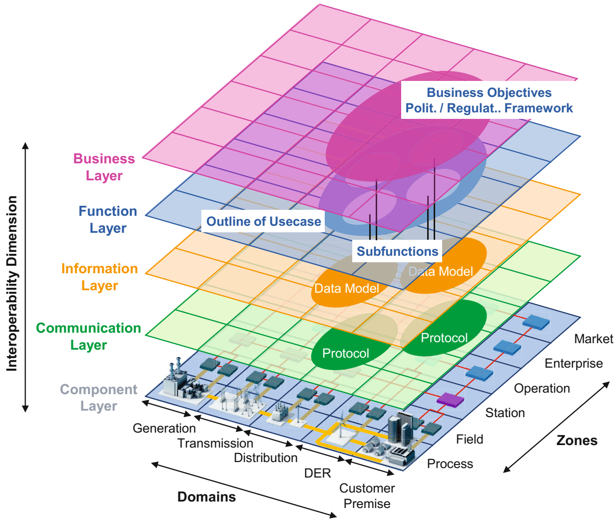

Fig. 1 Smart Grid Architecture Model (SGAM) [12]

2 Approach

As outlined in [3], it is challenging to handle the complexity of distributed systems, especially if they provide critical infrastructures, as in case of Smart Grids. A broadly accepted approach to cope with complexity during the engineering process is the concept of Model Driven Engineering (MDE), which serves as an umbrella term for model-based approaches. Considering the Smart Grid as an interdisciplinary System of Systems (SoS), the architecture-focused concepts of Model Driven Architecture® (MDA®) [9, 8] appear suitable to analyze, decompose and develop Smart Grid related systems. In contrast to Model Driven Software Development (MDSD), MDA focuses on the structuring of specifications rather than on the generation of implementation artifacts.

The utilization of model-based approaches to understand, analyze and design Smart Grid systems has been investigated and deemed valuable by Lopes et al. [7]. The authors strongly rely on the NIST Smart Grid Conceptual Reference Model [6] for the decomposition of Smart Grid systems. This is remarkable, as the NIST Reference Model has been one of the key influencing factors for the development of the SGAM [12].

Similar to [7] the presented work considers model-based approaches to analyze and decompose Smart Grid Systems. Beyond that it aims at the application of these concepts to the engineering task. Hence, initially a fundamental engineering process has been formulated. This process reflects the top-down engineering concepts and consists of a System Analysis Phase, a System Architecture Phase and a Design and Implementation Phase. The deliverables of these phases are the single MDA viewpoints as described in [8].

In more detail, the System Analysis Phase first delivers the Computation Independent Model (CIM), which is used to describe the functionality of a system without mentioning the implementation. Having a common understanding of the intended functionality, the System Architecture Phase can be started to elaborate the Platform Independent Model (PIM). Finally, the last phase delivers the Platform Specific Model (PSM) and the Platform Specific Implementation (PSI). This phase reflects agile ideas and is executed iteratively, with each iteration delivering a vertical slice of the architected system.

Having this development process formulated, it can be aligned with the Use Case Mapping Process (UCMP) as introduced in [12]. The mapping of the six individual tasks of the UCMP to the proposed process is illustrated in Figure 2.

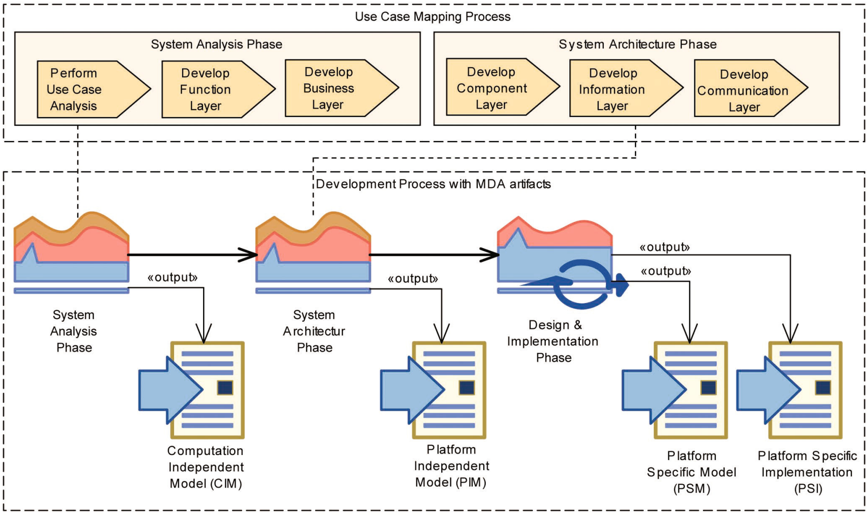

Fig. 2 Mapping of the UCMP to the basic MDA artifacts

3 Case Studies

In the following, two case studies will be outlined, which involve the model-driven architecture development for Smart Grid solutions. This way, the application context for the MDA-approach outlined in the previous section and design descisions regarding conceptual meta-models and tool support will be outlined. Finally, the concepts and experiences from the case study will be compared with each other in order to identify common concepts and approaches as well as differences that motivate future work in this area.

3.1 INTEGRA

In the “Smart Grids Model Region Salzburg”[1] various Smart Grid systems were realized as individual research projects. Currently, the project INTEGRA focuses on the secure and stable operation of the various, mutually influencing systems. In a first step, it is necessary to gain a comprehensive view of the single systems and their interactions. Hence, the MDA-based approach as proposed in Section 2 is utilized for reengineering and modeling selected projects in context of the SGAM.

One of the selected projects, named “Häuser als interaktive Teilnehmer” (HiT)[2], realizes a Smart-Grid-ready energy supply system (thermal and electric energy) for a building complex[3] with 129 flats on 11.000 square meter. A local “Energy Management Center” (EMC) controls the operation of the integrated energy producers and consumers and provides some flexibility to the Distribution System Operator (DSO).

For modeling this system in context of the SGAM, a Domain Specific Language (DSL) was formulated in a first step. This DSL utilizes the SGAM structure and is implemented as a UML-based meta-model. It consists of functional and structural components and their respective horizontal and vertical relations. The basic structure of the meta-model is illustrated in Figure 3. To keep the illustration compact, it does not comprise the attributes of the individual elements.

The depicted meta-model reflects the layered structure from the SGAM and is aligned with the elements from the modified Use Case Template (UCT) that is suggested to be used for the collection of use cases in [13]. The hierarchy between the use cases follows the ideas from [13]. A High Level Use Case (HLUC) invokes a number of Primary Use Cases (PUC). Each of them is composed of different scenarios, which are made up of a number of Use Case Steps that describe the functionality in detail. If a Use Case Step includes an information exchange, an appropriate Information Item element has to be created and associated to the Use Case Step. These Information Item elements can be used in the consecutive steps of the Use Case Mapping Process, e.g., to identify adequate standards or to model Information Object Flows in a consistent manner.

Following the ideas of the MDA, the described functionality is to be mapped to a technical viewpoint, which states the model transformation from the CIM to the PIM. Thus, if a logical actor is realized by a physical component, an adequate mapping has to be done. This takes place during the development of the component layer. Hereby, the logical actors can be mapped either to physical devices (”component”) or to applications that are hosted by physical devices. This mapping is represented by a “trace“ relation in the meta-model. On the component layer level the relations between individual components are expressed by unspecified ICT or Electric Associations. These relations are to be refined in the Information Layer (Data Model Standard and Information Object Flow) and the Communication Layer. The

[1] `http://www.smartgridssalzburg.at`
[2] Meaning “Buildings as interactive participants”
[3] `http://www.rosazukunft.at`

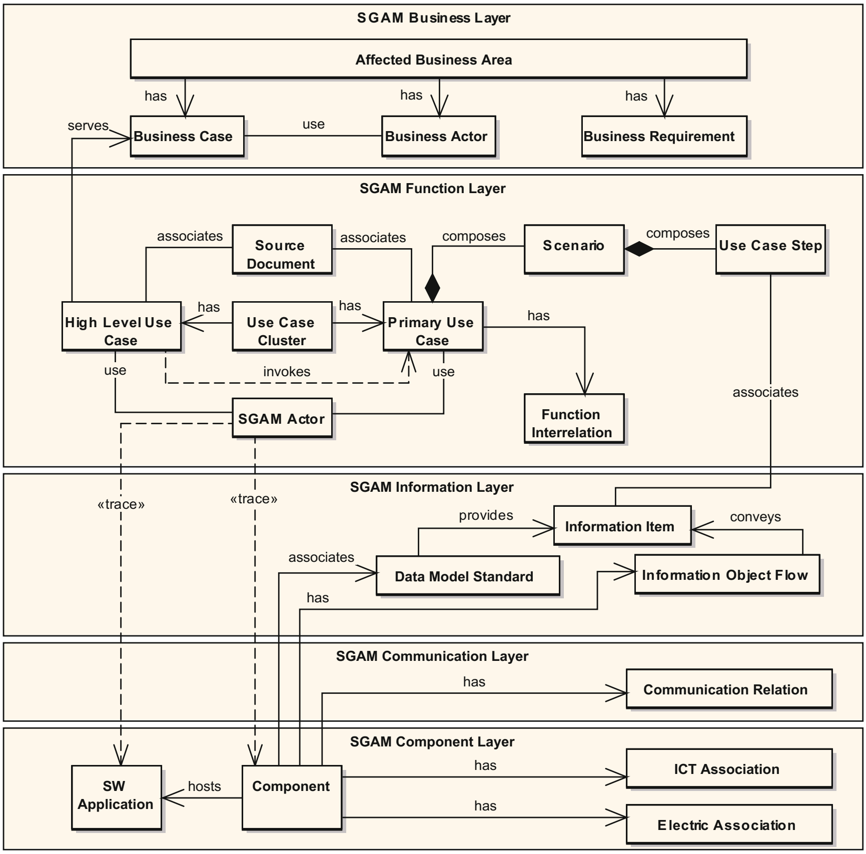

Fig. 3 The INTEGRA Meta-model

introduced Communication Relation comprises adequate attributes (not visible in the illustration) to specify the communication protocol and technology in detail.

Taking the described DSL as a basis, a UML-based toolbox[4] was developed as an extension to the "Enterprise Architect"[5] modeling tool. It was implemented by utilizing the integrated Model Driven Generation (MDG) functionality. In addition to the DSL, the toolbox comprises a number of templates that reflect the UCMP.

During the application of the toolbox some valuable experiences were made. First, it became clear that the analysis of the functionality constitutes a huge part of the total workload. To efficiently deal with this complexity, a more explicit definition of the hierarchy and the relations between the corresponding elements would be useful.

[4] The SGAM-toolbox is publicly available for download at `http://www.en-trust.at/SGAM-Toolbox`

[5] `http://www.sparxsystems.com`

Another experience addresses the interrelations between individual HLUCs. For example, the central HLUC "Optimize local energy" is related to the HLUC "Control power of CHP". It would be useful to explicitly define the horizontal interactions between the single HLUCs.

Also, the Business Layer needs some more attention. Due to the technology-driven character of the research projects, the underlying business cases and processes are not completely described and hence, a sufficient evaluation could not take place.

Another aspect is the integration of non-functional requirements. Even if the issue "Security" is discussed in detail in the Information Security Working Group report [11] it could be valuable to integrate the elicitation of non-functional requirements explicitly in the System Analysis Phase.

Besides the experiences mentioned above, the usage of an MDA-based toolbox turned out very helpful during the reengineering process. It was suitable to enhance the Requirements Engineering Process (System Analysis) and to gain a comprehensive view on the system's functionality and structure.

3.2 DISCERN

The EU FP7 project DISCERN[6] aims at providing a common view on Smart Grid solutions based on conceptual specification as well as its application in context of demonstration sites. The distribution grids represent the project's focus area, as this part of the power system faces considerable changes regarding the amount of decentralized generation. Thereby it represents an active part of the power system, resulting in new challenges for the DSOs. In this light, documenting the solutions in a consistent way shall provide the ability to determine the optimal amount of intelligence provided by Information and Communication Technologies (ICT) in the distribution grids, e.g., in terms of cost-effectiveness. Key Performance Indicators (KPI) shall be designed in order to express the solutions properties and provide the basis for comparative assessments between Smart Grid solutions.

To compare these in a holistic way, two dimensions are considered in DISCERN. The initial requirements elicitation of potential solutions is supported by a use case template based on the approach proposed by the Sustainable Processes Working Group in context of the M/490 Mandate [13]. Their architectural properties are afterwards documented by the means of SGAM models [12]. The DISCERN approach thereby builds on the proposal of the Smart Grid Coordination Group (SGCG) to align the creation of use cases and architecture models.

Beyond the initial scope of standardization gap analysis, the DISCERN project aims at applying use case descriptions and architecture models as the conceptual basis for the creation of KPI. To achieve this goal, the entities of both use case and SGAM model were formalized. The resulting model is shown in Figure 4.

To support the application of use cases and architecture models in DISCERN, several adjustments had to be done to the SGCGs results. The central concept in

[6] `http://www.discern.eu`

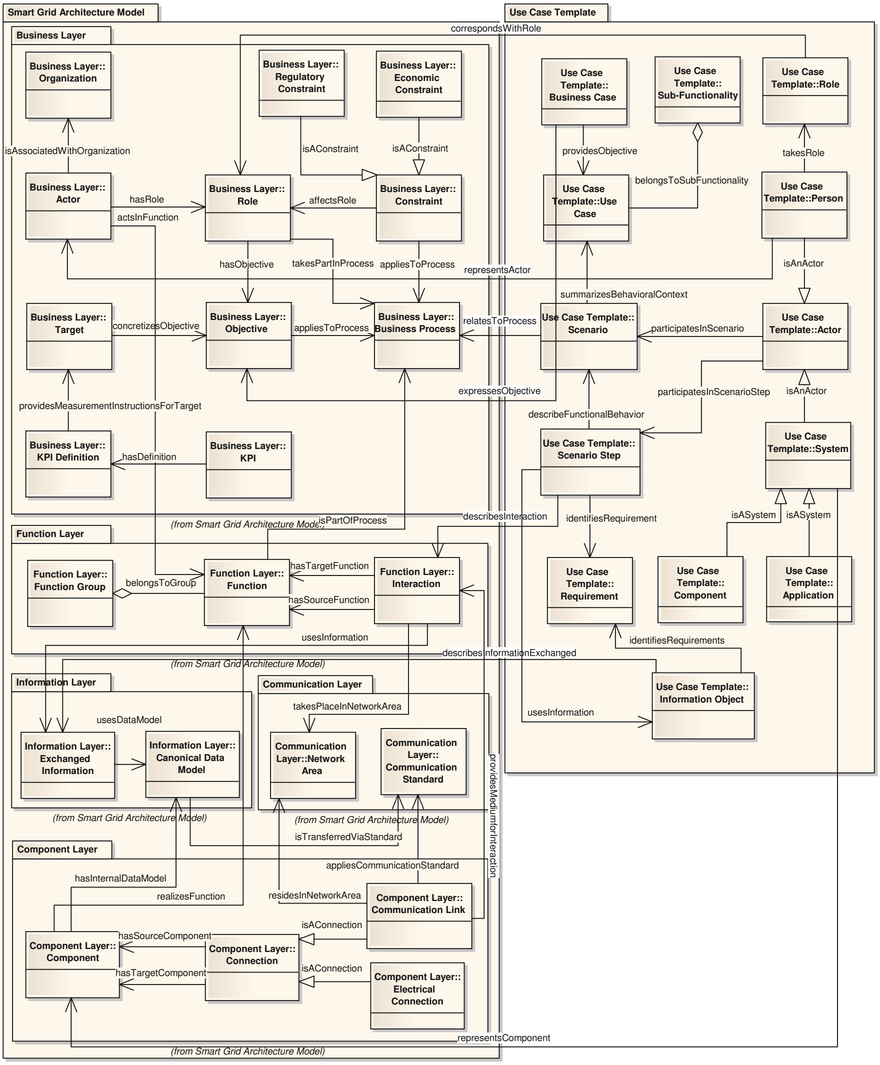

Fig. 4 The DISCERN Meta-model

DISCERN are sub-functionalities, which are used to structure objectives and approaches of a DSO regarding Smart Grid solutions in distribution grids. Use cases are organized under sub-functionalities and express business actors, objectives and business cases as well as the solutions behavior and technical requirements (e.g., technical actors and information objects) in context of scenarios.

For documentation of use cases in DISCERN, a use case template based on the proposal by the SGCG was created. This template incorporates additional information regarding the classification of use cases by sub-functionalities and the affected domains and zones of the SGAM, in order to further align the specification of use cases and SGAM models and to provide the means for analyses of sub-functionalities. Further, the possibilities for the explicit description of requirements were extended and KPIs relevant to the use case can be specified within the template.

Based on the textual specification included in the M/490 working group reports, also the SGAM was formalized, resulting in the DISCERN conceptual model shown in Figure 4. One main addition provided by the DISCERN approach is the explicit model for the business layer. While the SGCG reports state possible entities located on this layer, no examples or formal semantics are provided. Also, the relations between entities on different interoperability layers were explicitly defined within DISCERN. Finally, the interrelations between use case template and SGAM were expressed in the model. This way use cases can be created to express objectives and behavioral aspects of a sub-functionality, while the SGAM models are used to provide information on corresponding architectural options.

To ensure the structural consistency of the use cases as well as SGAM models in DISCERN, templates were provided based on the findings of the conceptual meta-model. While an integrated tool-chain to support the process is planned for a later stage of the project, the first version of templates is realized based on office applications. This decision was made in order to minimize the deviation from the established toolchain at the DSOs and also to enable the intial collection of data and evaluation of the approach in an early phase of the project. While the use cases are documented in form of Microsoft Word documents, the SGAM layers as well as the valid entities on each layers are provided by a Microsoft Visio template and stencil sets. Consistency on the instance level is ensured by lists of valid functions (based on the Interface Reference Models (IRM) [4] "Abstract Components" and automation functions based on the Logical Node (LN) model defined in the IEC 61850 standard [5]), actors (based on the IRM [4], the ENTSO-E Role model [2] and the SGCG reports [12, 13, 10]) and standards (based on the SGCG reports featuring a classification within the domains and zones of the SGAM).

The approach was discussed and initially validated within a series of workshops involving the DISCERN projects stakeholders. The work of the SGCG in context of the M/490 mandate was deemed a viable basis for the project's approach, yet, as outlined in this section, several adjustments were made to extend the approach beyond the domain of standardization. The modeling approach will be further evaluated by collecting instance data on the sub-functionalities of the DSOs involved in DISCERN. This will also include validation of the infrastructure provided by templates and lists to support the creation of consistent use cases and SGAM models.

3.3 Comparison

This section will compare the experiences gained so far in context of the research projects INTEGRA and DISCERN regarding the development of a model-driven approach towards the creation of Smart Grid solution architectures. Especially the differences between the approaches shall be discussed as it is planned to evaluate the creation of an integrated approach.

Scope and Objectives

The INTEGRA project aims at a stable operation of mutually influencing Smart Grid systems. Hence, a comprehensive understanding on the single, individual systems and their interrelations should be gained. Therefore, an MDA approach should deliver a basis for reengineering and analysis of already deployed systems. The tasks of the DISCERN project are quite similar. They involve analysis of Smart Grid solutions provided by DSOs acting as the "leader" for a specific solution. The demo projects involved include both planned as well as already deployed solutions. However, the projects' main focus lies on the comparison of solutions, e.g. regarding cost-effectiveness, and also includes simulation and implementation activities. DISCERN's scope therefore may be regarded as broader in comparison to INTEGRA.

Process Model

The process models of both approaches are based on the model proposed by the SGCG. However, the process proposed in the context of INTEGRA (see Figure 2) follows the SGCG's process more strictly. DISCERN currently proposes three different options, bottom-up, top-down and combined, differing regarding the order in which the SGAM's interoperability layers are addressed.

Conceptual Meta-model

As outlined by Figures 3 and 4, the meta-models used in context of the two projects, while sharing many concepts, show some structural differences. The INTEGRA meta-model was designed with the goal of tight integration between use case descriptions and SGAM and also covers some model-transformations along the development process. Contrasting, the DISCERN model, while also outlining related concepts between both, treats use case descriptions and SGAM models as individual entities. Due to the focus on quantitative comparisons between solution models, an additional objective during the creation of the meta-model was to achieve the maximum granularity regarding the concepts included without deviation from the SGCGs source material.

Tool Support

To support the creation of use case descriptions and SGAM models, both INTEGRA and DISCERN aim at providing appropriate tool support. INTEGRA uses the SGAM-Toolbox implemented in Sparx Systems Enterprise Architect. For the reasons outlined in Section 3.2 DISCERN currently uses Microsoft Word and Visio templates based on the meta-model shown in Figure 4 to enable the elicitation of data in an early phase of the project. However, work on an integrated tool support is planned for a later stage of the project.

4 Conclusions and Future Work

This contribution was motivated by outlining the complexity regarding the development of suitable architectures for Smart Grid solutions. To achieve a thorough solution architecture, requirements have to be elicited regarding the solution's functional capabilities as well as its qualitative aspects with a special focus on interoperability. Therefore, a process to elicit these requirements is required as well as a way to express the multiple perspectives towards the proposed solutions' architectures. As domain experts provide the respective requirements it was also proposed to regard the power system domain's functional perspectives. The approach proposed to deal with these challenges is based on the results achieved by the SGCG working groups in context of the European Standardization mandate M/490, which was originally designed to support the elicitation and management of requirements in context of Smart Grid standardization by means of a use case methodology as well as the SGAM as a model to document architecture properties. This contribution extended this approach regarding three aspects:

- Raising requirements to provide formal semantics for the SGAM
- Establishing a stronger integration between the design of use cases and SGAM architecture models
- Proposing tool support for an integrated MDA-approach based on these artifacts

Regarding these aspects, experiences from two research projects, INTEGRA and DISCERN, have been considered in order to achieve a consistent solution that takes advantage of best practices gained in both projects. The next steps are concluded from the findings so far:

- Integrate the two meta-models that had been developed independently in the projects (INTEGRA and DISCERN)
- Revise the SGAM-Toolbox based on the integrated model
- Couple the UML-modeling (INTEGRA) and the Microsoft Visio visualization (DISCERN) of SGAM models to combine conceptual integrity and applicability in the working environment of the DSOs.

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