A Standards-based Approach for Domain Specific Modelling of Smart Grid System Architectures

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***Abstract*—The ongoing integration of decentralized, renewable energies is a major challenge for today's power system. In order to control the volatile behaviour of these *Distributed Energy Resources* (DER), the electricity system has to evolve towards a *Smart Grid*. The development of this critical and complex System-of-Systems involves different stakeholder from different disciplines. Thus, domain specific engineering concepts on system level are needed. To foster the interdisciplinary development, the proposed approach presents a standards-based architecture framework, implemented as *Domain Specific Language* (DSL). Moreover, the DSL is used to develop a reference architecture on basis of the *NIST Logical Reference Model*. To evaluate the applicability of the reference architecture model it is used for instantiation of a particular system solution.**

I. Introduction

Today's electricity system faces a major challenge by the ongoing integration of renewable energies. Due to the volatile behaviour and the decentralized location of these *Distributed Energy Resources* (DER) a sophisticated management of energy flows is necessary. The main goal to be reached is the maintenance of an equilibrium between generated and consumed energy. To enable such operations today's energy system is going to evolve towards a *Smart Grid*. This term denotes a complex *System-of-Systems* (SoS) with a major share of ICT and strict quality requirements to be maintained [1]. In respect to the increasing amount of ICT, also on *Distribution System* (DS) level, the aspects of *IT Security* and *Privacy* gain importance.

The development of the Smart Grid has proven to be a challenging task. Besides the plain technical complexity, also the involvement of different stakeholder from different disciplines is a challenge. Not only technical disciplines with their different terminologies, techniques and knowledge but also stakeholder from non-technical domains such as business, regulation authorities and customer needs have a major share.

To meet the strict quality requirements of such a critical infrastructure, appropriate interdisciplinary and domain-specific engineering concepts need to be established. A common practice for interdisciplinary development is the utilization of *architecture models* that enable cooperation on a higher abstraction level. Numerous concepts and modelling notations such as *Model Driven Architecture* (MDA), UML or SysML exist. However, these concepts originate from software- or systems-engineering domains and only find little acceptance within the electric energy domain. Thus, domain-specific modelling approaches are needed. Different approaches arose in the past covering these issue but mainly they are on a very abstract level [2] [3] or focusing on a singular aspect, such as one particular communication protocol [4], [5].

More domain specific concepts were developed from different standardisation bodies, such as the *Smart Grid Architecture Model* (SGAM) [6], the *IEC 62559-2 Use Case Template* [7] or the *NIST Logical Reference Model* [8]. Even if these concepts provide valuable guidance, they lack possibilities for practical application as there is no appropriate tooling or guidance available. Moreover, the individual concepts are not perfectly aligned with each other. However, to foster the applicability of such standards, Dänekas et al. [9] published a concept on how to apply these concepts within a model-driven engineering approach. Also, an initial version of a modelling framework (*SGAM Toolbox*) has been introduced. The presented approach already has proven it's value and the SGAM Toolbox is used in different projects. However, to increase the applicability of this architecture framework, a reference architecture that can serve as blueprint is necessary.

The main contribution of the paper comprises two aspects. First, a revised version of the modelling framework is developed to better fit with standardisation concepts and second, the modelling framework is used to develop a reference architecture model. The reference architecture is derived from the *NIST Logical Reference Model* [8] and modelled in context of the SGAM. Thus, the American based NIST LRM is aligned with the European SGAM. Furthermore, the alignment and identified gaps are discussed in detail. Both developed artifacts, the architecture framework (implemented as *Domain Specific Language*, DSL) and the reference architecture model are made publicly available.

The rest of the paper is structured as follows. Section II briefly describes relevant standardisation work for the development of the architecture framework and the reference architecture. The overall approach with a more detailed discussion of these two artifacts is presented in Section III. Next, the evaluation of the developed concepts and the concerning findings are discussed in Section IV. Finally, Section V concludes with a discussion of the developed concepts and outlines actual work, triggered by the findings from Section IV.

II. Related Work

A. IEC 62559-2

Since the late 90s the utilization of *Use Cases* for requirements engineering is state-of-the art in software development. However, in other domains, a structured formal approach with controlled vocabularies is still subject to research. Within the Smart Grid domain, the IntelliGrid EPRI program first adopted the approach and provided a formal glossary and categorisation for non-functional requirements of domain-specific utility communications solutions [10]. Since then, the standards and use case modeling in general has gained much more attention and feedback from utility experiences [11]. Today, the *IEC 62559-2 Use Case Template* [7] is a broadly accepted structure for describing Smart Grid related Use Cases. Also, tool support for common development and information sharing, such as the DKE hosted *Use Case Management Repository* (UCMR)[1] is available and widely used.

B. M/490 Smart Grid Architecture Model

In the context of the European Commission's Standardization Mandate M/490, the Smart Grid Architecture Model (SGAM) has been developed to provide a holistic view on Smart Grid systems [6]. The SGAM, as depicted in Figure 1, is a three dimensional model based on the *NIST Domain Model* [12], the automation pyramid and the *GWAC Interoperability Stack* [13]. The *Domains*-axis of the model decomposes a Smart Grid system on basis of the NIST Domain Model whereas the *Zones*-axis depicts the automation functionality on basis of the automation pyramid. Thus, every element within the model can be aligned according to its position within the electricity grid and its role in terms of automation. To provide interoperability between particular elements, five interoperability layer derived from the GWAC Interoperability Stack are introduced. In the following itemization the layers of the SGAM are explained on basis of [6]:

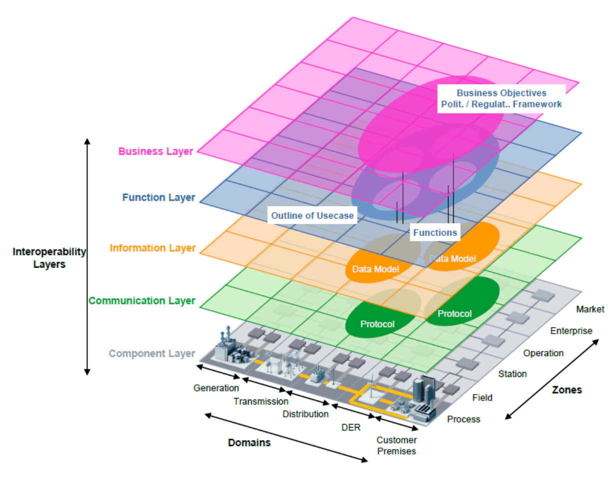

Fig. 1. The Smart Grid Architecture Model (SGAM) [6]

[1] https://usecases.dke.de/sandbox

Business Layer: Provides a business view on the information exchange related to Smart Grids. Regulatory and economic structures can be mapped on this layer.
Function Layer: Describes functions and services including their relationships from an architectural viewpoint.
Information Layer: Describes information objects being exchanged and the underlying canonical data models.
Communication Layer: Describes protocols and mechanisms for the exchange of information between components.
Component Layer: Physical distribution of all participating components including power system and ICT equipment.

Today, the SGAM is widely used as common basis for depicting and architecting Smart Grid systems.

C. NIST Logical Reference Model

The *NISTIR 7628 Guidelines for Smart Grid Cybersecurity* aims at delivering concepts for establishing security in Smart Grid systems. As part of the work different collections of Use Cases have been analyzed to obtain a set of Smart Grid actors. These actors were mapped onto one of the domains from the NIST Domain Model and described in more detail. Moreover, communication paths between these actors have been identified and individual interfaces for each of these communication paths were introduced. Thus, every actor has a set of interfaces with each being linked to another actor. The resulting model is denoted as *NIST Logical Reference Model* (NIST LRM) and it creates one single model out of particular solutions for individual Smart Grid scenarios such as *Advanced Metering, Wide Situational Awareness, Distribution Automation* and others.

Furthermore, all of the identified interfaces have been considered in reference to a set of elaborated *Security Attributes*. Depending on their Security Attributes, all Interfaces were assigned to one or more out of 22 *Interface Categories*. For each of these Interface Categories a set of *High Level Security Requirements* has been formulated. In total, 197 Security Requirements were delivered with each being tagged as *Common Governance, Risk and Compliance Requirements, Common Technical Requirement* or *Unique Technical Requirement* and detailed suggestions for realization.

The NIST LRM as part of the NISTIR 7628 Guidelines is of great value for the presented approach as it delivers a collection of Smart Grid actors, their assigned interfaces and the corresponding security requirements (derived over the concerning Interface Category). Figure 2 depicts the structure of the NIST LRM as conceptual model.

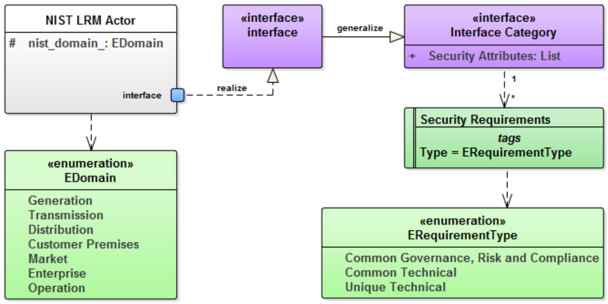

Fig. 2. Conceptual Model of the NIST LRM

III. Approach

As outlined in Section I, a holistic engineering approach on basis of standards is crucial for the interdiciplinary development of Smart Grid systems. Besides the plain process for engineering, a broadly accepted architecture framework as context for development is needed. Moreover, a reference architecture covering typical scenarios and "best practice" solutions on basis of commonly used elements is required.

The intention behind such a reference architecture is to be used as blueprint for the development of particular systems. Thus, one could benefit from a common notation, clearly defined interfaces between particular sub-systems and in general, the availability of a proven best practice solution for a certain problem.

The presented approach aims at the development of both, a standards-based *architecture framework* and a *reference architecture* that is modeled by utilization of this framework. To keep the applicability high, the development of these concepts is oriented on the main engineering phases as depicted in figure 3 and described in the following.

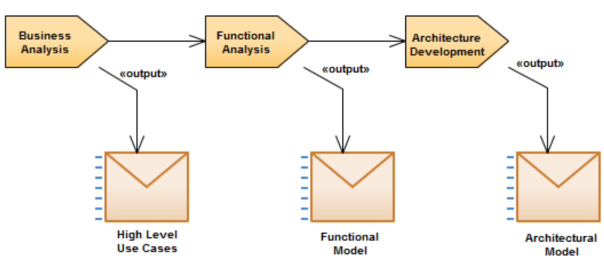

Fig. 3. Intended use of the presented architectural modelling framework

As the electric energy system is subject of governmental regulation, the *Business Analysis* is of major importance. Not only the individual *Business Goals* are to be considered but also potential regulatory constraints need to be taken into account. Thus, the framework should provide support for an extensive business analysis covering both, commercial and regulatory aspects. To be more precise, the framework should enable one to discover involved parties (*Business Actors*), to identify their individual goals (*Business Goals*, which also can be regulatory constraints) and to derive *Business Cases*. These Business Cases not only should satisfy the interests of all involved parties but also provide legal conformity.

On basis of these Business Cases, *High Level Use Cases* (HLUC) can be developed that describe a systems main functionality. The identified HLUCs serve as input for the *Functional Analysis* which aims at further decomposition of the desired functionality into more granular *Primary Use Cases* (PUC). Also, the identification of actors (*Logical Actors*) involved within these PUCs can be done during this step.

The final step *Architecture Development* covers the realization of the particular system. First, it transforms the functional model from the second step into an architectural solution by mapping the *Logical Actors* onto physical components. Moreover, specific technical aspects necessary to realize the described functionality such as communication between particular components can be developed in this step. The basic idea is to develop a black-box model (for the particular components) that can serve as a basis for the technical realization conducted by parties out of the supply-chain.

The architecture framework to be developed should be capable of covering all the above mentioned steps. Intentionally, these steps describe the step-by-step development of a system model covering business aspects, functional aspects and architectural solutions. Thus, the realization of the architecture framework should take place as *Domain Specific Modeling Language* (DSL) enabling one to utilize a model-driven engineering approach.

Besides the development of an architectural framework, a certain reference architecture should be derived on basis of broadly accepted standards work. This reference architecture should be developed as model by utilizing the above discussed architecture framework. To maintain compatibility, it is of great importance to not reinvent the wheel but to exploit and consolidate different existing work for both, the architecture framework and the reference architecture.

The underlying concepts of both, the architecture framework and the reference architecture model are explained in more detail in the following two sections.

A. Architecture Framework

The architecture framework described in this section is based on the considerations published by Dänekas et al. [9]. This paper discusses the development of Smart Grid systems in alignment with the Model Driven Architecture (MDA) [14]. On basis of the experiences gained during application in various projects such as INTEGRA [15], the architecture framework faced various revisions. The main adoptions being made adress the structure of particular elements. For example, the attributes for localization information have been removed, the HLUC element has been aligned with IEC 62559-2 as described in section II and the *Component Layer* view has been extended to reflect the structure of ICT network topologies. Especially the last change has been of great value for planning, engineering and maintaining the communication within distributed Smart Grid systems

However, in regard to the changes made and for the sake of clarity the architecture framework and the underlying concepts are described here in more detail.

The main cornerstone of the architecture framework is the *Smart Grid Architecture Model* (SGAM) as discussed in Section II. The SGAM provides a broadly accepted context for developing Smart Grid system architectures. As the framework is intended to deliver both, a context for modelling and a corresponding DSL, the SGAM layers have been chosen as main *views* to foster a step-by-step development as depicted in Figure 3

Following the considerations above, the structure of the DSL is aligned with both, the preliminary described workflow (figure 3) and the five SGAM layers. Basically the *Business Analysis* takes place on height of the *SGAM Business Layer*, the *Functional Analysis* is covered by the *SGAM Function Layer* and the *Architecture Development* ranges over the lower three layers *Information, Communication* and *Components*. To adress this mapping, the specified DSL provides separate elements for describing business aspects, functional aspects and architectural aspects and model transformations as vertical relations in between.

The described concept serves as a basis for the specification of the DSL. The simplified metamodel of the DSL, structured among the five SGAM layers as primary views is depicted in Figure 4. The implementation of this DSL has been conducted as UML profile. This concept is a simple mechanism for extending the UML, which provides different advantages such as integration with existing modelling tools or interaction with established modelling languages like UML or SysML. The latter is of very importance for the subsequent detailed development of particular components.

The implementation of this DSL, denoted as *SGAM Toolbox* has been made publicly available[2]. To foster the usability of this concept some additional help such as video tutorials is provided as well.

The underlying concepts of the implemented DSL are described in the following in more detail.

Business Analysis: To enable an appropriate business analysis as discussed earlier, the DSL provides various elements such as *Business Actors* (BA), *Business Goals* (BG), *Business Cases* (BC) and *High Level Use Cases* (HLUC) with the corresponding horizontal relations in between. As all of these elements are realized as stereotyped UML elements, it is possible to more deeply describe them for example by means of established modelling languages such as *Business Process Modelling Notation* (BPMN). The specification of the HLUCs within the metamodel has been aligned with the attributes for Use Cases as described by the IEC 62559-2. Thus, an easy integration of existing Use Case descriptions, for example from the *Use Case Management Repository* is possible.

For a better understanding of the ideas behind this structure a simplified example is provided: Two business actors, a *Distribution System Operator (DSO)* and a *Facility Operator* (FO) are given. The goal of the DSO is to delay the upgrade of the electric infrastructure and the FO is interested in optimizing his energy costs. To satisfy these Business Goals a particular BC *Flexibility* is established. This BC comprises time shifting of particular electric loads (e.g., electric vehicles or heat pumps) in order to prevent load peaks in the electricity network. In exchange for the provided flexibility the FO obtains an individual pricing concept. On basis of the described BC particular HLUCs such as *Shift E-Car loading* or *Shift Heat-Pump* are specified. As the intended functionality requires knowledge of the current electric condition at the *Customer Premises*, a third HLUC *Data Acquisition* is created. This HLUC is intended to fetch data from the *Advanced Metering Infrastructure* (AMIS), which is subject to regulation. Thus, a new BA *Regulatory Instance* is created. The BGs of this actor correspond with the maintainance of regulatory standards which introduces new constraints (e.g. metering frequency, data granularity and others) for the other HLUCs.

[2]www.en-trust.at/SGAM-Toolbox

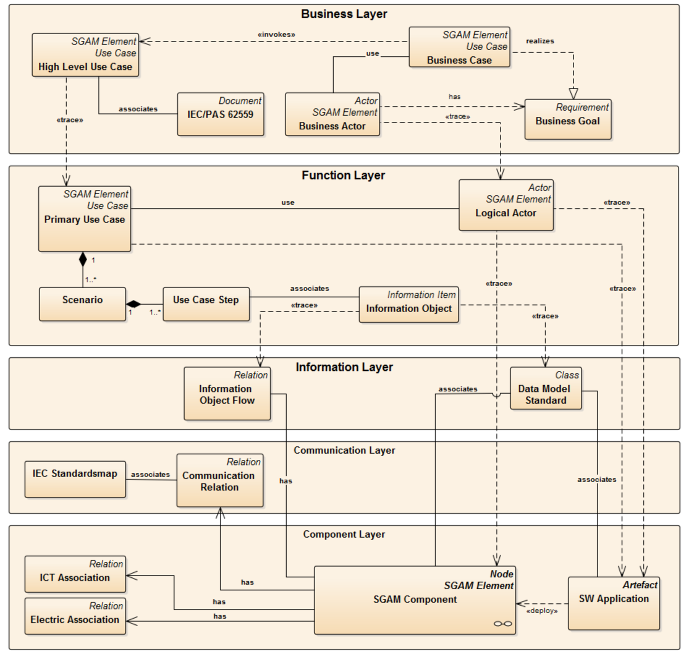

Fig. 4. Architecture Framework

Functional Analysis: Right after the identification and description of particular HLUCs, they can be decomposed into more granular *Primary Use Cases* (PUC). These PUCs, together with their concerning *Logical Actors* (LA) build up the SGAM Function Layer. The description of particular PUCs can be done by out-of-the box mechanisms of UML, such as *activity* or *sequence diagrams*. A major point of interest at this stage is the identification of *Information Objects* that are communicated between the LAs. These information objects are one of the key elements for the development of the SGAM Information Layer. Moreover, they represent a very important asset to be considered during security considerations.

Architecture Development: Subsequent to the functional description of the system the technical description can take place. In alignment with the SGAM, the architecture description covers the three layers *information*, *communication* and *components*. In a first step, the model transformation from the logical model into the technical one needs to be done. Basically, the logical actors are mapped onto physical components. In Figure 4 this step is depicted as *trace* relation. Next, the technical aspects can be developed in reference to the three corresponding views.

The *Information Layer* view focuses on describing both, the *business context view* and the *canonical data model*. First, the *business context view* is used to denote the information object flow between particular components. These information object flows are determined by the functional analysis (information objects exchanged between logical actors) together with the mapping of the Logical Actors onto technical components. It is important to notice that those information objects identified and described in the functional analysis are used here. Thus, on basis of this view an implicit data-flow-graph comes into being that can serve as a basis for further evaluations, such as privacy impacts [16]. Moreover, the canonical data model can be developed on basis of the information objects.

The *Communication Layer* represents a certain view on the components that allow for developing a communication infrastructure with focus on end-to-end communication. Having the elements aligned with the SGAM plane delivers support for the selection of appropriate communication protocols. For example, the IEC Standardsmap [3] delivers an online database for selecting appropriate communication standards in reference to the location within the SGAM plane.

The intended use and content of the *Component Layer* is described only very roughly. During the application of the SGAM Toolbox it turned out that it lacks a certain mechanism to develop and describe ICT network aspects such as network segments, firewall configurations and others. Thus, we suggest to utilize the Component Layer for initial modelling of ICT Networks. To enable this, besides the Smart Grid specific components also ICT specific equipment such as gateways, router and firewalls have been integrated. However, depending on the individual needs it is possible do consider different concerns on this layer such as “Electric Network“ or “ICT Topology“.

B. Reference Architecture

The NIST LRM as described in Section II provides a valuable reference architecture for particular Smart Grid solutions. Especially the integrated concept for dealing with security requirements is of great value. To utilize this reference architecture as blueprint for particular systems it has been modeled on basis of the preliminary described DSL. However, some differences between the SGAM concept as integrated in the DSL and the NIST LRM exist. First, the NIST LRM integrates *Interfaces*, *Interface Categories* and *Security Requirements* that are not mentioned within the SGAM. Thus, the DSL has been extended by these elements. The *Interface Categories* and *Interfaces* have been derived from the UML element *Interface*. In addition, the element *Interface Categories* has been extended with attributes for the *Security Attributes* as considered within the NIST LRM. For the realization of the *Security Requirements* the SysML element *Requirement* has been taken as basis. Furthermore, three particular requirement types have been derived to separate the three requirement groups *Common Governance, Risk and Compliance Requirements*, *Common Technical Requirements* and *Unique Technical Requirements*.

The second and most important aspect is the flat nature of the NIST LRM. Contrasting to the separation of *Business Elements*, *Logical Elements* and *Architectural Elements* within the context of the SGAM, all NIST LRM actors are located within one layer. Considerations on the provided NIST LRM actors made clear that these actors rather represent *SGAM Components* located on the lower three SGAM layer than *Logical Actors*. Thus, the particular elements of the NIST LRM were modeled as components with their corresponding interfaces.

The allocation of the individual components within the SGAM plane is a straight forward task as both, the SGAM and the NIST LRM originate from the NIST Domain Model [12]. The only difference is reflected by the *DER Domain* that is added within the SGAM. Considering the individual NIST LRM actors makes clear that the *DER* actor (within the domain *Customer Premises*) is the only element that has to be mapped to this newly introduced domain.

Another very important aspect is the documentation of the underlying Use Cases. Basically, the NIST LRM lists a number of Use Cases in reference to individual categories but it does not provide any detailed description on a similar level as introduced by the architecture framework. Thus, the Use Cases from NIST have been imported for further processing but are not yet linked with the architectural solution.
The complete reference architecture model, together with a click-through HTML export[4], has been made publicly available.

IV. Evaluation

The initial version of the presented architecture framework has been developed in the INTEGRA project [15] as part of the *Smart Grids Model Region Salzburg*[5] (SGMS). During this project, the *SGAM Toolbox* has been used to develop a consolidated architecture that covers all individual projects from the SGMS. To evaluate the work presented in this paper, the INTEGRA architecture has been re-engineered by utilization of the revised *SGAM Toolbox*. Moreover, it has been instantiated out of the developed reference architecture model.

During the evaluation various findings were made. First, the availability of a reference architecture has proven to be a very handy solution for developing a particular architecture.

[3]http://smartgridstandardsmap.com/

[4]www.en-trust.at/NISTIR

[5]www.smartgridssalzburg.at

However, as discussed in Section III, the reference architecture only provides elements on one abstraction layer. In order not to brake the original concepts of the NIST LRM, all of them have been mapped to only one layer, the component layer. Thus, no appropriate elements for the Business Layer and the Function Layer are delivered by the reference architecture. This draws the need for rethinking the NIST LRM concept. Basically, it would be necessary to separate the individual actors into Business Actors, Logical Actors and Technical Components which draws the need for a revision of the incorporated communication paths and interfaces. Moreover, it would be necessary to align especially the Business Actors with established descriptions such as the *ENTSO-E Role Model* [17].

Also, a detailed description of the provided Use Cases, together with an appropriate mapping of the involved Logical Actors onto technical components, is needed.

The integrated security concept delivers a valuable approach towards *security by design*. However, the main goal is to provide a robust system that also covers other quality requirements such as dependability or reliability. These terms are ambiguously used among the different stakeholder, so it would be necessary to first clarify the meaning of these attributes, for example by introducing an overall taxonomy. Next, on basis of this taxonomy, these attributes could be incorporated into the reference architecture in a similar way as security.

The last finding considers the instantiation of the reference architecture. Particular elements, such as *Intelligent Electronic Devices* (IED) can be instantiated multiple times. Also, communication among them is possible. The NIST LRM does not provide communication paths (including the concerning interfaces) between different instances of one element. Thus, the integration of such relations is of relevance.

V. Conclusion and Future Work

The concepts presented in this paper provide insight into the interdisciplinary and standards-based development of Smart Grid systems. An SGAM based architecture framework has been proposed that enables a domain specific modelling. Moreover, on basis of this framework, the NIST LRM has been utilized to develop a reference architecture that can serve as blueprint for particular solutions. The application of this reference architecture for modeling a particular system has proven its value. However, the findings made during this application drive the future work of the authors. First of all, a better alignment of the NIST LRM with the SGAM will be made by separating the NIST actors in reference to the SGAM layers. In addition, the reference architecture shall be extended by incorporation of additional dependability attributes. These revisions will be evaluated within the *Reference Architecture for a Secure Smart Grid in Austria* (RASSA) project that aims at the development of a Smart Grid reference architecture for Austria.

Besides these considerations, investigations will take place on how to exploit Smart Grid models as described for evaluating particular solutions on basis of individual *Key Performance Indicator* (KPI).

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