# Simulation: A Case for Interoperability based on LCIM

## - The µGrip approach -

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***Abstract*—In this contribution, we outline the need for a structured modeling approach based on international standards to drive forth a case study for integrating DER into a micro grid. While this µGrip project also addresses market aspects, we outline the need for a structured way to model interfaces to fit for simulation, our approach taken, and an extension to the current practice of M/490 SGAM-based modeling.**

***Keywords—simulation, mosaik, SGAM, LCIM, micro-grid, systems engineering***

## I. Introduction

Over the last years, more and more ICT has been introduced to so-called critical infrastructures in order to cope with the increasing complexity of daily operations. One particular example is the so called Smart Grid which has been getting a lot of attention as topic as of lately. One main driver of the Smart Grid was the introduction of renewable energies and distributed energy generation which leads to changes e.g. on the operation paradigm of the power grid.

While previously, the energy flow was from the top voltage levels from large generation plants over transmission and distribution grids to the consumer or industrial loads, this is not entirely true any longer. The loads flows change and the previous assumptions for grid state estimation as well as voltage and frequency regulation no longer work without more and more sensor data for operation. This introduces completely new technologies and complexities to the Smart Grid. In order to deal with those complexities, a new holistic system-of-systems (SoS) engineering effort was developed with a focus on integrating the knowledge from the various stakeholders and domains involved. The remainder of this very contribution is organized as follow.

### *A. Structure of this Contribution*

Within the next section, we will outline the need for a system-of-systems approach to deal with the rising complexity for introducing ICT to critical infrastructures in general, categorizing the operations ad extension of critical infrastructures as a so called wicked problem. Based on the problem definition, we show an example of a consistent, standards-based approach defined for the Smart Grid and derive requirements for the adoption of creating interoperable simulation interfaces. Afterwards, we will introduce the project context of the ERANET Smart Grids+ µGrip project. Our simulation environment which will be the very focus for the conceptual interfaces modeling is introduced later on. Afterwards, out methodological approach is presented based on preliminary results from simulation integration. We conclude with a section on future work in the context of the project.

### *B. Motivation for the need of a System-of-Systems Approach in Smart Grids*

The software engineering institute at Carnegie Mellon University (SEI-CMU) has initiated research in the scope of so called ultra-large scale systems (ULSS). Based on various attributes and emerging properties of those systems, one could define them as so-called wicked problems, as coined by Rittel et al. [14]. In literature, ULSS has an unprecedented scale in some of the following dimensions:

Lines of code; amount of data stored, accessed, manipulated, and refined; number of connections and interdependencies, number of hardware elements; number of computational elements; number of system purposes and user perception of these purposes; number of routine processes, interactions, and "emergent behaviors", number of overlapping policy domains and enforceable mechanisms, and, finally, number of people involved in some way [11], [12].

In order to deal with those structural as well as complexity problems, various strategies by both academia and industry have been implemented to tackle them. In the M/490 mandate for Smart Grids by the European Commission to its standardization bodies, various measures were developed to tackle the most prominent challenges. One was to actually integrate the various domains and stakeholders from automation, utilities, OEMs, standardization, integrators, regulators, communication and ICT into a common, harmonized modeling environment using use cases and reference architectures [3], [4].

To come up with a meaningful technical solutions to be created by this very heterogeneous group, a standardized use case process was developed in the M/490 mandate [6], leading to the IEC 62559 standards series. Including a controlled vocabulary, actors list, libraries for domain-specific non-functional requirements as well as use case structure, this makes for a much harmonized requirements process. This ensures the inclusion of all the views of the groups as well as creating a common understanding for systems development. Three main pillars were created in Smart Grid mandate which will be further described in the next two paragraphs [5].

### *C. Elements of the Methods for Smart Grids*

#### *1) IEC 62559 – Requirements Engineering for PS*

The IEC 62559 series covers a meaningful and structured way to elicit requirements from stakeholders. Within the Smart Grid, various stakeholders have to contribute, being form different domains and backgrounds. The standard template was developed with the focus of ensuring a common understanding using both the very same terminology and viewpoints to document a so called use cases. In addition, pre-defined definitions of actors as well as non-functional requirements like needed standards for communication, mitigation measures for securing system operations or classes for bandwidth, latency, uptime and needed organizational measures. Ten template covers two levels, the first providing a broad idea with some details, providing a base for discussion if the use case will be further pursued in a project. The full template adds technical and processual knowledge and can be used for implementation purposes later on.

#### *2) SGAM*

The SGAM is a reference designation framework based on the meta-model from ISO 42010 [9] in order to visualize a use case with some kind of explosion drawing. It takes into account the dimensions of interoperability of a given solution, the electricity distribution chain and the internal organization of an electric utility (see figure 1). Information needed to fill out the reference designation can be obtained from the IEC 62559 based use cases, thus, providing a way to add to the process and requirements view a meaningful way to depict the needed architectural, static solution for implementing a use case. Since this approach of use cases and reference designation using various dimensions for an architecture is not necessarily specific to the Smart Grid, the approach can be transferred to new domains, making it a traceable system-of-systems approach.

These two methods will be mainly used to deal with the requirements engineering process in the project, in addition to the actual merit they provide, they are also endorsed by the funding schema in order to achieve a proper comparison between the individual projects in the ERANET SG+ funding program. The next section will provide an insight on the scope and goals of the project µGrip in order to emphasize the needs of the stakeholders for simulation purposes.

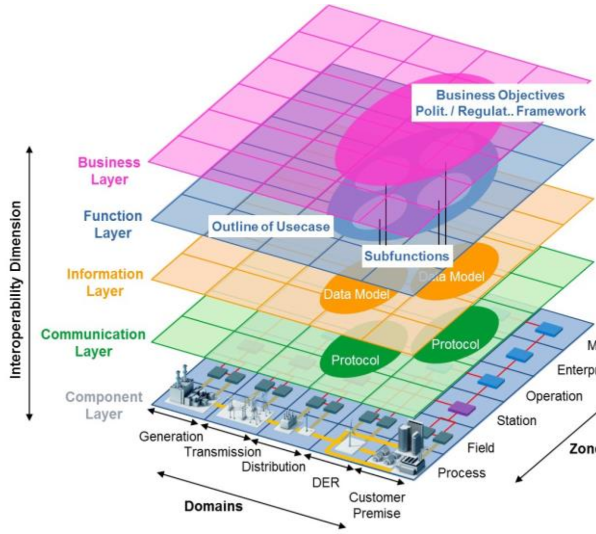


**Figure 1: SGAM model from [18]**

## II. µGRIP PROJECT OVERVIEW

µGrip[1] (Micro-grid Positioning) is a project within the ERANet Smart Grid Plus[2] initiative, which intends to support the development of technical, economic and social solutions for the integration of renewable energies by making consumption and production of energy more flexible. µGrip is based on the concept of a micro-grid, a part of the grid consisting of different flexible and non-flexible loads and generators as well as storages. Examples for such micro-grids are hospitals, shopping malls or smaller industrial plants. An important characteristic of a micro-grid is that it is controlled by a joint operator which makes it possible to provide flexibilities of the micro-grid to the grid operator or to local or wholesale markets.

The goals of the project are to assess the flexibility that a micro-grid can supply and to develop business cases with regard to grid operations and energy markets. The project also addresses IT-related issues focused on the development of communication architecture for such a micro-grid and the use of standardized communication protocols.

The development of business cases and operation strategies is done by using a simulation environment consisting of the micro-grid with its components, an energy management system, a micro-grid controller and the distribution grid the micro-grid is connected to. The energy management is based on business cases to provide flexibility to the grid operator and/or the buy and sell energy in local or wholesale markets. The task of the micro-grid controller is to keep agreed-upon schedules by balancing deviations of consumption and production caused by forecast errors, outages or other disturbances.

[1] http://ugrip.eu/

[2] http://www.eranet-smartgridsplus.eu/

The business cases and operation strategies are not only applied in pure software simulations but also tested and demonstrated in a lab environment. The Faculty of Electrical Engineering and Computing of the University of Zagreb (FER-UNIZG) provides a lab containing a hydro turbine, a wind turbine, a CHP plant (combined heat and power), a set of photovoltaic panels, a series of line models with circuit breakers and feeder disconnectors simulating high voltage power system network, a transformer substation fully equipped with circuit breakers, feeder disconnectors, current and voltage transformers, protection devices and control circuits. This equipment will be expanded by energy storage units and flexible loads.

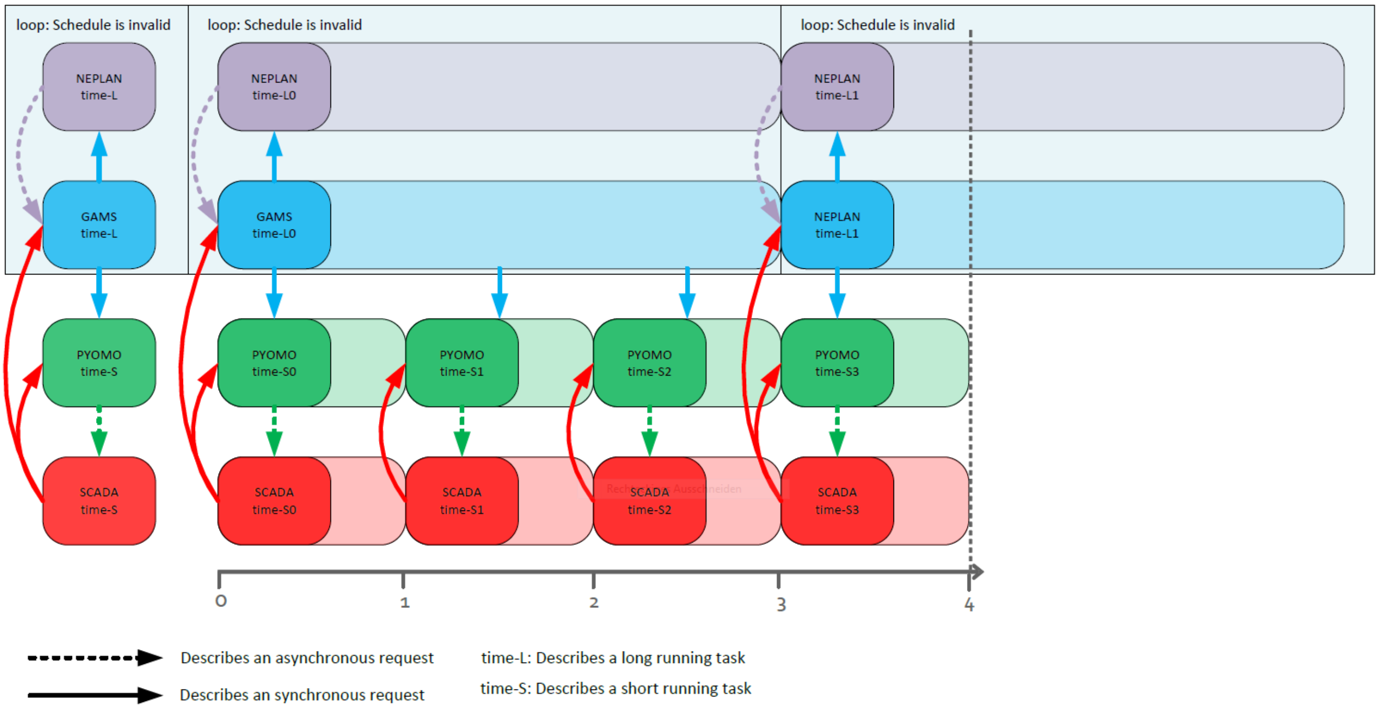


**Figure 2: Process for simulation between the components utilizing mosaic, orchestrating the individual systems**

FER-UNIZG is also developing the energy management system and provides business cases. A further partner is the Technical University of Denmark (DTU) who is developing the micro-grid controller. OFFIS, a partner from Germany, is covering the IT related topics.

## III. SIMULATION AND LAB ENVIRONMENT

The simulation and lab environment is developed based on a co-simulation approach. Co-simulation is an approach for the joint simulation of models developed with different tools (tool coupling) where each tool treats one part of a modular coupled problem. Intermediate results (variables, status information) are exchanged between these tools during simulation where data exchange is restricted to discrete intervals. Between these exchange intervals, the subsystems are solved independently [1]. The big advantage of this approach is that it allows the partners to develop their respective components on their own without having the overall simulation system in mind. They only have to provide an interface that allows to exchange data and to control the simulator.

The co-simulation tool mosaik[3], developed at OFFIS, is used to put the individual simulators together to a simulation environment. The tool mosaik provides mainly the core functionalities of co-simulation mentioned above, the data exchange between the components and a coordinated execution of the simulators.

The simulation environment consists of the micro-grid itself, an energy management based on an optimization with GAMS[4], a micro-grid controller based on an optimization with Pyomo[5] and a NEPLAN[6] simulation of the distribution grid (s. figure 5. As all these components are time discreet simulators the coordination [2] between them is quite straightforward. The only challenge is that the simulators representing the individual components run in different time steps (s. figure 2) However, mosaik's scheduler is able to handle this.

A further advantage of co-simulation in this application is that it is easy to exchange (semantic and conceptual) models. This enables to replace a simulated component with a real, technically interoperable component. Not all components of the lab environment are currently real units. In particular, the distribution grid for µGrip will also be simulated in the lab experiments. However, the simulation also imposes technical challenges for the requirements process which will be focused on in the later section.

[3] http://mosaik.offis.de/
[4] https://www.gams.com/
[5] http://www.pyomo.org/
[6] http://www.neplan.ch/

The co-simulation approach currently has two functions in the lab environment: One is to connect simulated components and real units, and the other one is to switch from pure software simulation experiment to lab experiment by replacing the simulated micro-grid with the SCADA (Supervisory Control and Data Acquisition) system of the lab.

The biggest challenge when setting up the simulation is a harmonized, common and interoperable data model. As described in Section II the components of the simulation are developed by the different partners in parallel. As the models are developed by experts from different fields the designation of data points may differ. To ensure that data is exchanged correctly, a data model has to describe the data points such that it ensures a data point in one simulator is connected to its counterpart in the other simulators. Within the next section, we will elaborate more on the problem and show a solution based on a conceptual way to deal with the semantics of the interfaces.

## IV. PROBLEM DESCRIPTION FOR SIMULATION INTERFACES

As the previous section has pointed out, the project heavily relies on simulations which have to be used in the context of the technical integration and impose challenges for integration. Several issues must be addressed and solved in order to deal with the problems arising.

First, we have to accept the overall complexity of the micro-grid problems to be solved. Like Sommerville [14] has pointed out, seconded by Rittel, looking for the definition of the problem might even be part of the problem. In simulations, one way of abstraction is not only to model the correct attributes which have the highest impact, but also deal with the likelihood of certain scenarios to happen and be taken into account for simulation parameters. If the simulation module to be connected to mosaik lacks this very feature needed for the scenario to be simulated or has no idea about the difference between continuous simulation and discrete-event simulation, the granularity becomes an issue. For this very purpose, it is also meaningful to come up an extension of the existing SGAM and use case methods to take into account those requirements at design time.

For assessing the needed interoperability aspects of either a technical interface or a simulation interface, conceptual levels have to be distinguished between. The SGAM has three main aspects used for reference designation. One is the aspect of the various technical interoperability dimensions which can also be seen as interoperability levels. In fact, the dimension is closely related to the concept of the GridWise Architecture Council interoperability stack [7]. The "interoperability stack" as it is called, is a derivative of the so called levels of conceptual interoperability model (LCIM) stack [10]. Figure 4 shows the meaning of this very stack.

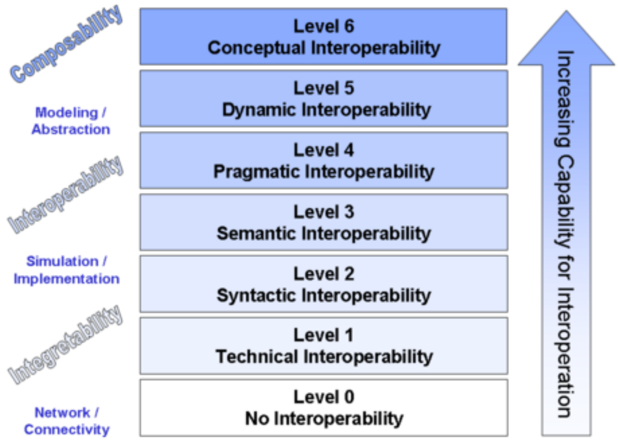


**Figure 3: Levels of Conceptual Interoperability Model (LCIM) (Source: [16])**

The interoperability concept can be clearly seen in line with the one already being implemented in the SGAM. While the SGAM focuses mainly on the interoperability in terms of the technical plug, syntax and semantics of the data objects exchanged (e.g. using CIM or IEC 61850), for simulation the aspect of composability is of high interest. Composability addresses the levels 5 and 6, which cover the dynamic and conceptual interoperability [15]. Composability is defined as the capability to select and assemble simulation components in various combinations into simulation systems to satisfy specific user requirements [16]. The defining characteristic of composability is the ability to combine and recombine components into different simulation systems for different purposes. This requires that conceptual models are documented based on engineering methods enabling their interpretation and evaluation by other engineers. In essence, this requires a fully specified, but implementation independent model [15].

Given the previous facts about composability and the needs to achieve this very level, it becomes apparent that the needed results for the aspect of composability in the simulations can be achieved with the help of the suggested M/490 methods toolbox [8]. In order to further emphasize this problem, it must be stated that ACM SIGSIM suggested to call composability one of the Grand Challenges of Modeling & Simulation. Therefore, stating the problem is of merit.

In the following section, we will provide an overview on how to tackle this problem from a methodological point of view in the context of µGrip and to deliver feedback on the first results gained.

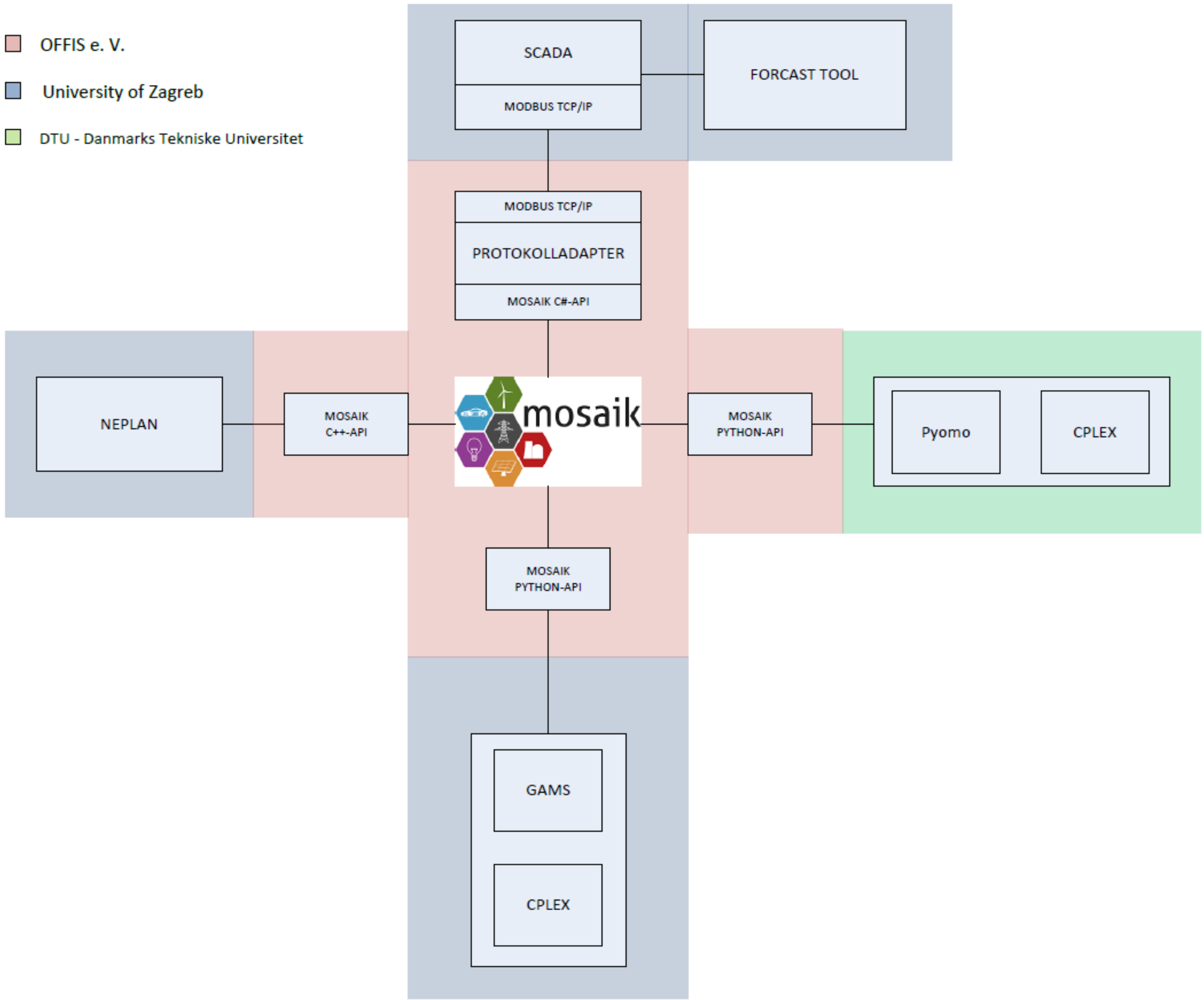


**Figure 4: Overall architecture of the µGrip simulation**

## V. Approach taken in µGrip

Within our project, the complex interfaces needed for simulation will be defined using the IEC 62559 template and the corresponding use case approach. The focus will be to thoroughly focus on the aspects of level 5 and 6 of the LCIM, The current template focuses on the data exchange comprising the semantic data objects exchanged but lacks some issues which focus on the non-functional requirements for the very context of the corresponding data exchanges. Just as misuse cases for unintentional behavior are missing, the current IEC 62559 template lacks the annex tables of the IntelliGrid template which provided a controlled vocabulary for the non-functional requirements. Those requirements can be used as the conceptual context needed for the levels 5 and 6 of the LCIM stack in order to ensure the composability. The levels 5 and 6 are defined as follows [16]:

Level 5: As a system operates on data being exchanged over time, the state of that system will change, and this includes the assumptions and constraints that affect its data interchange. If systems have attained the so called dynamic interoperability, they are able to comprehend the state changes that occur in the assumptions and constraints that each is making over time, and they are able to take advantage of those changes. When interested specifically in the effects of operations, this becomes increasingly important; the effect of the information exchange within the participating systems is unambiguously defined. This layer, therefore, ensures a common understanding of effects, in term of state changes, out parameters generated, etc. [17].

The information is currently not covered properly in the template and shall be further elaborated on.

Level 6: Finally, if the conceptual model – i.e. the assumptions and constraints of the meaningful abstraction of reality – are aligned, the highest level of interoperability is reached: Conceptual Interoperability. This requires that conceptual models are documented based on engineering methods enabling their interpretation and evaluation by other engineers [17]. Assumptions and constraints can be covered by the current template but there is a need to further extend the section 5 of the IEC 62559-2 template. This is how to proceed with the use cases. As the SGAM is based on the GWAC stack, we suggest adding the relevant layers needed to the SGAM and replace respectively add the regulatory/ business layer for the simulation architecture modeling purposes by the pragmatic, dynamic and conceptual layer providing modeling for the needed information for the context needed to ensure composability as the current SGAM focuses on integrability and interoperability.

## VI. Conclusion and Future Work

Within this contribution we motivated the aspect of composability for simulation. Simulation is one key element to deal with the overall complexity and needs from the new Smart Grid paradigm in order to find out which technologies shall be used. The different scenarios which will be simulated make for a meaningful solution to having addressing the Smart Grid as a wicked problem, where finding the problem is already part of the solution path. For the µGrip project, we will focus on the simulation of micro-grids. In order to solve the aspect of meaningful simulation interfaces to ensure composability, we need to extend and change the existing SGAM and IEC 62559 method which are the recommended best-practice nowadays. Our approach which deal with the dynamic aspects of the interfaces being derived from the use case descriptions and sequence diagrams in the IEC 62559 based repository and take into account static interoperability aspects for the needed architecture defined in the SGAM models. In addition, we will focus on the composability by changing the stack for the SGAM layers to a suitable version to address the composability issue. Those changes to the overall methodology shall make the existing M/490 work more fitting for the aspect of modeling simulation interfaces as it will be better suited to address the relevant aspects pointed out. The mapping of SGAM layers to different meta-models has already been shown by Andrén et al. [13], or Turnitsa [17] showing the usefulness of the SGAM as a mediator model. As the work evolves, the extension will be taken into account for standardization work with the IEC SRG SE (System Resource Group Smart Energy).

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