HOW TO ENSURE INTEROPERABILITY IN DEMAND RESPONSE SYSTEMS: THE EXAMPLES OF THE EUROPEAN PROJECTS H2020 GIFT AND MAESHA

Dune SEBILLEAU
Trialog – France
Dune.sebilleau@trialog.com

Marjolaine FARRE
Trialog – France
Marjolaine.farre@trialog.com

Olivier GENEST
Trialog - France
Olivier.genest@trialog.com

ABSTRACT

The decarbonization of the energy system as well as the digitalization of the electricity network make Smart Grid complex to operate. System operators increasingly rely on Demand Response (DR) schemes involving various flexibility sources to meet global and local constraints. To overcome the complexity inherent to the diversity of subsystems, interoperable systems are essential to ensure a smooth operation of DR schemes. The methodology described in this paper aims to develop an interoperability-by-design framework and deals with every aspect of interoperability in the system.

First of all, objectives of the DR system as well as its architecture should be defined. This is generally done through the definition of use cases and of the system architecture and with the support of relevant frameworks and reference architectures. Then, to achieve semantic and syntactic interoperability of the various components of the DR system, the methodology proposes to rely on mature standards and supports the selection of relevant protocols that make technologies work smoothly, reliably and securely together. Finally, as final step of the methodology, interfaces are tested to verify the compliance to the selected standards and a final integration test ensures that the system operates as expected.

This methodology has been developed in the Horizon 2020 project GIFT and further improved in the H2020 project MAESHA. Some examples of application will be presented. The results from applying this methodology show a fully interoperable system, ready for deployment.

INTRODUCTION

System operators increasingly rely on Demand Response (DR) systems piloting flexibility assets to optimize grid operation. Such systems are complex as they involve many actors from different sectors and technical ecosystems, that need to interact and exchange data to enable co-operated services at system level. Sharing meaningful data is thus of primary importance and interoperability is key to implement scalable DR systems.

This risk of non-interoperability has been faced by the two Horizon 2020 European projects GIFT and MAESHA. Answering the same call for proposal, those two projects are focusing on the decarbonisation of the energy systems of geographical islands through the use of high flexibility services from distributed generation, DR and storage of electricity. Both also aim at developing synergies between the different energy vectors (electricity, heating, cooling, water, transport, etc.).

To overcome this complexity introduced by the diversity of actors and ensure the system interoperability, we designed a **comprehensive methodology to develop an interoperability-by-design framework** addressing all levels of interoperability as described by the GridWise Architecture Council ([1]) - organizational, informational and technical interoperability.

LITERATURE REVIEW

At all levels of interoperability (organizational, informational and technical levels), several initiatives exist to ensure interoperability of energy services. And it is sometimes complex to find its way.

First, **at organizational level**, when defining the use cases that the DR system should support, partners have the choice between a large variety of frameworks promoting different methodologies and best practices. If they have clear ideas, partners can build them from scratch by following a methodology, for instance the one described in the IEC 62559-4 standard ([2]). Or they can rely on a set of generic and technology-agnostic use cases for comprehensiveness purposes and to ensure an effective discussion with a common terminology between partners. A useful starting point could be the energy services described in the Universal Smart Energy Framework (USEF) ([3]) or the business use cases described in the IEC 62913 series ([4]). Then, to complete the scenarios' description, partners can map the use case to the Generic Business Processes (GBPs) developed by the Data Management Working Group of the BRIDGE initiative ([5]). Those GBPs focus on harmonizing the roles, functions and interfaces in the flexibility ecosystem, enabling to extract a few recuring patterns in the provision of flexibilities.

Once use cases are defined, the system architecture of the DR system should be designed. We warmly recommend to use here a Reference Architecture that provides a common vocabulary for various stakeholders, reusable designs and best practices, and, for sure, we are not alone to recommend it. Once again, several Reference Architectures exist. For the energy domain, the most used frameworks are the Smart Grid Architecture Model (SGAM) [6] developed by CEN, CENELEC and ETSI and the National Institute of Standards and Technology (NIST) framework ([7]). However, the emergence of cross-sectoral projects leads architecture designers to consider new reference architectures also covering other domains. A good example is the Reference Architectures developed in the Horizon 2020 InterConnect project ([8]) that also cover the Smart Home, Building and IoT domains. Extensions may also be used, such as the IEC 63200 extending the SGAM for the interaction in the areas of Heat and Gas ([9]).

Finally, ensuring interoperability **at informational and technical levels** is usually achieved by relying on relevant protocols and standards that provide rules and guidelines to guarantee that technologies work smoothly and reliably together. But once again, the panel of communication protocols and data models is wide and developers can have difficulties selecting the most relevant one for their systems.

On this topic, the Horizon Europe *Interoperability Network for the Energy Transition* project (int:net) has initiated a catalogue of interoperability actions and best practices to increase interoperability of energy services, data and platforms, available on its website ([10]).

To overcome all these complexities, we designed a full methodology addressing all categories of interoperability: the interoperability-by-design framework, further described in the following sections.

METHODOLOGY

Use Cases definition

In its Interoperability Context-Setting Framework ([1]), GridWise identifies three main interoperability categories. The first category, the organizational interoperability, emphasizes the pragmatic aspects of interoperation. It represents the policy and business drivers for interactions. This level of interoperability is usually achieved through the definition of use-cases. Each use-case indeed represents a business process, detailing interactions between the actors of the ecosystem and the main functions of the overall system.

Use cases should be based on the future environment of the system, its constraints and opportunities to ensure that the developed system will answer the local needs and fits in its context. However, it is recommended to rely on a set of generic and technology-agnostic use cases as a starting point. In GIFT and MAESHA, we used respectively two main frameworks for the formalization of the business use-cases: the Reference Use Cases based on the Harmonized Electricity Market Role Model and the USEF flexibility market design.

In GIFT, partners relied on the Reference Use-Cases ([17]), defined in the European projects Mirabel ([11]) and GoFlex ([12]) and based on the Harmonized Electricity Market Role Model (HEMRM, [13]). They identified fourteen main use-cases for the use of flexibility in the electricity network, distinguished by the main roles involved and the grid level at which it is implemented. A particularity of this framework is its structure of nested ecosystem, enabling to trade flexibility at several levels, as can be seen in the Figure 1 below.

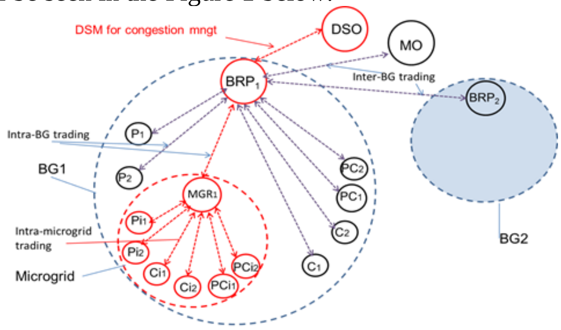

Figure 1: Structure of the Reference Use-Cases based of the HERMR

Similarly, the USEF flexibility market design ([3]) defines a series of models for the flexibility market, including the flexibility value chain, models for interactions, and coordination mechanisms. It focuses on the value stacking of flexibilities, with several intricated markets. This model, summarized in the Figure 2 below, was used in the project MAESHA ([14]) to model the flexibility exchanges.

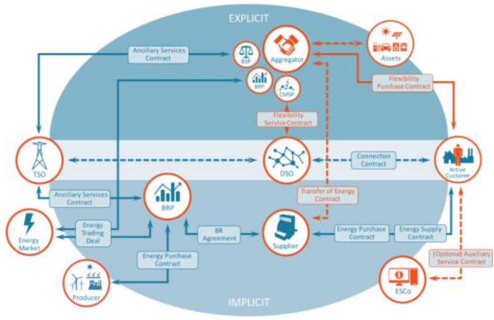

Figure 2: Structure of the USEF flexibility market design ([3])

The formal description of the use-cases is then based on the IEC 62559-2 template ([15]). It provides a comprehensive description of an use-case, focusing of the interactions in the ecosystem. The template breaks down this description into elemental bricks, linked together. Their definitions are, when possible, taken from standardized lists, such as the roles descriptions of the HEMRM ([13]), or the non-functional requirements from the InteGrid project ([16]), in order to improve the interoperability and standardization of use-cases. The information defined includes:

- Objectives of the use-case
- Actors and their roles

- KPI with associated metrics
- Scenarios of operation
- Information exchanged
- Non-functional requirements

UML diagrams are additionally used to improve the readability of said information. Use Case Diagrams, detailing the involved parties and their functions, and Sequence Diagrams, that show the process of each scenario, are therefore added to the use-cases.

Depending on the level of abstraction, we often considered two types of use-cases:

- High level use-case (or HLUC) that describes the business processes in a generic and technology-agnostic way,
- System use-case (or SUC) that describes the technical implementation of the use case in its specific environment by taking into account the local conditions and the systems/assets available.

Use-cases constitute the first bricks of an interoperable DR system at organization level as it defines the main business objectives and functions of the system. The next level, informational interoperability, is briefly addressed in the Information Exchanged section of the IEC 62559-2 template but further analysed in the design of the system architecture.

System architecture design

Once use cases are described, the architecture of the solution should be designed. It prepares technical solutions to efficiently interact to perform the functions defined in the use cases and thus to support them. The easiest way to define the system architecture is to use a Reference Architecture. This framework indeed guides the instantiation of solution architectures by providing reusable designs and best practices.

In the Smart Energy domain, the most used Reference Architecture is the Smart Grid Architecture Model (SGAM), defined by CEN, CENELEC and ESTI ([6]). It indeed gives a global view of a Smart Grid system by mapping its different actors and devices on a Smart Grid Plane subdivided in energy Domains and business Zones. This framework was selected in GIFT and MAESHA as the DR systems developed within those two projects are mostly focused on electricity with only few cross-domains interactions (Electric Vehicles, Water Pumping Station) that can all be mapped on the Smart Grid Plane (see [17] and [18]).

In its description of the Smart Grid Reference Architecture ([6]), CEN, CENELEC and ETSI defined some principles and guidelines on how to use the SGAM framework. The easiest way to design an architecture is to map the use case to the SGAM framework (see Figure 3).

If use cases are described using the IEC 62559-2 template ([15]), the mapping is quite immediate:

- The Component layer is developed by considering the use case information on actors. As actors can be of type devices, applications, persons and organizations, these can be associated to the relevant domain and hierarchical zone.
- The Business layer is intended to host the business processes, services and organizations which are linked to the use case.
- The Function layer represents functions and their interrelations in respect to domains and zones. This layer is developed by considering the scenario and step-by-step analysis of the use case.
- The Information layer describes the information that is being used and exchanged between functions, services and components. Latter information is usually found in the step-by-step analysis of the main scenario or in the Information exchanged table.
- Finally, the emphasis of the Communication layer is to describe protocols and mechanisms for the interoperable exchange of information between the use case actors. Please note that this layer is not covered in the IEC 62559-2 template.

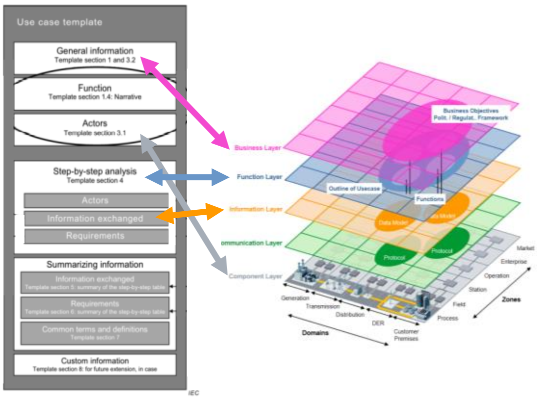

Figure 3: Use case mapping process to SGAM

In GIFT and MAESHA, the mapping was quite straightforward. However, from the Communication layer of the MAESHA architecture, it appeared that no unique or clear communication protocols were identified for some interfaces ([18]). We thus entered the third step of the methodology: the selection of relevant protocols for the DR system.

Selection of relevant standards

To ensure the interoperability of the DR system at informational and technical levels, we extended the methodology to support the choice of relevant protocols and standards. To find our way in the wide panels of communication protocols and standards, we:

- First, **identify the interoperability-critical interfaces**. Those interfaces can be highlighted from the system architecture designed previously and are the ones:
  - **Between different actors**. In such cases, there is a risk of different understandings of the interface and

therefore potential difficulties to align the implementations, possibly leading to interoperability issues.
  - **Where no clear standard is identified in the industry**. In such cases, additional work is required to identify a good solution. Furthermore, the lack of maturity of the solution may lead to interoperability issues.
- Secondly, **extract the data exchange requirements** from the use case description. For each information to be exchanged, the information producer/receiver as well as the frequency of exchange should be defined. To ease the standards assessment that comes as a fourth step, we recommend to link each requirement to a service for flexibility markets. It thus allows to only look at the coverage of the service by the standard, rather than looking for each individual information in the standard specifications. The services are typically the ones identified in the InterConnect project ([19]): Registration, Pre-qualification, Forecasting, Market operation, Delivery, Verification and Settlement.
- Thirdly, **identify relevant protocols for each interface**. To do so, several sources can be screened: the catalogue of standards initiated by the BRIDGE initiative in its Data Management Working Group ([5]), the IEC 63097 ([20]), the IEC Smart Grid standardisation map ([21]) or deliverables from European projects (e.g., InterConnect D4.1 ([19]), EU-SysFlex D5.5 ([22]), SENDER D3.1 ([23]), Merlon D4.1 ([24]), etc.).
- Then, as fourth step, **compare the different protocols identified regarding their service coverage and other criteria** (maturity, scalability and access to open specifications). For an example, please refer to MAESHA Deliverable 1.4 ([25]).
- Finally, from this analysis, draw the recommendations for each interface. It is usually recommended to rely on highly mature standards, covering most (if not all) services needed for the DR system, widely spread and with open specifications. If the functional coverage of a mature standard is almost complete (e.g., one service missing), one possible option is to extend it. Some extensions implemented in European projects are described in [5]. In other cases, we recommend to prefer the service coverage of a standard over its maturity.

Interoperability and integration testing

As a final step towards interoperability, a testing is performed to validate the compliance of the system to the specifications obtained through the previous steps. In order to reach full interoperability, the methodology uses a progressive approach, as it has been done in the GIFT project ([26], Figure 4).

First, components tests are performed to ensure that each component correctly performs the functions that have been assigned to it.

Then, interoperability tests are performed for each interface. The communications and information exchanged between two components are therefore checked. In particular, if a standardized protocol has been chosen to perform the communications, the tests should ensure that the interface is compliant to the standard, enabling its interoperability within its ecosystem and its reusability.

Finally, integration tests including all components are performed, based on the use-cases scenarios. These tests validate that the whole system behaves as expected in a realistic environment and fits the needs of the users.

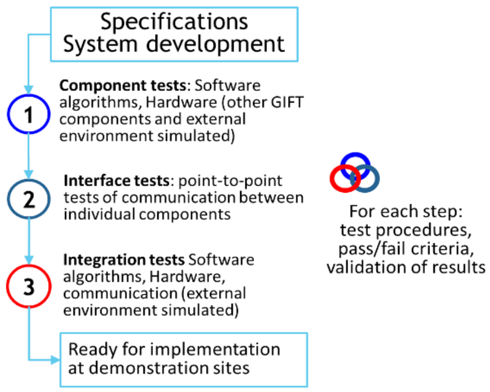

Figure 4: Testing strategy of GIFT ([26])

This progressive methodology ensures that all potential issues are detected locally, before moving on to the next scale.

RESULTS

The aim of this methodology is to reach a fully interoperable system, ready for deployment without several back-and-forth discussions between developers of communicating systems. The results are thus hardly quantifiable. In this section, we will nevertheless try to quantify the benefits of this methodology, based on the results of GIFT and of the preliminary results of MAESHA.

First, using the HEMRM allowed consortium partners from various domains to quickly use a common vocabulary setting the ground for the future discussion on use cases. Also, the USEF flexibility market design and especially the Implicit DR services described in the framework ([3]) has led MAESHA partners to consider user-centric use-cases benefitting active customer in addition to “classic” System Operator-centric use-cases, even with no local customer representatives in the consortium ([14]). With the help of external local stakeholders, the methodology has thus helped us in defining a system that will as best as possible fit in its environment and meet user’s needs.

On the architectural point of view, the SGAM framework has enabled us to design an architecture involving all actors and assets of the foreseen system, even if not from the Smart Grid domain (e.g., Electric Vehicles, Water Pumps) ([17]) and to highlight the interoperability-critical interfaces that required special attention ([25]).

In MAESHA, partners were hesitating on the communication standard to use for flexibility bidding and market clearing: the methodology allowed us to compare six different protocols (i.a., CIM, OpenADR) and to find a consensus on the most relevant one for the project, based on a comprehensive and objective analysis ([25]).

Finally, 43 interoperability tests as well as 2 full integration tests were performed in the GIFT project ([26]). This avoided additional delays in the deployment phase due to interoperability issues.

CONCLUSION

We applied this methodology in GIFT and MAESHA resulting in a fully interoperable system, ready for deployment:

- The use-cases ensure that business models and functions can be integrated in the existing ecosystem and fill the user's need. The architecture design prepares technical solutions to efficiently interact to perform the functions defined in the use-cases, considering the environment of the system. It provides a common understanding of the system, its functions and the work to be done for all actors,
- The architecture definition moreover highlights interfaces missing a standardized communication protocol, which can be chosen through the next step of the methodology. The use of a mature standard indeed improves the scalability of the system and facilitates the future integration of new actors and flexibility providers to the system,
- Finally, interoperability and integration tests validate that the specifications defined in earlier steps are correctly implemented and that the whole system behaves as expected.

The application of this methodology allows to better prepare the deployment phase, avoiding expensive back-and-forth adjustments on the field. It promotes the use of standardized, reliable interfaces, thus improving the resiliency, efficiency and integration of the system into its ecosystem. Finally, it facilitates the navigation through the range of standards, frameworks and models, without a deep dive into specific areas.

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