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Markets and platforms to coordinate the procurement of system services from large-scale and small-scale assets connected to the electricity network

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SUMMARY

The efficiency and the reliability of the electricity system depend on an efficient collaboration between different market participants. New challenges for the power sector, which require updating the roles of all agents involved, have emerged due to the growing importance of renewable energy sources, the advance of distributed generation, the development of self-consumption, the storage of energy, the electrification of heating and cooling loads and the mass integration of electric vehicles.
In this context, the safe and efficient functioning of the electricity system requires the exploitation of untapped flexibility in both generation and demand. Hence, the coordination of distribution system operators (DSOs) and transmission system operators (TSOs) in the procurement of system services provided by units located in both distribution and transmission grids becomes a major challenge.
The CoordiNet project, co-financed by the European Union (EU), is intended to a) demonstrate how the TSO, who is responsible for ensuring the balance of the power system in its control area and managing the very high voltage transmission grid, and the DSOs, who are the managers of the high-, medium- and low-voltage distribution grids, can act in a coordinated manner to purchase and activate system services, b) promote the cooperation of all actors and c) eliminate the barriers of active participation for customers in the market.
This paper describes the work performed to define the characteristics, functionalities and potential algorithms to ensure the interoperability of the different markets and platforms developed by TSOs and DSOs across Europe, including the proposed system architecture and the description of the blocks it consists of, as well as the implementations that are being used in the three demonstrators.

KEYWORDS

Flexibility, TSO-DSO cooperation, coordination scheme, market, platforms, system services.

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1. INTRODUCTION

The CoordiNet project [1] aims to establish different coordination schemes between transmission system operators (TSOs), distribution system operators (DSOs) and consumers to develop a smart, safe and resilient energy system. To this end, the available flexibility at different voltage levels will be identified and analysed in detail, with special attention to the active participation from consumers. CoordiNet aims to demonstrate how DSOs and TSOs, acting in a coordinated manner, can set the suitable conditions for the cooperation of different agents, removing barriers to the participation of consumers and other small flexible distributed energy resources (DER) connected to the distribution network in the energy markets. CoordiNet will also develop new mechanisms, more suitable for real-time operation, that allow to define the technical requirements of future standard European platforms for trading system services. While the development of such a standard platform is beyond the scope of CoordiNet, new tools and methodologies that allow the scaling of the project results will be designed. This paper summarises the main outcomes of the project until 15 December 2020[1].

2. DEMONSTRATION CAMPAIGNS

The CoordiNet project gathers the efforts of 23 companies from ten European countries to deploy ten large-scale demonstration projects in Greece (Kefalonia and Mesogia), Spain (Albacete, Cádiz, Málaga and Murcia-Alicante), and Sweden (VästerNorrland-Jämtland, Uppland, Gotland and Skåne).

2.1 Greek demonstrator

The main objectives of the Greek demonstration campaign (Figure 1) are to prepare consumers and renewable energy sources to obtain a more active role in the management and operation of the power system at national and regional level, to create new products and services to provide a reduced cost of energy and improved quality of supply to consumers, and to utilize existing operational and demonstration systems with new ones developed in the project.

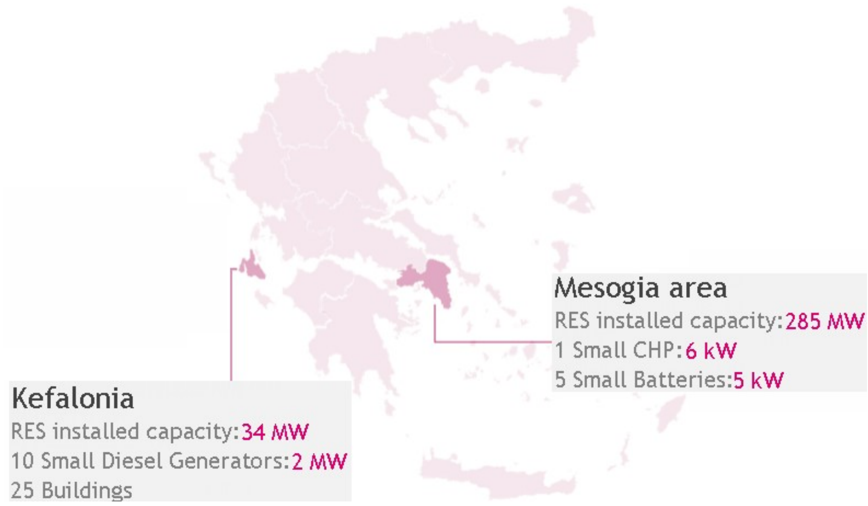

Figure 1: Greek demonstrator

2.2 Spanish demonstrator

The Spanish demonstration campaign (see Figure 2) will proof the technical and economic viability of a system that allows flexibility providers, regardless of their size and the voltage level of their connection point, to provide system services both to DSOs – to solve congestions, voltage and islanding operation problems – and to the TSO to solve congestions, voltage and balancing problems.

[1] Project results are regularly updated in the deliverables section on the project website, at https://coordinet-project.eu/publications/deliverables

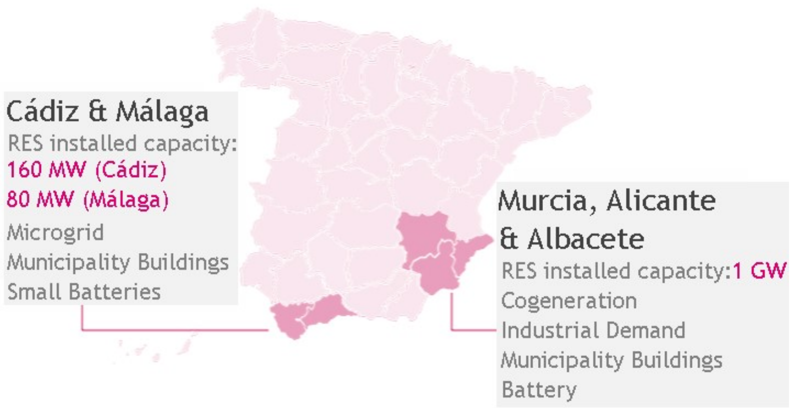

Figure 2: Spanish demonstrator

<u>2.3 Swedish demonstrator</u>

The Swedish demonstration campaign, located in four different regions (Figure 3), aims at enabling economic growth through a more flexible way of using the grid capacity over time. The established flexibility market allows the flexibility providers to offer capacity and DSOs to procure this flexibility, when needed. The developed flexibility products are incorporated into the DSO's operation and grid planning procedures, as well as into customers' routines. The market design and TSO-DSO coordination are supported by real-time data gathering and forecasting algorithms for both customer behaviour and grid status The demonstrator contributes to the national and local climate goals, as well as to the improvement of the economic efficiency of asset usage. Different DERs, such as storage, wind and small-scale customers, participate in the flexibility market, via aggregation. A digital Peer-to-Peer (P2P) market is in place to enable trading and economical transactions among flexibility providers and to support the DSO in the system expansion planning process.

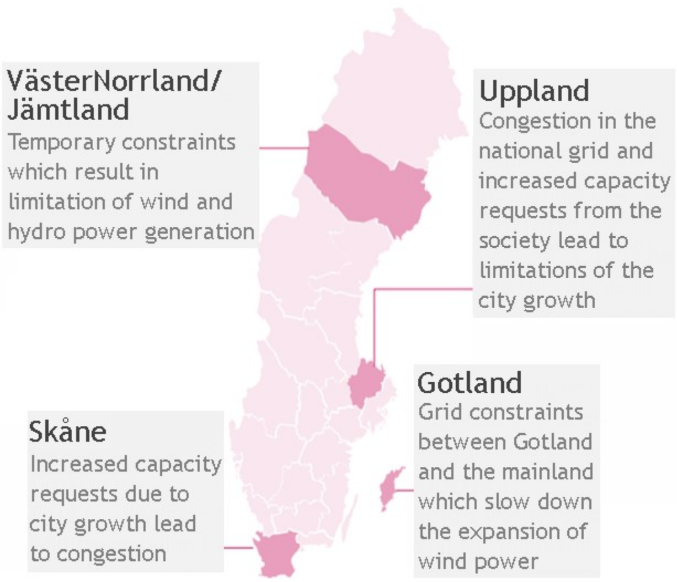

Figure 3: Swedish demonstrator

3. PRODUCTS, SERVICES AND COORDINATION SCHEMES

In CoordiNet, the services that guarantee the development and stable operation of the transmission and distribution networks, are called "system services" and defined as "services provided to DSOs and TSOs to keep the operation of the grid within acceptable limits for security of supply and which are delivered mainly by third parties" (based on [2]).

The system services considered in CoordiNet are balancing, congestion management, voltage control and controlled islanding. In order to acquire these services in a market environment, CoordiNet defines standard products, which are harmonized products for the exchange of system service(s) with common characteristics across Europe (i.e. shared by all TSOs or by all DSOs or by all TSOs and DSOs). Not all product attributes are defined in advance, as some of them can be left at the discretion of the TSOs and/or DSOs procuring the product [3]. Likewise, a single standard product can be used to provide several services, e.g. balancing and congestion management.

After defining the services and products, different alternatives for TSO and DSO coordination have also been specified, understanding a coordination scheme as "the relation between TSO and DSO, defining the roles and responsibilities of each system operator, when procuring and using system services provided by the distribution grid"[4]. TSO-DSO coordination is needed to ensure an optimal use of the inherent flexibility of DER and, thus, the market design must allow a close collaboration between system operators. Since there is no single solution that fulfils the needs of all power systems (due to local circumstances, market maturity or regulatory conditions) there are many possible TSO-DSO coordination schemes. In addition, certain features of the coordination schemes may have to mature, so it is convenient to present several alternatives, with a flexible categorisation structure. Hence, four classification layers have been defined: Need ("Where is the need located in the system?"), Buyer ("Who is the primary buyer of the flexibility?"), Markets ("How many markets are considered?") and Access ("Does the TSO have access to assets on distribution level?"). The detailed analysis of these layers leads to seven possible coordination schemes, see Figure 4:

1. Local Market Model: The DSO buys flexibility to solve a local need in one market and no interaction with the central flexibility needs is considered.
2. Central Market Model: The TSO acquires flexibility solely to solve a central need in a single market. If the TSO has access to DER, an information exchange with the DSO is needed.
3. Common Market Model: both local and central needs coming from DSO and TSO are considered in a single market and, thus, the TSO can use assets connected to the distribution grid.
4. Multi-level Market Model: it is a variation of the Common Market Model, in which each system operator uses its own market, rather than through a single market for both.
5. Fragmented Market Model: the market is split as in the Multi-level Market Model, but the TSO has no access to DER. Therefore, resources connected to the distribution grid can only offer their flexibility in the market used by the DSO.

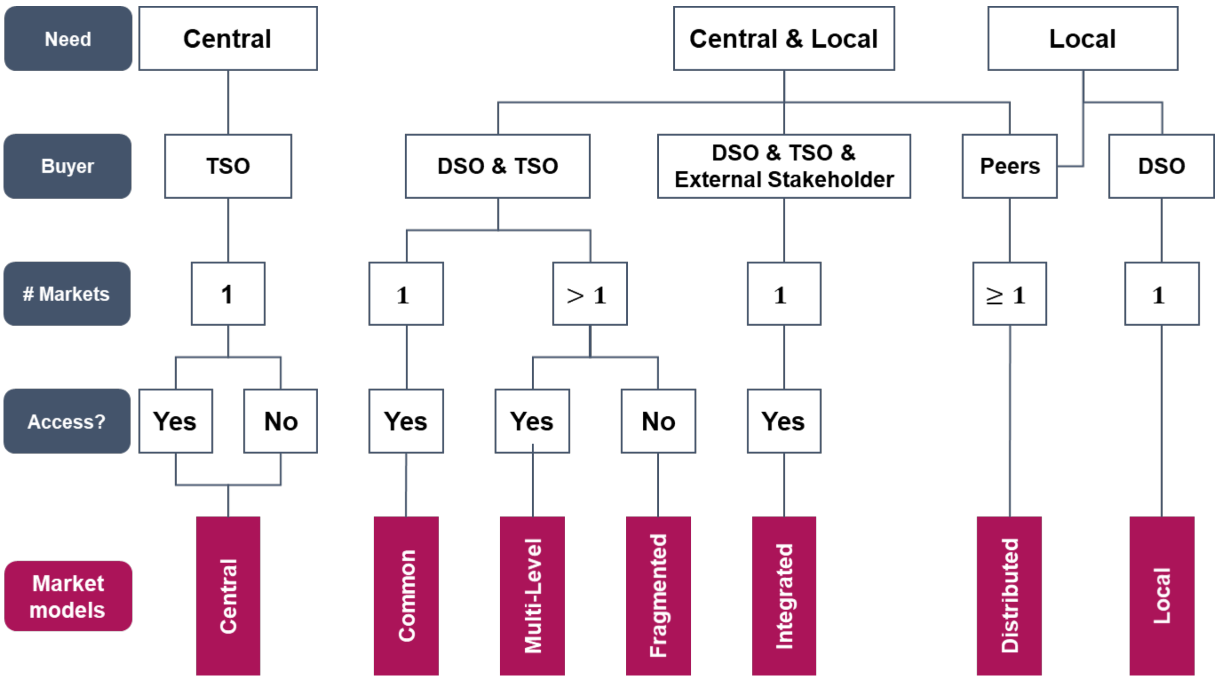

Figure 4: Overview of CoordiNet coordination schemes

6. Integrated Market Model: This coordination scheme also solves local and central needs, but, in addition to the TSO and the DSO, other market agents are also allowed to participate in order to acquire flexibility, both from transmission and distribution, in a single market.
7. Distributed Market Model (s): In this market model, either a local need or both local and central needs are solved through a P2P trade among DER, which are the only sellers and buyers in the market. DSOs and TSOs need to set the rules and mechanisms that align peers' self-interest objectives with global objectives so that agents take actions based only on local interactions and incomplete knowledge that improves or maintains system reliability levels and quality of service.

These coordination schemes can be applied to different services or even a combination of them, so they do not depend on the service to be considered. Likewise, coordination schemes focus on how services are procured, but do not detail the type of information that TSOs and DSOs exchange.

4. BUSINESS USE CASES

The products, services and coordination schemes have been used to define the Business Use Cases (BUCs) to be tested in the different demonstrators. A BUC has been defined for each service and coordination scheme, which will be tested in a demonstrator, as shown in Figure 5. In order to identify the advantages and disadvantages of the different setups, the congestion management service will be tested under two different coordination schemes in each country: the multi-level and fragmented market models in Greece; the local and the common market models in Spain; and the multi-level and the distributed market models in Sweden.

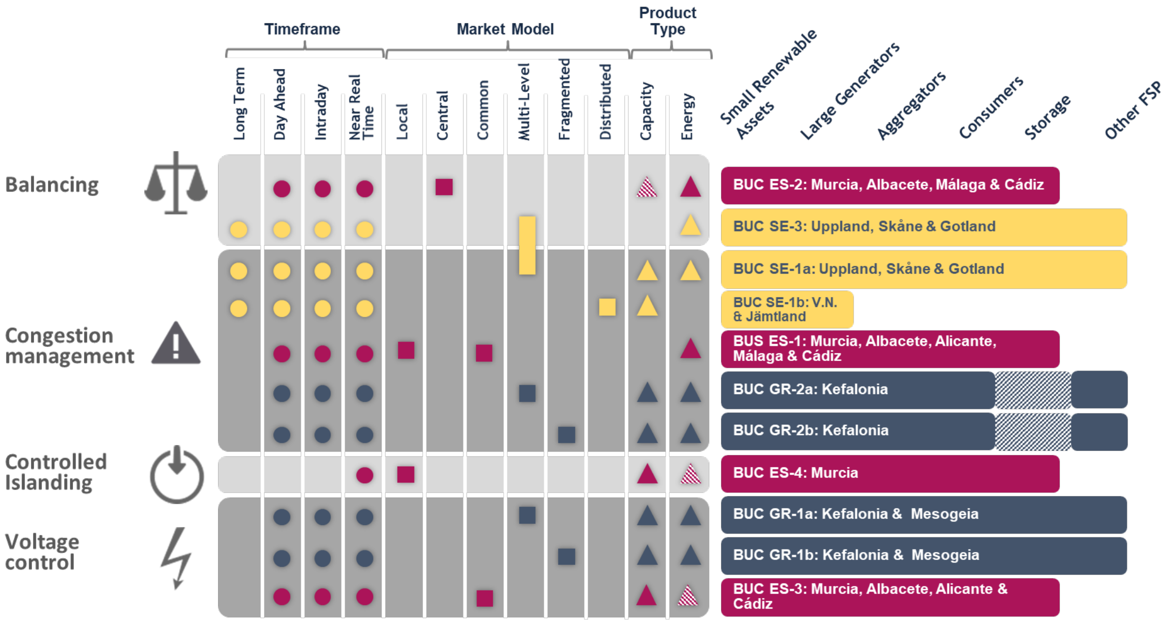

Figure 5: Overview of CoordiNet BUCs

5. EUROPEAN PLATFORM FOR THE PROCUREMENT OF SYSTEM SERVICES

European countries have achieved important milestones in the harmonisation of the electricity markets, such as the implementation of market coupling for the forward, day-ahead market and the continuous intraday market. The balancing markets, however, still diverge significantly among them [5], but agreements are being made as requested by the Electricity Balancing Guideline [6], which applies to all TSOs in the European Union (EU). The implementation of the Guideline has focused so far [7] in the implementation of different TSO-TSO platforms to create harmonised playing fields for all European market participants and to improve the procurement of different balancing products by establishing cross-border procurement procedures.

However, the increasing decarbonisation and the subsequent increase of production connected at distribution networks will demand a closer collaboration between TSOs and DSOs and, hence, the creation of TSO-DSO platforms is an emerging topic in Europe. In addition to CoordiNet, several other EU-funded projects are dealing with TSO-DSO cooperation to procure system services [8] and even commercial applications [9] are starting to emerge in Europe [10], [11], [12], [13].
In this context, the CoordiNet project is also defining the characteristics that (a) future pan-European platform(s) for the procurement of system services should have. The CoordiNet platform is an interface that is intended to manage different interactions between the TSO, DSOs and FSPs to coordinate the different functions necessary to perform the BUCs [14] of the different demonstrators shown in Figure 5. Some relevant functions to be performed by the platform include: data exchange between actors related to both market bids and technical limitations on networks, market clearing functions, communication of market results, submission of activation bids to service providers and grid operators, validation of bids activation, prequalification and settlement process. The focus of the definition process in CoordiNet is on the roles and functions this platform may have, but not on the ownership of the platform or on the governance structure. The deployment of this platform implies:

- Defining the architecture of the platform, which is made of three main blocks, representing grid monitoring & operation, market clearing and aggregation & disaggregation.
- Describing the characteristics and potential algorithms for the different functionalities (RES generation and demand forecasting, state estimation, flexibility bid creation, market clearing, dispatching of units, etc.) of the different blocks included in the integrated system, in order to ensure the interoperability of the different markets and platforms developed by TSOs and DSOs across Europe.
- Developing the various blocks of the market platforms in coordination with the demonstrators, as the latter will use them to test specific innovative standardised products.
- Specifying and developing common interfaces between the various blocks of the platform.
- Identifying potential gaps and needs of alignment between the demonstration projects to initiate the standardisation process of future system services and market platform solutions (including innovative technologies).

Figure 6 shows the three blocks to be developed and integrated within the CoordiNet platform and some of their functionalities, as well as the interfaces linking them.

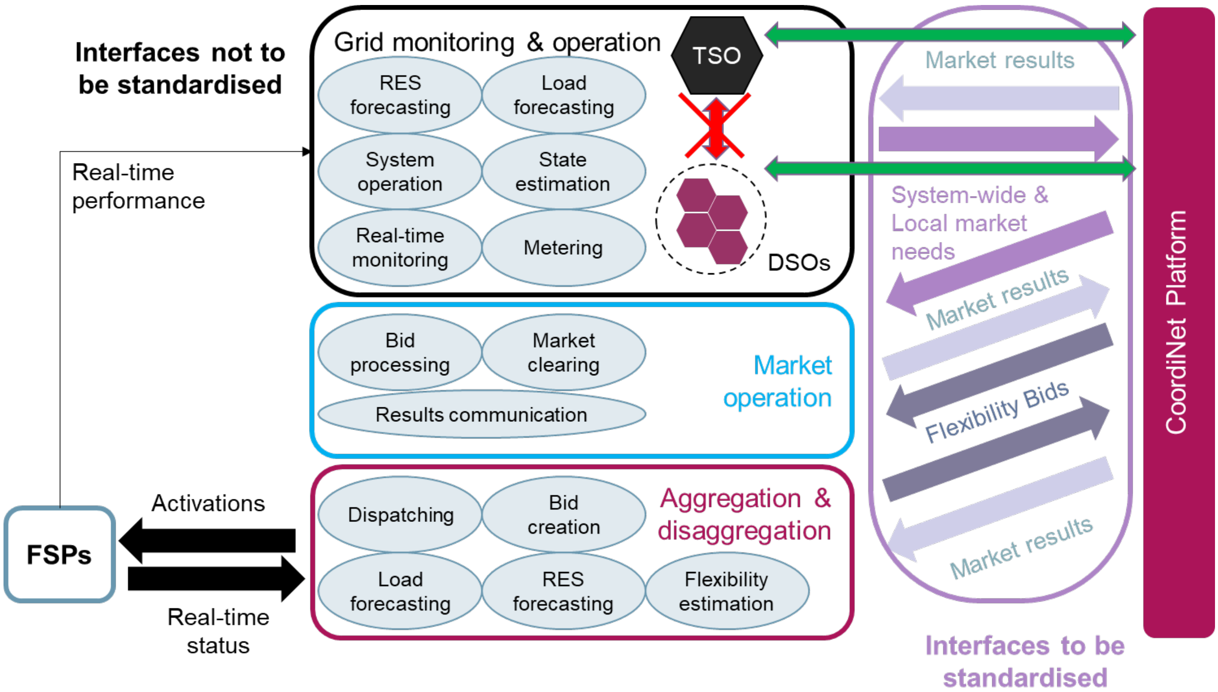

Figure 6: CoordiNet platform concept

5. 1 Grid monitoring & operation

The grid monitoring & operation module [15] identifies the flexibility needs and sends such information to the CoordiNet platform, so that it can be used by the market operation module as demand bids. In order to be able to identify the communication needs between this module and the CoordiNet platform, the functionalities and requirements of the tools for monitoring and operating the distribution and transmission systems have been reviewed in detail. For that purpose, a state-of-the-art literature review on the required tools was made, including generation and load forecasting and state estimation. This literature review was complemented by gathering real-life information from the different demonstration campaigns involved in the project. Initially, based on the needs of the BUCs, the three demonstration campaigns (Spanish, Swedish and Greek) identified the required functionalities to address these needs. Then, they identified the necessary tools to deliver these functionalities and, as a final step, they identified the generic requirements of the tools. This procedure was iterative, as new functionalities and requirements might be identified during the progress of the demonstration campaigns, as illustrated in Figure 7.

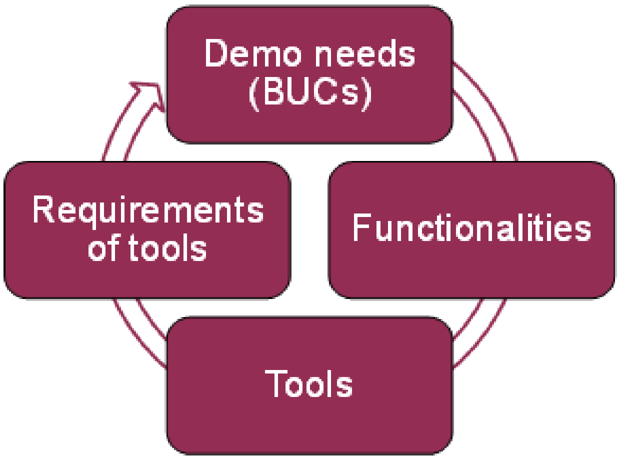

Figure 7: Procedure followed to identify the functionalities and requirements of the tools

For a better understanding of the work performed, the definitions of a tool, a functionality and a requirement are provided below. It must be stressed that these definitions reflect the interpretation of the CoordiNet project and they are not officially used outside of the project:

- A **tool** is defined as a system or a computer software used to perform an operation.
- A **functionality** is defined as a core function of a tool or a set of tools which should be performed for the tool(s) to meet the needs of the users. In other words, a functionality defines the objective of the tool(s).
- A **requirement** is defined as a criterion or a set of criteria which should be met in order for the tool to deliver the desired outcome. A requirement describes the tool behaviour, the simplifying assumptions which have been considered, data management procedures, the communication with other tools, etc. In other words, the requirements are the means by which a tool achieves its objective(s).

5.2 Market operation

The market operation module [16] matches the demand bids received from the grid monitoring & operation module with the offer bids sent by the aggregation & disaggregation module (see below). The market operation developed in CoordiNet requires the definition of local and central markets to procure system services from large-scale and small-scale assets connected to the electricity network. Therefore, the relation between central, regional and local markets, as well as the structure (bidding times, market horizon, clearing frequency, etc.) and the corresponding clearing algorithms need to be defined. As a first step, a common framework for the market design needs was established. Based on this guideline, the own designs implemented by the demonstration campaigns were analysed.

Lastly, through several dimensions (such as market efficiency, complexity, gaming opportunities, etc.), the market designs chosen by the demonstrators were assessed, as an input for the overall analysis of the most appropriate ones for an ideal future EU market design for these use cases that will be carried out in later stages of the project. Furthermore, a review of existing baseline calculation methodologies was made in order to assess the suitability of each of them to be used in the BUCs developed in the different demonstration campaigns.

5.3 Aggregation & disaggregation

The aggregation and disaggregation module [17] comprises two main processes. The aggregation process estimates the flexibility available in the different units (either small DER or large flexibility assets) and the best pricing strategy, in order to send the offer bids to the market operation module. Then, after market results are received, the disaggregation process sends the activation signals to the most appropriate units in the aggregator's portfolio. In the CoordiNet project, different aggregation and disaggregation alternatives for exploiting the aggregated flexibility of small resources into dedicated flexibility markets were investigated, focusing on the market architectures and the DER available at the different demonstration campaigns. The aggregation process is composed of three main optimisation steps:

1. **Flexibility models**, which describe how the power production or consumption of a given flexible resource changes with dynamic inputs and control commands.
2. **Market bidding optimization algorithms**, for market participation including various objective functions for the maximization of aggregator profits, maximization of offered capacity, etc.
3. **Resource operation**, which results in a disaggregation process for complying with market assignments based on optimised flexibility allocation considering the most recent resource status. It also comprises the detection and correction of deviations between agreed and the actual flexibility delivered.

Different algorithms and models were analysed for each category. For flexible resources with a well-known parametrisation (such as PV, CHP and other generation technologies), physical models can be used, while for processes with higher uncertainties (like HVAC, residential loads, etc.) grey-box models or black-box models will be used [18]. For the market bidding component, classical optimisation algorithms (mixed-integer linear programming or others) and algorithms based on artificial intelligence (genetic algorithms) were investigated. The real-time operation problem for disaggregation and correction of deviations was also addressed from different perspectives, both through classical optimisation (such as model predictive control) and evolutionary algorithms (like genetic algorithms).

5.4 Interfaces

In order to ensure the interoperability of the pan-European platform(s) for the procurement of system services, the different modules described so far must be able to communicate with each other, regardless of their internal processes. Therefore, the inputs and outputs of each module need to be identified, with a view to standardise the interfaces among the blocks. For that purpose, the work is based on the Smart Grid Architecture Model (SGAM) [19]. The CoordiNet project intends to develop the five Interoperability Layers defined in SGAM for the described demonstration campaigns and associated BUCs: the *Business Layer*, which maps the regulation and economic structures (business actors); the *Function Layer*, which describes functions and services; the *Information Layer*, which describes information objects within data models; the *Communication Layer* which describes communications mechanisms and protocols to transfer the information; the *Component Layer* which maps physical components of the smart grid, covering everything from information and communication technology equipment to the power system itself.

The Business and Function Layers have been carried out for each demonstration campaign and are presented in [14]. The Component Layer is presented in [20] and the rest of the layers are being created at the time of writing this paper (December 2020). As an example, the preliminary diagram of the architecture for the Spanish demo (Component Layer) is shown in Figure 8 [21].

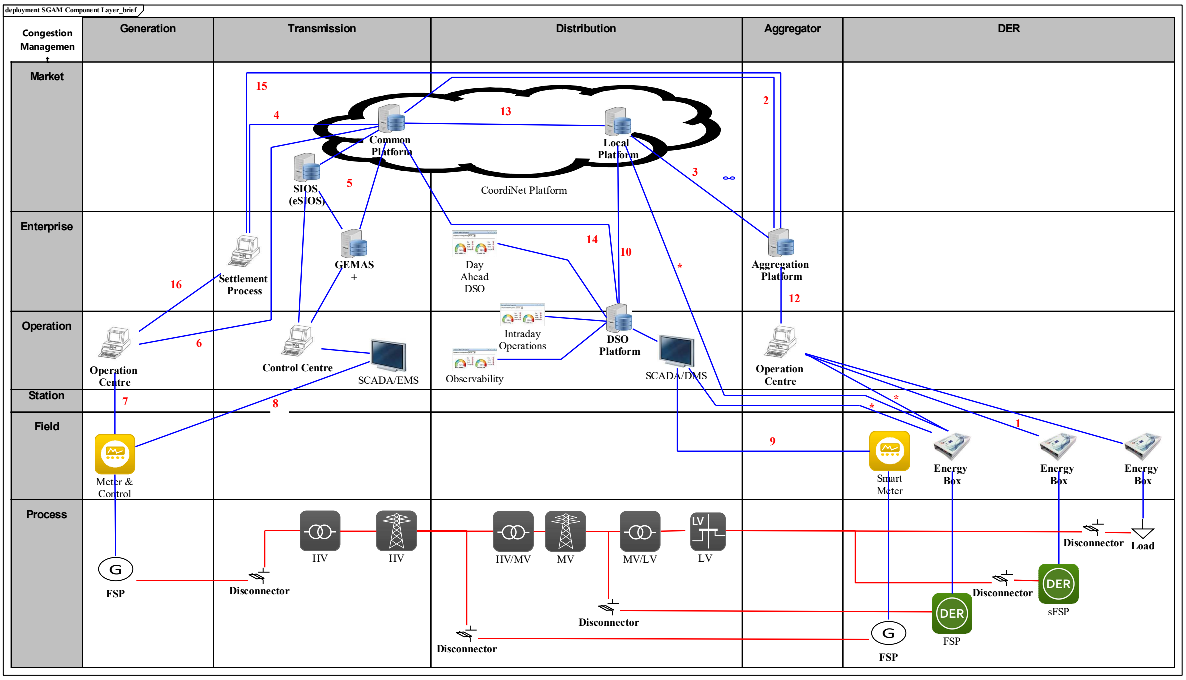

Figure 8: Preliminary Diagram of the Architecture for the Spanish demonstrator [21]

6. CONCLUSIONS

The CoordiNet project aims to demonstrate how DSOs and TSOs shall act in a coordinated manner to procure system services in the most reliable and efficient way. For that purpose, different products, services and coordination schemes have been defined and are being implemented in different demonstration campaigns in Greece, Spain and Sweden. In order to derive the recommendations to design and implement the future pan-European platform(s) for the procurement of system services, a generic architecture has been proposed, which is composed of three main blocks: 1) the one including the tools used by DSOs and TSOs to monitor & operate the system, 2) the one including market clearing tools and 3) the aggregation & disaggregation block, which estimates the available flexibility, creates the bids and, once the market is cleared, sends the right activation signals to the different units providing flexibility. The information exchanges among these three blocks have been identified and there is an ongoing work to create the SGAM diagrams for the five Interoperability Layers and for all the BUCs being implemented in the demonstration campaigns. Once these layers are completed, existing standards will be analysed and, if needed, new standardisation proposals will be made.

ACKNOWLEDGEMENTS

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