MODELING ELECTRICAL ENERGY FUNCTIONS OFFERED BY DISTRIBUTED ENERGY RESOURCES USING IEC 61850 – A REPORT FROM THE EUROPEAN RESEARCH PROJECT OS4ES.

1 Introduction

Today, mass presence of distributed energy resources (DERs) connected to the grid is often seen as having adverse effects on grid reliability and robustness, thus complicating or even compromising the network management by DSOs (Distribution System Operators) and other Balance-Responsible Parties (BRPs). In many networks, the contribution of intermittent generation from photo voltaic (PV) installations or from wind turbines has achieved 25% or more of the installed power. A large amount of these renewables benefit from a feed-in tariff that is guaranteed with a long term contract that was established by the regulation authorities to accelerate the investment in renewable technologies. This not only creates various problems for the DSOs, it as well creates a distortion of the energy market.

It is assumed that in the future, these guaranteed feed-in tariffs will not exist anymore and an owner of a DER system that wants to feed electricity into the grid may need as well to go in some way through the energy market in order to get financial compensation. Since this is however not realistic for small DER systems as roof-top PV installations, new scenarios need to be developed.

To investigate into technology that would be needed to support such new scenarios is the main goal of the research project Open System for Energy Services (OS4ES), which is sponsored by the European Community under the FP7 program. Partners in the project are industry and research organizations, a telecommunication service provider and a distribution system operator from Germany, The Netherlands, Switzerland, Spain, Croatia and Greece.

The project relies on the use of the international standard IEC 61850 as a base technology [1]. While IEC 61850 was introduced in 2005 for the use in substation automation, it become soon clear that the concepts defined in the standard can be used for other applications in the power system automation and can serve as a key technology for Smart Grids. As a first extension towards DERs, IEC 61850-7-420 “Basic communication structure – Distributed energy resources logical nodes” was published in 2009. That standard mainly focused on the modeling of DERs from the internal perspective of a DER unit. In 2013 a technical report (TR) IEC 61850-90-7 “Object models for power converters in distributed energy resources (DER) systems” was published. This report focused on the information models for the functions for power converters used in the information exchange with utilities, energy service providers or other entities that have to manage the volt, var and watt capabilities of these systems.

While IEC 61850-90-7 already addresses the modeling of aspects related to the connection to a grid (the so called grid codes), it was recognized that there was still the need for a generic model to describe all the aspects of the interface of a DER system and the public electrical network. Therefore, IEC TC 57, WG17 decided to start working on a TR IEC 61850-90-15 “DER grid integration using IEC 61850”. The purpose of that TR is, to define a generic model that provides all information needed for the interactions between the DER system, the grid operator where the DER system is connected and aggregators using the DER system.

As part of its scope, the project OS4ES is contributing to the work under development for the TR IEC 61850-90-15. Within IEC 61850-90-15, it is intended to model the generic characteristics of a DER system, the grid interconnection constraints and the electrical energy functions performed by a DER system at the so called point of common coupling (PCC). The point of common coupling is where the DER system is connected to the public electricity network. The DER system can be anything from a small DER unit like a rooftop PV up to the interface to a large facility grid consisting of local generation and load that offers electrical energy functions towards the public electricity network.

2 The approach used by OS4ES

As already mentioned in the introduction, OS4ES is investigating in technology used for new scenarios about DER grid integration. The basic approach is assuming, that a DER system will not participate directly in the market; instead it is offering its services through an aggregator. A distributed registry is used as a platform for the DER system to offer the services to the aggregator. Services provided can be based on a long term relationship between the DER system and the aggregator as well as on a dynamic, short term relationship.

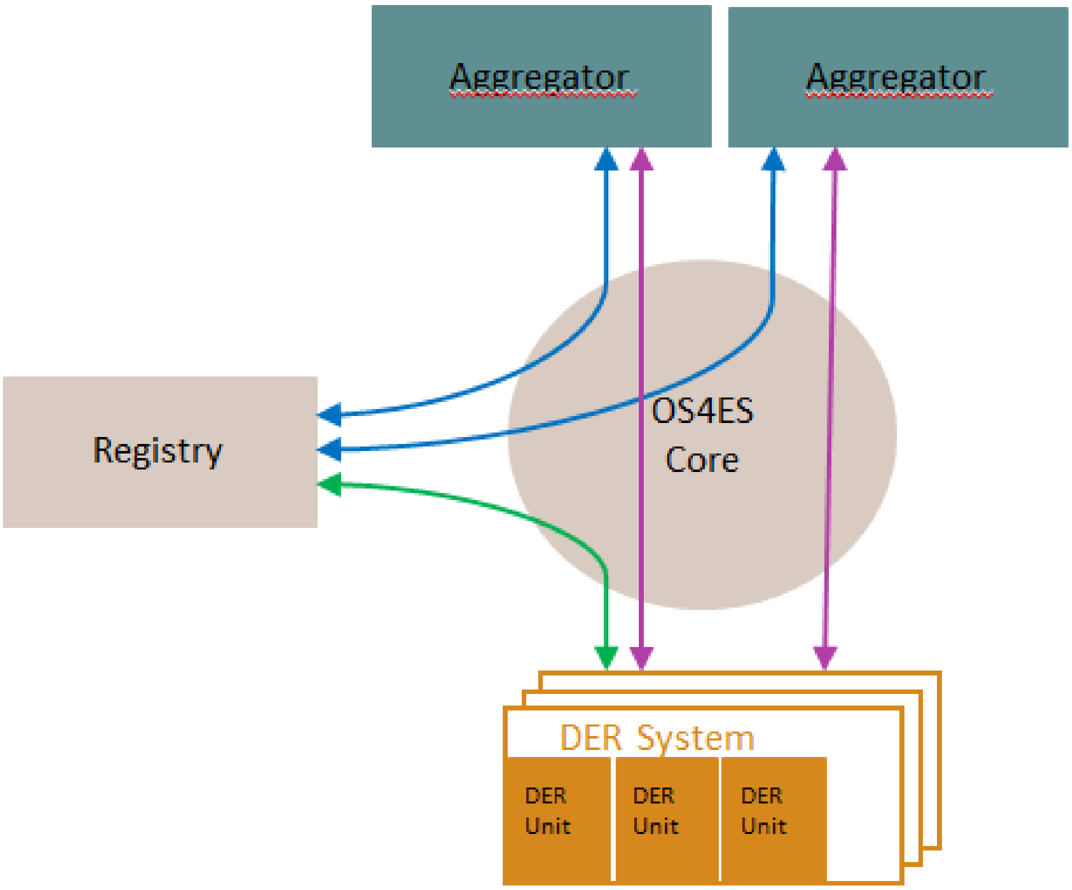

Figure 1: Interactions between DER system, registry and aggregator

The basic approach is visualized in Figure 1. A DER system registers itself with all relevant information including the information where in the electrical grid the DER system is connected and the electrical energy functions offered in the registry. The DER system continuously updates actual values for the electrical energy functions in the registry. Through the registry, authorized aggregators can search for matching electrical energy functions, so as to contract and reserve them, and finally operate them. When an electrical energy function, or parts of it, has been reserved by a specific aggregator, the registry informs the DER system of its reservation. Now, the aggregator can interact directly with the DER system. As part of this interaction, the DER system will send updates of the actual values as well as forecasts to the aggregator.

In the typical example of a virtual power plant (see Figure 2), an aggregator will maintain long term contracts with various DER systems. The DER systems will provide the forecast for e.g. the next day, taking into consideration own usage of resources, maintenance and maybe weather based conditions. Based on that information, the aggregator can create his schedule as VPP for the next day and can send schedules to the various DER systems. In such a use case, the registry mainly acts as a platform to establish the initial relation between an aggregator and the DER system.

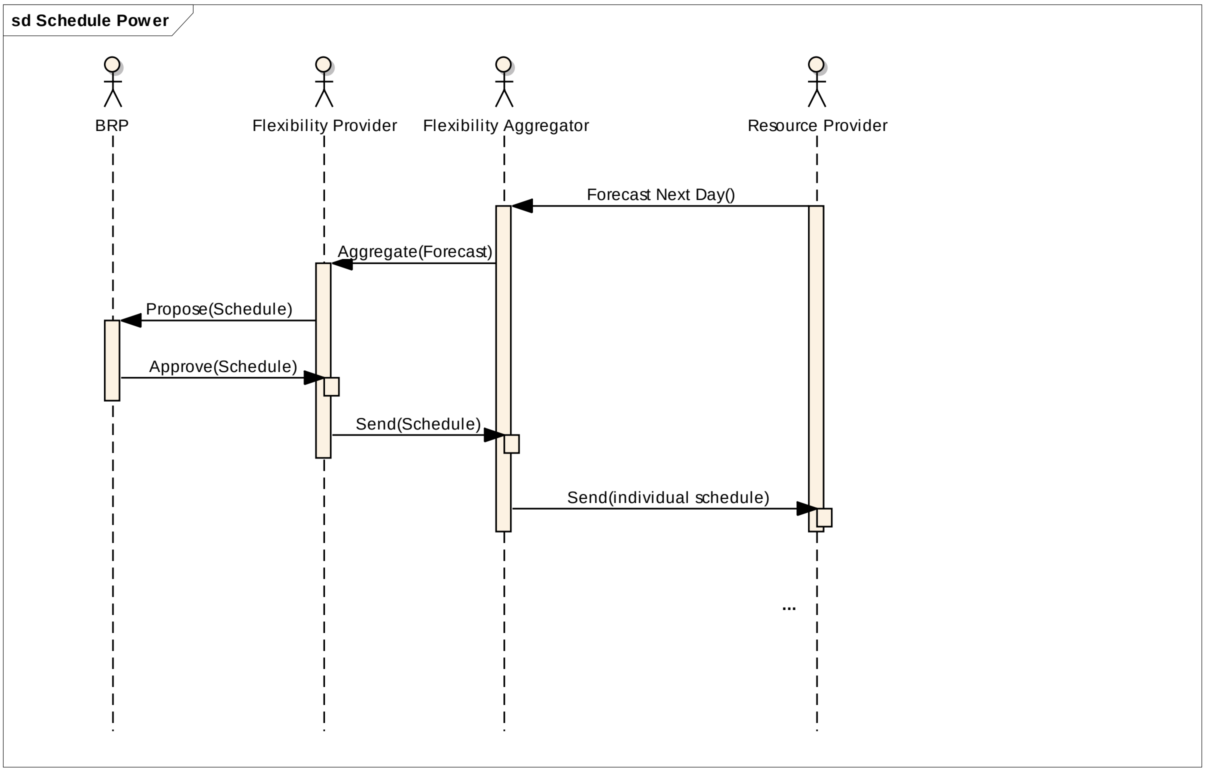

Figure 2: Example of a virtual power plant

Other use cases may be driven by critical situations in the electrical grid. In such a case, an aggregator or a DSO may search the registry for resources available in near time and maybe in a particular area of the grid. In such cases, the registry acts as a platform to offer flexibility. Contracts between the aggregator and the DER system may be of limited duration.

3 The DER system

Based on the current discussions in IEC TC57 / WG17, the key element for integration of DERs to the grid is a DER system. A DER system may be built up of 1-n DER units (e.g. PV unit, battery, CHP) or a hierarchy of any combination of DER units and systems. A DER unit is an individual appliance (DER) or a group of DERs of the same type – e.g. an array of PV cells is considered as a DER unit – that actually produces energy and/or consumes energy and can be accessed through a DER-system.

Other than a DER unit, the interface to the DER system is standardized and generic in the sense that it is agnostic to the type of underlying DER. For the integration of DERs to the grid, the interface at the PCC will be modeled as a DER system. This DER system describes the capabilities that can be provided at a PCC. The concept of the DER system and the interface to the utility grid is shown in Figure 3.

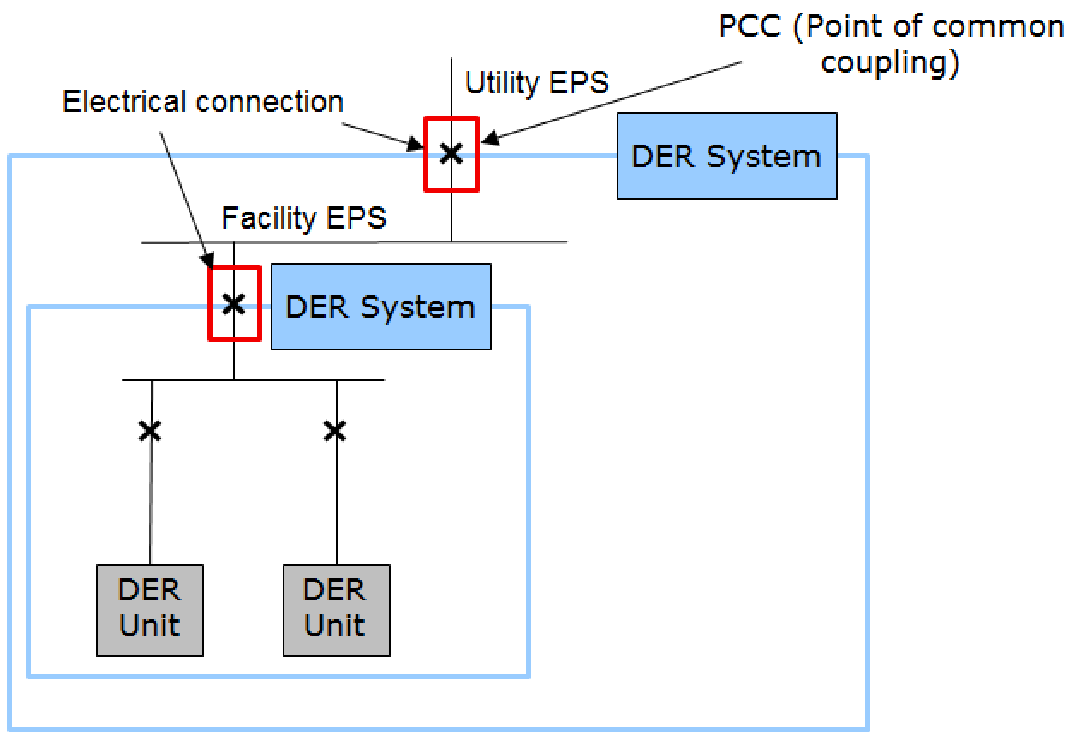

Figure 3: The concept of a DER system

In the simplest case, a DER system connected to the utility grid may just be a local DER unit like a PV installation. But it may as well be a system that has a local management system combining a battery with a PV system in order to optimize the local consumption. In such a case, the DER system at the PCC only models what is available to be supplied to (or consumed from) the grid. In the most generic case, there may be a facility electrical power system (EPS) as a microgrid that includes local generation, load as well as storage capabilities. Again, the DER system is modeling the characteristics of the interface between the facility EPS and the utility grid.

4 Electrical energy functions offered by a DER system

4.1 Basic concept

In OS4ES, electrical energy functions (called energy services in OS4ES) are introduced as the capabilities a DER system can provide at the PCC like supply of active power or reactive power. A single DER system may offer multiple electrical energy functions at the same time, depending on its capabilities. The actual values of a function offered may vary over time based on own usage and forecast. As described, an aggregator may reserve a function as a whole or part of it. Reservation of a function by an aggregator does not necessarily require immediate activation: a reserved and contracted function can be used as control reserve.

With the above definition, an electrical energy function is a consumable resource that can be contracted, reserved and activated by the aggregator. In order to make this scenario happen both a semantic data model for DER systems and the registry have been developed. It is so generic that it hides the complexity of single DERs - may it be generators, loads or storages - within a DER system and provides generalized and aggregated data. Besides, the data model allows matching algorithms to operate on clearly defined data objects and to find the correct aggregation of energy functions for a given network problem and use this function to e.g. perform frequency control or voltage regulation. The key elements of the data model are the energy functions provided by the DER systems and the associated parameters. Associated to these functions are rated values (static) as well as actual values (dynamic). That information is held in the registry. In addition, location and access related information as well as generic characteristics are stored. The model includes as well the objects required to control the DER system, to maintain reservation of energy functions, to enable partial reservation and additional detailed characteristics of DER systems that is not required to be stored in the registry. The available functions and the values for their dynamic parameters are updated by the DER system based on actual conditions and forecast taking into consideration both own usage of resources and dependencies that may exist between different functions offered.

4.2 Electrical energy functions in OS4ES

By analysis and means of abstraction the taxonomy of energy functions, shown in Figure 4 in UML syntax has been deducted. The functions defined can be categorized into functions related to active power and functions related to reactive power. Variants of the functions for active power include autonomous frequency control (used for primary control) and various models for providing flexibility. A variant of reactive power is autonomous voltage control (used for Volt/VAr control).

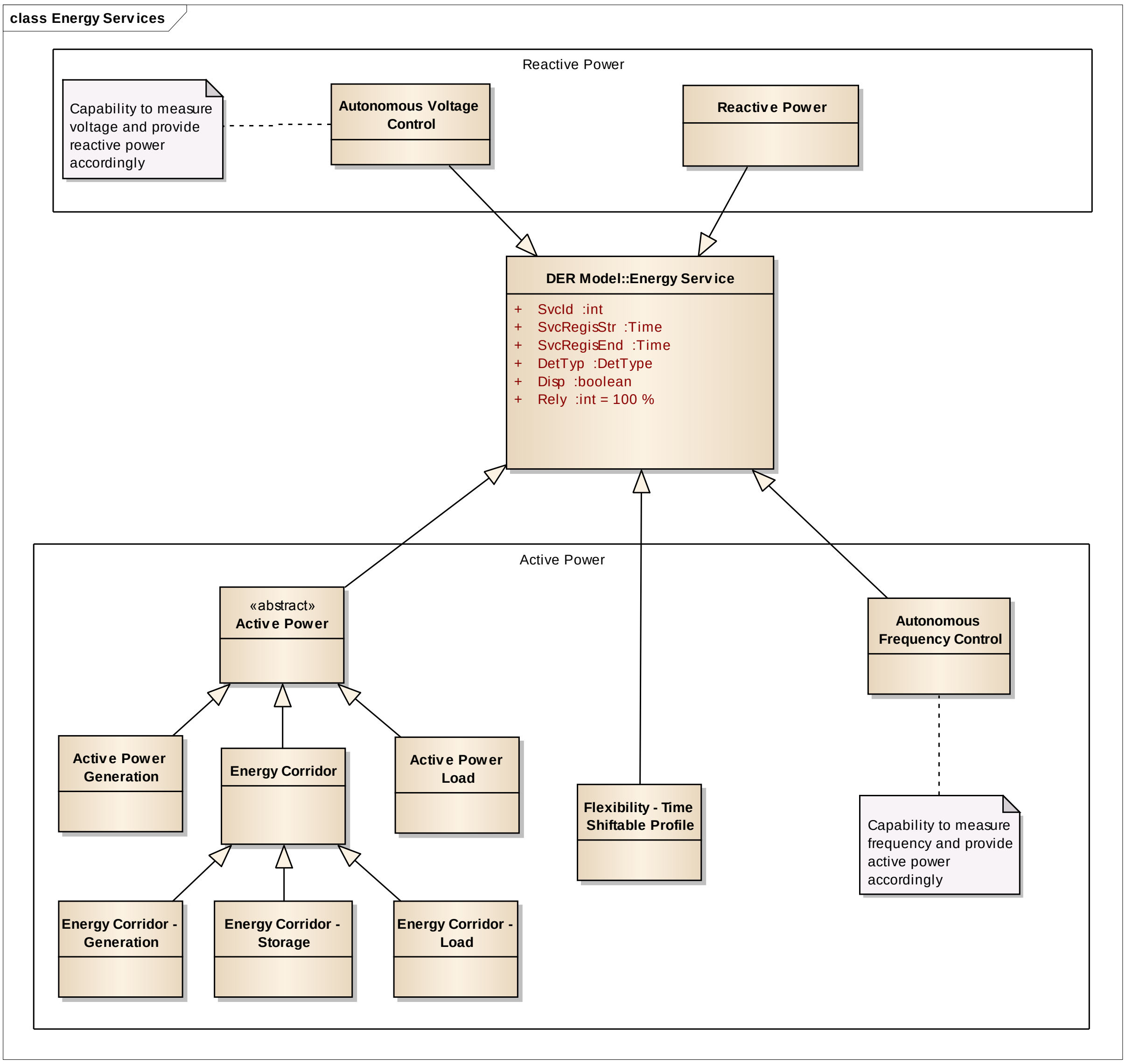

Figure 4: Electrical energy functions defined in OS4ES

Since electrical energy functions are defined from the perspective of a DER system, there is no need to differentiate if the capability to provide active power is used by an aggregator to deliver active power or if it is used to offer secondary or tertiary control power. However, in order to offer primary control power, the DER system needs to be able to measure the system frequency and autonomously provide active power accordingly. This is the reason why we model the primary control energy function as an additional function (autonomous frequency control) to the active power service. The same argument applies for reactive power function and autonomous voltage control function.

The electrical energy function only model what is offered at the PCC (Point of common coupling) and exclude local usage of the DER system (own consumption). That means values indicated are the remaining net values that are avail-able at the PCC.

One of the main problems in the provision of e functions are conditional interdependencies between them, i.e. the determinism of some functions which strongly depend on other functions. Some energy functions may only be provided if some amount of active power is already scheduled (e.g. reactive power, frequency control). They must rely on the scheduling, planning and credibility of the active power scheduling. In current grids, these energy functions are provided by must-run power plants that are always providing active power. Within the OS4ES project the requirement for must-run power plants shall be minimized as DER systems could also provide the needed capabilities (e.g. through modern inverter technology).

4.3 Reservation of electrical energy functions

A reservation of an energy function may be required. From the perspective of a generic model, a user of a function offered by a DER system may reserve that function for a specific time and a specific amount if applicable. Once the energy function or part of it has been reserved, the DER system cannot update its availability schedule anymore in a way that would violate the reservation. Partial reservation of an energy function is supported by the data model and concept of OS4ES where reasonable. However, what exactly partial reservation means depends on the energy function [5]. Partial reservation requires as well individual setpoints in the DER system for each of the parts that are reserved.

Reservation of a function can be schedule-based. This means, the function user can provide a schedule about what he wants to reserve from a specific function offered by a DER system.

4.4 Rated values, availability and forecast

When a DER system registers its data in the registry it provides general (generic) DER system information including the rated parameters of the DER system itself.

When a DER system registers an electrical energy function, it provides the function related rated parameter values. The function is then offered from the provided start time on until an optional end time. If no end time is provided, the function is available until further notice. The start time may be in the past – in that case the function is available immediately. The availability of the function may be further restricted in amount as well as in time by the availability schedule which takes into consideration own usage of the DER units.

Once the function is offered, the DER system provides continuously updates of the actual parameter values for that function. Optionally, a non-deterministic DER system may as well be able to provide a forecast as a schedule.

5 Semantic data model

In a first step, a semantic data model of the DER system has been developed. This model was then mapped to define IEC 61850 logical nodes. The semantic data model is explained in detail in the following subchapters.

5.1 Overview on the semantic model

Figure 5 shows the top level view of the model with the embedding of the DER system in the electrical network. A PCC is associated to a zone in the utility grid. Zones are logical representations of a physical system e.g. a local distribution network. DER systems are connected through a PCC to the utility grid. If multiple DER units are connected to the same PCC, these DER units can either be handled as a single DER system or as multiple DER systems.

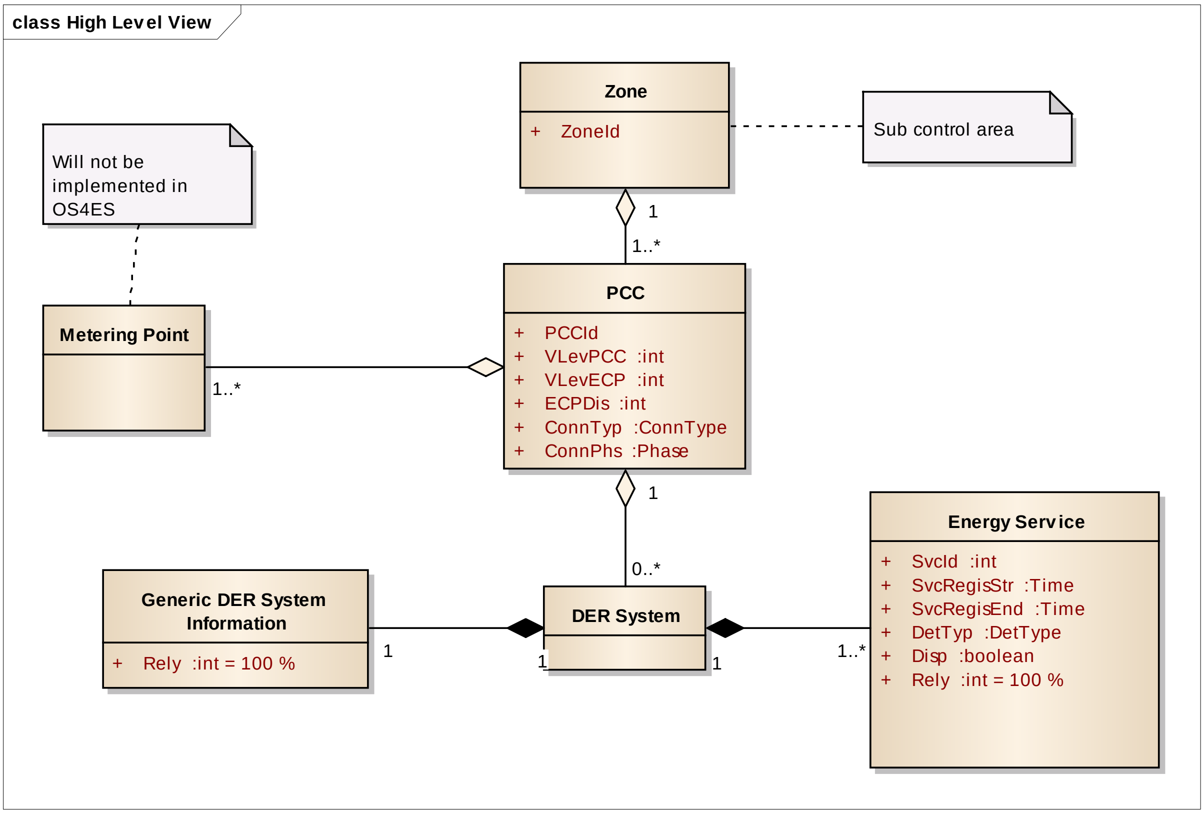

Figure 5: Embedding of the DER system in the electrical network structure

The information for a DER system consists of generic information related to the DER system and the energy functions supported by the DER system with its information. Details of the DER System are shown in Figure 6. The model consists of the characteristics of the DER system and the electrical energy services offered by the DER system with the rated characteristics, the actual values, forecast, and availability schedules and the required setpoints and controls as well as reservation information.

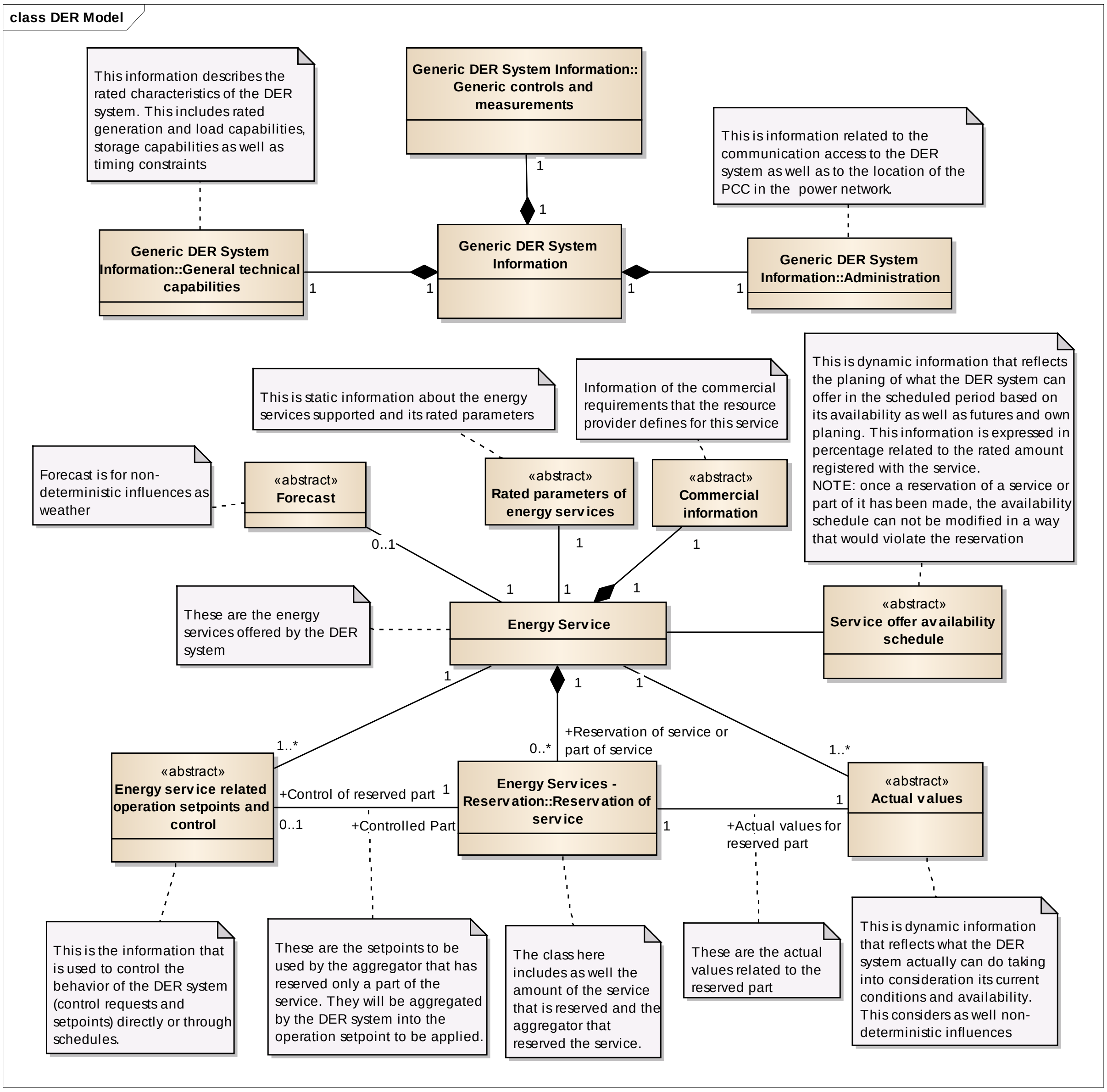

Figure 6: DER model – overview

5.2 Characteristics of the DER system

The characteristics of the DER system include:

- Connection characteristics at PCC like PCC identifier, voltage level at PCC, three phase or single phase connection and others
- Ratings of the DER system for generation, load and storage capabilities
- Other technical characteristics like timing constraints, generic controls and measurements
- Technical capabilities
- Administrative information

Technical capabilities are of relevance in the context of electrical energy functions. Technical capabilities describe

- The type of the DER system – generator, load, reversible storage or a mixture of them
- If the DER system is deterministic or not. Typically PV systems and wind turbines are not deterministic. In that case, a forecast is important.
- If the DER system is able to provide its own forecast.

- If the DER system is able to receive schedules instead of setpoints.
- If the DER system is able to provide an availability schedule as forecast that takes into consideration own usage and maintenance.

5.3 Description of the electrical energy functions

5.3.1 Active power generation

The main purpose of a DER system is, to supply active power, which is described by this function. The key rated parameter of the function is the maximum power that can be supplied under worst case conditions. But depending on the kind of generation device, there is as well a minimum power that can be supplied while switched on.

The actual parameter values for this function is the maximum and if applicable the minimum power that can be supplied under current conditions.

The control of the service is done using a setpoint or a schedule for active power.

5.3.2 Active power load

This function refers to a load that can be controlled from remote without any constraints. In reality, such a system may be rather rare. For this service, the same issues as discussed for generation apply.

5.3.3 Flexibility – Energy corridor

The function "Flexibility – Energy Corridor" is used to model the flexibility provided by DER systems with storage capabilities. This is illustrated in Figure 7 for generation.

The example (Generation) is a generator with storage capacity as e.g. a Combined Heat and Power Plant (CHP) with thermal storage. The DER system requires an average power but has some storage capacity (ΔE in the figure). The device can be switched on and off as needed and the generated power can be selected between the maximum and the minimum rated power of the device such that the power remains within the boundaries provided by the storage capacity, the average power requirements and the initial state of charge (generation starting point).

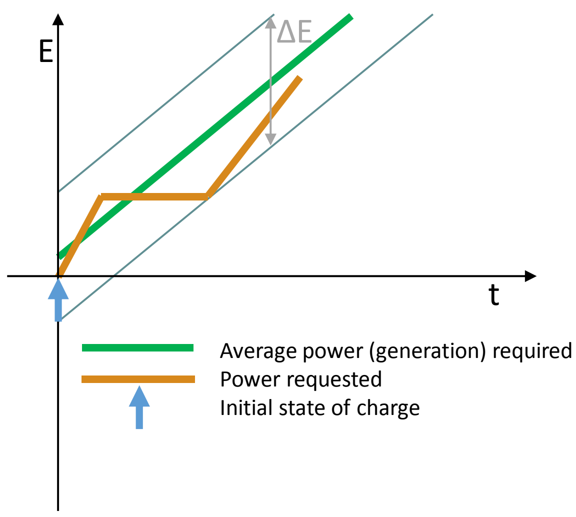

Figure 7: Flexibility – energy corridor

A similar example (Load) would be for controllable loads (e.g. a cool house).

DER systems with reversible storage capabilities (e.g. a battery) can be modeled the same way (Storage), with an average power a little bit below zero (corresponding to the loss of the storage system). Here, the power can either be between the minimum and maximum power for generation, between the minimum and maximum power for load or the DER system can be switched off.

The rated values of this energy function include the values from the active power load and / or active power generation function. In addition, there is a rated value for the energy storage capability, and in the case of reversible storage capabilities some additional parameters.

The actual values include as well the actual values of the active power generation and / or load function. In addition, the actual values describe the energy corridor as explained above.

If the offered function is an energy corridor load or generation and is not reserved by an aggregator, the DER system may need to produce / consume power on its own costs. It may as well update the start time and the function parameters depending on the capabilities.

For active power generation and active power load function, it is possible, that the function is not dispatchable. In that case, it can only be switched on or off. This needs to be done in a way that it stays within the storage limits.

5.3.4 Flexibility – time shiftable profile

This energy function describes typically a load (but could as well be a generator) with a fixed profile that has to be executed. As an example, this could be a charging of an electrical vehicle or a dishwasher. The rated parameters describe the profile. It as well describes if the profile can be interrupted – by default, once started the profile has to be executed without interruption to the end.

The function is offered with an earliest start time, a latest start time and a preferred start time. If the function is interruptible, interruptions are only possible as long as the profile ends within the function end time.

The function can only be reserved as a whole. If the function is not reserved, the DER system needs to decide when it has to start the profile at his own costs and remove the function from the offer or offer it for e.g. the next day.

5.3.5 Autonomous frequency control

This function is used to provide primary control power. The DER system is measuring the frequency and increases or decreases the power based on the frequency deviation. The rated characteristics include the upper and lower power band and the slope.

It is assumed that this service is only offered by deterministic DER systems or at least the service itself is deterministic.

5.3.6 Reactive power

This function is used to provide reactive power. The rated parameters include minimum and maximum values for both positive as well as negative reactive power (capacitive or inductive).

5.3.7 Autonomous voltage control

This function is used to provide voltage control. The system is measuring the voltage and provides reactive power if the voltage deviates from a setpoint. The forecasted values take into consideration already reserved parts of the DER system.

5.4 Model for active power generation function

Figure 8 provides an overview on the complete model for the electrical energy function “Active power generation”.

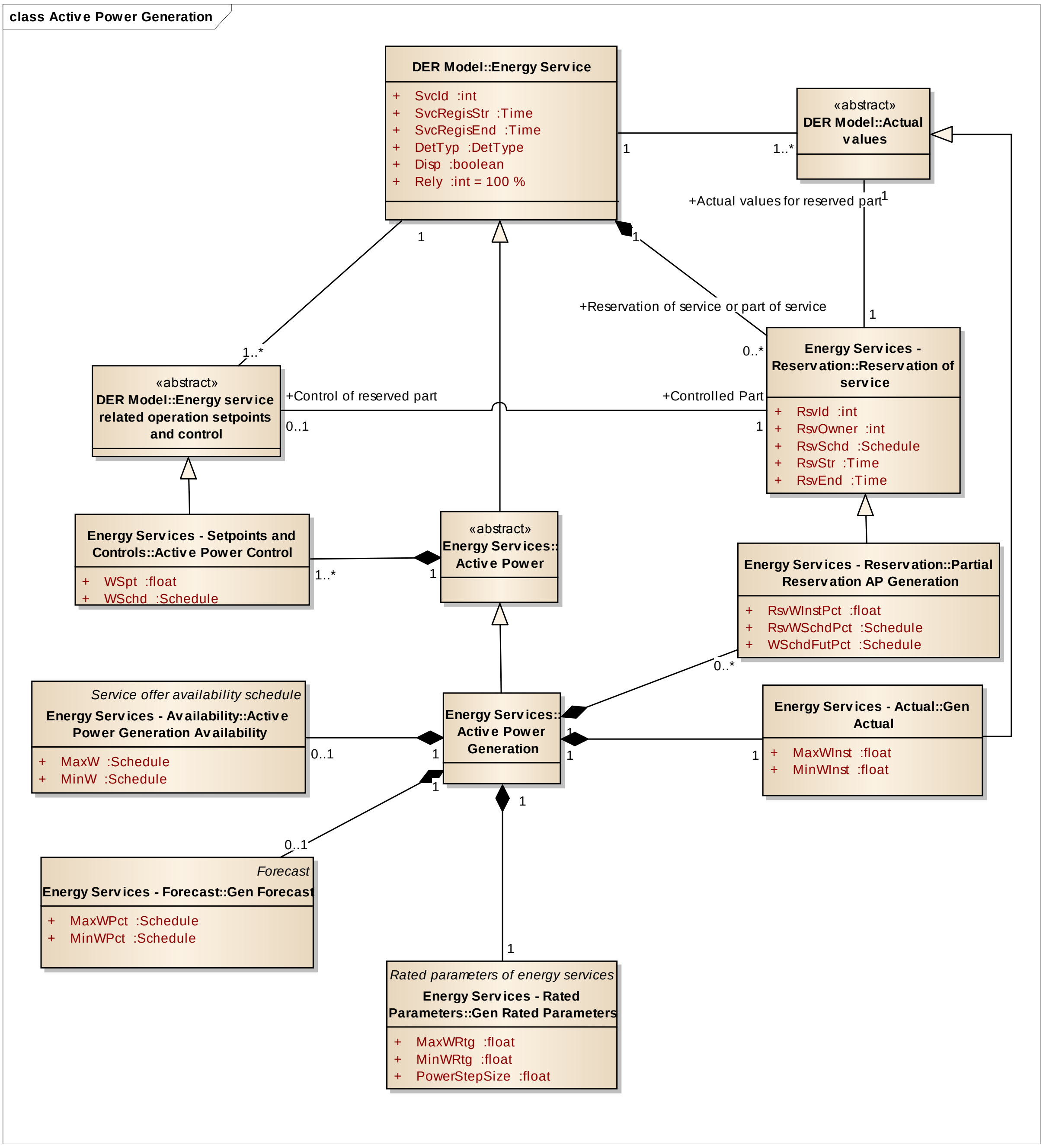

Figure 8: Semantic model for active power generation

6 Supporting functions

An aggregator using a DER system is interacting with a DER system controller. A DER system controller, besides controlling the DER system to execute the requested functions, may as well implement additional supporting functions. These functions include:

- Providing a forecast for non-deterministic DER systems
- Handling of reservations
- Planning the availability of energy functions, considering own usage as well as possible reservations

6.1 Forecast

A DER system may provide a forecast for non-deterministic DER functions. The forecast only applies to active power and reactive power. The forecast is always expressed in percentages of the corresponding rated value of that energy function.

6.2 Planning the availability

If a DER system is used as well locally, the actual values of the energy function offered at the PCC may vary over the time. If the DER system is able to plan this ahead, it may provide availability schedules.

7 IEC 61850 implementation of the model

The semantic model described so far is realized with various IEC 61850 logical nodes. As an example, the characteristics of the DER system are modeled with a logical node DDER. The electrical energy function “Active power generation” is modeled with the logical node DSPG for the rated and actual values as well as for the setpoints. The forecast for active power is modeled with the LN DFAP. It has to be noted that the names and details of these logical nodes may still change in the standard.

An example is given in Figure 9 for the logical node DSPG.

DSPG				
Data object name	**Common data class**	**T**	**Explanation**	**M/O/C**
Status information				
DetTyp	ENS		Behaviour of the DER system. Possible entries are: • deterministic • non-deterministic • hybrid	M
Measured and metered values				
Actual values				
MaxWInst	MV		Actual (instantaneous) maximal active power that can be delivered related to the reserved part	M
MinWInst	MV		Actual minimal active power that can be delivered related to the reserved part	M
Controls				
WSpt	APC		Setpoint for active power	M
Settings				
Disp	SPG		Dispatchable means that the DER system is able to be operated with setpoints provided from an aggregator. Note: It is assumed that all services can be switched off, so the capability to be switched off is not considered for assessing a service to be dispatchable or not. A DER system that is not dispatchable, once switched on, will provide the services based on the current capabilities; e.g. supply as much of active power as is produced	M
Rated parameters				
MaxWRtg	ASG		Maximal rated active power supply for generation	M
MinWRtg	ASG		Minimal rated active power supply for generation	M

Figure 9: LN DSPG for active power generation

8 Conclusion

As part of the OS4ES project, a systematic analysis of use cases for DER grid integration served to define a semantic data model of DER systems that fulfills the requirements. During lab and field tests the data model and the matching algorithms operating on the data of the data model will be extensively tested and if necessary revised.

The semantic model as it has been described in this article as well as the realization with IEC 61850 logical nodes as developed by OS4ES is currently used as contribution to the drafting of IEC 61850-90-15.

9 References

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