INTEROPERABILITY FOR AN OPEN ENERGY FLEXIBILITY MARKET WITH CONGESTION MANAGEMENT SERVICES

Jorrit NUTMA
TNO – The Netherlands
jorrit.nutma@tno.nl

Wilco WIJBRANDI
TNO – The Netherlands
wilco.wijbrandi@tno.nl

Bob RAN
TNO – The Netherlands
bob.ran@tno.nl

Joost LAARAKKERS
TNO – The Netherlands
joost.laarakkers@tno.nl

ABSTRACT

To enable Distribution System Operators to procure flexibility for congestion management, this paper presents a field-tested ecosystem architecture based on an open market for energy flexibility. In this architecture, flexibility can be monetized in multiple ways, for example by trading it on the energy markets or by selling it to a DSO for congestion management. Allowing flexibility to be used for multiple purposes results in a higher value which strengthens the, currently quite weak, business case of parties that aggregate flexibility of many energy resources. As a result, the use of flexibility for congestion management is more likely to be commercially feasible, so delaying or deferring grid investments. To research the former claims, the paper describes the development of an architecture that has a clear separation of roles and responsibilities, is scalable and is ready for real world deployment. A key feature of this architecture is that it uses existing (open) standards for communication between the different parties, preventing vendor lock-in and hence allowing an open market for congestion management services. The architecture covers the trading and dispatch of flexibility, as well as settlement. This full architecture is implemented in the H2020 project called Interflex, where a field test is performed to validate the correctness of the design. In this field test, all roles defined in the architecture are implemented by its corresponding party, being a DSO, commercially active aggregators, and party that is responsible for maintaining the Distributed Energy Resources.

INTRODUCTION

In the process of electrification of (domestic) energy appliances and the rise of Distributed Energy Resources (DERs), the electricity grid is required to transport more electricity, possibly even more than it was designed for. In particular in the Low Voltage and Medium Voltage grid this is expected to result in problems of grid overloading, that can lead to black outs, and Power Quality regulation violations, threatening the network stability. Distribution System Operators (DSOs) are questioning themselves whether they should invest in large scale grid reinforcements or whether they can also use flexibility of DERs to cope with those problems. Although a lot of research to the use flexibility for congestion management has been performed, there is, up to today, no clear answer to that question. An important reason is, among others, that it is unclear what the value of energy flexibility is.

However, the trend is clear: the electrification is increasing and more DERs are being installed. This means that the need for DSOs to find out what the price of flexibility is, now and in the future, is getting more relevant. At the same time, new market parties are emerging that enable the use of flexibility of DERs for several purposes, in particular Energy Service Companies (ESCo's) and aggregators. ESCo's are referred to as parties that have direct access to a physical DER and provide an IT-interface to other parties, allowing them to optimize the flexible use of a DER and to control a DER. Aggregators are referred to as parties that aggregate the flexibility of a large set of DERs allowing them to trade flexibility with other parties or monetize flexibility on the energy markets directly.

There are several pilot projects that aim at bringing the two trends, the questions of DSO regarding flexibility of DERs and the emerge of new market parties, together. However, a large-scale market that is accessible to all and where energy flexibility is traded for congestion management purposes is not operational yet. The reason for this can be found in the complexity of unlocking flexibility, while enabling it to be used for different purposes at the same time.

This paper addresses the problems of the complexity in unlocking flexibility for multiple purposes by introducing an architecture that has two characteristics. Firstly, the architecture defines an open market for flexibility, and secondly, it is designed for a nationwide scale. For the flexibility market to be open, the architecture uses interfaces that are agnostic to how parties implement their business logic, which allows aggregators to use flexibility for several purposes.

To validate the architecture, a demonstration is realized in the European Horizon 2020 Interflex project [1], where project partners *and* market parties represent all different stakeholders in the implementation of the architecture.

The outline of this paper is as follows. First an overview of related work is given. Secondly, the architecture requirements and design consideration are presented. The third part consists of an evaluation of two interfaces that have been chosen to be used in the architecture and which allow interoperability in the architecture. Before ending the paper with the conclusion, a brief description of the field test is given.

RELATED WORK

A similar project, which is also based on the concept of using a flexibility market for congestion management, is a project by the Dutch DSO called Alliander. In 'Nijmegen-Noord' [2]. Alliander uses flexibility of a large heat pump and industrial refrigerators to balance the electricity in a new neighborhood until a new cable will be in operation. The process of getting the new cable in operation takes around four years and until then a flexibility market is used to make sure that the existing grid will not be overloaded. However, 'Nijmegen-Noord' differs with respect to the H2020 Interflex project as follows. In the Interflex project there are two aggregators, which are real market parties, compared to one in 'Nijmegen-Noord'. In addition, applied research institute TNO has also implemented an aggregator system that is also active on the project's flexibility market. Having more than one aggregator allows for a fundamental property of a market-based systems: competition. Secondly, the business model of the two projects differ: in 'Nijmegen-Noord' it is based on deferring the immediate need for a new cable, whilst in the H2020 Interflex project the business model is both based on deferred/avoided grid reinforcements and mitigated component degradation. Finally, other types of DERs are involved, resulting in different flexibility characteristics.
In the H2020 Interflex project, exiting protocols have been used to achieve interoperability, which is crucial for the establishment of an open market. The USEF specification [3] (version 2015) provides an interface for communication between DSO and aggregator.

ARCHITECTURE FOR AN OPEN FLEXIBILITY MARKET

The first requirement of the architecture is that it should provide an open market for flexibility where a level playing field for aggregators is realized. The reason for this requirement is as follows: in the current legal framework, a DSO is not allowed to be active on energy markets if it wants to avoid congestion. However, current legislation does not refrain a DSO from a market for flexibility. In addition, from market theory it follows that an open market will result in an economic efficient outcome. So, if there is an open market for flexibility, where a DSO can procure flexibility for congestion management purposes, it will reduce the costs for those services because of the competition on the market. At the same time, an open market for flexibility also allows aggregators to monetize flexibility on other markets, for example the wholesale energy markets, spot energy markets and markets for ancillary services, which strengthens the business case for aggregators.
A second requirement of the architecture is that it should provide a scalable solution. The flexibility of DERs such as Electrical Vehicles (EVs) can only be used effectively for congestion management services and energy-market trade if it is based on large numbers. In that case, prediction errors that the aggregator will inevitably face can be dealt with by the law of large numbers. This means that the architecture should support systems that count a vast number of DERs.

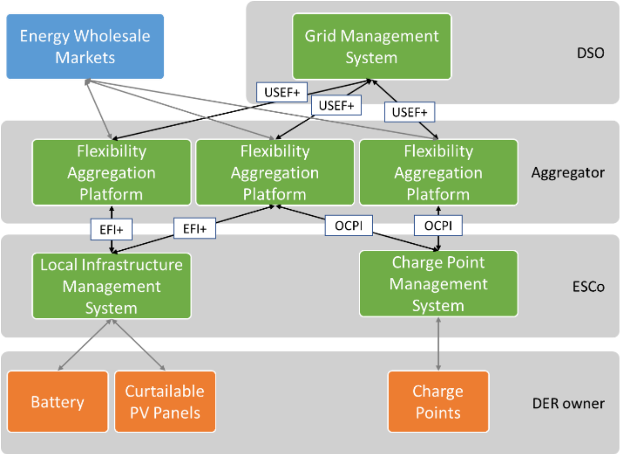

Figure 1: Interflex ecosystem architecture

Those are the main requirements and have led to the architecture shown in Figure 1. The architecture comprises functionality for trading and dispatching flexibility for congestion management, as well as settlement of traded flexibility.
The following sections give three design considerations that elaborate on how the architecture meets the requirements.

Separation of responsibilities

The first role in the architecture is that of the ESCo (at the bottom of Figure 1). ESCo's are responsible for maintaining and operating DERs and provide a communication interface to the party that takes the next role: the aggregator. The aggregator connects to the ESCo's where it receives information about the flexibility characteristics of the DERs. This information is used by the aggregator to optimize the use of the offered flexibility for one or multiple optimization goals. Those goals can include congestion management services and energy market positions.
The third role in the architecture is taken by the DSO. The main responsibility of the DSO is to transport electricity to/from all grid connections while maintaining a proper Power Quality in the LV/MV grid. The DSO might want to use flexibility for this purpose and therefore it has a place in the architecture. The subsystem in the architecture that the DSO uses for this purpose is called a Grid Management System, which forecasts congestion and dispatches congestion management services provided by the aggregators.

Interfaces to achieve interoperability

As Figure 1 shows, the interfaces between the roles in the architecture are USEF, EFI and OCPI. Those interfaces have been designed with interoperability in mind and use a proper data model for the information that needs to be exchanged. Also, none of those interfaces have been designed by a company that has economic interest that their interface is used, preventing vendor lock-in. Another important property of the interfaces is that those interfaces make the least amount of assumptions about the implementing systems. This allows the parties in the system to implement their own logic and minimally restricts them by implementation decisions of other parties. Those two properties of the interfaces contribute to the desired open market design.

Scalability by abstraction layers

One of the characteristics of the architecture is that the level of abstraction increases from the bottom to the top, which contributes to the scalability. At the DER level parameters such as power consumption, voltages levels, device temperatures and availability over time are relevant. However, when a DSO wants to use flexibility of those DERs for congestion management, it should not bother about all those details of individual devices. In contrary, it just should request what the need for flexibility is on an aggregated level. The ESCo translates DER specific parameters to flexibility information, a more abstract phenomenon, and provides it to aggregators. The aggregator translates the flexibility of devices to services such as congestion management services for the DSO or ancillary services on the balancing markets.
Furthermore, the architecture scales also to national level where multiple DSOs and several aggregators are active. One aggregator can be active in the areas of multiple DSOs and have a USEF connection to every DSO.

DSO – AGGREGATOR INTERFACE

The *Universal Smart Energy Framework* (USEF) is a market model for the energy system of the future, comprising currently present roles and envisioned roles in the energy system. Part of this framework is a specification for congestion management services between the DSO and aggregator. This part of USEF is used in H2020 Interflex project because it has proven its value in pilot projects. In addition, this part of USEF is suitable for the application in the Interflex project because it acknowledges that flexibility can be used to deliver various kinds of services. Finally, USEF specifies the aggregator role that matches the aggregator role in the Interflex architecture seamlessly. The USEF specification also contains a XSD that specifies how the messages for congestion management should look like and it contains a thorough description of how the message flow should be realized.
A typical messaging flow for congestion management in USEF is depicted in Figure 2. It works as follows: if a DSO expects congestion in its grid, it will send out a flexibility request to the aggregators that are active on that part of the grid. Aggregators subsequently determine their possibilities to meet the request and can send a flexibility offer to the DSO to indicate what they have to offer. The DSO may receive multiple flexibility offers and then considers which aggregators to send a flexibility order, establishing a deal between DSO and aggregator.

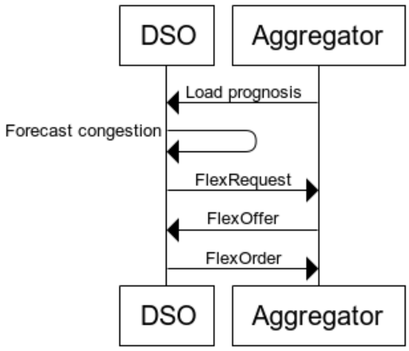

Figure 2: Typical message flow in USEF

USEF distinguishes four regions in the operational phase. Green: business as usual, the energy markets take care of system balancing and no request of DSO are needed for services such as capacity or congestion management. Yellow: the DSO predicts congestion in a part of the grid and requests to use flexibility on the (USEF) flexibility markets. Orange: the DSO can bypass aggregators to control DERs directly in order to avoid grid overloading or Power Quality problems. Red: power outage caused by traditional protection systems or component failure.
There are two problems determined with this model. In the first place, commercial aggregators express that it is unclear when and at what costs the DSO is allowed to switch to the orange regime. This makes them reluctant to trade flexibility with the DSO because the DSO may use the flexibility anyhow if it declares an orange regime to become active. In USEF it is specified that regulation should provide a framework for this but since this is not present yet, it is decided not to use the orange regime in the project. Secondly, there is no possibility to express how likely it is that an aggregator has availability over its forecasted flexibility. For example, it is possible that the EVs need more energy than predicted, then it may be very difficult for an aggregator to deliver the promised flexibility. On the other hand, there might be another aggregator with a big battery for which it is more likely that it can deliver the flexibility. However, USEF does not provide a manner to make a distinction between the flexibility of the two aggregators. This would be desired a feature and a possible solution is tested in the H2020 Interflex project. This results in a small enhancement with respect to the original USEF specification, therefore in Interflex another USEF version is used, referred to as USEF+.

Sanction price

The mechanism to distinguish between different flex characteristics is an important feature of USEF+. This mechanism is realized in the H2020 Interflex project by the addition of a sanction price to a flexibility request. When a DSO sends out a flexibility request to an aggregator, it should add a sanction price value in USEF+. The sanction price must be paid by the aggregator in case that the aggregator did not deliver the flexibility. As a result, if the sanction price is relatively high, aggregators will not offer flexibility of sources that have a high uncertainty of delivery (such as EVs). On the other hand, when an aggregator is sure about the DER to deliver its flexibility, it will accept a higher sanction price. In this way, aggregators will first offer flexibility of DERs that have a high probability that the flexibility will be present. In case that the DSO needs more flexibility, it can send a new flexibility request but now with a lower sanction price, making it more attractive for aggregators to offer flexibility of DERs that are less likely to be present.

Experiences with USEF

In this section some experiences with USEF are given. Although the market design of USEF is not necessarily restricted to day-ahead trade and contains descriptions of services for balancing and intraday purposes as well, the messaging specification and the XSD are designed such that trading on day-ahead basis is implied. Intra-day trade for congestion management purposes is possible but the messages do not support trades that cover a period starting a certain day end ending the next day. This refrains to perform intra-day flexibility trade in the same manner as on the EPEX market, i.e. with a rolling horizon till the end of the next day. In a later phase of the project, intra-day trade will be allowed and then it will be considered if there is need for additional changes to USEF+.
Furthermore, in USEF a design decision related to congestion management is made that has strong disadvantages. All messages in the USEF specification that can be used for congestion management, are congestion point based. This means that all flexibility trading messages only consider one congestion point while there can be a relation between two or more congestion points (via the physical grid). As a result, it might be that solving congestion for congestion point A will lead to (more) congestion on congestion point B. Research should point out if this will only result in extra iterations or that it results in not finding a solution at all.

AGGREGATOR – ESCO INTERFACE

The *Energy Flexibility Interface* (EFI) is a protocol for communication between a DER providing energy flexibility and control logic. The objective of EFI is to communicate the energy flexibility of a DER, without making any assumptions about how the DER operates, or what the objective of the control logic is. This way a clear separation of concerns is made. EFI models the energy flexibility itself. No device specific details (e.g. battery voltage) or market details (e.g. tariffs) are communicated. This way, the control logic is free to decide when the DER for which purpose is being used, e.g. day-ahead or intra-day. EFI is designed as a plug and play interface; no additional information or configuration should be necessary for control logic to interact with a DER. The EFI specification contains an XSD, which defines the XML messages that can be exchanged, as well as the interaction of these messages. EFI is governed by the Flexiblepower Alliance Network [4].
In the Interflex system architecture the control logic is implemented by the aggregator. The fact that EFI makes no assumptions on the working of the control logic fits the open market design and separation of responsibilities objectives of the architecture. With EFI, aggregators can change their control logic or business models, without requiring any changes in the systems of the ESCo’s.

EFI in the Interflex system architecture

EFI is originally designed as an interface between a DER and a *Customer Energy Manager* (CEM) as control logic. A CEM is a software component controlling all DERs within one building, functioning as a representative of the grid connection. It could, for example, aggregate the flexibility of all devices, and communicate this aggregated flexibility to an external aggregator, which would then utilize this flexibility for its own purposes. When an aggregator would like to provide congestion management services, the location of the DERs in the grid is an essential piece of information. This information is not present in EFI because the CEM would provide it to the aggregator.
In the Interflex system architecture however, EFI is used as interface between ESCo and aggregator, bypassing any CEM. The consequence of this is that location information is not available. Since congestion management is an important aspect in the architecture, a new version of EFI was created (referred to as EFI+), in which this information is added.
Within the Interflex system architecture, the ESCo is responsible for operating and maintaining the DERs. In order to do this, scheduled maintenance is required from time to time, making the DER unavailable for the aggregator. Since aggregators may have taken positions on day-ahead markets, it is important for them to know in advance when scheduled maintenance will take place. Given the scalability objective of the architecture, it is desirable that scheduled maintenance will be handled automatically. In EFI+ new functionality was added in which an ESCo can communicate availability of a DER in advance, so the aggregator can automatically incorporate this in their trading strategy.

Experiences with EFI

EFI is designed as an interface which can solve interoperability problems between many brands and models of DERs, and the variety of for control systems. It should be noted that, by having to support so many systems, some simplifications had to be made, which in some cases can limit the capabilities of a DER. It is simply a tradeoff between expressiveness and complexity. For some DERs (especially larger installations), it might be the case that these simplifications impact the capabilities in such way that a custom, device specific interface might be preferred. However, within the H2020 Interflex project, these simplifications had no significant impact on the capabilities of the DERs, and in this case the benefits of EFI clearly outweigh the disadvantages.

The objective of EFI to describe energy flexibility in a way that is both agnostic towards DERs as well as the control logic of the aggregator, fits the objectives of the Interflex system architecture. EFI allows for a clear separation of responsibilities, as well as a scalable and open market.

VALIDATION OF THE ARCHITECTURE

In a field test [5] of the H2020 Interflex project the architecture's correctness of design is being validated. The field test also contributes to find out what the price of flexibility could be, given that flexibility is unlocked by means of the proposed architecture.

To realize competition on the flexibility market, three parties have implemented the aggregator role. Two of them are aggregators that are commercially active. The third implementation is done by research institute TNO. The aggregators are in control of the flexibility of the following DERs: 26 public smart charging poles for EVs, a 315 kWh battery, and a curtailable PV installation. The DSO role is implemented by Enexis, a Dutch DSO, which operates the grid management system. The ESCo role for the battery and PV is implemented by a commercially active company and the Charge Point Management System by Elaad NL.

All subsystems and interfaces have been implemented and tested in so-called chain tests, which aimed at testing system functionality. In the chain tests, all functionality that the architecture defines to be present for using flexibility for multi objective optimizations has been tested. In those tests, aggregators have all implemented their own business logic. Currently, in the field tests scenarios are run to get a better understanding of the price for flexibility.

The procurement of flexibility is not only realized in technical sense, but also by the establishment of contractual agreements defining the financial flows between parties.

Lessons learned during the implementation and field test on the USEF and EFI interfaces are directly fed back to the respective organizations managing these protocols, enabling them to include the enhancement in future versions.

CONCLUSIONS

The architecture presented in this paper meets the requirements of providing an open market for energy flexibility and scalability. This is realized by the design decision to clearly define roles and their corresponding responsibilities. The interfaces between the roles, i.e. USEF, EFI, and OCPI, have already proven their value in other pilot projects and support this separation of responsibilities intrinsically. However, the interfaces are still being in development and, therefore, some improvements to the interfaces have been proposed in the project. The correctness of the architecture's design is validated in a field test, which is performed together with commercial parties. In the field test all roles have been implemented by relevant stakeholders. This shows that the architecture is capable of unlocking flexibility to market parties and exposing the flexibility to DSO's for congestion management. With this combination, the value of flexibility for congestion management can be maximized and, together with the open market design, result in the lowest costs for congestion management services.

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