Sub-aggregator as a Key Enabler in Harnessing Demand Response Potential of Electric Vehicles

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***Abstract*— The necessary balance between power consumption and production is at risk due to the diminishing amount of controllable resources in the grid. Demand response has the ability to provide the needed ancillary services for the power system management and create a new stream of revenue for the flexible resource owner. The increasing amount of electric vehicles contain a huge balancing power potential due to their ability to store the electrical energy flexibly from the grid in times of long term parking. Sub-aggregator is an actor who possesses capabilities to monitor and control distributed energy resources. In the case of electric vehicles, Sub-aggregator plans and coordinates the smart charging of vehicles to create additional value for all participants. This paper presents a business model for aggregating distributed energy resources in a cost-efficient manner that is based on minimum investments needed.**

***Index Terms*-- Aggregator Business Models, EV Charging, Demand Response, Smart Grids, Sub-aggregator**

I. INTRODUCTION

The need for flexibility in the electrical grid is increasing due to the integration of intermittent power production that is replacing traditional power production. Flexibility is needed to maintain the necessary balance between power consumption and production and to exploit all the available renewable energy. [1]

Demand response (DR) is being utilized more and more not only in large scale but also in households due to increased level of monitoring and controlling capabilities [2]. DR can yield benefit to a number of factors, for example, reducing the need for grid enhancements and wind power curtailement and also creating additional revenue for the flexible resource owner [3].

Energy storages could become a key part of the solution that is aimed to tackle the challenge of mismatch in power demand and clean power supply. Energy storages can be used to store the occasional excessive electricity production and to release it back to the grid when demand overweighs the renewable generation capacity. This would decrease the need for fossil based peak power production and thus decrease the carbon footprint of electricity production. There are already some grid-scale energy storages but so far they are hindered by economics [4], [5].

At the same time, the amount of electric vehicles (EV) is increasing rapidly which in one hand increases the dependency on electricity but also provides distributed energy storages. In case of EVs, the energy storage, i.e. battery is not meant primarily to support the power system management but to enable transportation. Nevertheless, it can be used to create additional value for other purposes too, e.g. for DR. Active management of EVs has a huge potential for providing auxilliary services for the power system due to the EVs' ability to store and release energy in a flexible manner [6], [7], [8].

In this paper we present a business model for smart EV charging including four stages. The key enabler of harnessing the DR potential from EV charging is stated to be Sub-aggregator who, in collaboration with EV users and Aggregator, predicts the power demand and flexibility potential of the EVs. This research is part of an on-going project between four companies and two research facilities both from Finland and Germany. In the project, named EVALIA, the main goal is to pilot the whole value chain of smart EV charging in a way that benefits all participants in the value chain. EVALIA project will continue for one year still, ending in March 2020. During that time the goal is to implement the Smart Charging schemes that have been chosen during the first year of the project. Our project consortium includes two charging point operators, both acting as Sub-aggregators combining the flexible capacity of their EV customers and trading it to Finnish ancillary service markets through a real Aggregator. This will give us insight and valuable experience on how the constructed model works and whether it should be improved.

II. SMART GRIDS

The energy sector is going through a radical transformation that is characterized by integration of renewable energy sources and the coupling of power system with advanced information and communication technologies (ICT) [8], [9]. Renewable energy production, such as solar and wind, causes new challenges for efficient power system management due to the intermittent and decentralized nature of such production. The necessary balance between power production and consumption needs to be addressed in a new way that requires advanced forecasting of renewable energy production and fast and reliable demand side management to balance the differences. The term ‘Smart Grid’ refers to a power system capable of monitoring and controlling distributed energy resources (DER) at least partly automated and with advanced optimization algorithms to operate the power system and the resources connected to it in the most efficient and economically viable way possible [8].

A. *Demand Response*

Traditionally, the balance between power production and consumption has been maintained by forecasting the consumption and controlling the power production side accordingly. However, due to the increasing amount of weather dependent power production the supply side is not only losing its controllability but also adding an X-factor to the power generation capacity. This intermittent production could be managed by activating matching amount of demand response.

Demand Response is an umbrella term used to identify the actions that the demand side is taking in response to some incentive or external signal. One of these signals indicates the occurring balance between power production and consumption and can be read by monitoring the grid frequency. In Finland, the Transmission System Operator (TSO) is in the end responsible that the power balance is maintained, so it operates a power reserve that is activated if needed. Energy resources that are capable of changing their electricity consumption or production can offer their flexible capacity for these reserves in exchange for money [10].

B. *Aggregation of Demand Response Targets*

Most of the untapped DR potential in Finland comes from small sources that are geographically distributed in the power system. Individual DERs usually have so little flexible capacity that they can’t be offered directly to reserve markets [11]. However, due to the widespread digitalization and improved communication capabilities it is possible to combine the flexibility potential of individual DERs and monitor and control them as one entity. Aggregator is an actor who combines the flexible capacity of multiple DERs and trades the aggregated capacity in electricity markets as one entity. The entity that is thus formed is called a Virtual Power Plant (VPP) [12], [13].

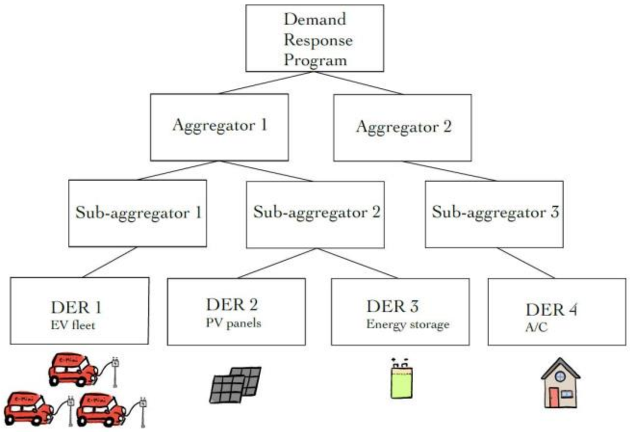

Figure 1. Proposed Model for Aggregated Demand Response

III. SUB-AGGREGATOR CONCEPT

In this chapter we present a definition for Sub-aggregator who is a key enabler for cheap flexible power to access DR markets. Sub-aggregator is a role in DR value chain, more specifically operating between DER owner and Aggregator, see Figure 1. We see it important to distinguish Sub-aggregator and Aggregator from each other, even though in some cases an actor may possess both of these roles. However, the roles require totally different set of expertise and tools so it is necessary to be able to separate these. First, we define Sub-aggregator in general, independent of any specific sector, defining basic requirements and suggested business model.

A. *Requirements*

Trading flexible power on reserve markets can be lucrative, but due to the critical nature of power system for our society the responsibilities are also very high. Requirements for reserve targets include, for example, maximum activation time, minimum amount of steps in activation and streaming real-time data from the reserve target [11].

The most important functions that Sub-aggregator has to have are capabilities to monitor and control the DERs in its portfolio and to reliably predict their flexible capacity in every cycle. One cycle means one tradable time slot in target DR market. The length of one cycle is typically one hour (1h) but at least European countries are gradually moving to a 15 minute cycle [14].

The capabilites to monitor and control the DERs and to predict their flexibility should be achieved with reasonably small investments due to the uncertainty of future market valuation of flexibility. However, the decision on the required investments should be considered by taking many aspects into account. For example, building the needed VPP might take some time and money, but if the potential to expand the portfolio is significant, then the overall costs per MW can be expected to decrease due to the scalability of such platform.

Usually the role of Sub-aggregator is easiest for hardware manufacturers and technical service providers to adopt due to their existing monitoring and controlling capabilities. Even though monitoring and controlling capabilities are existing in advance, some investments need to be made in the integration of these into a VPP to enable automation of DR actions. The authors see it vital to automate as much as possible, in order to maintain the scalability. Automation is also required in some reserve markets, e.g. in frequency regulation, where the power in-/output has to continuously follow the grid frequency.

B. *Sub-aggregator Business Model*

Because of the uncertainty of valuation of flexible power in future, big investments in the abilities to control and monitor DERs is seen to be unreasonable. However, there is huge amount of flexible capacity untapped that could be utilized in DR programs with relatively small investments. We have identified three sectors that have the capability to provide significant amount of flexible power by recognizing and adopting the role of Sub-aggregator. All of these sectors have actors that possess the capabilities to monitor and control DERs but are not currently using these capabilites to operate in the electricity markets. The reason is usually a lack of knowledgment about DR programs and market requirements. On hurdle to participate in the reserve markets is also the minimum bid size, which in Finland ranges from 0,1 MW to 10 MW depending on the reserve product [15]. In addition, for the DR operation to be as beneficial as possible, it would be needed to continuously consider all DR programs. This multimarket optimization requires such advanced algorithms and expertise of the markets that the use of Aggregator for market operations is seen reasonable.

Sub-aggregator is the representative of DER owner ensuring that the technical capabilites of the DERs are sufficient. DER owner is a passive actor in DR value chain, it only gives permission and boundaries for the trading of flexibility. Ideally, after giving the preconditions to Sub-aggregator, DER owner is not directly involved nor affected in any way in the DR actions. The boundaries for the flexibility creation should be set to a level that causes minimum harm for the DR owner.

Sub-aggregator is a service provider for the DER owner, so it should consider the end user needs. Flexibility is created by changing the normal behaviour of power consumption or production resource, which may result in inconvenience for DER owner. This is why some incentive need to be provided also for the DER owner. Incentive can be monetary benefit, e.g. share of the revenue from operating on reserve markets or it can be some additional services like parking space, proactive maintenance or improved living conditions. Sub-aggregator can also incentives DER owner by creating some additional value in forms of reliability or improved power quality.

IV. SMART EV CHARGING

Smart EV Charging means using Information and Communication Technologies (ICT) to plan and coordinate charging of EVs in a way that creates additional value or reduces harm. Concept of Smart EV Charging is already widely studied and different technical approaches have been identified to realize its potential benefits for the power system [16]. However, there is a lack of business models to support the adoption of such schemes. In project EVALIA we are piloting Smart EV Charging in real life with a business model that aims to create value for all participants. More specifically, our scope in the project is to pilot the smart charging providing ancillary service for the Finnish reserve market for frequency regulation. The actors in the proposed model are presented in Figure 1.

A. *Charging schemes*

Charging an EV takes usually a lot more time than fueling up a traditional ICE car. However, EV charging can be executed at home, working place, shopping mall and other such places where the car sits idle for long periods of time. This provides a huge potential for DR programs. In EVALIA project, we have estimated from real data that the average amount of energy charged per day for one EV is 10 kWh, whereas on average the vehicles are plugged in 15 hours a day. Even the slowest charging techniques are able to charge that in under 10 hours. This means that the vehicles are plugged in but not charging most of the time. Implication is that the charging could be scheduled to provide additional value for the power system.

If we consider a future workplace with a parking lot full of EVs, we can soon realize that the distribution network would need a huge strengthening to enable the charging of all the vehicles simultaneously. This would happen without any coordination as soon as the workers arrive to the workplace and plug in their EVs. However, most of the cars will sit there the whole working day (8h) and the charging itself would only take 2-3 hours on average. This means that if the charging was coordinated, the power could be controlled and the need for strengthening the local grid would decrease significantly. Coordination would also enable participation in electricity markets which could yield additional revenues or cheaper prices for the electericity. In Figure 2, different ways of charging EVs is presented. This highlights the possibilities which can be obtained by smart charging schemes.

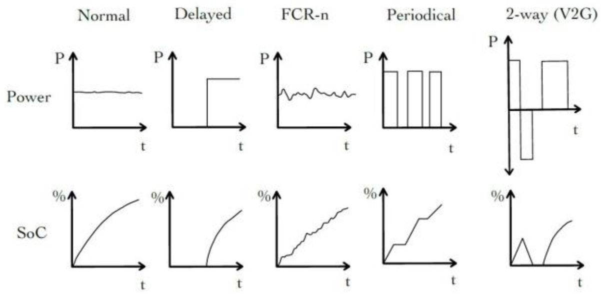

Figure 2. Different ways to charge an EV battery

As we can see from the Figure 2, EVs can be charged in different ways that all lead to the same result - the EV being fully charged. EV users don't usually care how the charging is executed as long as the battery is full when needed. Due to the realtively long time that it takes for the EV battery to charge, smart charging schemes have the risk of causing serious inconvenience for the EV user. This should be avoided, for example, by providing the EV user an interface to indicate boundaries for the charging event.

Due to the current technical constraints and features of EV charging points and battery systems it is not necessarily possible or convenient to charge an individual EV any other way than with uninterrupted one way power. However, all the schemes presented in Figure 2 are possible to achieve if the whole EV fleet is operated as one entity.

B. Sub-aggregator in Smart EV Charging

Sub-aggregator by the proposed definition is an actor who possesses capabilities to monitor and control DERs. In case of smart EV charging it seems to be the charging point operator who could adopt the role of Sub-aggregator most easily. However, the field of smart EV charging is still developing and the roles and responsibilities are shaping. The role of Sub-aggregator is to coordinate the charging of EVs and to act as an intermediary between EV users and markets. Due to the minimum bid sizes in energy and power markets and the complexity of multimarket optimization it is also recommended to use the services of an Aggregator for easier and more profitable market access.

In the project EVALIA we are piloting the smart EV charging participating in frequency regulation ancillary service. Participating in frequency regulation requires pooling the EVs into VPPs because the frequency regulation reserve has minimum bid sizes and single EVs are not big enough in capacity.

Smart EV charging schemes should also consider the user needs. The user is in the end the one that accepts or denies the use of the EV in DR programs so Sub-aggregator should prioritize the satisfaction of end user and minimize the risk of harm and inconvenience. Ideally, the DR programs are executed in a way that the EV user doesn't even notice that the charging event was intervened.

In order for the Sub-aggregator to trade flexible capacity of its EV fleet, it should be able to predict the behaviour of the fleet very accurately. Available capacity of the fleet is constantly varying based on the amount and need of plugged-in vehicles. At the moment there is no interface between EV users and Sub-aggregators in our project to indicate exact needs for the charging and content for the DR programs. Currently the only possible way to estimate the flexible capacity is to analyze history data and try to identify recurrencies. For example, the behaviour of EV users during working hours and night time is fairly predictable.

Ideally, the charging needs of EV user would be known in advance so the charging could be coordinated in the most value adding way possible. This would require an interface where the EV user could state the requirements for the state of charge (SoC). Smart charging schemes can be divided in two based on the planning principles. In the first and simpler scenario, EV user informs the Sub-aggregator about the SoC that is needed at certain time. In the second and more complex scenario the EV user lists the future journeys, e.g. 1-7 days forward and also the plugged-in times and places, and the Sub-aggregator plans the charging events based on these.

Getting the user requirements from EV users can also be executed in two ways. The simpler but possibly more expensive solution is to build an interface in the charging point where the EV user could easily give the requirements for the charging. The other solution, which would be required for the more complex smart charging, is a digital platform where the user could give the same information and possibly also more specific or time forward information.

In the first phase of piloting Sub-aggregator role in EVALIA, a third approach is tested. In this approach no input from EV users is gathered. The users are simply informed that the charging event might be delayed. This method requires accurate analysis of the EV fleet behaviour in order for the available flexibility to be realized. This approach was chosen in EVALIA because the goal is to test the technical solutions for monitoring and controlling of EV fleets.

V. DISCUSSION

One challenge in DR programs including several parties is the allocation of responsibilities and rewards. In the concept that we are presenting, Aggregator has direct responsibilities towards markets, meaning that Aggregator gets the penalties if some of the reserves it is providing fails to deliver. However, in a situation where Aggregator is merely the one operating on markets and Sub-aggregator the one responsible for the technical functioning of the DR targets it is not clear how the penalties should be divided. In addition, it is possible that the reason for failure in delivery lies within the actions of DER owner. For example, in EV charging case, if the EV user encounters an emergency in personal life and has to unplug the EV during reserve operation, it would leave the contract unfulfilled. Failure of delivery might be caused also by some communication link breakdown. This is an example of a special case that leaves the implications uncertain.

One could argue that Aggregator should provide some extra reserve as part of its services in case of failures in delivery. In the end, the authors feel that this is a special issue that needs to be agreed between the actors case by case. However the authors strongly suggest the penalties to be divided between the parties more or less based on the causation and the risk management principles agreed in advance.

VI. CONCLUSION

Renewable power production methdos, like solar and wind power, are replacing the controllable but polluting such as coal and oil based methods. This trend is jeopardizing the power system stability as power production and consumption need to be in balance at all times. Traditionally power production has been controlled to match varying consumption but current trend is forcing us to find new solutions.

Demand side management means actions taken in planning and coordinating the electricity consumption in a way that supports power system stability. Sub-aggregator is an actor who possesses capabilites to monitor and control DERs in a cost-efficient manner and does this to create additional value for the DER owner and power system operator.

One of the recognized trends is expansion of electric vehicles that are capable of storing electrical energy from the power grid. This feature enables electric vehicles to provide significant value for the power system management. By smart charging schemes, the EVs can be charged when the intermittent power supply from renewables is exceeding the power demand.

Smart EV charging is a challenging task, since the charging of individual car takes a lot of time and the end user need can change suddenly. Ideally the SoC would be maintained at least at a level that would get the user to a hospital or similar. However, by analyzing the user data, we have identified the average daily need for the energy and ended up to a conclusion that real flexibility can be achieved by smart charging. When considering the whole fleet, we can be certain that the amount of flexibility is significant, but due to the restriction in techincal capabilities, the charging has to be coordinated so that individual EVs are charged uninterruptedly in one burst. Switching individual EV's charging on and off would burden the battery and yield in error messages. Also due to the technical restrictions in the charging points, the charging power is not always controllable.

In project EVALIA we are piloting smart charging schemes with the whole value chain, consisting real life EV users, two charging point operators acting as Sub-aggregators, one Aggregator combining the flexibility from the Sub-aggregators into bigger tradable entities and Finnish marketplace for frequency regulation. Our main goal is to pilot the challenging task of coordinating the EV fleet to act as a frequency regulation reserve, while keeping the EV users content regardless of interventions in charging events.

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