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Dynamic Aggregation of Virtual Power Plants with a Registry System for Distributed Energy Resources

Tim Dethlefs, Thomas Preisler, Wolfgang Renz

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Abstract. A growing number of Distributed Energy Resources will be connected to the grid. These distributed energy resources have different technical capabilities, operational constraints and are distributed throughout the electricity network which results in an increasing operational complexity. Aggregators controlling these resources in a virtual power plant might need to reconfigure it in case of failing distributed energy resources (e.g. when the weather changes) or due to changing grid conditions on a system operators request. This means that both, aggregator and system operator, must maintain operational reserves such as frequency control which means also rising costs for the actors. Different approaches such as dynamic virtual power plants have been introduced to address these issues. Extending these approaches, the increasing automation and information as well as communication capabilities will allow the actors to exchange and share real-time data about these resource capabilities on demand, allowing the aggregator to dynamically reconfigure the virtual power plant with external capabilities of distributed energy resources prior operation and during runtime, allowing the virtual power plant to be adaptive towards changing situations. For this purpose a common, active registry system for energy resource capabilities is necessary. In this paper, we will describe a process to dynamically aggregate distributed energy resource capabilities a priori as well as during runtime allowing the adaptive reconfiguration of virtual power plants.

1 Introduction

New operational challenges arise with the increasing number of Distributed Energy Resources (DER) in the electricity grid. Extending the DER definition of the IEC 61850-7-420 standard, the DER definition in this paper should cover all intelligent (i.e. controllable and automated) generation, storage and demand side energy resources. These DERs are characterized through their heterogeneity in types, control paradigms, distribution and runtime constraints. Especially for environmental dependent DERs the fluctuating availability correlated to weather conditions adds another level of complexity. These challenges have led to several different approaches in DER management, such as demand following production (demand side management and demand response) or complexity management with Virtual Power Plants (VPP). The VPP concept with the aggregator role is

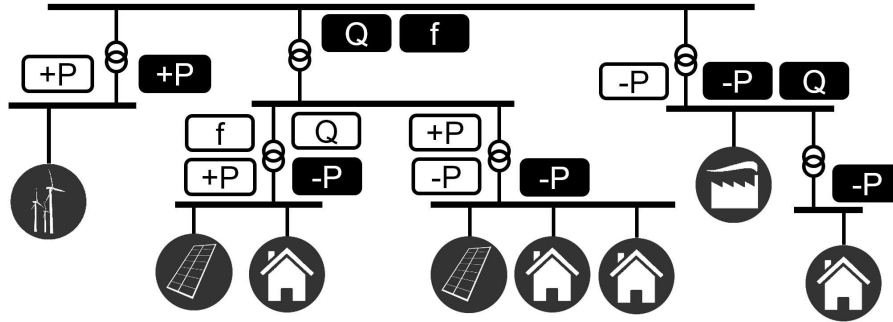


Fig. 1. Energy as a service. Energy service provision (white) and demand (black) by different DERs (circles) in different voltage levels. With $P :=$ active power generation (positive) or consumption (negative), $Q :=$ reactive power, $f :=$ frequency control. Considering also controllable loads (white box $-P$) and uncontrollable generation (black box $+P$.)

used to abstract the underlying complexity and allows grid actors (e.g. balance responsible parties or system operators) to address these resources like classical power plants [8]. The VPP concept also allows the participation of DERs in larger markets with higher requirements towards production volume and availability. Today, these VPPs are usually characterized through fixed portfolios of DERs which are long term contracted by the aggregator. The aggregator serves as an expert for the connected DERs and their characteristics, trying to optimally market the VPP itself. Apart from larger DERs, DER system providers are usually not able to market capabilities unused by the aggregator, which results in an imbalance of concerns as the aggregator may not always maximize the profit for the participating DER resources. Additionally, due to the rising number of DERs in the grid, aggregators are and will be confronted with several serious issues regarding the availability of DERs as well as operational challenges in the grid (e.g. congestion management). Given the rising level of automation, communication capabilities, and intelligence, DERs system capabilities can be understood as *Energy Services* which can be used by aggregators to solve certain issues in the grid (see Figure 1). To find these energy services, a discovery mechanism is needed.

In this paper, an approach for a highly automated process for the aggregation of VPPs is proposed, which allows the direct marketing of DER resources as well as allowing aggregators to reconfigure and adapt their VPPs to changing requirements. The process will extend the Dynamic Virtual Power Plant (DVPP) concept, originally introduced in [11], by utilizing a common, open registry system for the propagation of capabilities of DERs which supports the aggregation process of the aggregator role. The proposed dynamic aggregation process will enable a new class of VPPs which is able to adapt to failure and uncertainty situations during VPP operation - the *Adaptive Virtual Power Plant*.

The remainder of the paper is structured as follows: in the next section an overview on prior and related work on that topic will be provided. Section 3 describes the extended dynamic aggregation process in more detail while Section 4 provides a statement on Adaptive Virtual Power Plants as a future market and operation concept for Virtual Power Plants. Section 5 concludes the paper with an outlook to further research and development efforts planned.

2 Related Work

To achieve a dynamic aggregation of VPPs a priori and during runtime almost automatically, three different research topics are of special interest. At first the work already done in the field of DVPP will be described, then information systems as an ICT cornerstone will be introduced and finally how work on optimization problems in the energy domain can contribute to the process.

2.1 Dynamic Virtual Power Plants

The envisioned Dynamic Virtual Power Plant (DVPP) concept extends several existing approaches on VPP-aggregation of DER capabilities. An important step towards the introduction of DVPPs was the definition by [11]. There, the authors described a DVPP concept where a set of DERs aggregates autonomously in several VPPs for different business cases. These VPPs can be scheduled and rescheduled on demand during runtime. The four steps in detail are (cf. Figure 2 A):

1. *Dynamic VPP aggregation:* The DERs of a portfolio will be aggregated towards several VPPs for different business cases and markets.
2. *Market interaction:* The VPPs will be offered in established electricity markets.
3. *Intra-DVPP optimization:* The scheduling of the DERs within the reserved VPPs is done well before delivery.
4. *Continuous scheduling:* Rescheduling of the DERs during the operational phase if necessary.

The authors of [11] further described their principle in the context of active power business cases which are marketed usually day ahead or intraday with a timing horizon of 30 minutes prior delivery (continuous intraday trading on EPEX Sport market). Although the description is limited to active power and commercial Virtual Power Plants (CVPP), VPPs in general may also be used for Technical Virtual Power Plants (TVPP), providing ancillary services to the grid at the same time, as [12] proposed for capable DERs. It is assumed that this is not only true for VPPs but also for DVPPs.

From a conceptual perspective, the suggestions made by the authors allows the optimization of a portfolio towards multiple VPP for different business cases at the same time. In contrast to classical approaches, this allows much more

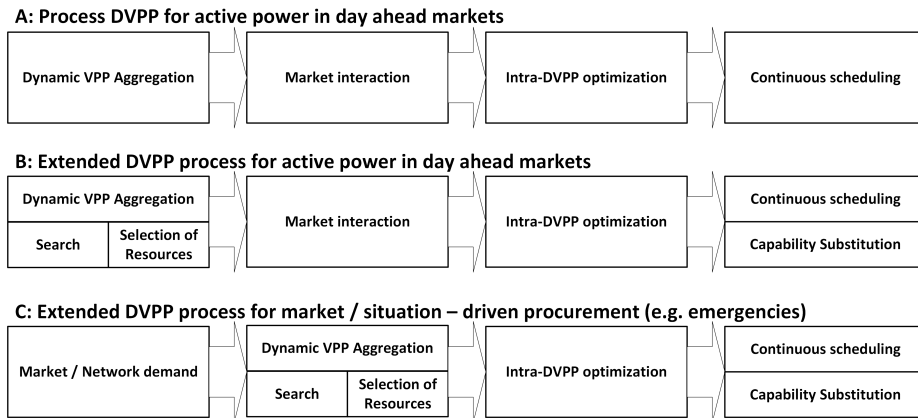


Fig. 2. Different application processes of the DVPP and extended DVPP concept. Process A. from [11]. Processes B. and C. describe the extension of the concept for addition of energy services to aggregated DVPPs as well as the extension for on-market demand aggregation of DVPPs (cf. Section 3.1 and Section 3.2).

flexibility in providing VPPs in different markets and dispatching strategies, although the approach is still limited to a fixed set of DERs (which we refer as the aggregators portfolio). The authors additionally suggest to optimize the scheduling of the DER within the VPPs to overcome issues, which is surely an extension of the VPP-approach but still relies on reserve capacities (e.g. secondary and tertiary reserve) for compensating issues beyond the scheduling capacities. In the application domain, apart from the decentralized control, this concept has been realized by several professional VPP control products (e.g. BOSCH Virtual Power Plant Manager [2])

2.2 Information Systems in the Smart Grid domain

Another important challenge towards a more dynamic and adaptive aggregation process is the need for information systems offering the necessary data to support the aggregation process. Information can be used to identify the location and characteristics of DERs capable to support the VPP portfolio of the aggregator, including data about the actual capabilities of the DER, i.e. its projected power potential over time allows a detailed planning and integration of the resource in established VPPs. Today, several different databases and storages with different levels of actual information exists. Additional to energy markets which provide information on the marketed capabilities of DERs, three different information system types can be distinguished: Metering databases, DER indexes, and operational databases.

Energy markets contain marketable capabilities of DER systems. Current established markets are just trading guaranteed available energy, which makes it difficult for non-deterministic DER systems (i.e. regenerative energy resources)

to participate. For Europe, the leading energy market is the EEX¹ for longterm trades and EPEX spot² for day-ahead and intraday trades. These markets contain little information about the resources itself, allowing mostly active power to be traded. An example for an ancillary service trading platform is regelleistung.net³ for frequency control tenders of TSOs. Aggregators can participate with VPP on the tendering process. In the research domain, especially matching platforms have been in focus, such as PowerMatcher [9], providing near real-time availability information. Some businesses already make use of supply-demand-matching principles. Although, it can be seen, that most markets have high qualification borders, are limited to specific business models, or focus on specific business cases. A generic discovery platform for energy services should further enable and support these market platforms instead of replacing them, but also enable new business cases and markets.

Metering databases are especially interesting during operation and for the settlement phase. As they do not provide direct support of the planning phase, they are out of main scope of this paper.

DER indexes or inventories help the smart grid actors to determine general structures of DERs connected to the grid. They support the analysis of the infrastructure and help to identify possible geographical problems, e.g. areas with a large impact of solar or wind dependent DERs. One example for this kind of specialized DER database is the EEG-Anlagenregister (renewable DER registry) of the German grid regulation agency [5]. It contains location and type information of new renewable energy resources in the German electricity grid. Most of these indexes, such as The Registry of the New Zealand Electric Authority [10], in which every grid connection point is listed, lack real-time data, live capability information and projections and forecasts of the capabilities.

Operational databases contain the information lacking the third category. These are the core system of every system operator or aggregator as they are the repository of all the operational characteristics and data regarding the controlled DERs. Usually closed source tailored software products containing company secrets, these databases contain many important information for DER operation and grid management.

In the *Open System for Energy Services* (OS4ES) project, a registry system should be developed which combines index data of DERs with capability information of DERs to provide an information system that allows DERs to market their free capabilities directly to aggregators, while aggregators should be able to search for DERs which can be used for their VPPs (see Figure 3). Similar to already established high level markets in the energy domain, the OS4ES registry system tries to establish a direct market for low level flexibility of DERs. The architecture of the system components has been described in [7]

The OS4ES registry will use the energy services principle, introduced in [6] DERs can provide energy services which are described by a set of standardized

¹ <http://www.eex.com> - Accessed: 15.06.2016

² <http://www.epexspot.com> - Accessed: 15.06.2016

³ <https://www.regelleistung.net> - Accessed: 15.06.2016

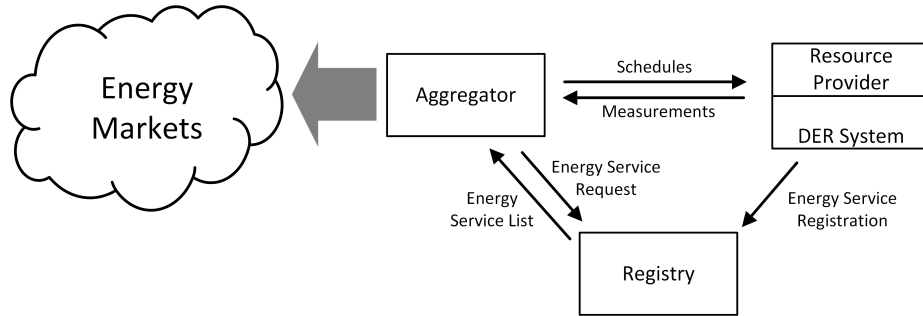


Fig. 3. Interaction between aggregators and DER systems using a common registry system for the exchange of dynamic energy service data. The aggregator utilizes the DER systems based on the energy service descriptions to participate in larger energy markets.

description models, called semantic data model. This model provides generalized description models for DER capabilities for active power, reactive power, voltage control, frequency control, and time shiftable flexibility (cf. [4]). The registry also stores information on the availability and forecasted capabilities of the DERs, providing these information to aggregators. The OS4ES system should allow aggregators to reserve certain capabilities of the DERs for their VPPs in an automatable process. The energy service concept allows DERs to provide energy services for both TVPP and CVPP at the same time.

With such a registry system a technical solution for a discovery mechanism for smart grid applications and energy service capabilities can be realized, such as required by Data Access Manager (DAM) concept described by [13].

2.3 Optimization and Scheduling of Energy Resources

In order to integrate the OS4ES registry and the extended DVPP process in the established energy market context, optimization and scheduling algorithms for VPPs are necessary. The process including the registry contains of three distinct steps: *Search*, *Selection* and *Scheduling*.

Search means the searching process in the registry. An aggregator identifies the need for external energy services and must identify suitable DERs by applying filter functions on the registry database. Although the process is a quite new research topic in the energy domain, established registry and information system concepts (Anlagenregister [5] and The Registry [10]) suggest that location of the DERs, type of installation and the availability will be probably the most important search criteria.

Selection describes the process of selecting energy services out of the search result list as the result list is probably longer than the actual need of the aggregator. Strategies on the selection are closely related to the actual scheduling and determines the configuration of the VPP structure. Examples in literature for basic selection mechanisms (mainly within the context of classical VPPs with

static portfolios) can be found e.g. in [1], which is also part of the DVPP concept described in [11].

Scheduling is the most researched and described step so far. It describes the scheduling and orchestration of the participating DERs within a VPP to achieve the business goals or the intended ancillary behavior. It includes classical optimization strategies and problems such as the application of evolutionary algorithms or constraint handling (e.g. [3] or [9]). The generation of such schedules is of great interest for aggregators, DER system providers and system operators as it determines financial compensations, grid congestion questions and other aspects. In classical VPPs, the scheduling step is thus the most important.

3 The Dynamic Aggregation Process

The dynamic aggregation process is an extension of the aggregation phase definition within the DVPP concept of [11]. The dynamic aggregation process utilizes the registry system and the generalized description model for energy services described in Section 2.2. The Registry for active DER capabilities enables the process of aggregation by providing an information infrastructure. A DER system D is able to provide its capabilities as a set S_D of energy services s to the registry where they can be searched by aggregators. Thus, aggregators are able to search for additional energy services during the initial aggregation as well as during the runtime of the DVPP. If the capabilities are not sufficient in case of failure or due to reserve requirements and cannot be compensated by internal scheduling, the aggregator will be able to adapt on demand. Also when an internal rescheduling is just too expensive, external resources may be applied to avoid the activation of frequency control. The process assumes two different types of initial situation which will be described in Section 3.1: a priori configured VPPs, that are already aggregated and VPPs, which are aggregated on demand. The process during operation will be described in Section 3.2.

3.1 Aggregation phase

In the normal operational state, it is assumed that the aggregator markets and reacts on market demands either with preconfigured VPPs (active marketization) or searches for appropriate Energy Services on demand (reactive marketization) and operates these resources usually for CVPPs. The aggregation on demand use case describes a process where the aggregator is appointed by a system operator (either TSO or DSO) to solve a specific problem usually with a TVPP.

Aggregated State: Today's classical modus operandi is an aggregator A with a portfolio P_A of long term contracted DER systems, forming a VPP. These VPPs usually participate in larger markets, partly even ancillary markets as far as they exist today (e.g. frequency control market in Germany). Typical business cases are the provision of active power or specific ancillary services. Problems arise when resources must be maintained, provide lower output than expected (e.g.

cloudy day), or specific grid parts may not be usable due to grid congestion. In this case, the aggregator sends a request r to the registry system in order to search and reserve resources that compensate the defects of the VPP (see Figure 2 B).

1. (*search*) The aggregator defines request criteria C_r to find suitable energy services (service type, location, grid segment, type of installation). The registry will respond a list S_r of energy services matching the criteria.
2. (*select*) The aggregator selects one or more energy services out of S_r , based on a personal weighting function $P(S_r)$ (for example merit order selection). These selected energy services S_s are reserved and added temporarily to the aggregator's portfolio P_A . The according DER systems must be informed that they may receive control signals from the aggregator. A decent security concept is needed to ensure the identity of the aggregator as well as the validity of the aggregator's control signals.
3. (*schedule*) The aggregator schedules all of his resources P_A (the original portfolio including the temporarily added energy services) according to the intended business case.

Other application are the reservation of additional reserves for the VPP, e.g. on days with unclear weather forecasts to provide a proper risk management of the portfolio or to bundle surplus capacities as additional products.

Aggregation on demand: The second and currently uncommon use case is the on demand aggregation of VPPs (case C in Figure 2). Usually a system operator requests a TVPP to solve a specific grid problem. An aggregator is appointed by the system operator to provide this VPP with very specific characteristics (e.g. congestion areas, islanded grid parts, frequency issues). The aggregator uses these characteristics to search for the appropriate DERs within the registry or the system operator allows exclusive use by the aggregator of specific energy services provided by DERs under control of the system operator which are declared in the registry. The registry then can manage the authentication and access rights management for all parties (system operator, aggregator and DER) as it is part of the OS4ES project (see prev. paragraph).

3.2 Operating phase

Despite the automated behavior for frequency and voltage control, DER show the scheduled, and thus planned behavior, during the operating phase of the VPP. Two cases may be problematic in this case: the sudden misbehavior of a resource (e.g. failure, lack of power due to weather etc.), and balancing errors due to the stochastic behavior of the consumers. There are some options for aggregators to compensate these situations. The authors of [11] suggest a continuous rescheduling of the VPPs resources to adapt. Aggregators may also use resources offered in existing intraday energy markets as a relief on longer

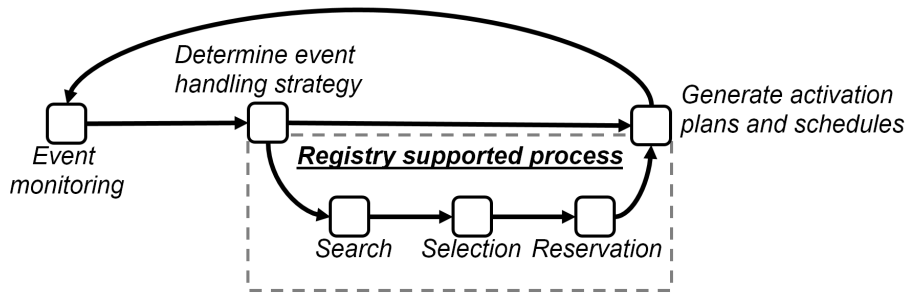


Fig. 4. Event loop for handling failures and changing situations by executing either VPP-intrinsic event handling strategies (i.e. re-dispatch and re-planning or resources) or the dynamic aggregation process supported by the registry by utilizing external resources.

timescales, due to the trading horizons (e.g. 30 minutes for EPEX Spot market). Additionally, aggregators can sometimes rely on ancillary services provided by the system operator (for example frequency control), which are considered as expensive. Although, all the introduced methods rely on either sufficient resources to reschedule or the availability and applicability of the approaches. The introduced registry system for DER capabilities may offer an additional platform which can be used by the aggregator to find substitutions and supplemental energy services for compensation. The general process consists of four steps (cf. Figure 4):

1. **Event Monitoring:** Detecting changing requirements, either by notification (e.g. by system operator) or measurements. This includes failures or shortages as well as congestion problems detected by the system operator. Today, usually countermeasures are dispatched by the system operator including re-dispatch, islanding, sequential cutoffs, activation of frequency control etc. But in the future many problems can be avoided or solved by including the aggregator into consideration allowing him to reconfigure.
2. **Determine Event Handling Strategy:** The aggregator A determines if the problem can be solved with the resources P_A of the VPP (e.g. through rescheduling) and continues with Step 4 or if not with Step 3 This step may also include an involvement of the system operator.
3. **(optional) Search, select, and reserve Energy Services:** If the event handling concludes that an internal rescheduling will be not sufficient or efficient to solve the issue, the registry can be searched for suitable energy services serving as replacements or additions. The aggregator can search, select and reserve resources for the VPP according to the description in Section 3.1.
4. **Scheduling:** Re-scheduling of the resources of the newly aggregated portfolio.

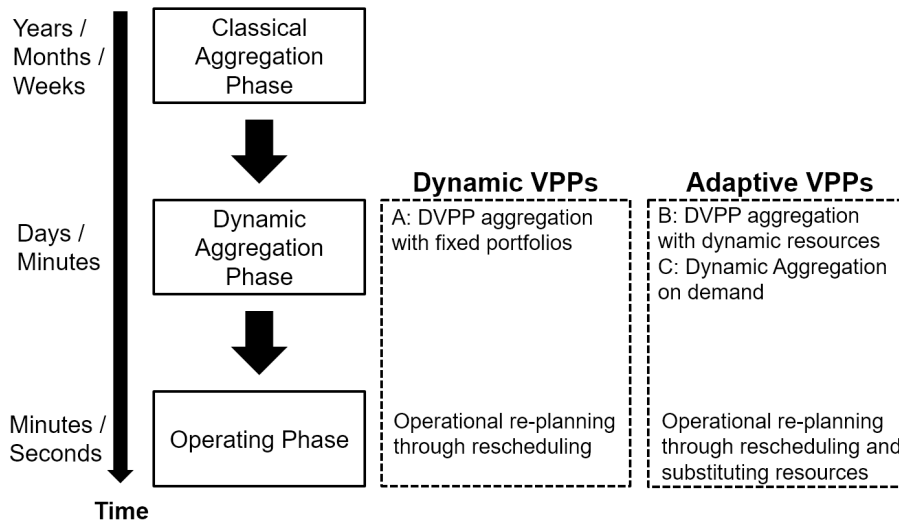


Fig. 5. Comparison of DVPPs and AVPPs in the context of aggregation and timing of Virtual Power Plants

It is very important to consider the role of the system operator in these steps. The system operator must be involved in order to adapt grid simulation and congestion models to the measures taken, so no further redispatch etc. is needed or other problems in grid management emerge.

4 Towards Adaptive Virtual Power Plants

Enabling the introduced dynamic aggregation process through the described dynamic registry for DER capabilities would allow DER system providers to market their capabilities directly, while aggregator are able to develop new flexible VPP concepts for large scale markets and even on demand aggregation. Such smart market scenario allows a new class of VPPs, the Adaptive Virtual Power Plant (AVPP). Zadeh [14] characterizes an adaptive system as a system that performs acceptably well towards several changing operational conditions, offering some degree of robustness and tolerance. Adaptive VPPs help to overcome the issues of growing uncertainty and heterogeneity in grid management by allowing not only to change the scheduling of resources as with DVPPs, but by changing the configuration of the VPP dynamically before and during runtime of the system (cf. Figure 5).

Although the general characteristics and features of AVPPs have been described in this paper, some requirements need to be addressed to enable the AVPP concept in the smart grid. Besides the need for a common, dynamic registry for DER capabilities, which is under development, a better, faster and improved communication processes between system operators and aggregators

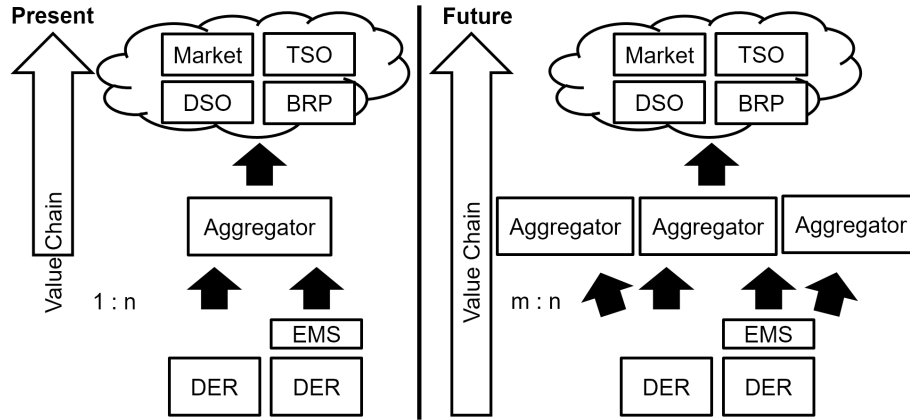


Fig. 6. Present situation with a $1 : n$ relation between aggregator and DER systems. Despite usage tariffs for the DERs, the true added value comes from the market behavior of the aggregator. The adaptive VPP concept allows DERs direct marketing with specialized aggregators in $m : n$ relations.

is needed to allow the aggregators to plan their AVPPs within the grid's limits. Current processes on data exchange about the congestion situation in the grid are slow and mainly based on reactive planning. Additionally the ICT infrastructure needs a higher degree of automation, sensors and controllers, allowing a more detailed perspective on the grid and its connected components.

This will allow a transition from classical, hierarchically organized VPPs with a $1 : n$ relation between aggregator and DER systems towards a $m : n$ relation between aggregators and DERs, as depicted in Figure 6. DER systems are thus enabled to market their capabilities towards multiple aggregators at the same time within different business contexts optimally. The business relation between aggregators and DERs changes from static contracting with fixed tariffs to market oriented behavior, because DERs are functionally not longer limited to the business field of one aggregator and can enhance their technical capabilities to cooperate with multiple specialized aggregators, e.g. by adding automated frequency control or phase control capabilities.

5 Conclusion

In this paper, a dynamic aggregation process for Virtual Power Plants was described. The process is an extension of the DVPP concept described by [11], as the introduced dynamic aggregation process adds real time dynamics during the aggregation phase and the operation phase. DERs are able to market their flexibility directly to optimize and maximize their degree of utilization. This uncouples the DER flexibility from the aggregators business operations to a certain degree. On the other hand, aggregators will be able to reconfigure their VPPs by

adding and removing energy services on demand to adapt to failures, changing grid situations and to emerge on new markets. This will allow the aggregator role to react beyond the rescheduling on misbehavior and unplanned situations, support the grid management and avoiding the activation of ancillary services. System operators will be able to appoint aggregators to solve congestion situations and additional ancillary service demands on request by aggregating special resources. This approach utilizes an information system with market capabilities, called registry system. The registry uses the energy service definition for describing the DER capabilities that can be used by aggregators. Both, the registry as well as the dynamic aggregation process enable the Adaptive Virtual Power Plant concept which allows dynamic configuration changes of the VPP before and during runtime.

A prototype of the registry system is under developed in the OS4ES project, including example scenarios and processes which will be demonstrated in lab and field tests. The architectural definition of the registry system and of the energy services will be brought into discussion in the future IEC 61850 standardization process.

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Dear Mr. Editor:

please find attached a table with the reviews comments and how we addressed these in the improved version of the paper. We hope we improved the quality of our paper to your convenience.

Best regards from Hamburg!

Tim Dethlefs

Short	Review Comment	Response
Paper is high-level, no new insights	Generally the paper stays at very high level, and does not really provide any new insights.	We believe that the paper offers an original contribution as it addresses liberalization efforts in the electricity grid, allowing new VPP business models and an increasing degree of automation and control over heterogeneous DER Systems. We revised the publication carefully to state this in more detail. Although, the research is in the beginning phase, and we wanted to point out envisioned applications of the system under development for the interested scientific audience.
More decent paper review, comparative analysis. Extend related work.	Reviewer 1: If this is to be an "overview" paper, then it should provide more references to existing work, and a comparative analysis. [...] There is generally lack of references to widely-known published work in the area (e.g., published in Journals). This is probably also due to the fact that the state of the art, present in the paper, is limited. Reviewer 2: The paper seems at the conceptual level. Is it possible to add some more related work?	As demanded, we've added some more state-of-the-art references.
Literature review regarding EU funded projects on aggregation	As a note there have been dozens of EU projects dealing with energy aggregation at various levels. Their developments are not considered (maybe even are not known) to the authors.	Most European projects (the authors are active participants of one) focus on specialized aggregation applications in highly specialized markets (e.g. EV or Demand Response). We suggest a more general approach towards the development of electricity markets, as e.g. suggested by the Data Access Manager initiative.

		We take the suggestion of an exhaustive analysis of EU-projects towards market capabilities as an extra paper as a broad range of EU projects have relevant contributions in this field.
More in-depth analysis either on technical or conceptual (requirements)	Otherwise, I would suggest to deep-dive into any of the topics presented and provide a better contribution. For instance describe technologies, implementations, potential architectures, requirements, etc.	Also considering comment 1, we revisited the paper regarding a better description of the dynamic aggregation process and possible applications.
Reference review	References 4 & 10 are not clear (ought to have more info or even a link). Is 13 really needed? -- the definition used is generic.	We've added more info to 4 and 10. We believe 13 is an important and formal definition of adaption with regard to the technical aspects of the system and thus should not be omitted.
Revise sbbreviations in Abstract.	It is not a must, but, if you put your abbreviations to Introduction (instead of Abstract), they look better.	We've changed it.
Ref. to Nieße in abstract	You may want to say in the Abstract that the work is an extension of (Niesse et al., 2014).	We've added DVPPs as a major contribution in the abstract.
Wording, Spelling Errors, and Grammar Issues	<p><i>Reviewer 2:</i></p> <p>Even though the paper is well written, there are some minor punctuation problems to be corrected. In the Introduction, use "In this paper, an approach" instead of "In this paper an approach". Also a missing dot in Section 2.3. Please generously use punctuation marks.</p> <ul style="list-style-type: none"> - In Section 2.2, 5th paragraph, what is "2" in the statement "... used for their VPPs (see 2)"? - 2nd sentence in the Conclusion needs some rephrasing, "... adding real time dynamic during ...". 	We've corrected the errors.