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Power Alliance – Extending Power Grid Capacity on the Medium Voltage Level by Incentivizing a New Class of Emerging Flexible Loads

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Abstract

The electrification of the energy system introduces new loads with high simultaneity, such as new storage technologies, sector coupling technologies or electric cars. This effect, together with the penetration of renewable energy sources causes an increased likelihood of grid congestions in times of high production or demand, which in turn entails an increased need of costly physical grid expansion. Demand flexibilities and dynamic load management solutions can be used to counter this effect. However, demand flexibilities are limited particularly in the industry sector, because market-based incentives to support the macro-economic goal of optimizing existing grid capacities are missing. The paper proposes a novel market-based approach to employing dynamic load management in the mid-voltage grid that overcome these hurdles. A smart method to utilize redundant grid capacity for a new class of loads called "conditional loads" is combined with an attractive tariff scheme for customers and incentives for DSOs that help increase competitiveness of electricity vs. fossil combustibles.

Introduction

In order to mitigate the risks of climate change an extensive energy system decarbonization needs to be realized until mid of this century. If the installation of renewable generation assets continues at the necessary high rates, the system will increasingly exhibit an excess power production, increased simultaneity of production and demand, and resulting grid congestions on all voltage levels. A means to avoid or mitigate costly physical grid expansions in the future are the utilization of demand flexibilities and dynamic load management solutions. However, a shift of demand towards times of abundant wind and solar power is rarely happening today: while a top-down enforcement of necessary measures is politically not desirable, market-based solutions are difficult to implement, because the demand is largely inelastic due to technical, regulatory and economical hurdles.

The paper proposes a market-based approach to utilizing demand side flexibilities on the mid-voltage (MV) grid, overcoming the existing hurdles. The approach consists of three main ideas: 1. We utilize the currently unused grid capacity reserved for n-1 security of supply for a special class of flexibilities called “conditional loads”, which are assumed to be the main drivers of future grid congestions. These loads are used by a "Regional Load Shifting" system to automatically resolve grid bottlenecks. 2. We propose a novel tariffication scheme for end customers that significantly reduces energy prices, grid fees, and taxes and levies for conditional loads. 3. We provide incentives for distribution system operators (DSOs) to offer conditional loads to their customers. We describe two new processes that are needed to implement the proposed scheme, and sketch the underlying technical solution, including a proof of concepts of technical and economic feasibility.

The proposed approach was developed as part of the EU project "Power Alliance", that involves research and industry partners from Austria, Germany and Switzerland. Participating DSOs contributed real data from pilot customers of power consumption and production as well as related auxiliary measurements. Here, an existing smart metering and load management solution has been adapted to implement a practical prove of concept for the "Power Alliance approach" presented here.

The paper is structured as follows: Section 1 discusses existing business models and principles that aim at avoiding future grid congestion. Section 2 discusses increased simultaneity as an effect of decarbonization, and section 3 discusses the main hurdles that are in place today that impede the use of demand flexibilities to mitigate grid congestions. In section 4, the Power Alliance approach is introduced as a solution to this problem. The paper concludes with a summary of proposed concepts and results.

1. Flexibilities to Mitigate Grid Congestion

The electric power system is undergoing a profound change driven by the continuously growing penetration of renewable energies, and the expected electrification of the transportation and industrial sectors. These two major trends increase the need for flexibility to avoid bottlenecks and blackouts at the distribution grid level.

In order to respond to these new challenges, the present grid technologies, business models and regulations need to be updated (Giordano & Fulli, 2012). This is particularly important for DSOs, who are in charge of accommodating decentralized energy generation even though this technology endanger their current business model. DSOs are highly

regulated entities, and thus the regulatory framework must be adapted to facilitate the implementation of new business models and incentivizes DSOs to try innovative solutions in order to keep the quality of supply at lower cost (Colle et al., 2019).
Presently, DSOs charge fees using the classic electricity tariff, which is based on the amount of energy transmitted. Consequently, the DSO revenues are largely affected when end-users start to require less energy due to the increase of distributed generation technologies (Honkapuro et al., 2014; Jansen et al., 2007; Picciariello et al., 2015).
Furthermore, even with lower revenues, a DSO is still compelled to keep the security and reliability of the electric supply with an aging infrastructure (Honkapuro et al., 2014). As a consequence, DSOs are in the need to find new ways of creating and capturing value. The use of information technologies in smart grid application opens large opportunities for new business models that benefit several stakeholders, including DSOs. The proposed "Power Alliance" provides such a business model, and particularly provides incentives also for DSOs.
The literature mentions mainly 3 types of business models that are enabled by smart grids: Vehicle to grid (or grid to vehicle), demand response and renewable energy integration. Among other benefits, these business models can help DSOs to reduce system costs, lower investment cost and grid capacity requirements (Niesten & Alkemade, 2016). The paper introduces a novel market-based approach to respond to above listed challenges that combines demand response for the MV grid with renewable energy integration with the allocation of currently unused grid capacity.

2. Decarbonization Entails High Simultaneity

The electrification of transport and heating that is necessary for decarbonization entails new loads that exhibit high simultaneity. This in turn amplifies an already existing lack of flexibilities available for grid capacity optimization.
Today low wholesale prices appear on the spot market when renewable production is high and power demand is low. With the increase of renewable power production, it is likely that we will experience situations in which - even during high load periods - wholesale prices will remain low, if only renewable production is high enough. Scenarios for a decarbonized power supply in Germany (Graichen, 2017) expect that, e.g. for solar photovoltaic (PV) production alone, an installed capacity in the order of 250 GW is necessary in a decarbonized energy system. Wind generation capacity onshore and offshore ranges in the same order of magnitude. Today the overall maximum grid load in Germany is in the order of 80 GW (Klobasa et al. 2013).
With the penetration of new storage technology, power-to-x technologies as well as electric cars, the maximum grid load has the potential to increase quite substantially. For example, if only 1 Mio. electric cars would charge simultaneously at a rate of 11 kW, the German grid load would increase by 11 GW already. While the average charging will likely be much lower than that, other, additional factors will contribute. E.g.,

- the number of passenger cars registered in 2019 amounts to approximately 47 Mio., some of which will likely be fueled by renewable hydrogen. This in turn - amongst other applications - drives the number of installations for electrolysers.
- the number of fossil fueled room heating systems is in the order of 15 Mio. units, which in majority need to be replaced by heat pumps or direct heating systems.

- with the phase-out of feed in tariffs for approximately 1.6 Mio existing solar generators, a substantial share will be upgraded with stationary batteries. The majority of new PV installations in the private and commercial sector dispose of a battery already .

With a penetration of smart meters and smart charging technologies these new loads will draw electricity from the grid, preferably during periods of low price, i.e., during periods of high renewable generation. These new loads therefore will exhibit a very high simultaneity and thus have the potential of becoming the main source of stress to the electricity grid on all voltage levels.

3. Main Hurdles for Exploiting Demand Side Flexibility to Counter Simultaneity Effects

Demand side flexibilities, together with dynamic load management solutions can provide a means to avoid grid congestions at times of high simultaneity. Yet, from a practical point of view, significant hurdles exist towards their implementation.

Hurdles in the household segment. In the *household segment* today, there is very little capacity installed which technically could be shifted. Apart from electrical water heaters, which in some cases follow a ripple control signal, most other appliances, e.g. cooking, washing, lighting, communication, etc. are nearly inelastic.
From a technical point of view the penetration of electric cars and solar storage systems as well as the substitution of fossil room heating systems through heat pumps will offer significant technical load shifting potential in the future.
From an economical point of view it is obvious that the cost of implementing and maintaining an energy management system including smart metering and communication can hardly be refinanced by the relatively little savings achievable through load shifting today. The household customer electricity predominantly consists of fixed charges for grid use and taxes and levies. The fraction for energy on the overall bill, e.g., in Germany is 30% or lower on average. Any gains through load shifting towards periods of lower prices thus only slightly affect the overall bill. In Switzerland the fraction the of energy is somewhat higher though, but in turn, the absolute price for electricity is lower than in Germany, and electricity in the overall household budget is mostly not an issue of concern.
The European Union is pushing for a mandatory rollout of smart meters for a long time, in an effort to let household customer participate in flexible rate schemes. In Germany this leads to the adoption of the Law for the Digitization of the Energy System Transformation ("Gesetz zur Digitalisierung der Energiewende", Bundesregierung 2016) which foresees a mandatory installation of smart meters for households over 6.000 kWh of annual consumption. This obligation however only enters into force as soon as a minimum of 3 independent suppliers of certified smart metering systems are certified by the state. Today only one such system is on the market due to the complexity of the data security prerequisites laid out in the law.

Hurdles in the industrial & commercial segment. In the *industrial and commercial segment*, practically all significant consumers are obliged to monitor their energy consumption electronically. From a technical-economical point of view several studies have shown that the available potential today is relatively small (Klobasa et al. 2013). The underlying reason for this is the fact that in industrial production the cost of electricity in the overall production for most companies is relatively low. The average share is around 5% on average only. Hence cost saving measures on other parameters e.g. labor, capital etc.

have a significantly bigger impact. In addition, the opportunity cost of permanently shifting planned production cycles into variable periods of lower energy costs will overcompensate the savings on the energy bill.
In those cases where the energy bill is a significant portion of the overall production cost, i.e. the basic materials industry, a number of policy related subventions are in place in order to keep production local in a global market (carbon leakage, local employment). One example is companies with baseload offtake profile (>7000h/a) in Germany will receive grid tariff discounts of 80 to 90 %. load shifting measures would compromise the offtake profile and hence jeopardize these very significant grid savings.

As a conclusion it can be stated that flexible loads for the energy system today are practically insignificant.

4. The Power Alliance Approach

The Power Alliance approach proposes a technical and economical scheme that allows to overcome the existing hurdles for utilizing demand side flexibilities to avoid grid congestions in future scenarios of increased electrification. It thereby supports the underlying macro-economic goals of avoiding negative prices for electric power, avoiding the shut- down of excess generation, and mitigating a future need for costly physical grid expansion.
To overcome the hurdles for utilizing flexibilities towards these goals, demand side load management is applied only to a specific class of new flexible loads, the so-called "*conditional loads*", which mainly emerge from sector coupling applications. For these loads, the currently redundant grid capacity used to provide today's high level of security of supply - the "*n-1 security*" – is utilized, thereby allocating additional capacity in the existing grid infrastructure. Conditional loads are subject to a simple security of supply, while n-1 security is maintained for all other loads.
Incentives for grid customers to declare suitable loads as conditional loads with the DSO comprise 1. significantly reduced grid fees for conditional loads (the "*Power Alliance Tariff*"), and 2. an automated dynamic load management solution (the "*Regional Load Shaping*" solution) that minimizes the customers' energy costs for conditional loads according to stock prices whenever regional grid capacity constraints admit it.
Power Alliance also advocates reduces taxes and levies for conditional loads: to support the long-term goal of significantly increasing competitiveness of electricity vs. fossil combustibles, it is necessary that electricity – wherever it is in competition with fossil energy carriers - is not burdened with associated costs as much as it is the case today.
The main incentives for DSOs to participate in the Power Alliance scheme are a better plannability and control over their grid, as well as more detailed insights into grid flows, which allows them to offer attractive products of choice to their customers.

4.1 Unconditional and Conditional loads

The Power Alliance approach distinguishes two classes of loads according their respective requirements regarding security of supply:

Unconditional loads are loads are price inelastic within the normal range of price fluctuations. These loads only depend on the demand of the respective energy service. Examples are loads in industrial production, household appliances, lighting, communication etc. For unconditional loads, a supply outage would incur significant costs.

The customer is willing to pay an adequate price for n-1 security of supply. As it is the case today, unconditional loads are supplied through the normal n-1 secure capacity band of the MV grid (cf. Figure 1).

Conditional loads are new emerging loads that are either connected directly to the MV grid or belong to premises that have their own grid level 6 transformer stations (e.g industrial sites or residential microgrids). They have *two defining characteristics*:

1. They can tolerate a lower security of supply compared to unconditional loads. This means that the (rare) event of an outage would *not* incur an unacceptably high financial damage.
2. They exhibit a significant price elasticity during a larger number of timesteps within a 24-hour period or longer.

Typical examples for conditional loads are industrial power-to-heat installations to substitute fossil-based combustibles, industrial electrolysers for hydrogen production (including synthetic fuel), electric cars charged at work, as well as buffer batteries that are used for PV-based self-consumption or for peak shaving in industry and in local micro-grids. Conditional loads are supplied through the redundant grid capacity that is today reserved for n-1 security (cf. Figure 1).

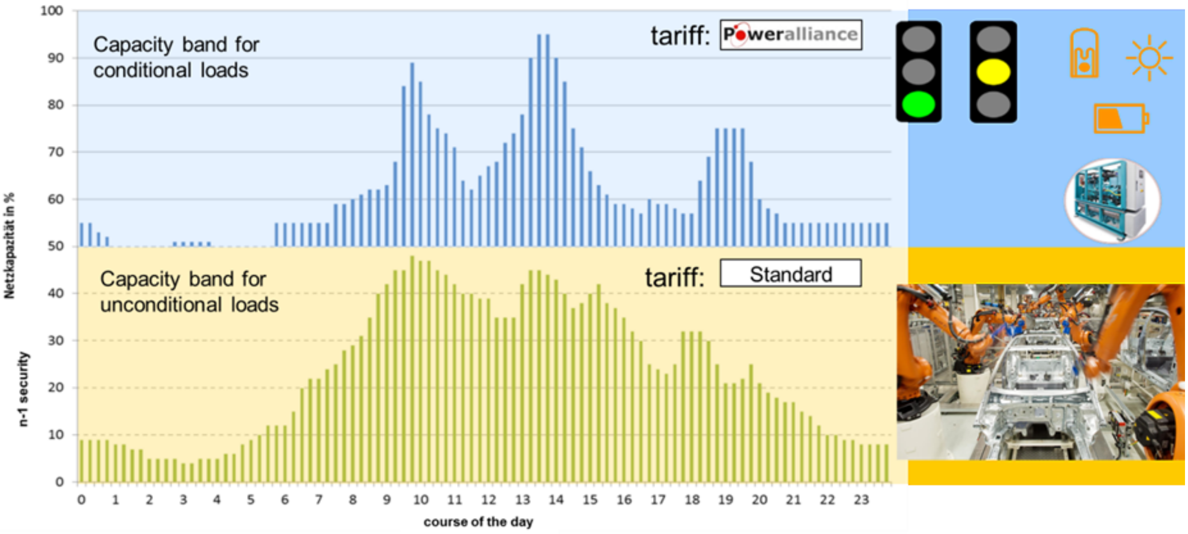

Figure 1: Conditional and unconditional loads

4.2 Incentives and Obligations for Stakeholders

The goal of Power Alliance is to provide a market-based scheme and corresponding incentives to stakeholder to support the macro-economic goal of avoiding costly physical grid expansion. Besides national economies, there are two main stakeholders participating in the Power Alliance scheme, namely grid customers on MV level, and DSOs.

The grid customer perspective. For *unconditional* loads, today's normal grid tariffication stays unaltered and is called the "*Standard Tariff*" (ST). For *conditional* loads we introduce a new tariff that is significantly lower than the ST, and we refer to it as "*Power Alliance Tariff*" (PAT). The PAT effects all three price categories of power supply, namely *grid fees, energy price*, and *taxes & levies*.

- **Grid fees.** The PAT for conditional loads offers customers significantly reduced grid fees compared to the ST, e.g., a reduction by -90%. In return, customers must guarantee that their conditional loads are either connected and controlled by separate electrical wiring, or that they are integrated in an energy management system that allows for an individual metering and control in relation to the signals which result from the Power Alliance system. They accept for their conditional loads a simple security of supply instead of the usual n-1 security of supply. I.e., in case of a grid capacity bottleneck, conditional loads are automatically shedded to ensure n-1 security of supply for unconditional loads. In addition, the customer (or its energy supplier/service provider) has the obligation to send daily schedules not only to the transmission system operator (TSO), but also to the DSO, thereby providing the DSO with better insights in their grid flows.
- **Energy prices.** The PAT allows end customers to participate in the spot market. Thereby they can leverage the spot market's demand flexibility for conditional loads, profiting from the daily energy price volatility it offers. The is achieved by applying a smart mechanism based on dynamic load management, the *Regional Load Shaping* (RLS) system (Christen et al., 2019). The RLS automatically shifts conditional loads to times of minimal spot prices, respecting the customer's technical and procedural constraints. Only if the available capacity limit for unconditional loads (i.e., the capacity of the n-a band) is reached at a certain time slot, grid customers are competing among each other for this time slot. Here, every individual customer is curtailed according to their individual allowance. A customer's allowance in turn is derived from a prioritization of customers according to their PAT scheme: The more customers are willing to pay for PAT, the higher is their prioritization in a competition setting. Thus, the Power Alliance approach utilizes the willingness to pay principle by creating scarcity-based market prices for grid use. To limit the energy price risk for conditional loads, customers are given the option to agree on price caps with their power suppliers. To mitigate the price risk for unconditional loads, customers directly use the ST to hedge the energy price under a full supply regime.
- **Taxes & Levies.** The PAT offers a significant reduction in taxes and levies compared to the ST (e.g., -50%). The Power Alliance approach uses this instrument to additionally incentivize the build-up of loads for decarbonisation through sector coupling and storage technologies.

Since reduced fees are only applied to conditional loads, the overall income situation of the energy system is not affected in a negative way.

The DSO perspective: Incentives and Obligations. In offering the PAT, DSOs can increase the distribution grid capacity of their MV grids without costly physical grid upgrade, increasing their income. They also gain more detailed insights into their grid flows, because Power Alliance customers are obliged to submit their daily schedules to them. This allows for a better plannability and control, and also helps DSOs to strengthen their customer relationships by offering attractive products of choice. Furthermore, the DSO is offering its unconditional and conditional capacity products to its customers on a regular basis e.g. annually or monthly.
In return, DSOs accept the obligation to monitor critical grid nodes, and to automatically submit respective measurements to Power Alliance. This enables Power Alliance to monitor grid capacity at bottlenecks, and, in case of excess demand of conditional loads, curtail them semi-automatically. More specifically, in case the daily ordered capacity demand of conditional loads exceeds the available n-1 capacity reserved for security of

supply at a critical node, the Regional Load Shaping (RLS) system automatically curtails customer loads according to their individual allowance under the Power alliance tariff scheme. I.e., in contrast to *local* load management solutions, the RLS combines *regiona*l grid capacity optimization for DSOs with *local* load shifting for energy price optimization for end customers within the respective grid branch (Christen et al., 2019). After curtailing, the RSL sends a suggestion to customers for shifting the curtailed portion of their loads to a time slot with the "next best" spot price. Customers are then given the option to accept or reject the automatic suggestion, and, in case of rejection, resubmit an adapted schedule suggestion to RSL, which again is checked automatically by RSL for compliance with the grid constraints at bottlenecks. The process is iterated for every customer until the customer accepts a schedule or until a temporal deadline is reached.
In open ring topologies grid bottlenecks usually appear on grid level 4 at the transformer stations from the high voltage transmission grid to the MV distribution grid - loads are highest at this point in the grid whenever no significant production is located within the local distribution grid.

4.3 New Processes

In order to practically implement the Power Alliance scheme, two additional processes must be devised and implemented.

The capacity purchase process.

- Grid customers purchase conditional and unconditional grid capacity from their DSOs on a regular basis (e.g., monthly or yearly) according to their needs. Curtailments might occur during high capacity demand, i.e., in times of low or negative energy prices. In this case, customer loads are curtailed in proportion to their capacity limit. In order to achieve a higher prioritization in case of curtailment, customers have the option to buy more unconditional grid capacity than they actually need (*willingness-to-pay principle*).
- The DSO sells unconditional capacity rights only to the extend such that he can meet all required unconditional schedules at all times.
- For the sale of conditional capacity no limit is stipulated. Grid customers are free to purchase as much as they need in order to improve their individual situation in case of possible curtailments.

The daily capacity nomination process. Customers (or their service providers) are submitting to their DSOs two day-ahead schedules on a daily basis:

1. The **schedule for their unconditional loads** is based on a normal day-ahead forecasting process that reflects their needs. Schedules for unconditional loads do not need to be approved by the DSO, since the DSO is obliged to fulfill them in any case as long as they do not exceed the contracted limit.
2. The **schedule for their conditional loads** results from automated stock price optimization by the RLS load management software. After the reception of all schedules well before the given deadline, the DSO is checking grid capacity constraints and accepts or rejects them. In case of rejection, the RLS software automatically suggests a revised schedule that complies with grid constraints and provides to all customers second best time-slots for their excess loads with respect to stock prices. The customer in turn can accept the suggested schedule revision or provide their own revised schedule. The process is iterated until a temporal deadline is reached.

The technical implementation of the capacity nomination processes comprises two components: the "*energy manager*" is a local energy management system installed at the customers' premises; the regional "grid manager" software system is installed at the DSO's premises and aggregates the individual day-ahead schedules (of unconditional and conditional loads) of all customers attached to a grid branch and checks each critical node in the branch against the available capacity limit. Energy manager and grid manager units are technically separated to comply with the requirement of the European Union of ownership unbundling.

4.4 Proof of concept

Technical feasibility. Even though conditional loads are not significant in capacity today, it is assumed that the emergence and penetration of such loads in a decarbonized energy system will be the primary driver of grid extension needs. In order to demonstrate the feasibility and the practical use of the Power Alliance approach, simulations have been performed that are based on real data from pilot customers projected to a one year period in 2035 (Christen et al., 2019). It could be shown that today's redundant grid capacity can be put into service for conditional loads without compromising n-1 security for unconditional loads. I.e., crucial consumers and processes are not effected by the Power Alliance scheme in case of an outage.

Economic feasibility. The successful implementation of the Power Alliance scheme and business models for stakeholders largely depends on several external factors such as the future electricity and gas prices as well as the price of the studied technologies. To assess the feasibility, simulations of future market scenarios have been performed.
According to Graichen et al. (2015) the wholesale electricity price will increase in the following years, from 3.8 cEUR per kWh in 2016 to 8.3 cEUR per kWh in 2035. Therefore, it is expected that the EEG Subvention decreases from 6.1 cEUR per kWh in 2016 to 2.2 cEUR per kWh in 2035. This means that the resulting retail electricity price in 2035 will be 6% larger than the electricity price in 2016. Regarding the end user gas and oil price, the forecasted scenarios show a rise in the next years due to an increase in the CO2- Price. As a result, according to (Swiss Federal Office of Energy, 2012) with very strong environmental policies, the gas price could reach the value of 13.5 EUR/kWh in the year 2035. This means an almost 30% growth in 15 years.
Furthermore, due to the learning effect the cost of the technology such as batteries and PtoH2 will significantly decrease. According to the projection of (Pleßmann & Blechinger, 2017) the capital cost of batteries will drastically decrease from 1192 EUR/kWh in 2016 to 289 EUR/kWh in 2035. At the same time, it is likely that the cost of the Polymer electrolyte membrane electrolyser sink from 2000 EUR/kW in 2016 to 530 EUR/kW in 2035 (Estermann et al., 2017).

Conclusions

Continuing the way of decarbonization with renewable energy sources will lead to congestions in Europeans electrical power grid. Causes are the penetration of renewable energy sources, progress in sector coupling but also the missing flexibility in loads. However, the missing flexibility is mainly related to the industry where no incentive is given from the economical point of view. The paper proposed a market-based approach to solving this problem for the MV grid. The approach utilizes the currently unused grid capacity reserved for n-1 security of supply for a special class of flexibilities called "conditional loads", which are assumed to be the main drivers of future grid congestions. While conditional loads are only equipped with simple security of supply, n-1 security is guaranteed for all other loads. A novel tariffication scheme is introduced that economically incentivizes the adoption of conditional loads for end customers and DSOs, and an automated "Regional Load Shaping" system shifts conditional loads to resolve grid capacity bottlenecks if needed. We described the new processes necessary to implement the "Power Alliance" scheme practically, and sketched the underlying technical solution, including a proof of concepts of technical and economic feasibility.

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