Coordination concepts for interactions between energy communities, markets, and distribution grids

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Abstract

The paper summarizes the qualitative analysis of stakeholder interactions and coordination concepts in respect to four major congestion management solutions of distribution system operators. Benefits and drawbacks of congestion management solutions and interactions are analysed from holistic system perspective and concluded to understand the overall state-of-the-art and development needs. The key result of the analysis is that the winning approach for DSO CM includes all four CM solutions, and the next step is to incorporate technical active network management as novel operation tools for congestion management.

1 Introduction

Electricity distribution system is transforming from a passive grid to a marketplace for prosumers, energy communities and aggregators. This transformation creates a need for Distribution System Operators (DSOs) to utilize Active Network Management (ANM) for grid operation to enhance grid hosting capacity for Renewable Energy Sources (RESs), electric vehicles, heat pumps, etc, to postpone grid investments and to enhance supply security. Coordination between stakeholders is vital to be able to unlock the flexibility potential and to avoid individual sub-optimization and causing simultaneously harms for others.

In the future smart grid, a DSO needs much more information about other stakeholders, and from its own grid status. For this purpose, the market actions of prosumers, energy communities, aggregators and retailers must become visible for a DSO. Stakeholders are considering their own interests by minimizing energy cost, or maximizing the value of flexibility which can create conflicts-of-interests in distribution grid. The coordination concepts should benefit all market stakeholders by optimizing the overall costs and benefits while maximizing the grid hosting capacity, provision of flexibility, and needs of grid customers.

General principles for coordination especially between transmission system operators and DSOs have been outlined in [1] and research on coordination between different actors has been active in several projects such as INTERRFACE [2], SmartNet [3] and CoordiNet [4]. This paper builds upon earlier research on coordination between actors and on ANM and aims towards holistic analysis of coordination concepts. The paper analyses stakeholder interactions and potential coordination concepts in relation to different Congestion Management (CM) solutions. Based on qualitative analysis the benefits and drawbacks of CM solutions and interactions are concluded.

2 Stakeholder interactions

Distributed Energy Resources (DERs) like distributed generators, energy storage, and flexible loads are owned by different stakeholders. The demand of passive consumer is not flexible for any stakeholder. Producer feeds in power to grid typically from RESs. A prosumer is a party that can act as producer and consumer interchangeably. Prosumers can actively manage their consumption and production profiles based on price signals and other external signals with the aim of achieving lower electricity bills. Aggregator is an energy service provider that has control over DERs of a group of stakeholders and represents them in markets. Aggregation makes small-scale DERs eligible to energy and ancillary service markets. An energy community is an entity formed by voluntarily participated consumers, producers, and prosumers. In an energy community, members may share resources to achieve economic, environmental, and social community benefits. It is evident that the mentioned stakeholders have different preferences, habits, and lifestyles based on which they may optimize operation of their resources. The autonomous and uncoordinated operation of these sources may however pose significant challenges to the overall system or other stakeholders.

2.1 Market prices create peaks in demand/production

The uncoordinated actions by individual stakeholders may threaten system efficiency and performance. Assuming time-varying electricity prices, many individual prosumers may transfer their flexible loads to periods with lower electricity prices, which can lead to a severe peak load for a

DSO, increased balancing cost of retailer and Balance Responsible Party (BRP), if the load shifting is not predictable enough, and decreased flexibility of an aggregator what it may provide for other markets. A similar situation may occur, if distributed generators increase their generation and prosumers discharge storage systems during periods with higher market prices. Low day-ahead market price indicates typically demand valley or excess production at wholesale market level, but the loading of local DSO grid might be highly loaded at the same time due to a different consumption pattern or as an origin of excess production. All external stakeholders need to understand what kind of price sensitivity and load shifting capability prosumers or energy communities have.

2.2 Grid bottlenecks limit the access to markets
Grid companies are market facilitators, which means that they should provide equal opportunities for all stakeholders to access markets. In case of a distribution grid, this means organizational separation of DSO and retailer businesses, and the grid itself should not create technical bottlenecks for market access. Penetration of RESs, electric vehicles, and heat pumps has introduced the congestion challenge for DSOs as well. Technical bottlenecks due to voltage rise problem caused by distributed generators are solved by production curtailment. Many practices exist to realize the production curtailment, which depends also on national legislation and grid connection contract. For a customer, the value of self-generation is typically much higher than market price due to grid tariff and taxes and, therefore, prior knowledge of production curtailment would motivate a prosumer for load shifting actions. However, an individual small customer cannot impact on grid congestion remarkably, but he/she may still be impacted by congestion when other customers are not realizing effective enough load shifting actions. Potentially, an energy community of congested grid area might coordinate necessary load shifting actions and guarantee maximal benefit of self-generation while grid congestion is avoided as well. Production curtailment based on technical aspects generates also an equality challenge because the curtailment is realized with the same resources most of the time especially in radial distribution grids. Too high loading of grid components or undervoltage at customer connection point due to DERs typically leads to grid reinforcement actions and therefore DERs access to markets is not limited.

2.3 DSO has priority for local flexibility
DSO may further develop the grid operation by collecting all kind of local flexibilities for CM. DSO takes a priority to utilize local flexibilities and if those are not needed by the DSO and the grid has capacity available, the flexibility may participate in other markets as well. This potentially increases the amount of flexibility available for DSO grid CM, but flexibility might lose opportunities on more profitable markets. Also, the access to markets becomes uncertain and therefore, the operational decisions of local flexibility are not foreseeable and the incentive to provide more flexibility might not be the best possible.

2.4 Utilization of flexibility on single market
The idea of traffic light concept is to inform stakeholders about grid capacity and to indicate if the local CM market will be opened. The grid capacity limits caused by uncoordinated operation of DERs or DSO priority for flexibility utilization may constrain stakeholders who would like to present their services in the market. Coordination of flexibilities becomes a challenge when the interests of prosumers or energy communities are combined with the interests of other stakeholders. Therefore, ancillary service markets have been proposed to enhance flexibility utilization. Too many markets are, however, a challenge for a Flexibility Service Provider (FSP) from flexibility allocation and operational efficiency viewpoints. Although, the profitability of aggregator business is based on capability to operate on multiple markets, in practice, FSPs focus on the few most liquid and profitable markets. If a local CM market is needed very occasionally, then the market may not become attractive enough for FSPs [3].

2.5 Easy multimarket participation of flexibility
Flexibility trading on multiple markets via a single interface and coordination platform, designed to fulfil the requirements of multiple market services and coordinating interactions of multimarket system, has been studied in [2]. The aim of the system is to simplify the access of flexibility to markets and therefore increase the liquidity of occasionally utilized and low volume markets like local CM market. The key element of the system is the information exchange platform to increase visibility of flexibility trading for grid operators and corresponding grid impacts deep in distribution grids, enhance the awareness of FSPs about local CM market opportunities, enable flexibility bidding on multiple markets simultaneously by integrating markets, and simplifying flexibility trading by introducing automated processes for resource, grid and bid qualification via flexibility register and grid coordination mechanisms.

3 Description of CM solutions

3.1 Copper plate
”Copper plate” CM method refers to traditional “fit-and-forget” style network planning and operation. It is a combination on passive network reinforcement methods combined with reactive network monitoring. Network investment decisions are made primarily based on network area demand projections, ageing of the existing network and/or technical constraints (e.g., security of supply, electricity quality). The optimal investment decision would have its useful lifetime runout at the exact same time as the network demand exceeds the technical constraints.

This management style incorporates no direct coordination between DSO and customers. Thus, DSO does not attempt to influence the customer behaviour in any manner. Downside is the excessive cost of passive components and the risk of mis-dimensioning. Investing too much will cause the increase in investment value, which will in turn cause higher capital expenditure and lower return of investment.

Investing too little carries the risk of violating the technical constraints of network operation during the investments' lifetime. This would force the DSO to re-invest to network.

3.2 Novel grid tariffs
Grid tariff is a mechanism for grid operators to cover costs related to grid infrastructure, operation, and maintenance. There are several ways to formulate grid tariff by considering energy, capacity, and fixed charges as well as considering time-varying terms by utilizing time of use or other dynamic grid tariffs. A DSO as a regulated actor could form the grid tariff such that its cost recovery is ensured. As a result, grid tariff could be considered a means of DSO to slowly steer the behaviours of customers.

Grid tariffs have a wide impact on all stakeholders. Grid tariffs would impact in every part of the grid and not only in congested area. In order to solve congestion problem, a DSO might increase the capacity charge weight in grid tariff. As a result, the probability for congestion is expected to decrease, because the approach should motivate for load shifting investments, i.e. customers becoming prosumers. However, prosumers utilizing more flexibility for their internal needs, less flexibility becomes available for markets and increase the price of flexibility for all markets. On the other hand, a negligible capacity charge term whether do insignificant changes in customers' behaviours or a notable change can only be realized over a long-time horizon. In addition, a grid tariff should not drastically decrease the predictability of customer's behaviour because otherwise it can increase retail and balancing cost.

3.3 Technical ANM
Technical ANM refers to management method where DSO utilizes the control potential of customer owned and DSO's own resources for increasing the hosting capacity of the network. These methods include, but are not limited to, reactive power control, load/generation curtailment, coordinated voltage control, dynamic line rating, enhanced grid monitoring, etc. Primary difference to market ANM is that the control of resources is naturally under control of DSO or mandated by DSO in network service contracts (grid codes), not purchased from flexibility market, and typical services are non-frequency related.

3.4 Market-based ANM
Market-based ANM could be seen as a new method complementing already existing technical solutions. The emerging ideas like local CM market aims to extend the feasible space of ANM for DSOs. The market-based solutions are not supposed to replace network planning deficiencies but as a short-term alternative to make full use of network capacity and to minimize production curtailment. Investment postponement is one of the use cases of market-based solutions that are achieved by linking DSOs to resources' flexibility through a market process.

Typically, local CM markets are short-term (day-ahead activation) or operational (day-ahead reservation and near real-time activation) markets. The stakeholder interactions among prosumer, aggregator, marketplace and grid operators creates the core processes of local CM market. Multiple alternatives exist and those are considered in [1,2]. If indirect impacts of local CM market for retailers, BRPs, etc. and interactions between markets are considered, the interactions may become rather complex. Long-term flexibility contracts as an auction outcome could be seen as a market-based ANM as well.

4 Analysis

The chapter analyses the combinations of the interactions and the CM solutions from holistic system perspective. High level Key Performance Indicators (KPIs) are utilized in the qualitative analysis. The quantification and the KPI analysis are based on expert judgement. KPIs are the following: (1) Technology availability (When it is available?), (2) Commercial feasibility (How easy the commercial arrangements are to realize?), (3) Grid regulation (Is the existing grid regulation enabling or incentivising the idea?), (4) Readiness of stakeholders (How widely the ideas have been accepted?), (5) Total system costs, (6) Robustness of a solution (Is it always applicable for the challenge or only in special cases?), and (7) Complexity of interactions (How much effort is needed to realize and maintain required information exchange?). The Table 1 summarize the findings of the KPI analysis. Following notation has been utilized: (+) "positive", (-) "negative", (?) unknown or uncertain, and (n) neutral. The order of notation is according to KPIs listed above.

Table 1 Summary of KPI analysis

	Copper plate	Grid tariff	Technical ANM	Market ANM
Market peaks	++++-++	+-n-+-+	+-?-+-n	
Grid bottlenecks	+-?--++	-------	+n?+++n	
DSO has a priority		++n-++-	+n?+++n	
Single market				++n?+--
Multimarket participation				--n?+-+

4.1 Copper plate
The technology for copper plate solution exist, those solutions are commercially straightforward to realize, most grid regulations incentivise capital expenditures like copper plate, DSOs have the expertise to utilize these solutions, technically the copper plate is very robust solution, and the information exchange between stakeholders is minimal. However, the grid reinforcement cost might become very significant when the penetration of RES and DERs increases and the existing grid has remaining lifetime. The

copper plate solution is the state-of-the-art for DSOs today and it will remain as a part of the toolbox because aging grids will require investments sooner or later.

Copper plate solution is technically also attractive for other stakeholders. Strong enough grid enables consumers to remain as passive as they wish, grid does not create obstacles for the integration of RES and DERs, and everyone has access to energy and ancillary service markets. However, the cost of grid connection and use might become extremely expensive, which might lead to non-optimal solution from societal viewpoint, energy poverty and off-grid solutions. With existing practices, the individual behaviour of prosumers will speed up this trend although they bring benefits for individual stakeholder.

Since the copper plate assumes a passive distribution grid, there are not many other capabilities to handle possible congestion conditions in the grid. Reinforcement of the grid is a very slow process and therefore, the congestion condition in copper plate leads to production curtailment, decrement of voltage quality or decline of components' lifetime. Regulation of congestion conditions varies among European countries and connection contracts and therefore clear and generic answer may not be given. Naturally, the customers are not ready to accept production curtailment, and customer inequality due to spatial impacts of production curtailment and voltage quality decline.

4.2 Novel grid tariffs

Grid tariffs potentially provides a long-term solution to CM by incentivizing customers to reduce their peak powers. Technologies with different level of intelligence exists for tariff control and load shifting. Demand peaks created by low market prices are cut, which makes the solution less attractive for prosumers. Although, there are some restrictions how DSOs may modify tariffs, in general, grid regulation does not prevent the utilization of the solution. The greatest benefit of effective enough grid tariffs is more efficient utilization of grid infrastructure, which is benefit for all stakeholders, if the benefit becomes visible as reduced grid tariffs. The capacity-based tariffs also divide the cost of passive grid according to need of grid infrastructure and therefore more equally. The complexity of the solution is related to capability of DSOs to explain the reasoning of the tariff structure for customers, otherwise the interactions are straightforward.

Grid tariff solution is unable to solve congestions as an operational challenge. Secondly grid tariffs are not designed to solve congestion related to RES because producer or prosumer feeding power to grid are not paying grid tariffs. Potentially the CM related to new customers of DERs and energy communities might be partly solved with capacity-based grid tariff by incentivizing them for load shifting.

One possible way to realize the DSO priority for flexibility is a special grid tariff for controllable customers. Technically DSO controls DERs directly within specified limits defined in the contract. This kind of contracts exists also for small-scale customers in Nordic countries prior the electricity market opening. Technology has advanced a lot in this area both at DSO and customer sides. While the load reduction is relatively easy to realize for heating and cooling type of loads to avoid overloading or undervoltage, the increment of load for overvoltage conditions is much more challenging, and therefore control of batteries or production curtailment are also needed. Grid regulation enables special tariffs, but defines limitations for example for the control of heating loads. Potentially the long-term cost of grid infrastructure may be reduced, if enough many customers are willing to accept the special tariff in congested area. The major drawback of the idea is the additional complexity of FSPs to participate in ancillary service markets.

4.3 Technical ANM

Advanced control possibilities of technical ANM extend the CM possibilities of DSO compared to copper plate and novel grid tariff. Although, numerous technologies have been proposed and many piloted, only the most basic ones are commercially available and accepted by DSOs. Therefore, the technical development and commercialization are further needed to utilize these solutions as a standard option for CM. Grid regulation has recently changed by European directive 2019/944 and especially by article 32 how to utilize flexibility in distribution grids [5]. National implementations of the directive and DSO practices are under development at the moment, and it is unclear how much the directive will incentivize technical ANM solutions in practice. DSOs who face serious congestion problems are more ready to accept technical ANM solutions compared to DSOs having strong grids at the moment. The main challenge on DSO side to accept technical ANM solutions is to incorporate possible solutions as a part of everyday grid planning. Technical ANM methods are easy to accept by other stakeholders because the methods are typically influencing on DSO's resources, reactive power of resources, and mandated by grid code or service agreement. These solutions provide a huge potential to reduce total system costs due to congestion, because the hosting capacity for RESs and DERs can be multiple times higher than for copper plate. However, as long as the grid regulation does not consider total expenditures instead of capital expenditures while defining allowed profit of grid company, the grid regulation will remain as an obstacle for the technical ANM. The robustness of the technical solutions is in general very good, but some limitations exists while they are designed for a specific challenges and integration of solutions to IT and automation systems of DSO is still burdensome. The complexity of stakeholder interactions is not significant.

DSOs may have ancillary service contracts with their customers to directly control DERs. Those are normally operated on energy and ancillary service markets, but in case of congestion, the direct control of DSO is utilized to activate CM services. Prior reservation of the service for DSO utilization may be required to reduce FSP's risks on markets. Although the technology exists for this kind of systems, the idea is not yet widely accepted. Also, the economic benefits of such services have not been clarified; sometimes the benefits are extremely attractive for FSPs and other times the expectations of service profit are unrealistic. Existing grid regulation is not supporting this arrangement enough; DSO should buy services instead of owning batteries itself, but services are considered as an operational cost, which will reduce the allowed profit.

4.4 Market ANM

Technical ANM may be further extended with market ANM by providing more comprehensive solutions and resources for CM. Ideally, local CM market could provide infinite resources to enhance hosting capacity for RESs and DERs as long as flexibility is cheaper than grid investments. Local CM market may simplify and enhance the flexibility utilization from DSO's perspective, but one additional ancillary service market increases the complexity of FSP's decisions. Therefore, the whole idea of utilizing market services for CM might be in danger, if local CM market is not one of the most attractive markets for FSPs. If copper plate and technical ANM are the primary CM solutions, the need for a local CM market is very occasional. In addition, the local congestions deep in the distribution grid may be challenging to solve in practice due to unavailability of flexibility. First pilots and commercial solutions for local CM markets exists [6]. Easy multimarket participation is an extension for those and currently under development in [2], but today the multimarket approach is too unrealistic scenario to proceed both technically and commercially compared to alternative approaches.

Grid regulation enables market ANM, but it has the same challenge than technical ANM has with allowed profits of DSO. Also, the readiness to accept the idea of local CM market among DSOs is still unknown. Among FSPs, the easy multimarket participation is more favourable especially in case of large amount of small-scale flexibility. Multimarket approach would require a very large acceptance among stakeholders and large-scale utilization of flexibility to become reality. The economic benefits of market ANM are similar than in technical ANM. Market-based solutions are more favourable from flexibility utilization viewpoint compared to DSO's priority case, where flexibility is easily locked for DSO's utilization only. Therefore, the market ANM and especially easy multimarket participation of flexibility is potentially providing cheapest flexibility resources for CM, while ensuring maximum profit for FSPs too. The robustness of the market-based solutions is seen negative at the moment due to lack of flexibility capable of impacting on congestion. However, the lack of resources is mainly due to early development phase of the whole approach. The complexity of stakeholder interactions is very different for market-based approaches; local CM market potentially leads to very complex interactions, while the easy multimarket participation has completely designed to solve these issues.

5 Conclusion

The paper described and analysed five stakeholder interaction cases, four CM solutions for DSOs and their combinations. The key result of the analysis is that the winning approach for DSO CM includes all four CM solutions; copper plate is requires to provide basic grid infrastructure, novel grid tariff is a DSO's methodology to incentivize prosumers for load shifting and to consider grid aspect in their internal decisions, technical ANM may significantly increase the hosting capacity for RESs and DERs while still keeping everything in DSO's hands, and market ANM is way to go forward when the more efficient utilization of flexibility is needed among all stakeholders.

The next steps for more enhanced DSO CM in addition to copper plate solution are recommended to include technical ANM solutions. Technological and commercial feasibility, readiness to accept the solution among all stakeholders, and robustness for different challenges are on a good level. Significant system level savings are expected to achieve without creating too complex stakeholder interactions or negative cross-impacts. Full-scale integration of technical ANM solutions as a part of DSO's planning and operational systems are required to get full benefit of the approach. At the same time with these immediate steps, the further development of market-based ANM should be continued to be ready for 100 % RES electricity system.

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