A proposal for implementing short-term congestion management market in distribution networks

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***Abstract*—The article provides a proposal for implementing a short-term congestion management market for a distribution system operator's congestion problem. Since congestion management market utilization for congestion management requires at least three stakeholders' interactions, including the distribution system operator, market operator, and flexibility service provider, the article discusses the interactions and proposes how the market utilization can be implemented in practice. The paper presents the market design and its implementation details, including defining and calculating flexibility need attributes. The conceptual work done in the article could be used as a guideline for actual congestion management market implementations; in addition, it can be used for simulating various scenarios in the future, enabling researchers to study issues related to congestion management.**

Keywords*— congestion management, congestion management market, distribution system operator, local flexibility market, relative sensitivity, voltage sensitivity matrix.

I. Introduction

Congestion is a common problem in distribution systems nowadays. It is understood as a network state that has violations in network operation limits, mainly concerning voltage and current. EN50160 [1] defines the steady-state voltage limitations applicable to public distribution systems in Europe. The intention of a distribution system operator (DSO) to avoid voltage-related congestion is mainly due to obligations introduced in the standard; otherwise, DSO is obliged to compensate customers for poor voltage quality. Unlike voltage, overloading, which is the result of violating the current limits, is dependent on the component and its operating situation, not standards. In fact, the DSO's concern about overloading is initiated from asset management of network components because customers are not affected by overloading unless overloading is significant and causes a protection system reaction or, at worst, a component failure. The component's operating current, ambient temperature, physical location, etc., impact overloading, and therefore, current constraints are not fixed, giving a degree of freedom in network operation. For instance, a pole-mounted distribution transformer might be allowed to operate over 100% capacity if the ambient temperature is freezing.

Several factors contribute to the increasing problem of congestion in distribution systems. In the consumption sector, about 2.5 billion people are expected to be added to urban areas worldwide within the next 30 years [2]. With this urbanization forecast, nearly 6.7 billion people will live in cities by mid-century [2]. In addition, transportation electrification as a decarbonization measure increases the consumption of electricity. According to the stated policy scenario incorporating the existing governmental policies, electric vehicles (EVs) will reach 145 million in 2030 compared to 7.2 million in 2019 [3]. In the electricity production sector, distribution systems not only supply customers but also host customers' electricity generations. [4] reports that the global installed capacity of solar photovoltaic (PV) has skyrocketed from 40 GW in 2010 to 580 GW in 2019.

Urbanization and decarbonization in transportation and electricity production sectors have pushed electricity networks to their limits. According to ENTSO-E [5], in 2020, congestion management (CM) costs in transmission system operators of Finland and Germany stood at about 650 k€ and one billion €, respectively. The massive amount of CM costs indicates the importance of congestion and its solutions and that the electricity network has fallen behind the development and transition in the whole energy sector.

CM alternatives can be grouped into market and non-market-based solutions. Non-market-based solutions such as network reinforcement and active power curtailment are already in use; however, because of high CM costs, there is an immediate need to develop and implement novel solutions based on the flexibility that can complement solutions already in use. In fact, obtaining more CM alternatives based on flexibility in hand enlarges the solution space, contributing to lower CM costs.

The article considers the DSO congestion management because, firstly, the congestion problem is becoming more dominant in distribution networks, and secondly, congestion management at the transmission level already has some market-based alternatives. Therefore, congestion management at the DSO level is the article's focus. It aims to propose a market-based solution for DSO's congestion problem using the congestion management market (CMM). The article shows how a market design proposed in [6] can be implemented for a DSO's congestion management. The current article continues the research done in reference [6], with more implementational aspects in place.

II. Problem definition

As a market-based solution, the local flexibility market (LFM) is proposed for CM. LFM can be used for grid operators' CM, portfolio optimization of balance responsible parties (BRPs), retailers, aggregators, and peer-to-peer trade between microgrids and energy communities. In fact, the

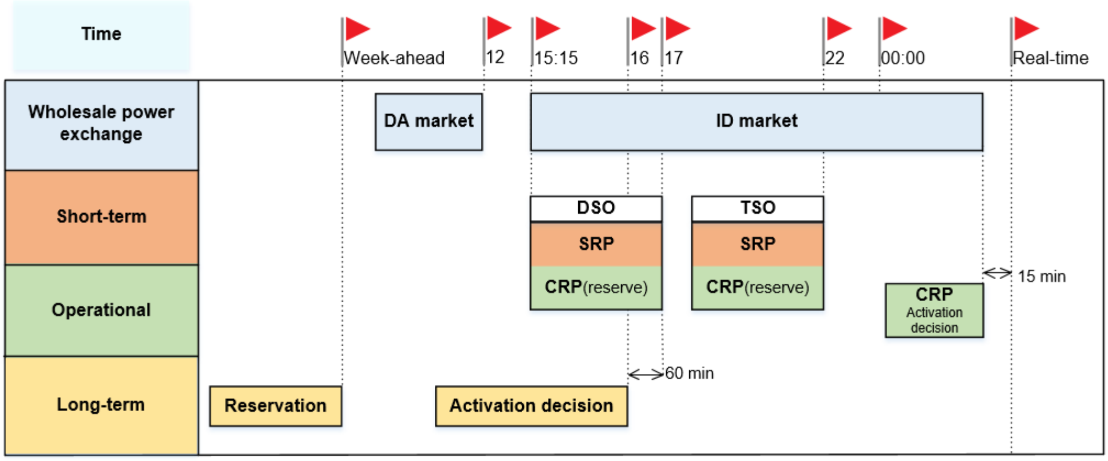

Figure 1- Congestion management market design [6]

article's CMM can be one use case of LFM. It should be mentioned that CMM design and its implementation can vary a lot, and this article proposes one way of implementing CMM, among others. Nevertheless, the paper tries to discuss possible ways of CMM implementation shortly. The objectives of the paper are:

- To propose how short-term CMM can be implemented and understand its operation mechanism in practice
- To consider the real-world problems that might arise in an actual CMM implementation.
- To understand, define and calculate flexibility product attributes for short-term CMM.

III. Market Design

Several market designs[1] have been proposed in [6]. Among them, market design, according to Figure 1, which illustrates the short-term CMM for DSOs' use, has been selected because the focus of the article is CM in DSO's grid, and the designated market design separates DSO and transmission system operator's (TSO's) CM. The market design prioritizes the DSO to TSO in flexibility procurement because of earlier DSO's gate opening time (GOT) compared to TSO's GOT. Knowing that TSOs can utilize the balancing market (e.g., manual frequency restoration reserve (mFRR) in Nordics) for CM, the prioritization is sensible because DSOs often do not have any means of CM through the market.

The market is proposed to operate a day before the actual operation time from 15:15 to 17. The CMM's operation window is influenced by the fact that CMM's liquidity is often low, and synchronizing it with intraday market operation time could facilitate increasing liquidity in CMM from the intraday market. In other words, If intraday bids contain locational information, they can be used in CMM as well, and this is one way of boosting liquidity in CMM.

A. Flexibility services

Short-term CM service [2] is used when DSO is sure about an upcoming congestion problem across its network. The product used in short-term CMM is a scheduled re-profiling product (SRP) [7] that obliges its corresponding FSP to deliver flexibility according to the specifications of the traded bid in the market.

Operational service can be used whenever a grid operator is unsure about congestion occurrence in the upcoming day. A conditional re-profiling (CRP) [7] product is used in this situation. CRP is described as when the flexibility seller must have a capacity to satisfy the traded flexibility with a specified demand or generation profile modification at a given period if the buyer requests it in real-time.

For the flexibility needs, which can be foreseen a long time in advance depending on the regularity of the market operation (e.g., annually, seasonally, monthly or weekly), the long-term CM service can be used. The grid operators are expected to assess the flexibility needs' outlook based on the scheduled maintenance (M)/construction plans, their grid's seasonal hosting capacity (HC) changes, expected load/production changes, etc.

Participation in all three CMMs requires a DSO to forecast its network's flow state. Depending on the network state forecast's accuracy and timing (i.e., week-ahead, day-ahead), the DSO can select its desired service if congestion is foreseen. The forecast forewarns the grid operator of potential congestion, and therefore, it is the cornerstone of CMM utilization because market utilization is impossible without predicting congestion.

IV. DSO's Flexibility Need

This section is devoted to discussing the process of congestion forecast and translating them to the flexibility need attributes. As mentioned before, to be able to utilize CMM, a DSO should forecast congestion for its network. As shown in figure 2, load and generation forecasts are required for network state forecast calculations. Those two processes feed the network state forecaster, a power flow tool. The results of the network state forecaster are all the buses' voltages and branches' currents. The network state variables (voltages and currents) are internal DSO data not useful in the market for market participants. In addition, publishing those data can be linked to the physical network and may breach the data security

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[1] Thorough discussions concerning different stages of CMMs (from prequalification in the first stage to settlement) are available in [6]. Therefore, detailed discussions on the CMM design is not provided here.

[2] The current implementation proposal takes into account only short-term CM service.

regulations. Therefore, the DSO must translate the network forecast state variables to flexibility need attributes[3]. The following sections of the chapter will explain the flexibility need attributes and how to calculate them.

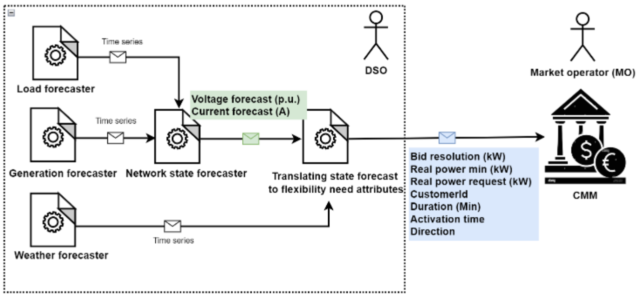

Figure 2- Process of flexibility need attributes' calculation

A. Flexibility need attributes

A flexibility need has several attributes available in [6]. The flexibility product (i.e., SRP in short-term CMM) is standardized in the current market design. Some of them are explained in the following:

Bid resolution in kW specifies the minimum margin between two flexibility offers with different flexibility volumes. For example, if *bid resolution* is 5 kW, then offers could be integer coefficients of 5 (e.g., 5, 10, 15, etc.).

Real power min is the minimum power in kW that is acceptable in the market. It must be equal to a positive-integer coefficient of *bid resolution*. *Real power min* is often smaller than the volume of the real flexibility needed because it lowers the entry barrier for smaller-scale flexibilities to participate in the market.

Real power request represents the real DSO's flexibility needs in kW that is expected to receive at a specific location and time. Therefore, it must be equal to a positive-integer coefficient of *bid resolution*.

Customer Id is an identification number unique for each customer, known to DSO and its corresponding FSP. When DSO knows the flexibility need's area, all *customer Ids* within the congestion area are found; therefore, using the *customer Id*, only FSPs that have customers inside the congestion zone participate in the CMM. *Customer Id* is used because grid data can be tied to private customers' information. Data protection mandates that the customers' data is not published to the market to which several parties have access.

Duration is the period when the flexibility is required to keep activated, for instance, a positive-integer coefficient of 15 minutes (e.g., 15, 30, 45, etc.).

Activation time is the time when flexibility must be activated. Activation time can be the same time when congestion is expected to happen, or even before that for the security issues.

Direction is either up-regulation or down-regulation, representing a need for addressing under and over-voltage problems, respectively.

B. Calculation of the flexibility need attributes

Two attributes, including *real power min* and *real power request*, both in kW, need to be calculated from voltage violation in volt. In addition, the *customer Id* attribute should be specified to inform the market about the area where the resources' flexibility is needed. The following sections of the chapter are dedicated to those issues.

1) Voltage sensitivity analysis

The sensitivities are determined by an approximate method proposed in [8]. Some simplifying assumptions have been made in the technique. Constant current models are used for loads and generators, and the phase difference between voltages is assumed to be negligible. As a result of these assumptions, the voltage sensitivities can be represented by the following simple equations:

$$\left[S_{I_p}\right] = -[R] \tag{1}$$

$$\left[S_{I_q}\right] = -[X] \tag{2}$$

where

$S_{I_p} = \begin{bmatrix} \frac{\partial V_1}{\partial I_{p1}} & \cdots & \frac{\partial V_1}{\partial I_{pn}} \\ \vdots & \ddots & \vdots \\ \frac{\partial V_n}{\partial I_{p1}} & \cdots & \frac{\partial V_n}{\partial I_{pn}} \end{bmatrix}$ is the voltage sensitivity matrix (VSM_{I_p}) in proportion to real node currents I_p,

$S_{I_q} = \begin{bmatrix} \frac{\partial V_1}{\partial I_{q1}} & \cdots & \frac{\partial V_1}{\partial I_{qn}} \\ \vdots & \ddots & \vdots \\ \frac{\partial V_n}{\partial I_{q1}} & \cdots & \frac{\partial V_n}{\partial I_{qn}} \end{bmatrix}$ is the (VSM_{I_q}) in proportion to reactive node currents I_q and R is the real and X the imaginary part of the impedance in the impedance matrix $[Z]$. The diagonal element of $[Z]$ (i.e., $[Z_{ii}]$) are equal to the sum of the branch impedances forming the path from the origin (i.e., substation to node i). The off-diagonal elements $\left[Z_{ij}\right]$ are equal to the sum of the branch impedances forming the path from the origin to the common node of the paths from the origin to nodes i and j, respectively. Node i is the node whose voltage change is analyzed, and node j the node whose reactive or real power is changed to control the voltage at node i. Hence, the controllable resource at node j can affect the voltage at node i more the longer (electrically) the common path from the origin to nodes i and j is.

Using the VSM_{I_p}, the voltage violation forecast in volt is translated to the flexibility need volume in kW[4]. In fact, VSM_{I_p} is used when filling the flexibility need attributes such as *real power* min and *real power request.*

2) Congestion area vs. flexibility need area

When a congestion forecast indicates a need for CM, the congested area includes network buses with voltage violations[5]. The flexibility need area is then the area where its

[3] In that stage, weather forecast data is used for dynamic component rating. For example a transformer's capacity can be increased in freezing temperatures.

[4] VSM_{I_q} is not used because the CMM doesnot consider flexibility procurement of reactive power compensation.

[5] Only voltage violation type of congestion is taken into account in the article.

flexibilitity is considered helpful for the DSO's CM. In other words, all FSPs that have a flexible resource inside the flexibility need area are allowed to participate in bidding for that specific congestion problem. The relation between congestion area and flexibility need area could be one-to-one. Nevertheless, the DSO might consider enlarging the flexibility need area to attract more flexibilities, especially in CMM, where liquidity is often low. Therefore, there is a need for DSO to translate its congested area to the flexibility need area using the VSM.

Relative sensitivity (rs) is a predefined parameter used to specify the relation between congested area and flexibility need area. It varies between 0 and 100. The larger the rs, the larger the flexibility need area. For example, suppose the value is 100, then flexibilities throughout the whole distribution feeder can participate in CMM. In contrast, if rs is zero, flexibility located only on the voltage violated buses can participate in the market. Therefore, the rs value should be reasonable so that the area is neither small nor too large. Finding an optimum rs value could be an interesting research question because it can significantly impact liquidity in the CMM, considering that an optimum rs is case-dependent.

a) How to specify the flexibility need area

As mentioned in the previous section, rs is a given parameter. Once congestion is forecasted, the DSO needs to decide on network areas where flexibility can participate in the CMM. To do so, S_{I_p} is used to calculate the relative sensitivity (RS) of all network buses with respect to the congested buses. Suppose bus i experiences congestion; then, the aim is to realize whether a flexibility resource connected to bus j is inside the flexibility need area or not. The flexibility resource connected to bus j can participate in the market only if:

$$RS_{j\rightarrow i} \geq 1 - \left({}^{rs}/_{100}\right) \quad (3)$$

where

$$Relative\ Sesitivity\left(RS_{j\rightarrow i}\right) = \frac{[S_{I_{p(i,j)}}]}{[S_{I_{p(i,i)}}]} \quad (4)$$

The VSM_{I_p} is used to assess the impact of flexibility at bus j on congestion at bus i. As a normalization measure, the division of voltage sensitivities is used in (4) to yield the relative sensitivity (RS) and to facilitate utilizing the rs as a given parameter from 0 to 100.

V. CM USING CMM

Several pieces of software (hereafter component) are required to realize congestion management using the market. On the DSO side, in addition to the components responsible for forecasting, predictive grid optimization (PGO) is required to first translate the network flow state forecasts to meaningful data representable in the CMM. Secondly, select the most cost-efficient bid from the market. In other words, PGO's functionality can be divided into two stages:

One is when the DSO announces its flexibility needs to the market, dependent on the DSO's market participation strategy. Technical data (voltage violation, violation's likelihood, duration, severity) and the DSO's risk policy play a role in calculating flexibility needs. The second functionality is DSO's decision-making to select the most cost-effective bid(s) from the market. The factors affecting the decision-making are the price per unit of the flexibility, certainty of congestion occurrence (i.e., involving a need for over purchasing or under purchasing of flexibility), flexibility's impact on congestion (depending on flexibility's location), etc.

On the FSP's side, economic dispatch (ED) is a component to optimize the FSP's bids in different markets. It aims to maximize FSP's revenue by participating in various markets such as CMM. The price for the flexibility could be the energy price difference between the original and changed schedule due to flexibility activation, a profit margin, and imbalance costs due to the change of the original plan if FSP considers the BRP's costs.

CMM is a component where short-term CM service is provided on the market side. In the day-ahead timeframe, CMM connects DSOs as flexibility buyers to FSPs as flexibility providers.

A. procurement

The workflow of components' interaction leading to flexibility procurement in the day-ahead time frame is shown in figure 3. It has been designed so that the CMM operates between 15:15 to 17 pm, one day ahead of the actual operating time. The network state forecaster (NSF) calculates the network's forecasted state according to the next day's load, production, and weather forecasts. Subsequently, PGO receives the state forecasts from the NSF and evaluates the voltage values according to the given limits (e.g., -10/+10 percent). Suppose the forecasted voltage values are not within limits. In that case, PGO creates flexibility need attributes including *activation time*, *duration* (min), area (*customer Id*), *direction* (up or down-regulation), *bid resolution*, *real power min*, and *real power request*. Then, the bids are formed and dispatched to the CMM. The market informs the EDs about the existing flexibility needs. According to the bid optimization results, EDs then send their offers to the market no later than 4 pm. The DSO's decision-making in PGO occurs between 4 to 5 pm, and PGO sends the selected offers to CMM. All the EDs are informed about the accepted offers at 5 pm by CMM.

B. Flexibility activation

Once an offer is traded in the market, the responsible FSP uses its ED to make new schedules of its flexibility resources to meet its promises. ED should send plans (i.e., considering all of the commitments resulting from participation in different markets) to the relevant flexibility resource's controller in the operational time frame. Afterward, the control state changes the flexibility resource's state, leading to flexibility activation. Finally, flexibility activation and its quantity are calculated in the settlement stage by comparing the flexibility resources' activation data (e.g., using smart meters logs) with the baseline[6] data.

[6] The baseline methology is beyound the scope of the article. Some baseline methodologies are available in [9].

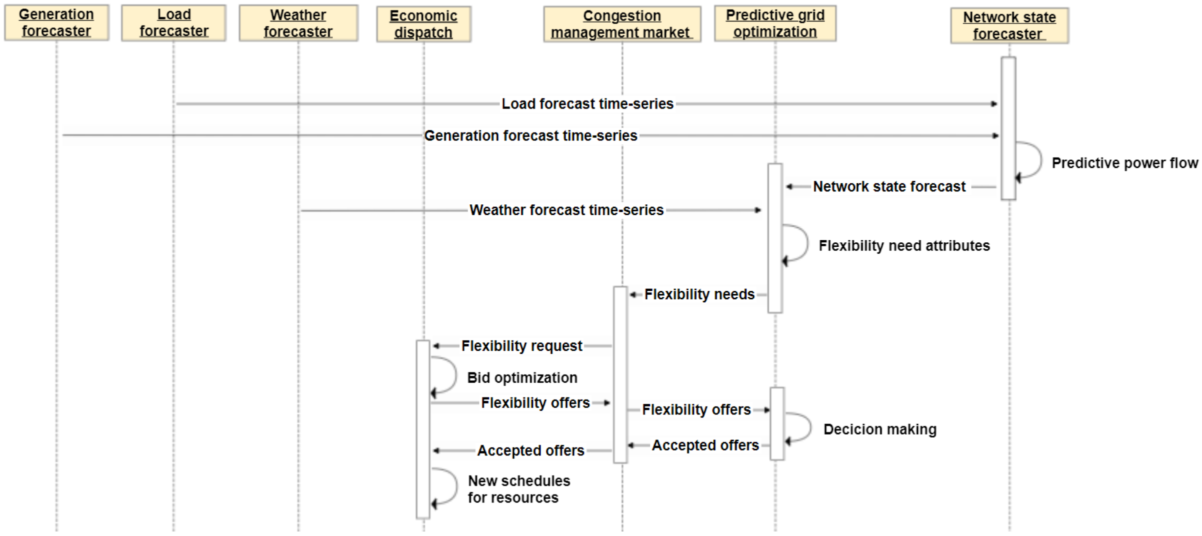

Figure 3- Components' interactions leading to flexibility procurement

VI. Discussion

This chapter contains some clarifying discussions concerning the market design and simplicity of the proposal.

A. Market design

In the market design stage, it is assumed that a DSO announces its flexibility need to the market, and FSPs react to that by offering their bids to the market. The downside is that FSPs somehow follow DSOs' actions in the market because FSPs have to meet the DSO's needs. The advantage is that FSPs, when participating in CMM, are sure about the current flexibility need and its requirements and thus can adapt their bids to the buyer's request. It should be noted that the proposed sequence of interactions is one way of implementing the market, acknowledging that several other approaches with different pros and cons can be proposed.

B. Simplicity

Simplicity is one of the design principles that has been taken into account in the article's proposed solution that paves the way for more straightforward implementation in practice. In fact, complicated solutions are a hurdle for stakeholders when it comes to adopting a new solution. For example, DSOs with legitimate concerns about a solution's practicality are often reluctant toward CM solutions with a complicated algorithm. Consequently, we have used an approximation method to calculate VSM_{I_p}, which makes the calculated values fixed as long as the network topology is the same. It reduces the need to recalculate it whenever the network's flow state changes. Although the accuracy is reduced compared to the methods that take into account network flow state in their sensitivity calculations, the proposed method is accurate enough to serve the DSO's needs in the market.

VII. Conclusion

This paper proposes how the congestion management market could be implemented for a DSO's congestion management. The paper conceptualizes the CMM while considering its interactions with DSO and FSPs. It provides a guideline that can be adopted for an actual congestion management market implementation and a possible simulation of CM-related scenarios. In addition, The article defines the flexibility need attributes and proposes a way to calculate them. It should be noted that the paper's work has been continued, and a few scenarios have been designed and simulated so far. Once more simulations are carried out, the results will be published.

Acknowledgment

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