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Potential Ancillary Service Markets for Future Power Systems

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***Abstract*—Future renewable-based power systems require more flexible energy resources that provide ancillary services. Ancillary services help transmission system operators (TSO) and distribution system operators (DSO) operate their networks. It is thereby necessary to know the existing ancillary services' technical requirements and market structures in order to design future ancillary or flexibility service markets. In this regard, this paper firstly introduces the existing TSO-level ancillary service markets in Nordic countries. Their technical requirements, capacity prices, and market outcomes are assessed based on the Finnish capacity markets. Then, the DSO-level markets are discussed by introducing the projects that develop markets for DSO needs. Finally, new ancillary service markets are proposed that are designed for the future renewable-based more decentralized system. In the proposed market, local flexible energy resources can provide active and reactive power related flexibility services for both TSO and DSO.**

***Index Terms*—TSO, DSO, ancillary service markets, frequency regulation, voltage control, congestion management.**

I. Introduction

Power systems are going through a major transformation in recent years. The strong growth in the intermittent weather-dependent renewable generation has increased the need for flexibility at different voltage levels of the power system. Both system operators TSO and DSO need to adopt more flexibility to be able to operate their networks in a reliable and efficient manner. At the TSO level, more flexible energy resources (i.e. flexibilities) for frequency control services provision in real-time and near-real-time horizons are needed. In addition, the DSO needs to utilize increasing amount of flexibilities to control local voltages, avoid congestion within feeders, and deal with the issues that arise due to distributed generation (DG) [1].

In this regard, as a first step, clear view about the existing ancillary service markets is required. Then, the new ancillary service markets should be designed to complement the existing ones and also fulfill the increasing future flexibility needs. In the future, also increasing cooperation is needed between DSOs and TSOs in order to maximize the potential collaborative benefits of different flexibilities located at different voltage levels in the system.

Regarding to the first step and existing ancillary service markets, there exists some previous literature. For example, in [2] the existing frequency-related markets in Nordics are briefly described, although some markets are being upgraded at the moment. In addition, the literature focused only on TSO-related ancillary services. However, in future power systems it is expected that also DSOs will need to procure ancillary services. Also, in [3] an evaluation was conducted about the existing ancillary service markets based on their products, architecture, services, and the levels of buyers' and sellers' agreement.

On the other hand, related to the future ancillary service markets, also previous research has been conducted. In [4] a local capacity market was developed for providing DSO needs as well as providing FCR services for the TSO. In [5], the authors presented an interesting framework for trading reactive power as an ancillary service. However, the future ancillary service markets should be able to trade active and reactive power related flexibility services as well as DSO-level flexibility services besides TSO-level ones.

In this paper, first the existing TSO-level ancillary service markets are introduced with a focus on Nordic and Finnish markets. Focus is on the discussion about the characteristics, prices and capacity trading of these services. Then, the paper discusses the DSO-level potential markets and the projects that aim to design markets for DSOs. Finally, the potential future ancillary/flexibility service markets are discussed. These future flexibility markets are proposed to enable participation of small-scale flexible energy resources for the TSO- and DSO-level flexibility services provision.

II. Existing TSO-level Ancillary Service Markets

The major share of electricity is traded in the day-ahead spot market. The day-ahead market is settled one day before delivery. Thus, it fails to fulfil the balance requirements of the power system because of forecast errors. There are entities named balance responsible parties (BRP) who are responsible for maintaining the balance within their regions in each trading period. BRPs are allowed to bilaterally trade in the intraday market to compensate for their imbalances. However, taking care of the real-time and near-real-time imbalances is the main responsibility of TSOs. TSOs control real-time imbalances by regulating the system frequency. A frequency deviation indicates the system imbalance. In Europe, the standard frequency is 50 Hz. A small deviation in the range of 0.1 Hz is allowed during normal operation. However, sustained larger deviations result in alert and emergency situations. Fig. 1 illustrates the frequency deviations in which alert and emergency limits are exceeded [6].

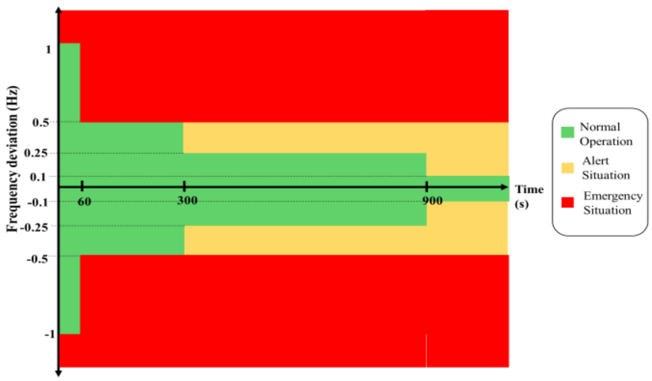

Figure 1. System status based on frequency deviation levels

TSO has different ancillary service markets to reserve the required frequency control capacities. In case of power imbalance (i.e. frequency deviation), full or part of the reserved capacity is activated to compensate/correct the deviation or imbalance. When the frequency is higher than 50 Hz, the TSO needs to increase consumption or decrease the amount of electricity generation. In this case, the TSO activates downward regulation services. Otherwise, if the frequency falls below 50 Hz, the TSO activates upward regulation services to increase the generation or decrease the electricity consumption.

Each level of frequency deviation requires its own frequency regulation service. Table I summarizes the technical requirements of the frequency regulation services, with a focus on the Finnish markets [7]. Fig. 2 is an example obtained from [6] showing which services are activated when a significant disturbance happens in the power system. Frequency deviations during normal operation are compensated by frequency containment reserves for normal operation (FCR-N). FCR-N services react to the frequency deviations in a range of ±0.1 Hz [8], [9]. In disturbance situations, frequency containment reserves for disturbances (FCR-D) are activated. FCR-D responds to the frequency deviations between 0.1-0.5 and -0.5-(-0.1) Hz [9]. Since the deviation in Fig. 2 is larger, it activates FCR-D and FCR-N is not activated. There also exist other services which aim to restore the frequency to the standard range after a disturbance or event. These services are called frequency restoration reserves (FRR). Automatic FRR (aFRR) is activated according to an activation request that is constantly sent by the TSO each 10 seconds. In this way, the volume of frequency deviation in the Nordic synchronous area is measured and the appropriate signal is made accordingly [10]. In case of Finnish aFRR service, when the reserve resource receives the aFRR signal, it should fully activate its reserved capacity in 5 minutes. Manual FRR (mFRR) is the other restoration reserve service. This service compensates for the forecasted imbalances that are expected to happen in a near future. The reserved resource has 15 minutes time to be fully activated when it receives the signal [11].

TABLE I. TECHNICAL REQUIREMENTS AND FEATURES OF RESERVE SERVICES IN FINLAND

Service	Activation Frequency (Hz)	main feature	Activation time for 100% activation (s)	Minimum bid size (MW)
FCR-N	49.9-50 50-50.1	Symmetrical capacity	180	0.1
FCR-D	49.5-49.9 50.1-50.5	Upward-downward capacity	30	1
FFR	49.7, 49.6, 49.5	Very fast upward capacity	1.3, 1, 0.7	1
aFRR	Not based on frequency	Activated by TSO signals	350	5
mFRR	Not based on frequency	Manual activation requested by TSO	900	5

Rather recently, also a service has been introduced and designed for low inertia situations. The modern power system aims to phase out conventional fuel-based generators and replace them with renewable-based units. This will decrease the power system inertia and imposes a risk of high power imbalance. The newly introduced service, named fast frequency reserve (FFR), is responsible for responding extremely fast in a short period of time in situations where the levels of kinetic energy (i.e. inertia) are low. The resource providing FFR is activated in even less than a second when the frequency falls into 49.5 Hz (see Table I) [12].

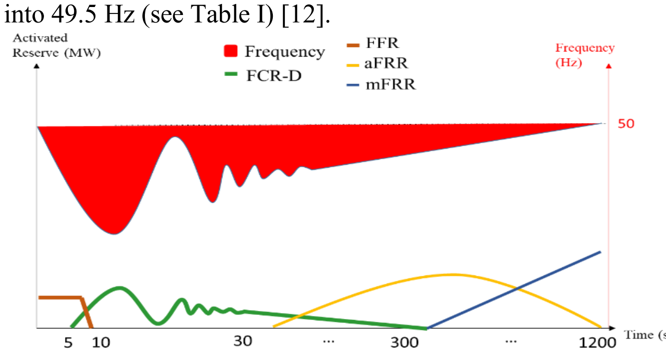

Figure 2. Services activated after a significant disturbance / under-frequency event

Fig. 3 compares the hourly capacity prices of FCR-N, upward FCR-D, FFR, and upward aFRR, in 2021, Finland. As the figure states, FCR-D had some price spikes during the year. Unlike FCR-D, upward aFRR prices did not experience high variations. FFR was more procured during summertime and autumn in low-inertia situations. FCR-N experienced many price volatilities, especially in the summer and autumn. Finnish TSO, Fingrid, has also published the updated annual income if 100 MW resource is reserved for FCR and FFR capacity markets illustrated in Fig. 4. The study considered volume weighted average prices in 2021 and the yearly prices in 2022. As it indicates, participating in the yearly FCR-D down market was the most profitable option while the yearly FCR-D up market leads to less outcome. Since FFR is not being procured as frequent as other services such as FCR-N, it leads to less outcome.

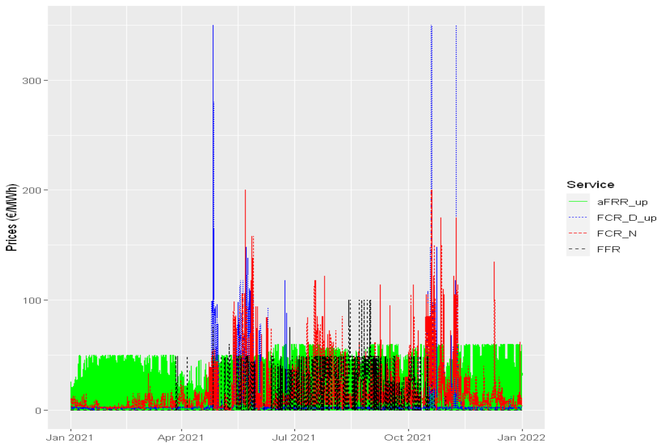

Figure 3. Prices of hourly capacity markets related to upward services in Finland

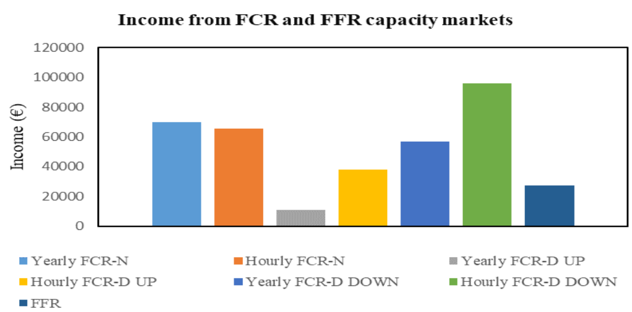

Figure 4. Outcome comparison if 100 MW resource is reserved for providing FCR and FFR services

The following subsection describes with more details the different capacity markets organized for these services.

A. FCR-N Markets

At the moment, there is not a common FCR-N market in Nordic countries. However, the TSOs may trade FCR-N capacities with each other. Finnish TSO Fingrid organizes yearly and monthly capacity markets. The yearly capacity markets are held every autumn. The highest accepted bid determines the price which will be fixed for each calendar year [13]. On the other hand, the hourly capacity markets for procuring FCR-N are organized before the wholesale day-ahead energy market. Fingrid determines the FCR-N prices for each hour of the next day using the marginal (uniform) pricing principle [13]. Fig. 5 compares the prices of hourly FCR-N capacity markets with that of the yearly capacity market in 2021, Finland. As the figure states, the yearly price guarantees a constant price but the hourly market can have volatile prices which can also increase in the summer and the autumn.

The Swedish TSO, Svenska Kraftnät, and the Danish TSO, Energinet, however, have a common hourly market with two auctions to procure FCR-N capacity: one before and one after the closure of the wholesale day-ahead market [6]. If the capacity of a reserve resource is accepted in the market, it receives payment according to its own offered price. Thus, the settlement is based on the pay-as-bid principle. Statnett, as a Norwegian TSO, also has two national hourly FCR-N sub-markets, before and after the wholesale day-ahead market. It also uses the pay-as-bid principle [6].

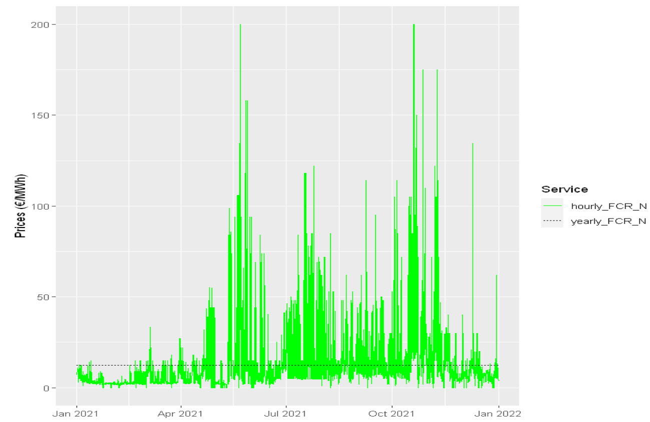

Figure 5. Yearly FCR-N price vs. hourly FCR-N prices in 2021, Finland

B. FCR-D Markets

Fingrid has two separate hourly and yearly markets to procure upward and downward FCR-D. Also, Energinet and Svenska Kraftnät use the same method as FCR-N and procure FCR-D from their common market. Statnett's FCR-D market follows the same rule as its FCR-N market [6].

C. FFR Markets

Fingrid purchases the FFR capacity from Estonia and/or the hourly market that is held one day before the actual day, after the wholesale day-ahead market [14]. A reserve provider has the option to submit a combined bid that includes both FCR-D and FFR services. In this way, if the bid is not accepted in the FFR market, it is deployed in the FCR-D market [15]. The FFR market has uniform pricing (marginal) principle.

Svenska Kraftnät organizes two markets for FFR procurement, one with a four-day time horizon (Tuesday-Friday) and the other one with a three-day time horizon (Saturday-Monday). The bids are organized based on a merit-order list and the resources are paid according to the marginal pricing principle [6].

Energinet purchases FFR by organizing hourly markets, similar to Fingrid while Statnett procures the FFR service by organizing a market from May to September. Statnett first reserves the required FFR capacity in the seasonal market. It then requests the short-term capacities from the resources, if needed. The reserve providers are remunerated based on the marginal pricing principle [6].

D. aFRR Markets

Similar to FCR and FFR markets, there exists no common market for Nordic TSOs procuring aFRR. However, they will define a common market in a near future and at the moment the

TSOs have the opportunity to purchase and sell aFRR bilaterally with each other via inter-TSO trades [16], [17].

At the moment, Fingrid organizes aFRR hourly markets on the day before, based on the marginal pricing principle. From 10th May 2022, Svenska Kraftnät will organize the daily-procured market for aFRR with the same pricing as Fingrid. At the moment Energinet does not have a national market for procuring aFRR [6]. Statnett, on the other hand, has a national hourly market for aFRR. Although it deploys the marginal pricing principle, more expensive bids may be accepted in some situations and be paid based on the pay-as-bid principle [6].

E. mFRR Markets

Although mFRR activation has a common Nordic market, each TSO organizes national markets to procure mFRR capacity. Currently, Fingrid sometimes procures mFRR from mFRR weekly capacity markets. In most of the times, it has its own reserves for providing mFRR[11]. Svenska Kraftnät does not have a national market for mFRR capacity whereas Energinet has an mFRR hourly capacity market for upward regulations within its first zone (DK1). These markets are organized on a day-ahead and marginal pricing basis. Statnett has two seasonal and weekly markets to procure mFRR capacity. One is held every Friday and the other market is organized for wintertime. The mFRR capacity is procured in these two markets based on the current situation of the power system and the related constraints [6].

III. DSO-LEVEL MARKETS

The increasing integration of inverter-based and intermittent renewable energy sources like solar photovoltaic (PV) in distribution networks and the growing number of electric vehicles (EVs) can lead to voltage limit violations and may create congestions in distribution network lines. Therefore, in order to avoid excessive investments in capacity upgrades by passive network components (lines, transformers etc.) DSOs could increasingly deploy coordinated and adaptive active network management (ANM) schemes based on distributed energy resources (DER) active and reactive power related flexibility services utilization and hosting capacity improvement [18]-[20]. In addition, DSOs may need a market to reserve flexible capacities to use them when needed. For example, flexible DER connected to the distribution network can support voltage control by their local voltage control functions like reactive power-voltage (*QU*) -droop and active power voltage (*PU*) -droop. [18]-[21].

To the best of the authors' knowledge, there is not a real-world DSO-level market that aims to help DSOs operate their networks. However, there are certain pilot projects and research studies that propose DSO-level markets for controlling local voltages and congestion [21], [22]. For example, two pilots have been developed to implement flexibility markets in distribution networks in NODES-project [23], [24]. They aim to analyze if the flexibility markets are able to solve voltage challenges on an island and mainland. The first area is far away from the main power system. The main challenge in this case were under-voltage problems at peak hours. Thus, the flexibility market was implemented to buy flexibility during these periods. The purchased flexibility decreases the loads in order to maintain voltage level between target limits [24]. The second flexibility market is implemented on an island in Norway. A local flexibility market aims to resolve future voltage limit violation issues due to the electrification of the ferry and other future activities related to the growing businesses on the island [22].

Enera is another project with a pilot located in the windy Northwest of Germany [21], [25]. The project aims to unlock flexibility in order to avoid wind power curtailment (i.e. increase wind power hosting capacity). In this project, DSOs purchase flexibility in the intraday timeframe to manage congestion within their networks. GOPACS is another interesting project based in Netherland. It is integrated into a national intraday platform called Energy Trading Platform Amsterdam (ETPA) and it tries to be connected to other market platforms as well. If flexibility offers have a locational tag, they can be sold to GOPACS. Accordingly, GOPACS finds the best and cheapest resources for alleviating congestion within the network [22], [26].

IV. POTENTIAL FLEXIBILITY MARKETS FOR THE FUTURE POWER SYSTEMS

Renewable-based power systems, with some share of synchronous generation and natural inertia, require ancillary/flexibility service markets that have the following features:

1- The new flexibility (ancillary service) markets should unlock the flexibility of small-scale resources as well as large-scale ones. They are established locally for local participants.
2- They need to provide the local DSO and the TSO with their flexibility requirements in coordinated manner (optimally also collaborative benefit of the flexibility could be simultaneously maximized for the DSO and TSO). In this regard, they should make some rules for local resources so that they would know how to react in different situations.
3- DSOs can utilize the reactive power (*Q*) related flexibility in distribution networks as well as active power (*P*) related flexibility services. Reactive power flexible resources such as inverter-based DER can thereby participate in these markets.

In the first stage, flexible capacities could participate in capacity markets. Capacity markets could be organized locally for each frequency control service. Correspondingly, a local DSO needs to define different services with different activation times for normal, alert, and emergency situations. Future low-/variable inertia power system frequency control may also require restructuring of the frequency markets and respective frequency deviation levels [18], [19]. Each flexibility service needs its own capacity market. Similar to the TSO services, a DSO might also define a fast symmetrical reserve service to overcome the real-time voltage variations resulting from renewable DER during normal operation and another fast service designed for unexpected situations that cause higher voltage deviations and/or congestion. A slower service is also required to avoid predicted congestion and to manage voltage at peak or off-peak hours of the day. The capacity markets guarantee the flexible capacities that are required for the near future (e.g. tomorrow in case of a day-ahead market). Fig. 6 summarizes the proposed markets.

The TSO and the local DSO can submit their flexibility offers as buyers. The DSO deploys both active and reactive-power flexibility. Flexible energy resources owners submit bids separately for their flexible active and reactive power. The DSO has an option to run optimal power flow and select the cheapest service according to the needs. There might be some time in which the needs of the TSO and the DSO contradict each other. For example, a DSO may ask for upward flexibility while the frequency deviation needs downward flexibility. In these situations, the DSO is better to use reactive power flexibility in order not to adversely affect the frequency. Hence, the DSO should reserve enough reactive-power capacity besides active power to operate its network cooperatively and effectively. Coordinated operation of different marketplaces at DSO and TSO level with certain main principles for services prioritization will be important in order to achieve maximum societal and collaborative value of flexibilities. It is also worth mentioning that, for example, voltage control related ANM schemes at DSO level could also be a combination of dynamic distribution tariffs and local flexibility markets.

Flexible resources have different flexibility levels [27]. For example, batteries are highly flexible because their operating time and power are controllable and they can respond to the flexibility signals very fast. However, thermal controllable loads are less flexible since their main objective is to maintain the thermal comfort of their owners at a good level. Thus, similar to the existing capacity markets, each future capacity market should have its technical requirement. The reserved resource must therefore pass the prequalification tests before entering the market.

Pricing is an important factor in organizing a market. It can motivate or discourage participants to continue trading in the market. The pricing principle of the future markets can be uniform pricing similar to most existing capacity markets. Reactive and active power capacity markets can have different prices. Upward and downward capacities can be settled separately. The flexibility providers submit their offers based on their marginal costs. For instance, the reactive power resources may consider the cost of losses, switching costs and lost opportunity costs when they submit their bids [28]. The time horizon and granularity of the capacity markets can be determined based on the flexibility needs of the system and the requirements of the service.

In real-time the resources would react based on the flexibility signals, they receive. TSO-level services mostly require a frequency measurement and the reaction should be according to the frequency deviation. The DSO also may transfer flexibility signals to the resources indicating which types of service it needs and whether it needs upward/downward or active/reactive power flexibility. The activation prices can be the same for all capacity markets or DSOs may determine their own activation prices. However, they should be competitive enough so to incentivize the flexible resources to participate in DSO capacity markets. As mentioned before, the DSO activates reactive power flexibility, rather than active power, if its flexibility needs contradict that of the TSO.

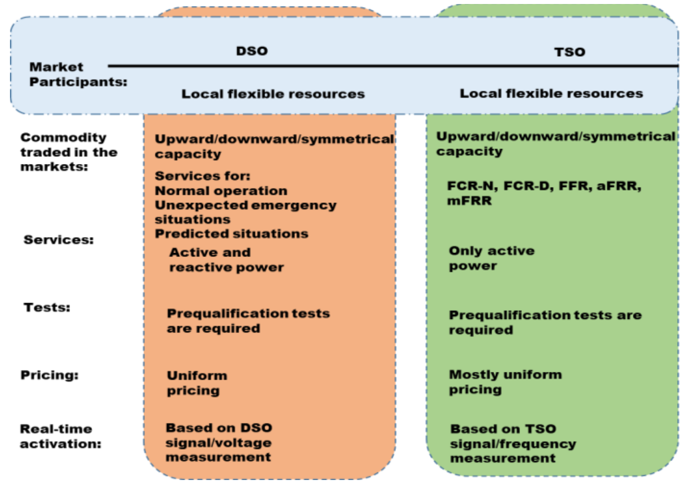

Figure 6. Some characteristics of the future capacity markets that can be organized by TSO and DSO

V. CONCLUSION

Flexibility/ancillary services play an important role in the future renewable-based power systems. This paper first introduced the existing technical ancillary service markets in Nordic countries. They are mainly designed for TSOs frequency control purposes. Each frequency deviation level requires its own flexibility/ancillary service market. For example, FCR-N reacts to the deviation in normal operation and FFR service is deployed to handle low-inertia situations and FRR services try to restore the frequency. The paper then discussed the technical requirements, market structures and the outcomes that a reserve service provider can achieve after providing these services.

The modern power systems have a number of DER units connected to distribution networks which can adversely affect the operation of the networks. Thus, DSOs also need to establish their local flexibility/ancillary service markets in the future. The paper discussed the related projects in this regard. Finally, we introduced the potential flexibility/ancillary service markets basic structure for the future increasingly decentralized power systems. Unlike the existing ancillary service markets that have a minimum capacity limit for the participants, the proposed markets are established locally for all-sized local resources. They provide both DSO and TSO with reactive and active power-based flexibility services. Each DSO and TSO market could organize separate capacity markets for their various operation needs in a coordinated/collaborative way and some of the related details were discussed in the paper. The work can be continued in the future by developing the proposed flexibility/ancillary service markets in terms of pricing method and market settlement. In addition, more future works are required to develop DSO-level services for normal, alert and emergency situations.

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