Assessment of flexibility in different ancillary services for the power system

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***Abstract*— To handle the changing power system and enable the energy transformation, several actions are needed, where the increase of digitalization, automation and more substantial production variability implies a need for flexibility. Solutions providing advances in flexibility are of importance for the future power system. The paper will contribute with knowledge that will support the diversified and efficient use of flexibility, making the electricity system more flexible and delivering the benefits for all system stakeholders. This will both be based on a review of definition and classification of flexibility, flexibility assessment solutions and example of how flexible resources can be utilized in different ancillary services. Different use cases have been developed showing how flexible resources can be utilized in different ancillary services, such as voltage control, management of bottlenecks in the distribution grid and balancing services. The use cases also include a description of the stakeholders involved.**

***Index Terms*—Flexibility, Congestion Management, Ancillary services, Voltage Control.**

I. Introduction

Flexibility of the power system is seen as a key to coping with some of the challenges in the future power system, both to handle the changing power system and enable the energy transformation. Due to the increased integration of non-dispatchable forms of generation, the higher rate of increase in peak load demand compared to total energy and the ageing network infrastructure, flexibility resources are becoming more economically attractive solutions. Moreover, the competitive advantage of flexibility is that they are deployed on need basis and there are other economical justifications for their very existence.

Flexibility may be required for varieties of services needed in the power system where the main ones are balancing, congestion management, and voltage control. The adoption of flexibility resources as standard solutions is further motivated by the increased digitilasation in the power system where control and price signals can be communicated to effect flexibility activation and also by increased integration of controllable distributed energy resources (DER) (such as electric vehicles (EVs) and Photovoltaic (PV)-Battery systems).

The paper will contribute with knowledge that will support the diversified and efficient use of flexibility, making the electricity system more flexible and delivering the benefits for all system stakeholders. This will both be based on a review of flexibility assessment solutions and example of how flexible resources can be utilized in different ancillary services. Different use cases have been developed showing how flexible resources can be utilized in different ancillary services, for relevant ancillary services such as voltage control, management of bottlenecks in the distribution grid and balancing services.

The focus is on the future power system in 2030/2040, where a larger share of flexible resources is available – both single resources and on an aggregated level. To realize the use of flexible resources, both regulations and new markets are necessary.

The paper is based on work within the research center FME CINELDI (2016-2024)[1], and work package focusing on interaction between Distribution System Operators (DSO) and Transmission System Operators (TSO). The objective of this work package is to contribute to concepts and solutions for cost-efficient utilization of flexible resources in different market products and ancillary services, on different grid levels.

II. Definition of Flexibility

Power system flexibility relates to the ability of the power system to manage changes. The flexibility term is used as an umbrella covering various aspects and power system needs. This situation makes it highly complex to assess flexibility in the power system and craves for differentiation to enhance clarity [1].

European system operators [2], define flexibility as active management of an asset that can impact system balance or grid power flows on a short-term basis (from day-ahead to real

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time). Flexibility can be provided by different assets, the first three can be both directly or through an aggregator: (i) generation (part of the dispatchable units, Renewable Energy Sources (RES)), (ii) load facilities (involved in a demand response programme), (iii) storage (pumped storage power station, batteries, etc.); and/or (iv) interconnectors (intraday energy exchanges).

Flexibility can be used by: (i) the TSO for balancing and congestion management in the short term and planning in long-term contracting, (ii) the DSO for congestion management in the short term and planning in long-term contracting and/or (iii) the Balance Responsible Party (BRP) for portfolio management both in the short and long term (investment) [2]. Flexibility assessment presented in this paper, supports an increased understanding of the flexibility needs, to be able to identify and select the most suitable flexibility solutions.

III. Ancillary Services

A. *Description of relevant ancillary services*

The European Directive on Internal Energy Market (IEM) defines ancillary services (AS) as necessary for the operation of a transmission or distribution system, including balancing and non-frequency ancillary services, but not including congestion management [3].

Definition from ENTSO-E: *'Ancillary services' refers to a range of functions which TSOs contract so that they can guarantee system security* [4]. This include services such as black start capability (the ability to restart a grid following a blackout); frequency response (to maintain system frequency with automatic and very fast responses); fast reserve (which can provide additional energy when needed); the provision of reactive power and various other services.

With the aim of better control of congestions and better utilization of flexibility, decisions has been made in the Nordic system to shift from Nordic level balancing to balancing of Area Control Error (ACE) on a bidding zone basis [5]. This was part of the solution to increase and utilize the flexibility from multiple sources. This indicates that new use cases need to be developed by modifying the ancillary services making them more suitable for tapping flexibility potential.

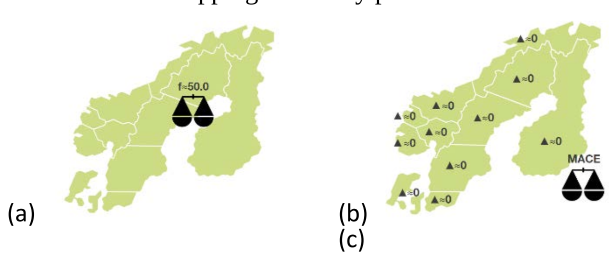

Figure 1 Illustration of current situation (a) and target model (b) for the new Nordic balancing concept with MACE (Modern ACE) [5]

"TSO-DSO data management report" [2] mentions different points of attention coming from DSOs and TSOs, where DSOs are essentially concerned about possible misalignments of actions between TSOs, DSOs and other market players, which could lead to loss of control over the distribution grid and drive inefficient grid expansion. DSOs think that certain balancing actions could be delegated to them to procure balancing services on their network as a subsidiary activity to support TSOs. An exhaustive overview of the existing ancillary services in Europe and outlook for the future needs is presented in [6].

B. *Alternatives for the market phase*

Several market architectures for TSO-DSO interaction necessary for procurement and activation of resources for congestion management and balancing, utilising flexibility have been developed during the recent years. One can mention models proposed in ASM report [7], International Smart Grid Action Network (ISGAN) [8] or so-called NODES market [9]. Considering possible implementation time frames, some of these models appear to be alternatives, while some other represent sequential steps in the future evolution of the market.

Five different architectures or coordination schemes (CSs) were proposed, where each presents a different way of organizing the coordination between transmission and distribution system operators (TSOs and DSOs) for dealing with congestion management and balancing (for detailed description see [10]).

- **A.** Centralized AS market model
- **B.** Local AS market model
- **C.** Shared balancing responsibility model
- **D.** Common TSO-DSO AS market model
- **E.** Integrated flexibility market model

Each coordination scheme is characterized by a specific set of roles, taken up by system operators and a detailed market design. The choice of the appropriate coordination scheme is dependent on multiple factors such as the type of ancillary service, normal operation versus emergency situations, the state of the grid, the amount of RES installed, the current market design and the regulatory framework. Coordination scheme A is in many ways already a "business as usual" for Norway. In addition, it defines that DSOs involvement is limited to prequalification of resources at distribution level to guarantee that no congestions are generated by the activation of such resources. Considering the above-mentioned alternatives, the coordination scheme B "Local AS market" appears to be the most suitable alternative for time horizon 2030-2040, since it deals with congestions in the distribution network and does not require significant changes in the existing regulation. This firstly provides resources to DSO (having priority) and the remaining resources are traded further to the TSO-operated market for ancillary services.

IV. Use cases for selected ancillary services

Coordination between TSOs and DSOs is essential to ensure that flexibility resources in distribution networks remain available for system balancing purposes without inducing unmanageable local congestions, which could affect the local grid. An optimal mix of flexibility resources can be obtained through a holistic approach considering technical, market and environmental aspects.

The need for a regulatory framework, with transparent market environment, properly designed systems for

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measurements, information and communication between all actors, monitoring, control and protection solutions, can provide benefits from available flexibility to all power system stakeholders.

To get an overview related to how flexibility can be utilised, developed use cases focus on voltage control, congestion management and balancing are presented in this section.

A. *Voltage control*

Active use of flexibility resources, such as battery storage systems, for supporting voltage regulation in LV network is becoming very common. One can find such use cases in [1]. Nevertheless, in this paper we would like to discuss a use-case on joint management of reactive power by TSO and DSO for purpose of voltage regulation.

TSOs are responsible to keep regional voltage levels to the standard limits while DSOs are responsible to keep the voltages within limits both at customer premises as well as at the coupling point to the transmission network. With the ever-increasing integration of power electronic devices, such as inverters, and due to the large variation of the generation of distributed generations, voltage level problems are becoming increasingly common. Hence, there is greater interest to deploy the controllable and distributed flexibility resources to solve voltage problems. In addition, there is greater interest to offer flexibility potential in DSO premises to voltage regulation in TSO areas and vice-versa.

The use case, we are developing further, aims to utilize reactive power provision capabilities of RES and DERs as well as emerging technologies in the distribution grids to increase the hosting capacity and to improve voltage profiles both in transmission and distribution grids. This involves coordination between two real-time Optimal Power Flows (OPFs) running at the TSO and DSO control centres. The method in the use case is discussed in [11] and the use case itself is formulated and presented in [12].

The sequence of actions in the use case are illustrated in Figure 0-1. In the initialization phase grid models and grid equivalents are mutually prepared. The next action is assessment of flexibility of DERs connected within DSO area to provide reactive power. Based on the announcement of capabilities from the DSO, TSO will run OPF to calculate optimal set points for reactive power assets including the utilization of the DSO flexibilities. After the TSO optimal setpoints are announced, the DSO utilizes an OPF to optimally distribute the requested reactive provision among its assets.

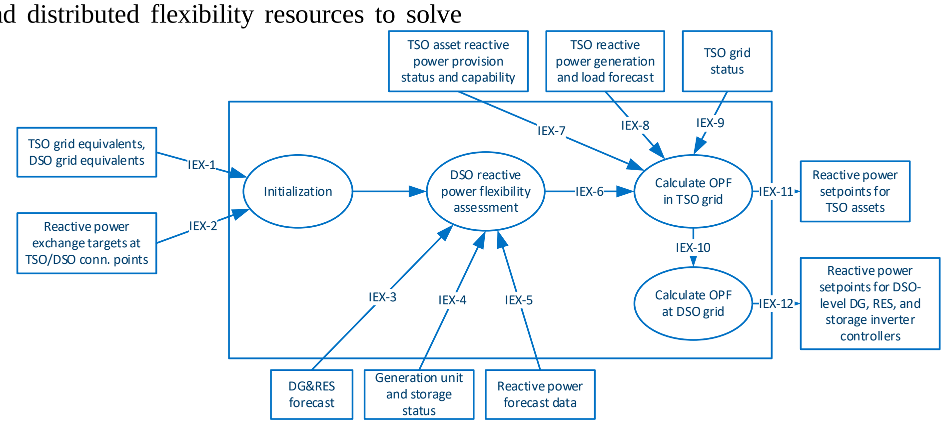

Figure 2 Sequence of actions for voltage control use case

B. *Congestion management*

Several types of congestions are normally defined: market, structural and physical. The present study focuses on the physical congestions, which are defined as any network situation where forecasted or realised power flows violate the thermal limits of the elements of the grid and voltage stability or the angle stability limits of the power system [13].

There are growing concerns about congestions in the distribution networks in the next decades, including electrification of transport and space heating as well growth of DERs such as photovoltaics . Congestion problems in the distribution networks are envisaged as voltage problems (bus voltage is close to or exceeding the limit (+/- 10%) and overloading problem (loading is close to or exceeding the thermal limits of the components) [14]. Originating in the distribution network, these challenges are likely to propagate into MV levels, and thus had to be dealt with at their primary stage.

Two main approaches for congestion management are normally defined: Indirect and direct control methods. Indirect controls can for example include day-ahead dynamic tariffs (DT), when the flexible demands are price-sensitive, and a DSO will find a theoretically lowest DT (time-varying) that would make the composition of flexible plus inflexible demand lower than the grid component loads. Direct control methods can be deployed, when the indirect methods are not sufficient or fail (for example due to forecasting errors). Among direct control methods can be mentioned reconfiguration, reactive power control and active power control [14].

1) *Phases in the congestion management*

The commons document, based on the European TSO-DSO cooperation [7] defines the following phases in the congestion management Product pre-qualification, which verifies whether the given unit can technically deliver its product. Grid (system) pre-qualification verifies, whether the given unit can realise the product delivery, considering characteristics of the grid.

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- Forecasting phase, where the grid utilisation is planned, and the potential congestions identified.
- Market phase, which includes collection of the bids and evaluation of the contracts.
- Monitoring and activation phase. Activation of bids for congestion management and cooperation among system operators in real time.
- Measurement and settlement phase: validation of the delivery.
- The following use case adapts the suggested phases, adjusting these to the selected market phase and specifics of the distributions network.

2) Description of Use Case "Congestion Management"

The Use Case presents a method to mitigate congestions in the distribution network by using flexible active power resources, procured via a specific two-step market arrangement. The selected "Local Market" architecture contains several local markets, operated by DSOs acting as Market Operators (MOs) and a central market for ancillary services, operated by the TSO, also acting as a Market Operator (MO). Trading of the resources for congestions management requires that the tradable market bids should have locational information, so they can be linked to a given congestion. This is addressed by using nodal bidding arrangements, where bids are submitted pr. node. DERs (including generation and consumption) contribute to ancillary services and congestion management at both transmission and distribution levels only through their local market. This means that DERs or Commercial Market Players (CMP) acting as aggregators cannot directly participate in the TSOs market. Solving the local congestions and balancing issues has a priority, so after completion of trade on the local market, the DSO retains the bids necessary for solving the local problems. Then the remaining bids will be traded by the DSO on behalf of CMPs on the central market, which is operated by the TSO, and where the resources connected to the transmission level can also participate. Upon reception of the TSO-AS market-clearing quantity and price, the local market efficiently allocates the assigned quantity to the different DERs or sub-aggregations thereof, according to the offers and bids submitted by CMPs to the local market. the TSO is the only buyer of SmartNet Reserve in the TSO-AS market. Furthermore, the aggregation and disaggregation processes (that is, the clearing of the local market) does account for local grid constraints. In other words, the transfer of local flexibility from the DSO to the TSO, and its subsequent use by the TSO, must guarantee that no new local balancing and/or congestion problems are induced.

3) Steps in the Use Case

- **System pre-qualification**: The DSO verifies whether the previously registered portfolios can realise the product delivery, considering characteristics of the grid.
- **Collection of bids**: CMPs submit bids to the DSO acting as a MO. The market clears after passing the deadline.
- **Planning and forecasting**: Based on the available information (information from the TSO, grid information etc.) the DSO undertakes an OPF analysis detecting the potential congestions. CMPs receive information about the activation schedule and volumes.
- **Activation and monitoring**: Based on the activation schedule i.e. time, location and volume, the CMP activate the appropriate resources in their portfolio.
- **Transfer of the residual resources to the TSO**: The DSO submits a bid (-s) with the remaining resources to the TSOs AS market
- **Control of activation**: Before, during and after the activation the DSO follows changes of physical parameters in the network, communicating this to the CMP.
- **Settlement**: Based on the results from the local market clearing, activation schedule and monitoring results the DSO makes a settlement with the CMP

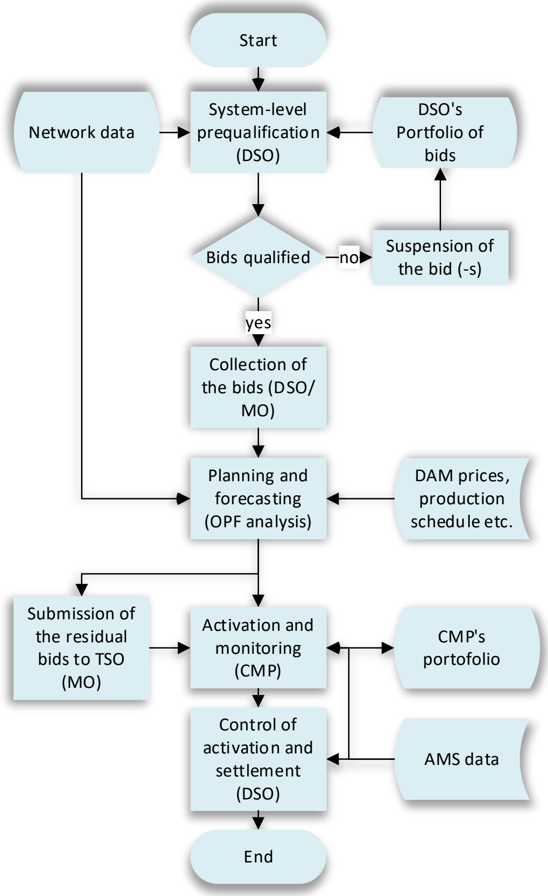

Figure 3 Flow chart for congestion management

C. Balancing services

To maintain the stability of the power system the instantaneous generation and consumption have to be in balance at all times, but the increasing amount of non-dispatchable forms of generation in the power system, makes it more challenging to balance the system. Today, TSO is responsible for the balancing of the grid, but according to [15], it is expected in the future that balancing services also will be

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necessary in the distribution grid. This implies that flexible resources located in the distribution grid should be utilized in different ancillary services – by both DSO and TSO.

1) Description of services

Several ancillary services with the aim of keeping the power system in balance, have different requirements related to the response. These services are shortly described below.

- Fast Frequency Reserves (FFR) are activated within 1 second, when the system frequency falls below a certain level (49.5 Hz or 49.7 Hz). In a pilot project in 2018 the Norwegian TSO demonstrated how industry, data centres and EVs (aggregated) could contribute with FFR [16].
- Primary Reserves (Frequency Containment Reserves - FCR) (often rotating reserves in the power generators) are activated automatically when the frequency is lower than 49.9 Hz or higher than 50.1 Hz [17].
- Secondary Reserves (Automatic Frequency Restoration Reserves - aFRR) are activated to release primary reserves (so they are available to handle new errors and unbalances). The response should be within 2 minutes. In Norway today, mainly generation are offering this service, but it is planned to also include flexible loads [18].
- Tertiary reserves (Manual Frequency Restoration Reserves - mFRR) are activated if there are further need for frequency regulation, or when handling regional bottlenecks and imbalances in the grid. These are manual reserves that activates within 15 minutes [19].

2) Use Case Balancing service - Tertiary reserves

A use case describing how flexible resources can be included in system balancing is presented in Fig. 4, focusing on utilizing flexible resources as tertiary reserves.

The first part is the capacity (option) market for balancing reserves, which is a market established to secure liquidity of reserves for tertiary regulation. Reserves from both generation and consumption can be included in the bids. The duration of the options is on season (typically October – April) and week.

After the bid(s) to the capacity market have been accepted, they can be included in the bids to the balancing market daily. In the Nordic countries a common list representing available bids are established. The bids are activated according to their price – where the bid with the lowest price is activated first.

When a bid is activated, the corresponding reserve should respond within 15 minutes – as an activation directly towards a single customer or as aggregated flexibility from several smaller resources. In the future it is expected increased volume of flexibility available from the consumption side.

Dependent on the grid level where the balancing market is implemented, the buyer of flexibility services could be the TSO or DSO. Today the capacity and balancing markets are implemented on the transmission level and the TSO buys the flexibility. If the DSO in the future is responsible for balancing services in the distribution grid, also the DSO can buy flexibility. Depending on how this will be arranged and coordinated, different market concepts as described in section III.B are relevant to establish.

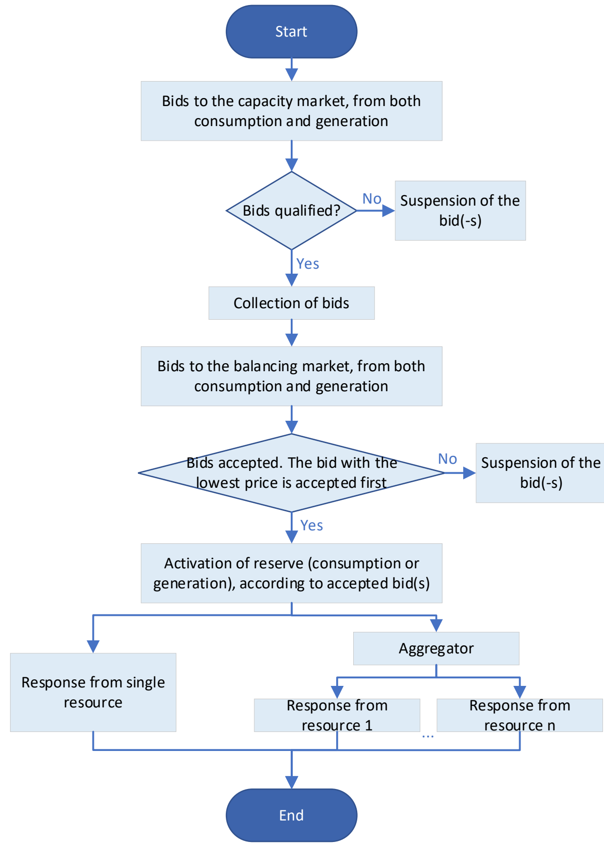

Figure 4 Flow chart for balancing use case related to tertiary reserves

V. Discussions and Conclusions

This paper is focusing on the future power system in year 2030/2040, with an increased utilization of flexible resources in ancillary services. Flexible resources can contribute into ancillary services on different grid levels. Geographic location of flexible resources is important in some services (voltage control), and not services related to frequency regulation.

With several stakeholders interesting in the same flexibility resource, the need for coordination is increasing. In the future it might also be the increased need for ancillary services in the distribution grid, with the DSO being responsible for certain local balancing actions [2], [20] to support TSOs. TSO/DSO-coordination is needed both for operation and planning of the grid, to avoid introduction of new imbalance due to flexibility activation.

Further research will be related to development of alternative and more detailed use cases within the selected topics, to evaluate the coordination needs between DSO and TSO, market products and business models for activating flexible resources in ancillary services.

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