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FLEXIBILITY MARKET AND SERVICES IN DISTRIBUTION GRID

Master's Thesis
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ABSTRACT

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The incorporation of Distributed Energy Resources (DER) is growing in many power systems globally. This incorporation presents a significant challenge to the maintenance and service of new power systems, leading to a growing need for proactive distribution network services. Congestion is an issue that is rapidly emerging in distribution grids due to the upward increase penetration of DG in distribution systems. The DSOs are also obligated to evaluate and enhance their maintenance costs by implementing smart grid features and functions to minimize investment. Out of a variety of solutions, congestion control is amongst the most optimistic methods for solving network problems. Congestion control systems have historically been handled at the level of the transmission grid. However, with the extensive utilization of Distributed Generators (DGs) and the anticipated extreme loading conditions, the control technique would have to be extended to the distribution network also. Methods for controlling congestion in distribution systems have recently gained the attention of academics and others operating in the electric grid domain. A variety of techniques are being extensively explored to overcome the complexities of direct switching behaviour. However, non-market-based interventions wouldn't be the most successful and cost-effective option. Besides that, smart strategies that harness the flexibilities of users need to be built to leverage existing grid infrastructure effectively. Flexibility services can enable network operators to always resolve grid restrictions, sustain stability and quality of service, and optimize the integration of distributed power sources. The implementation of a local flexibility market (LFM) would enable flexible trade to be carried out by both processing and consumption units at the distribution stage, ensuring access to markets to DERs, a Distribution System Operators Support Tool (DSOs), and a valuable source for energy providers. The concept of the study is to resolve congestion in distribution systems through market processes, particularly the local flexibility market. This study provides a detailed analysis of four pioneering scalable business projects: Piclo Flex, Enera, GOPACS, and NODES. Attempts have been devoted to present a comprehensive summary of market architecture, which includes the framework, participation, placing bids, and clearing processes, of the local flexibility market initiatives produced in recent years. However, system operators need to cooperate for ensuring reliable, consistent, and cost-effective utilization of scalable facilities, since these tools can theoretically be used both locally and throughout the grid. This paper gives a comprehensive overview of synchronization schemes in power networks between transmission & distribution power grid, with a specific focus on the implementation of balancing as well as congestion control services.

Keywords: Distributed Energy Resources (DER), Distribution grid, Congestion, Local Flexibility Market (LFM), Distribution System Operator (DSO)

The originality of this thesis has been checked using the Turnitin Originality Check service.

PREFACE

This thesis has been written to fulfill the graduation requirements of the degree Master of Science (Technology) at Tampere University. Foremost, I would like to thank all mighty Allah and then express my sincere gratitude to my thesis supervisors for their continuous support, motivation, and guidance to complete this thesis.

I am also thankful to my family and wife for supporting me during the process.

Tampere, 05 October 2021

Mahabub Hasan

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LIST OF SYMBOLS AND ABBREVIATIONS

ADN	Active distribution network
DER	Distributed Energy Resources
EV	Electric Vehicles
DSO	Distribution System Operator
TSO	Transmission System Operator
DG	Distributed Generation
CEER	Council of European Energy Regulators
ENTSO-E	European Network of Transmission System Operators for Electricity
LFM	Local Flexibility Market
DA	Day-Ahead Market
ID	Intra Day Market
MCP	Market Clearing Price
EUPHEMIA	Pan-European hybrid electricity market integration algorithm
FCR	Frequency Containment Reserve
aFRR	Automatic frequency restore reserve
mFRR	Manual frequency restore reserve
RR	Restore Reserve
BRPS	Balance responsible parties
LEC	Local Energy Community
GL	Grid Location
ETPA	Energy Trading Platform Amsterdam
EPEX	European Power Exchange
IDCONS	Intraday Congestion Spread
RTP	Real Time Pricing
RMS	Root mean square
FACTS	Flexible AC Transmission System
CM	Congestion Management
APC	Active Power Curtailment
RPC	Reactive Power Compensation
CVC	Coordinated Voltage Control
OLTC	On-load Tap Changer
SO	System Operator
FSP	Flexibility Service Provider
DRES	Distributed renewable energy sources
DR	Demand Response
DSR	Demand side response
CMP	Commercial Market Party

1. INTRODUCTION

Energy has become one of the prerequisites for good quality of life and the betterment of the economy. Global energy utilization in the fields of shipping, illumination, and heating, manufacturing, and supply of goods, for example, is projected to rise significantly, not least because of demographic growth and related demands. And thus, it leads to an uncertain situation where questions arise whether the world's electricity generation capacity is enough to keep pace with the increased demand or not. Fossil fuels have been the global primary energy source for producing electricity [1]. In 2019, it has been recorded that about 84% of the energy consumed by the whole world has been fed from fossil fuels such as oil, coal, and natural gas [2], whereas 64.5% of worldwide electricity generation comes from fossil fuels [3]. The amount of these resources are decreasing as they are non-renewable cannot be exchanged within a reasonable timeframe. It is estimated that the reserved fossil fuel may last for 50-120 years if the consumption stays like this [4]. In addition to being limited, fossil-based energy output results in emission by-products and harmful gasses such as CO2 and NOx. Responding to rising demands and protecting the atmosphere, as well as developing a viable future energy grid, is a tough hurdle. In this regard, finding alternatives to these fuel sources was an urgent issue; thus, the best option for these fossil fuels is renewable energy. Energy extracted by natural processes is renewable energy for instance sunlight and wind. Renewable energy sources are hydropower, solar, geothermal, wind, bioenergy, and ocean power. Renewable energy typically emits less CO2 than fossil fuels [5]. Renewable energy is clean, easy to maintain, quicker to grow, and sometimes much more economical than fossil fuel production, making it the ideal replacement for fossil fuels.

The prominence of the Renewable Energy Source-based generation process has made the electrical power distribution network shifting towards an active distribution network (ADN). Electricity-producing services or controllable loads that are connected to a central distribution grid are known as distributed energy resources (DER). They can also be connected to a host facility within the local distribution system. Common examples of DERs include gas turbines, wind turbines, microturbines, fuel cells, battery storage, biomass generators, electric vehicles (EV), and demand response applications. There are several advantages to the implementation of DER like it reduces the use of transmission lines, CO_2 emission decreases due to sustainable DG, self-consumption increases, and the customer's dependency on central grid power drops [7].

Low voltage grids are typically built to supply power to domestic consumers; however, it has gradually been utilized to carry bi-Directional electricity because of the higher number of implementation of Distributed Energy Resources (DER) [7]. According to the statement in "Art. 12 and 25 of the Electricity Directive (Directive 2009/72/EC)", DSO and TSO should “be able to supply the demands of distributions/ transmission electricity by securing a durable system” and “be responsible for operating, maintaining, and developing under economically stable and competent” distribution/ transmission system. DSO performs three tasks to ensure the grid’s reliability, and they are network reinforcement, voltage control, and load reduction. However, the massive spread of intermittent Renewable Energy Sources (RES) and, more typically, Distributed Generation (DG) to electrical grids has caused congestion problems and breached distribution grid limits [8].

Excessive power flows through transmission lines when there is an imbalance in demand and supply, although production and consumption are perfectly balanced at the system level. This excessive power flow in transmission lines causes infringement of the operating system's limitation and leads to congestion [10]. Unforeseen eventualities, for example, outages of generation, maintenance work, and failure of equipment, also contribute to the congestion occurrence. The existence of congestion causes system disruption, resulting in interconnected system outages, equipment damages, and degrading power quality. So, the system operator finds it a major problem to preserve system protection and efficiency in the presence of congestion [9].

Congestion management should be performed for both TSO and DSO to ensure reliable network operation. Congestion has traditionally been handled at the transmission stage, but increased renewable energy production in distribution grids is expected to pose a problem for DSOs [12]. Non-market and market-based approaches are two methods by which distribution network congestion is managed. The non-market approach aims to alleviate congestion by network reinforcement, active and reactive power control, etc. On the other hand, market-based methods, which are the key subjects of this study are described as the strategies used to alleviate congestion using prices or incentives [13].

Usually, DSO uses the grid reinforcement method to increase power lines, feeders, and the transformer's capacity to reduce distribution congestion. But it would be very costly if only grid investment is considered to meet the growing electricity demand and DER penetration. In addition, DSOs and TSOs do not have the power to increase the grid at the necessary speed due to the decentralization of production and the electrification of energy requirements as well as transportation [14].

DSOs are responsible for the cost-effective distribution of energy while preserving the protection and stable power grids [17,18], therefore, in addition to current operating procedures, DSOs are looking for cost-effective and new flexibility potentials for ensuring system security. In addition to network reinforcement, DSOs can obtain services in a market-based mechanism from resources to execute their system operations tasks, voltage management, and relieve congestion which is cheaper than grid investment and provide the same level of grid operational flexibility [19]. Flexibility markets are regarded as a stronger tool for using current distribution grids as they can be acclimated to restore reliable and secure functioning of the energy sector by reacting to volatility and instability in the supply and demand of the electrical power system [20,21]. Flexibility is specified as “Modifying the generation injection and/or consumption forms in reaction to an external signal (price signal or activation) to provide a service within the energy system” [22]. According to the survey organized by the Council of European Energy Regulators (CEER), the market-based purchase has been described as the optimal path to promoting the use of power system flexibility [23]. Moreover, the European Network of Transmission System Operators for Electricity (ENTSO-E) and the main organizations of European Distribution System Operators (DSOs) have released a study outlining the need for the acquisition of grid flexibility [24].

A few market-based approaches for reducing congestion have also been established, which are reviewed in the following subsection. A market-based strategy can always interact with markets; hence, it is important to have a clear understanding of the basic market framework, which will be discussed in the following chapter. In chapter 02, this thesis reviews the business dynamics of the Nordic electricity market, which is the basic premise for the discussion of market-based approaches.

1.1 Aims and Research Questions

The key goal of this study is to discuss different congestion management approaches in distribution networks through market-based mechanisms. Also comparing different market mechanisms especially LFM, followed by having an idea about grid regulation regarding usage of flexibility in grid management. To achieve this objective, Why congestion occurs and why it is important to manage, What type of congestion management techniques there exist, how DSO does the congestion management by utilizing flexibility via LFM will be answered in this thesis. Besides, regulatory issues concerning the utilization of flexibility will be investigated.

1.2 Tasks

The below-mentioned tasks should be done to achieve the thesis's goals and respond to the previously declared research questions:

- Giving an expansive point of view regarding flexibility and electricity markets.
- Describing the congestion and how congestion may occur in the distribution network.
- Defining some methods briefly to eliminate congestion based on the non-market solution.
- Understanding market-based congestion management for the distribution network by doing a literature survey of the different electricity markets, comparing key features of different flexibility market platforms, and at the end providing conclusions.
- Providing the necessary information about the rules and responsibilities of various market players concerning the utilization of flexibility.

1.3 Thesis Organization

In chapter 02, a brief discussion regarding various electricity markets has been presented, whereas chapter 03 contains information about the congestion that occurs in the distribution network. Congestion management in terms of the electricity market is devoted to chapter 04, and chapter 05 covers coordination requirements between different market stakeholders need to manage congestion. The conclusion is presented in chapter 06.

2. ELECTRICITY MARKETS

European Union has been working on Europe's energy policies for years to accomplish three main goals, and these are: Energy should be (i) affordable, (ii) competitively priced, and (iii) environmentally viable [25]. The liberalization of energy markets was the starting point for developing an internal European energy market in the 1990s. A wide range of enterprises coordinate the production, promotion, transaction, transmission, and allocation of electricity in this internal European energy market to achieve supply security, fair prices, better services to consumers contained by the context of acceptable regulations [26].

Unlike other products, storing grid-based electricity is very difficult. Besides, the electricity grid's frequency must always remain stable, meaning that a balance of demand and production should be ensured continuously [26]. One of the consequences of this is that the price of electricity varies all day long. It is common that prices get high when supply is in shortage. On the other hand, prices fall when demand is low for a large supply. For this reason, those who sell and purchase electricity must keep an eye on prices until it is supplied. Therefore, different electricity markets are organized to cope with different periods' uncertainty and facilitate market participants' profile management up to 15 to 60 minutes before consumption [27].

There are different electricity markets, but our focus will be on the Local Flexibility Market (LFM) because the thesis's main objective is to manage congestion on the distribution grid through LFM. However, due to their effect on LFM, the existing markets, such as the day-ahead (DA) market, intraday (ID) market, the energy balance market, and frequency reserve market, will also be briefly discussed.

2.1 The day-ahead market (Spot Market)

The primary task of power market prices is to establish demand-supply equilibrium because electricity storage is challenging and high expense linked with supply failure. The day-ahead market can be defined as an auction-based market where electricity prices and amounts are dependent on supply and demand. Elspot day-ahead market, operated by Nord Pool, is the mainstay of the Nordic electricity market. Examples of the most common European DA markets include GME, EPEX, Belpex, APX NL, and Mibel [28].

2.1.1 Existing DA market

Nord Pool operates Europe's largest electricity market, providing consumers with day-ahead and intraday trade-offs. The key forum for trade-off electricity is the day-ahead market, and the intraday market reinforces the day-ahead market by ensuring supply and demand equilibrium. Power producers submit bids stating how much electricity they can supply and the corresponding price to the NordPool power market whereas the amount of electricity demanded and price are submitted by consumers. The submission of these bids takes place 12 to 36 hours before delivery [29]. It sets a buy-orders-dependent demand curve and a sell-order-dependent supply curve, all for the next day's every hour. The intersection of both curves is the market-clearing price (MCP), which represents supply and demand. Depending on the market-clearing price (MCP), the spot price is then calculated for each hour [26]. If there is perfect competition, all suppliers are inclined to compete at their marginal cost, and all buyers are inclined to compete according to their marginal ability to pay.

Nord Pool region consists of 13 price zones presently. TSOs provide transfer capacities in these zones before market agents submit bids and Nord Pool then sets region prices [30]. Nord Pool Spot accepts three sorts of bids: individual hours, block bids, and flexible hourly bids, separate congestion control approaches in a single hour market considering hourly bids were presented in [30]. The market creates a merit order based on its cost and sensitivity, which implies its successful impact on congestion and approves acceptable bids. Accepted flexibility providers are told at 14:30 every day about the success of their bids. Congestions are normally marginally overcompensated because acceptance is often applicable for completed bids [31]. Refer to [32], [33], and the Nord Pool Spot and Nordic TSOs websites for more specific detailed examples of the congestion control approaches.

2.1.2 Distribution congestion management in DA market

With multiple distinct approaches, the congestions in distribution networks can be overcome. DSOs can eliminate congestion similar to the redispatch approach in the DA market by procuring flexibility. TSOs are managing transmission network congestion by the redispatch approach. In Europe, zonal pricing, and uniform pricing models are used for transmission congestion management [26]. Market operators and contributors do not mostly use nodal pricing because, in this model, price formation requires massive time due to having a vast number of prices [33]. For this reason, zonal pricing with a fixed zone focused on the "Pan-European hybrid electricity market integration algorithm (EUPHEMIA)" becomes Nord Pool's choice [34]. In the "uniform pricing" model, all the nodes share a common price and use redispatch to avoid congestion [10]. A uniform price per MW electricity for all market operators, regardless of their geographical location, is selected using the uniform pricing model. When there is congestion between two adjacent zones, a zonal pricing model is implemented. During this situation, the electricity price is set higher where production shortage exists and lower where production is higher by making bids up and down (redispatch) [10]. Redispatch thus helps not to infringe transmission capacities resulting in the reduction of congestion [35].

2.2 Intraday Market

Intraday power trade applies to the continuous purchasing and sale of power at a power exchange held on the same day as the distribution of power [36]. The intra-day market is a contract market that is bilateral and closed one hour before the real-time service. In this market, the operator may make contracts to avoid the possible cost of creating an imbalance in the system. Imbalance in the system may be caused by component failure, an inaccurate forecast [37]. ELBAS and EPEX are the intraday markets run by Nord Pool, and APX / Belpex are other examples of the European ID market [10].

As renewable energy production is increasing, to stay in the balance following the closure of a day-ahead marketplace is becoming more difficult for those market players who have RES in their portfolio and provide opportunities for others [38]. As a result, interest in intraday market trading is growing. Pricing is the element that separates the intraday market from day-ahead trade. Although day-ahead trades are linked to market-clearing pricing rules, where the last bid approved sets the price for all deals, intraday trading rates are determined through a 'pay-as-bid' mechanism. This implies that prices in continuous trade are measured on the basis of each transaction that is done. Because of this, in intraday dealing, bid prices are also used. The consequence is that the prices for products on the intraday market are not fixed. Depending on the moment the trade happens, getting different prices for the same products is far more common [36].

In Elspot which is a day-ahead market, the initial transaction between energy production and consumption occurs in a particular hour of operation [39]. After the closure of the Elspot market, a price is determined at which desired production and consumption coincide. Moreover, as the operating hour progresses, the expected balance might require to be adjusted as conditions shift in power production or usage. A new settlement is then formed between supply and usage, first in Elba's intra-day market (IDM) and then in the intra-hour regulatory market of electricity [40]. Intraday markets provide market players with the ability to balance their positions and exchange energy as close as possible in real-time to mitigate balancing steps. Intraday trading is especially useful in reacting to unpredictable shifts in power generation and demand by using the market process before control reserves are needed. This allows an operator of a power plant that unexpectedly loses production in a single block to buy additional power from other market players and keep the balance group. Therefore, intraday trade is a core component in direct selling in renewable energy-generated electricity as increasingly evolving weather forecasts result in an unplanned deficit or surplus of power plant power [36].

2.3 Balancing energy markets and Frequency containment reserve markets

To preserve the balance between supply and demand and maintain the power grid's security, imbalances in physical trading on the spot market must be leveled out. The balancing market is the key instrument for fixing such imbalances that happen due to the deviations from the number of bids on the spot market. This market fixes this imbalance by providing the requisite physical trade [29]. The balance difference between other forward markets and real-time energy delivery is bridged or reduced by balancing markets. The balancing markets are the last stage for selling electric energy that is usually used to balance production and demand as closely as possible before (e.g. half an hour in advance) the electricity supply [41].

The power grid frequency, which has a nominal value of 50.0 Hz, shows the equilibrium between production and consumption [42]. Frequency consistency specifications as per [43], “The standard is between 49.90 and 50.10 Hz for the maximum allowable difference in frequency during the stable state. The goal is for 50.00 Hz to be maintained. The number of minutes with a deviation of frequency shall be kept at a low. The target estimates for frequency variance shall be defined on an annual basis, and the amount of under-frequency and over-frequency variations shall be documented”. Market participants schedule and balance their demand and production in advance, but there are variations at each hour in operation. Different types of reserves from reserve markets are procured to manage these variations. Reservations are power plants, storage, and consumables that either increase or decrease their electricity according to the power system's needs [42].

The Frequency Containment Reserve (FCR) is regarded as the primary frequency regulator that instantaneously manages frequency deviation. By term, frequency containment reserves are operational reserves to balance the operation within the usual frequency band and in the event of disruptions [43]. To stabilize the frequency within seconds, FCR is activated non-selectively in a synchronous area [44,45]. There are two parts in FCR: When the frequency is between 49.9-50 Hz, FCR-N is initiated whereas frequency plunges under 49.9 Hz, FCR-D is triggered. FCR is replaced after a limited period (a few minutes) by a secondary control called an automated frequency to restore reserve (aFRR). The TSO replaces typically or complements the aFRR by tertiary regulation known as manual frequency restore reserve (mFRR) and restore reserve (RR) (not used in Ireland, Belgium, Netherlands, Germany, Denmark, and some Eastern European countries [46]) later when FCR is substituted by aFRR [10]. Their entire activation period is 15 minutes [47]. As shown in Figure 1, FRR activation raises the frequency progressively back to the normal range of variance.

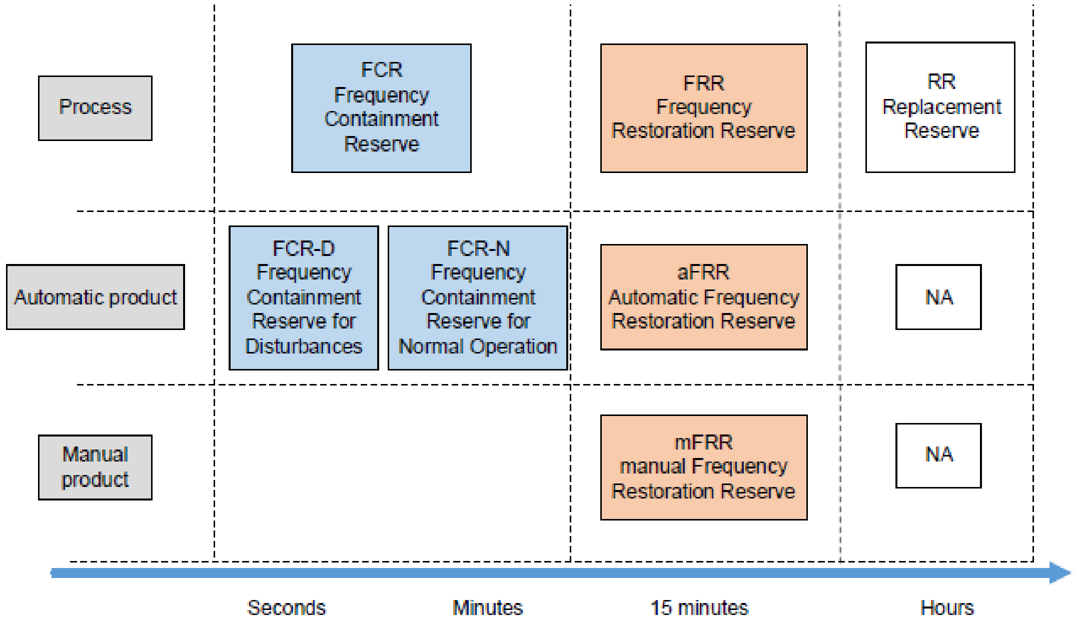

Figure 1*. Reserve products [48]*

2.4 Local Flexibility Market

The word 'flexibility market' has increasingly been used to define a market structure to provide local flexibilities, specifically for network operators to control their grid congestion [49]. There are three types of parties for a full functioning market, flexibility providers (aggregators, balance responsible parties BRPs), market (LFM, etc), flexibility buyers (DSOs, TSOs, sometimes BRPs). An aggregator is a party that contracts flexibility with flexibility owners (basically households, office buildings, farms), collects them, and forward them as bids to different markets to maximize its profit. Now LFM is the platform that is operated by a neutral party (often a third party) to ensure transparency and fairness. The main participants in the LFM are an aggregator, DSOs, BRPs, and Local Energy Community (LEC) members (consumers, producers, and prosumers). The concept of the LEC was recently incorporated in Article 16 of a proposal for a Directive on general rules for the internal market in electricity by European regulatory agencies [50]. LECs are a new trend aimed at involving end-users in the transition to a more sustainable energy future. The LFM's LEC members are selected from neighborhoods and arranged by an aggregator. It is entirely optional to join the LEC. The LEC might be controlled for a variety of reasons, including increasing renewable energy consumption or increasing economic profitability. The LEC may decide on this, and the aggregator could provide several optimization strategies. A local controller is required for all flexible members who use distributed energy resources. Each flexible device's power usage and production must be monitored. Furthermore, each flexible device's local controller should be able to receive control signals from the aggregator platform. Members of the LEC and prosumers in the LFM are accountable for:

- Performing the tasks stipulated in the contracts.
- supplying the necessary knowledge regarding flexible resources.
- Setting up local control devices that are linked to the aggregator platform.

There is a vast area of scholarly study exploring the use of energy system flexibility. In [51], Villar et al provided a review of the related research addressing products and marketplaces for flexibility. Writers clustered flexibility products, marketing practices within flexibility for TSOs that may be supported by transmission or distribution system controller. Also, the usage of distribution system operators (DSOs), who must be located in the relevant distribution system, has more flexibility. Managing congestion and regulation of the power output (voltage) of TSOs and DSOs are the situations when flexibility can be applied [51]. The idea of geographic flexibility marketplaces where DSOs are eligible for the flexibility-enhancing network offered by all kinds of prosumers is focused in [52].

Flexibility markets have the potential to improve the efficiency of present distribution grids. With a rise in the number of flexible suppliers (resulting from end-user access to energy markets and flexibility) and a growing number of flexible applicants (i.e. DSOs), the flexibility platform's idea is evolving. A flexibility platform is described as an IT platform capable of facilitating and organizing the exchange, clearing the bids, and/or settlement of flexibility on the demand side [53]. Run by independent third parties and often by a group of network operators, the new platform should use open standards to encourage competition and be open to all decentralized solutions to facilitate creativity and not choose winners by locking requirements tailored to existing technology. We are exploring four flexibility deployment projects: Piclo Flex, Enera, GOPACS, and NODES. The degree to which flexibility markets are incorporated into other established markets, such as usage of reservation fees, usage of standard products, and methods in which TSO-DSO coordination takes place, differs amongst the programs. Other research initiatives that involve flexibility markets are OSMOSE, SmartNet, and WindNode projects. ENTSO-E provides a summary of these research initiatives [54].

The Norwegian NODES is jointly owned by the marketplace Nord Pool and the energy firm Agder Energi. The dutch GOPACS is a partnership between the Dutch TSO TenneT and the DSOs. Germany's ENERA: EPEX The local flexibility markets spot is part of the German Federal Ministry of Economic Affairs and Energy's Smart Energy Showcases-Digital Agenda for Energy Transformation (SINTEG) growth program. Piclo Flex, an independent software firm in the United Kingdom [53]. The key features of recent commercial flexibility platforms are discussed in the subsection.

2.4.1 NODES

NODES is an independent platform for a renewable energy future where decentralized flexibility and resources can be shared between grid operators, energy suppliers, and customers. By incorporating the local flexibility market into the current intraday market and, in the future, reserve markets, NODES means that flexibility can be exchanged even though the local grid does not have an immediate need for flexibility. In this way, the flexibility owner (Prosumer) and the Aggregator / BRP have a greater chance of a good return on investment, enabling suppliers of flexibility to encourage the system to be more flexible [55].

In order to reduce grids from certain congestions, DSOs and TSOs might have flexibility at the local level. In NODES, providers of flexibility tag a grid location (GL). These purchasers must specify their interest in paying for flexibility activation at certain grid locations and continually transmit this information to NODES using an API. A local price region constitutes one of more GLs. The local price zones can vary depending on which flexibility is being bought by the TSO or DSO and can be dynamically changed on short notice [56]. The flexibility is provided by the flexibility providers who work for the owners of flexibility assets and supply NODES with these offers via another API. The flexibility is not required at a local level at the actual grid site for the bulk of the working hours during the year - it is frequently required only a few hundred hours annually. However, it may still have significance within rest of the system, such as for TSO balance reasons or in the ID marketplace for BRPs. NODES will create an interface that allows these marketplaces to be flexible. Flexibility providers can potentially distinguish their offerings based on the sale or central sale of the flexibility resources. Selling locally at a single grid site might be riskier in many situations since there are fewer options if the seller wants to rebalance owing to the lack of availability of some assets. It is considerably easier to equalize contractual holdings in the ID market. This market platform is very flexible from a product perspective because flexibility products are customizable in NODES meaning that there is no standardized product here. So flexibility providers send its bid with its own desired attributes and flexibility buyer has the capability to sort out bids and find the best bid.

2.4.2 GOPACS

GOPACS is a unique European project that emerged through constructive collaboration between the Dutch national grid operator (TSO) TenneT and regional grid operators (Distribution System Operators, DSOs) [57]. GOPACS, introduced by Dutch grid operators, are pooling platforms that allow system operators to provide flexibility with location details on congestion management [58]. GOPACS is not a conduit for competition (flexibility deals are not translucent on GOPACS). Instead, it acts as a bridge between network providers' and market participants' interests. It is linked to the Energy Trading Platform Amsterdam (ETPA), a national intraday platform in the Netherlands. GOPACS is not a retail channel but uses orders on established market channels. Furthermore, GOPACS can enable offers from ETPA-registered flexibility providers provided they include a geographical identifier. The ETPA does not identify any static geographic zones. By its algorithm, alternatively, GOPACS determines which assets are the cheapest option for fixing congestion [56]. By including their location data, GOPACS tests whether an order will address DSO congestion requirements.

For instance, if congestion in some parts of the grid is predictable, operators wish to see output decrease or a consumption rise. A bidding request is then submitted to marketing parties through GOPACS. Market participants in this field can thus issue an appropriate purchase order on an interconnected market platform for energy. Nevertheless, any measure to address congestion should prevent a detrimental influence on the national balance of the electrical system. For this reason, the reduction of power produced by a market party outside the congestion region is associated with a reverse order. GOPACS examines rapidly whether this instruction is causing any problems in any of the cooperating grid operators' electric grids elsewhere. If all of the indicators show green, the grid operators will cover the cost between both orders. Thus both orders are compared and congestion may be addressed on the market platform. GOPACS operates according to the major European guidelines on market-based grid mitigation and provides big and small market operators with the simplicity to make income and contribute to the resolution of congestive situations. The partnership between the grid operators also avoids the congestion in one section of the grid generating issues in another portion of the grid operator. Grid operators work for GOPACS in conjunction with the ETPA intraday commercial platform.

2.4.3 ENERA

Enera is a section of the German Federal Ministry of Economic Affairs and Infrastructure's Smart Energy Shows-Multimedia Agenda for the Energy Transformation (SINTEG) growth program. It aims to build and demonstrate flexible standard strategies for an environmentally sustainable, safe, and accessible power supply by using renewable energy. In the Enera network, the energy company EWE AG and the European Power Exchange EPEX Place, along with the grid operators Avacon Netz, EWE NETZ, and TenneT, introduced a local trading forum for flexible supplies [59]. Local order books concentrate flexibility features that can be exploited to relieve congestion by TSOs & DSOs. EPEX SPOT works as an impartial mediator between system operators' and regional suppliers' requests for flexibility, oversees pricing formation, and ensures a high degree of transparency on this growing market. In order to prove in actual circumstances, all the required processes are established in the project on the mobility suppliers and system providers' sides to operate on the market.

System operators assess their flexibility requests (location, time, quantity) and share their grid restrictions with the other system operators to ensure effective congestion management and to avoid new congestion. On the other hand, certified flexibility providers place their bids in the order books of the relevant market areas. Importantly, the traded products consist only of commitments to adjust physical schedules within a given market area. Such load/production changes are verified export within the “verification platform” which compares the metered in/out flows of the assets to a baseline as per the schedules.

Consequent to the change of schedule of an asset, the portfolio of the party responsible for the balance of this asset is affected so that the portfolio needs to rebalance. This is typically (but not mandatorily) done on the intraday market. However, there is no explicit interface between the Enera platform and the wholesale intraday systems: each market participant (or his Balance Responsible Party) remains responsible for his own balance, irrespective of the flexibility activations. For example, if a load is increased via the Enera platform to alleviate congestion, the load asset gets remuneration for this physical activation, but nonetheless needs to source the energy separately (this energy cost can thus be included in the market-based flexibility bid).

2.4.4 PICLO FLEX

Piclo [60] offers a marketplace for flexibility providers in the United Kingdom to increase network congestion areas' exposure to support flexibility planners. Distribution grid operators in the UK, incentivized by "total expenditure" legislation, are gradually using substitutes for grid strengthening. This involves flexible grid connection programs and bilateral procurement contracts with flexibility suppliers. In order to promote purchases and manage procurement procedures, operators and regulators are pursuing open markets, such as the Piclo Flexibility Marketplace [61,62].

The Piclo Market simply involves licensed firms to be flexibility suppliers. It also enables flexibility suppliers to sell flexibility that is currently not in use. Tenders are grouped by restriction area so that any flexible capital related to a predetermined geographical area can bid. Multiple tenders for various services, such as strengthening deferment, maintenance, and various contract periods, can be held for one restricted area [63].

2.4.5 Key Features of Flexibility Platforms

Important features of four flexibility platforms (NODES, GOPACS, ENERA, and Piclo Flex) are discussed in the subsection.

- **Market Integration**

Two projects have different platforms (Piclo Flex and Enera) and 2 projects (GOPACS and NODES) in the flexibility industry, for which the present market has been somewhat integrated [56]. In Piclo, a short/listed flexibility provider bidding in the procurement must submit both an available bid (the price in £/MW/h for availability) and a utilization offer (the price in £/MWh for utilization), as well as the highest operational time [64]. In Enera, flexibility suppliers make bids, and network operators submit flexibility requests, which are continually compared to the marketplace [56]. On other hand, GOPACS and NODES seek to encourage liquidity pooling by incorporating the flexibility market into developed markets and offering market parties the possibility of formulating a single bid that can be used for different services. GOPACS is solely connected to ETPA, although links to additional markets are being considered. Locational flexibility offerings for network providers are not placed on a distinct platform under ETPA. The same freedom is available for network operators and market parties (BRPs). NODES, like ETPA, is a daily trading platform, and network operators receive flexibility offers within the same marketplace [63]. Also designed for migration to other business platforms for example the intra-day cross-zone and balance market [65] – is the flexibility provided by the NODES network, which is locally not needed.

- **Product**

Piclo Flex, GOPACS, and Enera have standardized products. In Piclo Flex, at the time of the tender, the short-term activation product is determined per restriction area. A broader range of individualization of product features is provided by the Piclo marketplace. For example, the system operator specifies individual procurement cycles for flexibility purchasing contracts that are sold at auction through the Piclo Marketplace, offering various combinations of delivery payments, and choosing different weekdays, hours of the day, and intervals that need flexibility [63]. EPEX SPOT specifies standard product features in Enera along with network providers that enhance flexibility. The items appear like intraday products, at some point with energy blocks up or down for some time (such as 1 h or 15 min). When it comes to location tagging, each order belongs to a particular node predefined by Enera. GOPACs purchases standardized ETPA products to which a location tag called an EAN-code is added. The unique feature of GOPACS is it particularly aims to purchase two combined orders (purchase and sale orders) called Intraday Congestion Spread (IDCONS) [66]. Purchase and sale orders have the same structure as everyday wholesale orders, with orders that match starting times, volumes, and times, but in other locations. There are no standard product specifications defined in NODES; instead, flexibility suppliers can use a wide variety of characteristics to specify their offerings. Buyers with freedom can select the cheapest offer to fit their needs based on factors. Buyers with flexibility can filter offers based on parameters and then choose the cheapest offer that meets their requirements. Flexibility providers can show which grid locations (GL) they are linked to in relation to their location [56].

• DSO-DSO Coordination

All these projects work with multiple DSOs or have a tendency to work with multiple DSOs. As a result, numerous solution providers are attempting to establish themselves as the first-choice provider of flexibility platforms, as well as a leading player capable of spreading their platform all over the EU and beyond. Using a single platform that covers several DSOs allows it easy for providers of flexibility to communicate with each other. Six DSOs of the United Kingdom took part in the BEIS cases for Piclo Flex. Following that, a contract between three DSOs and Piclo has been made for flexibility purchasing operations. In Enera two DSOs are currently involved. In GOPACS, four DSOs use the same TSO-DSO communication platform in addition to the TSO. At present, only one DSO is involved in each NODES installation. Many DSOs are planned to enter the network shortly.

• Pricing

Nodes, GOPACS, and the Piclo follow a bid-based pricing strategy for price formation in which flexibility suppliers can set their prices [63]. Prices are agreed between the grid operator and the Flexibility Suppliers for various asset classes prior to bidding and trading. They are based upon the expense figures of the properties plus a mark-up. SINTEG Enera conducts open bidding for nonrenewable energy reserves but sets a price cap [63].

• Matching Process

Enera, Nodes, and GOPACS use a system comparable to trading practices in many European intraday markets [63]. Grid operators determine market areas in which the same sensitivity factor is assigned to flexible resources. Each area of the market refers to the local order book on the platform. When a bid is offered and bought in the same order book, it is immediately paired by the platform, which then reports the results back to the grid operators who chose the flexibility they need to alleviate congestion. Flexibility suppliers are then notified by the platform of their latest schedules.

3. CONGESTION IN DISTRIBUTION GRID

The power grid's primary role is to move electricity to consumption sites from generation sites. The electricity grid is typically configured for large centralized production units, linked to a high-voltage transmission grid that requires large volumes of low-loss power to be transmitted. However, high voltages are impractical and dangerous to use near customers and the voltage is transformed to lower levels and distributed through a distribution grid to customers [67]. When operating the power system, the main challenge is to keep the system in balance, i.e. to balance the energy supplied with the demand for electricity.

The purpose of the distribution network is to provide consumers with high efficiency of the active power Pd (as seen in Fig.2) as needed. Customers may consume any reactive power within the authorized range. Voltage dips can occur when providing both active and reactive power through a feeder. Likewise, Pd can be negative in obtaining renewable power output which may lead to issues with over-voltage. The feeder itself consumes or produces reactive power as well, which will have an impact on both the voltages and the currents. If the power flow surpasses the thermal limitations of power components, it can cause overloading difficulties in all instances. From the viewpoint of the distribution system operator (DSO), it is of utmost importance to deal with voltage and current restriction violations hereinafter referred to as limit violations. Overloading limits the lifespan of transformers and/or lines, on the other side.

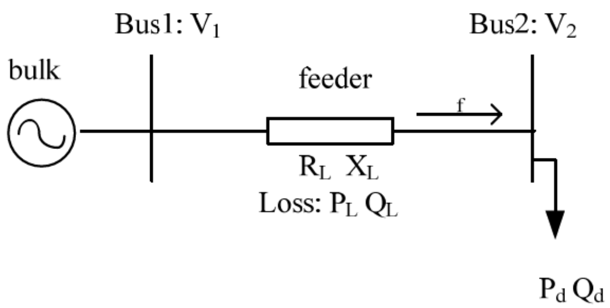

Figure 2. illustration of a simple distribution grid [68].

DG should, in theory, contribute to supply security, power efficiency, reduced congestion, reduced demand for long-distance transmission, and network investment postponement. However in fact, because of DG output profiles, location, and inflexibility, the introduction of DG into the distribution system creates a capacity issue [69]. DG is not always placed near the load, and it is not always possible to control DG output. DG output, however, does not always align with local demand. Furthermore, if the local capability reaches local load, higher voltage power injections must be handled. The distribution network's growth and function can be affected by this [70].

Distribution network congestion can arise as a result of the increasing infiltration of distributed energy resources (DERs) and also for the below-mentioned reasons:

(i) Failure of generator

(ii) Power lines failure

(iii) Uncoordinated operation of flexible loads (e.g. EV or Heat Pumps)

(iv) In liberalized markets, REPs' real-time pricing (RTP) schemes can exacerbate congestion in distribution networks by generating additional peak demand in response to time variable rates.

In this thesis, we will discuss congestion taking into account voltage magnitudes, current levels (i.e. overloading). Once the congestion dilemma itself is understood, it can have congestion remedies that fit the features of the distribution system.

3.1 Voltage Violation

The majority of voltage supply circumstances are within these limits, however severe variations from the normal voltage might cause devices or network components to malfunction or fail. The European standard EN 50160 lays down specifications for the characteristics of voltage at consumer connection points in distribution networks. The features discriminate between constant events & voltage occurrences. Constant events involve power frequency, fluctuations & sudden increases in voltage, while supply interruptions and voltage dips are found in voltage events [71]. In compliance with the minimum, the standard nominal voltage is 230V for LV networks. Under standard operating conditions, the supply voltage deviation is agreed to 95 percent of the 10 minutes mean root mean square(r.m.s.) readings at the consumer connection point should be within 10 percent of the nominal voltage [72].

The output power of the DERs can result in uncertain variations in the voltage profile, such as voltage sag or voltage swell. The optimal locations for distributed generation systems are frequently remote from the transmission network, and it is typically more cost-effective for the owner to connect the units to the nearest network node accessible.

The presumption that the distribution network will have unidirectional power flows will alter if DG units are connected close or at the ends of the distribution feeder.

With the implementation of reverse power flows, the voltage profile would change. The factors restricting the connection capacity of the DG unit in weak distribution networks are also the voltage increase effect induced by DG [71]. Because of the DG relation, how high the voltage can increase will be set by DSOs. Due to the lack of an active voltage management system, DSOs have difficulty keeping the voltage profile at client connection points consistent, especially at the low voltage stage. Grid control is not accessible in most nations, and most distributed generators don’t provide any support for the system. As a consequence, the supply of power is threatened and the network can ultimately fail.

3.2 Current Violation

Except when power generating and consumption are on the same bus, power must travel the physical distance between the places of output and consumption. When the volume of current flowing among output and consumption locations exceeds the capacity of subterranean cables, overhead lines, and other devices, congestion occurs [10]. Conductor reshaping, new line building, load allocation between neighboring feeders, etc. may be used as a solution for overload-induced congestion.

3.3 Thermal Violation

The thermal limit is defined as a limit on the current carrying capacity of equipment that prevents extreme temperatures from running. It varies with changes with temperature, wind speed, daylight intensity, equipment, duration of applied current, and current flow through.

For a steady current amplitude, the resistive loss in the conductor equals the resistance of the conductor. Electricity produced by solar power is affected by net solar irradiance, the content of the conductor, color, etc. Therefore, gloomy days prefer lower temperature transmission lines, pole-mounted transformers, etc. And solar power is zero for underground cables although the ground may have other heat sources like district heat pipelines. [10]. If with the exception of the energy consumed by local loads, a high quantity of energy is emitted at a node or in an environment, the remaining energy generated travels to surrounding loads, resulting in a breach of the thermal limit of components. Therefore, for the operation of the power grid, the thermal limit is a limiting factor that can generate congestion.

3.4 Congestion Management

The power transmission across the network has become unreliable due to congestion throughout the network and the power losses are also growing. There are two key choices for preventing congestion: network reconfiguration or changing the geographic patterns of generation and load [73].

Network operators can prevent congestion in the short term with strategic steps such as switching operations: reconfiguring the topology of the network so that the flow across a congested element of the network reduces. Another alternative is to postpone or delay scheduled maintenance outages of network components. Network congestion can be overcome in the long term by network extension (new lines or transformers) and improvements (increase in voltage, high-temperature lines or re-conduction, control of line temperature). Distribution grid voltage control is a very important congestion management tool. DG, tap changers, and reactive power compensation units are the primary resources for that. It is also possible to add phase-shifting transformers and FACTS that allow some degree of re-shaping of load flows and control of voltage/reactive power but they are very rarely used. At the distribution grid level, FACTS are too expensive for CM. They might have been used in voltage quality management in sensitive customer premises.

The other probability of altering load flow is to geographically "shift" generation and/or usage, e.g. by decreasing generation "before a congestion ("upstream") while increasing generation "behind a congestion ("downstream") at the same time. This operation keeps the demand and supply balance of the system unchanged but decreases the flow over the congested network portion [73]. In the long run, investments in power plants in regions of scarcity and consumption investments in regions of over-supply have the same impact. his principle might limit the amount of flexibility available in local grids and therefore make the CM more challenging for a DSO in practice. Instead of finding only one suitable flexibility resource/bid, the DSO needs to find a combination of two resources/bids, which is more demanding. From retailers and balance responsible parties viewpoint, this principle is good, because no unbalance in balance settlement is not created by DSO. However, the possible unbalance payments may be paid by DSO as well due to CM actions.

3.4.1 Active Power Curtailment (APC):

A variety of studies have been tried to model congestion control strategies (CM). Active power reduction is an easy and successful measure to prevent overvoltage and line overload by reducing a comparatively limited volume of energy during troublesome time intervals [74]. Thus, DSOs will use it as a way of deferring grid extensions. Grid policies, legislation vary between countries with respect to the capability and reimbursement systems for such a control action. Curtailment is a technique for keeping assessment parameters within predetermined limits [75]. By decreasing the power injected at a site, minimizing voltages at that location can be accomplished. However, APC is not a very favorable alternative since green energy has a lot of value and curtailment is just a waste of money in a way.

3.4.2 Reactive Power Compensation

Reactive power, based on grid features, for example, the X/R ratio, is beneficial in resolving together voltage and line overload concerns. In grid codes pertaining to Reactive Power Compensation (RPC), different connection contracts and distribution grid tariff contracts are contained. The most notable is the regulation of the power factor and reactive power as a function of the active power and voltage [76]. For reaching an optimum grid function, centralized RPCs or CVC utilizing active network management are executed by DSO. To lower bus voltage, the use of reactive power can be enhanced by DSO. Furthermore, DSO may regulate the flows of reactive power while keeping certain DGs inductive and certain DGs capacitive, resulting in less line and transformer filling [74].

Flexible AC transmission system (FACTS) reactive power support can mitigate the issue of voltage issue particularly in poor networks, where voltage issues take precedence over thermal issues. But as they are not cost-effective so there must be other voltage quality reasons for the investment of FACTS that cannot be resolved by larger cables or transformers. Operational costs of reactive power are negligible if the disadvantages of the systems due to the rise in apparent power are insignificant [68]. To fix congestion more effectively, writers of [77] propose the usage of an on-load tap changer (OLTC) combining reactive power management. Although, tap changer control of OLTC is not cost-free. It imposes operational costs but is often negligible compared to other voltage control methods. Tap changer control that benefits the distribution grid required SCADA, monitoring, and decision-making software in DMS. So to fully utilize a tap changer, the whole cycle should work well which imposes costs to DSOs.

3.4.3 Reconfiguration

The term "reconfiguration of distribution networks" refers to a change in the grid's arrangement. This is done by adjusting the state of normal-open and normal-close switches to keep the similar radial arrangement while providing consumers with more effective or sufficient electricity [68]. Distribution systems can be configured in metropolitan environments as weakly meshed networked systems, but for technical purposes, most distribution systems run with a radial topology. Thus in nearly all distribution extension and organizational planning problems, the topology limit is present. For distribution networks, network reconfiguration can be done automatically to discover a radial operational configuration that optimizes those priorities but meeting all organizational restrictions and does not isolate any nodes [78]. Reconfiguration may be done between substations as well. Typically MV feeders have connections to one neighboring substation as well. This is useful if the congestion happens in the primary transformer or in the backup connection between substations, etc. If there was no congestion in the network, the configuration with the least loss was considered to be the optimal configuration.

3.4.4 Load Shedding

Load shedding refers to an emergency action that is necessary to do to avoid a blackout. Typical load shedding action is low-frequency load tripping on substation level to prevent frequency instability. The tripping limit is about 47.5 Hz. If all available controls during an interruption or contingency are insufficient to sustain the security of system operation, effective enough load shedding would be used as the last resort to reduce blackout failure. The safest and accurate methods of congestion control to reduce or alleviate overloading from the power grid are called optimum load shedding. Some customers' load shedding can be established on a particular arrangement amongst the DSO and the customer that requires a DSO to discharge the loads for a few hours (i.e. yearly, monthly, etc.). It is one of the DSOs' temporary remedies for grid component overloading congestion [10]. It should be the last solution if previous market-based voluntary actions have not been effective.

3.4.5 Coordinated Voltage Control (CVC)

The distributed generation (DG) is typically associated with the "fit and forget" mode within distribution systems. The advancement of DG penetration within real power systems involves the management of the network infrastructure to be smarter and more scalable. OLTC and shunt capacitor banks are used in traditional voltage control calls “voltage/var control'. However, in the case of strong DG infiltration, it becomes less useful to cope with voltage fluctuations. One approach is to implement active voltage control by continuously monitoring the production of power from DG [79]. This method can be used in a coordinated or localized manner. The coordinated approach which works in a centralized way requires information from other nodes to attain the network state [80,81]. The control behavior of centralized voltage control (CVC) techniques is determined by knowledge of the whole distribution network so it is important to pass data between network nodes. The usage of control systems with inputs for example network status, technological restrictions, and even energy trade market knowledge is required by advanced CVC [82]. CVC methods may be divided into two classifications: those that use rules-based algorithms and those that use optimization algorithms [78].

It is possible to have a basic network structure and few controllable services based on rule-based approaches. In the case of the simplest rule-based CVC system, network voltage is maintained within the allowed range by controlling the voltage of the substation depending on the network maximum and minimum voltages. If the network's maximum voltage approaches its boundary, the voltage of the substation is decreased; if the network's minimum voltage goes below its boundary, voltage is increased. This procedure ceases execution when the network's maximum and minimum voltage limitations are both exceeded [83, 84]. Substation voltage coordination can also be used with local active and reactive power control of DG units. As the transformer automated voltage control relay and tap changer delays are significantly longer than the central active and reactive power controllers' latency so the local control would work faster than the substation control [85].

4. CONGESTION MANAGEMENT THROUGH MARKET

This chapter focuses on the usage of flexibility to handle physical congestion by market-based solutions as described in the introduction. Concerning the congestion problem in distribution networks, it should be noted that it is exacerbated by either excessive demand or excess supply in a region of the electrical power grid. Demand-supply mismatch in the local level leads to power transfer from stronger areas to weaker areas of the network almost without any effect on grid frequency. This level of power flow can exceed network capacity, creating congestion. The method of managing congestion can be defined in various stages, involving various participants, activities, and the exchanging of information. The aim is not to describe a completely harmonized and systematic European process, but to demonstrate how congestion management could be carried out in a general way. Concerning market-based strategies, the diagram below shows the key stages of the congestion management process.

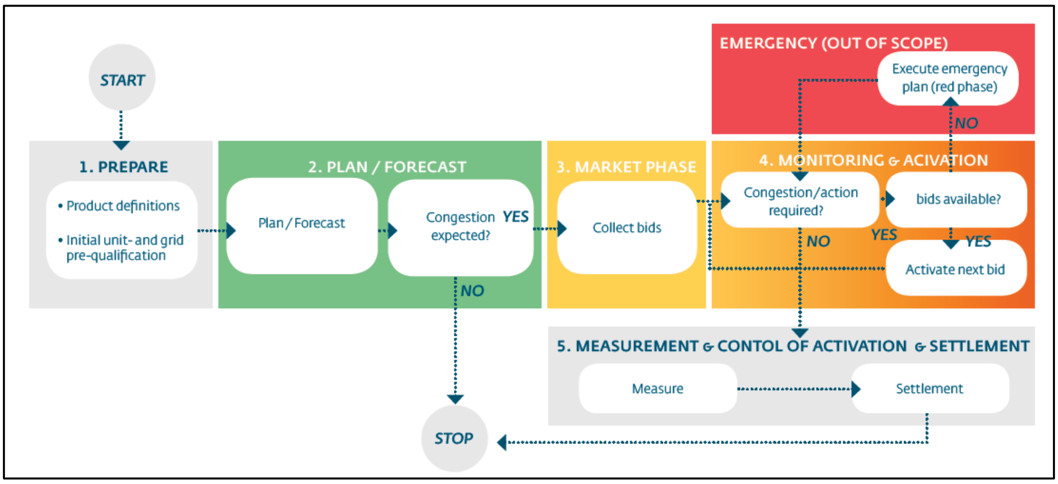

Figure 3. *CM process overview [86]*

4.1 Preparatory Phase

Product specification and pre-qualification are included in the preparatory step of the market-based congestion management process. There are two segments in pre-qualification: pre-qualification of product is done to govern if the unit is currently capable of operating in compliance with the specifications laid down by the system operator (SO) and the pre-qualification of the grid, to determine if the grid is capable of distributing the energy supplied or flexibility delivered to any market stakeholder. There is a common consensus that to perform commercially effective congestion control, products must meet the needs of system operators. These specifications should be explicitly defined to ensure the effective design and production of the product.

Pre-qualification is a procedure in which a prospective supplier informs that it satisfies both the technological criteria defined for the supply of the flexibility product (product pre-qualification) by taking information from TSO/DSO and grid capacity to supply the demanded product to which it relates (grid pre-qualification) [86]. Each information & communication system, evaluations, etc. needed for the provision of the service are covered by pre-qualification. It is understood that pre-qualification takes place at the unit level, but if this is technically feasible, it may also take place at the aggregate/portfolio level. Furthermore, in addition to pre-qualifying individual or aggregated flexibility suppliers, pre-qualifying the market party providing the service is frequently required. This is to guarantee that it has a settlement account, appropriate financial responsibilities, complies with regulatory requirements, and so on.

4.1.1 Product Pre-Qualification

The flexibility products used for congestion management must be fully coordinated to allow market-based flexibility provision. The goal of this effective allocation is to maximize the value of flexibility services. The same products are not necessitated in this, but rather interoperability across products that allows for market interchange.

The product should either be an alternative (the capacity available) that allows the purchase system operator to demand, which may either differ from a base or set upper or lower generation/consumption limitations at a certain time (activation) or simply be activated directly. If no need exists to enable the product for congestion control, this option can never be lost. Product availability should be carefully structured to minimize a reduction in market liquidity when contracted products are not activated. Moreover, in various conditions, additional short- and longer-term products or both may be required in the different Member States. Various conditions may also need either more short or longer-term products in the various Member States or a mixture of both of them. DSOs and TSOs shall agree upon how to synchronize this to achieve the proper balance with both availability and market liquidity.

In this study, the pre-qualification for a product is specified as the verification of the unit if it can produce the product that it needs to sell/deliver. TSOs and DSOs presume that the system operator who needs this product and will eventually be the buyer is the one who is conducting the pre-qualification. If TSOs and DSOs are customers of the same product, the system operators wishing to purchase this product should settle on the product pre-qualification procedure to preclude the pre-qualification from being performed twice, once for the TSO and once for the DSO.

4.1.2 Grid Pre-Qualification

The grid's pre-qualification is defined as a test to see if it can handle the distribution of the product that the unit needs to distribute (both congestion control and balancing products) in accordance with the agreement and relevant pre-qualification process between the various system operators. TSOs and DSOs acknowledge the entity performing this grid pre-qualification is the grid's system operator [86]. The explanation for this is that only this system operator understands the grid’s capabilities and when it is possible and when it is not owing to certain restrictions. There are two options for more flexible pre-qualification of the grid that would allow more market players to gain entry to the appropriate markets. The following are two non-exclusive alternatives:

- Dynamic grid pre-qualification reassesses the probability at regular intervals of increased grid connectivity for resource availability. Timeframes must be well specified, from long-term to near-real-time.
- Pre-qualification of the conditional grid, which grants increased grid access to flexibility services in compliance with requirements explicitly defined in advance. A Grid can be qualified conditionally in cases where the grid failed to meet the qualification fully Still, in the absence of a dynamic reevaluation, the constraint (conditionality) can be overly cautious if grid circumstances change over time.

These two alternatives are introduced and, based on the actual case, the decision can be made. The TSO is usually accountable for balancing the grid. The DSO is not engaged in grid balancing under usual grid operating circumstances. However, distribution customers may already engage in the balancing procedure in certain countries.

4.2 Forecasting Phase

The forecast process takes into consideration grid replenishment preparation (year and months ahead) as well as grid use projections (months, weeks, day-ahead, and intraday). Two important cases to consider in forecasting are maintenance and component failure analysis. The grid needs to be able to continue its normal operation in spite of maintenance or single component failure. As the network planner, the short- and long-term planning of network construction is done by DSO [87]. The DSO's network planning procedure is extremely important. The goal is to make strategic judgments about prospective network demands while taking into consideration the network's growing demand, DERs' widespread penetration, and urban development plans. For meeting up the rising demand for energy, network design entails updating current infrastructure through installing cables, transformers, and substations [69]. If the power grid capacity is inadequate to cope with the anticipated growth in electricity demand or output, or new user trends tend to disrupt regular grid activity, grid reinforcement is implemented.

A flexibility mechanism (implicit and explicit) should be used to resolve congestion as a step to the required grid reinforcing. Flexibility from distributed generators and consumers would help to elevate networks in the most cost-effective manner and to deal with local grid limitations. Network replenishment might be deferred till it is more profitable than the existing processes of DER services. This service may be dealt with in a long-term (network planning) context or with the goal of avoiding/solving security problems very close to real-time.

In various timeframes, forecasting is performed. Usually, the precision of the expected energy flow in a certain region increases when getting closer to real-time operation. Some predictions are made years in advance of long-term planning analysis and several predictions are revised and carried out in actual time. The year-on-year planning process helps DSOs to define potential congestion areas and criteria for flexibility resources for each area, using, for example, scenario-based analysis [88]. In addition, it will predict usable usability features (e.g. location, type of operation, length, etc.) and preparations for network reinforcement requirements. System controllers must have entry to reliable timetables and sufficient locational details for properly predicting congestion control and to make accurate and safe decisions. For identifying possible network interference at various time periods of the day, a network inspection may be conducted. The degree of limitation can be established by pre-set contracts with connection points connected to the grid area [69].

Using weather predictions, baseline items, and historical metering information, the DSO forecasts overload and voltage violations for relevant grid parts up to three days in advance [3]. One of the strategies for signaling congestion in the system is the traffic light principle. The principle is useful while information is shared amongst the service provider and market stakeholders at each stage of the congestion management procedure, including planning, forecasting, demand, then activation. The following is the fundamental protocol [86]:

- No congestion is predicted if the traffic signal is green.
- Congestion is predicted if the traffic signal is yellow. In such conditions, the system operator needs flexibility service provider (FSP) services to return the impacted grid area to its green condition. Such a condition is referred to as the market stage for the provision of flexibility. The system would reach the red state unless the system controller is able to restore the impacted region of the grid to the green condition.
- Red state is a state of emergency. In this condition, the system operator works differently than normal.

If a section of the distribution system is in the red phase then urgent corrective intervention will be done by DSOs in order to restore grid stability because the activation of flexibility requires planning and appropriate signaling (e. g. ensure local voltage stability). DSOs should collaborate and utilize the yellow phase for enabling market holders to submit tenders in the congestion control market to avoid entering into an emergency state. Where a region is likely to be congested, the DSO shall publish the necessity of flexibility in relation to a list of established local sources of flexibility to prevent this. The DSO must define possible areas of congestion in its grid planning phase in order to be able to execute this mission and look within markets for assured long-term stability (e.g. more than one year for 'options'). Increased grid-connected renewables and the use of flexibility by market holders, would make it impossible in the future to forecast the grid state without any expertise of energy markets, flexibility markets, consumer markets, industrial markets [89].

4.3 Market Phase

For the creation of resilient market mechanisms, information flows, market rules, and operational frameworks are crucial. The operation of a market is closely connected to its market infrastructure, which can be defined by the following parameters: market entrants, the form of market, and product distinction [90]. As for market holders or participants, it is possible to classify network operators, flexibility service providers, and BRPs. For secure and efficient grid service, TSO and DSOs are responsible whereas FSPs are heterogeneous: smaller and larger corporations and a plurality of private entities who own photovoltaic devices, for example. Their desires and reasons for flexibility to purchase or sell are distinct [90]. When congestion is expected, the market phase begins. The focus of the business process is on the selection and assessment of market bids which include long and short-term capacity products, and also short-term energy products up to real-time [86].

The result of the market phase is the procurement of flexible items. When assessing and activating bids connected to other grids, consideration must be given to the status of the system and the system needs in the electricity grids surrounding it [86]. In this step, information from the register of flexibility resources could be favorable. The flexibility resources register comprises fundamental information about connection point sites. In the future, the register might be used for connection registration and settle connections for flexibility services amongst market participants. The unit's location offering flexibility services should be shared with system operators in order for them to alleviate local congestion. The benefit to the user of a flexibility resources registration is that it is not only accessible to the system operator with whom it is connected, but also to all network operators who can offer a service. In addition, presenting the system operator with the relevant details is part of the contract for market entry. In order that commercially confidential data may be shared and the possibility of gaming and abuse of market power, the information which systems operators can return to the market participant should be carefully reviewed. In contrast, the fact that the information becomes available for all parties including rivals and the regulator reduces opportunities for manipulation and market power misuse.

The advantage of an owner of a flexibility resource/flexibility service provider is that not only the grid operators to which it is linked but all system operators to whom it can provide a service are visible. The competitiveness would be improved. The flexibility resources register can be used in the market phase to evaluate bids from FSPs. To guarantee economic efficiency, eligible offers are effectively categorized in a merit order list once they have been assessed. System controllers assess the offers to whose grid the flexibility offering unit is linked.

4.4 Activation Phase

The DSO evaluated the deals from multiple aggregators and chose the most suitable one(s). If multiple congestion bids are available to solve particular congestion, the DSO selects the most favorable congestion bid, i.e. a bid that solves the congestion with a minimum cost. The DSO sent its activation requests to the aggregators who shipped them through separate activation networks to their flexibility providers if there was a match between DSO demand and aggregator bids [69]. In doing so, the aggregators offered the necessary flexibility scheme at the lowest expense. The DSO's formulation of demands for flexibility, the bidding process, and the activation process for flexibility was channeled through both the DSO and aggregator networks and the related interfaces [69]. In scheduled reprofiling, activation is not realized but the flex product contains activation as well. So activation signal is not required. In conditional reprofiling, in contrast, activation is not included in the flex product, and if needed, the activation signal is sent by DSO. So, the payment then is reservation and activation.

After the bids for flexibility are enabled, the congestion is tracked. In an already congested environment, system operators must avoid initiating flexibility bids. In order to react to unforeseen incidents which can occur, or theoretically evoke more ideal system results, the assessment of bids may proceed until activation. The DSO checks the situation at the moment of execution to see if the requested capability exists beyond the limits and if it doesn't, orders flexibility based on open offers.

4.5 Settlement Phase

Enabled flexibility measurements can illustrate when the provision is currently provided. If the FSP provides a provision then the degree of flexibility must be determined, and the system controller must be charged the flexibility. In case of undelivered service or the delivered service disagree with the accepted features, liability will be imposed. The provided flexibility is calculated by taking the meter’s reading at the endpoint and compares it with the plan. Both an FSP and a supplier can be working simultaneously on one connection. In this situation, specific national guidelines must be set down to allocate energy to the FSP and the supplier. A baseline must be defined if just one meter is available at the connecting site. Without flexibility calculation, the baseline holds maximum energy. The FSP clusters the difference between the baseline and measurements.

In both markets, the flexibility suppliers sell the difference from the baseline. Services are offered to produce or use more or less energy than initially intended. Usually, it is done at times of 15 minutes or 60 minutes [63]. For this, flexibility suppliers will get dispatch fees (€/kWh) charged due to any divergence as of the initial dispatch of their assets, or availability disbursements (€/kW) given for preserving flexibility access, or a combination of both. The settlement of the quantities and services supplied will commence once all connections' energy volumes have been measured and all energy has been delivered to the relevant market participants. In order to provide the appropriate parties with the right quantities and resources, what BRP and providers are involved in a particular connection should be known [86].

4.6 Example of congestion management processes

There are many projects which are actively working to mitigate congestion in distribution grid. Congestion management process of some of them are described briefly below:

4.6.1 GOPACS

Assume that somewhere in the power grid, congestion is predicted. In order to fix, decreasing the output of electricity or amount of consumption increment of this portion of the grid is examined by grid operators. Then, an invitation for tenders is submitted to business parties via GOPACS. A suitable purchasing order on a forum for the intra-day market of this region is positioned then. However, because of this congestion-solving action, the nationwide power grid’s equilibrium can be preserved. Therefore, the decline in the output of power in the congested zone is paired by a reversal of the bid by a business group out of the congestion zone. GOPACS shall immediately verify that this order does not create any issues anywhere in the power system. If all situation seems to be in the green light zone then grid operator will charge the gap in price among the two orders [59]. In this process, all congestion can be overcome by pairing all orders. GOPACS operates in such a way that is compatible with main European directives on market-based grid congestion control and gives big and small business parties a convenient way to raise income with the versatility they have available and to help overcome congestion circumstances.

4.6.2 PICLO

Piclo is also referred to as a "Piclo match" which trades smart meter data, generator price, and information on customer preferences to meet consumer demands and supply of power for half an hour. This gives registered customers a method of selecting their own generator/provider, who they wish to match. The match includes many aspects such as location, costs, and ownership. The strong algorithms of the platform then match energy with the highest priority generators/producers as much as feasible. Electricity retailers are paying the platform for open-ended licensing and may offer a verifiable supply of renewable sources, which is becoming increasingly useful in competing marketplaces. Open Utilities think that the use of renewable energies would emotionally connect customers, decarbonize the environment, celebrate renewable energy life, and change consumer interaction.

5. COORDINATION SCHEME BETWEEN TSO AND DSO

As both market facilitators and grid operators, TSOs, as well as DSOs, have various roles and obligations in various countries. TSOs and DSOs are accountable for the stable running of their corresponding networks as grid operators, which includes congestion control and voltage control on their grid systems. TSOs including DSOs equally have a critical part to play in presenting information and helping energy market members at respective levels. They serve as impartial market mediators when they provide market participants with multiple services: customer interconnection and grid access; provider swapping, where applicable; adaptive resource activation; public data contact to market investors for example suppliers, integrators, producers, and governmental entities, etc [91]. These activities need to be carried out in a straightforward and non-discriminatory manner, ensuring that neither DSOs nor TSOs is involved as providers of commercial services.

The Energy Roadmap 2050 released by the European Commission sets the emissions reductions of the energy system as the main priority while maintaining energy stability and rising competitiveness [92]. The continuing transformation of energy systems, primarily inspired by these aggressive priorities of the European Union, demands a major integration of distributed renewable energy sources (DRES), while customers are increasingly involved in engaging in the market, either by self-production as well as utilization (prosumers) or through the provision of demand response (DR) services. Current planning and operating procedures are planned for the conventional power system whereby generation is centralized, linked to the transmission grid, and then transmitted to customers in one direction (from high-voltage to low-voltage networks). However, the further adaptation of distributed generation into power systems is shifting the flow direction of power. While this occurs, there is a drastic rise in the complexity of operational and planning activities of power systems, thereby raising the demand for enhanced collaboration amongst TSOs & DSOs. Academics and policymakers are already concerned about TSO-DSO synchronization. For example, when consulting on what will become of the Clean Energy Package, the European Commission declared that "Greater collaboration amongst DSOs & TSOs regarding network design, management concern is indeed of utmost importance and must be promoted significantly" [93]. ACER also emphasizes the significance of convenient communication in "European Energy Regulation: A Bridge to 2025" [94].

5.1 Significance of Coordination

High-quality sharing of data between TSOs and DSOs is required for a variety of purposes. These include the possibility of more optimizing operating as well as planning procedures that are not usually extensively organized between power grid, including ancillary services, congestion control, voltage regulation, grid topology reorganization, system planning, and management, etc. More precisely, it is essential for improving cooperation because of [95]:

- Build an effective, transparent, and centralized flexibility platform where all market players can deliver their flexibility in a competitive, market-based, and equitable manner, increasing their commitment to system protection and minimize total system costs;
- Solve congestions in both transmission and distribution grids through a coordinated active power/network management of distributed generators and demand.

A cooperative policy between TSOs & DSOs for market parties will encourage the inclusion of flexibility sources in all markets and facilitate the convergence of distributed energy supplies (DER) and demand-side response (DSR) by improved control and monitoring. Collaboration would have many benefits from a decision-making perspective because collaboration would lead to improved decision-making and thus lower costs. It would also ease access to all resources within the grid and allow for effective long-term usage of resources. Congestion market and products should be designed in such a way that both TSO and DSO may get maximal benefit from the market.

5.2 Coordination Models

First TSOs and DSOs need to give permission to distributed energy resources flexibility to take part in energy and grid-related markets. This is done to achieve distributed energy resources flexibility for balancing and local congestion management. Three key boundaries are being identified to this involvement [94]. The first barrier refers to the probability of DER flexibility being utilized by an independent aggregator. But an independent aggregation is currently exceptionally restrictive and often banned in certain nations. Restrictions of independent aggregators have a good reason, because they may create high costs for other stakeholders. If independent aggregators are allowed, then at the same time e.g. the balancing cost due to independent aggregators must be fairly taken care. The second barrier applies to possible disputes between Balance Responsible Parties (BRP) and aggregators which may render individual aggregation an unattractive business plan. The third barrier concerns the regulation on gain access to balancing markets and providing balancing services.

After solving the obstacles to DER flexibility in the provision of services for balancing and local congestion control, the next barrier is figuring out how to structure markets and dispatch such that the TSO and DSO can effectively purchase and enable resources without causing congestion. Such specific market designs were referred to as coordination schemes [96, 97, 98]. Market design, operating procedures, and data interchanges are examples of coordination structures. It also includes purchasing, activation of energy and networking system associated services for TSOs and DSOs. The coordinating scheme should be composed of the following [95]:

- DSOs shall carry out a comprehensive validation of TSO's dispatching orders on distributed energy resources linked at the distribution level, to ensure continuity between those dispatching orders and the operating constraints of the distribution grid.
- The procurement of ancillary services from the distribution grid should be transparent, equitable, and neutral. For smaller DSOs, this is especially important for procuring flexibility if they are widely deployed with an unregulated energy player.

The collaboration systems concentrate on defining market design roles for TSOs and DSOs and how they will work underneath each plan. Who monitors the energy and network-associated service marketplace is one of the major problems that the coordinating methods are attempting to solve. Who has the importance to decide details of markets, products, practices, etc.? How the pre-qualification is carried out? And by what method are the remaining resources moved between one SO and another in the scenario of separated markets? The current status of collaboration between TSO and DSO might well be evaluated to begin addressing these issues. In [99], it has been revealed that cooperation between TSOs & DSOs applies primarily to network configuration, shared data channels, or the exchange of metering data. In comparison, in the course of purchasing the flexibility-based services from the delivery grid, there is no cooperation with device operators. Today, in most situations, without the participation of the DSO, the TSO explicitly contracts services linked to the distribution network. Moreover, flexibility-based service providers in local markets that can be purchased are still not a certainty. Five coordination schemes: Centralized Ancillary Services Market Model, Decentralized Shared TSO-DSO Market, Local Ancillary Services Market Model, Integrated Flexibility Market Model, Trade Permission System are discussed in this thesis.

5.2.1 Centralized Ancillary Services Market Model

The TSO manages the ancillary services market for resources connected at both the transmission and distribution levels, according to the cooperation system Centralized Ancillary Services Market Model. Independent local market doesn't exist in this scheme, and the TSO does not take DSO limitations into consideration. To ensure the TSO's activation of distribution grid services does not result in undue limitations (e.g. congestion), a different mechanism (system prequalification) should be enforced to ensure that (DN). From there, until such a pre-qualification framework is introduced, the DSO will not be engaged in the TSO's procurement and activation of Ancillary Services. From the perspective of the SmartNet team, it should be the basis for TSO-DSO collaboration in 2030 [100];

5.2.2 Decentralized Shared TSO-DSO Market

DSO, as well as TSO both, run their flexibility markets, while there are cost functions to distribute flexibility. Coordination may occur at the day-ahead level, as in [101], where the DSO as well as TSO reserve flexibility by Shapley value divisions. Real-time synchronization is more troublesome since the viability of power flows must be assured at all times. The DSOs must then determine a viable space at the interfaces mostly with TSO for energy flows. Before removing the TSO balanced market, the DSO must do it when the DSO is thus agnostic regarding the realization of unknown variables. One approach is for the DSO will provide the market-clearing agent with a "residual supply function" with prices for various energy flow changes at the interface for real power, as has been done in [102]. Linked functions can be formulated from around the point of operation. The accumulated supply function can be expanded by integrating reactive power flow at the application, which is analogous to having a two-dimensional feasibility space for the TSO balanced market with separate flow change prices [103]. An expansion of this is to add the probabilities by stochastic optimization of the underlying feasible injection region [104] Under various realizations of unknown variables, this will cause the injection area to still be possible.

5.2.3 Local Ancillary Services Market Model

The Local AS Business Scheme (Coordination Scheme B-CS B) takes into account the DSO's situation of running a local market. The DSO manages the municipal market so that the services required to address local congestion are first chosen. After that, it also rebalances the system locally to compensate for the additional activations done to resolve congestion, so that the total system imbalance will not be modified by the TSO; The DSO guarantees that the AS sector will compete only in bids that conform with the constraints of DSO grid. In reality, such a framework works in two phases: firstly, DSOs will have access to all available resources to select the best options to resolve network issues that resolve local market; After that, the TSO resolves congestion for all TN-level resources and non-DN-level resources used among DSOs [100].

5.2.4 Integrated Flexibility Market Model

The Integrated Flexibility Market Model supports the implementation of a market that offers flexibility in a shared market for TSO and DSO and Commercial Market Parties (CMPs). An integrated market allows TSO and DSOs to exchange information what they would not exchange if markets are separated, which will reduce uncertainty. Moreover, a high degree of competition among operators may raise consumer prices. Many of these problems are dealt with extensively in [100].

5.2.5 Trade Permission System

The key proposal for collaboration here is to provide a single market that receives bids and proposals from both TSO as well as DSO-related units. Coordination is accomplished by the DSO preventing any exchange that is unfeasible inside its own network, which is achieved by predicting by the DSO. This scheme is called the "centralized ancillary services market" in the scenario of real-time collaboration. In order to take account of the unpredictable existence of unregulated loads and PV generation, the DSO must ex ante measure the power flow in its operation and then restrict the procurement and tendering of versatile loads and generators to the global markets.

The organization schemes described above concentrate primarily on how markets for TSOs as well as DSOs are coordinated. Another critical issue, though, is how to assure that the triggering of the acquired DER flexibility does not create real-time congestion. A "traffic-light system" may be an effective communication mechanism for this purpose

[105]. In many separate works, the traffic light idea was suggested to align the DSO with multiple markets [106-108]. The principle is to predict the system's congestion condition and run markets accordingly. The grid is not expected to be congested in a green state, and thus there is no need for a capacity market due to congestion. Flexible congestion markets are available in the orange state (congestion exists). However, they are yet congestion in real-time which refers to red-state, congestion alleviation precautions are applied. The DSO treating with the supervisory authority on DERs taking part in different markets has the concept which schedules or activates reserves and/or energy and defines various operational conditions as per traffic light colors. Congestion management is the main goal for the DSO, while it balances power as well as congestion management for the TSO [106]. When using flexible resources to act in response to RES uncertainty, it is sensible to assume coordination to occur as near to real-time as feasible when the majority of the unpredictability has been removed because of better short-term forecasts [109]. Most of the electricity is exchanged in the day-to-day market, however, and any degree of coordination will reduce the estimated cost of running the power system early on [107]. This claim can be modified by the fact that the market changes for electricity and balancing power shift closer to real-time.

6. CONCLUSION

Congestion issues have arisen because of the broad deployment of intermittent renewable energy sources (RES) and, more often, distributed generation (DG). To avoid congestion, there are two main options: network reconfiguration or altering the regional patterns of generation and load. Switching operations, which reconfigure the topology of the network such that the flow over a congested part of the network is reduced, are one way for system operators to prevent congestion in the short term. Another option is to postpone or postpone scheduled network component maintenance outages. Long-term network congestion can be alleviated by network expansion (additional lines or transformers) and upgrades (increase in voltage, high-temperature lines or re-conduction, control of line temperature). Aside from network strengthening, DSOs can acquire services from resources to relieve congestion using a market-based technique that is less expensive than grid investment. The use of flexibility markets is seen as a more potent tool for improving the energy sector's efficiency and security.

Markets for flexibility have the capability to enhance the efficiency of today's distribution networks. The flexibility platform's concept is developing as the number of flexible providers (as a consequence of end-user access to energy markets and flexibility) and flexible applicants (i.e. DSOs) grows. Piclo Flex, Enera, GOPACS, and NODES are four flexibility deployment initiatives that we looked into. The degree to which flexibility markets are integrated into other established markets, such as the use of reservation fees, standard products, and TSO-DSO coordination techniques, varies amongst the programs. A summary is given in below table:

Feature	Yes	No
Integration in the existing sequence of electricity market	GOPACS, NODES	Piclo Flex, Enera
Reservation Payment	Piclo Flex	Enera, GOPACS, NODES
Standardized products	Piclo Flex, Enera, GOPACS	NODES
TSO-DSO Cooperation	GOPACS, Enera, NODES	Piclo is soley a DSO platform
DSO-DSO Cooperation	Piclo Flex, GOPACS, Enera, NODES	

It becomes obvious that no definitive market design for a "smart market" exists yet. Most ideas are still in the early phases of testing and are looking into a variety of market design possibilities. The system operator should choose the solution that is best for the entire energy system and its consumers, considering variables such as cost, security, and sustainability. Each option has advantages and downsides; therefore, policy should allow for a variety of models that allow system operators to access and exploit flexibility. Congestion management may be characterized in stages, each including different participants, actions, and information exchange.

A cooperative strategy for market participants between TSOs and DSOs would support the inclusion of flexibility sources in all markets and allow the convergence of distributed energy supply (DER) and demand side response (DSR) through enhanced control and monitoring. Collaboration would offer several benefits in terms of decision-making since it would lead to better decision-making and hence decrease costs. It would also improve access to all grid resources and enable for more effective long-term resource use. Congestion market and products should be structured in such a way that both TSO and DSO profit from the market to the greatest extent possible.

REFERENCES

[1] Bengt Sundén Hydrogen, B”atteries and Fuel Cells”, 2019, Pages 1-13.

[2] Fossil Fuels - Our World in Data. [Online]. Available at: https://ourworldindata.org/fossil-fuels.

[3] World Nuclear Association. [Online]. Available at: https://www.world-nuclear.org/nuclear-essentials/where-does-our-electricity-come-from.aspx.

[4] “The energy debate: Renewable energy cannot replace fossil fuels”. [Online]. Available at: https://developmenteducation.ie/feature/the-energy-debate-renewable-energy-cannot-repl"ace-fossil-fuels/.

[5] “Renewable Energy vs Fossil Fuels: 5 Essential Facts”. [Online]. Available at: https://amigoenergy.com/blog/renewable-energy-vs-fossil-fuels/.

[6] “Benefits of Renewable Energy Use”. [Online]. Available at: https://www.ucsusa.org/resources/benefits-renewable-energy-use.

[7] “Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design”; Cherrelle Eid, Paul Codani, Yannick Perez, Javier Reneses, Rudi Hakvoort.

[8] M. Ángeles Moreno ; Julio Usaola, “Technical constraints and flexibility management in smart grids”, 2015 12th International Conference on the European Energy Market (EEM).

[9] Nurul Idayu Yusoff ; Abdullah Asuhaimi Mohd Zin ; Azhar Bin Khairuddin, “Congestion management in power system: A review”, 2017 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET).

[10] Mehdi Attar, “DISTRIBUTION SYSTEM CONGESTION MANAGEMENT THROUGH MARKET MECHANISM,” Tampere University, Tampere, 2019.

[11] Ashwani Kumar, S.C. Srivastava , S.N. Singh, “Congestion management in competitive power market: A bibliographical survey”.

[12] D. B. Nguyen, J. M. A. Scherpen and F. Bliek, “Distributed optimalcontrol of smart electricity grids with congestion management,” IEEE Trans. Autom. Sci. Eng., vol. 14, pp. 494-504, Apr. 2017.

[13] A.N.M.M. Haque ; M. T. Rahman ; P.H. Nguyen ; F.W. Bliek, “Smart curtailment for congestion management in LV distribution network”, 2016 IEEE Power and Energy Society General Meeting (PESGM).

[14] Hans de Heer and Willem van den Reek, “Flexibility Platforms”, White paper, USEF publication.

[15] “CENELEC - EN 50160, Voltage characteristics of electricity supplied by public electricity networks”, European Committee for Electrotechnical Standardization, CENELEC Std. Jul. 2010.

[16] Ioannis Bouloumpasis ; David Steen ; Le Anh Tuan, “Congestion Management using Local Flexibility Markets: Recent Development and Challenges”, 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe).

[17] DNV GL (2018), “Data Analytics in The Electricity Sector, Group Technology & Research”, White Paper 2018.

[18] Poudineh, R., and Jamasb, T. (2014), “Distributed generation, storage, demand response and energy efficiency as alternatives to grid capacity enhancement”, Energy Policy, 67, pp. 222–231.

[19] Daniel Engelbrecht ; Adolf Schweer ; Robert Gehrcke ; Edvard Lauen ; Benedikt Deuchert ; Jens Wilczek ; Henning Schuster ; Jens Buechner, “Demonstration of a Market-based Congestion Management using a Flexibility Market in Distribution Networks”, International ETG-Congress 2019; ETG Symposium.

[20] DNV GL (2017), “Flexibility in the power system: A white paper about the need, opportunity and value of flexibility”.

[21] IEA (2018), “Status of Power System Transformation 2018: Advanced Power Plant Flexibility”, International Energy Agency.

[22] “Flexibility: The role of DSOs in tomorrow’s electricity market”, EDSO Position Paper.

[23] CEER, 2018. Flexibility Use at Distribution Level. C18-DS-42-04.

[24] ENTSO-E, CEDEC, EDSO, Eurelectric, GEODE, 2019. TSO-DSO Report: an Integrated Approach to Active System Management. https://doi.org/10.4219/gct-2005-161.

[25] Le Hong Lam, Valentin Ilea, Cristian Bovo, "Impact of the price coupling of regions project on the day-ahead electricity market in Italy".

[26] "Basics of the Power Market." [Online]. Available : https://www.epexspot.com/en/basicspowermarket.

[27] "Electricity Market." [Online]. Available : https://www.smard.de/page/en/wiki-article/5884/5840

[28] Nordpool, "Day ahead market," 2020. [Online]. Available: https://www.nordpoolgroup.com/the-power-market/Day-ahead-market/.

[29] "THE NORDIC POWER MARKET - NordPool SPOT MARKET." [Online]. Available : https://www.wind-energy-the-facts.org/power-markets.html.

[30] Endre Bjørndal, Mette Bjørndal, Victoria Gribkovskaia, "Simulation of Congestion Management and Security Constraints in the Nordic Electricity Market'.

[31] Anna Christin Meiβner, Alexander Dreher, Kaspar Knorr, Mike Vogt, Hojat Zarif, Lucas Jürgens, Martin Grasenack, "A co-simulation of flexibility market based congestion management in Northern Germany".

[32] M. Bjørndal and K. Jörnsten. (2007), "Benefits from coordinating congestion management – the Nordic power market", Energy Policy, 35, pp. 1978-1991.

[33] T. Kristiansen, (2004), "Congestion management, transmission pricing and area price hedging in the Nordic region", Electrical Power and Energy Systems, 26, pp.685-695.

[34] "EUPHEMIA." [Online]. Available: https://www.n-side.com/pcr-euphemia-algorithm-european-power-exchanges-price-coupling-electricity-market/.

[35] M. Weibelzahl, "Nodal, zonal, or uniform electricity pricing: how to deal with network congestion," Front. Energy, vol. 11, no. 2, pp. 210–232, 2017.

[36] "Intraday Trading." [online]. Available: https://www.next-kraftwerke.com/knowledge/intraday-trading.

[37] Huang, Shaojun, Wu, Qiuwei; Nielsen, Arne Hejde, "Congestion management of electric distribution networks through market based methods".

[38] Nordpool, "Intraday market," 2020. [Online]. Available: https://www.nordpoolgroup.com/the-power-market/Intraday-market/.

[39] Nord Pool (2013) System Price. Available: http://www.nordpool.com/How-does-it-work/Day-ahead-market-El-/Price-calculation/

[40] Wang, Qi;, Zhang, Chunyu, Ding, Yi, "Congestion Management Strategies of Real-Time Market".

[41] "Balancing Markets". Available: http://pierrepinson.com/31761/Literature/reninmarkets-chap4.pdf.

[42] Fingrid, "Reserves and balancing power". [Online]. Available: https://www.fingrid.fi/en/electricity-market/reserves_and_balancing/.

[43] "Nordic Balancing Philosophy", entsoe Position Paper.

[44] "ENTSO-E: Network Code on Operational Security". Available: https://www.entsoe.eu/fileadmin/user_upload/_library/resources/OS_NC/130227-AS-NC_OS_final_.pdf – 30/05/2019

[45] FCR in the Netherlands - https://www.regelleistung.net/ext/static/prlnl – 03/05/2019

[46] ENTSO-E WGAS: Survey on ancillary services procurement, balancing market design 2017 – 04/05/2019

[47] "D2.2 Existing tools and services report", INTERRFACE. Available: http://www.interrface.eu/sites/default/files/publications/INTERRFACE-D2.2_v1.0.pdf

[48] Fingrid, "Reserve products and reserve market places," 2018.

[49] Dr. Jens Büchner, René Beune, Dr. Jan von Appen, "Real time flexibility markets development of fingrid's vision on the design of a finnish flexibility market; exploring the full value of flexibilities".

[50] European Commission. Proposal for a Directive of the European Parliament and of the Council on Common Rules for the Internal Market in Electricity (Recast); Technical Report; European Commission: Brussels, Belgium, 2016.

[51] Villar, J., R. Bessa, and M. Matos (2018), "Flexibility products and markets: Literature review", Electric Power Systems Research 154, 329–340.

[52] Apel, R., V. Berg, K. Geschermann, W. Glausinger, A. von Scheven, M. St¨otzer, and S. Wanzek (2014), "Regional Flexibility Markets: Market-based use of regional flexibility options as building blocks for the successful integration of renewable energies into distribution grids", published by Power Engineering Society of the VDE.

[53] “How flexibility markets can drive the energy transition.” [Online]. Available: https://www.engerati.com/energy-retail/how-flexibility-markets-can-drive-the-energy-transition/.

[54] ENTSO-E, 2018a, “Mapping of TSO-DSO projects”, Act. Syst. Manag. Distrib. (2018), Flexibilities value TSO-DSO Coop.

[55] Hans de Heer and Willem van den Reek, “Flexibility Platforms”, White paper, USEF publication.

[56] Tim Schittekatte, LeonardoMeeus, “Flexibility markets: Q&A with project pioneers”.

[57] GOPACS [Online]. Available at: https://en.gopacs.eu/about-gopacs/.

[58] Zheng Xu, Sciences Po, “The electricity market design for decentralized flexibility sources”.

[59] “SmartEn Position Paper Design Principles for (Local) Markets for Electricity System Services”. Available at: https://www.smarten.eu/wp-content/uploads/2019/09/20190903-smartEn-Flexibility-Markets-Position-Paper-Final.pdf.

[60] Piclo (2019) [online] Available at: https://piclo.energy/.

[61] Ofgem. (2017), “Unlocking the capacity of the electricity networks: overview”.

[62] Ofgem. (2019), “Position paper on Distribution System Operation: our approach and regulatory priorities”.

[63] Radecke, Julia; Hefele, Joseph; Hirth, Lion, “Markets for Local Flexibility in Distribution Networks”.

[64] Piclo, 2019a. Piclo Blog [WWW Document]. Available at: https://blog.piclo.energy/.

[65] NODES, 2018, “A Fully Integrated Market Place for Flexibility”. (White paper)

[66] GOPACS, 2019. IDCONS Productspecificaties. Version 1.0-Initial version

[67] David Steen, Joel Goop, Lisa Göransson, Shemsedin Nursbo, Magnus Brolin, “CHALLENGES OF INTEGRATING SOLAR AND WIND INTO THE ELECTRICITY GRID”.

[68] Shaojun Huang, Qiuwei Wu, Zhaoxi Liu, Arne Hejde Nielsen, “Review of Congestion Management Methods for Distribution Networks with High Penetration of Distributed Energy Resources”.

[69] A. N. M. M. Haque, P. H. Nguyen, W. L. Kling, and F. W. Bliek, “Congestion management in smart distribution network,” in 2014 49th International Universities Power Engineering Conference (UPEC), 2014, pp. 1–6.

[70] EURELECTRIC, Power Statistics & Trends 2013.

[71] HANNU REPONEN, “Coordinated voltage control in real time simulations of distribution network with distributed energy resources”, Tampere University, Tampere, 2016.

[72] EN 50160:2010, “Voltage characteristics of electricity supplied by public electricity networks,” July2010.

[73] Hirth, Lion; Glismann, Samuel, “Congestion Management: From Physics to Regulatory Instruments”. Available at: http://hdl.handle.net/10419/189641

[74] Stavros Karagiannopoulos, Petros Aristidou, Andreas Ulbig, Stephan Koch, Gabriela Hug, “Optimal planning of distribution grids considering active power curtailment and reactive power control”.

[75] K. Lemkens, F. Geth, P. Vingerhoets and G. Deconinck, “Reducing Overvoltage Problems with Active Power Curtailment –Simulation Results”.

[76] D. S.-M. Luke Schwartfeger, “Review of Distributed Generation Interconnection Standards,” in 2015 EEA Conference & Exhibition, 2015.

[77] F. A. Viawan and D. Karlsson, “Voltage and reactive power control in systems with synchronous machine-based distributed generation,” IEEE Trans. Power Deliv., vol. 23, no. 2, pp. 1079–1087, Apr. 2008.

[78] “Congestion Management in Distribution Networks”. Available at: http://www.tut.fi/eee/ide4l/ide4l-wp5---d5.2-3---v1.0---figure-3.1.3-corrected-1.pdf

[79] T. Xu, P. C. Taylor, "Voltage control techniques for electrical distribution networks including distributed generation, " in Proc. of the 17th World Congress, IFAC, Seoul, Korea, July, 2008.

[80] F. Bignucolo, R. Caldon, V. Prandoni, "Radial MV networks voltage regulation with distribution management system coordinated controller," Electric Power Systems Research, 78, pp634-645, 2008.

[81] A.G. Madureira, J.A.P. Lopes, “Coordinated voltage support in distribution networks with distributed generation and microgrids,” IET Renewable Power Generation, Vol. 3, Iss. 4, pp. 439–454, 2009.

[82] “Analysis of Grid Management Technologies for the distribution grid”. Available at: https://ec.europa.eu/research/participants/documents/downloadPublic?documentIds=080166e5b6638b24&appId=PPGMS

[83] C. M. Hird, H. Leite, N. Jenkins and H. Li, "Network voltage controller for distributed generation," IEE Proc. , Gener. Transm. Distrib., vol. 151, pp. 150-156, Mar. 2004.

[84] Kulmala, A.;Mäki, K.;Repo, S.;& Järventausta, p. (2007 IEEE Lausanne). “Active Voltage Level Management of Distribution Networks with Distributed Generation Using On Load Tap Changing Transformers”. Power Tech, 455-460.

[85] Anna Kulmala. “Active voltage control in distribution networks including distributed energy resources”, PhD Dissertation, Tampere University of Technology, http://URN.fi/URN:ISBN:978-952-15-3284-9.

[86] TSO – DSO REPORT, “AN INTEGRATED APPROACH TO ACTIVE SYSTEM MANAGEMENT”.

[87] S. Sarabi, A. Davigny, V. Courtecuisse, L. Coutard, and B. Robyns, “Distribution grid planning enhancement using profiling estimation technic,” 2016, pp. 82 (4 .)-82 (4 .).

[88] C. Zhang, Y. Ding, N. C. Nordentoft, P. Pinson and J. Østergaard, “FLECH: A Danish market solution for DSO congestion management through DER flexibility services, ”in Journal of Modern Power Systems and Clean Energy, vol. 2, n. 12, pp. 126–133, Jun. 2014.

[89] USEF DSO Workstream final report: An introduction to EU market-based congestion management models.

[90] Antony Zegers, Thomas Natiesta, “Single Marketplace for Flexibility”.

[91] “General guidelines for reinforcing the cooperation between TSOs and DSOs”. Available at:https://eepublicdownloads.entsoe.eu/cleandocuments/Publications/Position%20papers%20and%20reports/entsoe_pp_TSO-DSO_web.pdf

[92] E. Commission, “Energy Roadmap 2050”, Luxembourg: Publications Office of the EuropeanUnion,2012.URL:https://ec.europa.eu/energy/sites/ener/files/documents/2012_energy_roadmap_2050_en_0.pdf

[93] Launching the public consultation process on a new energy market design. Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2015%3A340%3AFIN

[94] Leandro Lind, Rafael Cossent, José Pablo Chaves-Avila, Tomás Gómez San Román, “Transmission and distribution coordination in power systems with high shares of distributed energy resources providing balancing and congestion management services”.

[95] WindEurope views on the TSO-DSO coordination Enabling flexibility from distributed wind power. Availbale at: https://windeurope.org/wp-content/uploads/files/policy/position-papers/WindEurope-views-on-TSO-DSO-coordination.pdf

[96] Basic schemes for TSO-DSO coordination and ancillary services provision. SmartNet Project Report. Retrieved from http://smartnet-project.eu/wp-content/uploads/2016/12/D1.3_20161202_V1.0.pdf

[97] SmartNet: A H2020 project analysing TSO-DSO interactions to enable ancillary services provision from distribution networks. 24th International Conference on Electricity Distribution, 2017 (June), 1998–2002. https://doi.org/10.1049/oap-cired.2017.0104

[98] Papavasiliou, A., & Mezghani, I. (2018). Coordination schemes for the integration of transmission and distribution system operations. 2018 Power Systems Computation Conference (PSCC). Dublin, Ireland, 11–15 June 2018: IEEE. https://doi.org/10.23919/PSCC.2018.8443022

[99] Helena Gerard, Enrique Israel Rivero Puente, Daan Six, “Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework”.

[100] D. Siface, G. Migliavacca, M. Rossi (RSE), I. Kockar (Strathclyde Univ.), A. Morch (Sintef), H. Gerard (VITO), Y. Vardanyan (DTU), P. Koponen (VTT), “Policy recommendations to implement and/or overcome barriers and enable TSO-ISO integration”.

[101] A. Vicente Pastor, J. Nieto Martin, D. W. Bunn, and A. Laur, “Evaluation of flexibility markets for Retailer-DSO-TSO coordination,” IEEE Transactions on Power Systems, 2018.

[102] Z. Yuan and M. R. Hesamzadeh, “Hierarchical coordination of TSO-DSO economic dispatch considering large-scale integration of distributed energy resources,” Applied Energy, volume 195, pages 600–615, 2017.

[103] J. P. Silva, J. A. Sumaili, R. J. Bessa, L. Seca, M. A. Matos, V. Miranda, M. Caujolle, B. Goncer-Maraver, and M. Sebastian-Viana, “Estimating the active and reactive power flexibility area at the TSO-DSO interface,” IEEE Transactions on Power Systems, volume 33, number 5, pages 4741–4750, 2018.

[104] D. M. Gonzalez, J. Hachenberger, J. Hinker, F. Rewald, C. Rehtanz, and J. Myrzik, “Determination of the time-dependent flexibility of active distribution networks to control their TSO-DSO interconnection power flow,” in 20th Power Systems Computation Conference (PSCC), IEEE, 2018.

[105] Hadush, S. Y., & Meeus, L. (2018), “DSO-TSO cooperation issues and solutions for distribution grid congestion management. Energy Policy, 120, 610–621”. https://doi.org/10.1016/j.enpol.2018.05.065

[106] J. Villar, R. Bessa, and M. Matos, “Flexibility products and markets: Literature review,” Electric Power Systems Research, volume 154, pages 329–340, 2018.

[107] S. Y. Hadush and L. Meeus, “DSO-TSO cooperation issues and solutions for distribution grid congestion management,” Energy Policy, volume 120, pages 610–621, 2018.

[108] D. Consortium, DREM project website, 2019. [Online]. Available: https://drem.dk/

[109] N. O’Connell, H. Madsen, P. Pinson, M. O’Malley, and T. Green, “Regulating power from supermarket refrigeration,” in Innovative Smart Grid Technologies Conference (ISGT), IEEE, 2015.