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EVALUATION OF FOUR EUROPEAN LOCAL FLEXIBILITY MARKET OPERATORS WITH THE AIM OF REDUCING GRID INVESTMENT THROUGH REINFORCEMENTS

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ABSTRACT

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Over the years, more distributed generation based on renewable energy sources are added to the distribution networks, therefore, active distribution network management is necessary to address local network congestion and voltage issues. Congestion control is one of the most hopeful approaches to resolving network issues among the diverse options. Traditionally, the transmission grid has been the level at which congestion management systems have been managed. However, the control method would have to be extended to the distribution network as well due to the widespread use of Distributed Generators (DGs) and the predicted harsh loading situations. Recently, scholars and others working in the electric grid industry have been more interested in strategies for reducing congestion in distribution networks and non-market-based approaches have been proposed. However, it might not be the best and most economical choice depending on the use case scenario.

This paper presents an evaluation of four local flexibility market operators with the aim of reducing investment on the grid through network reinforcement. While network reinforcement is expensive, it is often the first option used by DSOs to address congestion issues since DSOs have done it repeatedly and are technically capable of doing so. In addition, reinforcement is a trustworthy solution. To address these problems based on the market, local flexibility markets are being developed. Flexibility markets are an effective strategy for maximizing the efficiency of the current distribution grids. Piclo Flex, Enera, GOPACS, and NODES are four innovative initiatives that incorporate flexibility markets that we evaluated in this thesis. There are differences amongst the projects in terms of the degree to which the flexibility markets are integrated into other existing markets, the quality of flexible service, the third-party market operators, the use of standardized commodities, and grid rules that require TSO-DSO/DSO-DSO coordination. Because each project has a unique vision, set of use cases, or level of project maturity, the answers to these questions vary. Our case study examination of the four ground-breaking projects will help the reader to understand the local flexibility markets and identify the most promising flexibility market operator to use when we are trying to postpone or defer network reinforcement which in turn reduces the investment on the grid.

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

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

PREFACE

My journey to Finland was a dream come true for me and I still remember the excitement when I got admitted to this great institution (Tampere University). Since coming to Finland, it's been a whole lot of experiences and now is the time to move on to the next chapter of my life.

I would like to acknowledge and give my warmest thanks to my supervisor (Prof. Sami Repo) who made this work possible. His guidance and advice carried me through all the stages of writing my project. I would also like to thank my colleagues and friends for their input and support throughout my study period.

I would also give special thanks to my mum (Lady Grace Nwolisa) and my family as a whole for their continuous support and understanding throughout my writing period. Your prayers for me is what sustained me this far.

Finally, I thank God for seeing me through my study period. I have experienced your guidance day by day and your miracles are too numerous to count. You are the one who brought me this far and I will keep on trusting you with my future.

Tampere, 26 November 2022

Chinedu Nwolisa

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LIST OF SYMBOLS AND ABBREVIATIONS

AND	Active Distribution Network
LFM	Local Flexibility Market
LFMO	Local Flexibility Market Operator
DER	Distributed Energy Resources
DSO	Distribution System Operator
TSO	Transmission System Operator
DG	Distributed Generation
EU	European Union
CEER	Council of European Energy Regulators
ENTSO-E	European Network of Transmission System Operators for Electricity
DA	Day-Ahead Market
ID	Intra Day Market
LEC	Local Energy Community
GL	Grid Location
FCR	Frequency Containment Reserve
aFRR	Automatic Frequency Restore Reserve
mFRR	Manual Frequency Restore Reserve
MCP	Market Clearing Price
LEC	Local Energy Market
ETPA	Energy Trading Platform Amsterdam
EPEX	European Power Exchange
FACTS	Flexible AC Transmission System
CM	Congestion Management
APC	Active Power Curtailment
CVC	Coordinated Voltage Control
OLTC	On-Load Tap Changer
FSP	Flexibility Service Provider
SO	System Operator
VC	Voltage Control

1. INTRODUCTION

Electricity networks are experiencing a transition over the years which has brought about new features into the energy business. On the production side, wind and solar energy are quickly becoming a cornerstone of power generation. Two distinct high-growing sectors are evident when examining average growth rates: wind power, with a cumulative average growth rate of 40%, and solar power, with a cumulative average growth rate of 31%, over the period between 2010 and 2019. In order to meet the 2030 climate objectives, the development of wind and solar power facilities is now experiencing a boom in Finland. The media has paid a lot of attention to green hydrogen in addition to these two quickly expanding industries [1]. On the side of demand, electrification is beginning to gain traction: electric transportation and electric heating will dramatically increase household energy usage and alter its pattern soon and much bigger change is expected to happen in industry via hydrogen economy.

Similarly, distribution networks will face substantial hurdles because of the distributed energy resources which are connected to the distribution grids. Grid congestion is currently far more prevalent in European transmission and distribution networks than it was before, and distributed resources will certainly increase this development and necessitate extensive network upgrades [2]. The growing incorporation of distributed energy resources (DERs) in distribution networks has resulted in the necessity for the energy transition. Increased local power generation provides several benefits, including cheaper operating costs, decreased transmission losses, and a less environmental imprint because it is renewable. It is, however, linked to a rise in distribution network operating issues [3]. Distributed resources, on the contrary, present an opportunity because they suggest an immense potential source of flexibility: batteries can be charged and discharged to reduce power system stress, electric heating can be converted to flexible consumption by adding heat storage, and consumption can be shifted by smart appliances. Distributed resources can therefore be utilized to reduce grid congestion and postpone the need for grid investment if they are dispatched appropriately. The optimal synchronization of distributed flexibility to support network operation is a crucial part of the smart grid goal [2].

It is evident that depending exclusively on infrastructure investments as regard the grid to meet the rising power demand and linking decentralized generation to the distribution system would be cost intensive. In cases where the existing grid still have remaining lifetime, i.e., replacement investments would lead to economic losses in some cases. Economic losses are not always extremely high. For example, a replaced transformer might be reused elsewhere. Therefore, the extra cost is only the cost of replacement. Also, increasing a cable capacity may be realized by adding a second cable circuit next to existing one and this is less expensive. Most of the time congestion occurs during very few hours of a year. For example, the congestion requires that grid has a maintenance (one component out of service) and at the same time minimum loading and maximum generation situation appears. The probability of this condition might be very low and therefore make the investment “unnecessary” if flexibility dispatching might be used. In addition, during grid expansions in urban areas, especially underground cabling, it might take many years before the grid company will get authorization from the city authorities to be able to dig the ground because the cables are usually under the roads. Similarly, overhead lines need to pass environment evaluation, which might take several years. Therefore, grid expansion is very slow compared to the speed of DG and other DER expansion.

Congestion in the electrical power network happens when the power flowing through the network is beyond the network's transfer capacity. In general, congestion might be due to Voltage quality, Current capacity (ampacity), Stability (rotor angle, voltage, frequency, oscillations, etc.). Although stability is hardly ever an issue for DSO, it is the primary reason in many TSO grids. DSOs are currently primarily using grid reinforcement to manage predicted and unexpected congestion in distribution networks. Flexible connections are also used in large wind farms and district heating electric boilers (Caruna and Fortum case in Espoo for 100 MW boiler). Traditionally, the DSOs will try to expand the capacity of the existing electrical network when congestion or voltage issues are forecasted in each location. To do this, the capacity of the affected equipment is increased to take care of the forecasted situation. This comes at an extra cost for the DSO in terms of network reinforcement [2].

1.1 Objectives and Research Questions

The objective of this thesis is to compare the different Local Flexibility Market (LFM) operators that play in the European Electricity Market (Nord Pool, Epexspot, Henex, etc.). To compare the concepts of the LFMs when considering a particular use case stated in this thesis. In this thesis, the use case considered was reducing the investment in the electricity grid through reinforcements because of congestion. The technical requirements (analysis of needs and requirements for flexibility) were also stated in this thesis.

This thesis aims to give some answers to the following research questions: Is the flexibility market in line with the local DSOs requirements. Secondly, how the DSOs are utilizing these local flexibility markets? Thirdly, what stakeholders are important in the flexibility market.

1.2 Scope

The scope of this work focuses on the qualitative comparison of the concept of four different local flexibility market operators (Picloflex, Nodes, Enera, and Gopacs) in the European electricity market when it comes to reducing the investment in the electricity grid through reinforcements because of congestion. Also, there is a need to have a knowledge of how flexibility service providers are operating in the market.

1.3 Tasks

To answer the research questions which were stated above and fulfill the thesis objectives, some tasks need to be accomplished and they include:

· Overview of the electricity system with a focus on congestion and the need for LFM.

· Understanding the Local Flexibility Market in general. The relationship between LFM and other markets (day-ahead and intra-day markets).

· The role of DSOs in the electricity market and how the flexibility market meets the local DSO requirements.

· Stating the use case considered in this thesis which is to reduce grid investment through reinforcements.

· Analyzing four pioneering local flexibility markets to determine the more effective approach considering the use case.

· Proposing the local flexibility model that best suits our use case and the reason it was selected.

1.4 Structure of the Thesis

The overview of the electricity system with a focus on congestion and the need for LFM is explained in chapter 2. Also, the electricity market concept is briefly explained, including the day-ahead market, intraday market, balancing, and reserve markets. Chapter 3 talks about the local flexibility market, analysis of needs and requirements for flexibility, market participants, market timelines in LFM and introduction to local flexibility market operators (Picloflex, Nodes, Enera and Gopacs) in the European electricity market. The comparisons of the concept of the local flexibility market operators discussed in this thesis were handled in chapter 4, whereas the results of comparison, the proposed LFM selected considering our use case as well as discussions were handled in chapter 5.

2. CONGESTION IN THE ELECTRICAL SYSTEM

The term "network congestion" refers to a scenario in which the demand for active electricity exceeds the grid's capacity to deliver it [4]. Congestion has traditionally been addressed at the transmission level but increased renewable generation, electric vehicle charging and electrification of heating and cooling in distribution networks is likely to be a problem for DSOs, resulting in bidirectional and unpredictable power flows [6]. As a result, numerous research efforts have focused on the control of congestion on the distribution level [3]-[6].

The major function of the electricity network is to deliver electricity from the generating stations to the consumers. The power system network is designed in such a way that the generation units are connected to a transmission grid that operates at a high voltage with a minimal power loss. High voltages, on the other hand, are unfeasible and unsafe to use near consumers, thus the voltage is reduced and delivered to customers through a distribution grid [6]. Distribution networks, and how they are managed, will need to become more active and adaptable as electricity flows grow more sporadic and unpredictable. To offer more flexibility at a process, technology, and business model level, service providers must consider assets, behavior, and software-led solutions. Congestion in distribution networks can be due to increasing integration of distributed energy resources, power lines failure, generator failure or even uncoordinated operation of flexible loads. As a result, congestion control strategies are required [7].

The distribution network's goal is to offer high-efficiency active power Pd (as shown in Fig.2) to its customers when required. Customers are free to use as much reactive power as they like as long as they stay within the approved limit. When feeding both active and reactive power through a feeder, voltage dips might occur. Similarly, active power may be detrimental when it comes to acquiring renewable energy production, which can lead to over-voltage concerns. The feeder consumes or creates reactive power on its own and this has an effect on voltages and currents. In some cases, if the power flow exceeds the thermal limits of the power components, overloading problems might occur. The lifespan of the transformers and other power components connected to the power system can be limited due to overloading problems.

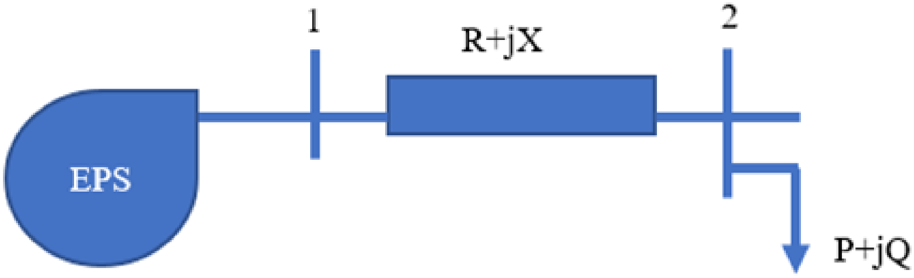

Figure 1. Illustration of a simple distribution grid [8].

In principle, the integration of DG into the electricity network should help to solve the problem associated with supply security, energy efficiency, congestion reduction, long-distance transmission demand reduction, and network investment deferral. The DG is not always connected close to the load and controlling DG output is not always achievable when even when the DSO wants to do so except in the flexible connection type of contract. However, DG output does not always match the local requirement and as such, the incorporation of DGs into the distribution system poses a capacity challenge due to the output profiles, location, and inflexibility of DGs [9]. The operation of the distribution network can be affected by the dynamic characteristics of DG units which could be as a result of uncontrolled operation of flexible loads (e.g heat pumps and EVs) in the system. The grid code technical requirements are always followed during the connection of a new DG unit first time to power system so that power injection into the distribution grid is managed to maintain the system’s stability and reliability [10].

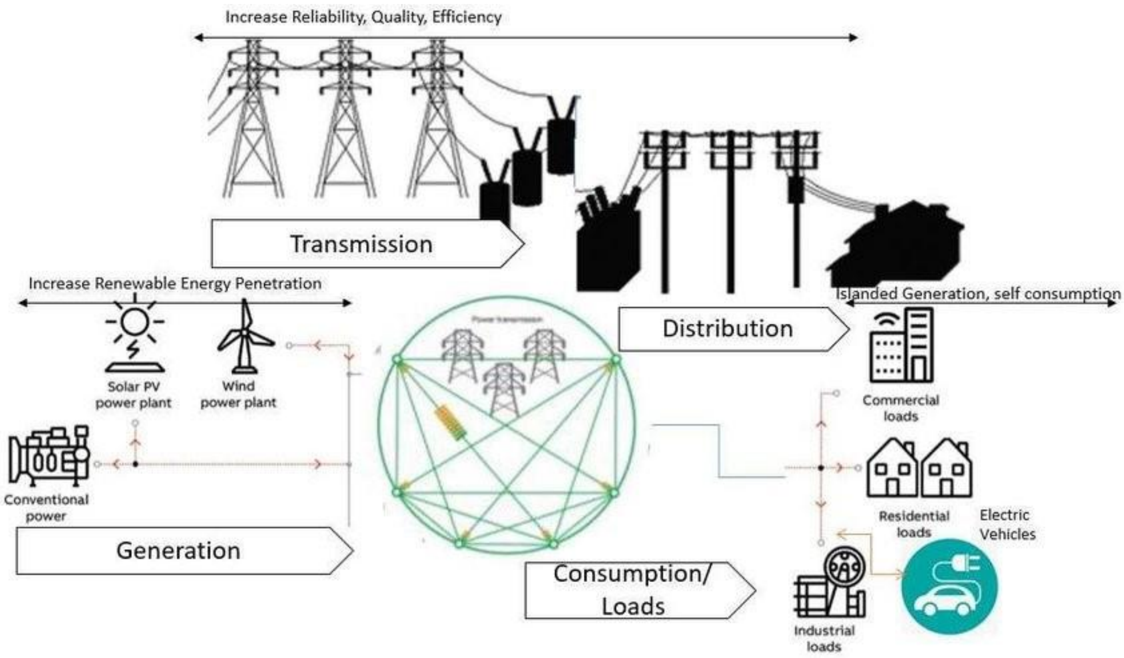

Figure 2. Electricity supply chain with integration of DERs [11]

2.1 Causes of Congestion in the Distribution System

Congestion in the electricity system can be caused by a variety of factors, according to technical literature. Congestion develops in a competitive market when distribution networks cannot handle all intended power flows owing to the network's operational limitations breaches. Congestion occurs when the thermal boundaries and line capacity are exceeded on distribution lines [12]. Congestion develops when power flows in the transmission or distribution lines exceed the flow permitted by operating reliability limitations. [13].

In addition, one of the reasons and events that induce congestion on distribution lines is the distribution network’s physical and system limits [14]. Physical constraints, such as the temperature limit of a distribution line or a transformer, can encourage congestion. Voltage constraint in a node, dynamic stability, transient stability, reliability, and similar scenarios are examples of distribution system limits that can lead to network congestion.

Furthermore, if there are not enough matching generating and transmission services, congestion ensues even on distribution networks. Unanticipated events such as equipment failure, unexpected escalation of load demand, and power outages are the primary reasons for congestion [15]. To guarantee network security and avoid repeated power failure, there is a need for congestion in the electrical grid to be resolved as soon as possible.

Power systems congestion causes system disruptions, which can lead to more power failures in an interconnected system. Congestion can also be induced by severe damage to network components because of repeated network disruptions. Congestion affects not just the equipment, but also the voltage quality [16]. Voltage quality is something which will impact on customers. Therefore, standards like EN 50160 define what kind of quality is expected to have in customer connection points. Congestion happens if DSO is unable to maintain good enough quality. Congestion management systems must operate rapidly to improve power quality and to prevent damage to power system equipment.

In order to ensure the security of the power system and the reliability of the transmission networks, congestion management has been highlighted as one of the major solutions. Congestion management fixes the financial issues brought on by congestion and returns the system to balance. Inattention to distribution grid congestion jeopardizes security of supply and might result in total system blackouts with significant social and economic implications both to the DSO and the customers.

2.2 Congestion Management Techniques

As shown in Fig. 2, technical and non-technical approaches are used to present the diverse ways of congestion management in the distribution network. Technical solutions such as the use of FACTS devices in the distribution grid to solve congestion related issues is very expensive for the DSO as much investment is needed. They also account for interruptions in congested network which have some economic impacts on the DSO and on the customer. The direct impact on DSO is the reduced allowed profit, because of reduced supply security. Indirect impacts are more related to customer costs, which might be extremely high. For example, when hospitals, industry, shops, elderly people taken care at home, etc. are buying backup generators or UPSs to prevent the consequences of interruptions, someone is paying these as well. Similarly, loss of lives, loss of production, etc. are also cost for individual, company or society which is as a result of distribution network congestion. The use of transformer taps and the use of FACTS devices, or phase shifters are some of the examples of technical solutions used in congestion management for both transmission and distribution grids. Security-constrained generation dispatches, congestion pricing, market-based methods, and network security factors solutions, are all examples of nontechnical or non-cost-free solutions. Distributed Generation (DG), load shedding, Generators Rescheduling (GR), nodal pricing systems and Demand Response (DR), are some of the most prominent approaches [17]. But considering congestion management from the DSO point of view, distributed generations can be used to take care of congestion in the distribution network by controlling the active power of DERs (EVs, battery storage, DGs, flexible loads) integrated at the distribution level, thereby increasing availability of active resources to improve the network reliability. Also, demand response has the potential to trigger congestion, but flexible loads also have the potential to alleviate it if an aggregator chooses to reduce consumption during times of high peak load on the local grid. In the same way, one of the short-term options used by DSOs to relieve grid overload-related congestion is load shedding. When there is a chance of a blackout or damage to network assets, load shedding can be an alternative. However, load shedding for specific customers should be based on a unique contract between the DSO and the customer that permits a DSO to shed the loads for certain hours.

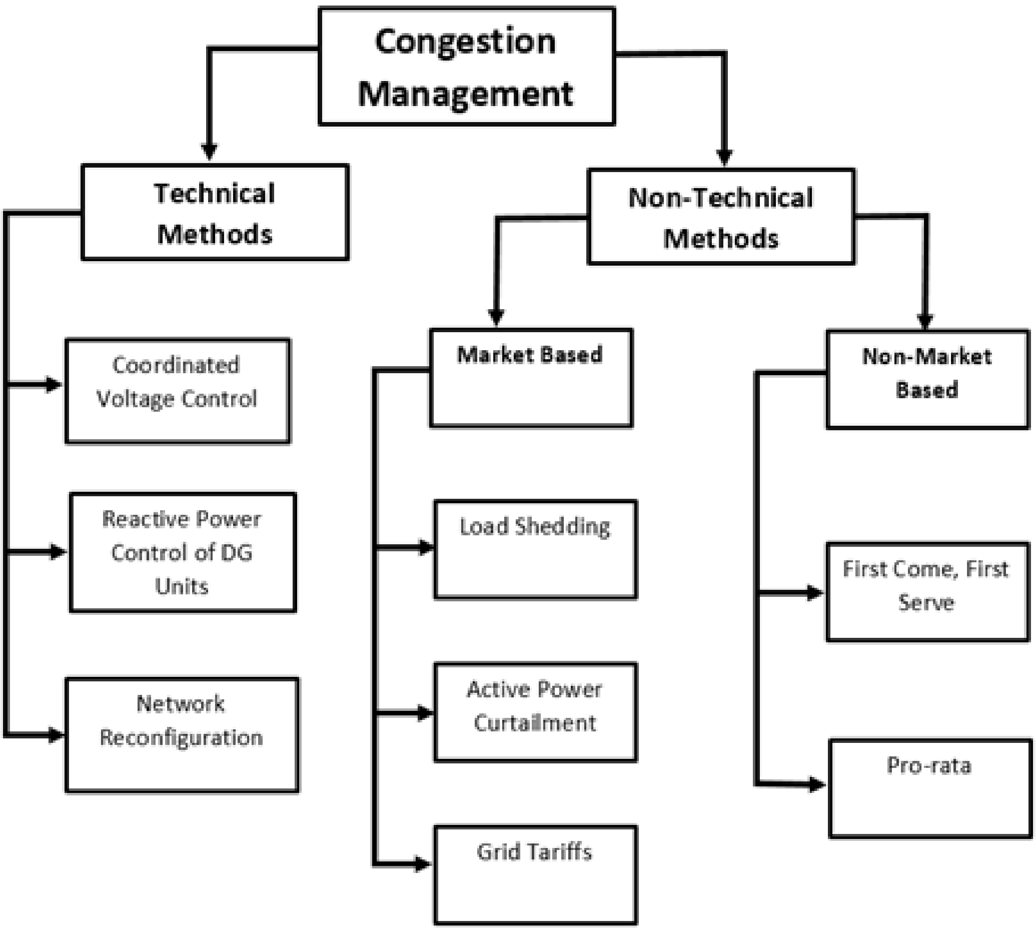

Fig 3. Summary of congestion management methods on the distribution networks

Some of the techniques frequently used by DSOs for congestion management in the distribution are:

I. Active power curtailment
II. Network reinforcement
III. Voltage control
IV. Reactive power control of DG units
V. Load shedding
VI. Network reconfiguration
VII. Grid tariff

2.2.1 Active Power Curtailment (APC)

This is one of the ways to manage congestion in the electricity network by limiting the active power of generators working in a distribution network [18]. However, while this strategy relieves congestion quickly, it is rarely financially sustainable eventually because of the excessive cost of compensation payments for feed-in curtailment.
Increased growth of Distributed Energy Resources (DER) may cause grid congestion, requiring power lines to run over their nominal current and voltage limits to convey all the generated electricity. This would result in unacceptably high levels of sag in overhead cables and equipment damage to the power system. Active power curtailment (APC) can be used to temporarily reduce some generators' output during peak hours to keep line operating within loading limits [19]. APC incurs considerable expenses owing to the reimbursement of curtailed energy or the requirement to acquire flexibility services, even though maintaining a congestion-free grid is effective. This is because controlled generators need to be part of SCADA/DMS system or other automation system that may manage generator output during the congestion. If we are talking about small-scale DERs, those are very expensive to connect to SCADA compared to DER investment itself. For example, when you ask a customer to pay 5000 € extra cost for his 10000 € PV system so that DSO would be able to control their PV system. There is no way the customer will agree to this because of the cost implication. Therefore, APC is limited in practice to be applied only for large wind and solar farms. LV grid congestion cannot be solved this way. DER unit voltage controller may however automatically limit generator output, if voltage exceeds certain selected value. This is a cost-effective solution for small-scale DERs, but functions only in voltage constrained congestion. Depending on the nation, the expenditures incurred because of APC might be addressed differently.

2.2.2 Network Reinforcement

Grid congestion can be alleviated by strengthening the grid, in addition to APC. To boost the grid's transport capacities, new power lines can be built in support of those that are overloaded. Replacing wires, building additional circuits on the same towers, replacing towers to make them stronger mechanically and have more space for additional circuits are some of the ways the network can be reinforced. We do not consider new right-of-way since they require regulatory permission, which might take a long time. High-Voltage (HV) grids, in general, have a mesh topology and are made up of overhead power lines. If feed-in peaks are rare, this metric is more useful during the building phase [20]. The most common solution to the congestion issue is network reinforcement; nevertheless, it cannot always be employed for two major reasons. It is first of all costly and time-consuming Second, the lengthy planning process raises the level of uncertainty around crucial planning aspects like energy production and consumption, city planning, etc., which makes decision-making more difficult. For example, feed-in tariffs are influencing prosumers to inject electricity into the grid (particularly intermittent renewable energy); at the same time, the advent of new technologies, such as electric vehicles (EVs), makes load forecasting more difficult owing to a shift in consumption patterns. Therefore, reducing the frequency and amount of network reinforcement makes sense. The change in impedance generated by line reinforcement influences the loading of other lines because of the meshed construction. This influence must be considered while planning the MV and LV grids. When planning the reinforcement of a power system, combining the reinforcement and APC can be a way to lower overall costs and produce a more cost-effective result than either step alone. It has been proposed that the grid be reinforced up to a certain point and then APC be used to clear the remaining congestion. Finding the ideal way to integrate APC and reinforcement, however, necessitates a detailed and thorough strategy. To get to such a trade-off point, an efficient method of determining a cost-effective mix of APC and reinforcement is required [21].

2.2.3 Voltage Control (VC)

Voltage fluctuation range and magnitude, which are significant power quality indicators, have a direct impact on the functionality, effectiveness, and lifespan of electrical equipment. The rated voltage under which the effect is optimized is used to design and build electrical devices. The high voltage offset is detrimental to both the user's daily operation and the safe and efficient operation of the power supply. A voltage that is too low can increase network loss and could jeopardize the system's ability to operate steadily. The insulation level of the electrical equipment will be compromised by excessive voltage, and the corona loss generated in the high-voltage network will increase. The power network's voltages are within permissible ranges, but to adjust the voltage, voltage control techniques are needed. [22].

Primary voltage control of OLTCs and DER units in power system substations is very essential. This is because the OLTC is a crucial piece of distribution network when it comes to voltage control. For distribution of significant loads, it is frequently fitted with OLTC. When the network is loaded, the transformer equipped with OLTC can change the ratio to adjust the node voltage and enhance power quality while also adjusting the load flow of the power system, lowering the cost of the reactive power compensation device, and saving electrical energy. This is done by changing the number of turns of the coil through the switching action. In a power system with sufficient reactive power supply, on-load voltage control is a simple, effective, and economical technique to regulate voltage quality. It has a low initial investment, a wide adjustment range, and may be altered whenever necessary. It may potentially reduce grid investment, avoid unintentional reactive power exchange, lessen the loss of parallel operating lines, increase the reliability of the power supply, and increase the adaptability of the grid scheduling. This is why the DSOs always think of this when they want to tackle network congestion [22].

Furthermore, another part of the voltage control scheme is the coordinated voltage control which is a type of secondary control methods. The goal of coordinated voltage control (CVC) is to find an effective way for the distribution system's function, considering both the multi-objective feature of the optimal power flow (OPF) and its limitations [21]. A multi-objective feature may be used to describe power loss minimization, OLTC tap changing operation, active power curtailment, and so on. Traditional voltage control, often known as "voltage/var control," employs OLTC and shunt capacitor banks. However, dealing with voltage swings becomes less effective when there is a lot of DG penetration. One solution is to perform active voltage management by continually monitoring the generation of electricity from DG [23]. This approach can be utilized in a highly organized manner. Within distribution systems, distributed generation (DG) is commonly related to the "fit and forget" method. The expansion of DG penetration in real-world power systems necessitates the better and more scalable administration of network infrastructure.

To achieve the network state, the coordinated strategy, which operates in a centralized manner, requires input from other nodes [24]. Because knowledge of the whole distribution network determines the control behavior of centralized voltage control (CVC) approaches, it is critical to communicate data between network nodes. Based on stipulated guidelines, it is feasible to create a rudimentary network structure and a few controlled services. The network voltage is kept within the permissible range in the simplest rule-based CVC system by adjusting the voltage of the substation based on the network maximum and minimum voltages. The substation's voltage is reduced when the network's maximum voltage approaches its boundary; it is increased when the network's minimum voltage falls below its border. When the network's maximum and minimum voltage limits are both exceeded, this operation is terminated [25], [26]. Local active and reactive power regulation of DG units can also benefit from substation voltage synchronization.

2.2.4 Reactive Power Control of DG Units

Since we must deal with both voltage drop and rise issues in this control technique, we want a source of reactive power that can operate in both inductive and capacitive modes in distribution systems connected to DGs. Synchronous machine-based DG units that can change their output reactive power to affect the system voltage can provide the system's necessary reactive power Because we must deal with both voltage drop and rise issues, we need a source of reactive power that can function in both inductive and capacitive modes in the DG-connected distribution systems. The system's necessary reactive power can be provided by synchronous machine-based DG units with the capacity to alter their output reactive power in order to affect the system voltage. In the case of doubly-fed induction generators (DFIGs), reactive power compensation is accomplished by regulating the rotor current. Active and reactive powers may be separately controlled by wind turbines built on DFIG technology [27].

When coupled with asynchronous induction generators, which are widely used to produce electricity from wind energy, a 10% larger converter can offer independent reactive power management. To synchronize with the grid, these generators employ power converters, which normally perform power conversion in the order of AC-DC-AC. Maximum Power Point Tracking (MPPT) is used in solar PV projects to increase power conversion efficiency. This again incorporates multistage current source or voltage source inverters, which depending on operating circumstances may be utilized to offer dynamic reactive power assistance and can operate as a reactive power source or sink. The primary lesson from these RES reactive power suppliers is that they are able to provide reactive electricity even in windy or extremely low-irradiation conditions. Given the technological limitations, this strategy enables the DSO to make use of a reactive power band from the generating units. The DSO can use the DERs to manage the reactive power for congestion control thanks to the modified reactive power flexibility [28].

2.2.5 Load shedding

To protect the network in the event of congestion, defense strategies for distribution power networks should be implemented and the method in this case is load shedding. In the case of a significant system disruption that causes congestion on a specific area of the distribution network, load shedding may be used as a fundamental defense. Since electricity cannot be simply and affordably stored, power balance in an electrical system must be maintained second by second. The generators in that region will speed up if there is an excess of generation or slow down if there is a shortfall when the load and supply for a single, isolated part of the power system are out of balance. When a power system's load is much greater than its generation, the system can only survive if enough loads are withdrawn from the grid. Traditional techniques of system load shedding are inefficient in calculating the right amount of load to be shed and are excessively sluggish. It was impossible to forecast how much load would be shed at a certain time and location since loads are not constant because system loading may fluctuate and the load may vary. The relationship between distributed generation and various power generating is another issue. Either an excessive or inadequate load decrease is the outcome. The functioning of load shedding systems using standard underfrequency relays in a distribution network will be insufficient [29].

Load shedding methods are used to balance equate the load to the generation available and recover from the under-frequency state to avoid the system from collapsing [30]. Electric utilities set various planning and operational guidelines to improve service quality to their consumers, so that the power grid may confront current uncertainties at any time. Nowadays, load shedding is the last resort for avoiding synchronization loss, voltage collapse, or overloads cascade throughout a large region of the power network after certain resources have been depleted, but big consumers are kept powered during corrective efforts. To tackle the load shedding problem in distribution networks, many approaches have been proposed.

2.2.6 Network Reconfiguration

By modifying the open/close state of tie switches in distribution networks, reconfiguration is an efficient liable method for achieving many goals, such as minimizing losses, lowering overall operation costs, and improving voltage stability. This is a reference to command-and-control systems that change the network's system configuration by shutting and opening the power distribution system's sectionalizing and tie switches, allowing control of the power flow from the substation to the consumers. In urban areas, networks can be built as weakly meshed networked systems, however, for technological reasons, most distribution systems use a radial architecture. For distribution networks, network reconfiguration can be done automatically to find a radial operating arrangement that meets all organizational constraints while not isolating any nodes and maximizes those priorities. Network reconfiguration is also possible between different substations. Medium Voltage feeders usually have connections to at least one nearby substation. This is beneficial if the primary transformer or the backup link between substations is congested.

2.2.7 Grid Tariff

Different kinds of grid tariffs have been proposed. Time of use grid tariff is especially good for heating load and electric vehicle charging type of loads in the voltage drop of current capacity constrained networks. Power-based tariffs would improve those situations further. Dynamic tariffs in different forms have been proposed as well. Although a grid tariff has a gradual impact on consumers' usage patterns, it may be considered as an effective tool for achieving a variety of goals, including energy efficiency, bill savings, loss reduction, and long-term infrastructure investment deferments. The grid tariff is highlighted because, if a capacity charge is added to the already existing grid tariffs, it may gradually sway customer behavior in favor of congestion control.

Some DSOs' current grid tariff is divided into the two portions listed below:

$$GT\left(\text{€}/_{kWh}\right) = \alpha + \beta\ (energy)$$

where GT represents grid rate that users. $\propto$ stands for subscription charge $(\text{€}/_{period})$, which includes regular costs for metering and customer services on a monthly or yearly basis. Customers also pay for the factor β, which stands for the volumetric charge $(\text{€}/_{kWh})$. The aforementioned grid pricing is not sufficiently cost-reflective since a DSO must invest in infrastructure and network capacity adequacy might be at risk if the grid tariff does not reduce power peaks. A DSO must maintain sufficient capacity to ensure service continuity, and if a customer causes peaks, the capacity charge income will be allocated to distribution network reinforcement in the future. As a result, it is recommended that it Y be added to the current grid tariff, similar to how some DSOs in Finland already did this practice.

$$GT\left({}^{\epsilon}/_{kWh}\right) = \alpha + \beta\,(energy) + \Upsilon(power)$$

Where Υ is representative of capacity fee $({}^{\epsilon}/_{kW})$ based on the connection point's maximum capacity or the amount of electricity utilized $({}^{\epsilon}/_{kW_{max}})$. The weight of fixed and volumetric charges should be sensibly lowered once the capacity fee is introduced to the grid tariffs since it is not meant to increase the grid tariff and restructuring is the goal.

2.3 Congestion Due to DG Integration

Power system operators may face issues as a result of the amount of power delivered into the energy grid from distributed generating units. Voltage fluctuations and component overheating are just a few of the issues. Increased electrical energy inflows into the power grid need extensive grid strengthening, particularly in distribution networks where voltage quality is critical. Reliability, security, technological advancements, regulatory challenges, and concerns about emissions reduction are all driving factors for rising renewable energy (RE) penetration levels. Electric power transmission lines are avoided when a DG is installed close to load centers, putting the generation in close proximity to the load centers. Due to its complicated generation, a traditional power system has low dependability. All consumers connected to that feeder are impacted when a single point of failure causes the entire feeder to trip. Therefore, the present power systems become more dependable with the aid of DG integration into the distribution system network.

In the past, electricity production, transmission, and distribution were all run independently. As the number of distributed generators (DGs) connected to the grid has grown, the traditional method of managing power networks has gradually changed. In most grids with DG integration, the DG is a concern only in DG connection phase. During grid operation, grid operators are not controlling DGs. Fault isolation might require isolation of DG units as well, but this is mostly done by protection relays and separate SCADA commands are not send to DG units as most DG units do not even have SCADA connection. The transmission and distribution networks might benefit and suffer from the incorporation of DGs into the grid. The effects of DGs on the distribution network are probably more significant because of how closely tied they are to it. To get the best grid performance, these impacts need to be extensively researched. As distributed energy resources grow more common on the power grid, the network's design and operation evolve to accommodate the bi-directional power flow [31]. The massive incorporation of renewable-based distributed generation (DGs) such as the wind turbines (WT) and the photovoltaic cells (PV), as well as some dynamic loads like Heat Pumps (HPs) and Electric Vehicles (EVs) in distribution networks, causes network congestion and voltage fluctuations [32].

When it comes to resolving disputes between utilities and electricity users, distributed generating might be tricky. Most utilities' normal business strategy, particularly in Africa, is to sell electrical energy while also acting as the only manager of grid infrastructure but in Europe, vertical utility companies do not exist therefore one company cannot control everything. If a utility customer deploys rooftop PV, he or she will be offsetting some of their power and most likely start selling to the grid operator. In the context of increased distributed renewables from consumers, there appears to be growing worries about the economic sustainability of utility income. Uncontrolled power input from DGs into the main grid might put stress on grid components, reducing the equipment's lifespan. Transformers and conductors burn down before their manufacturer's designated time when DG units inject power above a specific penetration level. When equipment wears out sooner than expected by the manufacturer, it raises system operators' operating costs, and electricity bills may be altered [33]–[35].

2.4 Need for LFM in Congestion Management

A paradigm change in the electrical system has resulted from the widespread integration of intermittent and variable Renewable Energy Systems (RES) and, more broadly, Distributed Generation (DG), into electrical grids. A more adaptable system must be created to meet the problems. The addition of flexible resources, such as storage systems and demand-response, as well as clever algorithms that plan ahead and manage all these resources in real time, may help achieve the needed flexibility. At least up to 90% of wind and solar power facilities are already integrated into distribution systems across Europe. The introduction of DGs into distribution networks alters the networks' scope and passive characteristics, creating operational and technical problems such as power and voltage congestions [36].

Distribution system operators (DSO) are still unsure on how to effectively reduce congestion threats. DSOs might reduce congestion by either making investments in reinforcing and extending networks or by creating active management solutions. The current infrastructure's extension and reinforcement may not be the most economical answer; thus, they must be combined, either permanently or temporarily, with alternative approaches. Therefore, it is crucial to look into other options and establish a strategy that can both meet the requirements of these new problems for DSOs and take advantage of what smart grids have to offer [37]. As a result, active management solutions that effectively utilize the current networks by taking advantage of users' flexibility must be created. In order to supply a service, a flexibility is frequently defined as "changing generation inputs and/or patterns of consumption in response to an outside signal (price signal or activation)". The duration, position, and quantity of power modulation are the three fundamental properties of each flexibility.. DSO management solutions may face a fresh threat from services marketplaces and/or forward contracts that make use of individual or groups of flexible resources. In the transmission and distribution grid, local flexibility may be efficiently used for a variety of tasks like balancing, supplementary services, voltage regulation, and congestion management [38]. Enabling demand side flexibility can increase network use and, as a result, delay grid reinforcement investments. In order to alleviate the problem of congestion, the smart grid idea encourages local flexibility as an alternate strategy.

Grid reinforcement (raising the capacity of electricity lines, feeders, and transformers) is typically used by DSOs to alleviate distribution congestion. The DSOs' costs will rise as a result of this strategy. Furthermore, approaches employed to relieve transmission congestion may not produce the expected outcomes in distribution, because distribution networks are more complicated because of the integration of small-scale DGs with unpredictable output [39]. Congestion and voltage control can both benefit from flexibility services. Flexibility may meet a variety of requirements in terms of frequency, stability, and energy supply. To efficiently prevent network congestions and keep voltage between limitations at the local level, flexibility for transfer capacity and voltage control can be used. Flexibility service activation times in these circumstances might range from seconds to hours [40], [41]. On the other hand, the local flexibility market seems to be the most viable option for managing congested related services since they provide system operators and flexibility providers with operational and financial benefits.

2.5 The Electricity Market Concept

Future power systems are being rebuilt such that end users, or consumers, are seen as the main component of the system. The Strategic Energy Technology (SET) program of the European Union contains this idea. End-users are now effectively framed as entities that actively participate in electric power networks thanks to this shift of their responsibilities. End-users can participate actively in the electrical system through aggregators, namely through (indirect) wholesale participation in electricity markets where they can sell excess production from locally generated renewable energy sources (RES). The extensive use of RES made distributed generation (solar and wind) widely available. Due to their unpredictability, which makes output forecasting difficult, the widespread use of distributed, renewable energy has presented the electrical system with additional obstacles and difficulties [42].

The intermittency of RES is addressed by the use of energy storage systems (ESS). Demand response (DR), which enables cutting, reducing, or shifting loads to adjust consumption to changing generation, is another way to address the RES issue. Two ideas that provide flexibility in actual contexts are DR and ESS. Up until this point, the transmission system operator (TSO) has employed flexibility as a tool to adjust local consumption to the demands of the energy network [43]. The distribution system operators (DSO) have recently needed to achieve flexibility in the distribution networks due to the addition of RSs. The aggregators served as a middleman to provide this flexibility. Aggregators so offer services that let the DSO get flexibility from the end users [44].

Electricity is a critical component of this low-carbon revolution. To begin with, more efficient power consumption and a greater amount of electricity generated from renewables would minimize GHG emissions from power production. Furthermore, the percentage of overall electrical energy usage has risen, particularly in heating systems (heat pumps). The combination of universal electrification and low-carbon power generation is viewed as a vital component in reducing GHG emissions. Over the years, the European Union has worked to achieve three major aims in Europe's energy policies: energy should be (i) inexpensive, (ii) competitively priced, and (iii) environmentally sustainable [45]. In the 1990s, the deregulation of energy markets served as a springboard for the development of an internal European energy market. To make these changes, considerable investments in power generation, transportation, and distribution, as well as electrical consumer items, are required. The problem is figuring out how to make these investments while keeping power affordable for both consumers and energy-intensive companies. Furthermore, investments and innovation are required to assure the stability of the power supply in considering the rising demand and unpredictable nature of renewable energy supply that is dependent on weather.

Today, different electricity markets exist in the energy markets but our focus in this thesis will be on the Local Flexibility Market since we are dealing with the operators in the flexibility market. Flexibility participates in all markets and it is always looking for the best economic profit. Therefore, the situation on other markets will impact on LFM. If one market has a lot of need for flexibility and prices are high there, most flexibility try to go there, which means that prices on LFM needs to grow as well, otherwise LFM does not have enough flexibility when needed. These interactions are not dependent on market structures, but more about market situations, market actors and their positions, etc. However, it is important to talk about other existing markets such as the intraday (ID) market, day-ahead (DA) market, the energy balance market, and frequency reserve market. Let’s have a brief discussion on these other markets and their impacts on the LFM as it will help us with a better understanding of how the electricity market works.

2.5.1 The day-ahead (DA) market

The DA market as the name implies often closes at the midday before the actual dispatch day. Therefore, before the gate closes (usually 12:00 CET) [46], the players in this market must submit their offers to the DA market. To produce the demand and supply curves, the market operator sets a buy-orders-dependent demand curve and a sell-order-dependent supply curve from which the markets traded volume and clearing price are determined by the intersection of the demand and supply curves for each hour [47]. The market-clearing price and the dispatched volume are therefore binding on market participants.

Europe's largest electricity market is been operated by Nord Pool and they offer day-ahead and trade-offs to customers. The principal marketplace for trading electricity is the day-ahead market, which the intraday market supports by ensuring supply and demand equilibrium.. Generation owners submit offers to the Nord Pool power market, saying how much electricity they can supply and the related price, whereas consumers submit bids expressing how much electricity they need and the corresponding price. Some large consumers are directly on market, but most consumers are represented by retailers These bids must be submitted 24 hours prior to delivery [48]. For each hour of the next day, it generates a supply curve based on sell orders and a demand curve based on purchase orders.. The market-clearing price (MCP), which represents supply and demand, is found at the junction of both curves. The spot price is then determined for each hour based on the market-clearing price (MCP) [49]. In a market competition, all providers will compete at their minimal cost, and all customers will compete according to their marginal ability to pay.

Only two of the three crucial pricing guidelines for energy auctions are often implemented in real-time markets; the single or uniform price market regulations and Market clearing regulations for pay as bid. The first is quite popular in the market for power auctions. In this procedure, even if the sellers bid less than that amount, they would still get the MCP for their power, and even if the customers bid more than that amount, everyone would still pay the MCP. The adoption of the uniform pricing scheme followed the deregulation of the electricity industry naturally since it is thought to provide bidders with incentives to disclose their genuine cost. The lowest price reached at the intersection of the combined supply and demand curve is known as the MCP and the volume of power at the intersection point is as MCV (Market Clearing volume). At this price, consumers and generation providers are satisfied, and the accepted bids would generate enough power to cover all the accepted purchase offers. In MCP's merit order, total sales bids are equal to total purchase bids up to that price. This would be the MCP. Based on the bidding mechanism, there are two types of markets [50].

In Nord Pool's Day-ahead market, various market participants exchange power with one another. Trading takes place on the day-ahead market, although electricity delivery takes place the next day on the market. Each hour, participants of the Nord Pool submit their purchase size for the following day in €/MWh format and this happens daily before 12:00 Central European Time (CET). A pricing algorithm designed by the Nord pool is used to determine the hourly price. The local supply, transportability, and demand are all inputs to this price algorithm. This results in distinct price zones and in Finland there is only one price region compared to Sweden with four price regions [45]. Other examples of the European DA markets other than Elspot which is operated by Nord Pool are APX NL, EPEX, Belpex, Mibel and GME.

2.5.2 The Intra-day (ID) market

The intra-day market, known as Elbas, is a complement to the day-ahead market. The primary goal of this market is to ensure the essential demand-supply balance. Few hours before delivery, power is traded continuously on the Elbas market. This last-minute trading opportunity allows players to alter their supply demand between the Elspot and Elbas markets [51]. This discrepancy in change on the day-ahead and intra-day markets might be due to unforeseen circumstances such as natural disasters, weather changes, and power plant malfunctions. Here, Elbas plays an important role in the markets by allowing power exchange nearing delivery time, which helps to maintain market equilibrium [52].

The increased use of renewable energy sources has increased the risk on the grid although the grids still remain stable. This is thanks to design and operation principles. Due to the fact that wind and solar power generation are weather-dependent; supply and imbalance will become even more unpredictable in the future. As a result, the intra-day market kicks in to balance off the existing imbalance.

The main difference between the intraday market and the day-ahead market is the pricing. Pricing distinguishes the intraday market from the day-ahead market. While intraday trading rates are established by a 'pay-as-bid' method, day-ahead trades are tied to market-clearing pricing regulations, where the last authorized bid sets the price for all negotiations. This means that in continuous business, prices are calculated on the basis of each transaction. As a result, bid prices are also employed in intraday trading and the prices of items traded on the intraday market are not fixed. Getting varied pricing for the same things depending on when the deal occurs is significantly more prevalent [53]. Intraday markets allow market participants to adjust their positions and trade energy closely in real-time to avoid balancing steps. Intraday trading is particularly beneficial for reacting to unpredictably changing energy production and demand by utilizing the market mechanism before control reserves are required. This permits a power plant operator who has lost production in a specific block to acquire extra electricity from other market participants while maintaining the balance group. Also, the opposite is possible as well in the sense that a wind producer does not sell all predicted wind power to DA market and wait until predictions become more certain and then start selling remaining part of wind power to ID market. Consequently, intraday trade is a critical component of direct selling of renewable energy-generated electricity, as weather forecasts continue to evolve, resulting in an unforeseen shortage or excess of power in power plants [53].

2.5.3 The Energy Balance Market and Frequency Reserve Market

Electricity is traded at markets, and balance responsible parties (BRPs) are required to keep track of their balances on a trading period basis, according to BRP guidelines. A smaller fraction of trading is conducted directly between two dealers on a bilateral basis. Energy imbalances are considered throughout each trading period on the energy market. BRPs must anticipate production and demand for trade periods, and the cumulative mistake has an impact on the overall imbalance. Financially, the BRPs are to blame for the imbalances and they will have to pay when their imbalance is in the same direction as the system imbalance. The total of all deviations from all input or outage locations in the grid within the price area for which the BRP is responsible is the imbalance power per price area. The entire system imbalance will be calculated as the sum of the deviations from all BRPs, and if this sum is non-zero, one particular BRP will either have caused the imbalance (for which it will be fined) or reduced it (for which it will be rewarded). As a result, the settlement for the BRP for that particular hour will either be positive, negative, or zero, with positive numbers signifying revenues and negative values signifying costs. The price is determined by the market that regulates it, which uses the difference between the net regulating price and the spot price. The net regulating price is the same as the down-regulating price if the overall system imbalance is positive. The net regulating price is equal to the up-regulating price if the system imbalance is positive.

From the stability of power system standpoint, one of the key responsibilities of a TSO is to maintain the power balance between energy demand and supply. The primary tool for resolving market imbalances caused by variations in the number of bids on the spot market is the balancing market. This market corrects the mismatch by facilitating physical trading [54]. Balancing markets bridge or limit the balance gap between other forward markets and real-time energy supply. The balancing markets are the final stage of selling electric energy and are often used to balance supply output and demand to the barest minimum before the power supply [55]. As a result, the TSO's balancing energy market is a market mechanism that ensures a real-time balance between energy demand and supply.

Power system stability requires that electricity production and consumption must always be equal, and frequency indicates that production and consumption are in balance. Market players, on the other hand, manage and balance their output and demand ahead (with a specific precision established by markets), therefore frequency variations from nominal value (50/60 Hz) are unavoidable within each hour. A TSO obtains several types of reserves from reserve markets to balance these discrepancies. Power plants and utilities that decrease or increase their electric power in response to power system demands are examples of reserves and storage has increased their trading and accepted bids on reserve markets recently [56].

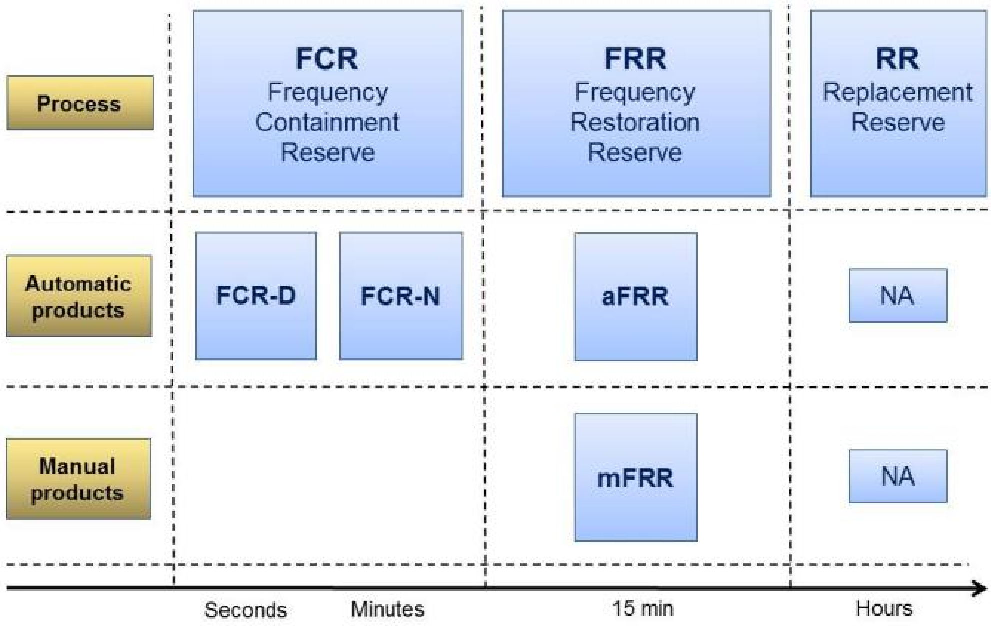

Figure 4. The Reserve Products used in Nordic countries [57]

Imbalance Pricing Schemes

Price signals can be a significant factor in motivating balanced market players to engage in effective interactions [58], [59]. Different imbalance pricing mechanisms are briefly explored in this section. In Europe, there are two methods for dealing with price imbalances: single pricing and dual pricing. The term "long imbalance price" refers to a BRP's production excess, whereas the term "short imbalance price" refers to its production deficit. The long and short imbalance prices are the same under a single pricing method [59]. It implies that aggregators or DERs owners pay the same amount if there is a shortage in the balancing market and get the imbalance price if there is an excess in generation. The long and short imbalances, however, are priced differently under the dual pricing approach, and their values are also influenced by the direction of the market party's imbalances relative to the direction of the net system imbalance. Or, to put it another way, DERs owners and aggregators frequently have to pay the price comparable to the day-ahead price if their imbalances are in the reverse direction as the system imbalance. If they are travelling in the same direction as the net system imbalance, they must pay a sum calculated by the marginal cost of the latest balancing unit deployed, which is frequently more than the day-ahead price. A single price structure is used in Germany, Belgium, and the UK [60]. A dual pricing strategy is employed in the Nordic nations, the Netherlands, France, and Spain [59]. The dual pricing strategy provides an aggregator with extra incentive to net its imbalance across many DERs. But whether or not an activated DER is in the aggregator's portfolio, DERs will always be obligated to pay their marginal cost under the single pricing technique. [61].

These are some of the market approaches that are being operated in the electricity market for the day-to-day activities.

2.6 Flexibility Services Utilized for Congestion Management

Flexibility service is an abstract definition of capability of flexibility resource to produce something useful for the buyer. Flexibility service is different from flexibility resource. Flexibility resource may provide multiple kinds of services like voltage control, frequency control, black starting, production/demand up/down regulation, etc. Key references for defining the flexibility services have been found in two sources. One of them is the Universal Smart Energy Framework (USEF) [62], which provides a single standard upon which to construct a crucial market for the trading of flexible energy consumption. The EG3's findings and recommendations on the use of flexibility with regard to regulatory suggestions for the rollout of smart grids serve as the second source [63]. DSO, BRP, and prosumers are typically categorized as functions of the flexibility customer.

DSO Services

The DSO demands are a representation of the amount of flexible resources required to maintain the distribution system inside the safe operating limit. These are some services that an ICT platform could provide to the DSO according to the main emphasis of the INVADE project:

- Congestion control: preventing the thermal overload of system components by lowering peak loads in areas where overload-related failure may happen.
- Voltage/reactive power control: To prevent exceeding the voltage limitations, employ load flexibility as a possible alternative.
- Controlled islanding: when a failure occurs, it prevents supply interruption in a specific grid region.

BRP Services

BRPs can balance their portfolio and obligations in wholesale markets with the aid of aggregators. Flexibility sources might be used to manage upcoming imbalances caused by a variety of factors, such as forecasting mistakes or a desire to keep BRP power bills as low as possible[64]. BRPs may use flexibility services such as:

- Day-ahead portfolio optimization: Before the day-ahead market closes, loads are moved from a high-price time interval to a low-price time interval. It makes it possible for the BRP to pay less for power overall.
- To allow value generation in the intraday market, which is similar to the day-ahead market, through intraday portfolio optimization.
- Optimization of a self-balancing portfolio: The BRP reduces imbalance within its portfolio to minimize imbalance charges. The BRP leverages its load flexibility inside its own portfolio rather than aggressively bidding on the imbalance market.

Prosumer Services

Lastly, prosumer power expenses can be reduced by using adaptable assets behind the meter. A home energy management algorithm may be implemented by an aggregator in their platform. For various applications, several methods were studied and compared. The following possible flexibility services for prosumers were mentioned by USEF [62]:

- Utilizing flexibility from high-price periods to low-price intervals is known as time-of-use (ToU) optimization.
- kWmax control: to lessen peaks in prosumer use within a set timeframe.
- Self-balancing: Making the most of the price discrepancy when buying, selling, and using power.
- Controlled islanding: to keep the energy flowing behind the meter while there is a grid interruption.

2.7 Flexibility Products for Electricity Markets

A product is a major element of a certain market or system and is an option that is bought, delivered, settled, and paid as required. To provide services, goods are traded on markets. It specifies the kind of services that are traded as well as any additional requirements. Products are made to encourage market players and regulated parties to buy, sell, and control goods or assets connected to the energy system. Here, the whole energy market and control over the electrical system are viewed as the sum of several sub-markets and other non-market-based processes, either connected to the regulated or competitive domain. A variety of electricity market methods are used to govern most aspects of power networks, including financial transactions, power balance, and energy flows. Multilateral flexibility marketplaces, where the flexibility products are traded, either don't exist in the present European power markets or don't have completely established or standardized definitions. Although flexibility is used in current markets, the phrase "flexibility market" here refers to marketplaces where services that existing products do not cover are enabled via flexibility product trading or other mechanisms. These include tools for managing congestion, tools for supporting voltage and reactive power, tools for adjusting network prices, and flexible network service agreements. [65].

- **Flexibility products for congestion management**

This section looks at the three alternatives available to SOs for obtaining resources from flexibility markets for to manage network congestion: locational intraday contracts, locational balancing products, and competitive bilateral contracts. The same balance or intraday platforms, as well as a different platform with specialized items, are all acceptable places to put offers for these products. Because these product categories are utilized by several SOs and flexibility projects in Europe, these choices were chosen from among many to be studied further.

- **Flexibility products for voltage support**

The availability of flexibility products for voltage and reactive power control enables enhanced reactive power reserve services, as well as other services that assure voltage quality and the necessary voltage management of system operators and network users resources. Flexible products can be utilized for maintenance duties, controlling outages before and after failures, and voltage compliance under normal conditions. Voltage support items are conceptualized differently. There are currently no or few market-based methods for networks to obtain voltage support. Reactive power trading on a market can be used to supplement current voltage support techniques. T Depending on the SO activation signal, the activations resulting from a flexibility contract may be self-dispatched or frequent during the contracted periods. Due to the erratic nature of voltage support requirements, SO signal is deemed to be neither a technically adequate nor a cost-effective method of service delivery[65]. Both self-dispatch and continuous fixed compensation based on locational phase-angle measurement, such as frequency dispatch of FCR, are acceptable methods. Resources are activated as a consequence of the tenders at the agreed times in order to offset the reactive power demand in accordance with the bilateral agreement.

- ### Dynamic Network Tariffs

Grid charges that are dynamically updated and displayed for the network user before or during delivery are referred to as dynamic network tariffs in this context. Because system-supporting behavior must be incentivized by the locational or system-level network,, this may result in implicit behavior. Although it is currently prohibited by law, these conceptual prices may also differ for comparable grid services inside the same SO's network region. To accomplish the desired result while respecting other market processes, it is challenging to determine appropriate price for dynamic tariff components. If price responsiveness is desired, tariffs should be consistent with other market mechanisms since network expenses might account for a significant portion of overall power costs. It takes a lot of calculation to define dynamic tariffs without using significant approximations. Due to system-level capacity adequacy, this might imply that there will be be a variable pricing structure for a customer for each market time unit of the day.

- ### Flexible network service agreement

A flexible network service agreement is one that is acquired through the network service agreement contractual process of making new connections or reinforcement of old connections. In this case, additional clauses in connection and network service agreements, separate service contracts or sometimes both, may be required. Although NWAs (Non-Wire ALternatives) can save costs for all users by preventing the socialization of unnecessary reinforcements through grid fees from all customers, the issue is presented from the standpoint of a single user or group of users inside a grid region. The proposed site might not have enough available transmission capacity if there is a plan for new or bigger connections to network. It would thus be useful for SOs to have more choices besides accepting or rejecting a request for a network connection. Using NWAs in these areas may result in more cost-effective grid service if the other option would involve an expensive strengthening of the grid for only a few hours of relatively mild overcapacity or the outright rejection of the extra subscription capacity. As an alternative, you may buy NWAs to provide network access while you wait for grid reinforcements. An example of this is when variable RES generators or large consumption units are connected to an existing network segment.

3. THE LOCAL FLEXIBILITY MARKET (LFM)

In this chapter, we will be talking on the concept of the local flexibility market and evaluation of four European local flexibility market operators (Picloflex, Enera, Nodes and Gopacs) with the aim of reducing grid investment through reinforcements which is the focus of this thesis. A qualitative and comparative study is carried out on the market concept of four European local flexibility market operators (Picloflex, Enera, Nodes and Gopacs) using a set of KPIs (Key Performance Indices). These KPIs will be discussed as we progress in this chapter.

Local flexibility markets (LFMs) are platforms where flexibility is exchanged between flexibility service providers and flexibility consumers (DSOs, TSOs, BRPs, etc.) in geographically confined locations [66]. To encourage and leverage the existing flexibility in distribution grids for congestion management, a number of solutions, such as dynamic prices (e.g., time of use, cheaper tariffs related with consumption limitations, essential peak pricing, etc.), or grid reconfiguration, have been proposed. On the other side, local marketplaces that exchange flexibility from end users to system operators seem to be one of the most promising remedies for congestion issues. A platform with well-defined norms and widely accepted trade methods is projected to raise awareness of flexibility usage among all participants, resulting in more appropriate use of flexibility in future energy systems. However, there are important legislative and operational difficulties that must be tackled before LFMs can be used on a broad scale in real-world applications (e.g., end-user participation, system operator role, existing regulations, etc). There have been various scientific and commercial approaches to LFMs in recent years. The scope (i.e., prevent expensive network reinforcement, real-time distribution network management, provide frequency and balancing services, etc.) and timing of flexibility exploitation vary amongst these systems (i.e., long-term, short-term, or real-time services) [68]. There aren't many choices that specifically address the reduction of congestion and voltage issues at the distribution level, despite the increased desire in making use of locally available flexibility. Some LFMs that have been discussed in the international literature intend to operate on top of local energy markets to develop local energy communities (LECs). [68]. Also, Energy communities may be flexibility service providers, but they might be interested to buy flexibility from LFM as well, if LFM is trading suitable products for them.

Additionally, each of the suggested LFMs focuses on a particular operational timeframe to provide DSOs with a variety of services. For example, one approach of the

LFM focuses on flexibility providers providing long-term services to DSOs as a cost-effective alternative to costly grid reinforcement which is where our scope covers. Another part of the LFMs focuses on operating horizons that are closer to real-time and target the effective distribution network management and imbalance control. Because of this, regardless of the timing of the necessary services or the nature of the anticipated challenges, the LFM structure focuses on assisting DSOs in effectively managing their connections through the purchasing of both activation and reservation of flexibility over a variety of time horizons. LFM intends to offer DSOs a market-based tool for effective network management, regardless of the source and characteristics of congestion problems, as well as the competing market actors' interests. Market participants can also trade both activation and reservation of flexibility under the LFM framework. DSOs can study the prospect of avoiding grid reinforcement by reserving the essential flexibility via a long-term market structure based on the outcome of the market operation [66]. DSOs can also reserve extra flexibility via the short-term market (i.e., for the next day) if the forecasting systems identify that greater flexibility is required. LFM offers DSOs a market-based tool to save long-term grid reinforcement costs while maintaining the distribution system's secure operation closer to real-time. In order to increase profits for its LEC members, the aggregator, as shown in Figure 5, manages local market operations. LECs and aggregators may have increased negotiation power with BRPs and DSOs thanks to their cooperation. Prosumers, BRPs, and DSOs can have independence while still receiving fresh money from an aggregator. For instance, if all of the LECs are connected to the same DSO and are a part of the same BRP portfolio, an aggregator may manage each LEC's own LFM. In this case, the aggregator may provide flexibility services from LECs to the BRP and the DSO at the same time. Our strategy, meanwhile, is not just applicable to LECs. An aggregator might also look after clients outside of LECs. For instance, a number of clients with the same DSO might provide services for managing grid congestion. Similar to this, clients covered by the same BRP might provide flexibility, such lowering deviation fines. An LEC, however, may benefit more from the LFM and have more leverage in negotiations than a single consumer.

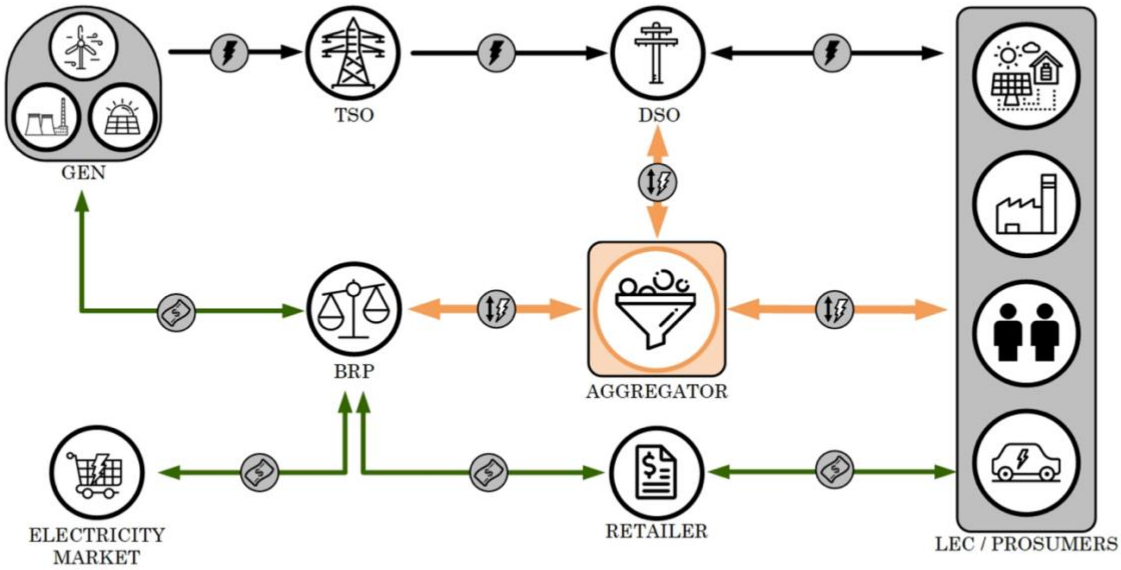

Figure 5. Local flexibility market overview. LEC, Local Energy Community [68].

3.1 Local Flexibility Market Operators

The LFMO is the organization in charge of running the LFM's most crucial functions, including market clearing and market settlements. The LFMO may be the DSO, a DSO-oriented entity, or a separate company, depending on the legislative framework in place. Economics literature usually asserts that the market operator should be a neutral, unbiased third party. Europex specifically suggests that the LFMs be operated by separate third parties that are not directly involved in the market in order to reduce any risk of a conflict of interest and provide equitable access for all market participants [69]. The four European local flexibility market operators evaluated in this thesis are discussed below.

3.1.1 Piclo Flex

Piclo Flex is a privately managed marketplace that enables flexibility to be traded across time and geography dimensions between FSPs and DSOs. It started its operation in 2019 in the United Kingdom and since then has been operational till date. The primary goal of Picloflex is to create a market place to standardize and ease the purchase of DSO flexibility, improve the usage of the current grid, and lessen the need for grid reinforcement. Piclo Flex offers a free platform for users to post flexibility requirements based on demand locations. The zones for constraint management contain qualifying assets that DSOs may observe. They can source flexibility with particular locational, technological, and temporal needs, thanks to the resultant map of competitors.

Regarding the market structure of the platforms, Piclo Flex is distinguished by a single auction buyer that is only the DSO, while the sellers of flexibility may be asset owners, aggregators, community and municipality, consumers, generators and EVs. The flexibility services offered by piclo flex are mostly for congestion management and voltage control and the products traded in the market includes capacity, activation, and active power. In this situation, market frequency is determined by an auction, and tenders and bid periods are planned with a lead-time of at least six months. Contract terms might range from a few months to four years, and the market is settled through remuneration (dispatch payment and availability payment). It should be highlighted that the market operator's income comes from the commercial contracts that have been negotiated with the DSOs, allowing DSOs to purchase flex and other "smart" energy services through Piclo's flexibility marketplace. Piclo Flex operates a different platform from the current sequence of electricity markets in terms of integration with other markets. [70].

To help flexibility planners, Piclo provides a marketplace for flexibility providers in the United Kingdom. This will boost the visibility of network congestion locations. Distribution grid operators in the UK are gradually considering alternatives to grid strengthening because they are encouraged to do so by "total expenditure" laws [71]. This involves programs for flexible grid connections and bilateral purchasing agreements with providers of flexibility. Operators and regulators are exploring open marketplaces like the Piclo Flexibility Marketplace in order to encourage purchases and control procurement processes. The Piclo Market only uses authorised businesses as flexibility suppliers. Additionally, it permits suppliers of flexibility to offer flexibility that is not presently in use. The grouping of tenders by restricted region enables anybody with flexible capital connected to a certain geographic area to submit a bid. Multiple tenders for various services, e.g. strengthening deferral, maintenance, and various contract periods, may be held for a same restricted region. In order to provide automated, API-enabled end-to-end services for flexible procurement, including secondary trading markets, settlement, activation, and validation, Piclo is building a platform [72].

3.1.2 Enera

The energy company EWE AG, the power exchange EPEX SPOT, one of the German TSOs TenneT DE, and the German DSOs Avacon Netz and EWE NETZ are all partners in the Enera project. The primary objective is to make flexible solutions possible to prevent the unjustified restriction of surplus wind energy and also to build and demonstrate flexible standard strategies for an environmentally sustainable, safe, and accessible power supply by using renewable energy [73]. This flexibility platform helps DSOs manage congestion, balances flexibility supply and demand, and minimizes the total curtailment of renewable energy. In order to leverage these flexibilities for network operation, ENERA continually balances supply and demand and provides DSOs with order books with unique region identifiers. The Enera platform's primary duties include bid gathering, market monitoring (platform for verification), market clearing, creating aggregation operations, settlement, calculating network impact (by grid operators), and enabling/activating individual flexibility. In terms of the market structure of the market platforms, Enera is characterized by a two-sided market having TSO and DSO as buyers of flexibility while the sellers of flexibility can come from Aggregators, asset owners. The flexibility services offered by Enera are mostly for congestion management and relation with ID market while the products traded in the market includes capacity and activation. In this instance, market frequency includes the clearing period, the ID trade interval of 15 minutes, and the gate closing of 5 minutes before delivery. The bidding period is continuous, and the platform then matches bids. All created transactions are gathered and billed to the appropriate market participants by the end of each month as part of the market settlement process, which is done through dispatch payment. Enera operates with "local order books" shared by the local impact on the network and is based on ID timeframe when it comes to market integration [70]. The qualifications for participation in Enera are substantially tougher than those in the ID market because it is not an energy market.

Network administrators can purchase flexibility in the intraday timeframe in Enera to strategically reduce congestion. Local order books are put up in Enera because grid congestion is peculiar to particular places on the grid. This local order books contains the records of the previous congestion on the network and the part of the network where the congestion occurred. EPEX SPOT supervises pricing development, assures high levels of visibility on this expanding market, and acts as an unbiased arbitrator between demands for flexibility from system operators and those of regional suppliers. All necessary procedures for system providers and mobility suppliers to function in the market are defined in the project in order to demonstrate in real-world situations.

To guarantee efficient congestion management and to prevent new congestion, system operators evaluate their flexibility demands (location, timing, and amount) and share their grid limits with the other system operators. On the other hand, authorised flexibility providers submit their bids through the applicable market areas' order books. It's significant because the only traded items are agreements to change physical schedules inside a certain market region. The portfolio of the person in charge of maintaining the asset's balance is impacted by the change in schedule of an asset, necessitating a rebalancing. This is often done on the intraday market; however, it is not required. The Enera platform and the wholesale intraday systems do not explicitly connect, and each market participant (or his Balance Responsible Party) is still in charge of managing his own balance regardless of flexibility activations. For instance, the load asset receives compensation for this physical activation if a load is increased via the Enera platform to reduce congestion, but still needs to source the energy independently (this energy cost can thus be included in the market-based flexibility bid).

3.1.3 NODES

Agder Energi, a Norwegian utility, and Nord Pool, a European power exchange, are partners in NODES which was created at the beginning of 2018. NODES is an independent platform for a future of renewable energy where grid operators, energy suppliers, and consumers may share decentralised flexibility and resources. NODES allow for the exchange of flexibility even when the local grid does not have an urgent demand for it by integrating the local flexibility market into the existing balancing market and, in the future, reserve markets. In addition to connecting the NODES marketplace with the current systems that run the ID and balancing markets, NODES wants to recognize and respect local flexibility. Moreover, flexibility that is not used locally might be offered to the TSO or to Balancing Responsible Parties in order to boost value for flexibility providers and save expenses for the DSO (BRPs). It can correct transmission imbalances. Both LongFlex (Availability) and ShortFlex are sought after by Nodes (Activation). Voltage control, congestion management and frequency regulation, are all benefits from flexibility. In terms of the market structure of the market platforms, NODES is characterized by a two-sided market having TSO, DSO and BRP as buyers of flexibility while the sellers of flexibility can come from FSPs: BRP, aggregators and microgrid. The flexibility services offered by Nodes are mostly for balancing and congestion management while the products traded in the market includes mFFR, RR and capacity. The timescale will be adjustable for each location and market in terms of market frequency, and it will work with existing markets' mechanisms for settling imbalances. All orders are automatically matched with one another or selected from an order book that the customer will activate. Monthly market settlement occurs. The FSP provides the asset baseline. Nodes is currently not connected to the wholesale market in terms of connection with other markets, but it is experimenting with various suppliers and TSO operating processes. Contracts with the DSOs provide the market operator with income [70].

DSOs and TSOs may have flexibility at the local level to relieve grids of certain congestion. Flexibility providers tag a grid location (GL) in NODES. These buyers must express a desire to pay for flexibility activation at certain grid locations and convey this desire to NODES continuously via an API. One or more GLs make up a local pricing area. Depending on the level of flexibility purchased by the TSO or DSO, the local pricing zones can change dynamically and quickly [74]. The flexibility is offered by the flexibility providers, who are employed by the owners of the flexibility assets and deliver their offers to NODES via another API. The majority of the working hours throughout the year at the actual grid site do not require the flexibility; usually, just a few hundred hours are needed each year. NODES will design a versatile interface for these marketplaces. On the basis of the sale or central sale of the flexibility resources, flexibility providers may be able to differentiate their solutions. Since there are fewer possibilities if the seller wishes to rebalance due to the unavailability of particular assets, selling locally at a single grid site may be riskier in many circumstances or even provide enhanced opportunities. In the ID market, it is much simpler to equalize contractual holdings. As a result, flexibility suppliers submit their bids with their specific required features, and flexibility buyers have the chance to compare bids and select the highest offer.

3.1.4 GOPACS

Grid Operators Platform for Congestion Solutions GOPACS, was introduced in January 2019. The Dutch TSO and four DSOs are the owners and operators of GOPACS. Since GOPACS is not a market platform (no flexibility offers are cleared on GOPACS), it differs from the other projects discussed here. Instead, it serves as a bridge between markets and network operators' demands. GOPACS is linked to the Energy Trading Platform Amsterdam (ETPA), a national intraday platform active in the Netherlands. At a later time, GOPACS hopes to link to other market platforms. 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. If a locational tag is added, offers from flexibility providers active on ETPA can be acquired by GOPACS [74]. The ETPA does not specify any fixed geographic zones. Instead, GOPACS uses its algorithm to determine which assets provide the most affordable way to alleviate congestion. By including their location data, GOPACS tests whether an order will address DSO congestion requirements This solution comes from using the flexible assets connected to the transmission and distribution grid which are active on GOPACS. Grid operators use GOPACS to predict and notify their needs for congestion control. Through the market platform, which serves as a portal to GOPACS, the flexibility providers provide solutions to this congestion. If a flexibility offer satisfies certain requirements, it may be posted as an IDCONS (Intraday Congestion Spread). A location tag must be included as well.

For example, if grid congestion in some areas is predicted, operators would prefer a drop in output or an increase in consumption. The marketing parties are then sent a bid request via GOPACS. This allows market players in the energy sector to place a suitable buy order on a linked market platform. However, any action taken to reduce congestion should avoid having a negative impact on the electrical system's national balance. As a result, a reverse order is connected to the decrease in power generated by a market participant outside the congestion zone. GOPACS quickly checks to see whether any other electric grids operated by collaborating grid operators are experiencing issues as a result of this command. The grid operators will split the cost between the two orders if all the indications are green. As a result, the two orders are compared, and market platform congestion may be handled. The collaboration between the grid operators also prevents congestion in one area of the system from causing problems in another. In connection with the ETPA intraday commercial platform, grid operators are employed by GOPACS. In terms of the market structure of the market platforms, GOPACS is characterized by a two-sided market having TSO and DSO as buyers of flexibility while the sellers of flexibility can come from FSPs: Residential, commercial, industry, and energy companies. The flexibility services offered by GOPACS are mostly for congestion management and relation with ID market while the products traded in the market includes activation [70]. When it comes to market frequency, GOPACS runs a continuous market in which grid operators can publish congestion predictions as needed, and the bidding session begins before the intraday gate closing time. The market platform also handles settlement in this market. A monthly fee, a price per interchanged MWh, and an admission fee are charged to FSPs taking part in ETPA. The ETPA (continuous trading platform in the Netherlands) and GOPACS are completely integrated.

3.2 Capabilities of Flexibility Trading/Procurement Process

Some factors must be considered before flexibility in the network will be considered. Some of these factors are but are not limited to the following:

3.2.1 Coordination

The main objective of flexibility coordination is to make sure that other stakeholders are not negatively impacted by flexibility trade. Potentially two parties like TSO and DSO may get synergy benefits by utilizing one well selected bid which benefits both of them. For instance, in the reserve or balancing power market, where small-scale aggregated flexibility is sold, TSO flexibility procurement should not generate congestion for associated DSOs. TSOs will require an increasing level of flexibility connected to distribution grids to meet their balancing demands, and this flexibility should not be shut out. To minimize negative interactions between TSOs and DSOs, proper coordination methods must be in place. The requirement for cross-party cooperation has increased as the usage of distributed energy resources has grown, not just on different voltage levels but also throughout the whole connected power system.

Cross-border flexibility commerce is growing, and in order to make it a reality, new systems are being created [75]. An outstanding example of TSO cooperation in cross-border markets is the cross-border intra-day market as well as the markets for manual frequency restoration reserve (mFRR), automated frequency restoration reserve (aFRR), and frequency containment reserve (FCR), in Europe. As a result, TSOs must cooperate with both their connecting TSOs and their linked DSOs. Asset utilization should be maximized from the standpoint of flexibility providers, and assets should be employed at all stages, from local to regional to cross-border. As a result, DSO, and TSO level cooperation is required.

Independent aggregators, for example, may have conflicting interests with retailers in situations when an aggregator's offered flexibility generates an imbalance in the BRPs of electricity marketers. An aggregator's flexibility trade, on the other hand, may eliminate retailer imbalances, allowing for better internal and coordination agreements. In this instance, the independent aggregators' approach should consider the interests of all parties. Flexibility can be used where it can provide the most value with good coordination between grid operators and flexibility suppliers, and there will be no repeated activation of flexibility [75]. Congestion management should be given freedom with an appropriate location rather than balancing since the criteria for balancing, for example, are less site sensitive than those for congestion management. Likewise, flexibility suitable for DSO-level congestion management should be delegated there instead of at the TSO level, where there are more options for choosing flexibility from a different location where another DSO is operating. Of course, this should not increase the potential threats to the stability of the power system. Flexibility is effectively utilised once, thanks to appropriate grid operator coordination, and a second transaction is not required to handle the negative effects of the first trade.

3.2.2 Data Exchange

TSOs and DSOs must work together with all market participants to manage the electrical system in the most cost-effective way possible while also ensuring sufficient support for the EU Green Deal's impending goals. By guaranteeing: no net emissions of greenhouse gases by 2050; economic development divorced from resource usage; and leaving no one and no place behind, the European Green Deal will convert the EU into a contemporary, resource-efficient, and competitive economy. Openness in data sharing is regarded as a need, as evidenced by EU legislation (e.g., Regulation No 1227/2011 on wholesale energy market integrity and transparency, Regulation No 543/2013 on data publishing and submission in the energy markets, and so on). The EU Network Codes address the very minimum criteria for data sharing. To effectively accomplish their job, particularly as a market facilitator, system operators' observability on their mutual network needs to be improved. This would enable improved coordination, including near real-time coordination [75]. Furthermore, any restrictions on a product's trade needs justification and it should be accessible in the market. For instance, balancing transactions executed by a DSO may cause congestion for TSOs; therefore, impacted TSOs needs to be notified by the DSO using the traffic light concept to know the present condition of the distribution grid. This enables the TSO to have knowledge of where potential problematic areas exists in the network. For instance, trades to relieve congestion in a DSO's feeder must not result in congestion in the network of a different DSO that is engaging in countertrades. As a result, before a trade is finalised, at least all the impacted parties should be notified. In addition to above data exchange ideas, the idea of flexibility register might be introduced here as well. The flexibility registers provides meta-data about the flexibility resources, their contracts, capabilities, etc. This may simplify the data exchange needs in LFM.

3.2.3 Interoperability

Interoperability is a critical factor in determining whether or not flexibility may participate in marketplaces. By leveraging similar and standard data formats, communication technologies for information transmission, interoperable platforms encourage market participation and hasten the communication process. Asides speeding up the process, the interoperability is completely mandatory. This is because marketplaces provide APIs, aggregator has own internal IT systems, which must have API toward LFM and other systems. Similarly, same applies to TSO-DSO coordination as there is no possibility for manual operations. Interoperability will become more important in situations when stakeholders and market platforms must interchange large amounts of data, such as when various market platforms, DSOs, data hubs, flexibility providers, TSOs, and other entities must communicate with one another on a regular basis. Furthermore, the demand for interoperable interfaces will grow as the characteristics of the electrical network and markets become more complex, necessitating real-time data sharing if market participants are to profit in a competitive market setting.

Various programmes and platforms are already in place that deal with system interoperability. ENTSO-E, for example, has created the ENTSO-E Communication and Connectivity Service Platform (ECCo SP), a platform that allows business applications to communicate with one another. Another illustration of interoperability is the common grid model, a pan-European grid model with which TSOs are required to exchange their grid models with other TSOs and regional security coordinators. Coordinators oversee combining the TSOs' various grid models and issuing unified grid models, which are exchanged with the TSOs for operational planning using this new regional data. Other examples includes: DataHUB, flexibility register, TSO-DSO coordination, APIs of marketplaces, APIs for weather forecasts, etc. [75].

3.2.4 Liquidity

All parties are interested in a sufficient degree of market liquidity. Flexibility providers desire to trade on marketplaces that allow them to quickly sell flexibility without producing a significant price shift and with low transaction costs. Flexibility user like to buy from a liquid market because it ensures that flexibility is available at a realistic price. A liquid market is a method that allows all potential flexibilities to be unlocked for the advantage of all parties concerned. Some of the enablers of a liquid marketplace as proposed by [75] includes:

- Reducing or modifying the standards for flexibility products' market inclusion can help improve liquidity. Having less demanding flexibility products, more resources will fulfill those. This can be achieved by lowering the standards for the inclusion of flexibility products into the market so that more products can be available in the market and market participants have different options to choose from. Also, verification and validation method should be built for aggregated small-scale DERs. By allowing aggregated bids, LFM will increase liquidity. Both of them have consequences as well. So liquidity is a tradeoff between large amount of offers and large amount of less useful offers (e.g. part of aggregated bid might not be behind a congestion depending on many factors).

- Flexibility services may be exchanged on many platforms, and a user-friendly mechanism to improve flexibility services should be established. This is possible if the same bid is offered to multiple markets at the same time and then through a single-entry point, the bid may be accepted only once. This improves liquidity if the flexibility products can be sold quick enough. Although a single access point to many market procedures may be a notion to study, interoperability and coordination features would be a more practical and realistic solution.
- Market participation and cancellation fees, as well as trading and exchange expenses, must be cheap enough for small stakeholders to participate. Competition should be promoted, as should collaboration and interoperability between market areas. This is another way to enhance liquidity because the small market participants will not be scared to go into the market if the trading expenses and cancellation cost is cheap enough especially for aggregators who are already on many other markets and paying similar fees for those markets as well.

3.3 Market Participants in the Local Flexibility Market

One of the most promising approaches to reducing congestion is the creation of local markets that trade flexibility from end users to system operators. Local flexibility markets (LFMs) are defined as platforms where flexibility is exchanged between flexibility providers (end users) and flexibility users (DSOs, TSOs, BRPs, etc.) in geographically constrained locations . It is anticipated that a market with well-defined regulations and accepted trade practices will raise everyone's understanding of the use of flexibility, resulting in its more effective application in upcoming energy systems. Before creating the markets for local trading flexibility, the participants and their goals in LFMs should be established. The participants' stated aims for market clearing can then be used in conjunction with a variety of strategies. These people are among the LFM framework's participants:

a. The Local DSO

The local DSO is in charge of notifying the market operator of the signal for market activation and the request for the required service. After determining that a service is required, the DSO sends the activation signal to the LFMO, which will then be in charge of establishing a specific order-book and advertising the service request to all participating aggregators. Prior to that, the DSO should assess the anticipated circumstance and make decisions on the volume of flexibility needed, the place where flexibility is needed, the length of the service, and the service's maximum pricing [76]. The market activation signal should specify the type of service (such as voltage control or congestion relief), service timeline (such as short or long-term), price (reservation and activation fees), location, duration, and other details like the maximum activation times and the potential activation window. It is also responsible for determining the requirement for flexibility services. The flexibility offered by the flexibility suppliers will involve a change in either the generation or consumption of active electricity. The obtained flexibility might be applied to address a variety of problems, including overloading of components, voltage limit violations, and deferring the need for network reinforcements [77].

b. The LFM Operator (LFMO)

The LFMO is the organization in charge of running the LFM's most crucial functions, including collecting bids, clearing, and market settlement. According to the current regulatory framework, the LFMO might be the DSO, a DSO-oriented organization, or an independent business. The idea that the market operator should be a neutral, unbiased third party is commonly mentioned in economics literature. Eurpex specifically recommends that the LFMs be managed by impartial third parties who are not directly involved in the market in order to reduce any risk of a conflict of interest and provide equitable access for all market participants. [69]. As a result, the LFMO shouldn't take part in the LFM as an aggregator. This would suggest that, in comparison to other aggregators taking part in the same LFM, this aggregator would have enjoyed an unfair advantage. The LFMO is crucial for effective management and the LFMO is in charge of the following:

- market activation
- conducting auctions
- market clearing
- contracts between the DSO and the successful bidders
- settlement

c. Flexibility Service Providers (FSPs)

The FSPs are in charge of gathering and managing the flexibility of their portfolios as well as representing them in the LFM by placing bids in response to the DSO's requests. These resources can be prosumers, local DER owners, EVs, building and storage owners, or even households with flexible loads. The participating aggregators should be capable of accurately estimating the cost, capacity, availability, etc of the flexibility services that will be offered by their related resources. They should also have a solid understanding of the local market processes. They are also in charge of representing their portfolio during the market's settlement phase. After receiving payment from the DSO via the LFMO for the services rendered, they are in charge of distributing the proceeds among their resources in accordance with their level of participation in each service [68] Payment happens after the settlement, when it has been verified that activation truly happened.

3.4 Market Timelines in LFM

Almost all LFM frameworks recommend one of three alternate timing modes so that the DSO has a technique to alleviate congestion at different time resolutions. The several market modes and their main traits are:

a. Long-term Market

Services that are anticipated to be needed for a specified time period and at a lengthy advance are handled by this market method (a specific month, the next year, etc.). In this approach, the flexibility reservation is traded in exchange for a reservation charge, allowing the DSO to get sufficient flexibility in areas where issues are predicted. Different approaches can be used in this market to reserve flexibility, and they include:

- Reservation only (e.g., obligation to bid for example on LFM on day-before operating hour) - if bid is accepted on day-before LFM, then activation will happen there.
- Reservation and optional activation – where the DSO will inform day before, if reservation is going to be utilized, i.e. activated. If not, bid may be allocated to another market.
- Reservation and activation – where everything (reservation and activation) are decided immediately. Reservation and activation may have separate fees.

When necessary, services might be triggered closer to real time although it might be very difficult or costly to guarantee that flexibility is available a whole year in any moment. In order to have reasonable priced flexibility bids, some mechanisms are needed to inform when the flexibility is needed. Other moments the same flexibility may be utilized for alternative usage. . The DSO will then make a payment for activation and registration. The real-time market will determine the actual charge, but the long-term market may agree to a maximum price ceiling for the reservation activation cost. The long-term market has the possibility for new activations over the defined period. The DSO might make the reserved flexibility accessible in the real-time market, for example with the predetermined maximum price limit, by making a request to the cleared aggregators closer to the delivery time. The DSO is aware of the maximum cost for the sought flexibility required to address anticipated congestions by adding together the activation and reservation price in the long-term market. Long-term contracts would increase consumer engagement, hence increasing market liquidity, while this market mode offers an alternative to grid reinforcement.

b. Short-term Market

This market mechanism handles the services anticipated for the next day that cannot be handled by long-term contracts. Forecasting errors resulting from the expected inaccuracy of the mechanisms used for long-term congestion forecasting, the potential underestimation of potential congestion by the DSOs, or the advent of a congestion problem that has not yet been anticipated all have an impact on these services (larger DER integration). The short-term market is open for a set period of time the day before (for example, from 12:00 on the day before), during which the DSO can purchase flexibility reservations for the next day. Similar to the long-term market, the short-term market will allow for the reserve and activation of aggregators' flexibility.

c. Real-time market

This market mode is in charge of activating the services for the upcoming time period (for example, one hour), as well as the capacity that has been reserved in the short-term or long-term market modes, including the flexibility needed to handle unanticipated contingencies that cannot be handled by the reserved capacity. This market mode's time resolution is 15 minutes. The DSO has two choices following the clearing of the relevant real-time market: either assume direct control of the resources or employ the approved resources in line with its requirements for the subsequent time step (15 min). This can be done by sending dispatch signals to the relevant aggregators, who will then be in charge of adhering to the schedule and deciding which resources from their portfolio will provide the necessary service. The DSOs supply a pricing curve for the relevant service because in-real-time grid reinforcement is not a possibility, and the aggregators submit their price curves based on the flexibility they are willing to provide in response to the request made by the DSOs. Most LFMs work differently, where aggregators publish their multiple flexibility offers (price, capacity, etc.) based on DSO's request (congestion area, capacity, duration, etc.) and DSO select the most suitable combination offers. Because of this, the DSO is ready to spend more in the real-time market to activate as much flexibility as possible to handle the upcoming issue.

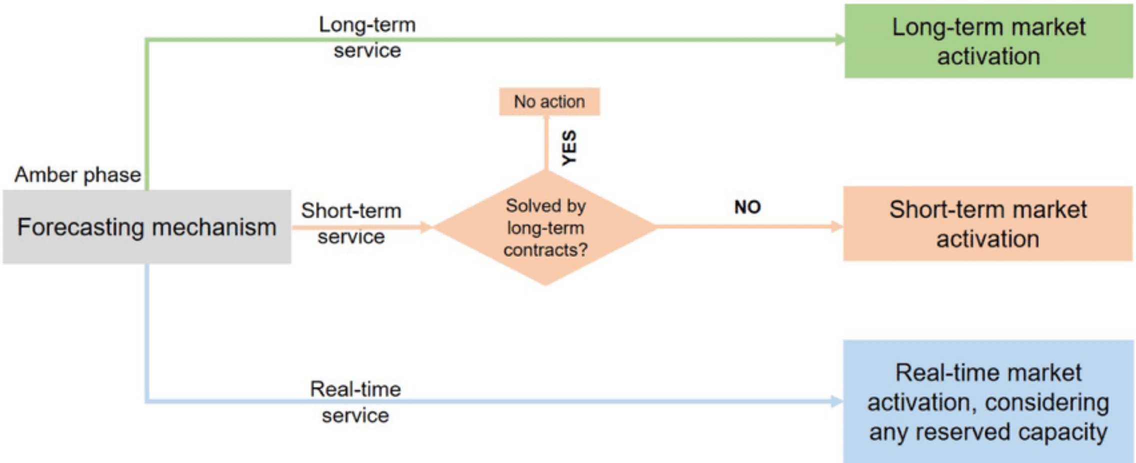

Fig.4 Depicts how several market modes interact with one another [76].

The figure above shows how the several market modes interact with one another. From the above figure, it is reasonable to suggest that the DSO uses a congestion forecasting method to continuously predict its future condition, and that when a problem is identified (the amber phase), it notifies the LFMO to activate the market. The market is idle when there are no issues found (green phase). When an emergency arises and the market cannot find a solution, the DSO directly takes control of the resources to run its network. When a service requirement is anticipated, the DSO notifies the LFMO through a signal to activate the appropriate market mode (i.e., short term, long term or real time).

4. COMPARISON OF THE LFMOs KEY PERFORMANCE INDICATORS

There are a variety of flexible applications for the resources connected at the distribution level. Their flexibility can help with system balancing and congestion control which can help to reduce or defer investments on the grid network. A market operator, whose primary responsibilities include establishing the market platform, clearing the market, and settling transactions, is required to do this. To preserve openness and stop foreclosure, this market operator must retain total independence from market activity. Also, there is need to include the long-term contracts and reservation payment used to guarantee the availability of flexibility reserves with an instantaneous market activation market are one of the potential concepts for flexibility markets. There is debate over whether and how flexibility service providers be allowed more autonomy when defining their services or if there is need to standardize the
the products that are exchanged in the flexibility markets.

4.1 Key Performance Indicators (KPIs) used for the Study

In the previous chapter, we have introduced the concept of Local Flexibility Market and also the European Local Flexibility Market Operators which is relevant in this thesis. In this part of the study, we will focus on the KPIs considered in the qualitative analysis during the course of this study and the results from the comparison of the KPIs. The KPIs used in this analysis include the following:

- Technical Performance (Market Integration)
- Organizational Aspect (Third party market operator)
- Economics (Reservation Payment)
- Quality of Flexible Service (The Product)
- Grid Regulation

The important features of four flexibility market operators (PicloFlex, ENERA, NODES, and GOPACS) are discussed in the subsection. The analysis is realized by comparing the above mentioned KPIs between the four flexibility market operators (PicloFlex, ENERA, NODES, and GOPACS) to see how they fared.

4.1.1 Technical Performance (Market Integration)

Here, our main emphasis is on how the flexibility markets can be integrated with wholesale and/or balancing plus, reserve market. Two projects that offer distinct platforms are Piclo Flex and Enera, while GOPACS and NODES are two other initiatives where the flexibility market is slightly incorporated into the present sequence of the energy markets.

Piclo Flex is a privately run marketplace that allows flexibility to be traded across time and geographical dimensions between FSPs and DSOs. Basically, there is no integration when it comes to Piclo Flex. Only aggregator has freedom to operate on other markets outside a service window. The primary goal of Piclo flex is to create a marketplace to regulate and ease the purchase of DSO flexibility, improve the usage of the current grid, and minimize the necessity for grid reinforcement. In terms of the market structure of the market platforms, Piclo Flex is characterized by a single auction buyer which is solely the DSO while the sellers of flexibility can come from asset owners, aggregators, consumers, generators, EVs, community and municipality.

Enera is a different platform as well. Enera operates throughout the intraday period. Network operators send flexibility demand orders and flexibility suppliers submit offers, which are continually matched on the platform. When using the services of EPEX SPOT, market participants can access the Enera trading platform using the same API used in the intraday (energy) market trading. Market participants may choose to submit bids for several markets using the same underlying asset (Aggregators IT systems and APIs). The prices of the deals may vary. The activations, however, wouldn't work together if all of the bids on all of the separate marketplaces were accepted. The flexibility providers are in charge of preventing duplicate activation [78].

GOPACS is incorporated into the existing market order. By drawing flexibility from existing schemes, the integration is accomplished. GOPACS only has a link to ETPA, but further market connections are anticipated. Instead of being placed on a separate platform, locational flexibility solutions for grid operators on ETPA are seen as a part of the (wholesale) ID order book. The same flexibility is available to both network operators and market parties (BRPs). By making two orders, flexibility suppliers might choose to give the same flexibility at two different costs (e.g., one portfolio offer with locational information and a second offer for the intraday wholesale). Avoiding multiple activations is the responsibility of the flexibility supplier. It is unclear how GOPACS will link the balancing markets and intraday markets since there is no link between the two markets currently.

NODES is included in the existing market order. Two methods are used to integrate. First, like ETPA and GOPACS, Network operators acquire their flexibility options on the same platform as BRPs since NODES is an intraday platform. Once more, flexibility providers could develop many offers using the same underlying assets at different prices, and they are responsible for avoiding repeated activations. Second, the NODES platform's flexibility, which is not needed locally, is anticipated to help the cross-zonal intraday and balancing markets.

4.1.2 Organizational Aspect (Third party market operator)

The platform is run by a third party in each of the four scenarios. A new player in the energy industry called Piclo runs Piclo Flex. Piclo creates software to make power networks intelligent, dynamic, and sustainable. The top independent platform for flexibility services is Piclo Flex. With more than 12GW of verified flexible capacity, Piclo Flex streamlines the whole process for System Operators (SO) to obtain energy flexibility from Flexibility Service Providers (FSP). The market opening and closing times in Piclo Flex are determined by the contract, which may be written months or even years in advance of the validity period. The resource might be provided to other markets or offered for other reasons beyond the availability window. The procurement mechanism in this market is through separate auctions. The activation method depends on the contract. Remuneration is based on a contract. Pricing options include fixed, regulated, and marginal pricing. Measurements in reference to a baseline based on units or other metrics are used to track compliance [79].

In Enera and GOPACS, the system operator can influence zonal market dispatch to prevent congestion by paying a congestion spread across offers when using locational intraday offers. The market opening time is mostly one day before delivery (similar as continuous trading on intraday markets) and closure time is based on intra-zone which is same as intra-day market, but most likely trading hours before delivery. The procurement channel in this market is through Power exchange (and a coordination mechanism), and for intraday trading where the same offers can be used. The mode of activation is by self-dispatch. Also, the renumeration utilized in this case is Pay-as-bid energy remuneration [79]. Measurements in respect to (unit-based market position), a supply schedule, or a baseline are used to track compliance. Also, GOPACS uses an independent new power exchange (ETPA) as its platform supplier and also acts as a mediator between the market platform and the network operators.

Similar to Enera, the second major European power exchange, Nord Pool has NODES support. NODES are owned by Agder Energi in addition to Nord Pool. Both generational assets and distribution network assets are held by Agder Energi. The market opening time is mostly one day before delivery (same as balancing market) and closure time is trading hours before delivery. The procurement channel in this market is through balancing energy market, and similar offers can be utilized for the balance mechanism and there is potential connection to capacity markets for regional balancing

and flexibility. The mode of activation is by system operator manual dispatch. Also, the renumeration utilized in this case is Pay-as-bid energy remuneration for utilization and compliance is verified through measurements [79].
Some market operating responsibilities may be delegated to external parties, but other functions like validating offers and product design may fall under the DSO's control. By delegating the market operation up to a third party (LFMOs), the neutrality of buyers and sellers is ensured [80]. The neutrality of the purchasers is ensured, for instance, when the flexibility market is incorporated into a local wholesale market or when both TSOs and the DSO utilize the same channel to order flexibility. The platform for flexibility procurement will be monopolistic by design if network operators (DSO or TSO) are in charge. But this isn't always the case if a third party manages the platform because the aggregators will also take part in the market. Also, supposing the network operator has access to batteries or other forms of distributed energy resources, neutrality would become even more crucial but this is not possible in the European energy market.

4.1.3 Economics (Payments)

Looking at the four initiatives in terms of economics, we consider the market frequency, pricing method, settlement, bidding period, and incomes of the market operator. Pay-as-bid, which aligns with continuous trading and selects bids that are reducing local congestions in each of their different order books, is the identical pricing strategy used by all four market participants that were taken into consideration for this study. Market frequency in Piclo flex is auction based for the bidding period and tenders are planned out at least six months in advance. The length of a contract might range from a few months to four years. and market settlement is done through renumeration (dispatch payment and availability payment). It should be highlighted that the market operator's income comes from the commercial contracts that have been negotiated with the DSOs, allowing DSOs to purchase flex and other "smart" energy services through Piclo's flexibility marketplace. The ability to contract with several additional services, known as revenue stacking, is a key component of the flexibility bids organized on Piclo Flex. Long-term agreements ensure that there will always be flexibility by managing the risk between the market participants and the grid operator. Long-term agreements with sufficient advanced notice and contract period are one conceivable solution to such a problem. As a result, flexibility suppliers are given the time and financial security to make the necessary investments. The notice period between the opening of the tender and the begining of the agreement for reinforcement deferral (caused by load increase) is either six or eighteen months. Right now, the principal use of UKPN is reinforcement deferral.

The lead periods may be drastically shortened in the future, maybe to only a week. There hasn't been a reservation made yet because Enera's purpose is to prevent curtailment.
In the case of Enera, the flexibility services offered by Enera are mostly for congestion management and relation with ID market while the products traded in the market includes capacity and activation. Market frequency in this case involves the clearing period; ID trade interval (15 min) and the gate closer which is 5 mins before delivery. The bidding period is a continuous process, then bids are matched by the platform. All created transactions are then gathered and billed to the appropriate market participants towards the end of each month once the market is settled by dispatch payment [70]. EPEX SPOT supervises pricing development, assures high levels of visibility on this expanding market, and acts as an unbiased arbitrator between demands for flexibility from system operators and those of regional suppliers.
In the case of Nodes, the flexibility services offered by Nodes are mostly for balancing and congestion management while the products traded in the market includes mFFR, RR and capacity. The timescale will be adjustable for each location and market in terms of market frequency, and it will work with existing markets' mechanisms for settling imbalances. All orders are automatically matched with one another or selected from an order book that the customer will activate. Each month, the market is settled, then baseline for assets is provided by the FSP. Here, one or more GLs make up a local pricing area. Depending on the level of flexibility purchased by the TSO or DSO, the local pricing zones can change dynamically and quickly.
The flexibility services offered by GOPACS are mostly for congestion management and relation with ID market while the products traded in the market includes activation. In terms of market frequency, grid operators can publish congestion predictions in GOPACS continuous market whenever they need to, and the bidding period is before the intraday gate closure time. The market platform also handles settlement in this market. A monthly fee, a price per interchanged MWh, and an eligibility fee are levied to FSPs taking part in ETPA. The ETPA and GOPACS are completely integrated into continuous trading platform in the Netherlands.

4.1.4 Quality of Flexible Service (The Product)

It can be stated that the products for three of the projects (Piclo Flex, Enera, and GOPACS) are standardized. However, there are significant differences across the projects in the designs of the standardized items. NODES do not standardize its products.

Standardized products are available in Piclo Flex. At the time of the tender, the activation product for short-term is selected for each designated area. In Piclo Flex, UKPN has 73 constraint regions specified as of this writing. The minimum and maximum running times, as well as the service window, which refers to the period of the contract during which this service window is valid, are the other crucial operational elements in addition to the location and voltage level. Throughout the prequalification procedure, all additional technical characteristics are verified.

In Enera, EPEX SPOT, in collaboration with the grid operators that buy the flexibility, determines the standard product definitions. The products have the same layout as intraday having loads of energy up or down for a specific amount of time (such as 1 hour or 15 minutes) for a specific place. Each order is tagged with its location and corresponds to a certain Enera-predefined node [78]. Orders from one or more nodes are included in the local order books.

In its current form, GOPACS buys standardized goods from ETPA and adds a locational identifier to them. A locational tag is identified by its EAN-code which is a standardized barcode used to exchange information between the network operator and the energy supplier. GOPACS is distinctive in that it always buys a mixture of two orders (a buy order and a sell order). An Intraday Congestion Spread (IDCONS) is what this item is called. The buy and sell orders are formatted similarly to intraday wholesale orders, but they are located in a separate region. A sale order in terms of energy will be acquired by GOPACS in that particular portion of the grid if congestion develops in one area of the network as a result of a high load and at the same time a buy order in terms of energy will be activated at the same time in a clear region. An energy imbalance is therefore prevented. Energy purchase orders will cost more money than energy sale orders, and vice versa. The network operator that wants flexibility is responsible for paying the price differential between the orders.

NODES doesn't establish any common product definitions. As an alternative, flexibility providers could decide to define their solutions using a range of factors. Examples include the financial and technical characteristics, but it is also possible to specify the source of the generation. Flexibility buyers may select offers from the catalog and then choose the lowest deal that meets their requirements. Network administrators can also establish a template with the parameters they want to be supplied using NODES. Flexibility offers can reveal the grid locations (GL) they are tied to in terms of location. The demarcation of GLs is determined by DSOs and TSOs; GLs are always smaller than bidding zone areas and smaller for DSOs than TSOs.

4.1.5 Grid Regulation

- **TSO-DSO Cooperation**

The way that TSO-DSO collaboration is handled varies amongst the projects. Piclo Flex is currently only utilized by DSOs, and there is currently only a limited amount of collaboration with the TSO. Any time a DSO engages a resource to help with congestion control, the TSO must be informed [80]. TSOs and DSOs can both acquire flexibility on the same platform, thanks to Enera and NODES. The TSO is not yet operational in the instance of NODES.

GOPACS is quite important in this context. One of the earliest TSO-DSO coordination systems to be used was GOPACS. GOPACS ensures that there are no incompatible activations in its present configuration. Future plans include locating mismatches between the requirements of various network operators. In the case of Enera, one DSO is acquiring flexibility, and the TSO has started engaging in active buying. In the initial stage of the Enera initiative, known as Enera 1.0, the DSOs and the TSO are expected to engage mutually when activating an offer in order to prevent disagreements. Future bids and offers will be screened on the market channel to avoid conflicting activation, similar to how cross-zonal offers or bids won't be available if cross-zonal links are congested during (horizontal) market coupling [78].
In a NODES implementation, no TSO is currently operational. The TSO will soon be operational in the prolonged Norwegian pilot. Future TSO-DSO collaboration will be addressed by screening out proposals made to one network operator if they will interfere with operations at other network operators. In order to prevent conflicting activations, the definition of grid locations (GLs), which are nothing more than collections of physical points, can also aid in increasing the transparency of one network operator’s operations for other network operators.

- **DSO-DSO Cooperation**

To establish their flexibility market platform as the de facto option in Europe, all platforms want to collaborate with more DSOs in the future. All six of Great Britain’s DSOs took part in the BEIS testing for Piclo Flex. Piclo has since inked business contracts with three DSOs to assist with recent flexibility procurement attempts. On Enera, there are presently two DSO operational (EWE NETZ and Avacon Netz). Vertical connections between DSOs exist in the instance of Enera; EWE NETZ is linked to Avacon Netz, which is linked to the TSO TenneT DE. Compared to Piclo Flex, this is different. For TSO-DSO cooperation in GOPACS, four DSOs in addition to the TSO use the same platform. There is only one DSO running at the moment in each NODES installation. It’s anticipated that more DSOs will shortly join the platforms [78].

If DSOs collaborate and use the same channel, the learning costs for flexibility providers with resources in different DSO regions to use the channel could be reduced to a minimum. If two DSOs are vertically connected, activations at their boundaries may have an impact on each other’s networks, just as they do when two TSOs are connected at the transmission level. Lets say there could be a congestion issue in the vicinity of one DSO, while less expensive flexibility exists in the region of another DSO which could be used to address the issue is accessible in the vicinity of another DSO. Coordination and cost-sharing agreements across DSOs must be created in such a situation, and these agreements are simpler to create if the same or comparable flexibility platforms are employed.

4.2 Results of Comparison

First, in terms of market integration, PicloFlex and Enera uses a separate platform and are not integrated in to the existing market. The primary justification for having separate platforms is that doing so shows the variations between the items (whether or not they are related to location), makes it simple to clear the market, and fosters pricing transparency. NODES and GOPACS are integrated into the existing market and one of the main reasons behind this is the ease of providing one platform to connect to and submit a single offer that may be used for balancing, congestion management, or for a BRP to balance its portfolio. This lessens the difficulty and expense of accessing many platforms. Additionally, allowing other market players (BRPs) to acquire locational flexibility in the same market as grid operators might actually turn that market into a secondary market for flexibility suppliers, which is another argument in favor of integrated markets.

Secondly, the flexibility market operators in all the four initiatives (Piclo Flex, Enera, Nodes and Gopacs) uses a third party as the market operator. Creating the market platform, clearing the market, and settling transactions are the key responsibilities of the market operators. The market operator must retain total independence from market operations in order to preserve transparency and prevent foreclosure, and the party acting as the market operator will depend on whether the flexibility market is connected or separated from other markets. The need of network operators acting as impartial market facilitators must be emphasized once more.

Thirdly, looking at the four projects, the flexibility services offered by piclo flex are mostly for voltage control and congestion management, and the products traded in the market includes capacity, activation, and active power. Market frequency in this case is auction based and for the bidding period and tenders and bid periods are planned with a lead-time of at least six months. The length of a contract might range from a few months to four years and market settlement is done through renumeration (dispatch payment and availability payment). The flexibility services offered by Enera are mostly for congestion management and relation with ID market while the products traded in the market includes capacity and activation. Market frequency in this case involves the clearing period; ID trade interval (15 min) and the gate closer which is 5 mins before delivery. The process of bidding is continual, after which the platform matches bids. The flexibility services offered by Nodes are mostly for balancing and congestion management while the products traded in the market includes mFFR, RR and capacity. In terms of market frequency, the duration will be adjustable for each location and market, a and it will work with existing markets' mechanisms for resolving imbalances. The buyer will activate an order book from which all orders are automatically matched or selected and every month, market settlement occurs. The flexibility services offered by GOPACS are mostly for congestion management and relation with ID market while the products traded in the market includes activation [70]. In terms of market frequency, GOPACS operates a continuous market in which grid operators can publish congestion predictions as needed and the bidding period is before the intraday gate closure time. Also, settlement in this market is carried out by the market platform.

Furthermore, three of the projects (Piclo Flex, Enera, and GOPACS) might be considered to have standardized products. The standardized goods' designs, however, vary greatly amongst the projects. NODES don't have standardized products. NODES accepts almost all flexibility. So, liquidity is very high this respect but buyers will finally decide what they really accept and therefore the liquidity is finite. The major justification for standardized goods is that they permit a sufficient amount of liquidity, allowing for the creation of a merit order to regulate the competition. Consequently, pricing transparency is encouraged with standardized items. When it comes to non-standardized items, comparing the value of offers is more challenging. As a function of the potential product characteristics, there are exponentially more distinct flexibility offerings that may be provided.

Finally, in terms of coordination between TSOs and DSOs, Piclo Flex is currently only utilized by DSOs, and there is currently only a limited amount of collaboration with the TSO. The TSO must be notified when a DSO activates a resource for congestion control [80]. One TSO and four DSOs have constructed and are using GOPACS. TSOs may purchase flexibility on the same platform as DSOs thanks to Enera and NODES. The TSO is not yet operational in the instance of NODES.

Also, in the case of DSO- DSO coordination, to establish their (customizable) flexibility market platform as the de facto option in Europe, all platforms want to interact with additional DSOs in the future. All six of Great Britain's DSOs took part in the BEIS testing for Piclo Flex. Piclo has since inked business contracts with three DSOs to assist with their ongoing flexibility procurement efforts. Currently, there are two DSO active on Enera.

The four European LFMOs (Piclo Flex, Enera, NODES and GOPACS) and some of their features in the electricity market is shown below:

***Table 1**: The four European LFMOs and some of their features in the electricity market*

FEATURES		YES	NO
Integration in the existing sequence of electricity market		GOPACS, NODES	Piclo Flex, Enera
Third Party Market Operator		Piclo Flex, Enera, GOPACS, NODES	NIL
Reservation Payment		Piclo Flex	Enera, GOPACS, NODES
Standardized Products		Piclo Flex, Enera, GOPACS	NODES
Grid Regulations	TSO-DSO Cooperation	Enera, GOPACS, NODES	Piclo Flex
	DSO-DSO Cooperation	Piclo Flex, Enera, GOPACS, NODES	NIL

4.3 LFM Use Case Analysis

In this section, we will analyze some use cases for some of the local flexibility market operators to know how they are used in congestion management process. Also, from here we tend to deduce the market operator that best fits the system when we are considering reducing grid investment through reinforcements. There are several projects that are actively trying to reduce grid congestion. Below is a quick description of some of them and how they handle congestion.

- **Case 1 (Piclo Flex)**

The long-term CM service may be utilized for the flexibility demands, which can be anticipated a long time in advance depending on how frequently the market operates (e.g., yearly, seasonally, monthly, or weekly). On the basis of the planned repair or construction, their grid's seasonal hosting capacity (HC) fluctuations, anticipated load/production variations, etc., the grid operators are expected to estimate the forecast for their flexibility needs. The choice to activate should be made one day before the real-time operation, and the capacity reservation takes place when the market operates (for example, a week in advance). As previously indicated, the long-term CMM lead time varies according on the legislation, requirements, and stakeholder concerns at the national level, from a yearly to a weekly market. This allows signed-up users a way to choose the generator or provider they want to match with. The match covers a wide range of factors, including ownership, cost, and location. Because the bids are organized by constraint area, any flexible resource tied to a certain geographic region is eligible to participate. Multiple tenders may be held for the same constrained area for various services (such as maintenance and reinforcement deferral) and various contract lengths.

- **Case 2 (GOPACS)**

Let’s assume that there will be congestion on the electrical grid someplace. System operators assess the amount of demand growth in this area of the grid or decrease in power generation as a possible repair. Following that, business parties receive an invitation to tender via GOPACS. Then, an appropriate purchase order is placed on a forum for this region's intraday market. However, the equilibrium of the national power system can be maintained thanks to this activity that relieves congestion. As a result, the reversal of the offer by a business group to leave the congested zone coincides with the decrease in the output of electricity in the congested zone. As soon as possible, GOPACS must make sure that this directive doesn't cause any problems anyplace in the power system. If everything appears to be in order, the grid operator will charge the difference in price between the two orders [73]. By matching all orders, congestion in this process may be completely eliminated. GOPACS provides both large and small business parties with an easy option to collect money using the variety they have available and to help deal with congestion conditions. GOPACS functions in a manner that is compliant with the major European guidelines on market-based grid congestion control.

- **Case 3 (NODES)**

Assuming that the 110-kV-network System's condition is characterized by a large inflow of renewable energy, particularly in the network regions. As a result, these network locations have an excess of the total produced electricity. The extra-high-voltage (EHV) systems require the DSO to transfer the produced power to the points-of-common coupling. To do this, the DSO must add additional EHV grid connection points and new, higher transmission capacity lines to the current grid. The DSO's daily responsibility is to ensure secure network operation. Congestion control techniques are required up until the grid expansion is finished. When this happens, flexibility providers tag a grid location (GL) in NODES. These buyers must express a desire to pay for flexibility activation at certain grid locations where congestion is happening and convey this desire to NODES continuously via an API. One or more GLs make up a local pricing area. Depending on the level of flexibility purchased by the TSO or DSO, the local pricing zones can change dynamically and quickly. The flexibility is offered by the flexibility providers, who are employed by the owners of the flexibility assets and deliver their offers to NODES via another API. The majority of the working hours throughout the year at the actual grid site do not require the flexibility; usually, just a few hundred hours are needed each year. Additionally, flexibility that is not used locally might be offered to the TSO or to Balancing Responsible Parties (BRPs), increasing value for flexibility providers and lowering expenses for the DSO.

- **Case 4 (ENERA)**

This flexibility platform balances supply and demand for flexibility in situations when there is network congestion, assists DSOs in managing congestion, and lessens the total curtailment of renewable energy. Supply and demand are continually matched by ENERA, and the company provides DSOs with order books that have unique region identities so that these flexibilities may be exploited for network operation. The main functions of the Enera platform includes bid collection, market monitoring (verification platform), clearing, settlement, computing network impact (by grid operators), developing aggregation activities, and individual flexibility activation. In Enera, network managers may buy flexibility in the intraday timeframe to proactively lessen congestion. Local order books are put up in Enera because grid congestion is peculiar to particular places on the grid. This local order books contains the records of the previous congestion on the network and the part of the network where the congestion occurred. To guarantee efficient congestion management and to prevent new congestion, system operators evaluate their flexibility demands (location, timing, and amount) and share their grid limits with the other system operators.

5. CONCLUSION

The major function of the electricity network is to deliver electricity from the generating stations to the consumers. The power system network is designed in such a way that the generation units are connected to a transmission network that operates at a high voltage with minimal power loss. Distribution networks, and how they are managed, will need to become more active and adaptable as electricity flows grow more sporadic and unpredictable. Congestion in distribution networks can be due to increasing integration of distributed energy resources, power lines failure, generator failure or even uncoordinated operation of flexible loads. As a result, congestion control strategies are required. The most common solution to the congestion issue is network reinforcement; nevertheless, it cannot always be employed for two major reasons. It is first costly and time-consuming. Second, because the planning process is so long, the uncertainty around key planning factors like power generation municipal planning, and consumption, etc. increases, making it hard to make quick decisions. The introduction of the LFM for solving network congestion problems is what was proposed in this thesis and evaluation of four LFMO (Piclo Flex, Enera, GOPACS, and NODES) in Europe was carried out to see how each of them fared in the fight against network congestion.

The findings and research done for this thesis are compiled in this chapter. The conversation is summarized and the research issues from this study are presented and addressed. This thesis considers the congestion distribution system so there is need for the flexibility market to be in line with the local DSO requirements. As discussed in the thesis, the local DSO oversees notifying the market operator of the signal for market activation and the request for required service. Therefore, we can see that the flexibility market is in line with the DSOs requirement because after the DSO confirms that a service is required, he sends the activation signal to the LMFO who will now oversee establishing a specific order book and advertising the service request to all participating aggregators. Prior to that, the DSO will access the anticipated circumstance and make decisions on the volume of flexibility needed, the place where flexibility is needed, the length of service and the maximum pricing of the service. All these actions coming from the local DSO will not be possible if the flexibility market does not meet DSOs requirements.

LFM structure focuses on assisting DSOs in efficiently managing their own part of the distribution networks through the purchase of activation and reservation of flexibility over a variety of time frames, regardless of the schedule of the required services or the type of the anticipated challenges. LFM intends to offer DSOs a market-based tool for effective network management, regardless of the source and characteristics of congestion problems, as well as the competing market actors' interests. Market participants can also trade both activation and reservation of flexibility under the LFM framework. The prospect of reducing or totally avoiding grid reinforcement can be enhanced by DSOs by reserving the essential flexibility via a long-term market structure based on the outcome of the market operation [66]. If the forecasting systems determine that more flexibility is needed, DSOs can however reserve additional flexibility (for the next day) through the short-term market. LFM offers DSOs a market-based tool to save long-term grid reinforcement costs while maintaining the distribution system's secure operation closer to real-time.

It is anticipated that a market with well-defined regulations and accepted trade practices will raise everyone's understanding of the use of flexibility, resulting in its more effective application in upcoming energy systems. Prior to designing the local markets for trading flexibility, it is important to first define the participants and their goals for LFMs, which in this case is reducing investment on grid reinforcements. Stakeholders in the LFM framework include the local DSO who is in charge of notifying the market operator of the signal for market activation and the request for the required service, the LFMO which is the organization in charge of running the LFM's most crucial functions, including collecting bids, market activation, contracts between DSO and successful bidders, market clearing, and market settlement, also the FSPs who are in charge of gathering and managing the flexibility of their assets as well as reflecting them in the LFM by submitting bids in response to the DSO's requests. These resources can be prosumers, local DER owners, EVs, building and storage owners, or even households with flexible loads.

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