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Bericht 3.3.1, 3.3.2: Modeling of local markets-systems at distribution network level

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Modeling of local markets-systems at distribution network level

1. Background and research gap

➢ 1.1. Formation of a local energy market

The rate of development of decentralized transactive management systems has accelerated considerably as a result of expanding renewable energy source technologies and communication infrastructure at the distribution system level. Such bilateral energy exchanges have altered the structure of electricity markets and led to the formation of a local energy market within the distribution network system.

➢ 1.2. General goal of the electricity market

The energy market's overall goal is to provide electricity in a cost-effective manner while fulfilling consumer demand.

Different methods of achieving this goal include:

- ✓ competition
- ✓ legislation

The traditional energy market is struggling to:

- integrate new electrical generation sources
- technology
- infrastructure
- rising demand
- consumer-oriented market

It has moved the paradigm toward a new market structure that can fit into the current market structure. The local electricity market is one of these markets.

➢ 1.3. Local Electricity Markets (LEM) as the solution for Traditional Electricity Markets (TEM)

The management of power distribution systems has witnessed many changes as the structure of power systems has changed.

The systems are under severe pressure due to:

- Increased demand growth

- Irrational tariff policies
- Network constraint
- Lack of investment resources

As a result, it must transition fast from a traditional system to one that is intelligent and decentralized [1].

With the beginning of restructuring, it will be possible to sell energy in a competitive environment, and energy exchanges between different producers and consumers will be possible through the mechanisms of the electricity market. Distribution companies can buy energy from wholesale markets and sell it through retail markets using these processes. Such competition over retail electricity supply has created a good opportunity to choose the electricity supplier to different distribution system consumers [2].

However, energy is frequently provided from large-scale generators to various consumers across long distances using this traditional system, which is essentially one-sided. At the distribution level, distributed generation (DG) units based on renewable energy sources (RES) have increased dramatically in recent decades. Traditional energy customers become prosumers who can both consume and create energy as these resources increase [3]. Because of the intermittency of these energy sources, a prosumer's surplus can be stored, transmitted to the power grid, cut off, or sold to other energy users [4].

In recent years, demand response (DR) concepts in distribution systems have been developed to:

- balance energy production and consumption
- avoid network congestion problems
- peak load control [5,6].

With different DR approaches, each consumer can benefit from a variety of monetary incentives by controlling all or part of their load. In this regard, following items encourage the transition of traditional electrical loads with passive behavior to ones with proactive and flexible behavior [7]:

- advances in information and communication technology (ICT) devices
- smart meters
- and telecommunication platforms

Prosumers are currently involved in managing consumption, production, and storage, and this attitude can influence prosumers' perceptions of electrical energy, ranging from their participation in energy communities to their need for greater flexibility in trading energy on local energy exchanges. The advent of these future modifications may open up a new space for energy trade for entities who have equal access to a common energy source via cooperating infrastructure [8]. For these reasons, the need to reorganize the electricity markets based on decentralized management and cooperative principles with a bottom-up approach is inevitable to capture prosumers' capabilities [9]. In the new structure of the electricity market, the energy exchange between loads must be done in a decentralized market environment. The balance of power in their service areas is maintained dynamically, considering predefined regulations and reducing dependence on the utility [10]. Accordingly, as new actors, prosumers will transform traditional electricity markets into consumer-centric markets where actors can trade locally to manage their energy [11]. This market, known as the local energy market (LEM), is built on a local community based on the micro-market concept.

LEM includes:

- Prosumers
- and different types of consumers
- storage facilities in such a community.

Different forms of enabled smart grid services can connect these participants and other market players [12]. Trading in local energy markets is a concept that should enable electricity trading between different peers (decentralized generation, processors, and consumers) in the local distribution network, thereby provide adding value for the participants.

This concept also accelerates the:

- integration of renewable resources in the distribution network
- improves network stability,
- and provides auxiliary services to the rest of the power system [13].

- **1.4. An Overview of Transactions in the Electricity Market**

The several methods of energy trading in the power system are briefly discussed in this section. Following that, the role and strategy of the local energy market inside the distribution system will be examined in several cases.

- **1.4.1. Energy Trading in Power Systems**

Many countries moved towards the formation of competitive electricity markets by liberalizing integrated electricity companies in centralized sectors as the electricity industry structure changed [15].

The electricity market is a system in which electricity suppliers and customers interact to decide energy prices and quantities. As a result, the market (electricity and services) was created for various generating, transmission, and distribution companies in order to make a profit.

In general, the electricity market is divided into:

- Wholesale systems
- retail systems

that conduct transactions based on well-defined protocols [16].

- **1.4.1.1. Wholesale Electricity Market (WEM)**

Large power generators and large power consumers are two main components of power transmission system who participate in wholesale electricity markets to sell and buy energy.

Who are large electricity consumers???

Large electricity consumers are electrical distribution systems that buy energy from wholesale markets to meet consumers' energy demand in different regions.

The wholesale market, which operates at the transmission network level, is responsible for:

- Ensuring the balance of supply and demand
- Maintaining the system's reliability and security

- Minimizing the cost of supplying demand at a system level to the regional level [17].

Participants in this market include:

- Power generation companies,
- Transmission companies,
- Distribution companies,
- Large consumers,
- Independent system operators (ISO)

Electricity is sold through various contracts, such as:

- a central auction (e.g., PoolCo model)
- bilateral contract

Despite interaction between supply and demand, WEM has following drawbacks:

- ✓ Small consumers do not have the option of choosing their supplier and get power only from their affiliated Disco. The benefit of price from the wholesale competition is not accessible to customers as the price is still regulated for them [18].
- ✓ Due to transmission constraints, the supplier raises the electricity price above the competition level [19]. It results in strategic bidding through locational marginal price and thus results in market power causing market inefficiency. Expansion of transmission lines involves all the stakeholders and is a complicated process which requires economic analysis [18]. Thus, transmission lines limits act as a bottleneck between the generation and increasing electricity demand.
- ✓ Liquidity, the ability to sell or purchase the electricity without much change in bid-offer price, is required in WEM to trade and manage the risk. Small generating units face barrier during entry in the market due to the insufficient liquidity and transparency [19]. It limits the competition and ability to manage risk.

➢ 1.4.1.2. Retail Electricity Market (REM)

The retail market was introduced at the level of electricity distribution businesses with the introduction of the Distribution System Operator (DSO), whose role is to purchase high voltage energy from the wholesale market and distribute it to consumers and clients (potential customers). The DSO serves as a point of access to the market's services. In reality, participants can request general services from DSO, and it can introduce and provide them. This market is highly competitive because consumers have access to a wide range of retail services and have free entry into the market, allowing them to switch retailers for better service and reasonable pricing [20]. A flat energy price is commonly established in this market based on the price of the transmission node, which can lead to market inefficiencies if the distribution system's restrictions are ignored [21].

Profit-focused retailers must therefore design their strategies based on two goals in order to produce more profit and lower the financial risk of the commitment:
(1) buying from the wholesale market
(2) selling in the retail market

What procedures are used to handle planning?
The planning is managed through one of the following two ways:

- wholesale markets (such as Real-time markets)
- wholesale contracts (such as Future Contracts)

Some retailers prefer to get some of their electricity through bilateral contracts with small-scale power units at specific times, in addition to buying energy from large power plants. These units can include:

- Renewable energy sources
- Traditional generators such as diesel engines [22].

Overall, the market can obtain the required energy by:

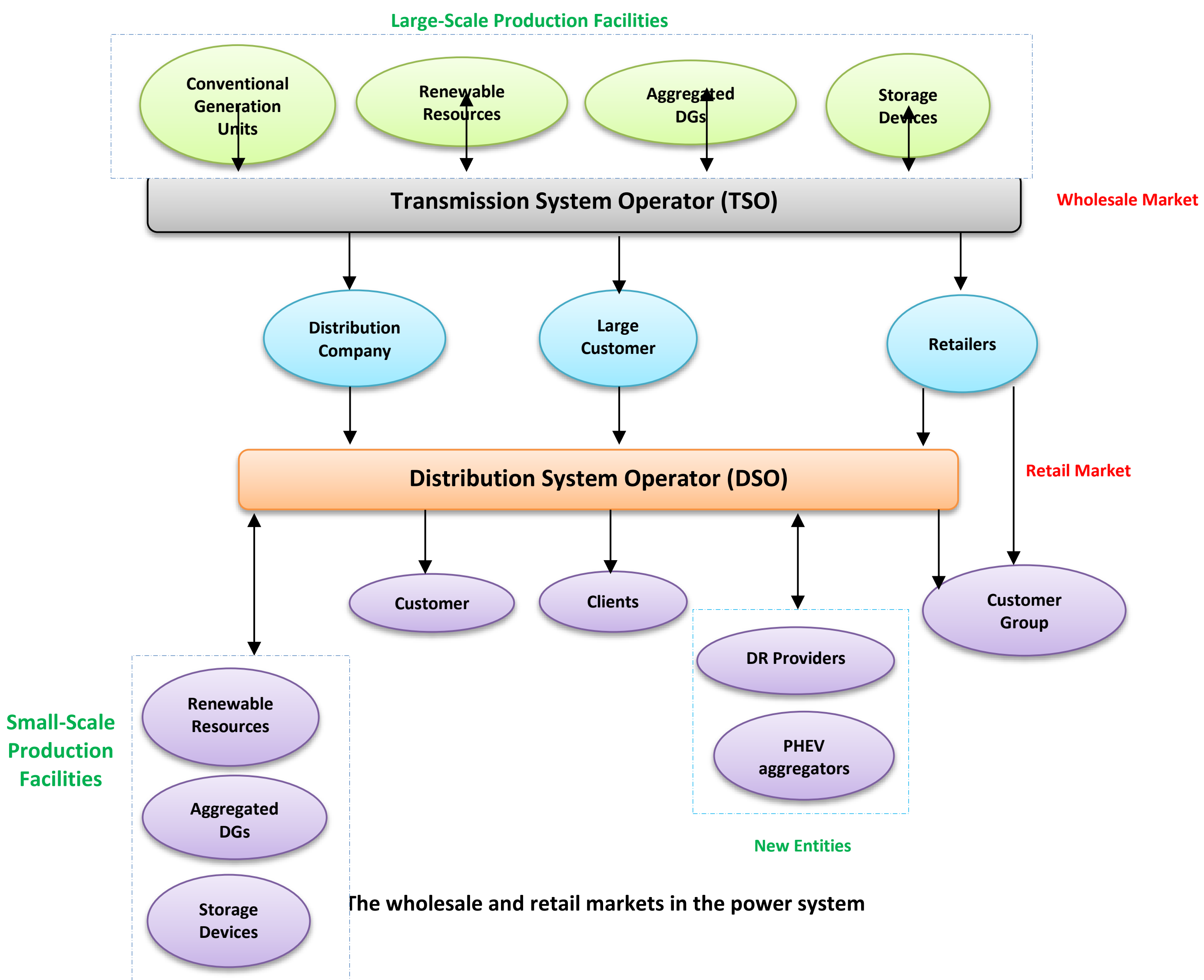
- actual generation sources (traditional and renewable generator)
- and virtual production (DR and electric vehicle response) [23].

DR service providers and electric vehicle aggregators are new entities have been able to offer new capacities to promote the efficiency of power systems as a result of recent advancements in electrical networks.

The retail market is going through following challenges:

- ✓ The customer pays a fixed amount even on varying cost of electricity production [24]. Thus, the system operator is not able to alter the energy use pattern of the customer to shed peak power demand. Unavailability of demand response creates local power in electricity market which reduces competition.
- ✓ Consumer demand is inflexible, unplanned and follows seasonal change. The system operator keeps track on the generating unit and spinning reserve to balance the system. Due to variable RES and requirement of backup generation adds to the flexibility requirement for system operator [25].

Figure 1 shows an overview of the wholesale and retail markets, according to the above explanations.



The wholesale and retail markets in the power system

- **1.4.2. Local Energy Markets at Power Distribution network Level**

The expansion of different DG choices at the distribution system level, as well as the rise of prosumers, are two critical aspects that have posed new difficulties to power production supply and demand dynamics, as well as the requirement for on-site flexibility.

The current market environment necessitates the simplification of entities, structures, and a more consistent behavior after years of centralization.

The goal is to develop a:

- ✓ more predictable model
- ✓ more standard model
- ✓ more transparent model [26].

Transactive Energy (TE):

In response to these challenges, system operators and suppliers began to develop new strategies, which are called Transactive Energy (TE), to achieve a more decentralized system. Therefore, the role of transactive energy is to coordinate active consumers using market-based structures.

That is, the solution is local energy management, which is the decentralized coordination of:

- ✓ energy supply,
- ✓ energy storage,
- ✓ energy transport,
- ✓ energy conversion,
- ✓ energy consumption

in a specific geographical area [27].

Transactive energy, in fact, can be thought of as a free market with internet-enabled facilities, where consumers, prosumers, and networks can trade securely for a fair price and near-real-time settlement to address their mutual problems [28].

In this respect, a decentralized, smart and integrated market model for energy in 2016 was proposed by the European Commissioner to accomplish sustainability targets in the decarbonization of the electricity sector in Europe [29].

In a brief, the concept attempts to empower customers by restructuring the energy industry and giving them greater control over their choices. As a result, consumer-centric electrical markets [8] or micro market/local electricity markets [30] were presented as an alternate market organization.

Local electricity markets can provide two different types of services in the Distribution Systems:

- ✓ Flexibility services
- ✓ Energy services

Difference Between two Services:

The way the parties participate in the market differs between the two services and is as follows:

- ✓ Energy services are used when merely a source of energy is required.
- ✓ However, if it is used to implement demand response methods, it might be classified as a flexibility service.

P2P Energy Trading:

Direct energy trading of consumers and prosumers is called P2P energy trading, which is developed based on the concept of the “P2P economy” and is usually located within the distribution system [32]. The participants' transactions are done separately, one-to-one, and based on pay-as-bid under this architecture, so each transaction has a different price [31]. Another option is the prosumer community group, which strives to create a common platform for adjacent prosumers to coordinate their energy and information exchanges with the local community and even external energy institutions [33]. The concepts of P2P and Community-based transactions are firmly following the principle of participatory economics because it is a structure that eases exchange between members of all agents or peers, so it will be very suitable for local electricity markets.

What is Blockchain?

The P2P approach in energy markets is made with the help of a well-known Distributed Ledger Technology (DLT). The most famous branch of this technology is blockchain. Blockchain can be defined as a distributed and digital transaction technology that allows secure storing of information and execution of smart contracts in P2P networks [34]. Based on a smart contract, energy data transactions must first be approved by peers using a kind of agreed protocol embedded in a common execution path. Instead of having a central body responsible for coordinating, settling, and archiving, the technology does this in a decentralized manner and relies on several institutions that work parallel with a specific ledger copy [35].

The essential applications of local energy markets in the distribution system will be described in the subsections that follow.

1.4.2.1. Flexibility Services in the Local Market

DR and end-user accompaniment can be used to provide flexibility services at the distribution level. Load response has shifted to intelligent load control with two-way communication since the implementation of smart grids. As a result, the program shifts its focus to real-time interactions with the user.

End-user flexibility is required as renewable energy supplies grow in number, in order to maximize their integration and profitability. In fact, dealing with the uncertainty of renewable output and demand-side variability necessitates a high level of flexibility. As a result, flexible power service can be defined as a power adjustment from a specific point in the network at a specific time during a certain period [36].

Despite energy prosumers and distributed energy production (such as PV) or consumption (such as EV), it is predicted that in smart grids, the optimal use of local resources and their benefits due to their physical proximity to the load can be a good factor of local stakeholder interactions through the local energy market [37]. As a result, DR will be a complicated matter in the new environment. In this scenario, transactive control refers to using the local market to manage consumption rates and generation resources on the demand side. As a result, interactive nodes are defined as power transmission connection points between different network sections [38]. Each node in the electrical network is a physical point that represents consumers or prosumers, substations, and power companies. These nodes decentrally and constantly share information for local decision making. The use of open automated demand response (OpenADR) is one of the valuable methods for DR data transmission between different levels of transactive energy systems. All pricing and demand-side information can be transmitted in a common language across nodes and upstream transactive system levels using this technology [39].

As a result, transactive control demand response can be viewed of as a system that involves end-users in an interactive market and optimizes the usage of the power company's intelligent loads and equipment depending on consumer preferences and local network conditions. The use of DR programs in residential and commercial buildings with transactive control has risen in recent years. The major targets of transactive control using DR schemes include loads such as air conditioning systems (ACs) and thermostatically controlled loads (TCLs) [40,41].

Home energy management systems (HEMS) and building automation systems (BAS) have also been used in the transactive control procedures by enhancing and expanding their capabilities. These systems can be useful as a control interface for implementing DR programs in the context of the transactive energy system [42,43]. Electric vehicle charge management can also be utilized as a type of DR program in the context of transactive control. DSO can force different consumers to inject excess surplus vehicle storage power into the network at specific periods to modify the demand pattern in a decentralized transactive system by pricing interactive nodes. In such a system, a fleet operator can act as a network's low-level monitoring agent, preventing congestion and violations of limits [44,45].

Local control of power consumption and generation resources is also possible with TE-based grid management, which includes microgrids and aggregator models.

Interactions and energy management in these situations can be executed in two ways:

- Centralized and decentralized
- Transactive control

In general, microgrids can be divided into three categories, depending on the parties' participation in energy supply and demand.

The goal of energy management in the first class is:
to minimize energy costs one-sidedly.

The second category is hierarchical with two sides:

- microgrid operator
- the end-user

The last category has several parties, each of which can act as a producer or consumer of energy [46]. In each situation, the transactive control system must set the demand-side price such that DR procedures can be executed while the microgrid is operational. As a result, alternative DR models between the virtual power plant and customers are developed, based on cost and the distribution of additional profits between the parties; pricing processes are developed [47].

The aggregator can promote mutual benefits between itself and the electrical system by providing flexibility from available resources by integrating transactive energy technologies within the DSO. An aggregator, in fact, can interface directly with the demand side, tweak registered customers, consumers, and prosumers, and set costs and incentives between them [48]. The load aggregator seeks to maximize its profits by bidding for transactive services in this situation. As a result, in such a local market, aggregators can be managers who offer flexibility to third parties such as DSOs while limiting end-user flexibility by dropping their electricity bills during periods when no third parties have requested it [49].

1.4.2.2. Energy Services in the Local Market

Transactive energy systems, as previously indicated, can use intelligent devices to enable P2P management on smart grids.

To this end, the system introduced a P2P market among all subscribers, consumers, and prosumers equipped with DERs [8]. P2P markets represent only one of the successful models of transactive energy markets, and similar measures can be taken at the distribution network level [50]. For instance, there is the concept of a local pool in the energy transaction of distribution networks, which balances supply and demand with the lowest production cost. In [51], two types of P2P electricity trading mechanisms in distribution systems are introduced for the future distribution system; auction-based P2P trading, bilateral contract-based P2P trading.

To implement the auction-based P2P energy trading mechanism, the Distribution System Operator (DSO), in addition to its responsibilities for the safe and reliable operation of the system, is designed to manage a competitive P2P electricity trading market. In this case, prosumers are considered entities with self-centered economic purposes. In such cases, as a local market's participants, each prosumer submits a price offer to buy or sell to DSO confidentially so that after receiving all the offers, the DSO runs the market mechanism with an iterative negotiation process. According to this mechanism, if the DSO is independent of the utility, the company can submit its offers to the DSO and others.

In the bilateral P2P energy trading mechanism, the DSO's tasks, in addition to its previous responsibilities, was not to manage the market but to provide a platform in which trading offers are sent and traded. Also, to prevent arbitrage, prosumers must register as buyers or sellers in this platform during a particular operation period [51]. In this case, price offers are offered to DSO, and all buyers and sellers can see these prices. If the buyer is willing to trade with a seller, he can send a contract to the bidder and ask for its approval. The approved contract must be sent to the DSO for final approval to review issues such as safe system operation; otherwise, the contract will be canceled.

P2P energy trading allows each peer (a consumer, a prosumer, a manufacturer, or even a supplier) to choose a peer to trade (buy or sell) energy according to their specific goals, such as:

- **minimizing cost**
- **maximizing profit**
- **minimizing pollution**
- **acquire more reliable energy supply [4].**

Customers in P2P markets, if they are prosumers, can trade surplus production with customers who request energy. The energy transaction can also be based on multiple long-term or temporary contracts between all network players.

In general, two types of contracts can be considered:

- **between prosumers and consumers**
- **between energy providers and consumers [52].**

In general, the value of the P2P architecture originates from the sharing economy, unlike the existing distribution approach, which only attempts to save on scale and benefits of the goal. Furthermore, regardless of the market matching mechanism chosen, large-scale P2P interactions are predicted to have an impact on the power company's ability to operate an efficient and reliable distribution network [53]. Figure 2 gives an overview of the local distribution market (LEM).

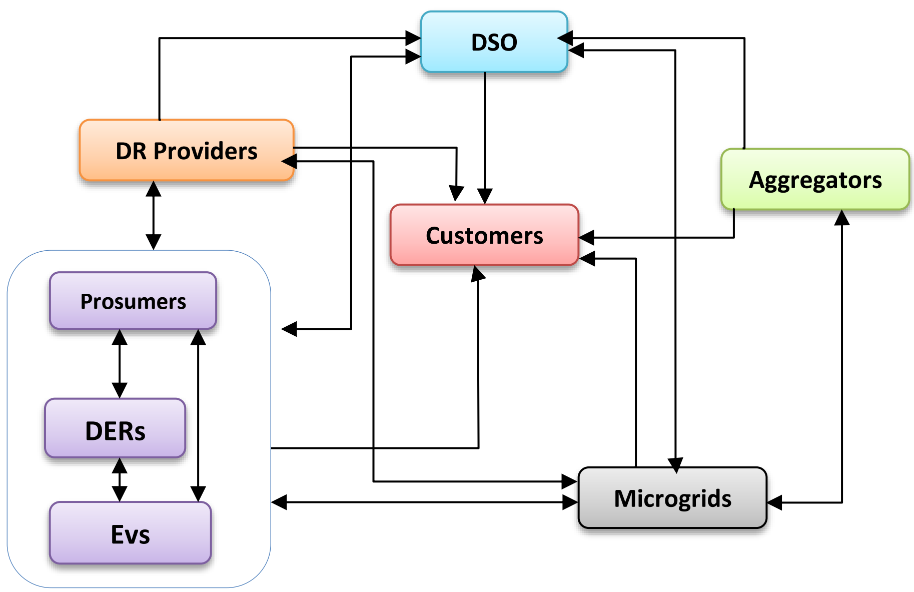
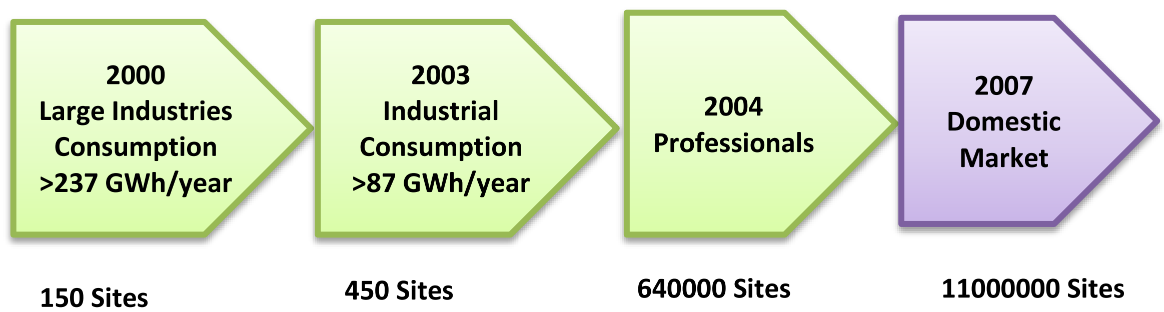


Fig 2: Overview of the local distribution market (LEM)

1.5. An Overview on the Electricity Market in France

1.5.1. The stages in opening up the electricity market in France

With Directive 96/92 of 19 December 1996, the European Union began opening up the energy market. Directive 2003/54 of 26 June 2003 on the internal electricity market complemented these European provisions in order to liberalize the electricity market. In France, the supply of electricity was then a state monopoly provided by EDF, and in some localities by the ELDs- entreprises locales de distribution- (local distribution companies). In France, the two European Directives were transposed by laws No. 2000-108 of 10 February 2000 and No. 2004-803 of 9 August 2004, amended by law No. 2003-8 of 3 January 2003 and by law No. 2006-1537 of 7 December 2006. The liberalization of the electricity market has been gradual, starting in 1999 by companies consuming more than 100 GWh / year and progressively opening up to all professional customers and then to domestic customers in 2007. On 1 July 2007, the entire electricity supply market became open to competition [54].



1.5.2. Opening up the energy market in practice

1.5.2.1. Organization of the players

The first step to opening up the market was to privatize EDF, the incumbent supplier. The company was split into two: a subsidiary for marketing and a subsidiary for managing the distribution networks.

Opening up the sale of electricity to competition involved the arrival of new so-called "alternative" suppliers, including Eni. However, the distribution of energy continued to be a monopoly. Distribution system operators (DSOs) must provide an equitable service to all suppliers. Thus, Enedis, in charge of the electricity distribution network for most of the French territory, offers the same services to EDF (the incumbent electricity supplier) as to alternative suppliers.

To become an energy supplier, an authorization from the Ministry of Industry is required. There are numerous obligations, including providing proof of a solid financial base and purchasing power. Eni holds this authorization for all markets: professionals, public markets and domestic customers [54].

1.5.2.2. Choices for consumers

Only the incumbent suppliers, EDF and the local distribution companies (ELDs) are able to offer electricity at regulated tariffs, set by the authorities. Alternative suppliers, such as Eni, are able to propose market price offers for which they set their prices in line with market conditions.
When you change electricity provider, it does not require any special intervention, you keep the same facilities and the same electricity meter, owned by the distribution system operator (DSO). Your new supplier will contact the former supplier in order to terminate the contract, and you will then be sent a final invoice.

When moving, regardless of which provider and electricity supply was used by the former occupant, you may choose between a regulated price offer or a market price offer. Simply subscribe with the supplier of your choice to the electricity supply that best suits you [54].

1.6. An Overview of electricity Market in Germany

1.6.1. Introduction

The basic principle for energy policy is laid down in the German Energy Industry Act (Energiewirtschaftsgesetz **(EnWG)**). The purpose of the EnWG is to bring about a reliable, fairly-priced, consumer-friendly, efficient and environmentally compatible supply of electricity increasingly based on renewable energies. The regulation of electricity networks aims to safeguard effective competition in energy supply as well as sustain efficient and reliable operation of electricity networks [55].

The German electricity market began to open up as early as 1998. In order to implement the First Energy Package, the EnWG was amended in 1998, providing for full market opening and the introduction of competition in the electricity sector in one step. Key elements of the German implementation were:

- The introduction of negotiated third party access to the grid (the implementing EU Directive gave Member States the option to choose between regulated and negotiated third party access)
- The enactment of unbundling provisions obliging vertically integrated undertakings to separate their transmission and distribution businesses from the other activities in the electricity business in terms of accounting (unbundling of accounts).

Furthermore, the so called "demarcation agreements" between electricity suppliers reserving the right for each party to exclusively supply electricity in a demarcated area were no longer allowed under German competition law.

The second step of liberalization, as provided for in the Second Energy Package, was implemented by means of an amendment of the EnWG in 2005.

Cornerstones of this amendment were:

- The introduction of regulated third party access based on approved and published tariffs applicable to all customers and applied objectively and without discrimination between network users.

- The creation of the Federal Network Agency (Bundesnetzagentur **(BNetzA)**), as the regulatory body that falls under the authority of the Federal Ministry of Economics and Technology.
- The introduction of legal, functional and account unbundling of those transmission system operators (TSOs) and distribution system operators (DSOs) serving more than 100,000 customers.

The implementation of the Third Energy Package, by way of amendment of the EnWG in 2011, has tightened the unbundling regime for TSOs. In keeping with the option provided for in the Third Energy Package, the German legislation has not implemented the legal unbundling obligation on integrated electricity undertakings in the distribution sector serving fewer than 100,000 connected customers. The sector has organized itself accordingly. To avoid advantages from vertical integration, DSOs above this threshold are not allowed, in their communications and branding, to create confusion in respect of the separate identity of the supply branch of the vertically integrated undertaking [55].

1.6.2. Structure of electricity market

The German electricity market is characterized by a large number of companies acting in different sectors of the market, i.e., generation, transmission, distribution and supply. The net electricity consumption in Germany totaled around 540TWh in 2011 with a share of the industry of 250TWh and the residential sector of 140TWh.

As a consequence of liberalization, the market has undergone substantial changes resulting in numerous mergers, acquisitions, joint ventures and other alliances to achieve and maintain competitiveness. The number of suppliers has increased considerably, along with rising trading volumes. The European Energy Exchange **(EEX)**, based in Leipzig, is the leading energy exchange in continental Europe. The opening of the market for metering services further increases competitive choices for customers [55].

1.6.3. Key Players

Most generation companies are privately owned, while all TSOs, with the exception of TenneT, are privately owned. DSOs and supply companies are, on the other hand, mostly owned by municipalities, some in private-public ownership. Often, the local electricity companies supply gas and water, waste disposal services and public transport services as well.

The vertical integration in the German electricity sector remains strong. The strict unbundling rules applying to the transmission and – less strictly – to the distribution sector have separated them from the integrated sectors. The ongoing trend is re-municipalisation *(Rekommunalisierung)*, underpinned by the expiry of many of the so-called "concession agreements" with municipalities granting the exclusive right to build and maintain distribution lines in the municipal area, which has led to a shift in vertical integration as well. Concession agreements formerly held by the Big Four have usually not been renewed, allowing municipal undertakings to successfully bid for and take over the concession and the operation of the distribution grid [55].

1.6.4. Distribution

1.6.4.1. Structure of distribution sector

The medium and low voltage levels form part of the distribution system and are operated by the local DSOs. Household and small commercial customers are connected to the low voltage grid.

The distribution sector comprises around 900 network operators which are partly privately owned and operated on the basis of concession agreements with the municipalities but in many cases in public ownership of and operated by the municipalities. The re-municipalisation trend in the course of the declining market position of the Big Four will further increase the number of municipal DSOs.

Due to the fact that there is no obligation for legal unbundling on integrated electricity undertakings in the distribution sector serving fewer than 100,000 customers, distribution and supply of electricity to customers is often in the hands of the same local utility [55].

2. Research goal and questions

The massive integration of distributed energy resources in power distribution systems in combination with the active network management that is implemented thanks to innovative information and communication technologies has created the smart distribution systems of the new era. This new environment introduces challenges for the optimal operation of the smart distribution network. Local energy markets at power distribution level are highly investigated in recent years and the aim of local energy markets is to optimize the objectives of market participants, e.g., to minimize the network operation cost for the distribution network operator, to maximize the profit of the private distributed energy resources, and to minimize the electricity cost for the consumers. In General, the objective of this research is to deepen the impact of modeling of Local Energy Market on Distribution network responding to the following research questions:

1. How can LEMs affect grid operation?
2. What are the technical requirements needed to implement LEM within the distribution system?
3. What are the technical effects (impacts) of Local Trading on the Distribution System?
4. What are the possible problems and benefits of LEM operation?
5. How can self-consumption in the context of LEMs impact the grid?
6. What are the methods to include network constraints in LEM models?
7. What is the Impact of LEM on the distribution network infrastructure?
8. What are the challenges of local energy market in the presence of prosumers?

3. Research hypotheses

Several scholars from around the world have emphasized the need for local energy markets [56,57]. The work [56] published in 2001 underlined the need for local energy markets in Poland, which are mostly handled by distributors. The study [57] published in 2006 emphasized the need of local energy markets in Denmark for ensuring the large-scale integration of variable wind generation into the energy grid. Several projects throughout the world have already demonstrated the benefits of LEMs, including better energy efficiency, reduced carbon emissions, and lower electricity costs [58,59]. In addition to these advantages, the LEM offers the following opportunities:

- **Support Smart-Grid**

As a home management system, LEM assists in the construction of the smart grid by utilizing smart meters and energy efficiency products. ICT's contribution aids in the transmission of information and provides space for all of the generating and storing elements, hence promoting automation.

- **Support to Medium-Size Renewable Energy Power Plant**

In the wholesale energy market, medium-sized (5-50 MW) power plants have a problem to competing with large power producers [60]. As a result of the advent of LEMs, medium-sized Renewable energy power plants can stay in the market and operate on the distribution network.

- **Offers Support Services**

  The load response is made up of several small producing units and is thus useful in delivering supplementary services in both normal and emergency situations. Continuous control, load following, energy imbalance, spinning reserve, replacement reserve, and backup supply are some of the functions LEMS can provide [61,62].

- **Market power reduction**

  For the local market power, demand response serves as a congestion-reduction technique. LEM's load demand forecasting is used as a decision variable in the TSO's optimization process. The market price is determined by customer demand and aids in lowering congestion costs as well as the value of surplus energy given by a remote generating source [27].

4.Methodology

In this context, we have reviewed some of existing adopted methodology which studied the computational intelligence for the impact of LEM on distribution systems, which we'll look at in the next subsection.

4.1. Computational Intelligence (CI) for LEM in Distribution networks

In the solving of difficult optimization problems, computational intelligence (CI) methods have proven to be particularly effective. Furthermore, CI approaches are excellent at anticipating complicated processes. CI approaches have been effectively employed in the context of LEMs for the optimal scheduling of large-scale smart distribution networks, with complicated LEMs, multiple market players, and numerous DERs. Furthermore, CI approaches have been used to solve power forecasting problems for volatile and intermittent renewable DG units such as WTs and PVs, which are then optimally scheduled within LEMs [137].

This section provides an overview of cutting-edge computational intelligence technologies for optimizing the operation of local energy markets.

Multi agent systems (MASs), particle swarm optimization (PSO), genetic algorithm (GA), fuzzy sets, artificial neural networks (ANNs), and support vector machines are examples of cutting-edge CI approaches (SVMs).

Table below classifies the computation intelligence methods of the reviewed works.

Computational Intelligence METHOD	Reference
Ant Colony Optimization	[66]
Approximate Q-Learning	[67]
Artificial Bee Colony	[68]
Artificial Neural Network	[69]
Differential Evolution	[70]
Expert System	[71]
Fuzzy Sets	[72,73,74,75]
Genetic Algorithm	[76,77,78,80,81,82]
Geometric Clustering with Unsupervised Learning	[64]
Heuristic Optimization	[83]
Imperialist Competitive Algorithm	[84]
Multi Agent Systems	[85,86,87,88,89,90]
Particle Swarm Optimization	[91-101]
Reinforcement Learning	[102]
Scatter Search	[103]
Simulated Annealing	[104]
Support Vector Machines	[105]

We'll go over four different ways in the next few paragraphs. You can see the table's reference for further information on various ways.

4.1.1. Ant Colony Optimization

Ant colony optimization (ACO) was introduced in the early 1990s as a novel nature-inspired algorithm to solve difficult combinatorial optimization problems. ACO belongs to metaheuristic optimization methods that are approximate techniques applied to find good enough solutions to hard combinatorial optimization problems in a reasonable computational time. The nature inspiration of ACO is the food searching of real ants. Ants initially search randomly for food in the area around their nest. When an ant finds food, it carries some food back to the nest, and during the return trip, the ant deposits on the ground a quantity of pheromone trail that depends on the quantity and quality of found food. Pheromone trails help ants find the shortest paths between food sources and their nest. This property of real ants is exploited by ACO metaheuristic to solve complex combinatorial optimization problems [137].

In [66], a local energy market is combined with a wholesale electricity market. Each distributed generation unit submits energy offers to the microgrid operator, and load representatives submit load declarations for each trading interval. Then, single-sided auction is applied to find the market clearing price in every time interval. The proposed local energy market allows microgrid operator to maximize profits by optimally scheduling generation and loads. The objective of the optimization problem is to minimize the electricity production cost by optimally operating distributed energy resources using hourly day ahead scheduling as well as real time scheduling. Multi-layer ant colony optimization is proposed to solve this optimization problem. Simulation results show that in comparison with particle swarm optimization, the proposed ant colony optimization method finds an optimal solution 24 times faster at a 2.9% lower total generation cost.

4.1.2. Approximate Q-Learning

Reinforcement learning (RL) is a CI-based method where the learner (agent) must learn, without a supervisor, but through trial-and-error interactions with a dynamically changing environment. One of the classical RL algorithms is the basic Q-learning algorithm that has the disadvantage of discretizing the infinite state (search) space that implies a high computational time for learning. On the other hand, the approximate Q-learning solves this problem by using features instead of states. The feature-based approximate Q-learning algorithm provides better results, better adaptation to new environments, and reduced learning time [137].

In [67], a local energy market is considered at the low voltage power distribution level. Demand response aggregators are responsible for scheduling controllable loads. If a demand response schedule causes voltage and/or line congestion problems, the distribution system operator rejects the demand response schedule and penalizes the demand response aggregator. In the considered local energy market, the objective of each demand response aggregator is to maximize his profit and to avoid the rejection of part of his demand response schedule that implies penalties. Approximate Q-learning is proposed to optimize the scheduling of each demand response aggregator. Simulation results on a real low voltage distribution network with seven PV plants, 70 households out of which 12 households participate in demand response through four aggregators, show that the proposed approximate Q-learning method is an efficient demand response scheduling method thanks to its capability to learn to avoid paying penalties by avoiding demand response schedule rejection. Results show that the economic DR schedules are rejected by almost 20%, while the DR schedules of the proposed method are rejected at most by 0.4%.

4.1.3. Artificial Bee Colony

The artificial bee colony (ABC) is an evolutionary, nature-inspired, metaheuristic algorithm that solves complex optimization problems by simulating the food search of bee swarms. The population of artificial bees is split into worker bees and non-worker bees (scouts and onlookers). The total number of food areas (possible solutions of the optimization problem) is equal to the number of employed bees. The employed bees search for food and give information to the onlookers for the quality of food. The objective of onlooker bees is twofold: to find good food areas and further search for food around the selected food areas. Those worker bees leaving non good food areas become scout bees [137].

In [68], a local energy market is developed to facilitate power trading among microgrids. Each microgrid has distributed generation units, electric vehicles, and elastic loads.

In order to simultaneously optimize three objectives, a multi-agent based transactive energy system is presented:

- minimize energy imbalances in microgrids
- minimize the charging cost of electric vehicles and the operating cost of elastic loads participating in demand response
- maximize the profit of electric vehicles from discharging while considering life cycle degradation cost.

The formulated optimization problem is solved using artificial bee colony method. The optimization model determines, for each microgrid, the optimal scheduling of distributed generation units, electric vehicles, and elastic loads. The method is applied on the modified IEEE 37-node power distribution system that has three microgrids. Simulation results show that the proposed transactive energy market reduces the operating cost of elastic loads, reduces the reliance of microgrids on the utility grid, and reduces by 13.6% the total operating cost of microgrids thanks to the increased participation of demand response, electric vehicles, and distributed generation units.

4.1.4. Artificial Neural Network

An artificial neural network is a biologically inspired technology that mimics the computations and interactions of neurons within the human brain [69,70]. ANN is widely accepted as a very efficient mathematical tool for solving highly complex, nonlinear, and ill-defined, forecasting and classification problems. ANN can learn from examples. ANN is robust and fault tolerant, because it can successfully handle incomplete and noisy data. Once trained, ANN can perform, at high computational speed, generalization, i.e., classification and forecasting for unknown input data that was not used during ANN learning (training) phase [137].

In [69], customers are rewarded by coupons to reduce their demand during peak hours, and this is known as customer coupon demand response (CCDR). A local energy market is considered that serves a meshed secondary distribution network and the market mediators are several load serving entities (LSEs), each one having multiple load aggregators who represent load customers.

The objectives of CCDR, which is executed during peak hours, are:

- minimization of economic loss of the LSE
- maximization of the reward of customers

Artificial neural network is proposed to estimate the new locational marginal price (LMP) for a load serving entity after implementing CCDR. The feasibility of CCDR is investigated for a real heavily-meshed secondary distribution network with 1905 buses, and 97.9 MW peak demand. Three load aggregators and eight LSEs are considered, out of which one LSE participates in CCDR. Simulation results show that CCDR helps reduce peak demand, and reduce the economic loss during peak hours, which provides 5.5% higher profits for the entire day for the participating LSE in comparison to the net profits without CCDR.

5. Results

In this section, the result of analyzed research work and studies on the impact of LEM models on distribution network infrastructure, which will answer relatively much of the research questions raised in the second part. In addition, In the following, the results for technical requirements and technical effects of LEM on the distribution network will be presented.

5.1. Impact of LEM models on distribution network infrastructure

In the following subsections, we present analyzed research work and studies on the impact of LEM models on distribution network infrastructure. Voltage fluctuations, phase imbalance, influence on peak power and congestion, impact of LEMs on cyber-attack vulnerability, increased distribution network design complexity, and increased control complexity are all identified.

5.1.1. Voltage variations

Voltage variations are identified as the most significant potential challenge posed by LEM models in much of the existing research. Voltage fluctuations are systemic voltage variations whose magnitude does not normally exceed specified voltage ranges (0.9 to 1.1 p.u.) [106]. The main drivers for voltage variations are high DER penetration and the number of simultaneous energy transactions between prosumers.

References	Examination of voltage Variation	Major Impact
[107]	Examination of simultaneous P2P transactions on bus voltage	Scenario with high rooftop PV penetration level
[13]	investigated the impact of peer-to-peer trading on voltage variations	Scenarios without including prosumers' trading Strategies. (High Voltage) Affected by prosumers' trading strategies (Minimization of voltage drops)
[109]	A positive impact on voltage variations is further presented in [109] by including a power flow equations and voltage constraints optimization model of TE	Affected by prosumers' trading strategies
[48]	Investigate of moderate level of P2P energy trading on phase voltage imbalance and voltage profiles	No specific effect
[135]	Investigate the effects of self-consumption rate (SCR) of prosumers in an LV feeder on voltage quality	-
[110]	Development of a new analytical method for voltage sensitivity analysis	-
[112]	Development of a data-driven method that mitigates voltage violation	-

- According to Azim et al. [107], simultaneous P2P transactions can raise bus voltages above the grid code's limits. As a result, P2P trading inside a single feeder has the potential to cause network overvoltage. Many of these transactions will be curtailed for voltage regulation if photovoltaic (PV) inverters are equipped with voltage controllers, and non-dispatchable PV is the most common DER at the household level because other DERs like wind, geothermal, and biogas are location-specific [108].

- Herencic et al. [13] investigated the impact of peer-to-peer trading on voltage variations. The results indicate that prosumers' demand strategies have the greatest impact on voltage levels and power flows. They argue that the effects of energy trading on voltage levels are primarily dependent on the level of power flows coming from and/or going to the upstream grid, and that improving local electricity supply-demand balancing behind the substation is driven by a change in the pattern of local demand, which leads to voltage drops being minimized and voltage levels being increased.
- By including a power flow equations and voltage constraints optimization model of TE in [109], a positive impact on voltage variations is further presented. Without TE and with observed PV penetration, studies show that overvoltage violations occur at the same time as peak PV generation in the system, and undervoltage occurs when peak load occurs. Because the market mechanism also includes network constraint optimization, when TE is implemented, all voltage issues are eliminated
- A moderate level of peer-to-peer energy trading (i.e., one that does not increase the system's peak demand) should have little impact on network operational performance in terms of phase voltage imbalance and voltage profiles, according to Hayes et al. [48].
- Nousdilis et al. [135] investigated to what extent the self-consumption rate (SCR) of prosumers in an LV feeder can affect the voltage quality. The results show that consumers must effectively maintain their average monthly self-consumption rate above a certain system defined value depending on the quality of the network to which they are connected.
- Jhala et al. [110] have developed a new analytical method for voltage sensitivity analysis that allows for stochastic analysis of change in grid voltage due to change in consumer behavior and to derive probability distribution of voltage change on buses due to random behavior multiple active consumers, for both fixed [110] and the spatially random [111] distribution of active consumers.
- In [112] they developed a data-driven method that mitigates voltage violation by taking a control action before actual voltage violation happened. To date, the method has been developed and tested for only single-phase systems.

5.1.2. Phase imbalance

Voltage and current unbalance are also part of phase unbalance [113]. The current imbalance factor is defined by the IEC as the ratio of the negative to positive sequence component [114,115]. As the consequence of voltage and current unbalance, the power values on the three phases are also unbalanced. The majority of LEM studies assume phase balance and ignore the phases to which families are tied. Larger voltage rises and losses can result from a network imbalance between phases.

- Horta et al. [116] presented a method to minimize the negative impact of market participants, which are considered to have the highest impact on voltage unbalance due to their DER installation. This is ensured by dynamic phase switching by the system operator. The paper presents results of a simulation that shows dynamic phase switching does not have a negative impact on the outcome of the LEM (market mechanism explained in [117]) and can effectively increase the capacity of the distribution grid for hosting renewable energy.
- Further, in [118], they included a real time e control mechanism that copes with forecast errors by driving households towards a final exchange with the grid that benefits the prosumer and respects the DSO’s quality of supply requirements, in particular voltage deviations and current intensities along the feeder.
- Hayes et al. [48] showed that Phase Voltage Unbalance Rate (PVUR), the maximum voltage deviation from the average phase voltage as a percentage of the average phase voltage slightly reduced in the P2P case (as compared to the base case without trading).

5.1.3. Increased power peak and congestion

Factors which cause Congestion: Due to the lack of matching generation and available transmission infrastructure hosting capacity, LEMs have the potential to boost DERs in distribution networks, causing greater congestion in the system [119]. Unanticipated events like as power outages, unexpected escalation of load demand, and equipment failure can also generate congestion [120].

References	Examination on System Power Peak	Major Impact
[121]	Scenarios without including prosumers' trading strategies	Increased system power peak
[122]	Network capacity tariff has higher impact on peak power reduction	Reduced power peak
[123]	Impacted by flexibility market shifting demand	Reduced power peak
[136]	Impacted by prosumers strategies and market mechanism	Reduced power peak
References	**Examination on Line congestion**	**Major Impact**
[121]	Scenario with uniform pricing mechanism	Reduced line congestion
[121]	Scenario with heterogeneous pricing mechanism	Increased line congestion

Le Cadre et al. [121] simulated the impact of several pricing distributions (uniform, heterogeneous, symmetric, and local trade preferences with uniform prices) on network congestion and came to the conclusion that price development mechanisms influence the LEM's outcome and can create congestion. In the case of heterogeneous prices, energy amounts transacted are substantially bigger, and over half of the lines are congested, whereas in the case of uniform market prices, certain lines are essentially idle. As a result, we may conclude that the network impact of LEMs is highly influenced by market and pricing design. Aside from these two approaches, network tariffs can influence prosumer behavior and, as a result, network performance.

Almenning and colleagues [122] looked at how network tariffs and peer-to-peer trading effect the energy import management of a small neighborhood that can trade energy locally and use a variety of flexible loads. On two tiers, two network tariff systems (capacity and energy based) were studied (neighborhood and consumer). All consumers functioned independently and were unaffected by the actions of other customers at the consumer level. When examining a customer level and a neighborhood level, the results suggest that power peak has dropped by 11% and 7%, respectively. The decreased grid imports in the area were recorded using a capacity subscription tariff rather than an energy tariff.

Tushar et al. [136] also proposed a P2P energy trading scheme that could help a centralized power system to reduce the total electricity demand of its customers at the peak hour.

Morstyn et al. [123] studied how the DSO could manage overall distribution peak demand by obtaining flexibility from aggregators and prosumers with small-scale flexible energy resources. These types of flexibility markets could also be integrated into future P2P electricity markets. One of DSO management options in reducing local grid peaks is also by integrating storage devices (either community-based or local) together with energy management systems.

5.1.4. Vulnerability to cyber attacks

Cyber security attacks represent a risk to distribution grid functioning since LEM models rely on data from smart meter devices [124], while this risk is not exclusively of LEM or P2P architectures [125]. By simulating an attack on demand data and an attack on electricity price signals, Jhala et al. [126] evaluated the impact of a false data injection attack. The impact of an attack on electricity prices is greater than that of an attack on electricity demand, because the attack on electricity prices involves just one parameter manipulation. The power system may still rely on the other nodes if one node fails or is attacked, according to Le Cadre et al. [121], because information and choices are not optimized by a single central entity. This could increase resilience when compared to a centralized management approach.

5.1.5. Distribution network planning

Although planning frameworks to incorporate flexibility into the planning process have been proposed [127], as well as methodologies for joint planning and operation of distribution networks [128], the planning of distribution networks in the LEM network environment has not yet been widely studied in the identified literature. Delarestaghi et al. [129] investigated how including a P2P market influences the investment plans of various players in the distribution network. According to the study, implementing a P2P market result in less energy being purchased during peak hours, which means less power is transferred through the substation and feeders, saving the utility money on unneeded investment.

5.1.6. Control mechanisms

With the grid under increasing strain as a result of increased reliance on power and the entry of DERs, the DSOs' task in maintaining supply quality within acceptable bounds is becoming increasingly difficult. It is costly and time consuming to reinforce or replace elements of the system. To keep the voltage within limitations, one viable approach is to actively exploit the active and reactive power regulation capabilities of those DERs. The Smar Test project [131] investigated different methods to deliver P2P schemes, including distributed grid control, multi-agent systems, coordination across different control algorithms, use of power electronic devices, and decentralized voltage control algorithms, to deal with problems arising from increased DERs penetration and integration of P2P markets in the network.

Almasalma et al. [132] developed a voltage control algorithm that regulates the voltage within allowed limits. The approach is based on dual decomposition theory, linearization of the distribution network around its operating points and P2P communication and its experimental validation was presented in [133]. The results show that distributed voltage control systems can provide satisfactory regulation of the voltage profiles and could be an effective alternative to centralized approaches. The proposed P2P system could help in delivering easier access to prosumers' flexible supply and demand by making their active participation in the grid possible, and subsequently making LEM easier to integrate in the existing system.

In the following subsection the respond about technical requirements and technical effects on the distribution network will be presented.

5.2. Technical Requirements

Characteristic of distribution system:

- As the final link in the electricity supply chain, has its own set of characteristics in terms of structure and fundamental concepts.
- This system's network is primarily radial and one-side supply.
- Protection devices of network and even customers are designed based on a one-way network.
- Despite recent progress toward smart grids, most distribution networks do not fully monitor all electrical parameters so it is difficult to control and observe the network with high penetration of DER units.

Effective factors on the reliability of the distribution network:

- **Different level of voltage:** Due to these systems' structures, the distribution network's reliability also has different values at different voltage levels.
- **Different areas and consumers:** Unlike transmission networks, the distribution network's reliability may have a considerable difference depending on the city and village or different geographical areas (mountainous, plains, etc.) or even the type of consumers (industrial, residential, etc.).
- **Different factors:** Recently, despite the improvement in the reliability of electricity distribution networks, factors such as investment, management policies, and load sensitivities have affected the classification of different network reliability levels.

Thus, it must be said that the reliability of the distribution network has a considerable difference compared to the transmission network [134].

Fundamental change in the performance of the distribution company:

Furthermore, despite efforts to integrate ICT infrastructure into smart distribution networks, embedded platforms are unlikely to support all real-time activities in the future. Data from consumers, producers, and electrical grid parameters are also stored and managed in a near-centralized manner. Any change in the presentation of data in a decentralized context will be impossible with such a centralized structure based on retailer attitudes. The dominant view of the distribution company is still as a service enterprise. As a result, a transparent financial transition from consumption to production is likely one of its managers' top concerns, and changes in these conditions will necessitate a fundamental shift in the distribution company's performance [134].

Implement the P2P market in the distribution network:

By changing the approach to transactive energy, the structure and technical requirements will undergo fundamental changes. In general, the term transactive energy refers to methods used to manage the generation, consumption, or electrical power flow in an electrical system through economic or market-based structures, while at the same time, the reliability constraints are considered.

The views and equipment required to implement the P2P market, which is associated with the entry of many DERs into the distribution network, must be reviewed and revised. These are divided into the following three groups:

1. **Electrical network**
2. **Control layer**
3. **ICT layer**

1. **Electrical network:** Rethinking the network's design and planning to take into account the possibility of a two-way or multi-way power supply. This should be seen in the:

- network topology and typology,
- the selection of new equipment,
- and the choice of feeder and
- network capacity

so that the new approach should provide a suitable redundancy in the planning of network elements. Other important Factors:

  - measurements of Conventional electrical parameters such as (power, frequency, voltage.)
  - new electrical values like (harmonic, voltage fluctuation . . .)
  - determining the direction of power flow in a real-time and intelligent way at the consumer, producer, distribution stations.

Equipment such as smart meters, data loggers, or data recorders are equipment which can measure such values [134].

2. **Control layer:** Given that each end-user may also be a prosumer in this situation, network protection and control principles must be adapted to the new situation.

In this case, the concept of a control system can include:

- Power supply sustainability (i.e., voltage control, frequency control, active power control)
- Power quality (e.g., harmonics level, flicker level, voltage fluctuations) and
- even network load flow.

To meet the goals of the new paradigm, control equipment should be installed at the network level and at the location of prosumers [134].

3. **ICT layer:** Given the size and volume of the distribution network, the new structure's implementation will necessitate the use of appropriate and reliable platforms, devices, and telecommunications protocols. Much data is generated in modern architecture, and managing this data, validating it, and securing data exchange between multiple parties are among the most complex processes in such an environment. The sending of transaction signals and requests, as well as the exchange of consumption or production data on an instantaneous basis, should be done with appropriate ICT facilities. That is, one of the primary concerns of LEM architecture will be information flow.

Options which are require to establish intended data flow is telecommunication devices such as:

- sensors,
- routers,
- servers
- wired or wireless communication channels
- communication protocols
- along with communication applications.

5.3. Technical Effects of Local Trading on the Distribution System

The development of local energy markets has economic, social, and technical effects on the electrical distribution companies [52].

Economic effects: can be summarized as impacting customers’ energy bills and energy-sales revenue at the distribution level.

Social effects: The effects that individuals can experience independently and as part of families, households, communities, and society can be called social effects. Factors such as influences on lifestyle, culture, welfare, and environment are included in this category.

Technical effects: The technical effects that local energy markets have on the electricity distribution system are unknown and opaque. These effects can be observed in:

- Network layout changes
- Network planning and operation approaches
- Network electrical analysis methods
- Network maintenance programs
- Staff technical skills
- Regulation

Accordingly, the technical implications discussed below will include a wide range of items, including impacts on technical infrastructure, network constraints, skill requirements, regulatory rules.

1. **Principles of network layout:** The current structure of the power distribution system transfers power from upstream to customers. The design and development of the network have been considered over time in such an architecture, and feeders, transformers, and other equipment have been installed using the radial structure. With the increasing penetration of low and medium voltage generation resources, all network equipment must be capable of distributing power on both sides and even transferring excess power to higher voltage levels. As a result, the capacity of feeders and transformers, the provision of multi-way feeding facilities for feeders, the creation of conditions for power transmission to higher levels, the review of the protection method for all distribution voltage levels, and even the customers' side may be impacted. So, the revision and modification of the network layout will be based on the structure’s goals that can produce and consume in each network node. Besides, it should be able to be used as a microgrid in all special situations [134].
2. **Network planning and operation:** The distribution system's planning and operation are also impacted by the local energy market approach.

Planning Perspective: Any network design should consider production and consumption at load points. This viewpoint will undoubtedly leave many questions unanswered in the planning process. On the other hand, as production sources become closer to load centers, the need to invest in upstream network assets decreases. This can help to manage the risk of uncertainties, allowing the network schedule to be prepared with acceptable accuracy over a given time frame.

Operation Perspective: In the local energy market environment, the approach to grid operation needs to be seriously reconsidered. It must be extremely intelligent, because each node has the ability to generate power while also allowing the network's power circulation to be altered. Items that should be considered is as follow:

- Instantaneous changes in the operation of such a structure should be monitored from this perspective to avoid potential network problems. The impact of this space can significantly reduce operational problems by moving toward automated operation. However, until this level of automation is achieved, having appropriate and intelligent controls in place across the network may be a temporary solution.
- In these circumstances, network constraints must also be carefully considered. The most critical operating constraints of such an architecture in terms of distribution system reliability are **network density** and **feeder and transformer loading limits**. As a result, the network density constraints should be checked on a regular basis due to the possibility of significant changes in the power flow along the feeder.
- Network losses are also a constraint that must be managed in the network's operation and according to the flow path.
- The widespread presence of renewable and non-renewable energy sources will increase the possibility of power quality issues (harmonics, flicker, etc.) in different nodes, which are additional problems caused by the new paradigm. The operation of such a network should examine the effects of power quality concerning changes in the power supply methods of the network nodes to prevent potential hazards to equipment.
- Apart from the above, in cases where there is a surplus generation at the distribution level, the return of power upstream or distribution at points where there is a shortage can also affect the network's operation [134].

3. **Electrical network analysis methods:** The current approaches to analyzing the electrical grid must also be changed in order to create a local energy market structure. In traditional distribution networks, especially those with radial structures, load flow calculations are one of the most common analyses. Depending on the nodes' production or consumption status, such calculations must be performed under the new structure for two-way or multi-way feed analysis. In fact, electrical analysis of networks with nodes that can be converted to consumption or production nodes should be considered in other analyses, such as calculating short circuit levels, line loading limits, node voltage values, and network stability threats**.**

- **Power Quality Analysis:** Analysis of the power quality of such a network can be one of the most complex analyses.
- **Renewable Generation Analysis:** A wide variety of renewable generations with different technologies and active prosumers may have adverse effects on various nodes, adjacent loads, and even the entire distribution system. Such an analysis, given the diversity of electricity generation types, should be done to make the necessary arrangements before damage occurs to the equipment.
- **Reliability Analysis:** Distribution network reliability analyzes are also likely to be changed in this architecture. Due to the nodes' dynamic state in terms of production or consumption, it can be assumed that the reliability analysis of such a distribution system will be associated with many complexities. Perhaps new definitions should be introduced in such a structure to reflect the concept of reliability better.
- **Stability Analysis:** Also, network stability analysis should be added at the distribution level. The diversity of production resources in the distribution network will require unique methods of sustainability analysis [134].

4. **Network maintenance and repair programs:** Distribution system repair programs can also be affected the local energy market environment. In a traditional distribution system, the profitability of selling energy to customers is the primary driver of decision making in network maintenance and repair programs. In the new architecture, the diversity of factors will complicate such a decision. On the one hand, the preferences of prosumers should be taken into account, and on the other hand, the stability of the network structure for the overall satisfaction of customers should be considered. These can affect the duration of repair programs, the type of programs, and even the period of their implementation. As a result, asset management in such a market is a complicated issue involving a

number of variables and constraints, and it will be heavily reliant on the new distribution network's complex structure [134].

5. **Technical skills of employees:** Employees who, in addition to recognizing and understanding the true meaning of structure, have the mental and practical readiness to implement ideas in line with the goals are required for any action in such a new environment. Although ongoing staff training is important, intelligent and creative personnel in such a structure can have a significant impact on the system's ability to function properly in critical situations. Following factors should be considered for capable employees' skills:

- Variety of actions
- Many changes in the type of analysis
- The need for up-to-date knowledge
- Very high concentration
- Correct knowledge of the situation

6. **Regulations and laws:** A P2P transaction agreement is a contract for the sale of goods in general. Because electricity is a physical phenomenon, it is subject to the laws of nature, particularly Kirchhoff's laws, which place physical constraints on the electricity trade. In practice, the trade parties agree to change their supply and demand for electricity by a certain amount of money rather than exchanging electricity. As a result, the rules that govern the parties must consider this viewpoint. The laws may be defined in accordance with any country's or region's restrictions. The amount of generation capacity at the distribution level (local or general), the amount of high-level transmission capacity, and the timing of such actions can all be adjusted by these regulations. As a result, they have an impact on the growth and development of the local energy market. Regulators should also establish frameworks for meeting the requirements for two-way power flow. Because of voltage stability issues and the challenges of safe microgrid operation, particularly during island operation, these regulations should be defined. Furthermore, because local energy systems rely on distribution infrastructure, the rules for using the network should take into account the various local conditions as well as the network structure (urban or rural) [134].

7. CONCLUSION AND DISCUSSION

7.1. Discussion

Overall, LEM research has been shown to be quite transdisciplinary, making it difficult to distinguish between the impact on power distribution systems and market model design or current policy and regulatory frameworks. As a result of our research, we can conclude that research in this area is still constrained by existing market and policy frameworks, implying that more research is required. We presented a general overview of the impact of LEM at the distribution network level on phase imbalance and voltage in the following subsection.

According to a slew of studies, LEMs will have a significant impact on voltage violations and congestion. Prosumer demand methods appear to have an impact on voltage levels, but the magnitude of the impact, as well as whether it is positive or negative, is dependent on the market mechanism used. There will be no significant impact on network performance in terms of voltage imbalance and voltage quality if a mechanism is used that does not increase the system's peak demand. It should be emphasized that most studies focused on developing market models, control mechanisms, and participant models that had a positive technical influence on voltage, implying that negative repercussions were avoided by design and hence were not noticed in the data.

The majority of phase imbalance studies assumed phase balance and neglected the phases to which families were tied. Because network phase imbalance might result in higher voltage rises and losses, future study should delve more into the implications of LEMs on phase imbalance concerns, especially since most of the use cases are geared toward prosumers who are connected to LV networks.

7.2. Conclusion

For this report, we conducted a thorough literature review in order to determine and discuss the network impact of LEM on the distribution network. The purpose of this report was to find out how LEM modeling at the distribution network level affects grid operation, as well as the potential challenges and benefits of LEMs, and also the grid impact of self-consumption in LEM settings. The papers that dealt with LEM's impact on the distribution network were grouped together (in relation to voltage variations, phase imbalance, power peaks, congestion, vulnerability to cyber-attacks, network planning and control mechanisms). Finally, we highlighted and listed a number of difficulties that must be solved in respect to the network impact of integration LEM models in the distribution network. We also discussed the concept of new local market services, such as flexibility and energy services, which are fundamentally reshaping distribution companies' strategies. Bilateral energy exchange, market decentralization, and widespread end-user participation are some of the most important characteristics of such a market. The technical implications of the local market on distribution systems have also been investigated, including the impact on technical infrastructure, network constraints and skill requirements, and regulatory rules. We also provided a quick overview of the state-of-the-art of CI methodologies for LEMs at the power distribution level.

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9. Abbreviation

ABC: Artificial Bee Colony

ANNs: Artificial Neural Networks

ACO: Ant Colony Optimization

BAS: Building Automation Systems

BNetzA: Bundesnetzagentur

CCDR: Customer Coupon Demand Response

CI: Computational Intelligence

DG: Distributed Generation

DSO: Distribution System Operator

DR: Demand Response

DLT: Distributed Ledger Technology

DERS: Distributed Energy Resources

EU: European Union

EnWG: Energiewirtschaftsgesetz

EEX: European Energy Exchange

GA: Genetic Algorithm

HEMS: Home Energy Management Systems

ICT: Information and Communication Technology

ISO: Independent System Operators

LEM: Local Electricity Markets

LMP: Locational Marginal Price

LV: Low Voltage

LSEs: Load Serving Entities

MASs: Multi Agent Systems

MISOCP: Mixed Integer Second-Order Cone Programming

MV: Medium Voltage

PSO: Particle Swarm Optimization

P2P: Peer-to-Peer

PVUR: Phase Voltage Unbalance Rate

RES: Renewable Energy Sources

REM: Retail Electricity Market

RL: Reinforcement learning

SCR: Self-Consumption Rate

SVMs: Support Vector Machines

TEM: Traditional Electricity Markets

TE: Transactive Energy

TCLs: Thermostatically Controlled Loads

WEM: Wholesale Electricity Market