Impact of local energy markets integration in power systems layer: A comprehensive review

Viktorija Dudjak [a,*], Diana Neves [b], Tarek Alskaif [c], Shafi Khadem [d], Alejandro Pena-Bello [e], Pietro Saggese [f], Benjamin Bowler [a], Merlinda Andoni [g], Marina Bertolini [h], Yue Zhou [i], Blanche Lormeteau [j], Mustafa A. Mustafa [k,l], Yingjie Wang [l], Christina Francis [m], Fairouz Zobiri [l], David Parra [e], Antonios Papaemmanouil [a]

[a] *Lucerne University of Applied Sciences and Arts, Switzerland*
[b] *IN+ Centre for Innovation, Technology and Policy Research, Instituto Superior Técnico, Universidade de Lisboa, Portugal*
[c] *Wageningen University and Research, Netherlands*
[d] *International Energy Research Centre, Tyndall National Institute, Ireland*
[e] *Energy Efficiency Group, Institute for Environmental Sciences and Forel Institute, University of Geneva, Switzerland*
[f] *IMT School for Advanced Studies Lucca, Italy*
[g] *Heriot-Watt University, United Kingdom*
[h] *University of Padova, Italy*
[i] *Cardiff University, United Kingdom*
[j] *Université de Nantes, France*
[k] *Unversity of Manchester, United Kingdom*
[l] *KU Leuven, Belgium*
[m] *University of Edinburgh, United Kingdom*

HIGHLIGHTS

- Previous research was restricted due to limited or non-existent historical trading data in Local Energy Markets.
- Voltage variations, high system peak levels, congestion and phase imbalances are identified as the most common issues.
- Inclusion of network constraints is possible using following methods: power flow equations, network tariffs signals and power losses signal.
- Integration of network constraints in market mechanism models asks for inclusion of DSO in a decision-making process, since it concerns critical infrastructure information.

KEYWORDS: Local Energy Markets; Peer-to-Peer; Transactive Energy; Network Constraints; Impact; Power System Integration; Review Paper; Energy Trading.

ABSTRACT

In recent years extensive research has been conducted on the development of different models that enable energy trading between prosumers and consumers due to expected high integration of distributed energy resources. Some of the most researched mechanisms include Peer-to-Peer energy trading, Community Self-Consumption and Transactive Energy Models. To ensure the stable and reliable delivery of electricity as such markets and models grow, this paper aims to understand the impact of these models on grid infrastructure, including impacts on the control, operation, and planning of power systems, interaction between multiple market models and impact on transmission network. Here, we present a comprehensive review of existing research on impact of Local Energy Market integration in power systems layer. We detect and classify most common issues and benefits that the power grid can expect from integrating these models. We also present a detailed overview of methods that are used to integrate physical network constraints into the market mechanisms, their advantages, drawbacks, and scaling potential. In addition, we present different methods to calculate and allocate network tariffs and power losses. We find that financial energy transactions do not directly reflect the physical energy flows imposed by the constraints of the installed electrical infrastructure. In the end, we identify a number of different challenges and detect research gaps that need to be addressed in order to integrate Local Energy Market models into existing infrastructure.

* Corresponding author.
E-mail address: viktorija.dudjak@hslu.ch (V. Dudjak).

1. Introduction

In June 2018, the European Union (EU) agreed a legal framework for prosumership as part of the recast of the Renewable Energy Directive (RED II) [1]. This puts consumers in the centre of energy transition and introduces Citizen Energy Communities and Renewable Energy Communities, encouraging consumers to acquire ownership in distributed energy resources (DERs) and become prosumers, that is individuals who both consume and produce energy [2]. The framework supports the integration of DERs in the distribution network that can potentially provide services to power systems [3] and enables new energy business models.

DERs are defined as small or medium-sized resources directly connected to the distribution network [4]. They include distributed generation, energy storage systems (ESS) and controllable loads such as electric vehicles (EVs), heat pumps or demand response (DR). A high penetration of DERs can potentially be problematic for the stability and reliability of the distribution network and is expected to cause overvoltages, under-voltages and congestion [3], phase unbalance that may have negative impact on power quality [5], and unpredicted bidirectional power flows [6] for which the system was not originally designed. On the contrary, if managed intelligently, DERs could provide ancillary services to system operators through price-based incentives [7] as well as local system services to the Distribution System Operator (DSO) to solve issues related to voltage regulation, power quality and distribution network congestion [8]. Beyond economic and technical aspects, business models must address social and environmental concerns, as well as privacy issues regarding the origin of energy among households and business customers.

Increasing trends of DER deployment and grid digitalization allow for the emergence of decentralized energy exchange paradigms to promote endogenous and local resources, increasing environmental benefits [9]. One example of this is the Local Energy Market (LEM). Mengelkamp and Weindhardt [10] define the LEM as a socially close community of residential prosumers and consumers that have access to a joint market platform for trading locally produced electricity among each other. Such user-centric markets can be typified as Peer-to-Peer markets (P2P), Transactive Energy markets (TE), and Community Self Consumption (CSC). The Common denominator of the different types of models is that they use information and communication technology (ICT) for sustainable and efficient energy transactions [11]. In the context of P2P market platforms, the most used technologies are distributed ledger technologies, namely, blockchain [12].

P2P electricity trading is a business model, first proposed in 2007 [13], based on an interconnected platform that serves as an online marketplace where consumers and producers "meet" to trade electricity directly, without the need for an intermediary [12]. Since it was first proposed, P2P electricity trading has risen in popularity within research as one of the possible paths to encourage power systems energy transition. It is expected to decrease participants' electricity bills by trading within peers and increase self-consumption of (surplus) locally produced renewable energy, in contrast to being supplied entirely under the rules of a centralized retailer or market [14,15]. In addition, it is claimed that P2P markets are fairer and more transparent [16]. P2P markets have been the focus of an increasing number of pilot and demonstration projects in the recent years [17], namely Brooklyn Microgrid [18], Quartierstrom [19,20], Monash Microgrid [21], LAMP-Project [22], ENERCHAIN [23], NRGCoin [24], Energy Collective [25,26], P2P-SmarTest Project [27,28], Invade [29–31], Pebbles [32,33] and Interflex project [34,35]. Different market structures can be implemented for P2P energy trading, for example centralized community-based markets, and distributed bilateral trading market [36].

A TE system is defined as a set of mechanisms that use economic-based instruments to achieve a dynamic balance between generation and consumption while considering operational constraints of the power system [37]. Within the TE system, DER generation and consumption can automatically negotiate their actions with each other using energy management systems and electronic market algorithms, allowing a dynamic balance of supply and demand [38]. Often, TE is used interchangeably with P2P. However, TE represents a broad set of activities that includes much more than energy exchange transactions between peers [39].

CSC is a framework that supports the energy transition in the electricity sector by facilitating the collective sharing of renewable electricity generation assets within a community of prosumers, generally restricted to a neighbourhood, a district or an industrial consortium connected to the public network. It allows multiple end-users to benefit from shared distributed generation installations [40]. Such communities can be an actor in TE models or recognize each other as peers (similar to P2P models) and create a nested community-of-communities [41].

Electricity trading is different to other forms of exchange or trading of goods for two main reasons: (1) as opposed to other goods, electrical energy cannot be stored economically and on a large-scale; and (2) electricity generation must match simultaneously electricity demand, considering that electricity delivery is implemented according to the laws of physics [42]. Customers are part of a power system, and in case of small customers, largely connected to a distribution network. The distribution network imposes technical constraints on energy trading, and these constraints need to be represented in trading models in some way. While a certain schedule of DER and local consumption may be profitable from an economic perspective, these actions might violate current network constraints and cause reliability issues.

One of the major challenges in implementation is to assure that network constraints are not violated during the energy trading [43]; therefore constraints such as line, cable or transformer limitations and bus voltages should ideally be taken into consideration in the design of LEM models [44,45]. P2P markets might also contribute to changes or relaxation of some of the constraints, or even force a redesign of the network [46].

Network constraints and integration issues of LEMs are part of the physical LEM layer (layer 1), which together with ICT (layer 2), market (layer 3), economic (layer 4) and policy and regulation layer (layer 5) defines the high-level architecture of LEMs presented in Fig. 1.

In the recent years, a number of literature review publications have covered different aspects of LEMs, including P2P energy trading [47,48] and blockchain technology implementation possibilities [49,50]. Nevertheless, in LEM research and pilot projects to date, insufficient attention has been given to the potential integration issues in the physical layer, and only a small number of articles, for example Tushar et al. [45], refer to this topic in more detail. Latter is written with an aim of identifying potential barriers to implementing P2P sharing in existing electricity market frameworks and regulatory regimes, and not with focus of identifying technical barriers when integrating these models.

This leads us to the conclusion that a more profound assessment of this issue should be taken in the literature. To bridge the knowledge gap in this paper, we focus on the integration and impact of LEMs on power systems by performing an in-depth and systematic literature review of the state-of-the-art, extending the review to classify the impact on specific technical characteristics of the power systems. The main contributions of this paper are to:

- Identify the impact of LEM operation on power systems operation, planning and constraints;
- Provide an overview of commonly used methods to include the network constraints dimension in LEM modelling, including network tariffs signals;
- Provide an overview of commonly used methods to allocate power losses in LEMs;
- Identify knowledge gaps and open topics for future research.

The structure of the paper is as follows. Section 2 provides an overview of the research methodology used to study the state-of-the-art relating to the integration of LEM with power systems. In Section 3, the possible impact of LEM models on the power systems layer are described. Section 4 provides an overview of methods to include physical grid parameters and Section 5 describes methods to allocate network fees and power losses using LEM transaction data. Section 6 discusses research gaps and future research directions, then Section 7 concludes the paper.

2. Methodology

This section describes the literature review methodology. In this work we intend to deepen the understanding of the impact of LEMs on power systems, responding to the following research questions:

1. How can LEMs affect grid operation?
2. What are the possible problems and benefits of LEM operation?
3. How can self-consumption in the context of LEM impact the grid?
4. What are the impacts of interaction between multiple LEMs?
5. What are the methods to include network constraints in LEM models?
6. What is the impact of LEMs on the transmission network operation?

To define a paper selection metric, we used two review stages. In the first review stage, the Web of Science (https://apps.webofknowledge.com/) databases were searched, with the databases being accessed during the period from July 2020 to January 2021, using the following inclusion criteria:

AB ~~(~~(“peer to peer market” OR “peer-to-peer market” OR “P2P market” OR “local energy market” OR “local energy markets” OR “self consumption” OR “transactive energy market” OR “energy community”) AND (distribution grid OR distribution network) AND (impact OR constraint)).

All relevant papers were included, irrespective of publication date. Additionally, authors included papers that they considered valuable according to their expert knowledge. The selected papers then went through a first review for analysis against the inclusion criteria listed below:

1. The paper was written in English;
2. The paper concerned LEMs (P2P, TE, CSC);
3. The paper included the impact of operation of LEMs (P2P, TE, CSC) on power systems;
4. The paper was published in a peer-reviewed journal or presented at a conference.

As a final step, the list of references at the end of each reviewed paper were considered, and additional, relevant papers were extracted where they met the inclusion criteria.

In the second review stage, a detailed data extraction table was created, allowing the selected papers to be reviewed in line with the previously proposed research questions.

The paper identification and selection process and corresponding results are shown in Fig. 2.

Out of 145 papers identified in the literature search, 65 papers passed the inclusion criteria (1st review). Of 65 papers that passed inclusion criteria, 49 papers went through the final review process. It is interesting to observe that the papers that effectively directly address LEM impacts on power systems were few. This indicates that although there is a common agreement that these kinds of market models impact power systems, the depth and terms of that impact is yet to be fully explored in literature.

Fig. 3 shows the distribution of papers that passed the initial criteria review (1st review) and full review process (2nd review), according to their year of publication.

The distribution of papers shows that the area of our search interest has been gaining in popularity since 2014. The number of published papers has been growing, especially in the period 2017 – 2019, with a smaller number of papers published in 2020. The number of papers published in 2021 is misleading as the literature search was finalized in January 2021.

During the review process, each analysed publication was assigned to at least one of the three following categories as shown in in Fig. 4:

- Impact of LEM on the power systems layer: such as in voltage variation, phase imbalance in LV network, system power peak, line congestion, cyber-attack vulnerability and distribution system planning; (Section 3)
- Methods to include physical grid constraints in market models, namely power equations, and network tariffs; (Section 4)
- Methods to calculate power losses and network tariffs that reflect trading flows between LEM actors (Section 5).

However, regarding research questions number 4 (what are the

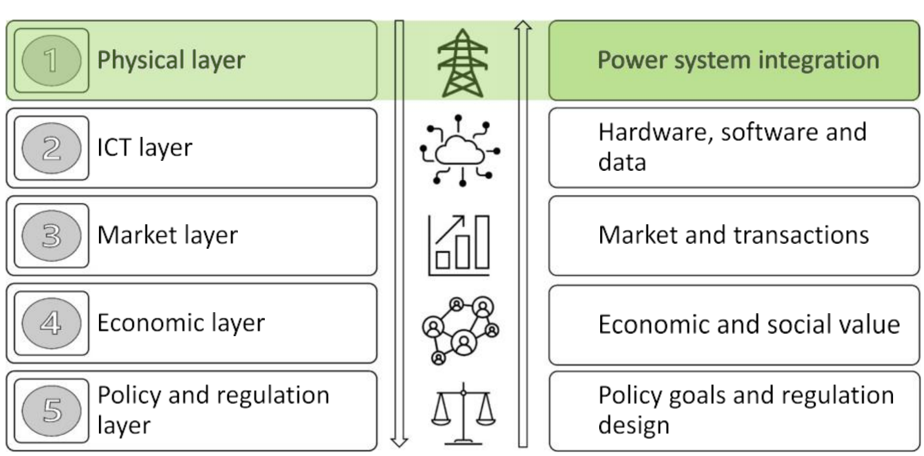

Fig. 1. Five layers architecture of LEMs.

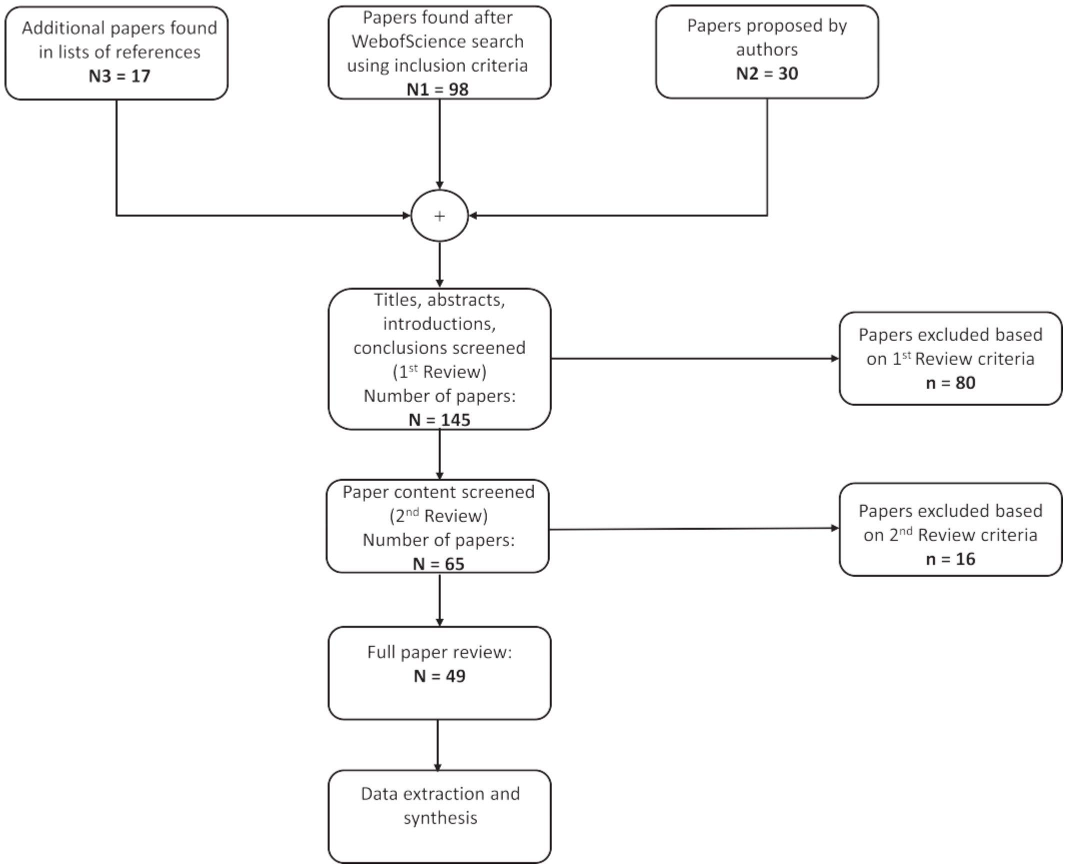

Fig. 2. Workflow of literature review process.

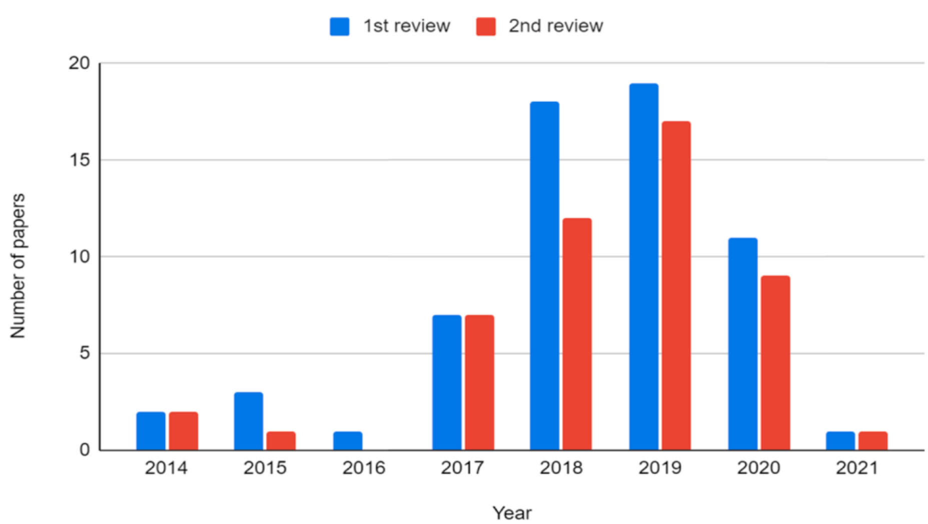

Fig. 3. Number of papers per year that passed 1st review (blue) and papers that went through 2nd review (red).

impacts of interaction between multiple LEMs?) and 6 (what is the impact of LEMs on the transmission network operation?), we did not find scientific evidence on the studies analysed that was worth reporting.

3. Impact of LEM models on power systems

In this section, we first summarise the technical impact of LEMs on distribution systems, as identified in literature. We present the test cases that are most commonly used in literature. We then present analysed research work and studies on the impact of LEM models on distribution network infrastructure, according to the category of impact. We go on to analyse how impacts can be mitigated through different prosumer behaviour or market designs, and identify gaps that could be addressed in future research.

Historically, distribution grids have been designed and operated in a centralized manner with a unidirectional power flow in mind [44]. In this context, large generation units were responsible for power generation injected into a high voltage (HV) transmission grid that had been adequately designed to transport large power quantities over long

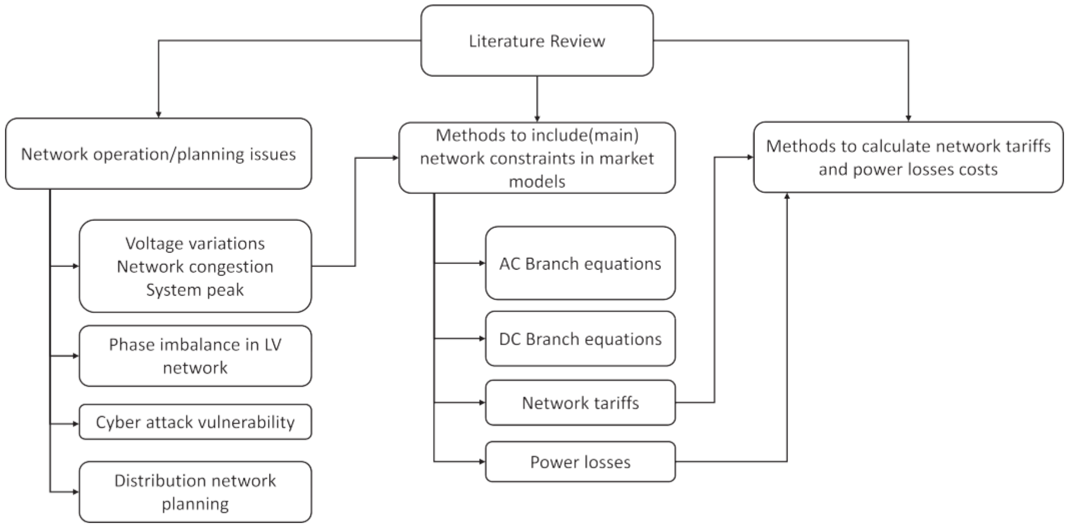

Fig. 4. Overview of paper categorization process.

distances to load centres. In the contemporary system, the point of connection between upstream (transmission) and downstream (local, distribution) grid is usually a transformer (in a substation), after which power is often delivered to final customers using a radially operated, weakly meshed distribution grid. Radially operated feeders are designed to support worst-case peak loading expected across the feeder coming from the upstream grid. This planning approach is designed to sustain an 'N-1 redundancy criterion', a requirement to ensure quality and security of supply are maintained within the network. The criterion can lead to extensive capital investments with a high probability that the resulting network will be over dimensioned and only partially utilized. While the over-dimensioning of the network ensures adequate performance in a traditional system, it is not clear if this design can cope with a growth of DER or with LEM trading volumes coming from DERs connected to the LV network. LEMs have anticipated benefits, for example more efficient grid utilization through a reduction of exchanges of the LEM network (when defined on specific local area) with the main grid [51] due to local matching of supply and demand. However, LEMs can also potentially create issues within the distribution network.

Existing research primarily considers the impact of high penetration of DER on the low voltage (LV) and/or medium voltage (MV) grid when evaluating the impact of LEM models in distribution systems, and how this impact can be mitigated. It identifies voltage variations, phase imbalance, impact on peak power and congestion, impact of LEMs on cyber-attack vulnerability, increased complexity of the distribution network planning and increased complexity of control. Table 1 summarizes the expected impact of LEMs on the distribution network, as identified during the literature review process.

As seen in Table 1, different studies show diverging results. In our opinion, one of the reasons for diverging results is the scenario-based design of current studies. Studies are normally performed on synthetic test cases, with assumptions about possible prosumers' trading strategies in market models that differ from one study to the next, therefore leading to results that are heavily scenario specific.

Table 2 shows a summary of the most used test cases in the reviewed literature, according to the type of data used, as well as detailed simulation data. It can be observed that the majority of studies were conducted on synthetic prosumer data due to a limited real-life application of LEM, and hence a limited availability of real-life prosumer data.

In the following subsections, we present analysed research work and studies on the impact of LEM models on distribution network infrastructure, according to the category of impact, as presented in Table 1. We further analyse how that impact can be mitigated by modelling different prosumer behaviour and/or market design mechanisms, the main conclusions they bring as well as identified gaps for future research.

3.1. Voltage variations

Much of the existing research identifies voltage variations as the biggest possible challenge arising from LEM models. Voltage fluctuations are systemic variations of the voltage, the magnitude of which should not normally exceed specified voltage ranges (i.e. 0.9 to 1.1p.u.) [78]. The main drivers for voltage variations in LEMs are high DER penetration and the number of simultaneous energy transactions between prosumers. Azim et al. [52] reveal that simultaneous P2P transactions can raise the bus voltages beyond the limits defined in the grid code. Therefore, P2P trading inside a single feeder has the potential to cause over-voltage in the network. Conversely, if photovoltaic (PV) inverters are equipped with voltage controllers, many of these transactions will be curtailed for voltage regulation. Non-dispatchable PV is the most common DER at household level since other DERs like wind, geothermal, biogas are location-specific [79]. The impact of P2P trading on voltage variations has also been studied by Herencic et al. in [53]. The study shows that voltage levels, as well as power flows, are primarily affected by prosumers' strategies for demand. They argue that effects of energy trading on voltage levels primarily depend on the level of power flows coming from and/or going to the upstream grid and conclude that improvement of local electricity supply–demand balancing behind the substation, driven by change in pattern of local demand, leads to minimization of voltage drops and increases voltage levels. A positive impact on voltage variations is further presented in [54] by including power flow equations and voltage constraints optimization model of TE (more details on constraint modelling is given in Section 4). The studies performed show that without TE and with observed PV penetration, overvoltage violations occur concurrently with peak PV generation in the system and undervoltage occurs when peak load occurs. When TE is introduced, all voltage problems are removed, since the market mechanism also includes network constraint optimization. Hayes et al. [55] indicate that a moderate level of P2P energy trading (more precisely, at a level that does not increase peak demand of the system) should not have a significant impact on network operational performance in terms of phase voltage imbalance and voltage profiles. These diverging results therefore largely depend on the market mechanism employed. If a market mechanism is employed in the way that does not increase the peak demand of the system, there will not be a significant impact on network performance in relation to voltage imbalance and voltage quality.

Table 1
Summary of detected technical impact of LEMs on power systems.

Technical impact	Impact	Reference	Major impact driver
Voltage variation	High voltage	[52]	Scenario with high rooftop PV penetration level
		[53]	Scenarios exclude prosumers' trading strategies
	Minimization of voltage drops	[53]	Affected by prosumers trading strategies
		[54]	Once LEM mechanism is introduced, voltage issues are removed
	No specific effect	[55]	
Phase imbalance in LV network	Imbalance across different phases	[56,57,58]	Affected by prosumers' trading behaviour Introduction of control mechanism does not have negative effect on market mechanism outcome [58]
System power peak	Increased system power peak	[59]	Scenarios exclude prosumers' trading strategies
	Reduced power peak	[51]	Reduction of peak load in scenario with LEM when compared to base case (no LEM)
		[56]	Battery installation in LEM has high impact on peak reduction
		[60]	Network capacity tariff has higher impact on peak power reduction
		[61]	Impacted by prosumers strategies and market mechanism
		[62]	Impacted by flexibility market shifting demand
		[63]	Impacted by inclusion of physical network constraint
Line congestion	Reduced line congestion	[59]	Scenario with uniform pricing mechanism
	Increased line congestion	[59]	Scenario with heterogeneous pricing mechanism
		[64]	Scenarios without network fees and with unique (constant) network fee
Cyber-attack vulnerability	Reduced vulnerability	[59]	Distributed management approach
	Increased vulnerability	[65]	Increased vulnerability on electricity price attacks
Distribution system planning	Reduced investment needs	[66,67]	–

Nousdilis et al. [68] 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. [72] developed a new analytical method for voltage sensitivity analysis that allows for stochastic analysis of change in grid voltage due to change in consumer behaviour and to derive a probability distribution of voltage change on buses due to random behaviour of multiple active consumers, for both fixed [72] and spatially random [71] distribution of active consumers. In [73] a data-driven method was developed that mitigates voltage violation by taking a control action before the actual voltage violation happened. To date, the method has been developed and tested for only single-phase systems.

Table 2
Summary of use cases used when studying LEM impact in reviewed literature.

Test case	Voltage level	Simulation data	
		Synthetic	Smart Meter / Real system data/ Daily representative curves
IEEE LV European Feeder	Low voltage	[53,55,68]	[62]
IEEE 9 bus test system	Medium voltage	[64]	
IEEE 13 bus test system	Low voltage	[69]	
IEEE 14 bus test system	High voltage	[59]	
IEEE 37 bus test system	Low voltage	[54]	
IEEE 39 bus test system	High voltage	[64,70]	
IEEE 69 bus test system	Medium voltage	[25,65,71–73]	
IEEE 123 bus test system	Low voltage	[54,69]	
Various non-standard LV test systems	Low voltage		[63]
LV test systems based on real system characteristics	Low voltage		[76,77]

3.2. Phase imbalance

Phase imbalance includes both voltage imbalance and current imbalance [80]. IEC defines current imbalance factor as the ratio of the negative sequence component to the positive sequence component [81,82]. As the consequence of voltage and current imbalance, the power values on the three phases are also unbalanced. Most LEM studies assume balance between phases and do not consider the phases to which households are connected. Network imbalance between phases can lead to bigger voltage rises and higher losses. Horta et al. [57] presented a method to minimize the negative impact of those market participants that are considered to have the highest impact on voltage unbalance due to their DER installation. This was 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 [56]) and can effectively increase the capacity of the distribution grid for hosting renewable energy. Further, in [58], a real-time control mechanism was included 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. [55] 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).

3.3. Increased power peak and congestion

LEMs have the potential to increase penetration of DERs in distribution networks and so may subsequently cause increased congestion in the system due to the absence of matching generation and available transmission infrastructure hosting capacity [83]. Congestion is also caused by unexpected eventualities such as generation outages, unexpected escalation of load demand, and equipment failure [84]. Le Cadre et al. [59] simulated the impact of different price distributions (uniform, heterogeneous, symmetric, and local trade preferences with uniform prices) on congestion in the network and concluded that price development mechanisms impact the outcome of the LEM and can cause congestion. Energy quantities traded in case of heterogeneous prices are much larger and almost half of the lines are congested, whereas some lines are almost unused in case of uniform market prices. This leads us to the conclusion that network impact of LEMs is heavily dependent on market and pricing design.

Besides these two mechanisms, network tariffs can also have an impact on changing prosumers' behaviour and subsequently impact on the network (more details on network tariffs modelling are given in Section 5). Almenning at al. [60] studied how network tariffs and P2P trading affect the energy import management of a small neighbourhood that is able to trade energy locally as well as utilize several different flexible loads. Two network tariff structures were modelled (capacity and energy based) on two levels (neighbourhood and consumer). For the consumer level, all consumers worked individually and were unaffected by the operation of other consumers. Results show decreased power peak by 11% and 7% if considering a consumer level and neighbourhood level, respectively. A capacity subscription tariff (instead of an energy tariff) registered the lower grid imports in the neighbourhood. Tushar et al. [61] 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. [62] 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 the DSO's management options in reducing local grid peaks is the integration of storage devices (either community-based or local) together with energy management systems [85–88].

3.4. Vulnerability to cyber attacks

Since LEM models rely on the data coming from smart meter devices, cyber security attacks pose a risk to distribution grid operation [89], although this risk is not exclusively related to LEM or P2P architectures [90]. Jhala et al. [65] investigated the impact of a false data injection attack by simulating an attack on demand data and an attack on electricity price signals. Results show that the impact of an attack on electricity prices is more severe than an attack on electricity demand since the attack on electricity prices requires manipulation of only one parameter. Le Cadre et al. [59] note that in case of failure or if one node is attacked, the power system can still rely on the other nodes as the information and decisions are not optimized by a single central entity. Decentralized approaches could therefore increase resilience in terms of cyber-security when compared to a centralised management approach.

3.5. Distribution network planning

The planning of distribution networks in the LEM market environment has not yet been widely studied in the identified literature, although planning frameworks to incorporate flexibility into the planning process have been proposed [91], as well as methodologies for joint planning and operation of distribution networks [92]. Delarestaghi et al. [66] studied how the inclusion of a P2P market affects the investment plan of different stakeholders in the distribution network. The study showed that the deployment of a P2P market results in less energy purchased during peak hours, which in turn means less power passed through the substation and feeders, helping to prevent the utility from unnecessary investment. Difficulties associated with network planning in the context of DERs do not come from the market itself, but rather from the risk of consumers disconnecting from the network, increased costs of facilities and equipment common to the network for consumers remaining connected, increased operating costs and increase in electricity prices due to climate policies.The same authors [67] developed a novel distribution planning framework that uses scenario-based investment planning approach by clustering historical data (energy wholesale prices, loads and PV generation) into several representative day clusters and solved the optimization problem using mixed integer second-order cone programming (MISOCP). The paper showed that, for scenarios where neighbourhood energy trading is allowed, the total cost of electrification decreases, while end-users' investment in batteries and PV units increases.

3.6. Control mechanisms

With the grid under increasing stress because of growing reliance on electricity and the introduction of DERs, the role of the DSOs in controlling quality of supply within the allowed limits is increasingly challenging. Reinforcing or replacing parts of the system is expensive and time consuming. A possible solution is to actively use the active and reactive power control capabilities of those DERs to keep the voltage within limits. To cope with problems coming from increased DERs penetration and integration of P2P markets in the network, the SmarTest project [93] 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 decentralised voltage control algorithms. Almasalma et al. [94] 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 [95]. 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.

4. Methods to include physical grid constraints in market models

In the previous section we explained that the physical impact of LEM models can vary greatly depending on whether network constraints are implemented in the market model. Methods to include a consideration of the physical grid layer alongside the market layer vary significantly in literature. In this section, we describe methods for including network constraints in market mechanisms in more detail based on our literature research. We cover the integration of branch flow equations into market mechanism models to accurately reflect grid constraints and/or give dynamic price signals to the prosumers to adapt their behaviour in a way to comply with network constraints. Additionally, power losses and network fees can be used as signals to include network constraintse, and we summarize them in Table 3 alongside branch equations. Since network tariffs and power losses costs are not only used to mimic network constrains, but to recover network costs, they are covered separately and in more detail in Section 5.

4.1. Branch flow equations

Branch flow equations represent constraints imposed by power flows on radial distributions systems by substituting conventional AC power flow equations. They were introduced first by Baran and Wu [102] to model power flows in a steady state in a balanced single-phase distribution network. In the next two sections we present current research in the area of LEMs that uses branch equations as a tool to include network constraints in the market mechanism design.

4.2. AC branch flow equations

Munsing et al. [96] propose an architecture for P2P energy markets to guarantee that operational constraints are respected, and payments are fairly rendered. The network was modelled as an undirected radial graph and power flow constraints formed a non-convex set. They used Alternating Direction Method of Multipliers (ADMM) to decompose the

Table 3
Overview of methods used to include network constraints in LEM mechanism clearing algorithm.

Reference	Network constraints in market clearing algorithm	Optimal power flow calculation
Guerrero et al. [43]	- Voltage Sensitivity Coefficients - Power Transfer Distribution Factors - Loss sensitivity Factors	No
Azim et al. [52]	Yes/No - Power flow calculated after the market solution is obtained	No
Munsing et al. [96]	Branch flow equations	Yes – decentralized OPF
Li et al. [54]	Branch flow equations	Yes - decentralized OPF
Wang et al. [97]	DC branch flow equations approximation	Yes
Qin et al. [98]	DC branch flow equations approximation	No
Masood et al. [69]	DC branch flow equations approximation	No
AlSkaif et al. [99]	AC branch flow equations	Yes AC OPF
Van Leeuwen et al. [63]	AC branch flow equations	Yes AC OPF
Xu et al. [100]	Matching of supply and demand with minimum power transmission losses	No
Guerrero et al. [70]	- Voltage Sensitivity Coefficients - Power Transfer Distribution Factors - Loss sensitivity Factors	No
Baroche et al. [64]	In form of network fees	No
Moret et al. [25]	In the form of spatial and temporal varying network fees	No
Zhong et al. [101]	Branch flow equations	No

convex optimization problems resulting from the network and DERs' constraints. The work assumed that each party in the system had full knowledge of network topology in the system. Wang et al. [97] also included branch flow equations as network constraints to schedule DERs in an optimal way by solving the Optimal Power Flow (OPF). Further applications of OPF can be found in [54] which showed a positive impact on solving voltage variations (c.f. Section 3), as well as in [63] where the AC OPF problem was combined with a bilateral trading mechanism in a single optimization problem. It led to a fully decentralized algorithm that achieved maximum total social welfare by minimizing both grid import costs and trading costs for every agent separately and in parallel while respecting global grid constraints and balancing supply and demand. The model was tested with dataset from a real prosumer community in Amsterdam and results showed that inclusion of physical network constraints in the optimization problem meant the algorithm would avoid using the grid excessively during peak hours, not just because of cost incentives, but also because of possible congestion issues.

4.3. DC branch flow equations

Qin et al. [98] proposed linearizer DC approximation of the AC power flow equations. Constraints were modelled as capacity constraints and equality constraints over the entire network (demand equal to supply). The system operator ensured that network constraints were not violated by curtailing trades if network constraints were violated, and by publishing information about the network state to guide participants regarding how subsequent trades could avoid overloading congested lines. DC power flows were also included in optimization problems in [69] and [103] for an interaction between the DSO, TE market operator and aggregators that represent interests of flexible customers (e.g. EV owners). In the first stage, the aggregator collected the charging requirement of an individual EV. Based on these requirements an initial aggregated charging schedule of EVs was created and an energy profile was provided to the DSO. In the second stage, if the flexibility call was activated, the aggregators accumulated the available flexibility from consumers to offer bids in the form of flexibility profiles with the information about EVs that will refrain from charging. The study case showed that by incorporating network constraints in the bidding optimization problem, the solution was technically much more effective as it led to the activation of only technically feasible bids. The model was tested for a larger test network for scaling purposes and showed that it could be solved more quickly as a result of it being based on linear programming. Decentralized ADMM-based OPF on a private blockchain-smart contracts platform has been tested in [99]. Smart contracts could be expanded to allow trading mechanisms, although the study does not assume any trading between different households.

4.4. Post market-clearing constraints

Additional studies [98,104] propose market models without network constraints, but in order to ensure that transactions do not cause violations, at a certain point of a time, the DSO collects all the contracts, and rejects those that cause violation.

5. Methods to calculate network tariffs and power losses that reflect trading flows

Currently, the main method for recovering distribution network costs is through network usage fees. As described in a report by the European Commission [105], the majority of distribution grid tariffs in Europe consist of volumetric charges (i.e. €/kWh). In a traditional setting, consumers connected to the distribution network are not able to react strongly to price signals and volumetric tariffs are only slightlycost-reflective. Higher penetration levels of DERs, as well as introduction of LEMs at the consumer-side, are challenging the traditional use of volumetric network charges. Specifically, volumetric charges with net-metering, implying that a consumer will be charged for the net consumption from the grid over a certain period (e.g. month), are deemed inadequate with the massive deployment of solar PV [106]. In the context of LEMs, the objective of the network fees allocation could be for system operators to achieve cost recovery but also to reduce congestion risks (i.e. to influence prosumers to behave in a certain way).

The technological advances of LEMs give an opportunity for development of new allocation methodologies of power losses. There is a possibility to assign power losses to every transaction in the system, contrary to prevailing approach of evaluating power losses in the system by estimating them at the highest demand (using some loss estimation method) and applying the loss factor to predict the total energy losses [107]. Besides allocation, similar to network fees, power losses can also be used to mimic network constraints in the system as introduced earlier in Section 4.

Table 4 summarizes the research studies and methods used to allocate network fees and power losses in the system, as well as where those methods were used as network constraint or price signals in LEM market models.

5.1. Network fees

Guerrero et al. [43,70] proposed a methodology to assess the impact of P2P transactions based on voltage sensitivity factor (VSC), power transfer sensitivity factor (PTSF) and power loss sensitivity factor (PLSF). VSC was used to calculate voltage variations leading to transactions not being allowed where they caused voltage issues in the network. PTSFs values were proposed to assign congestion charges: agents paid charges for using a physical network, and this could also be used to estimate the congestion in the lines. PLSFs, together with VSCs, were used to calculate costs associated with losses caused by each transaction. Simulation results showed that the proposed method

Table 4
Overview of methods used to calculate network tariffs and power losses that reflect trading flows.

Reference	Allocation of network fees method	Allocation of power losses method	Included in market algorithm as constraint
Guerrero et al. [43]	PTSFs values	PLSFs, together with VSCs	Yes
Lilla et al. [74]	No	Proportionally attributed to the transactions that create flows in branch	Yes
Guerrero et al. [70]	PTSFs values	PLSFs, together with VSCs	Yes
Baroche et al. [64]	Exogenous costs (unique unit fee, distance unit fee, uniform zonal unit fee).	No	Yes
Paudel et al. [108]	Power transfer distribution factor	Yes	Yes, if factors published in advance
Moret et al. [25]	Relative transaction cost between energy communities	No	Yes
Zhong et al. [101]	Network usage tariff with defined upper and lower limit	No	Yes
Di Silvestre et al. [77]	No	Proportional Sharing Rule (PSR) index	No
Nikolaidis et al. [109]	No	Graph-based framework (3 phase)	No

reduced the energy cost of the users and achieved the local balance between generation and demand of households without violating the technical constraints. Baroche et al. [64] tested three incentive frameworks in a form of exogenous costs (unique unit fee, distance unit fee, uniform zonal unit fee). The distance unit fee showed the ability to limit the stress put on the physical grid by the market. On the downside, the approach may lead to inefficient or unfeasible solutions when network charges are not chosen wisely. Similarly, Paudel et al. [108] proposed a method to calculate network fees based on power transfer distribution factor. The network owner provided the charging rate for network utilization in advance before the P2P negotiation started. The network owner considered the capital cost recovery, cost of maintenance and modernization of power lines, taxes, and policies, etc. to decide the rate for the network utilization. Approximated losses were also considered. Moret and Pinson [25] investigated additional costs that mimic network constraints when an energy collective is formed by prosumers from different neighbourhoods. Flow was defined for each line connecting the neighbourhoods and geographical differentiation was included as a relative transaction cost. This formulation allowed representation of technical constraints, typical of power flow analysis, in the form of spatial and temporal varying grid tariffs. Zhong et al. [101] proposed a cooperative energy market model where buyers and sellers trade energy in a P2P manner and pay network tariff to the network operator. A network usage tariff that is too high discourages buyers and sellers from P2P energy trading, while a network usage tariff that is too low discourages the network operator from providing P2P power delivery services.

5.2. Power losses costs

Allocating power losses cost for each transaction between prosumers in LEM is a complex problem since the missing link between virtual and physical transactions makes correct power losses allocation difficult. Di Silvestre et al. [77] proposed a Proportional Sharing Rule (PSR) index that gives a more accurate evaluation of the power losses to be and associated with the energy transaction between a specific couple generator/load. Nikolaidis at al. [109] proposed a graph-based framework for allocating power losses in 3-phase 4-wire distribution networks among the P2P contracts or energy communities. Each transaction was not only defined by the transaction path between nodes (that can be connected to different phases), but also with the "mirrored" path on the neutral layer. Results show that simplifying assumptions in terms of net demand unbalances at the LV level and may introduce significant error in the calculated losses and their allocation. Omitting the influence of neutral flows on total losses may introduce non-negligible errors in the loss allocation process. Xu et al. [100] proposed a novel discounted min-consensus algorithm to discover the optimal electric power-trading route with minimal power losses in DC microgrids and avoid congestions in the grid. It considered network constraints in the form of power losses in power lines. An advantage of this approach is that it requires only local and neighbourhood information for each agent, without the knowledge of the system parameters. Lilla et al. [74] presented a method of day-ahead scheduling of LEM using ADMM, previously developed by Orozco et al. [75]. The goal of optimization is to minimise energy procurement costs of the community considering power loss in the internal LV network by allocating internal network losses to various power transactions between two prosumers or between a prosumer and the utility grid. The results confirm that, in the considered LEM framework, each prosumer achieves a reduction in costs or increases revenues by participating in the LEM compared to the case in which it can only transact with an external energy provider.

6. Discussion

Key aspects of LEM impact on power systems have been identified discussed, including voltage variations, congestion and peak load issues, distribution system planning, control mechanisms, cyber-attack vulnerability, network constraints modelling and power losses alloca- tion. For each key aspect, existing research and practice have been reviewed. In general, it was found that LEM research is very trans- disciplinary, making it hard to decouple the impact on power systems from market model design or existing policy and regulation frameworks. It is seen that although a number of efforts have been made in addressing the issues of physical layer of LEM model, research in this area is still limited by existing market and policy frameworks. Detailed concluding remarks are presented below.

6.1. Research design constraints of previous case studies

49 scientific papers were surveyed in order to study the impact of LEM models on physical layer of power systems. Most of the papers primarily focused on market design, and the impact on physical layer was not a main focus, but rather it was often a by-product of the study. Therefore, it was difficult to fully draw systematic conclusions due to the research design associated with previous work. Additionally, previous research was restricted due to limited or non-existent historical trading data in LEMs, meaning that research only had access to simulation data on future prosumers' behaviour. Prior work is therefore scenario-based and dependent on model assumptions for future prosumers' trading strategies. Prosumers' trading strategies were often modelled using mathematical optimization methods that might not unambiguously translate to reality once LEMs are implemented in the real distribution system. This makes it challenging to study their impact on distribution network operation. Further research is therefore needed in the area of prosumers' behaviour strategies to study their impact realistically. In addition, most of the case studies used standardized one-phase networks or balanced three-phase cases. In real-world LEM markets, most of the prosumers are expected to be connected to an unbalanced LV network and future research should explore what level of detail in network modelling is actually needed and optimal, in addition to appraising the benefits of detailed system modelling. In addition, at times the

assumptions for simulations presented in literature were contradictory, leading to opposing conclusions in relation to certain topics.

6.2. Voltage and congestion problems and benefits

A large number of researchers anticipated voltage violations and congestion as being an important impact of LEMs. There appeared to be consensus that prosumer strategies for demand affect voltage levels, but the extent of the impact, and whether it is positive or negative, depends on the market mechanism employed. If a mechanism is employed in the way that does not increase the peak demand of the system, there will not be a significant impact on network performance in relation to voltage imbalance and voltage quality, and vice versa. It should be noted that most studies focused on designing market models, control mechanisms and participant models that had a positive impact on voltage from the technical point of view, meaning negative consequences were avoided by design and so not observed in the results.

6.3. Phase imbalance

For phase imbalances, most studies assumed balance between phases and did not include a representation of the phases to which households were connected. Some studies show that increased DER penetration because of LEMs could cause further enhance network imbalance between phases and lead to higher voltage rises and losses. Therefore, future studies should investigate the effects of LEMs on phase imbalance issues in more detail, especially considering that most of the use cases are designed with prosumers connected to LV networks in mind. Future research should study in detail different control mechanisms options that could mitigate the effect of phases imbalance and extend the hosting capacity of distribution networks.

6.4. Network control solutions

To realise benefits in practice and the limit potential issues mentioned above, the system requires improved dynamic and decentralized network control solutions as well as active operation and planning from the DSO side. We believe the role of digitalization is crucial to enable that. Once digitized, systems become more efficient and responsive, which allows innovative solutions, including DERs and LEMs to integrate more rapidly. On the other hand, it gives DSOs an opportunity to increase their reliability, efficiency, and customer engagement.

6.5. Distribution system planning

Novel distribution system planning methodologies and procedures are necessary to cope with changes LEMs are bringing to distribution grid. Peak capacity driven investments in network are therefore not sustainable in the long-term planning horizon. Stochastic prosumer models, distributed control mechanism and active participation of consumers empowered by flexible load, generation and storage devices need to be considered, allowing for market and operational driven active distribution planning.

6.6. Methods to include physical network constraints in market models and the role of DSO

The review also reported methods to include physical grid constraints in market models, and the associated role of the DSO in such systems. While branch equations solutions or power losses allocation methods to include network constraints in market mechanisms seem to be promising, they could require complex computation requirements and detailed knowledge of the network infrastructure. We believe there are two options: (a) a centralized approach where central entities have infrastructure knowledge, or a (b) distributed approach, where each prosumer needs to have infrastructure knowledge of their immediate neighbourhood.

This leads to the conclusion that the DSO needs to be involved to a great extent in the LEM mechanism development and decision making when creating LEM market mechanisms that include network constraints. It is therefore of great importance to study how to integrate DSO or a central entity within the LEM in case of a centralized marketplace design. In case of distributed marketplace design, information sharing and responsibilities between involved actors need to be properly defined, especially when it concerns critical infrastructure information.

6.7. Network tariffs as network constraints signals

Research identified that, instead of branch equations, increased use of dynamic network tariffs by the DSO could be a signal to prosumers to change behaviour that led to undesirable consequences in local networks. Network tariffs are already part of the current power system structure and therefore could be adapted and fit into existing regulatory frameworks. Future work should therefore focus on developing methodologies for designing dynamic network tariffs in way that does not lead to undesired effects, for example an inability of the DSO to recover its operational costs.

6.8. Methods to calculate power losses

The literature review reported studies that allocated power losses to transactions in LEM markets, mainly using graph-based allocation methods. As with including network constraints, simplifying the network may lead to false results which are not negligible. Conversely, the level of detailed information needed for three phase studies might not always be available or feasible and future work should focus on finding the optimal balance between information and computational burden on one side, and acceptable level of errors on the other.

6.9. Impact on the transmission network operation

The literature review did not identify research works that studied the impact of LEMs on transmission system level operation and planning. Most of the study cases identified in the literature were based on small test cases in terms of number of prosumers, peak power, feeder and location. The impact of LEMs could become a challenge to the transmission network in the case of a high number of LEMs, so future research should cover LEMs providing services to transmission networks, reversible flows issues, network tariff redesign (i.e., to cover TSO cost recovery), and how the role of transmission network changes once a significant amount of DERs are connected to the distribution network and supplying LV customers almost exclusively through LEMs.

7. Conclusion

We conducted an extensive literature review to identify and discuss the network impact of integrating Local Energy Market models in the distribution network. The intention of the research was to identify how they affect grid operation, the possible problems and benefits, the impact of self-consumption on the grid in the context of Local Energy Markets, the impacts of interaction between multiple Local Energy Markets, the methods used to include network constraints, and the impact on transmission network operation. First, we categorized papers that deal with the impact of Local Energy Markets on the power systems (in relation to voltage variations, phase imbalance, power peaks, congestion, vulnerability to cyber-attacks, network planning and control mechanisms). Second, we categorized different methods to include physical constraints in market models (considering branch flow equations and different tariffs). Third, we covered in detail different methods to calculate and allocate network tariffs and power losses, which are possible due to digital advances of Local Energy Markets, when comparing to methods used in traditional networks setup. Finally, we addressed several challenges in relation to network impact and integration of Local Energy Market models in power systems in order to facilitate and accelerate their implementation.

CRediT authorship contribution statement

Viktorija Dudjak: Investigation, Methodology, Conceptualization, Writing - original draft. **Diana Neves:** Investigation, Conceptualization, Writing - review & editing. **Tarek Alskaif:** Investigation, Conceptualization, Writing - review & editing. **Shafi Khadem:** Investigation, Conceptualization, Writing - review & editing. **Alejandro Pena-Bello:** Investigation, Writing - review & editing. **Pietro Saggese:** Investigation, Writing - review & editing. **Benjamin Bowler:** Methodology, Writing - review & editing. **Merlinda Andoni:** Investigation, Writing - review & editing. **Marina Bertolini:** Investigation, Writing - review & editing. **Yue Zhou:** Investigation. **Blanche Lormeteau:** Investigation, Writing - review & editing. **Mustafa A. Mustafa:** Investigation, Writing - review & editing. **Yingjie Wang:** Investigation. **Christina Francis:** Investigation. **Fairouz Zobiri:** Investigation. **David Parra:** Investigation. **Antonios Papaemmanouil:** Writing - review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

This publication is part of the work of the Global Observatory on Peer-to-Peer, Community Self-Consumption and Transactive Energy Models (GO-P2P), an Annex of the User-Centred Energy Systems Tech- nology Collaboration Programme (Users TCP), under the auspices of the International Energy Agency (IEA). GO-P2P benefits from the support of Australia, Belgium, Ireland, Italy, The Netherlands, Switzerland, the United Kingdom and the United States.

References

[1] 'DIRECTIVE (EU) 2018/ 2001 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL - of 11 December 2018 - on the promotion of the use of energy from renewable sources', p. 128, 2018.
[2] Lowitzsch J, Hoicka CE, van Tulder FJ. Renewable energy communities under the 2019 European Clean Energy Package – Governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 2020;122:109489. https://doi.org/10.1016/j.rser.2019.109489.
[3] IRENA. Innovation landscape for a renewable-powered future: Solutions to integrate variable renewables. Int. Renew. Energy Agency Abu Dhabi 2019:164.
[4] Damsgaard N, Helbrink J, Papaefthymiou G, Grave K, Giordano V, Gentili P. 'Study on the effective integration of Distributed Energy Resources for providing flexibility to the electricity system. Report to the European Commission' 2015. https://doi.org/10.13140/RG.2.2.35386.39360.
[5] V. Monteiro, J. L. Afonso, V. Monteiro, H. Gonçalves, and J. L. Afonso, 'Impact of Electric Vehicles on Power Quality in a Smart Grid Context', in 11th IEEE International Conference on Electrical Power Quality and Utilisation (EPQU), 2011, pp. 1–6. doi: 0.1109/EPQU.2011.6128861.
[6] X. Tang and G. Tang, 'Power Flow for Distribution Network with Distributed Generation', in 2010 Asia-Pacific Power and Energy Engineering Conference, Chengdu, China, 2010, pp. 1–4. doi: 10.1109/APPEEC.2010.5448305.
[7] IRENA. Innovation landscape brief: Innovative ancillary services. Int. Renew. Energy Agency Abu Dhabi 2019:24.
[8] IRENA. Innovation landscape brief: Future role of distribution system operators. Int. Renew. Energy Agency Abu Dhabi 2019:20.
[9] F. Ponci and A. Monti, 'The Digitalization of Distribution Systems - IEEE Smart Grid'. https://smartgrid.ieee.org/newsletters/september-2016/the-digitalization-of-distribution-systems (accessed Mar. 18, 2021).
[10] E. Mengelkamp and C. Weinhardt, 'Clustering Household Preferences in Local Electricity Markets', in Proceedings of the Ninth International Conference on Future Energy Systems, Karlsruhe Germany, Jun. 2018, pp. 538–543. doi: 10.1145/3208903.3214348.
[11] F. Teotia and R. Bhakar, 'Local energy markets: Concept, design and operation', in 2016 National Power Systems Conference (NPSC), Bhubaneswar, India, Dec. 2016, pp. 1–6. doi: 10.1109/NPSC.2016.7858975.
[12] IRENA. Innovation landscape brief: Peer-to-peer electricity trading. Int. Renew. Energy Agency Abu Dhabi 2020:20.
[13] H. Beitollahi and G. Deconinck, 'Peer-to-Peer Networks Applied to Power Grid', presented at the International conference on Risks and Security of Internet and Systems (CRiSIS)' in conjunction with the IEEE GIIS'07, Marrakech, Morocco, 2007. Accessed: Oct. 17, 2021. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.134.7160&rep=rep1&type=pdf.
[14] Zepter JM, Lüth A, Crespo del Granado P, Egging R. Prosumer integration in wholesale electricity markets: Synergies of peer-to-peer trade and residential storage. Energy Build. Feb. 2019;184:163–76. https://doi.org/10.1016/j.enbuild.2018.12.003.
[15] Neves Diana, Scott Ian, Silva Carlos A. Peer-to-peer energy trading potential: An assessment for the residential sector under different technology and tariff availabilities. Energy 2020;205:118023. https://doi.org/10.1016/j.energy.2020.118023.
[16] Alam MR, St-Hilaire M, Kunz T. Peer-to-peer energy trading among smart homes. Appl. Energy Mar. 2019;238:1434–43. https://doi.org/10.1016/j.apenergy.2019.01.091.
[17] A. U. N. Ibn Saif and S. K. Khadem, 'Consumer-centric Electricity Market: Review of key European projects', in 2020 17th International Conference on the European Energy Market (EEM), Stockholm, Sweden, Sep. 2020, pp. 1–6. doi: 10.1109/EEM49802.2020.9221946.
[18] Mengelkamp E, Gärttner J, Rock K, Kessler S, Orsini L, Weinhardt C. Designing microgrid energy markets: A case study: The Brooklyn Microgrid. Appl. Energy Jan. 2018;210:870–80. https://doi.org/10.1016/j.apenergy.2017.06.054.
[19] L. Ableitner, A. Meeuw, S. Schopfer, V. Tiefenbeck, F. Wortmann, and A. Wörner, 'Quartierstrom – Implementation of a real world prosumer centric local energy market in Walenstadt, Switzerland', ArXiv190507242 Cs, Jul. 2019, Accessed: Oct. 17, 2020. [Online]. Available: http://arxiv.org/abs/1905.07242.
[20] Wörner A, Meeuw A, Ableitner L, Wortmann F, Schopfer S, Tiefenbeck V. Trading solar energy within the neighborhood: field implementation of a blockchain-based electricity market. Energy Inform. Sep. 2019;2(S1):11. https://doi.org/10.1186/s42162-019-0092-0.
[21] Khorasany Mohsen, Mishra Yateendra, Ledwich Gerard. Market framework for local energy trading: a review of potential designs and market clearing approaches. IET Gener. Transm. Distrib. 2018;12(22):5899–908. https://doi.org/10.1049/gtd2.v12.2210.1049/iet-gtd.2018.5309.
[22] E. Mengelkamp, J. Gärttner, and C. Weinhardt, 'Decentralizing Energy Systems Through Local Energy Markets : The LAMP-Project', Multikonferenz Wirtsch. MKWI 2018 Lünebg. 06 - 09 März 2018, p. 924, 2018.
[23] 'ENERCHAIN - Decentrally Traded Decentral Energy'. https://enerchain.ponton.de/index.php (accessed Mar. 06, 2021).
[24] Mihaylov M, Razo-Zapata I, Nowé A. NRGcoin—A Blockchain-based Reward Mechanism for Both Production and Consumption of Renewable Energy. In: Marke A, editor. Transforming Climate Finance and Green Investment with Blockchains. Academic Press; 2018. p. 111–31. https://doi.org/10.1016/B978-0-12-814447-3.00009-4.
[25] Moret Fabio, Pinson Pierre. Energy Collectives: A Community and Fairness Based Approach to Future Electricity Markets. IEEE Trans. Power Syst. 2019;34(5):3994–4004. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2808961.
[26] 'The Energy Collective project – Towards direct sharing and trading of energy!' http://the-energy-collective-project.com/ (accessed Mar. 06, 2021).
[27] 'P2P-SmarTest Project', p2p-smartest. https://www.p2psmartest-h2020.eu (accessed Mar. 06, 2021).
[28] Olivella-Rosell Pol, Bullich-Massagué Eduard, Aragüés-Peñalba Mònica, Sumper Andreas, Ottesen Stig Ødegaard, Vidal-Clos Josep-Andreu, et al. Optimization problem for meeting distribution system operator requests in local flexibility markets with distributed energy resources. Appl. Energy 2018;210:881–95. https://doi.org/10.1016/j.apenergy.2017.08.136.
[29] Invade, 'The Project – Invade'. https://h2020invade.eu/the-project/ (accessed Mar. 06, 2021).
[30] Mendes G, Honkapuro S, Nylund J, Kilkki O, Annala S, Segerstam J, et al. Ljubljana Workshop. Ljubljana, Slovenia, Jun. 2018;2018:5. https://doi.org/10.34890/443.
[31] G. Mendes, C. Trocato, J. R. Ferreira, O. Kilkki, S. Albuquerque, and S. Repo, 'Pushing the Transition Towards Transactive Grids Through Local Energy Markets', in Proc. of the 25th International Conference on Electricity Distribution (CIRED 2019), Madrid, Spain, Jun. 2019, p. 5. doi: 10.34890/183.
[32] M. Vasconcelos, W. Cramer, C. Schmitt, S. Jessenberger, A. Amthor, F. Heringer, et al., 'THE Pebbles Project – Enabling Blockchain-Based Transactive Energy Trading of Energy & Flexibility Within a Regional Market', p. 5, 2019.
[33] Chunyu Zhang, Yi Ding, J. Ostergaard, H. W. Bindner, N. C. Nordentoft, L. H. Hansen, et al., 'A flex-market design for flexibility services through DERs', in IEEE PES ISGT Europe 2013, Lyngby, Denmark, Oct. 2013, pp. 1–5. doi: 10.1109/ISGTEurope.2013.6695286.
[34] 'Interflex - Home'. https://interflex-h2020.com/ (accessed Mar. 06, 2021).
[35] C. Dumbs, G. Jarry, M. Willems, T. Gross, A. Larsen, E. On, et al., 'Market Models for Local Flexibility Procurement: Interflex' Experience and Main Challenges', in Proc. of the 25th International Conference on Electricity Distribution (CIRED 2019), Madrid, Spain, Jun. 2019, p. 5. doi: 10.34890/979.
[36] Khorasany M, Azuatalam D, Glasgow R, Liebman A, Razzaghi R. Transactive Energy Market for Energy Management in Microgrids: The Monash Microgrid Case Study. Energies Apr. 2020;13(8):2010. https://doi.org/10.3390/en13082010.

[37] Ambrosio R. Transactive Energy Systems [Viewpoint]. IEEE Electrification Mag. Dec. 2016;4(4):4–7. https://doi.org/10.1109/MELE.2016.2614234.
[38] Lezama Fernando, Soares Joao, Hernandez-Leal Pablo, Kaisers Michael, Pinto Tiago, Vale Zita. Local Energy Markets: Paving the Path Toward Fully Transactive Energy Systems. IEEE Trans. Power Syst. 2019;34(5):4081–8. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2833959.
[39] 'Understanding Peer-to-Peer, Blockchain, and Transactive Energy'. https://guidehouseinsights.com/news-and-views/understanding-peertopeer-blockchain-and-transactive-energy (accessed May 16, 2021).
[40] 'Collective Self Consumption projects: The lever to unlock access to local renewable electricity', ENEA Consulting, Jul. 07, 2020. https://www.enea-consulting.com/wp-content/uploads/2020/07/ENEA_CollectiveSelfConsumption-web.pdf.
[41] R. Baetens, 'Peer(s)-to-Peer(s) | 3E', Feb. 24, 2020. https://3e.eu/news/blog/peers-peers (accessed May 16, 2021).
[42] Georgilakis PS. Review of Computational Intelligence Methods for Local Energy Markets at the Power Distribution Level to Facilitate the Integration of Distributed Energy Resources: State-of-the-art and Future Research. Energies Jan. 2020;13(1):186. https://doi.org/10.3390/en13010186.
[43] Guerrero Jaysson, Chapman Archie C, Verbic Gregor. Decentralized P2P Energy Trading Under Network Constraints in a Low-Voltage Network. IEEE Trans. Smart Grid 2019;10(5):5163–73. https://doi.org/10.1109/TSG.516541110.1109/TSG.2018.2878445.
[44] Md Fakhrul Islam, A. M. T. Oo, and S. H. Chowdhury, 'The Traditional Power Generation and Transmission System: Some Fundamentals to Overcome Challenges', in Smart Grids: Opportunities, Developments, and Trends, A. B. M. S. Ali, Ed. London: Springer London, 2013, pp. 1–21. doi: 10.1007/978-1-4471-5210-1_1.
[45] Tushar Wayes, Saha Tapan Kumar, Yuen Chau, Smith David, Poor H Vincent. Peer-to-Peer Trading in Electricity Networks: An Overview. IEEE Trans. Smart Grid 2020;11(4):3185–200. https://doi.org/10.1109/TSG.516541110.1109/TSG.2020.2969657.
[46] Sousa T, Soares T, Pinson P, Moret F, Baroche T, Sorin E. Peer-to-peer and community-based markets: A comprehensive review. Renew. Sustain. Energy Rev. Apr. 2019;104:367–78. https://doi.org/10.1016/j.rser.2019.01.036.
[47] Tushar Wayes, Yuen Chau, Saha Tapan K, Morstyn Thomas, Chapman Archie C, Alam M Jan E, et al. Peer-to-peer energy systems for connected communities: A review of recent advances and emerging challenges. Appl. Energy 2021;282:116131. https://doi.org/10.1016/j.apenergy.2020.116131.
[48] Tushar W, Yuen C, Mohsenian-Rad H, Saha T, Poor HV, Wood KL. Transforming Energy Networks via Peer-to-Peer Energy Trading: The Potential of Game-Theoretic Approaches. IEEE Signal Process. Mag. Jul. 2018;35(4):90–111. https://doi.org/10.1109/MSP.2018.2818327.
[49] Siano Pierluigi, De Marco Giuseppe, Rolan Alejandro, Loia Vincenzo. A Survey and Evaluation of the Potentials of Distributed Ledger Technology for Peer-to-Peer Transactive Energy Exchanges in Local Energy Markets. IEEE Syst. J. 2019;13(3):3454–66. https://doi.org/10.1109/JSYST.426700310.1109/JSYST.2019.2903172.
[50] Andoni Merlinda, Robu Valentin, Flynn David, Abram Simone, Geach Dale, Jenkins David, et al. Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renew. Sustain. Energy Rev. 2019;100:143–74. https://doi.org/10.1016/j.rser.2018.10.014.
[51] Zhang C, Wu J, Zhou Y, Cheng M, Long C. Peer-to-Peer energy trading in a Microgrid. Appl. Energy 2018;220:1–12. https://doi.org/10.1016/j.apenergy.2018.03.010.
[52] M. I. Azim, S. A. Pourmousavi, W. Tushar, and T. K. Saha, 'Feasibility Study of Financial P2P Energy Trading in a Grid-tied Power Network', in 2019 IEEE Power & Energy Society General Meeting (PESGM), Atlanta, GA, USA, Aug. 2019, pp. 1–5. doi: 10.1109/PESGM40551.2019.8973809.
[53] Herenčić L, Ilak P, Rajšl I. Effects of Local Electricity Trading on Power Flows and Voltage Levels for Different Elasticities and Prices. Energies Dec. 2019;12(24):4708. https://doi.org/10.3390/en12244708.
[54] Li Jiayong, Zhang Chaorui, Xu Zhao, Wang Jianhui, Zhao Jian, Zhang Ying-Jun Angela. Distributed transactive energy trading framework in distribution networks. IEEE Trans. Power Syst. 2018;33(6):7215–27. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2854649.
[55] Hayes BP, Thakur S, Breslin JG. Co-simulation of electricity distribution networks and peer to peer energy trading platforms. Int. J. Electr. Power Energy Syst. 2020;115:105419. https://doi.org/10.1016/j.ijepes.2019.105419.
[56] J. Horta, D. Kofman, D. Menga, and A. Silva, 'Novel market approach for locally balancing renewable energy production and flexible demand', in 2017 IEEE International Conference on Smart Grid Communications (SmartGridComm), Dresden, Germany, Oct. 2017, pp. 533–539. doi: 10.1109/SmartGridComm.2017.8340728.
[57] Horta J, Kofman D, Menga D, Caujolle M. Augmenting DER hosting capacity of distribution grids through local energy markets and dynamic phase switching. In: in *E-Energy'18: Proceedings of the 9th Acm International Conference on Future Energy Systems*; 2018. p. 314–8. https://doi.org/10.1145/3208903.3208937.
[58] Horta J, Altman E, Caujolle M, Kofman D, Menga D. Real-time enforcement of local energy market transactions respecting distribution grid constraints. In: in *2018 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm)*; 2018. p. 1–7. https://doi.org/10.1109/SmartGridComm.2018.8587495.
[59] H. Le Cadre, P. Jacquot, C. Wan, and C. Alasseur, 'Peer-to-Peer Electricity Market Analysis: From Variational to Generalized Nash Equilibrium', ArXiv181202301 Cs Math, Dec. 2018, Accessed: May 05, 2020. [Online]. Available: http://arxiv.org/abs/1812.02301.
[60] O. M. Almenning, S. Bjarghov, and H. Farahmand, 'Reducing Neighborhood Peak Loads with implicit Peer-to-Peer energy trading under Subscribed Capacity tariffs', in 2019 International Conference on Smart Energy Systems and Technologies (SEST), Porto, Portugal, Sep. 2019, pp. 1–6. doi: 10.1109/SEST.2019.8849067.
[61] W. Tushar, T. K. Saha, C. Yuen, T. Morstyn, Nahid-Al-Masood, H. V. Poor, et al., 'Grid Influenced Peer-to-Peer Energy Trading', IEEE Trans. Smart Grid, vol. 11, no. 2, pp. 1407–1418, Mar. 2020, doi: 10.1109/TSG.2019.2937981.
[62] Morstyn Thomas, Teytelboym Alexander, McCulloch Malcolm D. Designing Decentralized Markets for Distribution System Flexibility. IEEE Trans. Power Syst. 2019;34(3):2128–39. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2886244.
[63] van Leeuwen Gijs, AlSkaif Tarek, Gibescu Madeleine, van Sark Wilfried. An integrated blockchain-based energy management platform with bilateral trading for microgrid communities. Appl. Energy 2020;263:114613. https://doi.org/10.1016/j.apenergy.2020.114613.
[64] Baroche Thomas, Pinson Pierre, Latimier Roman Le Goff, Ahmed Hamid Ben. Exogenous Cost Allocation in Peer-to-Peer Electricity Markets. IEEE Trans. Power Syst. 2019;34(4):2553–64. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2019.2896654.
[65] Jhala Kumarsinh, Natarajan Balasubramaniam, Pahwa Anil, Wu Hongyu. Stability of Transactive Energy Market-Based Power Distribution System Under Data Integrity Attack. Ieee Trans. Ind. Inform. 2019;15(10):5541–50. https://doi.org/10.1109/TII.942410.1109/TII.2019.2901768.
[66] Delarestaghi JM, Arefi A, Ledwich G. The impact of peer to peer market on energy costs of consumers with PV and battery. In: in *2018 IEEE Pes Innovative Smart Grid Technologies Conference Europe (isgt-Europe)*; 2018. p. 1–6. https://doi.org/10.1109/ISGTEurope.2018.8571771.
[67] Delarestaghi JM, Arefi A, Ledwich G, Borghetti A. A distribution network planning model considering neighborhood energy trading. Electr. Power Syst. Res. 2021;191:10. https://doi.org/10.1016/j.epsr.2020.106894.
[68] Nousdilis AI, Chrysochos AI, Papagiannis GK, Christoforidis GC. The Impact of Photovoltaic Self-Consumption Rate on Voltage Levels in LV Distribution Grids. In: in *2017 11th Ieee International Conference on Compatibility, Power Electronics and Power Engineering (cpe-Powereng)*; 2017. p. 650–5.
[69] Masood Arsalan, Hu Junjie, Xin Ai, Sayed Ahmed Rabee, Yang Guangya. Transactive Energy for Aggregated Electric Vehicles to Reduce System Peak Load Considering Network Constraints. IEEE Access 2020;8:31519–29. https://doi.org/10.1109/Access.628763910.1109/ACCESS.2020.2973284.
[70] J. Guerrero, A. C. Chapman, and G. Verbic, 'Peer-to-Peer Energy Trading: A Case Study Considering Network Constraints', in Proceedings of the Asia Pacific Solar Research Conference 2018, Dec. 2018, p. 12. [Online]. Available: http://apvi.org.au/solar-research-conference/wp-content/uploads/2018/11/010_D-I_Guerrero_J_2018.pdf.
[71] Jhala K, Pahwa A. 'Probabilistic voltage sensitivity analysis (PVSA) for random spatial distribution of active consumers', *2018 IEEE Power Energy Soc.* Innov. Smart Grid Technol. Conf. ISGT Feb. 2018. https://doi.org/10.1109/ISGT.2018.8403341.
[72] Jhala Kumarsinh, Natarajan Balasubramaniam, Pahwa Anil. Probabilistic Voltage Sensitivity Analysis (PVSA)—A Novel Approach to Quantify Impact of Active Consumers. IEEE Trans. Power Syst. 2018;33(3):2518–27. https://doi.org/10.1109/TPWRS.2017.2745411.
[73] K. Jhala and B. Natarajan, 'Data-Driven Preemptive Voltage Monitoring and Control Using Probabilistic Voltage Sensitivities', 2019 IEEE Power Energy Soc. Gen. Meet. PESGM, p. 5, Aug. 2019, doi: 10.1109/PESGM40551.2019.8973956.
[74] Lilla Stefano, Orozco Camilo, Borghetti Alberto, Napolitano Fabio, Tossani Fabio. Day-Ahead Scheduling of a Local Energy Community: An Alternating Direction Method of Multipliers Approach. IEEE Trans. Power Syst. 2020;35(2):1132–42. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2019.2944541.
[75] Orozco C, Lilla S, Borghetti A, Napolitano F, Tossani F. An ADMM Approach for Day-Ahead Scheduling of a Local Energy Community. IEEE Milan PowerTech 2019:6. https://doi.org/10.1109/ptc.2019.8810578. in 2019.
[76] Almasalma H, Engels J, Deconinck G. Dual-decomposition-based peer-to-peer voltage control for distribution networks. CIRED - Open Access Proc. J. Oct. 2017;2017(1):1718–21. https://doi.org/10.1049/oap-cired.2017.0282.
[77] Di Silvestre ML, Gallo P, Ippolito MG, Sanseverino ER, Zizzo G. A Technical Approach to the Energy Blockchain in Microgrids. IEEE Trans. Ind. Inform. Nov. 2018;14(11):4792–803. https://doi.org/10.1109/TII.2018.2806357.
[78] Masoum Mohammad AS, Fuchs Ewald F. In: Power Quality in Power Systems and Electrical Machines. Elsevier; 2015. p. 207–312. https://doi.org/10.1016/B978-0-12-800782-2.00003-8.
[79] S. A. Aleem, S. M. S. Hussain, and T. S. Ustun, 'A Review of Strategies to Increase PV Penetration Level in Smart Grids', Energies, vol. 13, no. 3, Art. no. 3, Jan. 2020, doi: 10.3390/en13030636.
[80] M. Krarti, 'Chapter 4 - Utility Rate Structures and Grid Integration', in Optimal Design and Retrofit of Energy Efficient Buildings, Communities, and Urban Centers, M. Krarti, Ed. Butterworth-Heinemann, 2018, pp. 189–245. doi: 10.1016/B978-0-12-849869-9.00004-1.
[81] 'Definitions of Voltage Unbalance', IEEE Power Eng. Rev., vol. 21, no. 5, pp. 49–51, May 2001, doi: 10.1109/MPER.2001.4311362.
[82] A. K. Singh, G. K. Singh, and R. Mitra, 'Some Observations on Definitions of Voltage Unbalance', in 2007 39th North American Power Symposium, Sep. 2007, pp. 473–479. doi: 10.1109/NAPS.2007.4402352.

[83] Yusoff NI, Zin AAM, Bin Khairuddin A. Congestion management in power system: A review. In: in *2017 3rd International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET)*, Apr; 2017. p. 22–7. https://doi.org/10.1109/PGSRET.2017.8251795.

[84] Yousefi A, Nguyen TT, Zareipour H, Malik OP. Congestion management using demand response and FACTS devices. Int. J. Electr. Power Energy Syst. May 2012; 37(1):78–85. https://doi.org/10.1016/j.ijepes.2011.12.008.

[85] D. Menniti, A. Pinnarelli, N. Sorrentino, A. Burgio, and G. Belli, 'Management of storage systems in local electricity market to avoid renewable power curtailment in distribution network', in 2014 Australasian Universities Power Engineering Conference (AUPEC), Perth, Australia, Sep. 2014, pp. 1–5. doi: 10.1109/AUPEC.2014.6966536.

[86] Resch Matthias, Bühler Jochen, Schachler Birgit, Kunert Rita, Meier Andreas, Sumper Andreas. Technical and economic comparison of grid supportive vanadium redox flow batteries for primary control reserve and community electricity storage in Germany. Int. J. Energy Res. 2019;43(1):337–57. https://doi.org/10.1002/er.v43.110.1002/er.4269.

[87] Santos JM, Moura PS, de Almeida AT. Technical and economic impact of residential electricity storage at local and grid level for Portugal. Appl. Energy Sep. 2014;128:254–64. https://doi.org/10.1016/j.apenergy.2014.04.054.

[88] Terlouw Tom, AlSkaif Tarek, Bauer Christian, van Sark Wilfried. Optimal energy management in all-electric residential energy systems with heat and electricity storage. Appl. Energy 2019;254:113580. https://doi.org/10.1016/j.apenergy.2019.113580.

[89] M. A. Mustafa, S. Cleemput, and A. Abidin, 'A local electricity trading market: Security analysis', in 2016 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Ljubljana, Slovenia, Oct. 2016, pp. 1–6. doi: 10.1109/ISGTEurope.2016.7856269.

[90] 'The five worst cyberattacks against the power industry since 2014'. https://www.power-technology.com/features/the-five-worst-cyberattacks-against-the-power-industry-since2014/ (accessed Mar. 06, 2021).

[91] Klyapovskiy S, You S, Cai H, Bindner HW. Incorporate flexibility in distribution grid planning through a framework solution. Int. J. Electr. Power Energy Syst. Oct. 2019;111:66–78. https://doi.org/10.1016/j.ijepes.2019.03.069.

[92] Karagiannopoulos Stavros, Aristidou Petros, Hug Gabriela. A hybrid approach for planning and operating active distribution grids. IET Gener. Transm. Distrib. 2017;11(3):685–95. https://doi.org/10.1049/gtd2.v11.310.1049/iet-gtd.2016.0642.

[93] A. Pouttu, J. Haapola, P. Ahokangas, Y. Xu, M. Kopsakangas-Savolainen, E. Porras, et al., 'P2P model for distributed energy trading, grid control and ICT for local smart grids', in 2017 European Conference on Networks and Communications (EuCNC), Oulu, Finland, Jun. 2017, pp. 1–6. doi: 10.1109/EuCNC.2017.7980652.

[94] Almasalma H, Claeys S, Deconinck G. Peer-to-peer-based integrated grid voltage support function for smart photovoltaic inverters. Appl. Energy Apr. 2019;239: 1037–48. https://doi.org/10.1016/j.apenergy.2019.01.249.

[95] Almasalma H, Claeys S, Mikhaylov K, Haapola J, Pouttu A, Deconinck G. Experimental Validation of Peer-to-Peer Distributed Voltage Control System. Energies May 2018;11(5):1304. https://doi.org/10.3390/en11051304.

[96] E. Munsing, J. Mather, and S. Moura, 'Blockchains for decentralized optimization of energy resources in microgrid networks', in 2017 IEEE Conference on Control Technology and Applications (CCTA), Mauna Lani Resort, HI, USA, Aug. 2017, pp. 2164–2171. doi: 10.1109/CCTA.2017.8062773.

[97] Wang Shen, Taha Ahmad F, Wang Jianhui, Kvaternik Karla, Hahn Adam. Energy Crowdsourcing and Peer-to-Peer Energy Trading in Blockchain-Enabled Smart Grids. IEEE Trans. Syst. Man Cybern. Syst. 2019;49(8):1612–23. https://doi.org/10.1109/TSMC.622102110.1109/TSMC.2019.2916565.

[98] Qin Junjie, Rajagopal Ram, Varaiya Pravin. Flexible Market for Smart Grid: Coordinated Trading of Contingent Contracts. IEEE Trans. Control Netw. Syst. 2018;5(4):1657–67. https://doi.org/10.1109/TCNS.650949010.1109/TCNS.2017.2746347.

[99] T. AlSkaif and G. van Leeuwen, 'Decentralized Optimal Power Flow in Distribution Networks Using Blockchain', in 2019 International Conference on Smart Energy Systems and Technologies (SEST), Porto, Portugal, Sep. 2019, pp. 1–6. doi: 10.1109/SEST.2019.8849153.

[100] Xu Yinliang, Sun Hongbin, Gu Wei. A Novel Discounted Min-Consensus Algorithm for Optimal Electrical Power Trading in Grid-Connected DC Microgrids. IEEE Trans. Ind. Electron. 2019;66(11):8474–84. https://doi.org/10.1109/TIE.4110.1109/TIE.2019.2891445.

[101] W. Zhong, S. Xie, K. Xie, Q. Yang, and L. Xie, 'Cooperative P2P Energy Trading in Active Distribution Networks: An MILP-Based Nash Bargaining Solution', IEEE Trans. Smart Grid, pp. 1–1, 2020, doi: 10.1109/TSG.2020.3031013.

[102] Baran ME, Wu FF. Optimal capacitor placement on radial distribution systems. IEEE Trans. Power Deliv. Jan. 1989;4(1):725–34. https://doi.org/10.1109/61.19265.

[103] Hu Junjie, Yang Guangya, Ziras Charalampos, Kok Koen. Aggregator Operation in the Balancing Market Through Network-Constrained Transactive Energy. IEEE Trans. Power Syst. 2019;34(5):4071–80. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2874255.

[104] Liu Y, Wu L, Li J. Peer-to-peer (P2P) electricity trading in distribution systems of the future. Electr. J. May 2019;32(4):2–6. https://doi.org/10.1016/j.tej.2019.03.002.

[105] 'Study on Tariff Design for Distribution Systems'. European Commission, 2015. [Online]. Available: https://ec.europa.eu/energy/sites/ener/files/documents/20150313%20Tariff%20report%20fina_revREF-E.PDF.

[106] 'Introduction to Network Tariffs and Network Codes for Consumers, Prosumers and Energy Communities', ERRA. https://erranet.org/download/introduction-to-network-tariffs-and-network-codes-for-consumers-prosumers-and-energy-communities/ (accessed Feb. 21, 2021).

[107] Queiroz LMO, Roselli MA, Cavellucci C, Lyra C. Energy Losses Estimation in Power Distribution Systems. IEEE Trans. Power Syst. Nov. 2012;27(4):1879–87. https://doi.org/10.1109/TPWRS.2012.2188107.

[108] A. Paudel, L. P. M. I. Sampath, J. Yang, and H. B. Gooi, 'Peer-to-Peer Energy Trading in Smart Grid Considering Power Losses and Network Fees', IEEE Trans. Smart Grid, pp. 1–1, 2020, doi: 10.1109/TSG.2020.2997956.

[109] Nikolaidis Alexandros I, Charalambous Charalambos A, Mancarella Pierluigi. A Graph-Based Loss Allocation Framework for Transactive Energy Markets in Unbalanced Radial Distribution Networks. IEEE Trans. Power Syst. 2019;34(5): 4109–18. https://doi.org/10.1109/TPWRS.5910.1109/TPWRS.2018.2832164.