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Techno-economic Assessment of Peer to Peer Energy Trading: an Egyptian Case Study

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ABSTRACT Peer-to-peer (P2P) energy trading has emerged as an innovative approach for selling electricity from prosumer to consumer at the distribution level. This paper is the first to conduct a techno-economic assessment of P2P energy trading in Aswan, Egypt. Different scenarios under different electricity tariffs, which consider photovoltaic systems, energy storage systems, and electric vehicles deployment, are analyzed to assess the performance of P2P trading considering different distributed energy resources (DERs) installations. The variety of these scenarios enables a thorough analysis of P2P trading and a clear comprehension of how P2P trading impacts distribution networks. The study offers new perspectives on the impacts of implementing P2P trading on the distribution network since it uses a real demand profiles. Results show that P2P can reduce community electricity costs, improve self-consumption by reducing exports to distribution system operator, and rise self-sufficiency compared to home energy management system (HEMS). The distribution network operation limits are not violated in any of the studied scenarios and electricity tariffs. The impacts on the distribution network for P2P energy trading scenarios and equivalent HEMS are very similar for flat tariff. However, for ToU tariff, P2P energy trading scenarios with flexible devices result in higher impacts on the distribution network than the equivalent HEMS.

INDEX TERMS P2P energy trading, energy community, local electricity market, transactive energy, impacts on distribution networks.

I. INTRODUCTION

The rapidly increasing penetration of distributed energy resources (DERs) connected to low voltage (LV) or medium voltage (MV) levels, such as photovoltaic systems (PV), energy storage systems (ESS), electric vehicles (EVs), and flexible loads, has resulted in a paradigm shift in the power systems industry [1].

The increase in DERs is altering the game from technological and commercial viewpoints [2]. From a technological point of view, critical challenges for the planning, operations, and protection of modern power systems are presented due to the bidirectional power flow caused by distributed generators and the extreme intermittency and randomness of distributed renewable power generation. Flexible DERs (i.e., ESS, EVs, etc.) offer system operators new measures to address challenges. From a commercial point of view, DERs are connected to large numbers of small users at the ends of power systems and diversify the power supply, providing a chance for localized energy markets to emerge and develop. The power system is confronting a transition to a more decentralized model from its traditional structure by introducing an innovative type of trading in distribution networks called peer-to-peer (P2P) energy trading.

P2P trading is a next-generation energy trading technique dependent on the sharing economy concept. Customers with DERs—referred to as "prosumers" since they may generate and consume electricity—are able to trade and share energy with one another directly through P2P energy trading. It is different from conventional energy trading in that both cash and energy flow are bidirectional, compared to unidirectional flow in the traditional power system [3]. Furthermore, the cost of purchasing electricity from distribution system operators (DSO) is higher than the feed-in tariff to sell electricity back to DSO [4], giving customers an incentive to trade with one another before dealing with DSO. Customers are further encouraged to establish a local peer-to-peer energy trading market due to the reduction of the feed-in tariff subsidy in several countries.

P2P energy trading presents a viable measure from the power system operational perspective to manage significant DERs penetration in the future [5]. The edge of power systems is home to a wide range of DERs, each with its own types, features, capabilities, locations, and owners. Due to these facts, managing DERs conventionally and centrally is impracticable and costly. If suitable P2P energy trading platforms are created, DERs by themselves may be able to improve the local power balance in addition to maximizing social welfare [6]. This could reduce uncertainty and release pressure on the upstream power grid [7]. In addition, DERs in P2P energy trading markets can provide numerous ancillary services that support the primary power grid through specialized contract or mechanism designs [8]. Home energy management systems (HEMS) are also introduced, enabling prosumers and consumers to individually optimize their energy consumption and reduce electricity costs. End customers can utilize this technique to shift their load to off-peak times and use cheap electricity. This might be thought to be appropriate when the penetration of DERs in the distribution network is low.

The paper is organized as follows: The following section presents a literature review and summarizes the contribution of the paper. Section III presents the P2P trading model and the evaluation of impacts on the LV distribution network. Section IV describes the studied LV distribution network, demand profiles, generation profiles, DERs characteristics, electricity prices, and the studied scenarios under different tariffs. Section V discussed the results of the seven studied scenarios and the assessment of the impacts on the LV distribution network. Finally, conclusion is given in section VI.

II. LITERATURE REVIEW

Local energy trading has been considered an efficient solution that enables prosumers to trade in their excess renewable generation within their local energy market, promotes self-consumption and self-sufficiency of local renewable generation, and reduces energy costs.

Recent years have seen the deployment of multiple case studies for P2P market implementation in various countries around the world [9, 10]. In Europe, in a case study in Germany, an optimal business model for a sustainable P2P energy trading platform is developed. Business models assist households in increasing their level of energy independence, reducing their reliance on the public grid, and achieving cost savings [11]. Another study used a real data of an energy community in the Netherlands. The P2P multi-energy market benefits most individuals and increases overall economic benefits for all peers [12]. P2P offers a trading algorithm that is more cost-effective, according to a case study on residential buildings in Steinkjer, Norway, and London, UK, since it often encourages trade and reduces grid imports [13]. A series of case studies that were performed on a real-world distribution network show that P2P trading helps prosumers in different communities in Finland save an average of 17.09% on their net energy costs [14].

In America, a case study of 75 members in a community in New York, USA, shows that prosumers can successfully engage in P2P transactions by reducing their costs by 24% and offering superior performance in terms of both economic and technical parameters [15]. By simulating eight homes in a community with real-world data and implementing the technique on a Canadian microgrid, the distribution system operator saves an average of $1.02 million by avoiding transformer upgrades because the permissioned blockchain-based renewable energy trading system can lower peak demand by up to 48 kW (62%) [16].

In Asia, a P2P market clearing model based on auctions is being suggested in Malaysia to demonstrate the viability and prospective of the suggested P2P energy trading model and encourage users to trade energy [17]. A case study focusing on rural India showed how P2P local energy markets might help rural areas develop economically by providing users with a supply of electricity that would otherwise be disconnected during outages of the main power grid [18]. A user-centric cooperative strategy that increases user engagement in P2P energy trading is described in the Higashi-Fuji demonstration experiment, which was carried out in Japan. Consumers could buy renewable energy whenever it was available, and prosumers could sell their excess electricity locally [19]. An effective real-time operation method for prosumers based on optimization is proposed to achieve the local energy supply-demand balance while reducing daily operating costs and making use of all of their flexible energy resources. The case study was carried out for 94 prosumers in a Chinese urban community microgrid [20].

In Africa, in case studies from Burkina Faso, Cote d'Ivoire, Gambia, Liberia, Mali, and Senegal, a decentralized energy system based on blockchain is suggested to accelerate the electrification of rural and urban areas by enhancing service delivery, reducing generation costs, and reducing cyber security risks in sub-Saharan Africa [21]. In a case study in South Africa, a P2P energy trading scheme reduced the operating costs of prosumers by regulating internal energy trading between the prosumers, increasing the usage of energy from renewable energy sources, and decreasing the use of electrical energy supplied [22]. In order to improve community energy sharing in Tunis, an intelligent P2P energy trading strategy including smart homes, non-smart homes, and a local energy pool is proposed [23].

Focusing on Egypt, the viability of an energy trading system is demonstrated through a case study of the distribution system in Alexandria after being optimally divided into islands. Results demonstrate how implementing blockchain technology for energy trading has reduced energy costs [24]. The positive impact of applying the P2P energy trading system on energy costs at the parking lot of the Arab Academy for Science and Technology and Martine Transport campus with PV distributed generation and plug-in hybrid electric vehicles [25]. The viability of implementing P2P-based optimal energy management in a smart railway flexible substation, accounting for various traction system energy sources and the wayside distribution network, with an improvement in the energy economy of the system [26]

In this context, a case study in Aswan, Egypt, is proposed, as it is the city with the highest solar irradiance in Egypt and a high potential for small PV installations. This is the first paper to present the effective implementation of P2P energy trading in Aswan. The proposed architecture is tested and validated in seven different case studies under different tariffs based on one month of realistic energy consumption data for residential consumers in Aswan.

Most of the previous studies focused on the market design of P2P energy trading. However, other studies tried to understand the impact of P2P energy trading on LV distribution networks. According to [27], an appropriate level of peer-to-peer trade has no large effect on the network's operation. The community's peak demand increased as a result of community energy trading [28]. In all scenarios, the transformer is just lightly loaded. Some lines exceed the limit of violations, while most are weakly loaded. At some nodes, voltage magnitude and voltage unbalance were over the allowed limits. According to results in [29], the suggested Nega Watt P2P trading can maintain total power loss and voltage profiles within acceptable ranges, reducing the need for network protection structures necessary for voltage regulation and minimise prosumers electricity costs. The results in [30] demonstrate that the P2P market's grid operation is unaffected when the system is equipped with only PVs. When decentralized ESS was available, P2P trading increased voltage fluctuations and losses (14%) in the local area compared to no local market. On the other hand, the local market results in overall cost savings for the consumer and provides the framework for developing pricing strategies (such as managing losses) that are specific to DSO operations. Results in [31] demonstrate that energy is shared between users under the P2P scheme without violating network constraints and those users can still benefit financially from the P2P architecture. Analysis in [32] demonstrates that lower-priority distributed generators are susceptible to excessive curtailment levels when combined with autonomous P2P trading. P2P transactions have been shown in [33] to successfully reduce network loss and relieve network congestion in the distribution network. In [34], it is discovered that on a typically sunny day, the difference between P2P and non-P2P scenarios in 24-hour network losses is negligible for a large-sized distribution network with noticeable residential users. Through self-consumption and energy arbitrage, energy storage leverages smart homes gains significantly [35]. However, during the winter, the voltage stability of the network is decreased by energy storage operations under the smart community-based electricity market. It can be seen that the impacts are different depending on the LV distribution network's condition, installed DERs, DER penetration levels, etc. Therefore, in this paper, an Egyptian case study is considered with real demand data and several operation scenarios.

Contributions to this study include the following:

- Model a P2P energy trading within a community containing PV, ESS, and EVs connected to an unbalanced LV distribution network.
- An assessment of the techno-economics of coordinated DERs management using P2P energy trading and HEMS under different tariffs considering an Egyptian case study.
- Evaluate the impacts of P2P energy trading and HEMS on the LV distribution network.

III. MODELLING APPROACH

Network operators need to simulate the effects of P2P energy trading on distribution networks and possible impacts on network reliability and performance in order to gain acceptance of this emerging DER management approach.

The modeling approach used in this study consists of two distinct cascading steps. A centralized P2P optimization is carried out in the first step, and the output represents the energy dispatches of houses. A 3-phase AC power flow is carried out in the second step to assess its effects on the physical grid according to the outputs of the first step. It is considered that the market and the power flow models operate at an hourly resolution. The optimization problem is solved using linear programming.

Matlab was used for P2P energy trading optimization. The power flow is carried out using Pandapower software [36, 37]. Matlab's inputs (first step) include the demand profiles for all houses in the LV network, PV generation profiles, and DERs ratings, along with electricity (import and export) prices. The prosumers' net demand profile required for power flow as well as DER dispatch are the market's output. Pandapower's inputs (second step) include houses net demand profiles and the LV distribution network data, which perform a 3-phase power flow. Pandapower's outputs include voltage magnitude in various phases, the value of voltage unbalance, and component loading. Figure 1 shows a schematic diagram for the P2P energy trading optimization and impacts assessment

Nomenclature

Sets

$t \in T$	Time step t at time horizon T
$h, p \in H$	House h and peer p in a community H

Scalars

ψ^{P2P}	P2P trade loss factor
$\bar{C}_{Ess}$ and $\bar{D}_{Ess}$	ESS upper levels of charging and discharging powers
$\bar{C}_{EV}$ and $\bar{D}_{EV}$	EV upper levels of charging and discharging powers
$\bar{S}_{ESS}$ and $\underline{S}_{ESS}$	ESS upper and lower levels of storage levels
$\bar{S}_{EV}$ and $\underline{S}_{EV}$	EV upper and lower levels of storage levels
η^{c}_{Ess}	ESS charging efficiency
η^{d}_{Ess}	ESS discharging efficiency
η^{c}_{EV}	EV charging efficiency
η^{d}_{EV}	EV discharging efficiency

Parameters

$Dem^{(t,h)}$	Demand of house h at time step t
$PV^{(t,h)}$	PV generation of house h at time step t
$p_G^{(t)}$	Import price at time step t
$p_E^{(t)}$	Export price at time step t
$P_n^{(t,h)}$	Net active power demand of house h at time step t
$a^{(t)}$	Binary parameter that indicates whether or not an electric vehicle is connected to the charger

Variables

$I_{P2P}^{(t,h)}$	P2P energy purchased by house h at time step t
$X_{P2P}^{(t,h)}$	P2P energy sold by house h at time step t
$I_{p,P2P}^{(t,h\leftarrow p)}$	P2P energy purchased by house h from peer p at time step t
$X_{p,P2P}^{(t,h\rightarrow p)}$	P2P energy sold by house h to peer p at time step t
$G^{(t,h)}$	Energy purchased from DSO by house h at time step t
$E^{(t,h)}$	Energy sold to DSO from house h at time step t
$S_{Ess}^{(t,h)}$	ESS energy stored of house h at time step t
$S_{EV}^{(t,h)}$	EV energy stored of house h at time step t
$D_{Ess}^{(t,h)}$	ESS discharge power of house h at time step t
$D_{EV}^{(t,h)}$	EV discharge power of house h at time step t
$C_{Ess}^{(t,h)}$	ESS charge power of house h at time step t
$C_{EV}^{(t,h)}$	EV charge power of house h at time step t

A. P2P TRADING MODEL

The P2P trading model is treated as a linear multi-period optimization problem and is subjected to a set of constraints that are broadly categorized as P2P trading constraints, DERs operational constraints, and energy balance constraints. P2P energy trading aims to increase revenue from selling excess energy to DSO while minimizing the costs of purchasing energy from DSO as stated in (1) as proposed in [38-40].

$$Min \sum_t \sum_h (p_G^{(t)} \cdot G^{(t,h)} - p_E^{(t)} \cdot E^{(t,h)})\, \Delta t \qquad (1)$$

In P2P scenarios, the sum of house revenues from selling energy locally equals the sum of house purchase costs, so the objective function does not include them.

P2P trading enables the direct trade of energy between all peers in the community, regardless of how physically connected they are. Therefore, at each time step t, the import of house h from peer p equals the export of peer p to house h as represented in (2).

$$I_p^{(t,h\leftarrow p)} = \psi^{P2P} \cdot X_p^{(t,p\rightarrow h)} \qquad \forall p \neq h, \forall t \in T, \forall h \in H \qquad (2)$$

ψ^{P2P} stands for P2P trading loss factor; 5% losses are considered ($\psi^{P2P} = 0.95$).

Any consumer in the community can purchase energy from any house that has DERs installed. The total energy sold through P2P trade $X_{P2P}^{(t,h)}$ from any house $h \in H$, at each time step t, is the sum of energy exported $X_{p,P2P}^{(t,h\rightarrow p)}$ from this house h to another peer $p \in H$, as represented by (3).

$$X_{P2P}^{(t,h)} = \sum_{p\neq h} X_{p,P2P}^{(t,h\rightarrow p)} \qquad \forall t \in T, \forall h \in H \qquad (3)$$

The total purchased energy $I_{P2P}^{(t,h)}$ by any house $h \in H$, at each time step t, is the sum of energy imported $I_{p,P2P}^{(t,h\leftarrow p)}$ by this house h from another peer $p \in H$ as represented in (4).

$$I_{P2P}^{(t,h)} = \sum_{p\neq h} I_{p,P2P}^{(t,h\leftarrow p)} \qquad \forall t \in T, \forall h \in H \qquad (4)$$

A constraint to ensure that the sum of houses energy sales must be equal to the sum of houses energy purchases, considering the P2P trading losses at the LV distribution network, is represented in (5).

$$\sum_h \psi^{P2P} \cdot X_{P2P}^{(t,h)} = \sum_h I_{P2P}^{(t,h)} \qquad \forall t \in T \qquad (5)$$

A P2P price is considered to be limited between import and export prices, making it beneficial for all participants to trade energy locally. Energy is purchased from peers at a price that is lower than that of import price of DSO, and it is sold to consumers at a price higher than that of feed in tariff (FIT).

For scenarios including batteries (ESSs), for each battery, there are upper and lower rates for charging and discharging, represented by (6) and (7). 0 is the lower rate for both charging and discharging powers. Equation (8) represents the lower and upper levels of energy stored in kWh for each battery. The state-of-charge of the batteries will stay between 20% and 100%to extend their life span.

$$0 \leqslant C_{ESS}^{(t,h)} \leqslant \bar{C}_{ESS} \qquad \forall t \in T, \forall h \in H \qquad (6)$$

$$0 \leqslant D_{ESS}^{(t,h)} \leqslant \bar{D}_{ESS} \qquad \forall t \in T, \forall h \in H \qquad (7)$$

$$\underline{S}_{ESS} \leqslant S_{ESS}^{(t,h)} \leqslant \bar{S}_{ESS} \qquad \forall t \in T, \forall h \in H \qquad (8)$$

The state-of-charge for each battery in each time step depends on the state-of-charge for the previous time step as

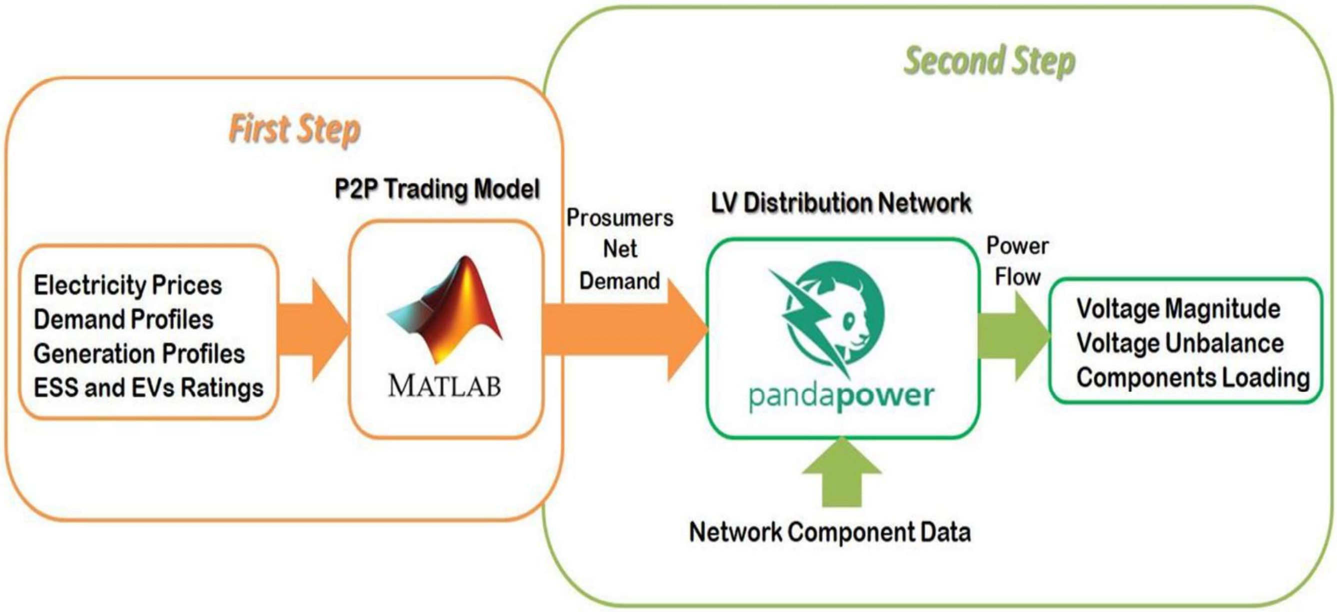

FIGURE 1. Schematic diagram for P2P energy trading optimization and impacts assessment.

well as the charge and discharge rates for this time step. The stored energy for each battery in a time step t is represented by (9).

$$S_{ESS}^{(t,h)} = S_{ESS}^{(t-1,h)} + \eta_{Ess}^{c} \cdot C_{Ess}^{(t,h)} \Delta t - (1/\eta_{Ess}^{d}) \cdot D_{Ess}^{(t,h)} \Delta t \quad \forall t \in T, \forall h \in H \qquad (9)$$

$S_{ESS}^{(t-1,h)}$ is the stored energy at time step $(t-1)$. Day 1 starts with a random value for each battery that is more than or equal to 2.7 kWh (20% state-of-charge). The final battery storage level value from day 1 is used as the battery storage level for day 2's first hour. Any other day operates by the same principle.

For scenarios including electric vehicles (EVs), for each electric vehicle, there are upper and lower rates of charging and discharging, represented in (10) and (11). 0 is the lower rate for both charging and discharging powers. Equation (12) represents the lower and upper levels of the energy stored in kWh for each electric vehicle. The state-of-charge of the electric vehicle battery will stay between 20% and 100%.

$$0 \leqslant C_{EV}^{(t,h)} \leqslant \bar{C}_{EV} \, . \, a^{(t)} \qquad \forall t \in T, \forall h \in H \qquad (10)$$

$$0 \leqslant D_{EV}^{(t,h)} \leqslant \bar{D}_{EV} \, . \, a^{(t)} \qquad \forall t \in T, \forall h \in H \qquad (11)$$

$$\underline{S}_{EV} \leqslant S_{EV}^{(t,h)} \leqslant \bar{S}_{EV} \qquad \forall t \in T, \forall h \in H \qquad (12)$$

The binary parameter $a^{(t)}$ indicates whether or not an electric vehicle is connected to the LV distribution network for charging at time step t. When an electric vehicle is connected to the LV distribution network, $a^{(t)}$ has a value of 1, and when disconnected, it is 0.

When an electric vehicle is used for transportation, the state-of-charge of the battery decreases, and the initial value of the state-of-charge once the electric vehicle begins charging depends on the state-of-charge when the electric vehicle is disconnected from the grid and driving distance. The stored energy at a time step t for each electric vehicle that is connected to the grid is calculated by (13).

$$S_{EV}^{(t,h)} = S_{EV}^{(t-1,h)} + \eta_{EV}^{c} \cdot C_{EV}^{(t,h)} \Delta t - (1/\eta_{EV}^{d}) \cdot D_{EV}^{(t,h)} \Delta t \quad \forall t \in T, \forall h \in H \qquad (13)$$

$S_{EV}^{(t-1,h)}$ is the stored energy at time step $(t-1)$. On day 1, each electric vehicle starts with an initial energy storage that is randomly greater than or equal to 4.8 kWh (20% state-of-charge). The last value of day 1's electric vehicle storage level is used as the electric vehicle storage level for day 2's first hour. Any other day is equivalent in concept. From 5 p.m. to 8 a.m. next day, the electric vehicles are connected to the grid and are driven for transportation the rest of the day. The state-of-charge of each electric vehicle battery value at departure time (8 a.m.) should not be less than 75%.

The energy balance equation in the P2P trading model is represented in (14). This constraint ensures that, at each house h, at each time step t, the supply equals the demand.

$$G^{(t,h)} + I_{P2P}^{(t,h)} + PV^{(t,h)} + D_{Ess}^{(t,h)} + D_{EV}^{(t,h)} \geq E^{(t,h)} + X_{P2P}^{(t,h)} + Dem^{(t,h)} + C_{Ess}^{(t,h)} + C_{EV}^{(t,h)} \quad \forall t \in T, \forall h \in H \qquad (14)$$

By removing some terms, (14) will be different for other houses with other DERs installed or without DERs.

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For HEMS scenarios, which do not involve energy trading, the objective function for each house h, at each time step t, is represented by (15).

$$Min \sum_t \left(p_G^{(t)} \cdot G^{(t)} - p_E^{(t)} \cdot E^{(t)}\right) \Delta t \qquad \forall t \in T \qquad (15)$$

DERs constraints are represented by (6) to (13).

The objective function subjected to energy balance constraints for each house h, at each time step t, represented by (16).

$$G^{(t,h)} + PV^{(t,h)} + D_{ESS}^{(t,h)} + D_{EV}^{(t,h)} \geq E^{(t,h)} + Dem^{(t,h)} + C_{ESS}^{(t,h)} + C_{EV}^{(t,h)} \qquad \forall t \in T, \forall h \in H \qquad (16)$$

B. EVALUATION OF IMPACTS ON THE LV DISTRIBUTION NETWORK

A power flow model is the next step to be performed once the P2P trading model and HEMS have determined the optimal decision. The power flow analyzes the effects of DERs dispatches resulting from the P2P trading and HEMS on the distribution network. The net active power demand is the sum of the capacity imported to the connection point minus the capacity exported from the connection point. Therefore, the net active power demand of each house h, at each time step t, is represented by (17).

$$P_n^{(t,h)} = G^{(t,h)} + I_{P2P}^{(t,h)} - E^{(t,h)} - X_{P2P}^{(t,h)} \qquad \forall t \in T, \forall hH \ (17)$$

$P_n^{(t,h)}$ is an input that Pandapower software receives to run the power flow. Both battery and electric vehicle charging and discharging are assumed to occur behind the node connection point; they are not included in the equation. The P2P trading model considers only the trade of active power and ignores reactive power. Therefore, the power flow considers a 0.95 pu power factor.

IV. CASE STUDY

P2P trading impacts on the LV distribution network are investigated using a case study carried out on IEEE European low voltage test feeder [41], which is supplied by an 11 kV/0.416 kV substation with a capacity of 800 kVA and delta/grounded-star winding connections.

The LV distribution network is connected to 55 single-phase consumers, each with a unique connection point. Each consumer's connection point is identified by its number and colour (phase A in red, phase B in blue, and phase C in green). For phases A, B, and C, there are 21 consumers, 19 consumers, and 15 consumers connected, respectively, as shown in Figure 2.

A. INPUTS DESCRIPTIONS

Demand profiles: The profiles are measurements of Aswan consumers. The measurement is from the transformer's point of connection. From this data, the real power of the three phases is added, divided by the total number of consumers, and then the profile is multiplied by a random number between 0.6 and 1.3 to generate 55 profiles for the houses. A one-hour-resolution sample is used for the load profiles. The consumption profiles for June 2020 were used. Aggregated demand profiles for 55 houses in 48 hours are shown in Figure 3.

PV generation profiles: PV generation historical data for Aswan was retrieved from the Renewables.ninja website [42]. The website uses the NASA MERRA-2 database, which has meteorological data for the area going back to 2019 [43]. PV generation's power rating is 3 kW. 60% of prosumers have installed PV in the community (33 PV). PV generation for one house in 48 hours is shown in Figure 4.

Battery (ESS) characteristics: Batteries with a 13.5 kWh energy rating are installed. An inverter with a nominal power of 5 kW restricts both charging and discharging. Both charging efficiency η_{ESS}^{c} and discharging efficiency η_{ESS}^{d} are 95%. 40% of prosumers have installed batteries in the community (22 ESS).

Electric vehicle (EV) characteristics: Electric vehicles are equipped with 24 kWh batteries and 3.6 kW chargers. Both charging efficiency η_{EV}^{c} and discharging efficiency η_{EV}^{d} are 96%. Electric vehicles have bidirectional chargers that allow for either energy absorption (G2V) or injection (V2G). 33% of prosumers have installed electric vehicles in the community (18 EVs). Table 1 displays the DERs installed at each house.

Electricity prices: Egyptian prices for selling and buying energy to and from DSO are applied. Prosumers purchase based on DSO tariffs and sells based on FIT prices in Egypt. Purchasing prices for 2022–2023 are obtained from the Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA) [44] and selling prices from [45]. Import and export prices for 48 hours are shown in Figure 5 for flat and time of use (ToU) tariffs. Currently, only flat tariff is used in Egypt. However, future regulations may adopt ToU to encourage consumers to shift part of their loads to low price hours. Therefore, ToU is investigated in this study.

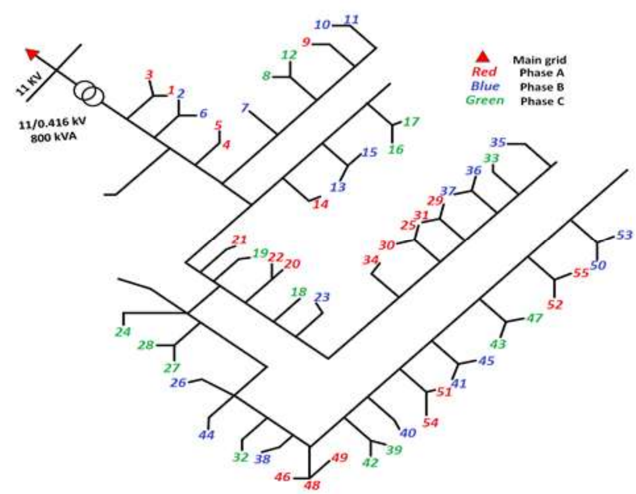

FIGURE 2. The studied IEEE European LV distribution network schematic diagram.

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TABLE 1. THE INSTALLED DERS AT EACH HOUSE

House	DER	House	DER	House	DER	House	DER
1	PV+ESS	15	PV+ESS	29	No DER	43	PV
2	PV+ ESS+ EV	16	PV+EV	30	PV+ESS	44	No DER
3	PV+ ESS	17	No DER	31	EV	45	PV+ESS
4	No DER	18	PV+ESS	32	PV	46	EV
5	PV+ ESS	19	No DER	33	PV+ESS	47	No DER
6	No DER	20	PV+ESS+EV	34	PV	48	PV+ESS
7	PV+ EV	21	No DER	35	EV	49	PV+EV
8	PV	22	No DER	36	No DER	50	PV+ESS+EV
9	PV+ESS+EV	23	PV+ESS	37	PV+ESS	51	No DER
10	No DER	24	PV	38	No DER	52	PV+ESS
11	No DER	25	PV+EV	39	PV+EV	53	PV+ESS+EV
12	PV+ ESS+EV	26	No DER	40	PV+ESS	54	PV+ESS+EV
13	No DER	27	PV+ESS	41	PV+EV	55	PV+ESS+EV
14	No DER	28	EV	42	No DER		

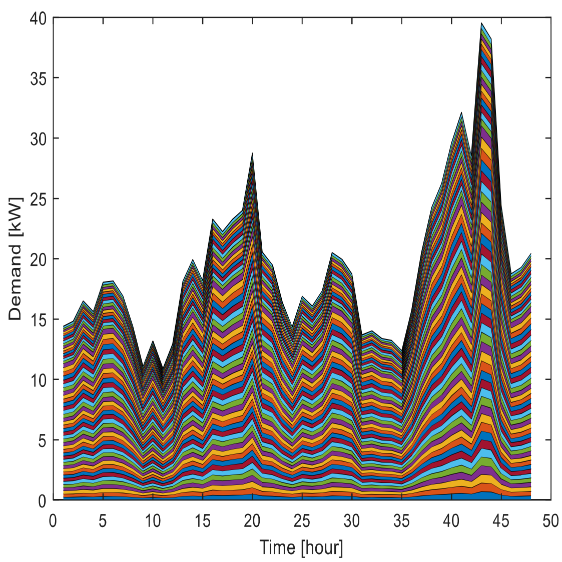

FIGURE 3. Aggregate demand profile for 55 houses in 48 hours.

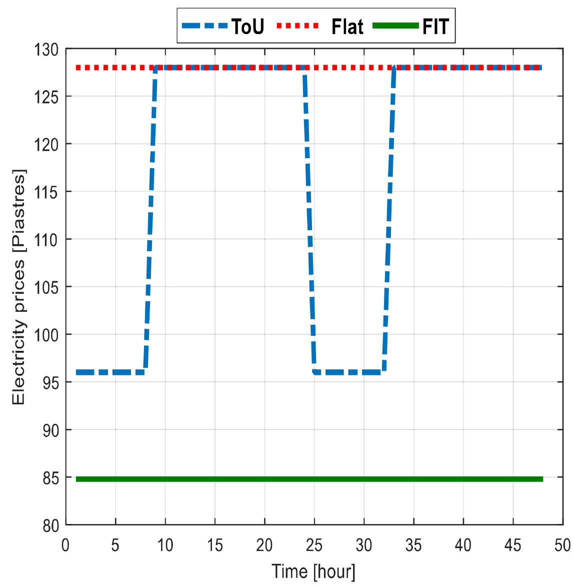

FIGURE 5. Import and export prices in 48 hours.

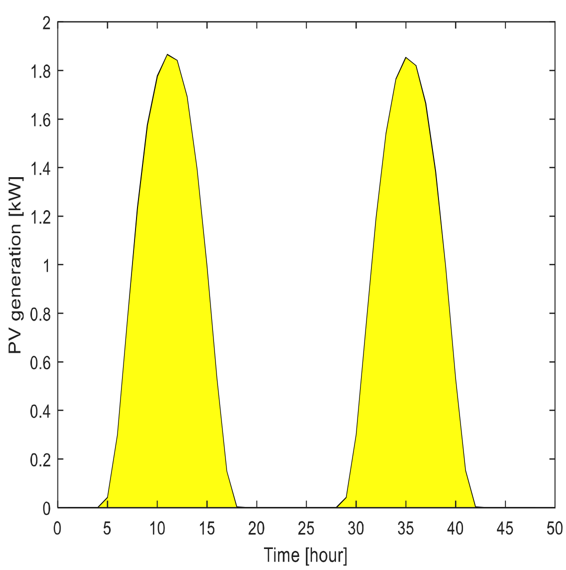

FIGURE 4. PV generation for one house in 48 hours.

B. SCENARIOS DESCRIPTIONS

In order to accurately represent the impact of DSO tariffs on DER integration, we compare the P2P market with regard to flat and ToU tariffs. A FIT is used as an export tariff.

The flat tariff is constant over the year and time-invariant. Therefore, this type of price does not encourage consumers to make demand responses. The ToU tariff, on the other hand, divides the 24 hours of the day into a number of time blocks, each with a number of hours. For each block, the price of electricity is disclosed in advance and is constant. It features two price ranges: a low price range lasting from 12 p.m. to 8 a.m. and a high price range lasting the remainder of the day. In this real-life case, we apply seven scenarios with the following details:

Base scenario: This scenario demonstrates that there is no PV, batteries, or electric vehicles installed in any house. Consumers purchase their electricity from DSO at a fixed tariff.

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PV scenario: This scenario assumes that PV is installed on most of the houses. PV generation, or DSO, can meet the house's demand. They can sell any excess PV generation to DSO and receive the FIT price. PV-equipped houses are unable to trade their excess generation locally to other houses.

PV-P2P scenario: This scenario assumes that PV is installed in most of the houses. The houses' PV generation, other community prosumers, or DSO meet the houses' consumption. If no consumers in the community are ready to purchase energy at that time, the PV owners can sell excess generation to DSO.

PV+ESS-HEMS scenario: This scenario assumes some prosumers who had PV now have a house battery. No energy trading is allowed. HEMS manages the PV and the battery of each house to lower electricity costs and increase revenues.

PV+ESS-P2P scenario: This scenario assumes some houses have installed PV and a battery. If no consumers are in the market for purchasing energy at that time, owners can sell excess PV generation or stored energy to DSO. The battery might be charged from the PV house, purchased from DSO, or from other prosumers.

PV+ESS+EV-HEMS scenario: This scenario assumes PV, batteries, and electric vehicles are installed in some houses. No energy trading is allowed, and HEMS manages each house's PV, battery, and electric vehicle to increase revenues and lower the cost of electricity.

PV+ESS+EV-P2P scenario: This scenario assumes some houses have PV, batteries, and electric vehicles installed. PV-owners can store PV generation in batteries and electric vehicles, they can trade it with prosumers, or sell excess PV generation to DSO. Batteries and electric vehicles might be charged based on the energy of PV installed at the house, energy purchased from another prosumers, or energy purchased directly from DSO.

V. RESULTS AND DISCUSSIONS

Presentations of the results are divided into three parts. The first part explains how various housing types—with or without DERs—meet their electricity demands and manage DERs in various scenarios under different tariffs. Then, there is a comparison of the scenarios that were studied in the second part. The third part shows how various scenarios affect the LV distribution network.

A. COMMUNITY HOUSES OPERATION

Using seven different scenarios, a detailed analysis was conducted. A customer with no DER assets and no access to energy trading is regarded as the base scenario. Other scenarios are organized according to the combination of DER assets owned by prosumers, self-optimization, and the availability of energy trading within the community. For all scenarios, DSO tariffs (flat and ToU) impact the DER integration and community energy trading. Figures 6–9 depict that a flat tariff results in a longer trade period. Since the prices (export and import tariffs) are constant at all hours in the day, local trade occurs continuously throughout the day. However, the case with a ToU tariff shows that prosumers trade when they can achieve better economic benefits. At night, prosumers may not be willing to trade as they prefer to charge batteries and electric vehicles at low prices or to meet their own demand. To demonstrate how different houses meet their electricity demands and how DERs react in various scenarios, the operations of different houses are provided for the scenarios under study. There are no DERs in house 4, only PV generation in house 24, PV and ESS in house 48, and PV, ESS, and EV in house 54.

1) OPERATION FOR HOUSES WITH NO DERS

For houses with no DERs, when there is no P2P, house 4 meets all its demand from DSO, as shown in Figure 6(a). Once P2P is implemented, a large quantity of demand is met by purchasing from other prosumers in the community because P2P prices are lower than DSO prices. Purchasing from prosumers occurs in the PV-P2P scenario when excess PV generation is present at other houses in the community. The house demand is covered by DSO at night and early in the morning when there is no PV generation in the community houses, as depicted in Figure 6(b). With the presence of batteries owned by other prosumers in the PV+ESS-P2P scenario, which charge during periods when PV generation is high or when prices are low and discharge during periods when prices are high, it can be noticed that purchasing from prosumers occurs over a longer period of time than in the PV-P2P scenario, as seen in Figure 6(c). The presence of batteries and electric vehicles owned by other prosumers in the PV+ESS+EV-P2P scenario causes purchasing from prosumers to take longer period than PV-P2P scenario, while on some days, prosumers prefer to charge batteries and electric vehicles during early hours to utilize stored electricity for the rest of the day to meet their demand rather than sell them to other houses in the community, as depicted in Figure 6(d). House 4 has the ability to participate in P2P and lowers its electricity costs by purchasing electricity from other prosumers in the community at lower cost than DSO cost, despite not having any DERs. It can be noticed that, in scenarios including batteries and electric vehicles, purchasing from prosumers occurs over a longer period of time in a flat tariff than in a ToU tariff.

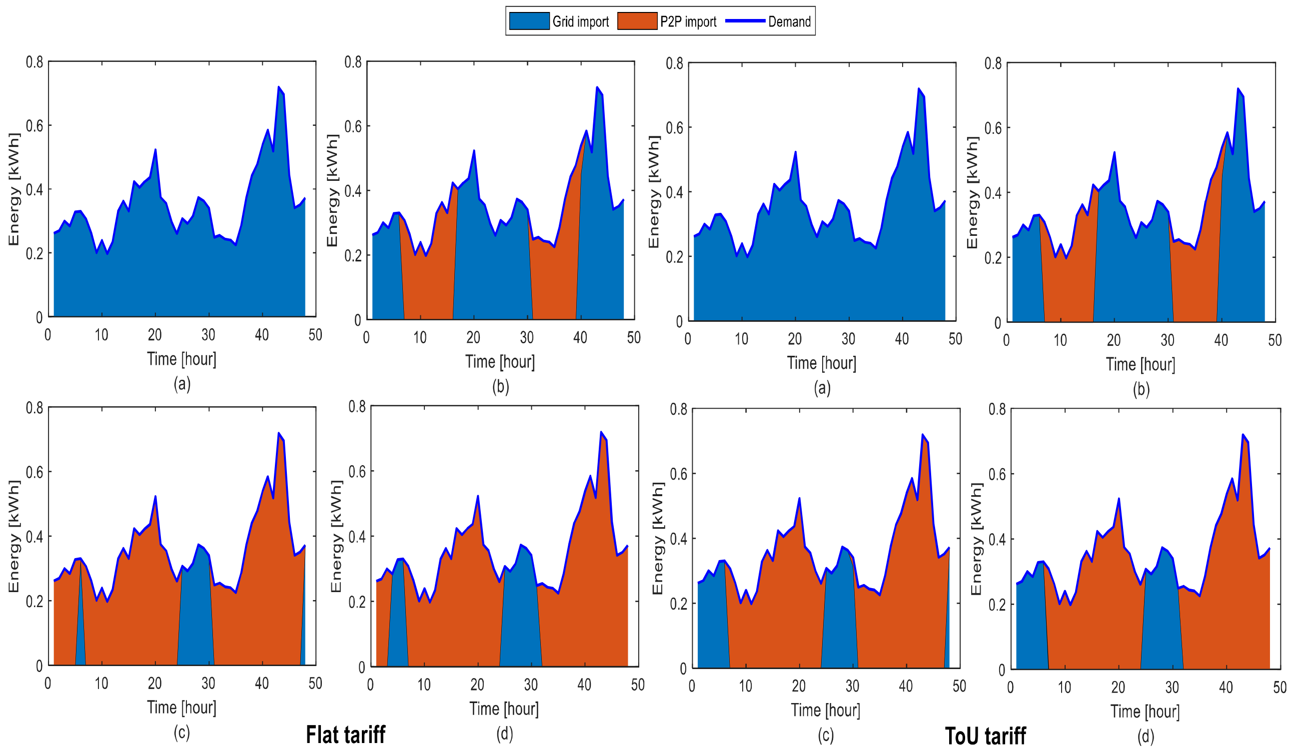

FIGURE 6. Operation of house 4. (a) Non-P2P scenarios, (b) PV-P2P scenario, (c) PV+ESS-P2P scenario, (d) PV+ESS+EV-P2P scenario.

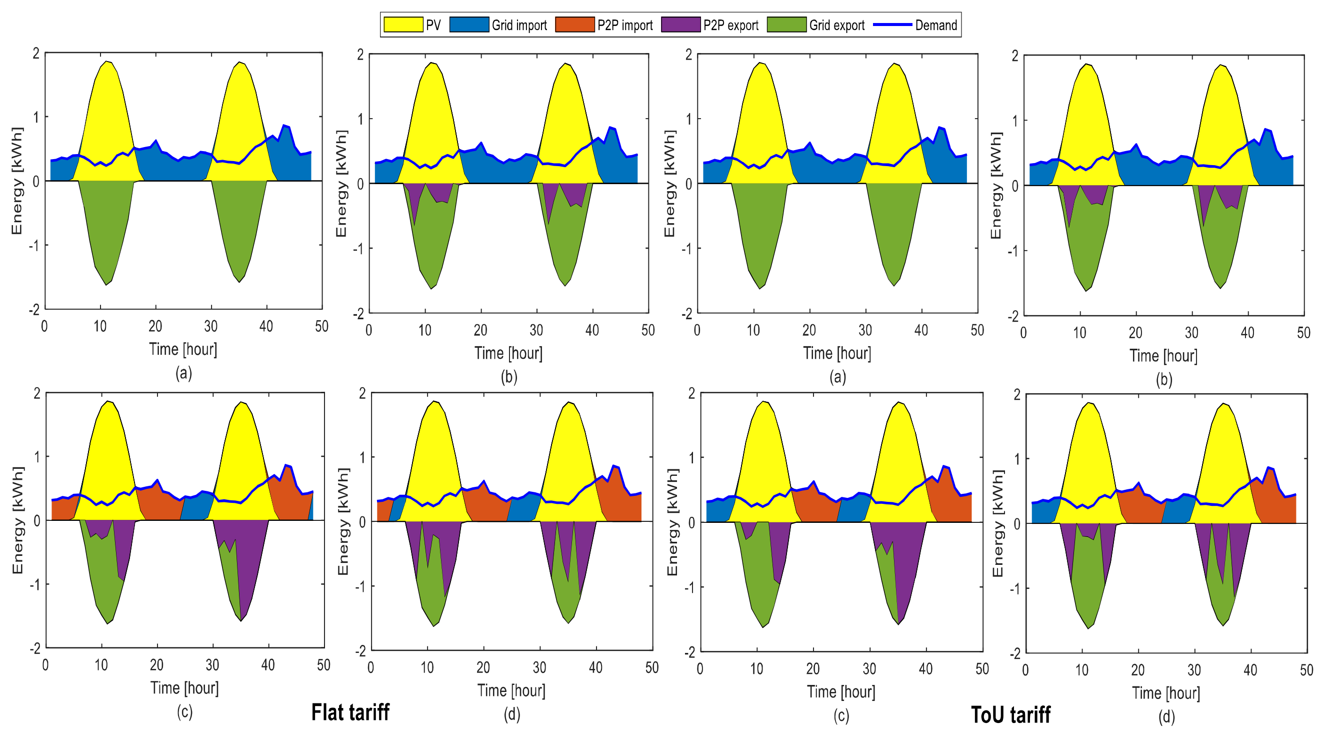

FIGURE 7. Operation of house 24. (a) Non-P2P scenarios, (b) PV-P2P scenario, (c) PV+ESS-P2P scenario, (d) PV+ESS+EV-P2P scenario.

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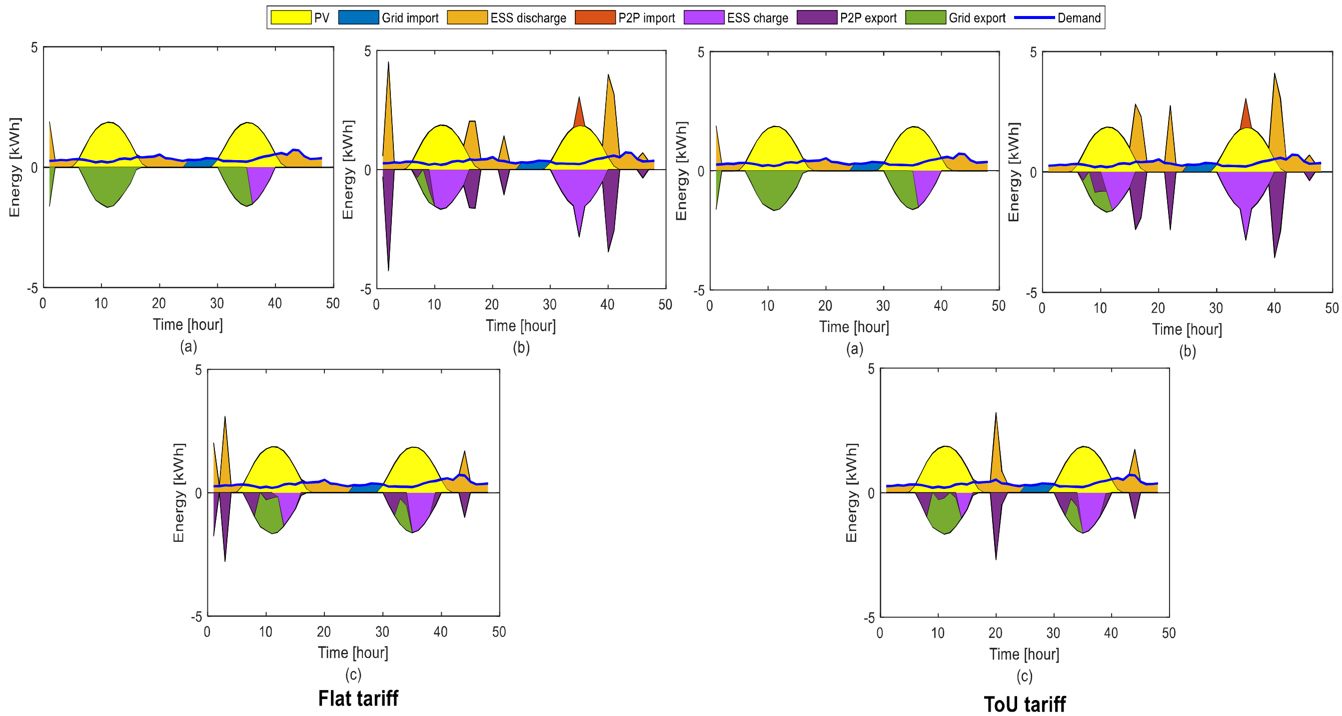

FIGURE 8. Operation of house 48. (a) Non-P2P scenarios, (b) PV+ESS-P2P scenario, (c) PV+ESS+EV-P2P scenario.

2) OPERATION FOR HOUSES WITH PV ONLY

For houses with PV only, when there is no P2P, house 24 sells all of its excess PV generation to DSO and purchases the electricity it needs from DSO during the night, as shown in Figure 7(a). Once P2P is implemented, house 24 in a PV-P2P scenario sells excess PV generation to other consumers who are ready to purchase electricity or DSO if no other houses need this energy, and it purchases the electricity it needs from DSO during the night, as depicted in Figure 7(b). Figure 7(c) illustrates that the presence of batteries at other houses in the community in the PV+ESS-P2P scenario causes house 24 to sell a larger quantity of excess PV generation locally to other houses who are ready to purchase electricity, selling it to DSO at times when no houses want to purchase, and purchasing electricity from other prosumers to meet its demand, as their prices are lower than those of DSO. The presence of a battery and electric vehicle in the PV+ESS+EV-P2P scenario, house 24, met a larger quantity of demand from other houses in the community than in the PV-P2P scenario, as seen in Figure 7(d). In scenarios involving batteries and electric vehicles, purchasing from prosumers occurs over a longer period of time in a flat tariff than in a ToU tariff.

3) OPERATION FOR HOUSES WITH PV AND ESS

For houses with PV and batteries, in HEMS scenarios, house 48 almost meets its demand through PV generation during the day and discharging batteries at night. Limited electricity is purchased from DSO, and excess PV generation is either utilized for charging the battery or sold to DSO, as shown in Figure 8(a). In P2P scenarios, house 48 meets its demand through PV generation during the day and battery discharge at night and during periods of low PV generation, as depicted in Figure 8(b) and (c). House 48 promotes selling excess PV generation or battery discharge to consumers rather than DSO, so DSO purchases less electricity. The prosumer is discharging their batteries for self-consumption or selling them in the community. In all scenarios, the prosumer is mainly self-sufficient during PV generation and battery discharge during the day and night. The differential pricing under the ToU tariff has resulted in batteries and electric vehicles not discharging at low price hours of DSO because the P2P energy trading prices are low at these hours as well.

4) OPERATION FOR HOUSES WITH PV, ESS, AND EV

For houses with PV, ESS, and EV, Figures 9(a) and (b) illustrate how house 54, in the PV+ESS+EV-HEMS and PV+ESS+EV-P2P scenarios, respectively, meets a significant percentage of demand through PV generation during the day and battery/electric vehicle discharging at night and when PV generation is low. House 54 prefers to sell PV generation, battery discharge, or electric vehicle discharge to other consumers instead of selling to DSO. In the PV+ESS+EV-P2P scenario, the battery and electric vehicle of house 54 engage in electricity trading by purchasing electricity from DSO at lower costs, discharging at higher costs, or selling electricity to other houses. In the ToU tariff, in the HEMS scenarios, prosumers want to charge batteries and meet electric vehicle mobility needs at night due to a cheaper import tariff, whereas in the P2P scenarios, prosumers are getting ready for trading times. This situation is different from the flat tariff because the daily price for trading is constant.

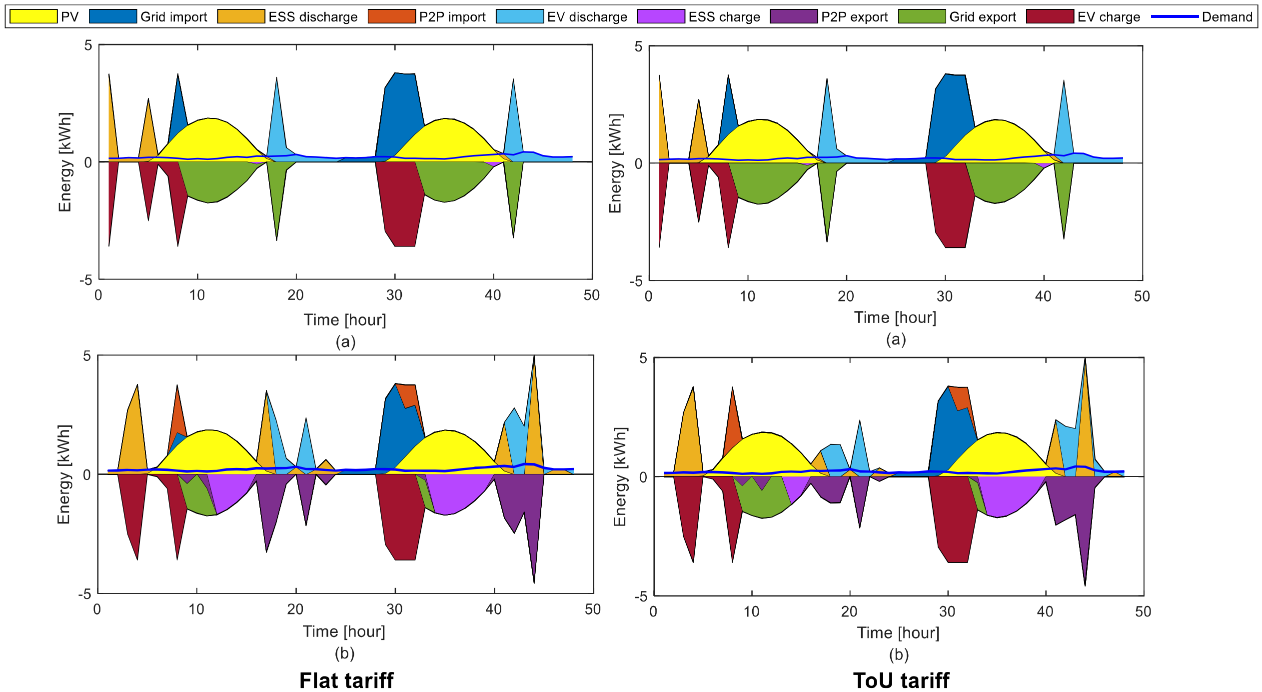

FIGURE 9. **Operation of house 54.**
(a) PV+ESS+EV-HEMS scenario, (b) PV+ESS+EV-P2P scenario.

B. SCENARIOS TECHNO-ECONOMIC COMPARISON

This section compares the investigated scenarios in terms of operation costs, energy imports/exports, demand covered by DERs, total energy trading, and peak grid consumption.

1) OPERATION COSTS

Since the optimization model aims to reduce electricity-related costs for the entire community, DERs significantly reduce the community's electricity costs for the two electricity tariffs. Tables 2 and 3 present the total community costs for the simulation period for each scenario and are compared with the HEMS scenario for the two electricity tariffs. The costs and revenues of the community from DSO imports and exports are also given.

1.1) Operation costs under a flat tariff

Results in Table 2 show that P2P reduces electricity costs by 8.58% for PV-P2P scenario, 15.82% for the PV+ESS-P2P scenario, and 11.76% for the PV+ESS+EV-P2P scenario for community compared to the equivalent HEMS scenarios. This result from the local generation of electricity, reducing the community's reliance on centrally provided electricity by DSO.

1.2) Operation costs under a ToU tariff

Table 3 shows that P2P scenarios reduced the community electricity costs, compared to the equivalent HEMS scenarios. Moreover, P2P scenarios with flexible devices have lower community costs at ToU tariff than the equivalent scenarios at flat tariff. This is a result of the ToU tariff pricing differences, which increase energy arbitrage provision through batteries, electric vehicles, and P2P trading. Moreover, the price at off-peak hours is lower than the price at these hours in flat tariff. The ToU tariff provides a greater economic benefit for community energy trading than the flat tariff.

2) ENERGY IMPORTS AND EXPORTS

Since the community has the ability to utilize the generated electricity more effectively, P2P scenarios result in less dependence on DSO imports. Figure 10(a) shows the amount of energy purchased from DSO in P2P scenarios for the two electricity tariffs. It demonstrates that there are hours where there are no imports from DSO in P2P scenarios, where prosumers meet their demand by utilizing their own DERs or purchasing from other prosumers at lower prices than DSO.

As the prosumers prioritize trading in the community over exporting to DSO, the amount exported to DSO in all scenarios with P2P is much less than the equivalent HEMS scenarios. Figure 10(b) demonstrates that, in P2P scenarios, a limited amount of energy is sold to DSO for the two electricity tariffs. This shows how P2P can increase the energy community self-consumption. Tables 2 and 3 present the total energy imports and exports from and to DSO through P2P trading for the two electricity tariffs for the simulation period.

2.1) Energy imports and exports under a flat tariff

Results in Table 2 show that P2P trading reduced the energy purchased from DSO by 17.24% for the PV-P2P scenario, 41.46% for the PV+ESS-P2P scenario, and 32.48% for the PV+ESS+EV-P2P scenario compared to the equivalent HEMS scenarios.

TABLE 2. RESULTS OF THE DIFFERENT SCENARIOS STUDIED FOR FLAT TARIFF

	No DER	PV		PV+ESS		PV+ESS+EV	
	Base	PV	P2P	HEMS	P2P	HEMS	P2P
Costs of DSO import (EGP)	26071.08	19793.40	16379.42	15911.80	9314.37	22956.87	15500.22
Revenue of DSO export (EGP)	0	7759.02	5378.22	4982.29	114.99	5957.48	499.38
Costs of total operation (EGP)	26071.08	12034.37	11001.19	10929.51	9199.38	16999.39	15000.83
P2P_ cost reduction	-	-	(-8.58%)	-	(-15.82%)	-	(-11.76%)
Total DSO import (kWh)	20368.03	15463.59	12796.42	12431.10	7276.85	17935.06	12109.54
Total P2P import vs. HEMS			(-17.24%)		(-41.46%)		(-32.48%)
Total DSO export (kWh)	0	9149.79	6342.24	5875.34	135.60	7025.33	588.89
Total P2P export vs. HEMS			(-30.68%)		(-97.69%)		(-91.61%)
Total_P2P trade (kWh)	0	0	2807.54	0	6095.80	0	6605.99
Demand by DSO (%)	100	75.93	62.83	61.04	35.73	88.06	59.46
Demand by DERs (%)	0	24.07	37.17	38.96	64.27	11.94	40.54
Peak grid consumption (kW)	61.20	61.20	61.20	38.46	38.46	90.84	90.84
Compared to base (%)	-	0	0	-37.15	-37.15	+48.43	+48.43

TABLE 3. RESULTS OF THE DIFFERENT SCENARIOS STUDIED FOR TOU TARIFF

	No DER	PV		PV+ESS		PV+ESS+EV	
	Base	PV	P2P	HEMS	P2P	HEMS	P2P
Costs of DSO import (EGP)	24139.86	18247.49	15010.34	14370.70	7836.56	19238.33	11851.63
Revenue of DSO export (EGP)	0	7759.02	5378.22	4982.29	165.36	5957.485	532.05
Costs of total operation (EGP)	24139.86	10488.46	9632.11	9388.41	7671.19	13280.84	11319.57
P2P_ cost reduction	-	-	(-8.16%)	-	(-18.29%)	-	(-14.76%)
Total DSO import (kWh)	20368.03	15463.59	12796.42	12432.78	7492.60	17936.74	12278.49
Total P2P import vs. HEMS			(-17.24%)		(-39.73%)		(-31.54%)
Total DSO export (kWh)	0	9149.79	6342.24	5875.34	195.00	7025.33	627.42
Total P2P export vs. HEMS			(-30.68%)		(-96.66%)		(-91.06%)
Total_P2P trade (kWh)	0	0	2807.54	0	6919.72	0	7251.85
Demand by DSO (%)	100	75.93	62.83	61.10	36.79	88.07	60.29
Demand by DERs (%)	0	24.07	37.17	38.90	63.21	11.93	39.71
Peak grid consumption (kW)	61.20	61.20	61.20	38.46	95.72	90.84	161.12
Compared to base (%)	-	0	0	-37.15	+56.40	+48.43	+163.26

Furthermore, P2P trading decreased the energy sold to DSO by 30.68% for the PV-P2P scenario, 97.69% for the PV+ESS-P2P scenario, and 91.61% for the PV+ESS+EV-P2P scenario compared to the equivalent HEMS scenarios and substantially promoted community self-consumption by encouraging houses of the community to meet their own consumption through trade of local generation. At the time P2P was introduced, most PV generation was traded in the community and 37.17% of demand is covered by DERs for PV-P2P scenario. When batteries and electric vehicles are involved, P2P trading increases community self-sufficiency, where DERs meet 64.27% of demand for the PV+ESS-P2P scenario and 40.54% of demand for the PV+ESS+EV-P2P scenario. These values are significantly higher than equivalent HEMS scenarios.

2.2) Energy imports and exports under a ToU tariff

Results in Table 3 show that P2P trading reduced the energy purchased from DSO by 17.24% for the PV-P2P scenario, 39.73% for the PV+ESS-P2P scenario, and 31.54% for the PV+ESS+EV-P2P scenario compared to the equivalent HEMS scenarios. The ToU tariff increases the energy purchased from DSO for P2P scenarios compared to the flat tariff because of the high energy purchased from DSO during hours of low prices under ToU tariff to charge batteries and electric vehicles for energy arbitrage or to meet electric vehicle mobility needs.

Furthermore, P2P trading decreased the energy sold to DSO by 30.68% for the PV-P2P scenario, 96.66% for the PV+ESS-P2P scenario, and 91.06% for the PV+ESS+EV-P2P scenario compared to the equivalent HEMS scenarios. The ToU tariff increased the amount of energy sold to DSO compared to the flat tariff for P2P scenarios with the presence of batteries and electric vehicles, due to their energy arbitrage attributes (importing electricity at low price hours, storing it, and then using it for self-consumption or selling it to other houses at high price hours through P2P trading or selling it to DSO at hours with high price). Moreover, the ToU tariff decreased community self-sufficiency, where DERs meet a slightly lower percentage of demand than in a flat tariff, 63.21% for the PV+ESS-P2P scenario (about

1.06%) and 39.71% for the PV+ESS+EV-P2P scenario (about 0.83%). The differential pricing under the ToU tariff has resulted in batteries and electric vehicles being utilized for energy arbitrage, which has led to more energy exports to earn revenue through the feed-in tariff.

3) TOTAL ENERGY TRADING

Tables 2 and 3 present the total energy traded through P2P trading for the two electricity tariffs for the simulation period. There will be an increase in the trading period and the amount of traded energy between prosumers when batteries and electric vehicles are installed, since prosumers can charge batteries and electric vehicles during periods of high PV generation and sell them during periods of low PV generation and at night. Figure 10(c) shows the total energy traded in P2P scenarios for the two electricity tariffs. The ToU tariff allows for energy arbitrage because of having different prices at off-peak and peak hours, thus increasing the total energy traded compared to a flat tariff.

4) PEAK GRID CONSUMPTION

Since the distribution network needs to be sized for peak capacity, this value of peak consumption is very important for DSO. Tables 2 and 3 present that installing PV did not change the peak demand of the community (the values provided for peak demand represent the highest aggregate demand for imports from the external grid via the transformer for the community in one time step) for the two electricity tariffs since the peak demand of inflexible loads occurs at night when there is no PV generation as shown in Figure 3, Figure 10, and Figure 11. However, the integration of electric vehicles does result in a large increase in peak value compared to base scenario.

4.1) Peak grid consumption under a flat tariff

Results in Table 2 and Figure 10(a) show that, the peak consumption is the same for the base scenario, PV, and PV-P2P scenarios since the peak of inflexible loads occurs at night. With the presence of batteries in PV+ESS-HEMS and PV+ESS-P2P scenarios, the energy stored at batteries covered part of the community demand at night. As a result the peak consumption is reduced by 37.15% in these two scenarios compared to the base, PV, and PV-P2P scenarios. The additional load that electric vehicles cause on the grid in the PV+ESS+EV scenarios leads to an increase in the peak of grid consumption by 48.43% compared to the base scenario. This is a result of the larger energy storage capacity provided by the size of the electric vehicle batteries. This results in a doubling of peak grid consumption in comparison to PV+ESS scenarios. The charging of electric vehicles usually occurs at early day hours to satisfy mobility needs at departure time.

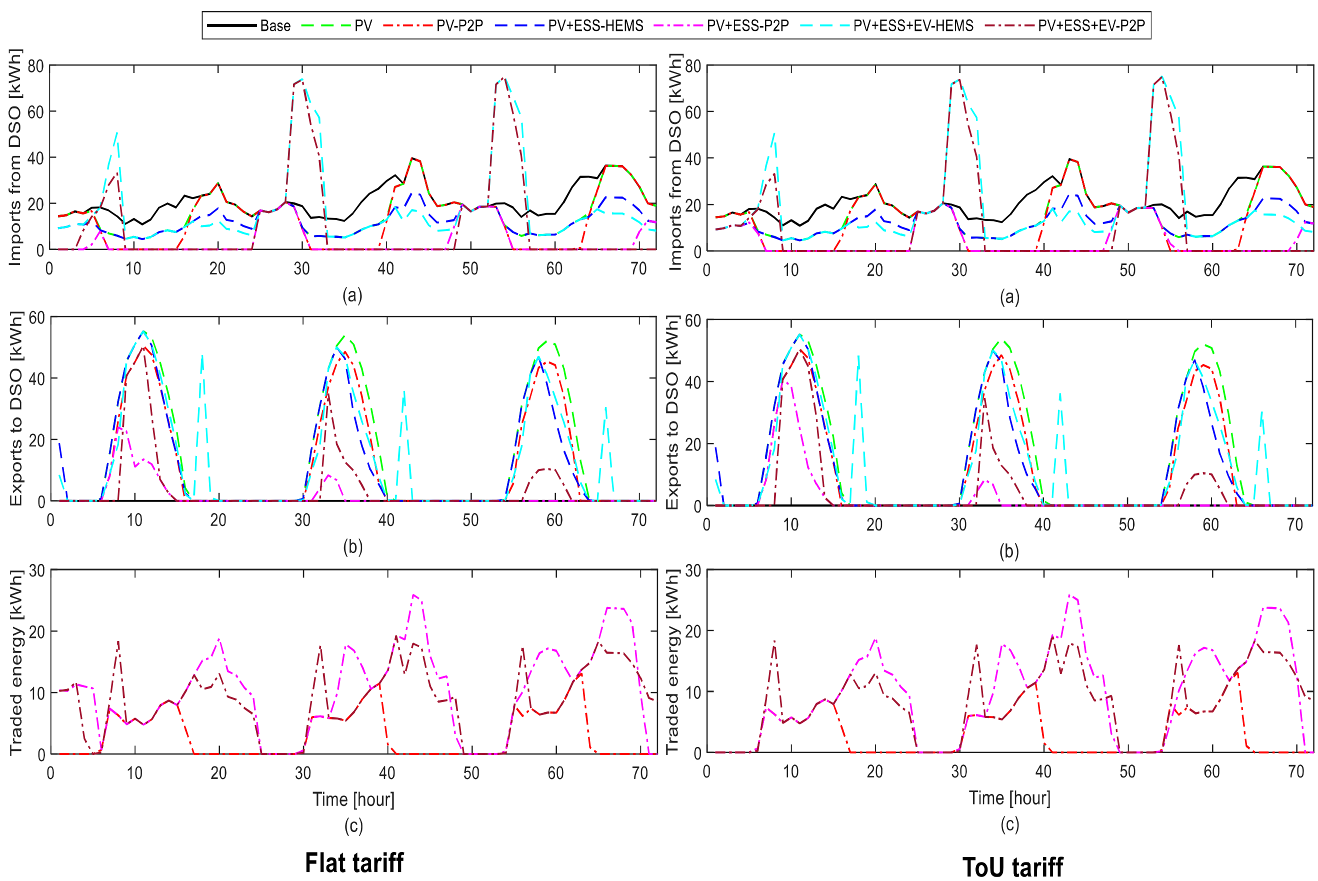

FIGURE 10. Comparison of the studied scenarios over 3 days.

4.2) Peak grid consumption under a ToU tariff

Results in Table 3 show that the peak consumption was not affected by the tariff in base, PV, and PV-P2P scenarios because there are no flexible devices installed that could change their behavior. However, the ToU tariff increased the peak of grid consumption, compared to the base scenario, by 56.40% for the PV+ESS-P2P scenario, 48.43% for PV+ESS+EV-HEMS, and 163.26% for the PV+ESS+EV-P2P scenario. These are a result of the energy arbitrage attributes of batteries and electric vehicles or simultaneous charging of batteries and electric vehicles. P2P scenarios with batteries and electric vehicles have higher peak consumption that the equivalent HEMS as shown in Figure11.

C. IMPACTS ON THE LV DISTRIBUTION NETWORK

High DER penetration on the LV distribution networks could result in a violation of network constraints [46]. Therefore, it is imperative to understand how the integration of DERs impacts the LV distribution network. Tables 4 and 5 show the voltage values for the three phases, the maximum voltage unbalance factor (VUF), the maximum transformer loading, and the maximum line loading recorded during the simulation period for all studied scenarios for the two electricity tariffs. The same physical energy flow occurs in both PV and PV-P2P scenarios; hence, both have identical impacts on the LV distribution network.

1) IMPACTS ON VOLTAGE VARIATIONS

The LV distribution network under study is unbalanced, and each phase includes a unique set of prosumers with distinct characteristics. Each phase's voltage is recorded simultaneously. The voltage being displayed was measured at the load 53 connecting point, which is where the line ends; as high voltage variations are anticipated at this node (the voltage variation on the feeders' end nodes is typically higher than that on other nodes near the transformer). When the local demand is high, the LV distribution networks may have a high voltage drop, and when the local generation is high, they might encounter a voltage rise. According to EN 50160, the voltage of the LV distribution network must be between 0.90 and 1.10 pu. Figure 12 shows the voltage values over three days for the two electricity tariffs. All scenarios exhibit voltage variations across the day. Since all excess PV is injected into the grid, the voltage variations in the PV and PV-P2P scenarios for the two electricity tariffs remain unchanged and they recorded higher maximum voltage variation than base scenario. The voltages increased at noon

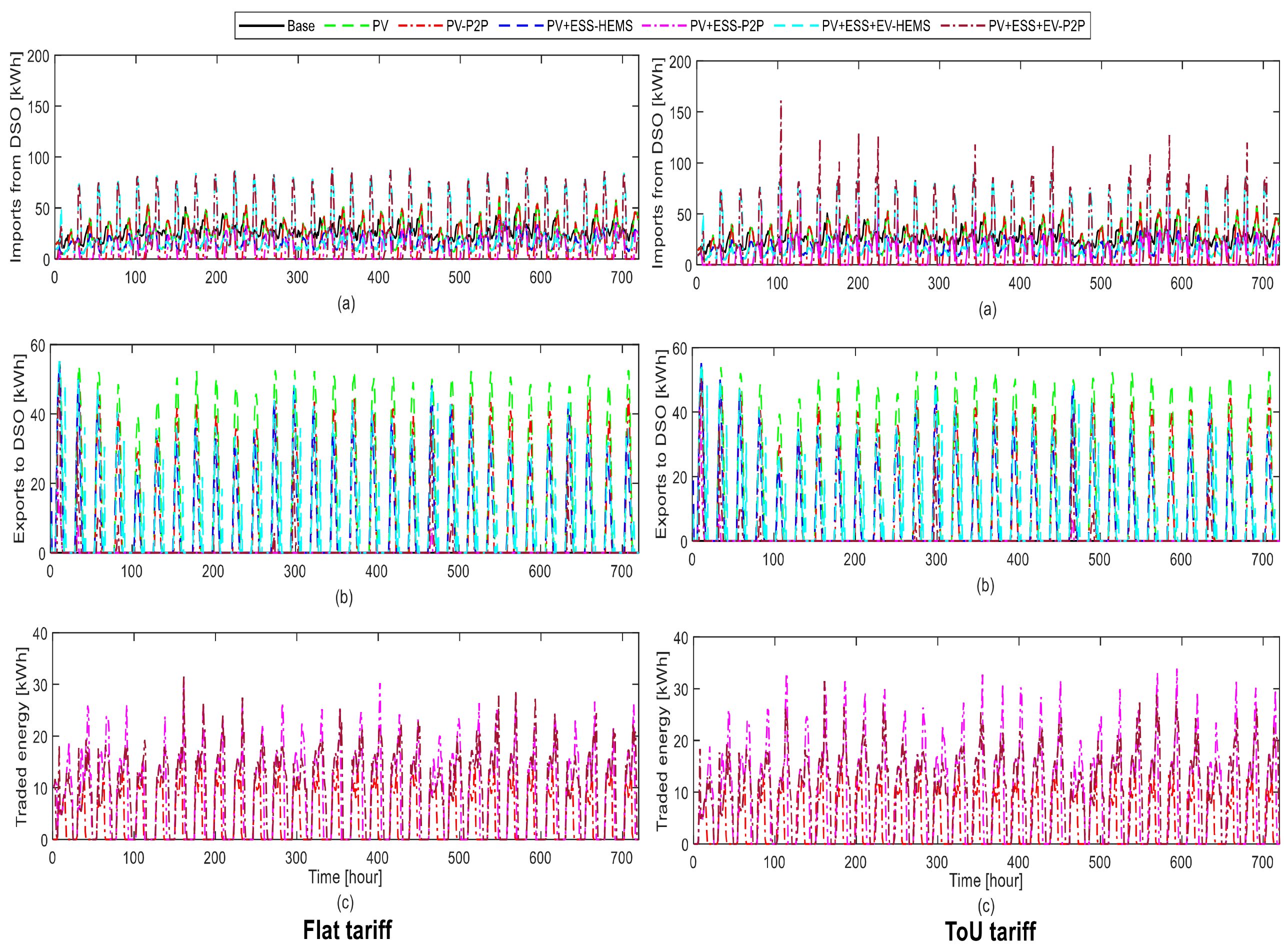

FIGURE 11. Comparison of the studied scenarios over 1 month.

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due to the PV energy injection into the grid. The PV+ESS+EV-HEMS and PV+ESS+EV-P2P scenarios exhibit sharp and sudden changes due to large variations in the load and generation profiles. This high voltage variation happens when high energy is imported from DSO to charge batteries and electric vehicles at low prices or to meet electric vehicle mobility needs. These changes are more obvious with the ToU tariff as consumers change their consumption patterns to reduce the cost of electricity due to the different pricing levels in the ToU tariff especially with P2P scenarios in the presence of batteries and electric vehicles. Moreover, prosumers in the HEMS scenarios are charging batteries at night because of the cheaper import tariff, whereas in the P2P scenarios, prosumers are preparing for trade periods. This situation is different with the flat tariff due to the constant daily price for trading. Therefore, the minimum voltage values in the PV+ESS-P2P and the PV+ESS+EV-P2P scenarios are only under 1 pu when using a ToU tariff as given in Table 4 and Table 5.

2) IMPACTS ON VOLTAGE PHASE UNBALANCE

The load connected to the 3-phases is balanced at optimal operating conditions, and the neutral line has no current flowing, which reduces losses in power. However, there is always an imbalance in the loads connected to each phase of the distribution networks. Due to the relatively identical consumption patterns of customers within a given geographic area, it is simple to keep the phase imbalance level within acceptable limits by dispersing the loads equally at each phase. With the installation of various single-phase DERs, this situation is anticipated to significantly change. Moreover, DER owners' consumption and production patterns could vary as a result of P2P trading. The impact of P2P energy trading on LV distribution network voltages can be measured using a voltage unbalance factor (VUF), which measures the variations between the magnitudes of the voltages for each phase. Based on symmetrical components of the voltage, the IEC [47] defines the voltage unbalance factor (VUF), which corresponds to the "true definition" of voltage imbalance as given in (18).

$$VUF = (V_2/V_1) * 100\ (\%) \quad (18)$$

V_1 and V_2 stand for the phase voltages' positive and negative sequences, respectively. The maximum permitted level for VUF is 2%.

Figure 13 shows the VUF values for the studied scenarios over three days for the two electricity tariffs and the maximum VUF values are given in Table 4 and 5 for the two electricity tariffs. The VUF values are recorded at the connection point of load 53, which is at the line's end, and anticipate high voltage variations. VUF remained below 1% on the flat tariff in all scenarios and the presence of flexible devices and P2P energy trading increase the VUF value. While in the ToU tariff, VUF has increased, as can be seen for the PV+ESS-P2P scenario to reach 1.074% and the PV+ESS+EV-P2P scenario to reach 1.919%. This occurs mostly because electric vehicles and batteries are charged simultaneously during times of low electricity prices or to meet the mobility needs of electric vehicles. Furthermore, no scenario for the two electricity tariffs exceeds the permitted level and P2P scenarios result in higher VUF values than the equivalent HEMS scenarios.

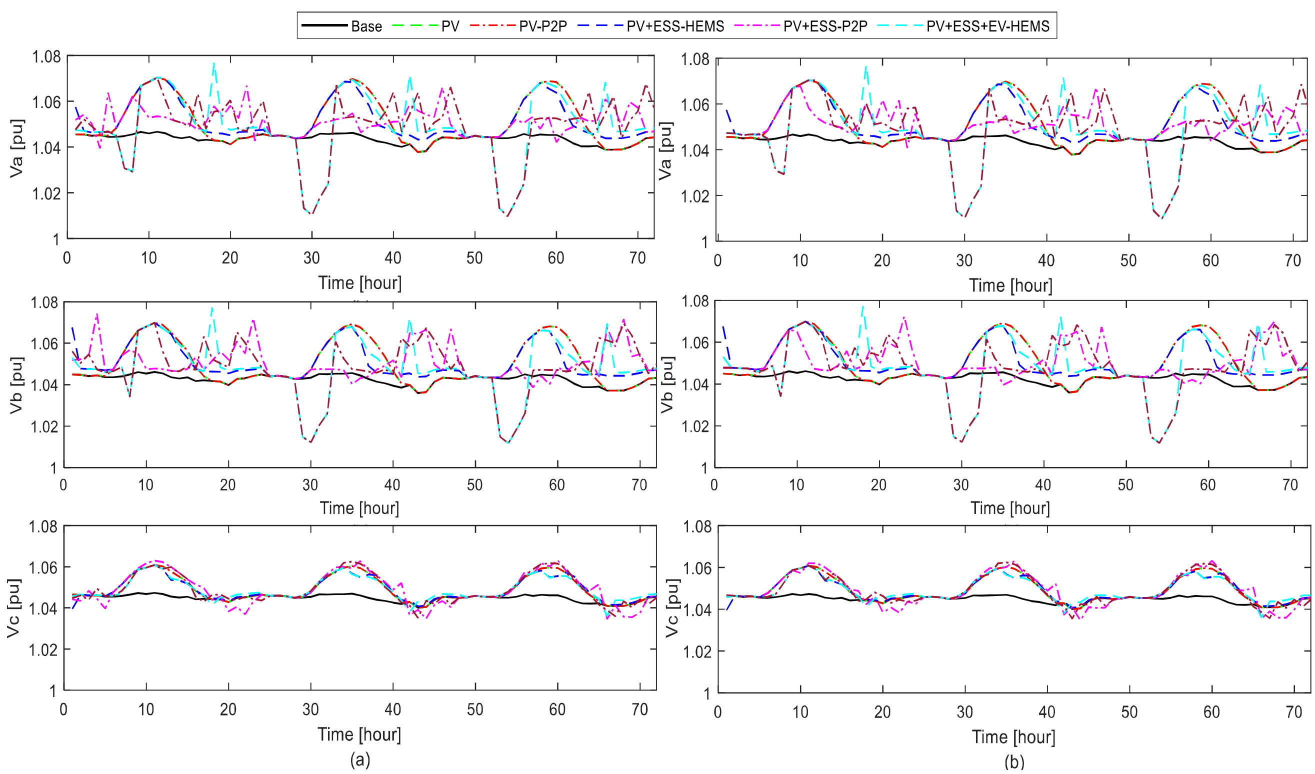

FIGURE 12. Phase voltages (a) Flat tariff, (b) ToU tariff.

TABLE 4. RESULTS OF P2P ENERGY TRADING IMPACTS ON THE LV DISTRIBUTION NETWORK FOR FLAT TARIFF

	No DER	PV		PV+ESS		PV+ESS+EV	
	Base	**PV**	**P2P**	**HEMS**	**P2P**	**HEMS**	**P2P**
Minimum Va (pu)	1.031	1.031	1.031	1.038	1.037	1.004	1.004
Maximum Va (pu)	1.046	1.070	1.070	1.070	1.072	1.076	1.077
Minimum Vb (pu)	1.028	1.028	1.028	1.036	1.034	1.005	1.005
Maximum Vb (pu)	1.046	1.069	1.069	1.069	1.078	1.077	1.081
Minimum Vc (pu)	1.034	1.034	1.034	1.035	1.029	1.03	1.028
Maximum Vc (pu)	1.047	1.060	1.060	1.060	1.064	1.060	1.062
Maximum VUF (%)	0.105	0.160	0.160	0.412	0.671	0.679	0.697
Maximum line loading (%)	22.45	22.45	22.45	19.81	14.00	39.31	39.31
Maximum transformer loading (%)	8.16	8.16	8.16	6.88	5.09	13.40	13.40

TABLE 5. RESULTS OF P2P ENERGY TRADING IMPACTS ON THE LV DISTRIBUTION NETWORK FOR TOU TARIFF

	No DER	PV		PV+ESS		PV+ESS+EV	
	Base	**PV**	**P2P**	**HEMS**	**P2P**	**PV**	**P2P**
Minimum Va (pu)	1.031	1.031	1.031	1.038	1.008	1.004	0.966
Maximum Va (pu)	1.046	1.070	1.070	1.070	1.075	1.076	1.074
Minimum Vb (pu)	1.028	1.028	1.028	1.036	0.988	1.005	0.948
Maximum Vb (pu)	1.046	1.069	1.069	1.069	1.080	1.077	1.076
Minimum Vc (pu)	1.034	1.034	1.034	1.035	1.026	1.033	1.026
Maximum Vc (pu)	1.047	1.060	1.060	1.060	1.063	1.060	1.062
Maximum VUF (%)	0.105	0.160	0.160	0.412	1.074	0.679	1.919
Maximum line loading (%)	22.45	22.45	22.45	19.81	43.97	39.31	76.82
Maximum transformer loading (%)	8.16	8.16	8.16	6.88	14.74	13.40	25.64

3) IMPACTS ON THE TRANSFORMER AND LINE LOADING

The installation of PV in the PV and PV-P2P scenarios reduced the energy imported from DSO because part of the community demand is covered by the PV generation. However, the community's peak demand occurs at night, when there is no PV generation. That's why the maximum transformer loading doesn't change with the presence of PV generation in the community, as given in Tables 4 and 5. Figure 14 depicts the transformer loading for the studied scenarios over 3 days for the two electricity tariffs. All scenarios result in low transformer loading, and the maximum loading in the PV+ESS+EV-P2P scenario was 13.40% in the flat tariff and 25.64% in the ToU tariff. The PV+ESS-P2P scenario results in the lowest transformer loading in the flat tariff (5.09%), as the excess PV generation is stored in batteries and used at night or sold to other houses in the community instead of purchasing from DSO. Transformer loading increased in ToU to 14.74% as the peak of grid consumption is increased. The equivalent HEMS scenarios in the ToU tariff recorded a lower transformer loading than P2P scenarios, as the peak of grid consumption is lower than the P2P scenario. In the flat tariff, the PV+ESS+EV-P2P scenario recorded the same loading as the equivalent HEMS scenario, as they have the same peak of grid consumption.

Figure 15 shows the loading of the line connected to the LV side of the transformer for the studied scenarios over 3 days, and Tables 4 and 5 show the maximum line loading for the two electricity tariffs. Equal current capacity exists across all of the network's lines. This maximum loading occurs when batteries and electric vehicles are charged at the same time. It can be noticed that line loading increases in the ToU tariff compared to the flat tariff in the PV+ESS-P2P scenario (43.97%) and PV+ESS+EV-P2P scenario (76.82%) as batteries and electric vehicles simultaneously charge during a period of low electricity prices. The equivalent HEMS scenarios recorded a lower line loading than P2P scenarios, and it has the same value in the two electricity tariffs.

4) IMPACTS ON DIFFERENT SCENARIOS USING BOXPLOT REPRESENTATIONS: A COMPARISON

This section presents a statistical study of voltage variations, transformer loading, line loading, and voltage unbalance, for the simulated period.

Figure 16 shows that the voltage at all phases is within acceptable limits for the two electricity tariffs for the entire simulation period. In flat tariff, the presence of DERs in the community increases the voltage variations compared to base scenario. Similarly, in Tou tariff, the presence of DERs in the community increases the voltage variations compared to base scenario. Moreover, P2P scenarios with batteries or electric vehicles result in higher voltage variations than the equivalent HEMS. Phase b has the highest voltage variations and phase c has the lowest voltage variations. The voltages are always lower than 1.08 pu. The voltages are less than 1.05 pu in the base scenario and rise with the PV generation reaching a level above 1.06 pu. In the PV+ESS-P2P and PV+ESS+EV-P2P scenarios, battery and electric vehicle charging and discharging, along with the opportunity to trade within the community, increase the voltage levels and tend to fluctuate more. Comparing P2P and HEMS scenarios with the same resources, P2P is inducing more voltage variations.

Figure 17 shows the loading for transformers and lines and the voltage unbalance factor for the two electricity tariffs for the entire simulation period. For the PV+ESS+EV-P2P scenario with a high impact on the LV distribution network**,** the transformer's average load is 7% for most of the hours throughout the month for the two electricity tariffs, with outliers reaching a maximum of 13.40% in the flat tariff and 25.64% in the ToU tariff. Similarly, the line's average load is less than 20% for most of the hours over the month for the two electricity tariffs, with outliers of 39.31% in the flat tariff and 76.82% in the ToU tariff. Comparing P2P and HEMS scenarios with the same resources, P2P scenarios result in more loading of transformer and lines than HEMS in ToU tariff. The VUF is 0.732% for most of the hours during the month for the PV+ESS+EV-P2P scenario in the flat tariff and is less than 1% with outliers with a maximum of 1.919% in the ToU tariff. P2P scenarios result in higher values of VUF compared to the equivalent HEMS scenarios.

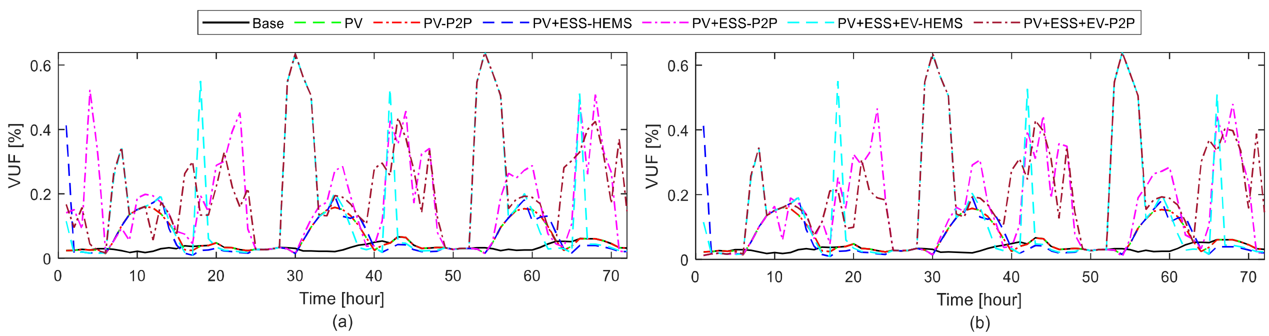

FIGURE 13. Voltage unbalance factor (a) Flat tariff, (b) ToU tariff.

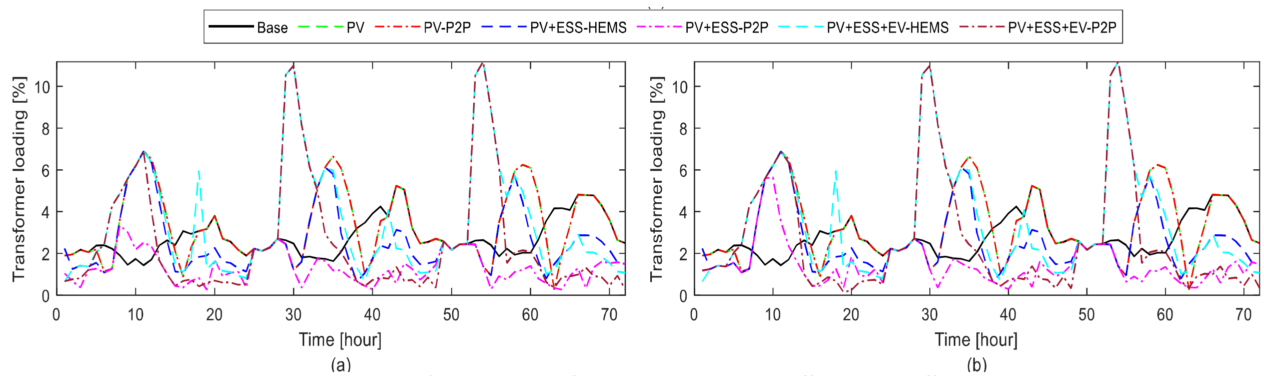

FIGURE 14. Transformer loading (a) Flat tariff, (b) ToU tariff.

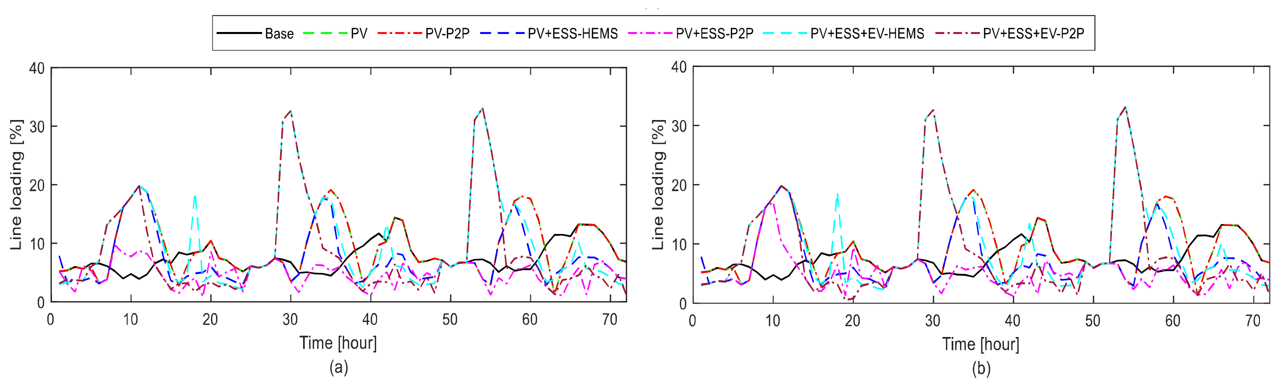

FIGURE 15. Line loading (a) Flat tariff, (b) ToU tariff.

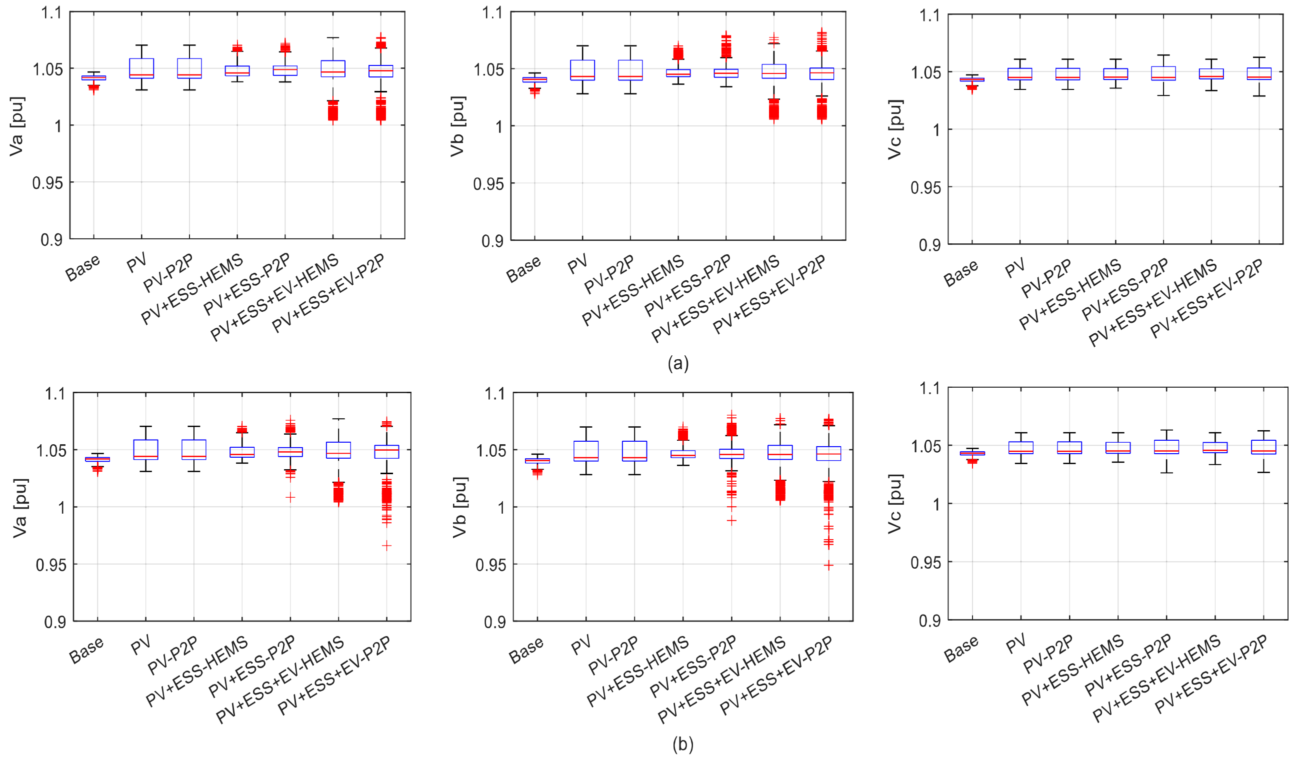

FIGURE 16. **Comparison of the voltage variations impacts of different scenarios using boxplot representations (a) Flat tariff, (b) ToU tariff.**

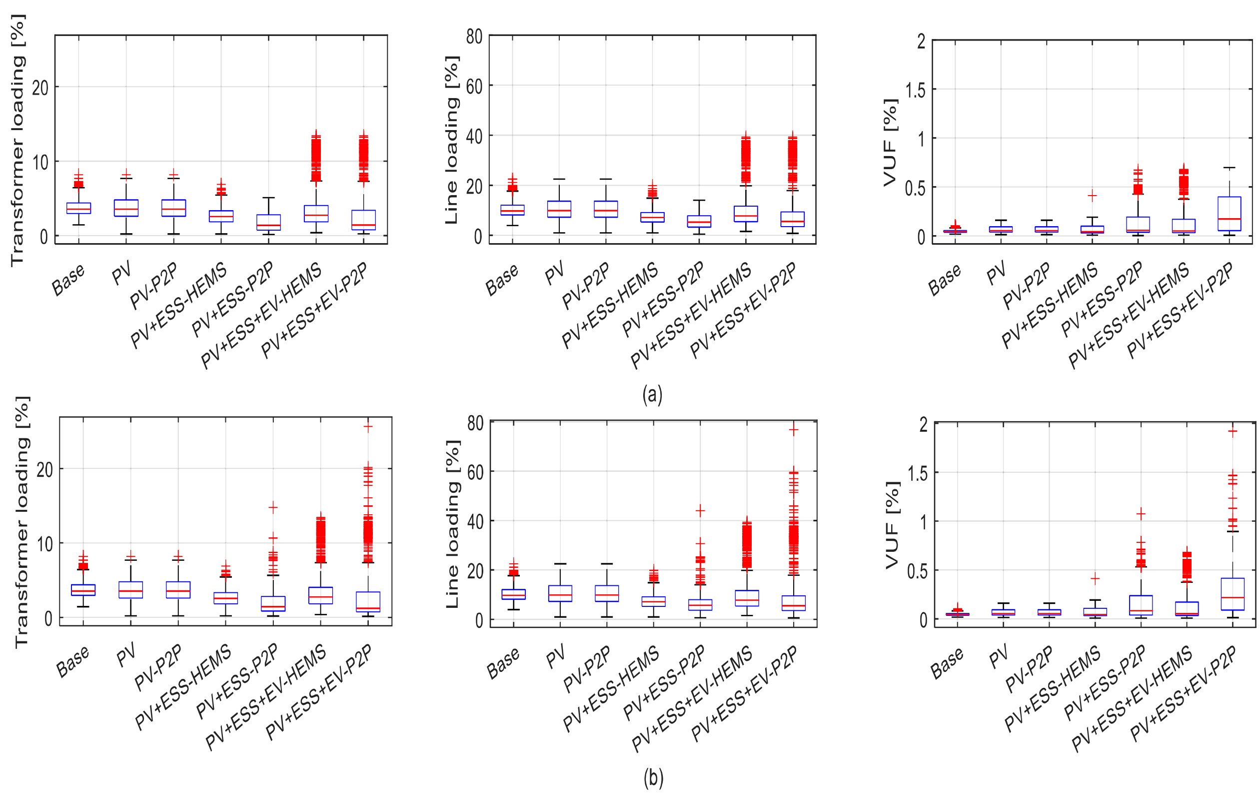

FIGURE 17. **Comparison of the transformer loading, line loading, and phase unbalance impacts of different scenarios using boxplot representations (a) Flat tariff, (b) ToU tariff.**

VI. CONCLUSION

This paper studied seven operation scenarios where different DER types and techniques for managing DERs (P2P and HEMS) are considered. Moreover, the electricity pricing (flat tariff and ToU tariff) effect on the performance of P2P energy trading and HEMS and on the LV distribution network are analyzed, considering a realistic Egyptian case study. The results demonstrated P2P's effectiveness over HEMS in lowering electricity costs, lowering energy purchases from DSO, and increasing self-consumption. The economic benefit of P2P energy trading is higher under the ToU tariff compared to the flat tariff. Compared to HEMS, P2P scenarios have higher peak demands on energy imported from DSO in ToU tariff. The impacts of P2P on the LV distribution network are compared to HEMS for the two electricity tariffs. The study showed that for voltage variations and voltage phase unbalance, no scenario exceeded the permitted level for the two electricity tariffs and the highest impacts are observed for PV+ESS+EV-P2P scenario for ToU tariff. Furthermore, for P2P scenarios, the transformer and lines are more loaded than HEMS in ToU tariff. Results indicated that the continuous charging of batteries and electric vehicles during times of low pricing or to meet electric vehicle mobility needs is the reason for these P2P-related impacts. These changes are more obvious with the ToU tariff as consumers change their consumption patterns to reduce their electricity costs, considering the different pricing levels in the ToU tariff. The case study demonstrates that the chosen energy trading system has a non-negligible impact on the physical quantities that network users' trade. Therefore, network constraints may be violated more frequently depending on the mechanism utilized and the same resource conditions.

Future research could assess the impacts of P2P energy trading on different levels of power systems (i.e., generation and transmission). Moreover, approaches for mitigating the impacts of P2P energy trading on distribution networks could be studied.

REFERENCES

[1] A. Zhou, M. Yang, T. Wu, L. Yang, "Distributionally Robust Energy Management for Islanded Microgrids With Variable Moment Information: An MISOCP Approach," *IEEE Trans. on Smart Grid, vol. 14, no. 5, pp. 3668-3680, Sep. 2023,* 10.1109/TSG.2023.3236019

[2] Y. Zhou, J. Wu, C. Long, W. Ming, "State-of-the-Art Analysis and Perspectives for Peer-to-Peer Energy Trading," *Engineering, vol. 6, no. 7, pp. 739-753, Jul. 2020,* https://doi.org/10.1016/j.eng.2020.06.002

[3] K.Umer, Q.Huang, M.Khorasany, M. Afzal, W. Amin, "A novel communication efficient peer-to-peer energy trading scheme for enhanced privacy in microgrids,"*Applied Energy, vol. 296, p.117075,Aug.2021,* https://doi.org/10.1016/j.apenergy.2021.117075

[4] P.A. Gbadega, Y. Sun,"Centralized peer-to-peer transactive energy market approach in a prosumer-centric residential smart grid environment," *Energy Reports, vol. 8, no.15, pp. 105-116, Nov. 2022,* https://doi.org/10.1016/j.egyr.2022.10.080

[5] M.E. Honarmand,V. Hosseinnezhad, B. Hayes, P. Siano, "Local Energy Trading in Future Distribution Systems", *Energies, vol.14, no.11, p.3110, 2021,* https://doi.org/10.3390/en14113110

[6] J. Li, D. Xu, J. Wang, B. Zhou, M. H. Wang, L. Zhu, "P2P Multigrade Energy Trading for Heterogeneous Distributed Energy Resources and Flexible Demand," *IEEE Trans. on Smart Grid, vol. 14, no. 2, pp. 1577-1589, Mar. 2023,* 10.1109/TSG.2022.3181703

[7] S. Rezaei, A. Ghasemi, "Stochastic scheduling of resilient interconnected energy hubs considering peer-to-peer energy trading and energy storages," *Jour. of Energy Storage, vol. 50, p.104665, Jun. 2022,* https://doi.org/10.1016/j.est.2022.104665

[8] Y. Zhou, J. Wu, G. Song, C. Long,"Framework design and optimal bidding strategy for ancillary service provision from a peer-to-peer energy trading community," *Applied Energy, vol. 278,p.115671,Nov.2020,* https://doi.org/10.1016/j.apenergy.2020.115671

[9] L. Nasrat, M. Zedan, A. Ali, G. Shabib, "Review on Energy Trading of Community-Based Projects around the World," *IEEE 23rd Int. Middle East Power Systems Con. (MEPCON), Cairo, Egypt, 13-15Dec.2022,*10.1109/MEPCON55441.2022.10021688

[10] M. Nour, J. P. Chaves-Ávila, Á. Sánchez-Miralles, "Review of Blockchain Potential Applications in the Electricity Sector and Challenges for Large Scale Adoption," *IEEE Access, vol. 10, pp. 47384 - 47418, Apr. 2022, 10.1109/ACCESS.2022.3171227*

[11] M. Karami, R. Madlener, "Business models for peer-to-peer energy trading in Germany based on households' beliefs and preferences," *Applied Energy, vol. 306, p.118053, part B, Jan. 2022*, https://doi.org/10.1016/j.apenergy.2021.118053

[12] N. Wang, Z. Liu, P. Heijnen, M. Warnier, "A peer-to-peer market mechanism incorporating multi-energy coupling and cooperative behaviors," *Applied Energy, vol. 311, 118572, Apr. 2022,* https://doi.org/10.1016/j.apenergy.2022.118572

[13] J. Heilmann, M. Wensaas, PC. del Granado, "Trading algorithms to represent the wholesale market of energy communities in Norway and England,"*Renewable Energy, vol. 200, pp. 1426-1437, Nov. 2022,* https://doi.org/10.1016/j.renene.2022.10.028

[14] M. Khorasany, A.S. Gazafroudi, R. Razzaghi, T. Morstyn, "A framework for participation of prosumers in peer-to-peer energy trading and flexibility markets,"*Applied Energy, vol.314, p.118907,May.2022,* https://doi.org/10.1016/j.apenergy.2022.118907

[15] B. Zhang, Y. Du, X. Chen, E.G. Lim, L. Jiang, K. Yan, "Potential Benefits for Residential Building with Photovoltaic Battery System Participation in Peer-to-Peer Energy," *Trading Energies, vol. 15, no.11, p.3913, 2022, https://doi.org/10.3390/en15113913*

[16] S. Saxena, H. E. Farag, A. Brookson, H. Turesson, H. Kim, "A Permissioned Blockchain System to Reduce Peak Demand in Residential Communities via Energy Trading: A Real-World Case Study," *IEEE Access, vol. 9, pp. 5517 – 5530, Jan. 2021,* 10.1109/ACCESS.2020.3047885

[17] Y. Yap, Jinnie, W. Tan;N. Ahmad, C. Wooi, Y. Wu, "Motivational Game-Theory P2P Energy Trading: A Case Study in Malaysia," *IEEE 2nd Int. Con. on Smart Power & Internet Energy Systems, Bangkok, Thailand, 15-18 Sep.2020,* 10.1109/SPIES48661.2020.9243056

[18] C. Etukudor, B.Couraud,V. Robu, W. Früh, D.Flynn, C.Okereke, "Automated Negotiation for Peer-to-Peer Electricity Trading in Local Energy Markets," *Energies, vol.13, no.4, p.920, 2020,* https://doi.org/10.3390/en13040920

[19] Y. Takeda, Y. Nakai, T. Senoo, K. Tanaka, "Designing a User-Centric P2P Energy Trading Platform: A Case Study—Higashi-Fuji Demonstration," *Energies, vol.14, no.21,p. 7289, 2021,* https://doi.org/10.3390/en14217289

[20] X. Wang, Z. Wang, Y. Mu, Y. Deng, H. Jia,"Rolling horizon optimization for real-time operation of prosumers with Peer-to-Peer energy trading," *Energy Reports, vol. 9, no.1, pp.321-328, Mar. 2023,* https://doi.org/10.1016/j.egyr.2022.10.438

[21] O. Samuel, A. Almogren, A. Javaid, M. Zuair, I.Ullah, N. Javaid, "Leveraging Blockchain Technology for Secure Energy Trading and Least-Cost Evaluation of Decentralized

Contributions to Electrification in Sub-Saharan Africa,"*Entropy vol. 22, no.2, p.226, 2020,* https://doi.org/10.3390/e22020226

[22] K. Kusakana, "Optimal peer-to-peer energy management between grid-connected prosumers with battery storage and photovoltaic systems," *Jour. of Energy Storage, vol. 32, p.101717, Decr.2020,* https://doi.org/10.1016/j.est.2020.101717

[23] M. Mahmoud, S.B. Slama, "Peer-to-Peer Energy Trading Case Study Using an AI-Powered Community Energy Management System," *Applied Sciences, vol.13, no.13, p.7838, 2023,* https://doi.org/10.3390/app13137838

[24] A. El-Zonkoly, **"**Feasibility of Blockchain-Based Energy Trading within Islanded Microgrids in Alexandria, Egypt," *Jour. of Energy Engineering,vol. 147, no. 3, Mar 2021,* 10.1109/ATEE58038.2023.10108240

[25] M.A. El Din, A. El Zonkoly, O.M. Hebala, "Energy Trading Strategy Incoporating Electric Vehicles," *IEEE 13th Int. Symp.on Advanced Topics in Electrical Engineering (ATEE), Bucharest, Romania, 23-25 Mar. 2023,* 10.1109/ATEE58038.2023.10108240

[26] A. El-Zonkoly, "Optimal P2P based energy trading of flexible smart inter-city electric traction system and a wayside network: A case study in Alexandria, Egypt,"*Electric Power Systems Research, vol. 223, p.109708, Oct.2023,* https://doi.org/10.1016/j.epsr.2023.109708

[27] B.P. Hayes, S. Thakur, J.G. Breslin,"Co-simulation of electricity distribution networks and peer to peer energy trading platforms," *Int. Jour. of Electrical Power & Energy Systems,vol. 115, p.105419, Feb.2020,*https://doi.org/10.1016/j.ijepes.2019.105419

[28] M. Nour, J.P. Chaves-Ávila, M. Troncia, A. Ali, Á. Sánchez-Miralles," Impacts of Community Energy Trading on Low Voltage Distribution Networks,"*IEEE Access,vol. 11, pp. 50412 – 50430, May. 2023,* 10.1109/ACCESS.2023.3278090

[29] M.I. Azim, W. Tushar, T.K. Saha, "Cooperative negawatt P2P energy trading for low-voltage distribution networks," *Applied Energy, vol. 299, p.117300, Oct. 2021,* https://doi.org/10.1016/j.apenergy.2021.117300

[30] M.F. Dynge, P.C. del Granado, N. Hashemipour, *M. Korpås*, "Impact of local electricity markets and peer-to-peer trading on low-voltage grid operations," *Applied Energy, vol. 301,* Nov. 2021, p. 117404, https://doi.org/10.1016/j.apenergy.2021.117404

[31] J. Guerrero, A.C. Chapman, G. Verbič, "Decentralized P2P Energy Trading Under Network Constraints in a Low-Voltage Network,"*IEEE Trans. on Smart Grid, vol. 10, no. 5, Sep. 2019, pp. 5163 – 5173,* 10.1109/TSG.2018.2878445

[32] M. Jenkins, I. Kockar, "Impact of P2P trading on distributed generation curtailment in constrained distribution networks," *Electric Power Systems Research, vol. 189, p.106666, Dec. 2020,* https://doi.org/10.1016/j.epsr.2020.106666

[33] H. Liu, J. Li, S. Ge, X. He, F. Li, C. Gu, "Distributed Day-Ahead Peer-to-Peer Trading for Multi-Microgrid Systems in Active Distribution Networks," *IEEE Access, vol.8, pp.66961 – 66976, Mar. 2020,* 10.1109/ACCESS.2020.2983645

[34] M.I. Azim, W. Tushar, T.K. Saha, "Investigating the impact of P2P trading on power losses in grid-connected networks with prosumers," *Applied Energy, vol. 263, p.114687, Apr. 2020,* https://doi.org/10.1016/j.apenergy.2020.114687

[35] A. Saif, S.K. Khadem, M.F. Conlon, "Impact of Distributed Energy Resources in Smart Homes and Community-Based Electricity Market," *IEEE Trans. on Industry Applications*, *vol. 59, no. 1, pp. 59 - 69, Jan.-Feb. 2023,* 10.1109/TIA.2022.3202756

[36] Pandapower 2.3.0 Documentation. [Online] Available: https://pandapower.readthedocs.io/en/v2.3.1/index.html, [Accessed: 10-July-2023].

[37] L. Thurner, A. Scheidler, F. Schäfer, J.H. Menke, J. Dollichon, F. Meier, S. Meinecke, M. Braun, "Pandapower - An Open-Source Python Tool for Convenient Modeling, Analysis, and Optimization of Electric Power Systems," *IEEE Trans. on Power Systems, vol. 33, no. 6, pp. 6510–6521, Nov. 2018.* https://ieeexplore.ieee.org/document/8344496

[38] A. Saif, S.K. Khadem, M.F. Conlon, "Impact of Distributed Energy Resources in Smart Homes and Community-Based Electricity Market," *IEEE Trans. on Industry Applications, vol. 59, no. 1, pp. 59-69, Jan.-Feb. 2018,* 10.1109/TIA.2022.3202756

[39] A. Lüth, J.M. Zepter, P.C. Del Granado, R. Egging, "Local electricity market designs for peer-to-peer trading: The role of battery flexibility," *Applied Energy, vol. 299, pp. 1233-1243, Nov. 2018,* https://doi.org/10.1016/j.apenergy.2018.08.004

[40] M. Nour, J.P. Chaves-Ávila, M. Troncia, Á. Sánchez-Miralles, "Mitigating the Impacts of Community Energy Trading on Distribution Networks by Considering Contracted Power Network Charges," *IEEE Access, pp. 1-1, Feb. 2024,* 10.1109/ACCESS.2024.3365630

[41] "Resources – IEEE PES Test Feeder." [Online] Available: https://cmte.ieee.org/pes-testfeeders/resources/, [Accessed: 20-June-2023].

[42] Renewables.ninja, website [Online] Available: https://www.renewables.ninja, [Accessed: 17- July-2023].

[43] M.M. Rienecker, M.J. Suarez, R. Gelaro, R. Todling, J.Bacmeister, E. Liu, M.G. Bosilovich, S.D. Schubert, L.Takacs, G-K. Kim, S. Bloom, J. Chen, D. Collins, A. Conaty, A. da Silva, W. Gu, J. Joiner, R.D. Koster, R. Lucchesi, A. Molod, T. Owens, S. Pawson, P. Pegion, C.R. Redder, R. Reichle, F.R. Robertson, A.G. Ruddick, M. Sienkiewicz, J. Woollen, "MERRA: Nasa's modern-era retrospective analysis for research and applications, " *vol. 24, no. 14, pp. 3624–48, Jul. 2011,* https://doi.org/10.1175/JCLI-D-11-00015.1

[44] Egyptian Electric Utility and Consumer Protection Regulatory Agency (EgyptERA), website [Online] Available: http://egyptera.org/ar/Tarrif2022N.aspx, [Accessed: 18-July-2023].

[45] Behira Electricity Distribution Co. website [Online] Available: https://www.bedc.gov.eg/newsun_product_system/, [Accessed: 18-July-2023].

[46] M. Nour, J.P. Chaves-Ávila, G. Magdy, "Review of Positive and Negative Impacts of Electric Vehicles Charging on Electric Power Systems," *Energies, vol. 13, no. 18, p. 4675, 2020,* https://doi.org/10.3390/en13184675

[47] IEC. IEC 61000-3-14: Assessment of Emission Limits for Harmonics, Interharmonics, Voltage Fluctuations and Unbalance for the Connection of Disturbing Installations to LV Power Systems; IEC: Geneva, Switzerland, 2011. https://webstore.iec.ch/publication/4147

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