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DERs Orchestration and Gen3 Blockchain Integration in P2P Trading based Distribution Network

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Abstract— This paper discusses the advantages of orchestrating distribution energy resources (DERs) within the distribution network and integrating third generation (Gen3) blockchain technology among a diverse range of customers. The implementation of peer-to-peer (P2P) energy trading aims to optimize local energy utilization, reduce energy costs for participants, and provide insights into profit margins for aggregators and the distribution system operator (DSO). The study focuses on three types of DERs, namely electric vehicles (EVs), photovoltaic (PV) systems, and battery energy storage systems (BESSs), to facilitate transparent and secure P2P energy trading. The results underscore the importance of Gen3 blockchain technology in expediting and enhancing energy trading processes, thereby benefiting a wide range of participants.

Keywords—Distribution network; P2P Trading; blockchain; distribution system operator; electricity cost reduction.

I. INTRODUCTION

Although P2P trading breaks the centralized energy market structure and facilitates more flexibility for demand-side management, mutually settled transactions can introduce several challenges in a real energy market. One of the most prominent challenges is evaluating the design complexity of P2P trading-based distribution network in comparison with the centralized market structure [1]. Another crucial aspect is to optimally schedule and plan P2P transactions to create win-win scenarios for all associated participants and stakeholders so that they are motivated to join LEM [2-3]. Further, the performance of P2P trading in enhancing electricity grid resilience needs to be assessed, as lucrative distribution network offers can encourage several distribution network participants to export and import more than their business-as-usual (BAU) cases [4]. Moreover, the technical constraints of the electricity grid are required to be satisfied during each P2P transaction to evade any potential distribution network issues [5]. Moreover, the integration of different blockchain technologies and their economic viability for distribution network usage could be challenging as well [6].

The utilization of energy storage systems (ESS), such as BESSs and EVs, can cut on down energy usage expenditures further while introducing distribution network participants' flexibility to a greater extent. Recent research studies stress

the use of BESSs and EVs in the distribution network. As an illustration, a multi-agent-based platform for managing energy storage systems is developed in [7]. An optimal scheduling of energy storage systems is performed in [8] to integrate them into the distribution network. A shared ESS-facilitated P2P trading model is planned in [9-10]. A cost-benefit analysis related to backing up an electricity grid via BESS-dominated P2P trading is conducted in [11]. To settle the operational costs of such a charging station autonomously, a billing model is also presented in [12]. The concerns of the stakeholders, like network operators and retailers, are also considered in some existing literature. A network operator interest-aware P2P trading mechanism is planned in [13-14]. A collaborative trading framework is proposed, incorporating a network operator and distribution network participants [15]. Such an integrated approach is also used for reserve trading and shared BESS scheduling in [16-17]. Furthermore, a P2P trading model is developed in [18-19] that not only benefits distribution network participants but also motivates retailers.

Last, some research studies also outline the necessity of distributed ledger platforms, such as blockchain technologies, to organize P2P trading settlements in the distribution network securely and store them permanently. distribution network structures based on distributed ledger technologies are surveyed and analysed in [20]. A Hyper ledger blockchain technology-empowered framework for online energy trading is reported in [21-22]. The consortium blockchain technology is also utilized in [23-24] for arranging localized P2P trading in a protected fashion in the presence of EVs. An Ethereum blockchain-assisted P2P trading platform is designed in [25-26]. In addition, Polygon blockchain-enabled decentralized and secured smart contracts are constructed in [27] that can be used for P2P transactions. A comparative study between Ethereum and Polygon blockchain technologies for executing P2P transactions is also provided in [28].

While the first-generation (Gen1) and second-generation (Gen2) blockchain studies contribute to accommodating P2P trading in the distribution network, P2P transactions can be arranged more swiftly by the application of a third generation (Gen3) blockchain platform. This paper takes the pioneering step of integrating a Gen3 Proof of Stake (POS) and Proof of History (POH) blockchain technology [29] into the distribution network that takes diverse types of participants and stakeholders into account. This study addresses a diverse range of participants within the distribution network,

encompassing consumers, EVs, prosumers with solar PV systems, and prosumers with solar PV systems coupled with BESSs. The proposed distribution network enables secure and transparent Gen3 blockchain-based P2P energy trading of surplus renewable energy. The study delves into participants' behaviors of energy trading, and blockchain deployment expense. It is observed that insufficient research has been conducted to analyze the cost and speed of Gen3 blockchain technologies, as well as to explore implementation approaches within distribution networks.

The remainder of the paper is structured as follows. An overview of P2P trading-driven distribution network is provided in Section II, followed by its deployment and integration with the blockchain technology in Section III. The formulation is defined in the Section IV. The simulation results and analysis are illustrated in Section V. Finally, the concluding remark and future work are outlined in Section VI and Section VII, respectively.

II. DISTRIBUTION NETWORK MODEL

The distribution network has been conceptualized to create close communities with geographical dispersion, comprising consumer entities and prosumers equipped with either PV systems or PV systems paired with BESSs and EVs. The fundamental principle underlying distribution network is the alignment of locally generated electricity supply with demand, operating within defined time intervals, often in 15-minute increments. Where the energy generated exceeds the demand of a prosumer, the surplus energy is made available for trading stipulated trading protocols. Notably, energy bought from and sold to the distribution network are priced at rates lower than the standard grid tariffs. P2P trading is facilitated by blockchain technology, ensuring the secure and precise exchange of trading information within a system wherein all stakeholders can arrive at a consensus regarding the shared data. As a testament to its commitment to transparency and security, the distribution network grants all participants access to a blockchain-based dashboard, facilitating a more transparent and secure viewing of energy transactions. By harnessing DERs more effectively within the network, the distribution network empowers consumers to access energy that is not only cost-effective but also sustainable.

The trading mechanism not only yields financial advantages but also ensures the security of information exchange, underpinned by the utilization of blockchain technology. It offers sellers substantial value, as the P2P selling price surpasses that of the feed-in tariff (FiT) yet

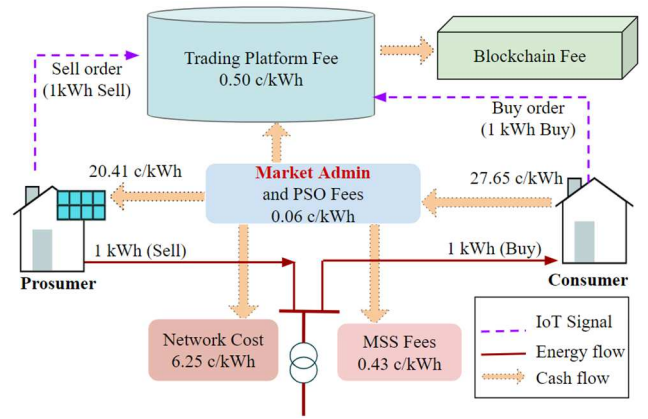


Fig. 1. Energy and cash flows among consumers and prosumers.

remains below the grid purchase rate. The magnitude of this margin is contingent on the FiT rate, with higher margins attainable when the FiT is lower. Participants with energy requirements are incentivized to acquire P2P energy from fellow participants, as this proves to be a cost-effective alternative compared to direct grid procurement while still safeguarding the DSO's profit margins. This price point is dynamic, adjusting in response to energy demand fluctuations, a crucial feature for enhancing energy value during peak periods and moderating it during off-peak times.

The distribution network platform has been constructed upon a microservice-oriented architecture underpinned by a high-throughput, energy-efficient proprietary blockchain infrastructure. This design facilitates seamless scalability to accommodate the potential expansion of the project. The research in question leveraged the tariff structure for electricity in Singapore [30], as explained in Table I. In the Singapore BAU model, the flat tariff structure encompasses various components, including network costs, market administration, power system operation (PSO) fees, market support service (MSS) fees, and energy costs. For the proposed model, the FiT value has been established at 18 c/kWh. Within this framework, the P2P trading range is more than 18 c/kWh and less than 28.7 c/kWh. Fig. 1 explains the interplay of energy, monetary, and internet-of-things (IoT) exchanges between consumers and prosumers, thereby explaining the distribution of the distribution network tariff amounting to S\$0.2765 among various stakeholders.

III. BLOCKCHAIN TECHNOLOGY AND INTEGRATION

In this model, participants submit their bids through a user interface (UI) before the bidding window closes. The UI also contains information about participants' trade history, P2P trade information, and data from the blockchain. Once the bid rates are provided by participants, the data entry processing unit receives and verifies the bid data and stores it in the database. A forecasting service generates load and generation profiles for each participant. The forecasting data is generated and supplied to the trading engine for matchmaking. The trading engine facilitates matchmaking between buyers and sellers. The P2P matchmaking record is also stored in the database. Finally, the settlement is done where electricity bills for each participant are calculated for both distribution network and BAU case. The benefit of using distribution network is also calculated. The settlement data is displayed on the UI. To store trade data on the blockchain, blockchain

TABLE I. TARIFF STRUCTURE

Tariff Breakdown [30]	FLAT TARIFF	
	BAU	Distribution Network
FIT (c/kWh)	18	
Network Cost(c/kWh)	6.25	6.25
Market Admin PSO Fees (c/kWh)	0.06	0.06
MSS Fees (c/kWh)	0.43	0.43
DISTRIBUTION NETWORK transaction fee (c/kWh)	0	0.5
Energy/P2P price (c/kWh)	21.96	P2P Price < 21.96
Tariff (c/kWh)	28.70	18 < Tariff < 28.70

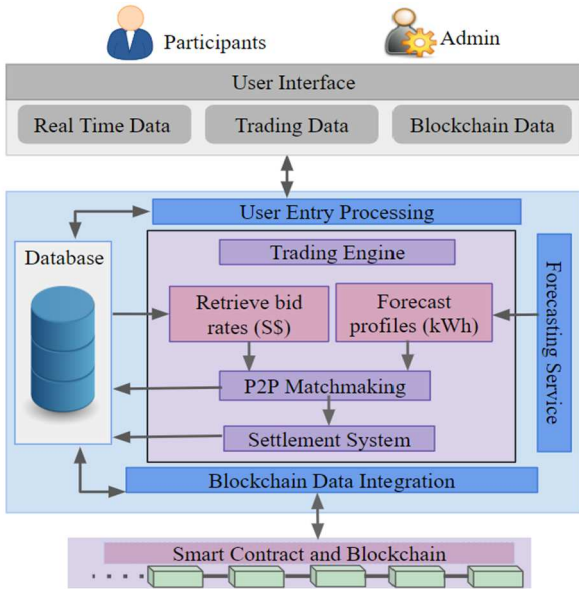


Fig. 2. Blockchain Technology Integration.

data integration connects the UI and trading engine via smart contracts. This architecture guarantees the secure storage of historical bid information, records of energy trading, and billing information within the blockchain service. In advancing the proposed model, a pivotal phase involves the seamless integration of blockchain technology, as depicted in Fig. 2.

Data is extracted from the database, which includes participants' bid rate, quantity and P2P traded quantity, P2P traded rate, electricity bill in distribution network and BAU, and benefit of using distribution network. Following this, the transaction is signed with the participant's private key for authorization and then sent to the distribution network smart contract using the smart contract address. This is part of blockchain data integration and is done using the Web 3.0 (web3) library. Once the transaction is received by the smart contract, it processes the transaction according to the codes written in the smart contract and broadcasts the transaction for node verification. Once verified, transactions are integrated into the upcoming block, and a consensus process occurs where validators agree as significant as the transaction and the state of the blockchain. When consensus is reached, the newly created block is linked with the existing blockchain, and the transaction confirmation message of this process is communicated to the participant. If the transaction verification fails, an error message of this process is communicated to the participant.

IV. OBJECTIVE FUNCTION

Suppose i represents the index of each distribution network participant, and their set is indicated by I . A distribution network participant is allowed to trade with their peers either as a seller $i \in A \subset I$ or as a buyer $i \in B \subset I$, depending upon its energy status at a given time slot $c \forall C$, where A, B and C denote the sets of all sellers, buyers, and P2P trading slots in the distribution network, respectively. Assume $E^p(i, c)$ and $D^p(i, c)$ imply the profit and saving of each distribution network participant i at c . The objective of the distribution network is to maximise either $E^p(i, c)$ (if trading as a seller) or $D^p(i, c)$ (if trading as

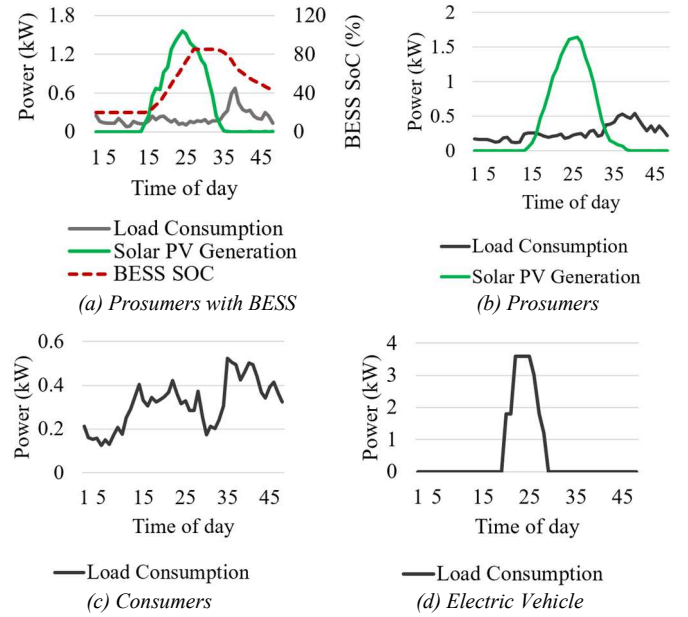


Fig. 3. Average profiles of distribution network participants.

a buyer), and, hence, the objective function can be drawn as follows:

$$\max (u E^p(i, c) + v D^p(i, c)), \forall i \in I, \forall c \in C \quad (1)$$

where variables u and v are binary variables, where $u, v \in [0, 1]$, and $u \neq v, \forall c \in C$.

V. RESULTS AND ANALYSIS

The implementation of a distribution network architecture comprising 52 participants, categorized as 30 consumers, 10 prosumers equipped with PV systems, 10 prosumers possessing both PV systems and BESSs, and 2 prosumers with EVs and solar PV systems. The prosumers, on average, maintained PV systems with a capacity of 6 kW and BESS units with an inverter of 12.5 kW and an average size of 3.3 kW. For reference, Fig. 3 [31-32] illustrates the average load profiles of each type of participant, along with the average PV generation data. The P2P trading within the distribution network framework was conducted within the context of Singapore, with trading occurring at 30-minute intervals. Smart contracts for an EVM-based blockchain are authored in the REMIX IDE using Solidity programming language [33] and underwent testing on the Ganache CLI version 6.12.2. The web3.py library facilitated the connection between the smart contract and user interface, as well as the blockchain database. These smart contracts for SOL blockchain are written in Rust programming language. SOL's SDK and libraries, including SOL Web3.js, are used to facilitating the development and deployment of smart

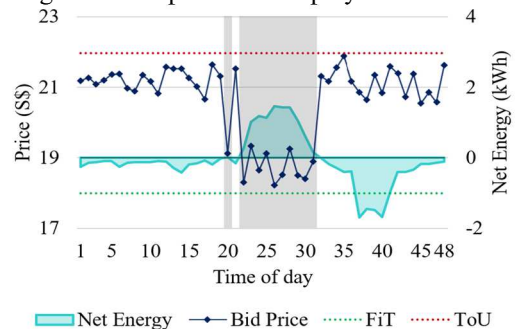


Fig. 4. Bidding strategy of a prosumer for a day.

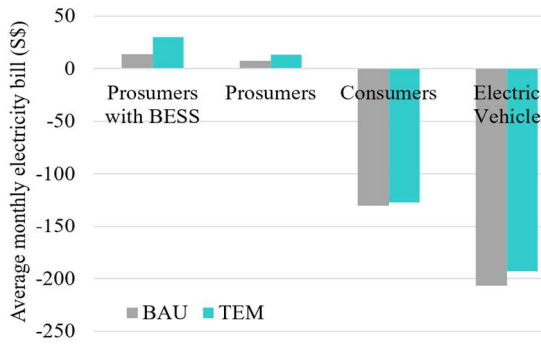


Fig. 5. Participants electricity bill savings comparison.

contracts. A local SOL blockchain network was created using SOL's built-in tools to emulate the SOL main net.

Fig. 4 displays a daily energy profile and the bidding prices set by a prosumer. During the morning and evening periods when the net energy (generation - load) is negative, prosumers buy energy to meet their load requirements. Consequently, the prosumer's bidding price is positioned below the energy component of the grid's ToU purchase price. In the afternoon, when the net energy is positive, as indicated by the shaded region in Fig. 3, prosumers can sell their surplus energy. Therefore, prosumers submit selling bids on their excess energy at a rate higher than the FiT rate.

A. Participants' electricity cost reduction

Fig. 5 presents data on the average monthly electricity bill savings for distinct groups, namely consumers, prosumers equipped with PV systems, prosumers possessing both PV systems and BESSs and EV, across two scenarios: BAU and the distribution network. In the distribution network scenario, all participants are benefitting, where prosumers and prosumers with BESS are increasing their revenue and consumers and EV are reducing their electricity bills. Specifically, the increase in revenue for prosumers and prosumers with BESS amounts to S\$6 and S\$16. The reduction in electricity bills for consumers and EV owners amounts to S\$2.7 and S\$13.7 over the course of a month. It is important to note that all participants realize an electricity bills savings, with those who have made larger investments in DERs experiencing the most substantial benefit.

B. Transaction Energy Market Supports Market Operators

Fig. 6 illustrates the profiles of electricity import and export for the examined network across three distinct scenarios: BAU without BESS (referred to as Case-A), BAU with BESS (referred to as Case B), and distribution network with BESS (referred to as Case C). Compared to the BAU

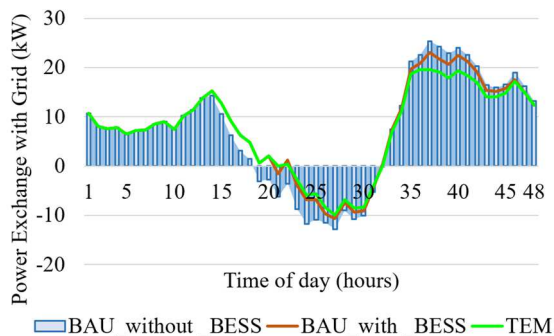


Fig. 6. Grid import and export reduction through distribution network.

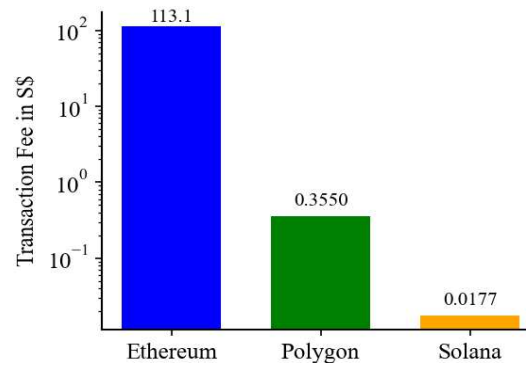


Fig. 7. Transaction cost.

scenario, the proposed distribution network demonstrates a noteworthy reduction in the peak power sold to and bought from the power grid during the afternoon and evening hours, amounting to 21.9% and 22.6%, respectively. This reduction can be attributed primarily to the implementation of P2P contracts within the distribution network framework.

C. Gen3 Blockchain Supports the Local Community

It is essential to consider the costs and speed of using blockchain. It is very important to know about the total number of transactions within distribution network. Bidding and settlement records are systematically recorded on the blockchain at the end of each bidding time interval. Ethereum operates at a gas price of 10 GWEI, while Polygon uses 80 GWEI. The market prices of ETH, MATIC, and SOL are 2,093 S\$, 0.68 S\$, and 31.46 S\$, respectively [34]. The daily transaction fee for storing energy transaction data, displayed in Fig. 6, differs significantly among different blockchain networks. Ethereum transactions cost about 113 S\$, whereas Polygon offers a more cost-efficient alternative at around 0.35 S\$, and SOL stands out as the most cost-effective option with a mere 0.017 S\$.

In terms of transaction speed, Ethereum processes 30 transactions per second, while Polygon boasts 7000 transactions per second, and SOL leads with an impressive 65,000 transactions per second. The time required by each blockchain to process and validate all transactions for each time interval is shown in Fig. 7, and it shows remarkable disparities: Ethereum takes 1.64 seconds, Polygon a swift 0.007 seconds, and SOL an exceptionally rapid 0.00075 seconds. These findings underline the substantial differences in transaction costs and processing speeds among these blockchain platforms.

The insights provided by Fig. 7 and Fig. 8 highlight the notable disparities in transaction cost and speed among the Ethereum, Polygon, and SOL blockchain platforms. Polygon

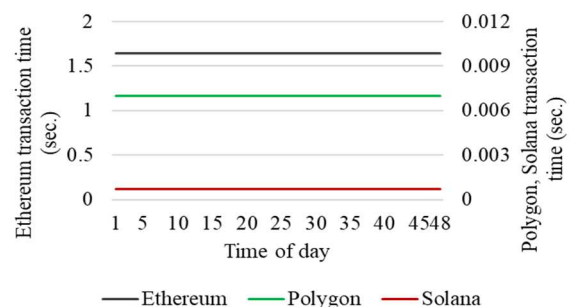


Fig. 8. Transaction time.

has 300 times lower transaction costs and approximately 200 times faster transaction speeds than Ethereum. SOL is approximately 6,000 times cheaper and 2,000 times faster than Ethereum. Furthermore, SOL offers exceptional value compared to Polygon, with transaction costs that are approximately 20 times lower and processing speeds that are approximately 9 times faster. In projects characterized by high transaction volumes and frequent interactions, such as the distribution network, SOL emerges as the optimal choice, offering unparalleled affordability and speed to meet the demands of such endeavours.

VI. CONCLUSION

The development of a blockchain-powered platform for the distribution network has been undertaken, facilitating the regular trading of energy among diverse users. Importantly, this trading has occurred within the constraints of technical and operational considerations, encompassing aspects like power equilibrium, pricing dynamics, and the operational capabilities of BESS and EV. Notably, all stakeholders, including the DSO, are confirmed to gain financially from their involvement in this initiative.

The results underscore that the proposed distribution network framework offers significant advantages to its participants, particularly benefiting those with substantial investments in DERs assets. Prosumers and prosumers with BESS experience an increase in revenue amounting to S\$6 and S\$16 respectively. Furthermore, consumers and EV owners witness a reduction in electricity bills totaling S\$2.7 and S\$13.7 respectively over the span of a month. The incorporation of BESS has successfully diminished the gap between maximum grid export and import, resulting in reductions of 21.9% and 22.6% respectively. This decrease has been accomplished through the strategic control of charging and discharging cycles at predetermined intervals.

A comparative analysis highlights the significance of Gen3 blockchain technology, emphasizing its capacity to accelerate and improve throughput within distribution networks. Gen3 blockchain guarantees secure and swift P2P energy trading, delivering advantages to various stakeholders, including consumers, PV owners, BESS users, and EV owners. Such blockchain implementations are essential for the broader acceptance of transactive energy technologies.

VII. FUTURE WORKS

Future research avenues may concentrate on expanding the capabilities of the trading market by incorporating more sophisticated attributes. These could include dynamic operating envelopes, network support services, dynamic connections, and enhanced distribution network visibility. Such advancements aim to amplify the advantages for all stakeholders engaged in energy trading. Additionally, forthcoming studies will delve into network challenges, real-time operational aspects, and insights gleaned from the technological adoption of energy trading.

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REFERENCES

- [1] C. Liu and Z. Li, "Comparison of centralized and peer-to-peer decentralized market designs for community markets," *IEEE Transactions on Industry Applications*, vol. 58, no. 1, pp. 67–77, Jan.-Feb. 2022.
- [2] H. Yao, Y. Xiang, S. Hu, G. Wu, and J. Liu, "Optimal prosumers' peer-to-peer energy trading and scheduling in distribution networks," *IEEE Transactions on Industry Applications*, vol. 58, no. 2, pp. 1466–1477, Mar.-Apr. 2022.
- [3] M.I. Azim, Md. T. Islam, J. H. Rakib, Md. R. Islam, L. Ali, S. Alzahrani, H. Masrur, S.M. Mueeen, "Coalition game theoretic P2P trading in a distribution network integrity-ensured local energy market," *Sustainable Energy, Grids and Networks*, Vol. 36, 2023, 101186, ISSN 2352-4677, <https://doi.org/10.1016/j.segan.2023.101186>.
- [4] Y. Wang, D. Zhang, Y. Li, W. Jiao, G. Wang, J. Zhao, Y. Qiang, and K. Li, "Enhancing power grid resilience with blockchain-enabled vehicle-to-vehicle energy trading in renewable energy integration," *IEEE Transactions on Industry Applications (Early Access)*, doi: 10.1109/TIA.2023.3312639, pp. 1–16, Sep. 2023.
- [5] M. I. Azim, L. Ali, J. Peters, M. H. Shawon, F. R. Tatari, S. M. Mueeen, et al., "A proportional power sharing method through a local control for a low-voltage islanded microgrid", *Energy Rep.*, vol. 8, pp. 51-59, Dec. 2022.
- [6] L. Ali, M. I. Azim, N. B. Ojha, J. Peters, V. Bhandari, A. Menon, V. Tiwari, J. Green, and S. Mueeen, "Balancing usage profiles and benefitting end users through blockchain based local energy trading: A German case study," *Energies*, vol. 16, no. 17, pp. 6315: 1–18, Aug. 2023.
- [7] H. K. Nunna, A. Sesetti, A. K. Rathore, and S. Doolla, "Multiagent-based energy trading platform for energy storage systems in distribution systems with interconnected microgrids," *IEEE Transactions on Industry Applications*, vol. 56, no. 3, pp. 3207–3217, May-Jun. 2020.
- [8] C. Garc'ia-Santacruz, P. J. G'omez, J. M. Carrasco, and E. Galv'an, "Multi P2P energy trading market, integrating energy storage systems and used for optimal scheduling," *IEEE Access*, vol. 10, pp. 64302–64315, Jun. 2022.
- [9] W.-Y. Zhang, B. Zheng, W. Wei, L. Chen, and S. Mei, "Peer-to-peer transactive mechanism for residential shared energy storage," *Energy*, vol. 246, pp. 123204: 1–12, May 2022.
- [10] L. Ali, M. I. Azim, J. Peters, V. Bhandari, A. Menon, V. Tiwari, et al., "BESS-facilitated local energy market: A case study on typical Australian consumers", *Proc. IAEE Int. Conf.*, pp. 1-2, Jul./Aug. 2022.
- [11] H. Sahebi, M. Khodoomi, M. Seif, M. Pishvae, and T. Hanne, "The benefits of peer-to-peer renewable energy trading and battery storage backup for local grid," *Journal of Energy Storage*, vol. 63, pp. 106970: 1–11, Jul. 2023.
- [12] A. S. Akhter, T. Z. Arnob, E. B. Noor, S. Hizal, and A.-S. K. Pathan, "An edge-supported blockchain-based secure authentication method and a cryptocurrency-based billing system for P2P charging of electric vehicles," *Entropy*, vol. 24, no. 11, pp. 1644: 1–19, Nov. 2022.
- [13] S. Deacon, G. Taylor, and I. Pisica, "Peer-to-peer energy transactioning—a DSO-centric proposal," in *International Universities Power Engineering Conference*, Middlesbrough, United Kingdom, pp. 1–6, Aug. 2021.
- [14] L. Ali, V. Bhandari, J. Peters, W. Tushar, S. Nizami, A. Menon, V. Tiwari, J. Green, and T. Saha, "Discover How You Can Save Money and Help the Environment with Local Energy Markets: An Australian Case Study!," *Smart Energy Council, Industry Updates, Press Releases*, 1–4, 2023.
- [15] H. Sheng, C. Wang, X. Dong, K. Meng, and Z. Dong, "Incorporating P2P trading into DSO's decision-making: A DSO-prosumers cooperated scheduling framework for transactive distribution system," *IEEE Transactions on Power Systems*, vol. 38, no. 3, pp. 2362–2375, May 2023.
- [16] D. Botelho, L. de Oliveira, B. Dias, T. Soares, and C. Moraes, "Integrated prosumers-DSO approach applied in peer-to-peer energy and reserve tradings considering network constraints," *Applied Energy*, vol. 317, pp. 119125: 1–11, Jul. 2022.

- [17] L. Ali, V. Bhandari, J. Peters, and J. Green, "How Local Energy Markets Benefit Distribution Utilities," *Powerledger, Whitepaper Revision 1*, 1-34, 2023, <http://dx.doi.org/10.13140/RG.2.2.23163.69925>.
- [18] M. Mehdinejad, H. Shayanfar, and B. Mohammadi-Ivatloo, "Peer-to-peer decentralized energy trading framework for retailers and prosumers," *Applied Energy*, vol. 308, pp. 118310: 1–13, Feb. 2022.
- [19] K. F. R. Tatari, H. Bizhani, S. M. Muyeen, L. Ali and P. Sanjeevikumar, "A Game Theory Based Optimal Planning for a Hybrid Energy System Considering Time of Use Tariffs," 2022 4th Global Power, Energy and Communication Conference (GPECOM), Nevsehir, Turkey, 2022, pp. 552-557, doi: 10.1109/GPECOM55404.2022.9815742.
- [20] G. C. Okwuibe, T. Brenner, P. Tzscheuschler, and T. Hamacher, "Survey and analysis of local energy markets based on distributed ledger technologies," *IEEE Access*, vol. 11, pp. 23771–23791, Mar. 2023.
- [21] D. Zhang, Z. Zhang, L. Chen, S. Li, Q. Huang, and Y. Liu, "Blockchain technology Hyper-ledger framework in the internet of energy," in Proc. of the International Conference on Renewable Energy Technologies, Kuala Lumpur, Malaysia, pp. 16–18, Jan. 2018.
- [22] L. Ali et al., "Integrating Forecasting Service and Gen2 Blockchain Into a Local Energy Trading Platform to Promote Sustainability Goals," in *IEEE Access*, vol. 12, pp. 2941-2964, 2024, doi: 10.1109/ACCESS.2023.3347432.
- [23] J. Kang, R. Yu, X. Huang, S. Maharjan, Y. Zhang, and E. Hossain, "Enabling localized peer-to-peer electricity trading among plug-in hybrid electric vehicles using consortium blockchains," *IEEE Transactions on Industrial Informatics*, vol. 13, no. 6, pp. 3154–3164, Dec. 2017.
- [24] L. Ali et al., "P2P as a Smarter Way of Energy Trading: A Game Theoretic Case Study for Multi-microgrids," 2022 10th International Conference on Smart Grid (icSmartGrid), Istanbul, Turkey, 2022, pp. 285-289, doi: 10.1109/icSmartGrid55722.2022.9848556.
- [25] Iskakova, H. K. Nunna, and P. Siano, "Ethereum blockchain-based peer-to-peer energy trading platform," in Proc. of the IEEE International Conference on Power and Energy, Penang, Malaysia, pp. 327–331, Dec. 2020.
- [26] L. Ali et al., "Blockchain-Based Local Energy Market Enabling P2P Trading: An Australian Collated Case Study on Energy Users, Retailers and Utilities," in *IEEE Access*, vol. 10, pp. 124429-124447, 2022, doi: 10.1109/ACCESS.2022.3224936.
- [27] S. K. Rana, A. K. Rana, S. K. Rana, V. Sharma, U. K. Lilhore, O. I. Khalaf, and A. Galletta, "Decentralized model to protect digital evidence via smart contracts using layer 2 Polygon blockchain," *IEEE Access*, vol. 11, pp. 83289 – 83300, Aug. 2023.
- [28] L. Ali, M. I. Azim, J. Peters, S. Padmanaban, V. Bhandari, A. Menon, J. Green, and S. Muyeen, "Singapore Local Energy Market Development Using Blockchain Enabled P2P Trading," 2023 IEEE 14th International Conference on Power Electronics and Drive Systems (PEDS), Montreal, QC, Canada, 2023, pp. 1-6, doi: 10.1109/PEDS57185.2023.10246687.
- [29] "SOL: A new architecture for a high performance blockchain v0.8.13." [Online]. Available: <https://SOL.com/SOL-whitepaper.pdf>.
- [30] "Understanding the Tariff" [Online]. Available: <https://www.spgroup.com.sg/sp-services/understanding-the-tariff>, (Accessed: 07-March-2023).
- [31] "AusGrid residential data Dec 2013." [Online]. Available: <https://www.ausgrid.com.au/Industry/Our-Research/Data-to-share/-home-electricity-data>, (Accessed: 07-March-2023).
- [32] L. Ali et al., "A Win-Win Local Energy Market for Participants, Retailers, and the Network Operator : A Peer-to-Peer Trading-driven Case Study," 2022 IEEE 20th International Conference on Industrial Informatics (INDIN), Perth, Australia, 2022, pp. 175-179, doi: 10.1109/INDIN51773.2022.9976167.
- [33] "REMIX" [Online]. Available: <https://remix.ethereum.org/#lang=en&optimize=false&runs=200&evmVersion=null&version=soljson-v0.8.18+commit.87f61d96.js>, (Accessed: 06-November-2023).
- [34] "Explore the cryptoeconomy" [Online]. Available: <https://www.coinbase.com/explore>, (Accessed: 07-October-2023).