Smart Grid Energy Trading using Peer-to-Peer Blockchain Technology.

Nasim Ahmed
Institute of Information & Communication Technology
Bangladesh University of Engineering and Technology
Dhaka-1000, Bangladesh
nasimahmed@pg.iict.buet.ac.bd

Md. Ziaur Rahman Khan
Electrical and Electronic Engineering
Bangladesh University of Engineering and Technology
Dhaka 1000, Bangladesh.
zrkhan@eee.buet.ac.bd

***Abstract*— The convergence of blockchain, distributed renewable energy, and IoT has given rise to the possibility of a decentralized energy trading market. This presents opportunities for prosumers and consumers to engage in peer-to-peer energy exchange. In this paper, we propose a design for blockchain-based P2P energy trading in a smart grid. Our system is centered around a single-phase grid-connected inverter-based smart grid that delivers 220V and 50Hz output. We utilize IoT and blockchain technologies to facilitate energy trading. The inverter is designed using the sinusoidal pulse width modulation (SPWM) technique, and grid connectivity is established through the phase control technique. The inverter section is implemented in MATLAB, while the IoT and blockchain sections are developed using the python programming language.**

Keywords—blockchain, peer-to-peer (P2P), energy trading, inverter, internet of things (IoT), smart grid.

I. INTRODUCTION

The use of distributed generation (DG) in electric power systems has proliferated in recent years due to a variety of technical, ecological, and economic benefits. Renewable sources will account for roughly 30% of global power generation by 2022 [1]. Low-cost renewable energy sources such as solar and wind harvesting devices, as well as demand for electronic smart appliances, are on the rise. Electric vehicle adoption is also increasing, resulting in a higher standard of living. In traditional power grids, energy is produced by massive energy plants with megawatt output located in distant regions and delivered to end-user customers via the utility network over a long distance. Electricity flows from suppliers to customers, while revenues in the opposite direction. In the traditional energy supply and marketing system, both energy and cash move in one way. In recent years, the energy business has shifted to a decentralized paradigm as a result of information technology advancements, and distributed renewable technologies have progressed [2]. The number of prosumers and consumers in the distributed energy trading market is enormous in a free energy trading environment, where each prosumer has complete control over the power-producing equipment. Both prosumers and consumers look for greater equality, security, and the absence of discrimination. A large number of conventional centralized trades face immense challenges in fulfilling the requirements of energy trading fairness and data safety [3].

Blockchain technology utilizes asymmetric cryptography like public-private key (PKI) infrastructure, merkel tree, proof of work (PoW), consensus algorithm, hash function, and other technologies to allow trade data in a distributed system to be verified, identifiable, and spoofing proof stored. It is effectively a succession of block lists, with each block containing all transaction details for a specified time [4]. Confidentiality, transaction tracking, smart contract, and other components of blockchain systems satisfy the requirements of a trustworthy technology that supports data authentication, authorization, and in-transit data security in distributed energy platforms. Based on cryptographic concepts, blockchain ensures the entire transaction process is explicit, secured, fully automated, and avoids several problems of centralized marketing, such as ineffectiveness, excessive costs, and lack of clarity [5].

II. RELATED WORK

Many works have been reported on blockchain-based P2P energy trading. Though P2P energy trading has been implemented by IoT and blockchain in [6], it is developed by using the internet and a basic electrical circuit without a considering community microgrid-based trading system. While IoT and blockchain have been used to establish P2P energy trading in [7], it also has been designed by a rudimentary electrical circuit without taking into account microgrid architecture and lacks the details of PKI, hashing, and PoW algorithms. Through detailed analysis of smart contract of blockchain-based power trading has been done [8] for a smart grid environment via Southern California Edison's (SCE) 56-bus test feeder deploying wireless networks, the authors have not mentioned the registration process of wireless nodes, wireless security analysis, the PKI, hashing, and PoW algorithms of this work. Through meticulous investigation of market mechanism and microgrid system has been done in [9-10], the core components of blockchain such as PoW, consensus algorithms, the number of participating nodes and their registration process, security experiment, grid constraint, and optimization are not covered.

The paper proposed blockchain-based P2P energy trading implementation in a desired truly private P2P network, implementing POW, consensus, registration of participating IoT nodes in a microgrid architecture with inter-community and intra-community energy trading using grid-connected inverters.

III. SYSTEM DESIGN

A. Grid Connected Inverter

To eliminate the transformer and achieve high efficiency (90%) in the circuit, the input voltage has been selected to 400V. To get the angle of grid voltage, a phase-locked loop (PLL) has been employed. Since one input of PLL has been zero voltage, the output of PLL has been taken as the angle of grid voltage. H-bridge topology has been chosen for this inverter circuit. To drive the MOSFET switches of this topology, a controller has been designed to produce a dynamic SPWM signal according to PLL output. To synchronize the inverter output voltage, the modulation index is multiplied with dynamically developed SPWM parameters to obtain the precise magnitude of the output voltage. Finally, in this design, a low pass filter such as an LC filter has been used [11]. Fig. 1 illustrates the block diagram of the proposed inverter and Table 1 represents the various parameters used to build this inverter in this experiment.

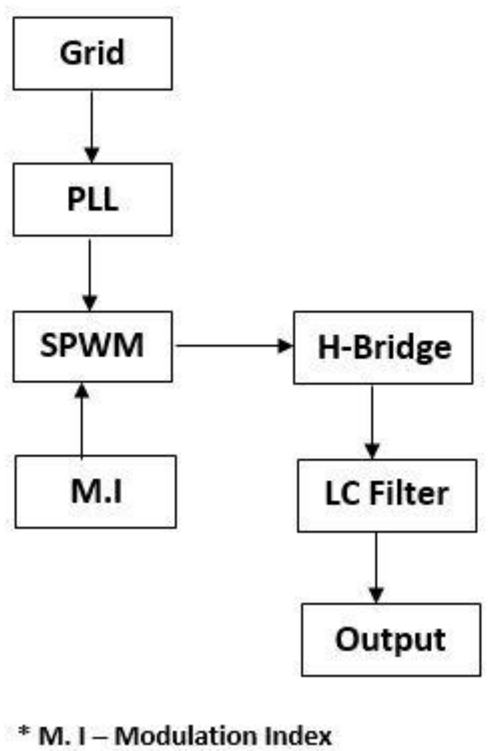

Fig. 1. Block diagram of Grid Connected Inverter.

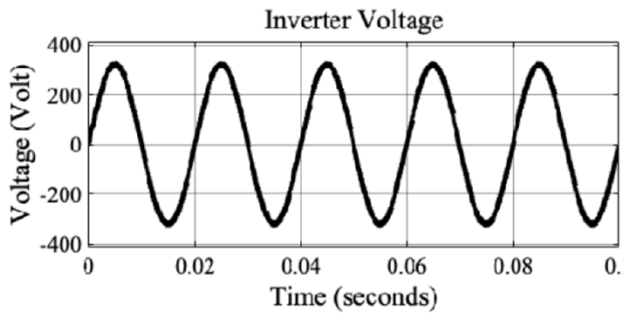

Fig. 2. Inverter output voltage.

TABLE I. TABLE OF PARAMETERS OF GRID-TIE INVERTER

	Parameter Name	Value
1.	Input Voltage	400V
2.	Modulation Index	80%
3.	Efficiency	90%
4.	Power rating	1KVA
5.	Total Harmonics distortion (Voltage)	2.80%
6.	Total Harmonics distortion (Current)	2.40%
7.	SPWM Frequency	3KHz
8.	PLL Frequency	10KHz
9.	Output Voltage	220V
10.	Output Frequency	50Hz
11.	Filter Inductor	177mH
12.	Filter Capacitor	10uF

B. Grid Connectivity

The suggested system uses the phase control technique for grid connectivity with islanding detection facility. The method can be shown in equations 1 and 2, where V_g and V_{inv} are shown as grid and inverter voltage and difference of phase angle is shown by delta.

$$P = \frac{V_{inv}V_g}{\omega L}\sin\delta \qquad (1)$$

$$Q = \frac{(V_{inv} - V_g)\,V_g}{\omega L} \qquad (2)$$

To provide active current to the grid, the inverter must provide an output voltage that is equal to the grid voltage but at a little angle difference. This active current can be multiplied or reduced by altering this angle. The inverter must induce a greater voltage than that of the grid voltage to feed the lagging current to the grid, but both phase angles must be matched. The inverter must create a smaller voltage than that of the grid voltage to feed the leading current to the grid, but both phase angles must be synced [12].

C. System Diagram

The grid-tied inverter based power network and blockchain network of this work have been depicted in Fig. 3. Every islanded microgrid has four components. They are inverter based distributed power generation, local load smart meter and circuit breaker. The distributed generation (DG) and local loads are represented by renewable energies like wind or solar energy and household load. Smart meters have the ability to run blockchain-based programs. Finally the microgrid has been connected by Circuit breaker.

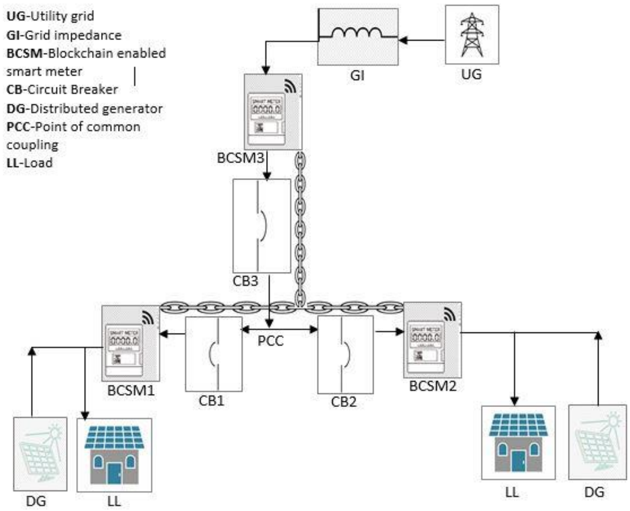

Fig. 3. System Architecture.

D. IoT Section

Both the IoT and blockchain system of the proposed architecture has been implemented in python language. Since the code is composed in Python, it is compatible with a wide range of operating systems, including Windows, Linux, and Mac. The program codes are also tested in raspberry pi, which is popularly known as a single-board microcomputer. This raspberry pi eventually has been chosen as a smart meter. The microcontroller-based inverter has been connected by raspberry pi through USB to TTL converter. The IP address of the raspberry pi is used to view the inverter output voltage, current, and other parameters. The suggested solution has been verified respectively private and public networks [13].

E. Blockchain

A blockchain is a continuous set of data, referred to as blocks, that are cryptographically linked all together. A cryptographic hash of the preceding block, as well as a timestamp and transaction data, are included in each block. Since each block includes data about the one before it, they form a network, with each new block reinforcing the preceding ones. As an outcome, blockchains are immune to data manipulation since, once logged, the data in any one block cannot be modified later without impacting all following blocks. Fig. 4 shows the block creation process of the proposed blockchain.

1) Blocks: Every block of this blockchain has been comprised of five elements. They are index, timestamp, transactions list, proof of work, and previous block hash.

a) Index: Though it is not mandatory, it is very helpful to track the block having a sequence number or an index of a block.

b) Timestamp: The timestamp ensures that the transaction data was present when the block was created, enabling it to be encrypted. To track a block, the timestamp of the block creation is a mandatory element. The proposed system uses the time module of the python library.

c) Transaction: Transactions or data of blockchain consist of the following key terms sender, receiver, energy-consumption, unit-price, credit, event, sell, buy, time-duration, etc. This transaction list has been implemented in python by using a popular data type called a dictionary.

d) Proof of Work (POW): To protect the system from being compromised, POW is a decentralized consensus approach that involves network participants to bother completing an unpredictable mathematical puzzle. Proof of work is often used in bitcoin mining to inspect, validate, and create new coins. Because of proof of work, Bitcoin and other cryptocurrency transactions can be analyzed securely peer-to-peer, eliminating the need for a trusted third party. The puzzle must be feasible but relatively complex on the prover or requester side but simple to verify on the verifier or service provider side. To solve this puzzle, prover needs a significate amount of CPU power. A simple POW has been implemented in this project. To make a block, a node must try to solve the mystery of the first four digits of the hashing result of string catenation of previous proof, predicted proof, and previous hash which must all be zero.

e) Previous Block Hash: The last and final element of the block is the previous block hash. In this section, a function takes a previous element block, cryptographic hashes it, and is added to the block as a dictionary element of python. Sha256 hashing algorithm has been used in the proposed system. The SHA-256 method is a variant of the SHA-2 (Secure Hash Algorithm 2) algorithm, that was developed by the National Security Agency in 2001 as a replacement for SHA-1. The SHA-256 encryption technique is a proprietary method that produces a result of 256 bits. Encryption puts data into a secure format that can only be viewed by someone who has the key. Data of any size is mapped to data of a fixed size in hashing. Cryptographic hashing alters encoded data in a format that it is no longer understandable. The most common purpose is to double-check private data content.. Hashes are used to validate digital signatures similarly.

2) Consensus Algorithm: It is otherwise known as the resolving conflicts method of blockchain. It denotes the rules and regulations of the blockchain. The price of per unit energy, transportation loss, transformer core loss, copper loss, and demand charge has been discussed and coded previously among nodes.

3) Genesis Block: The first block of the blockchain is called the genesis block. It is a special block because there is no previous block, or previous block hash and PoW values. So, it is created by a consensus algorithm, where the previous block hash and PoW have been taken as some random values.

4) Nodes: The participating parties are called nodes. The communication between nodes are done by asymmetric encryption method. Every node use its own private key to digital signed in block, so it ensure transit layer security. RSA algorithm, presently one of the most popular encryption method, has been chosen in this experiment. Its base is the Prime Factorization method. RSA requires large keys to achieve a secure level of encryption security. Like blockchain, SSL/TLS certificates, cryptocurrencies, email encryption, and a variety of other applications are also employ this algorithm. Because RSA is an asymmetric cryptography technique, it has two separate keys: the public key and the private key. The public key is distributed to everyone, but the private key is kept secret. The public and private keys are both created by multiplying two huge prime numbers. The encryption strength will be exponentially boosted if the key size is doubled or tripled. The length of an RSA key is typically 1024 or 2048 bits.

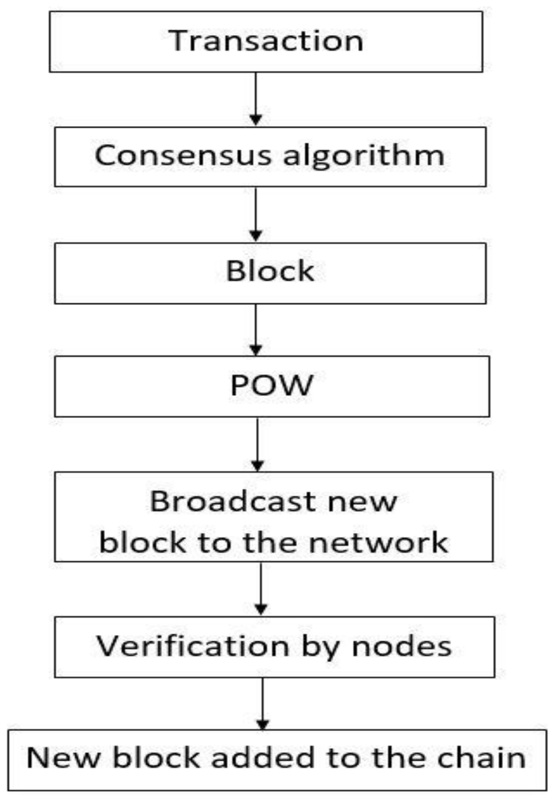

Fig. 4. Block creation process.

IV. RESULT

In the genesis block, the PoW and the previous hash value are taken as 100 and 1. The next two blocks are created by node1 after solving the PoW values. The third block is created by Grid-node by getting the next PoW value. The third block confirms the node1's money transfer from Grid to node1 wallet. Table 2 shows the first four blocks' details of this blockchain including transactions and Table 3. shows the PoW values of the top six blocks in three iterations, which ensures the randomization nature of the proposed puzzle. This mystery remains unpredictable even if the system has been hacked.

TABLE II. BLOCK DETAILS

	Genesis Block	**Block 2**	**Block 3**	**Block 4**
Index	1	2	3	4
Previous Hash	1	e66b1..	028861..	01072e846..
PoW	100	90966	25665	6500
Timestamp	16509…	165094..	1650947	16509477
Transaction	--	{'event': 'start', 'receiver': 'Grid', 'sender': 'DG-1'}	{'event': 'stop', 'receiver': 'Grid', 'sender': 'DG-1'}	{'amount': '10 taka', 'duration': '60 min', 'power': '1kw', 'receiver': 'DG-1', 'sender': 'Grid', 'unit_price': '10 taka'}

TABLE III. POW VALUES IN DIFFERENT ITERATION.

block	**1st iteration**	**2nd iteration**	**3rd iteration**
1	100	100	100
2	20700	45272	20068
3	65906	93730	3814
4	53104	16545	320293
5	30388	7732	49418
6	212101	40795	17103

V. CONCLUSION

The suggested peer-to-peer energy trading mechanism features a novel and straightforward design. The proposed scheme is user-friendly, open-source, and has the potential to boost productivity and competitiveness when compared to the conventional energy trading systems. The contemporary P2P energy trading systems mostly concentrate on software-based monetary transactions. However, the developed scheme in this research not only addresses the economic tasks of blockchain technology but also introduces a hardware structure of grid-connected inverter that can directly supply energy to the grid with IoT functionality for real-time transferring energy in order to gain economic advantages, as blockchain provides a stable and trustworthy system for financial activities. The inverter based grid architecture is simulated in a MATLAB environment and the IoT and blockchain parts are developed by python language. A self-designed blockchain network has been investigated rather than using a framework. The designed system offers a complete open-source approach for P2P energy trading, including energy transmission, metering, and payment transfer.

REFERENCES

[1] "IEA – International Energy Agency," IEA. [Online]. Available: https://www.iea.org/. [Accessed: 19-Apr-2022].

[2] J. Ferreira and A. Martins, "Building a Community of Users for Open Market Energy," *Energies*, vol. 11, no. 9, p. 2330, Sep. 2018, doi: 10.3390/en11092330.

[3] J. Conti, P. Holtberg, J. Diefenderfer, A. LaRose, J. T. Turnure, and L. Westfall, "International energy outlook 2016 with projections to 2040," Office of Scientific and Technical Information (OSTI), 2016.

[4] M. J. Fell, A. Schneiders, and D. Shipworth, "Consumer Demand for Blockchain-Enabled Peer-to-Peer Electricity Trading in the United Kingdom: An Online Survey Experiment," *Energies*, vol. 12, no. 20, p. 3913, Oct. 2019, doi: 10.3390/en12203913.

[5] T. Li, W. Zhang, N. Chen, M. Qian, and Y. Xu, "Blockchain Technology Based Decentralized Energy Trading for Multiple-Microgrid Systems," in *2019 IEEE 3rd Conference on Energy Internet and Energy System Integration (EI2)*, Changsha, China, Nov. 2019, pp. 631–636. doi: 10.1109/EI247390.2019.9061928.

[6] M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "IoT and Blockchain Based Peer to Peer Energy Trading Pilot Platform," in *2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, Vancouver, BC, Canada, Nov. 2020, pp. 0402–0406. doi: 10.1109/IEMCON51383.2020.9284869.

[7] M. Jabbar Aziz Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Peer-to-Peer Energy Trading in a Micro-grid Using Internet of Things and Blockchain," *ELS*, vol. 25, no. 2, pp. 39–49, Dec. 2021, doi: 10.53314/ELS2125039B.

[8] Z. Liu, D. Wang, J. Wang, X. Wang, and H. Li, "A Blockchain-Enabled Secure Power Trading Mechanism for Smart Grid Employing Wireless Networks," *IEEE Access*, vol. 8, pp. 177745–177756, 2020, doi: 10.1109/ACCESS.2020.3027192.

[9] A. Paudel, K. Chaudhari, C. Long, and H. B. Gooi, "Peer-to-Peer Energy Trading in a Prosumer-Based Community Microgrid: A Game-Theoretic Model," *IEEE Trans. Ind. Electron.*, vol. 66, no. 8, pp. 6087–6097, Aug. 2019, doi: 10.1109/TIE.2018.2874578.

[10] C. Long, J. Wu, Y. Zhou, and N. Jenkins, "Peer-to-peer energy sharing through a two-stage aggregated battery control in a community Microgrid," *Applied Energy*, vol. 226, pp. 261–276, Sep. 2018, doi: 10.1016/j.apenergy.2018.05.097.

[11] N. Ahmed and Z. R. Khan, "A Single-Phase Grid-Connected Inverter using Phase Control Method," 2021 IEEE International Conference in Power Engineering Application (ICPEA), 2021, pp. 183-187, doi: 10.1109/ICPEA51500.2021.9417760.

[12] N. Ahmed and M. Z. R. Khan, "Logistic Regression based Islanding Detection for Grid-Connected Inverter," 2021 IEEE Kansas Power and Energy Conference (KPEC), 2021, pp. 1-4, doi: 10.1109/KPEC51835.2021.9446257.

[13] N. Ahmed and M. Z. R. Khan, "A Secure IoT Based Grid-Connected Inverter using RSA Algorithm," 2021 31st Australasian Universities Power Engineering Conference (AUPEC), 2021, pp. 1-5, doi: 10.1109/AUPEC52110.2021.9597724.