Peer-to-Peer Energy Trading in a Micro-grid Using Internet of Things and Blockchain

Mirza Jabbar Aziz Baig, M. Tariq Iqbal, Mohsin Jamil and Jahangir Khan

***Abstract*——With advancements in renewable energy technologies, consumers are becoming prosumers, and renewable energy resources are being used in distributed networks. In an isolated distributed system, peer-to-peer (P2P) energy trading is one of the most promising energy management solutions. In this paper, we propose a P2P energy trading method for micro-grids using open resources and technology. The proposed setup comprises an Internet of Things (IoT) server to transfer energy amongst the peers without human intervention, and an Ethereum based private blockchain is suggested for money transfer in the form of cryptocurrency. The IoT server enables the peers to control and monitor self-produced energy. Arduino UNO, ACS 712 hall-effect current sensor, and a relay are the main components used in the hardware setup. The current sensor data is sent in real-time to Arduino for onward communication to the IoT server. A user-friendly interface has been developed on the server to perform various energy trading tasks. Peers have the choice to access the server remotely to perform energy trading tasks. The energy trading events can be shared amongst peers through e-mail notifications. For financial transactions, we utilized Ganache graphical user interface (GUI) a private Ethereum blockchain eliminating the need for financial institutions. The proposed peer-to-peer energy trading model has been successfully tested for energy trading between two peers. This paper provides details of the proposed hardware and software setup and explains how low-cost P2P energy trading can be achieved.**

***Index Terms* Keywords—Blockchain, Energy Trading, Ethereum, Internet of Things (IoT), Micro-grid, Peer-to-peer (P2P), Smart Contract.**

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I. Introduction

INCREASING demand of electric vehicles (EV), use of smart appliances and higher living standards may increase the demand for electrical energy by 20% in the next decade [1]. In recent years, increased utilization of renewable energy sources (RES) has been seen worldwide. By 2022, renewable energy will be around 30% of world's energy production [2]. To meet the electricity demand and reduce greenhouse gas emissions, countries around the globe are focusing on renewable energy sources such as solar and wind [4]. The rise in prosumers (buyers and sellers) has been witnessed because of less expensive renewable energy technologies. Interest has been high to sell or share self-produced energy within communities [3].

In conventional power systems, power is produced by larger power plants with megawatts capacity situated in distant regions and sent to end-use customers over a significant distance by the utility network. The electrical energy goes from the producers to the consumers, and the cash flow goes the other way. The flow of both energy and cash is unidirectional in the conventional system of energy transmission and trading. In recent years, the energy industry is switching towards the decentralized model as information technology, and the distributed energy technologies have been further developed [5]. At present, energy is produced at larger scales by conventional energy production methods such as hydropower, natural gas, coal etc., causing huge environmental deterioration and high transmission losses.

In the case of renewable energy sources, the consumers can control their power consumption and production. The energy trading between the prosumers and consumers without the involvement of any third party is called peer-to-peer P2P energy trading. The prosumers and consumers here are referred to as peers. It also means that the peers are trading amongst themselves, and they do not rely on any mediator. Energy market prices are usually set on the national level. While in P2P energy trading, the participants have the liberty to set the prices themselves. The basis for P2P energy trading in a distributed network is founded on a shared economy model [6].

The IoT platform facilitates the energy trading process. The advantage of using the IoT platform is that it minimizes human intervention. In traditional energy trading networks, the energy transactions are unidirectional from a source of energy generation over a long distance, causing transmission loss with a contrary cash flow. On the other hand, P2P energy trading is not unidirectional in terms of both cash and energy transactions [7].

Peer-to-peer (P2P) energy trading became an advanced level of energy management solution for smart grid, which permits peers to participate in electricity market either by reducing their demand or by selling excess energy [8]. P2P energy trading platform enables prosumers to buy or sell energy generally or within a community. P2P energy trading is thought to be an appropriate trading model in microgrids [9].

Blockchain is an open ledger where different peers can connect with each other and are able to perform and verify transactions. Otherwise, considered as an accounting record system, blockchain keeps the details of all the transactions without allowing any interference. These transactions are based on smart contracts [10]. Blockchains are distributed data arrangements used to store digital transactions with no central authority. They can allow numerous users at a time to make changes to the ledger without requiring any central authority. Every participant has access to the records' chain in the blockchain network. All the new transactions are linked with the previous transaction with cryptograph making it more adaptable and secure. Every network participant can confirm the validity of the transactions in blockchain which authenticate the transparent, tamper proof and trustable transactions [11].

In this paper, we propose an IoT-based energy trading platform associated with blockchain-based financial transactions. The primary concept is to enable energy trading locally and to get financial incentive in the form of cryptocurrency. The proposed platform is a decentralized platform that allows the peers to connect and trade energy with no involvement of any third party. The proposed IoT and blockchain-based P2P energy trading platform connects the participants using a web-based user interface. The platform can facilitate prosumers in a cost-effective utilization of distributed generation. It is beneficial to both the energy producer and the consumer as the pricing mechanism is based on the negotiations between the peers, which may be lower than the local energy markets. In this particular work, energy trading is considered between two peers only. The seller will be paid depending on the energy export, and the consumer will be charged according to the negotiated price and energy consumed. The IoT platform is used to monitor and control energy export and energy consumption, and the blockchain technology is used for secure and transparent financial transactions.

The significant contribution of this paper is that it covers both the financial side and the technical side of a Peer-to-Peer energy trading platform. As the current published research only address the complex financial solutions of the P2P energy trading systems and ignoring the practical transfer and monitoring of renewable energy. This paper is unique because it provides full implementation details of a P2P energy trading setup. We have provided a complete server setup including electrical side and software implementation. The technical side helps the peers in the physical transfer of electric power, energy metering, and available energy monitoring. At the same time, the financial side is helpful for financial transactions on a secured blockchain network. It also enables the platform participants to decide the price of energy themselves which may be lower than the local energy markets. To the best of our knowledge such information is not found in any publication. The proposed research work is successfully tested, and the results are presented in the following sections of the paper.

II. Related Work

In [5] an IoT and blockchain-based system is proposed. IoT is used to account for power flows, while a blockchain platform eliminates the need for a central authority. The proposed system developed a local energy market to deal with distributed energy transactions and eliminated central authority. In [12], the authors proposed an energy tag (smart contract embedded in the blockchain) system. The IoT applications are used to collect data regarding the energy needs of a consumer or prosumer within a smart home. Based on whether the prosumer has surplus energy to sell, or a consumer wants to fulfill its own energy needs, a purchase or selling tag is established and sent to all members of the platform. The participants who are interested in the energy transaction confirm the energy tag with the original prosumer or consumer. After the transaction becomes valid, the tag is assigned to a block. A ledger is then triggered between the participants involved in that particular transaction once the block is generated and then sent out to all the participants of the energy-transaction platform. The work proposed in [12] furthers categorize pure P2P and hybrid P2P energy trading.

The research work presented in [13] suggests a P2P energy trading system for a Virtual Power Plant (VPP). The authors focused on the financial side using the Ethereum blockchain and smart contract and developed a P2P energy trading and bidding mechanism. The platform addressed cost and security concerns using a public blockchain, and the concept of smart contracts is used for auctions. A blockchain-based bidding platform was developed, and a cryptography testing environment was set up to achieve economic P2P energy trading with efficiency and transparency. The suggested auction-based bidding model interlinks various software, e.g., Solidity, Remix, Metamask, Infuro.io, and Ropsten, to enable a real-life cryptographic environment in blockchain-based energy trading.

In reference [14], the operational costs of alternating current (AC) and direct current (DC) operated electrical devices are evaluated using bill sharing and the mid-market rate method for various levels of PV penetration considering both households and communities. All the peers in the network share the operational cost and income as per the share of energy they generate or consume using a bill-sharing method. Total generation and demand relationships are used in the mid-market rate method to calculate the internal price at the average of export and import price. In another research work (see [15]), the authors recognized seven different microgrid power market standards and evaluated the Brooklyn Microgrid based on those standards. The authors established and shaped a local electricity market with a focus on a private Ethereum blockchain that enables participants to trade self-produced energy on a distributed trading system with no contribution of any central authority.

TABLE I
SUMMARY OF PREVIOUS WORK

Blockchain platform/ Method used	Objective	Proposed approach
Steemit platform, Public blockchain [5]	Prosumers engagement in the energy market. Considered privacy and security of participants, accounting of energy flow.	An IoT (Internet of Things) system to account the energy flows and blockchain approach to eliminate the need for a central control unit.
Smart contract and public blockchain [12]	For efficient electrical energy transaction between prosumers, categorize pure P2P and hybrid P2P energy trading	Proposed an energy tag (smart contract embedded in the blockchain) system
Smart contract and public blockchain [13]	To address cost and security concerns and to achieve efficient, transparent, and economic energy trading	Auction-based bidding mechanisms is introduced
Operational cost comparison [14]	Boost energy trading	Mid-market rate and bill sharing method for different levels of PV penetration.
Private blockchain [15]	Reduce electricity cost in the local market	A decentralized market mechanism using a private blockchain is proposed
Local Energy trading blockchain and renewable energy trading blockchain [16]	To enhance the efficiency of power trading and renewable energy utilization	An energy trading system using blockchain by improving security of wireless networks. Also introduces an incentive mechanism.
Byzantine based blockchain [17]	Enhancement of energy and information data security in trading process between	Byzantine general problem framework is utilized to feature the application of blockchain.
Game-theoretic model [18]	EVs and DN Substantial financial and technical benefits for P2P community	Noncooperative game is used for sellers and for the buyers' evolutionary game theory is applied. Stackelberg game approach to maintain the attraction between the participants

The authors in [16] employed wireless networks to develop a blockchain based secure power trading structure designed for the smart grid. In the proposed system, power data collected by the wireless network is recorded using blockchain, and trading decisions are made using the smart contract. To improve power trading and renewable energy utilization, the authors introduced local energy trading blockchain and renewable energy trading blockchain named dual-chain structure. They also modeled a renewable energy incentive method. The authors proposed the energy trading system using blockchain by employing a wireless network with improved security. Here, issues such as data transmission and single point of failure are addressed in the electricity market. The suggested system performs reliable distributed energy trading without any central party between consumers and prosumers.

In [17], the Byzantine-based blockchain consensus framework is utilized for energy trading amongst EVs and distribution networks (DN). DN begins the energy trading by requiring more power from the EVs for the duration of the peak load period. In this energy trading practice, the blockchain is used to secure the shared energy and information from vulnerable attacks. Byzantine general problem structure is used to feature the application of blockchain. The research work in [18] emphasizes P2P energy trading between the prosumers in a community using a novel game-theoretic platform. The energy needs of the consumer can be adjusted based on the quantity of energy offered by the sellers and the price. The authors considered two different trading competitions: 1) price competition among the sellers; and 2) seller selection competition among the buyers. The price competition between the sellers is designed as a noncooperative game. For the buyers to select the sellers, an evolutionary game theory is applied. Additionally, an M-leader and N-follower Stackelberg game method is employed to shape the interaction between the buyers and sellers. To maintain the equilibrium between the games, two algorithms are suggested. The research shows how P2P energy trading delivers substantial technical and financial benefits to the community, and it appears to be an alternative to cost-intensive energy storage systems. The summary of previous work is presented in table 1.

The latest research work is presented as a part of the literature review in this paper section. All the papers use public blockchain except [15], which uses private blockchain to adopt only bill sharing techniques. None of the papers above is presenting a complete solution for energy trading. The related work shows that the authors benefitted the P2P community by providing accounts of power flow, categorizing P2P and hybrid P2P energy trading, cost analysis, and efficiency of power trading between DN and EVs. Contrarily the proposed Peer-to-Peer energy trading platform gives a state-of-the-art energy trading solution to the P2P community. The peers can monitor and trade energy and get full benefits of blockchain technology in financial transactions on a private blockchain. The system can efficiently perform real-time energy and financial transactions, which is not addressed in published work. The system proposes a complete buying and selling platform including financial transactions which have not been addressed in the previous work.

III. INTERNET OF THINGS (IOT)

Internet of Things (IoT) is a generalized notion of connecting *things* to the internet. It minimizes the human intervention with the *things* and automates them. Ultimately, we can get better service and information. In IoT, we connect humans, objects, etc., to the internet and gather various information for further processing and analysis. Moreover, the IoT comprises actual and virtual objects with their own individual features and is all around incorporated into the data organization. IoT can convey/respond to things, conditions, and information. The things also respond based on the conditions and the information detected. To understand IoT, it is important to utilize sensor, devices and technologies that can incorporate with IoT platforms [19].

IoT devices are primarily used for accumulating data and information from the physical things around to facilitate our daily life. The IoT platforms are also used to control IoT devices remotely and hence increasing the quality of life. IoT communicates with things by utilizing sensors and communication technologies [20], and in response, objects respond autonomously without the involvement of humans, thereby increasing the efficiency. In this way, IoT can play an essential role in the transformation of the energy sector towards decentralization, which, in turn will yield economic benefits to the prosumers or renewable energy producers.

Fig. 1. Internet of things and renewable energy trading

Fig. 1 depicts the IoT connecting different components that are considered important in a P2P energy trading network. IoT platforms can connect different peers to transfer energy in a decentralized network and can manage energy storage and renewable energy resources. They can also be utilized for charging electric vehicles from distributed energy resources. IoT platform provides the peers a decentralized network to monitor and control energy trading sessions.

After navigating through a decade-long journey, IoT technology is currently ushering in various opportunities. Numerous IoT gadgets and modules with multiple communications protocols, computation technologies, and security algorithms have been developed, while others are still in a developing phase. IoT platforms use different communication protocols such as MQTT, CoAP, DDS, XMPP, and HTTP for communication with IoT devices [21]. However, the wired communication protocol can also be used to facilitate communication between the IoT platform and the IoT devices.

IV. Blockchain

Blockchain uses a distributed ledger technology controlled by the participating peers with no involvement of any central authority. The idea of blockchain was hailed through a white paper by Satoshi Nakamoto on October 31st,2008. He presented the concept of an online platform of bitcoin transactions between the participating peers and eliminated the need for a financial institution [20]. In a blockchain, the blocks are assembled in the form of chains, and each block stores the data for all transactions. Each block performs a vital role in linking the earlier block to the next block instantly after the next block appears in the network [20]. All the participants in a network store historical data. These are distributed in a block format, called a set of transactions. Every node has a public and a private key. The participating peers can perform digital signatures on the performed transactions using the hash function and private key. The blocks holding these transactions are organized in the form of chains and are connected without any interruption together with the time flow after being formed. As the blocks are linked in the form of chains, the information stored in the blocks cannot be changed. All the network participants can verify the transactions by accessing the ledger they hold. The transactions without validations cannot be stored in blocks [10]. Hence, the characteristics of blockchain are data integrity, security, and decentralization.

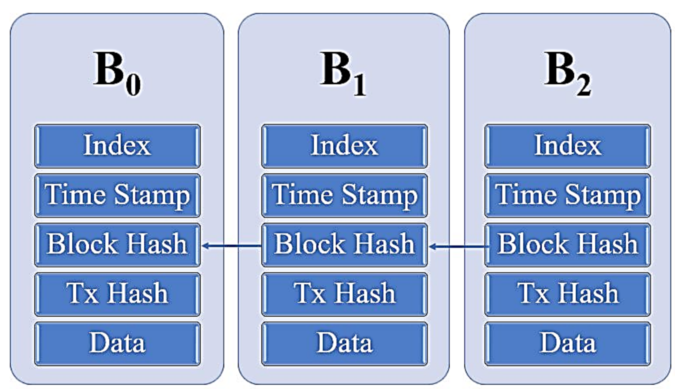

Fig. 2. Basic blockchain

Fig. 2 represents the basic blockchain structure. Each block contains information such as index; timestamp, which keeps the record of the exact block mining time, block hash, the unique block identity; Tx hash (Transaction hash, the unique identity of every traction performed on a blockchain), and data. Each block is also connected to the previous block making a chain of blocks. Referring to fig. 2, block $B_{0,}$ always present in the blockchain, is called genesis block, the first block of every blockchain. The rest of the blocks in the blockchain stacks over the genesis block. In a P2P network, the participating peers manage the blockchain independently without the involvement of any central authority. As we shift the energy sector from a centralized to a decentralized network, blockchain is an essential factor, as it can address security and transparency issues in energy trading. Such a process can be either local (between the peers) or wholesale [22].

V. Smart Contract

Nick Szabo introduced the smart contract concept in 1994. He defined a smart contract as "*A computerized transaction protocol that executes the terms of a contract*." Consequently, the advent of blockchain unfolded the significance of smart contracts. In terms of blockchain, smart contracts are scripts recorded on the blocks forming a blockchain. Each contract has a unique address as it dwells on a chain. These contracts are generated by addressing transactions to them. Afterward, smart contracts execute automatically in a specified method on the network nodes [10]. Fig. 3 shows the working of a smart contract, where a response is dependent on the pre-set conditions. Once the pre-decided conditions are fulfilled, the desired response willAs compared to traditional agreements, smart contracts do not depend on any mediator. This idea of executing smart contracts without any mediator became successful only because of blockchain−a system that can self-execute the contracts.

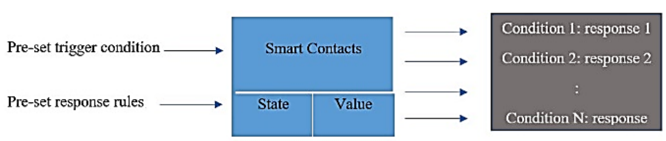

Fig. 3. Working of smart contract [17]

There are different platforms to develop smart contracts, e.g., NXT, Bitcoin, or Ethereum [23]. On a blockchain, a smart contract shall not be changed. However, it can be monitored, authenticated, and self-enforced. Bitcoin first implemented smart contracts. In 2015, Vitalik Buterin developed Ethereum−a blockchain-based decentralized network for payment execution inclusive of a development environment for a wide range of smart contracts on blockchain [24].

Ethereum blockchain allows smart contracts to execute independently. In this platform, at first, the contract amongst the participating peers is applied as a script and then deployed to the blockchain network. On the execution of the digital commands, the smart contract is initiated automatically on the blockchain network, and the condition already set up in the smart contract are followed. Hence all the transactions are executed independently without relying on any central authority. In cryptocurrency, the smart contracts can be deemed as wallets because they contain balance and account addresses like traditional cryptocurrency accounts [13].

VI. System Description

In most countries, the conventional energy trading model is entirely managed by utility companies, and the energy consumers are altogether dependent on the service providers. Besides, the electric power is produced by large-scale power plants installed at distant locations from the load centers. There is also no uniform policy regarding the pricing mechanism, and the energy price is decided centrally without the direct involvement of the end-users. As described in Section I, increasing demand for electric energy and the penetration of renewable energy witnessed an increasing number of prosumers. Also, modern technologies emphasize decentralized networks where people can deal with each other without the involvement of any mediator. Peer-to-Peer (P2P) energy trading is the most advanced solution towards decentralized energy trading involving independent production, consumption, and financial incentives. In a P2P network, the peers can decide the energy price by themselves and manage their energy needs without relying on any central entity.

In this work, the proposed peer-to-peer (P2P) energy trading model consists of an IoT server with a user interface associated with a private Ethereum blockchain. The user interface is developed in a user-friendly manner and is simple to use. The developed system enables the participating peers of the proposed P2P energy trading model to manage their energy needs either by selling the excess amount of energy or they may buy the energy if their energy demand is increased. The participating peers may be the energy buyers or the energy sellers.

The P2P energy trading model connects Prosumers together and facilitates the energy trading amongst them. In this P2P energy trading model peer can consume self-produced energy and sell the excess energy by using the developed user interface (UI) of the server. The UI enables the prosumers to give buy or sell calls, transfer energy, measure the energy transferred, and execute payments. There are also options to refuse the buyer in case energy is not available to sell. Also, an emergency stop button may be used to stop energy flow if an emergency occurs. The peer (buyer or seller) can show the willingness to buy or selling by using the "Buy" or "Sell" button on the UI of the server. Once peer1 initiates the buy call with the buy call button, it will send an e-mail notification to peer2 showing the inclination of peer1 to buy energy. If peer2 to have enough energy and is ready to sell energy to peer1, peer2 will transfer energy to peer1 by using the "Energy Transfer" button on UI. For financial incentives, we used here a fully private Ethereum based blockchain technology to ensure secured, transparent and tamper proof financial transactions. Blockchain enables the peers to perform efficient and speedy transactions to get incentives for the energy exported. It allows direct financial transactions between peers and eliminates the need for any central financial institution.

Fig. 4 shows the block diagram of a P2P energy trading model. The P2P energy trading process starts from buy or sell calls. After a peer receives a buy call, he/she will be able to sell energy. If a sell call is received, the peer may accept the energy

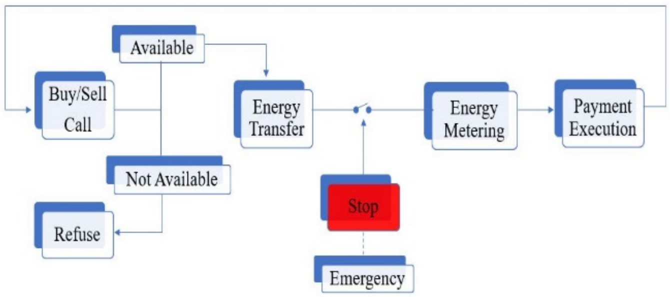

Fig. 4. Block diagram of P2P energy trading

selling offer. The next step is to transfer the energy between the peers if enough energy is available. If the available energy is not sufficient for selling purposes, this peer has the choice to refuse the other peer. When ready, the peers may utilize the UI to initiate the transfer of energy. The developed system is fully decentralized and reduces human interventions to a minimum. Once the peers transfer energy, the system automatically disconnects the power supply according to the predetermined time intervals. The server of the P2P energy trading model is developed using Node-Red visual programing language, which can measure the energy consumed and send e-mail notifications of energy consumption to the peers. The block diagram also shows a payment execution block that shows that the system is also enabled to perform the financial transactions in response to the consumed energy.

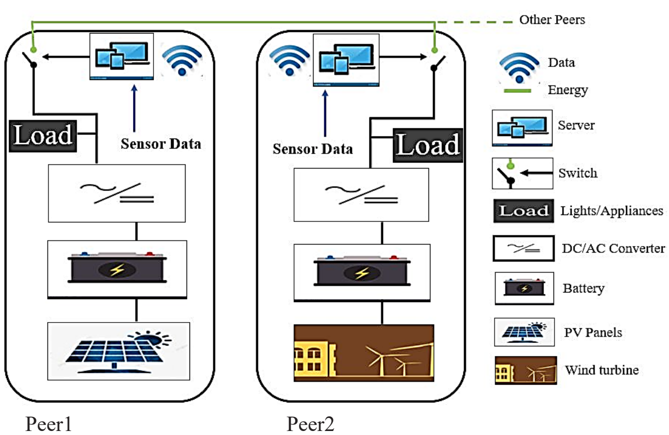

Fig. 5. Schematic diagram of the proposed System

The developed model is also associated with the fully private Ethereum blockchain to perform financial transactions. After the energy transaction is completed between the peers, the buying peer (energy importer) will receive an e-mail notification to pay for the energy consumed, and the financial transactions are then performed using the Ethereum blockchain. The P2P energy trading model, in addition to empowering the participating peers to refuse if sufficient energy is not available, has also an option to stop energy transfer in case of an emergency. The block diagram shows how the P2P energy trading model facilitates the P2P energy trading in a decentralized manner and eliminates the need for any central authority.

The P2P energy trading model presented in this paper is fully autonomous and works in a decentralized manner. The system can transfer energy between the peers without human interventions, and the associated Ethereum blockchain enables the peers to get the incentive for energy trading. There is no central authority to decide the price of energy. In this P2P energy trading model, the electric energy price is pre-decided amongst the peers allowing energy prices lower than the local energy market. The system can manage energy needs and measure energy consumption in real-time, and the buyer must also pay for the energy consumed using the Ethereum blockchain under sufficient security and transparency. The P2P energy trading model developed here is adequate to accommodate 10 participants. However, as an initial test, we have applied it for only two peers, the details of which are presented in the next sections.

Fig. 5 presents the schematic diagram of the P2P energy trading model. In the figure, two peers named “peer1” and “peer2” are shown. Both the peers are equipped with the distributed energy resources. Peer1 is equipped with solar energy resource as photovoltaic panels appears in the figure while peer2 is utilizing wind energy to fulfill its energy needs. The P2P energy trading models enables the participants to share energy after fulfilling their own energy requirements and get the financial benefits in the form of crypto currency. The details of each component are presented below:

- Server: A server has been developed for the P2P energy trading model to facilitate energy trading between peers. Peers are programmed in a Node-Red IoT platform and Ethereum blockchain.
- Data: All the information regarding the energy trading and financial transaction is transmitted between the participating peers of the system using a private network.
- Energy: For the physical transfer of energy services, wires are used in this P2P energy trading model.
- Switch: Switch is used for the physical transfer of energy between peers.
- Load: Load can be lights, motor, appliances, etc. However, for testing this system, two light bulbs of 100 watts each have been used.
- DC/AC Converter: DC to AC converter can be used as most of the renewable energy resources gives DC output, and commonly used household loads are in AC.
- Batteries: Batteries can be used to store energy and supply surplus energy between peers.
- Photovoltaic panels represent a renewable energy source.
- Wind turbine: Represents a renewable energy source.

The proposed peer-to-peer energy trading model has major contribution to facilitate P2P community, it satisfies all the requirements of a fully decentralized P2P energy trading network which has not been addressed yet. IoT platform enables the peers to trade energy with high efficiency. Blockchain technology allows peers to perform and verify financial transactions without relying on any third party.

VII. Experimental Setup

The proposed P2P energy trading model has two main components: (1) hardware setup and (2) software-based setup.

A. *Hardware Setup*

The hardware setup of the proposed system is presented below in fig. 6. The structure comprises an Arduino UNO microcontroller, ACS 712 Hall-effect current sensor, relay board, jumper wires, LED, a resistor, and wires to supply energy to the connected load. Arduino UNO is selected based on its compact size and is programmed using Arduino IDE to receive data from the current sensor and onward transmission

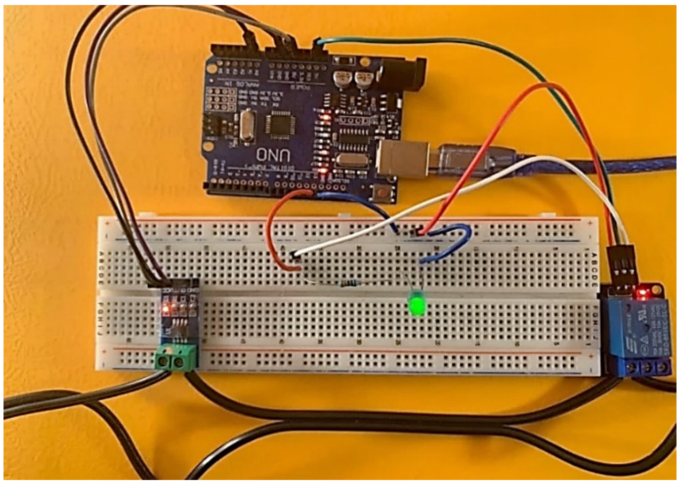

Fig. 6. Hardware setup of P2P energy trading model

of data to the IoT server. In this setup 30A module of ACS 712, Hall-effect current sensor is used to measure the current ranging from 0A to 30A. The switching capacity of the SRD-05VDC-SL-C relay board used in this hardware setup is 10A. Fig. 7 shows the load connected to the system for testing. The load is composed of two light bulbs: 100 watts each. A wired communication protocol is used for the communication of data between the hardware setup and the IoT server.

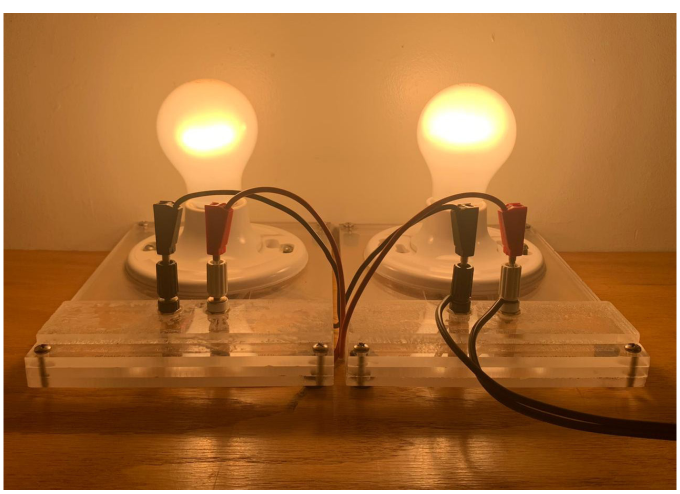

Fig. 7. Load connected to P2P energy trading model

After connecting the load to the system, the current sensor senses the current flow and transmits the sensed values to the IoT platform. The IoT platform starts measuring the consumed energy by taking the voltage value as standard AC 120V using payable energy node and based on the information transferred by the Arduino microcontroller (The system is tested in St. John's Newfoundland, Canada with standard values of AC as there is no voltage fluctuation here). Arduino UNO analog pins are used to transfer the data sensed by the current sensor to the server, and digital pins support the energy transfer process. The relay here is used to perform automatic switching operations. The relay operates based on the signal received by the IoT platform. Once the relay gets the signal from the IoT platform automatically starts or stops the energy transfer process. As soon as the energy transfer is complete, an e-mail notification is generated and sent to the energy consumer, and the system is disconnected. Here, an LED is used to indicate the trading session. Once the trading session starts, it turns on. After the trading session is over, it automatically turns off. Table 2 summarizes the hardware used in the proposed P2P energy trading model and the purpose of the hardware being used.

Table II
Hardware Description

Hardware used	**Purpose**
Current sensor	Used to sense current drawn by the load.
Arduino board	Arduino microcontroller digital pins are used to perform energy transfer function/indication. Analog pins are used to transmit sensed current value.
LED	LED is used to specify trading session.
Power Supply	Standard 120 V 60 HZ AC power supply is used for testing purposes
Relay	To start or stop energy transfer process automatically
Electric wires	To supply energy to the load
Jumper wires	To connect circuit components
Light bulbs	Two light bulbs 100 watts each are used to serve as load

B. *Software Setup*

The software setup comprises a Node-Red IoT platform, Ganache graphical user interface (GUI), Ethereum blockchain, and MetaMask. Node-Red visual programming language is used to develop the flow-based server and create the UI for the proposed P2P energy trading model. Node-Red flow is used to assign tasks to the nodes and to connect the nodes with each other, while the user interface helps the peers to perform the required tasks for efficient energy trading. The peers may access the server remotely and are able to complete required transactions even not being on-site. After completing energy transactions, payment execution can be done on the private

Ethereum blockchain using ganache GUI and MetaMask. In this platform, occasionally, the participating peers will have to pre-decide the price of energy themselves without being dependent on any intermediary. Table 3 describes the software used to build the server. The hardware setup communicates with the software setup through USB serial ports.

TABLE III
SOFTWARE SETUP DESCRIPTION OF THE PROPOSED ENERGY TRADING MODEL

Program	Purpose
Node-Red	Used to develop the flow to connect different nodes using Node-Red visual programming language.
Node-Red User Interface	Helps peers to perform different tasks, such as ‘Buy’, ‘Sell’, ‘Refuse’, ‘Transfer’, or ‘Stop’.
Ethereum Blockchain	Ganache GUI is used to develop local Ethereum blockchain for test run.
MetaMask	MetaMask is used to perform transactions.

a) *Node-Red flow*

Fig. 8 represents the flow, programmed using Node-Red visual programming language for the proposed P2P energy trading model. It represents buttons to facilitate ‘Buy’ and ‘Sell’ calls and respond to the respective calls. Peers are connected to each other through e-mail communication.

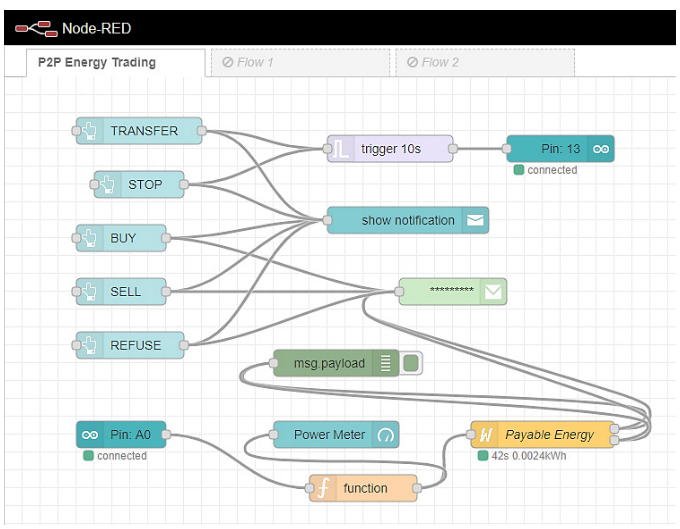

Fig. 8. Node-Red flow for the proposed P2P energy trading model

Arduino nodes represent the connection with Arduino board. After the connection is established between the Arduino nodes and the Arduino board the current sensor transfers the data to the server, which facilitates the power measurement through ‘Power Meter’ and energy measurement using the ‘Payable Energy’ node as shown in fig. 8. Node-Red node named ‘Payable Energy’ is placed to notify the energy consumption of a ‘start event’, to calculate the energy consumed in KWh, and to show the event time in seconds. It also declares a ‘stop event’ after energy transfer is over. Once the stop event is declared by the specific node, it sends an e-mail notification to the peer (energy exporter) notifying the consumed energy and the time for which energy was consumed. For sending e-mail notifications between the peers, the Node-Red e-mail notification node is used, shown in fig. 8. A trigger node is also shown in fig. 8, which is used to facilitate the energy transfer for a particular interval of time. After the pre-set time span is over, the trigger node generates a signal that halts the energy transfer process by actuating the relay. A debug node is also used to display all the data on the server itself.

b) *Node-Red User Interface (UI)*

Fig. 9 shows the Node-Red dashboard user interface (UI) composed of different buttons and a power meter. A peer can give different calls by tapping on this UI and able to monitor the supplied power on the power meter.

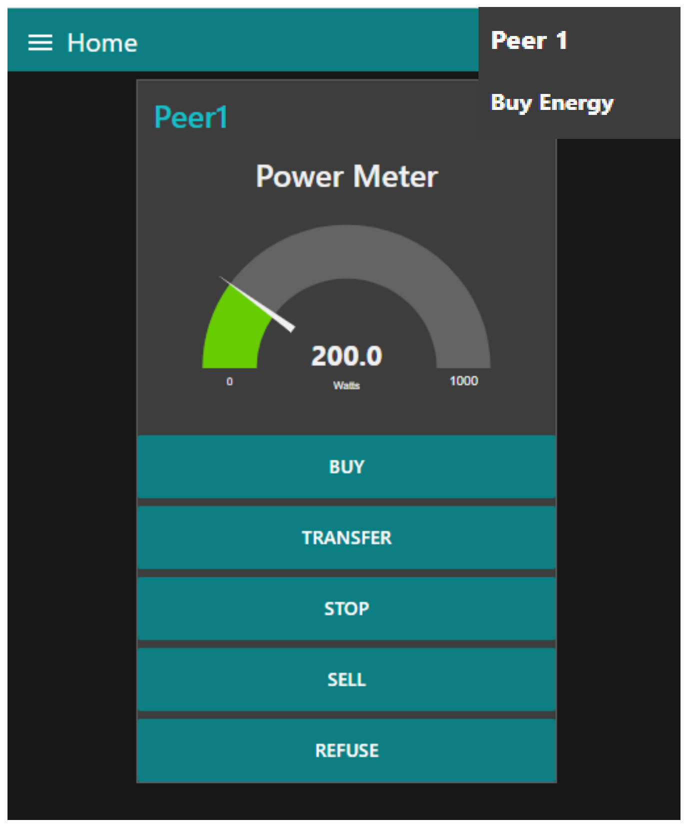

Fig. 9. Node-Red User Interface

It also shows the notification in response to a ‘Buy’ call generated by peer1. When peer1 makes a ‘Buy’ call showing the willingness to buy energy, a notification will pop up on the screen. At the same time, peer2 will receive an e-mail notification, as shown in fig. 10.

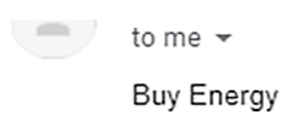

Fig. 10. E-mail notification of energy

If the excess energy is available or peer2 is willing to sell energy, peer2 will transfer energy using the ‘Transfer’ button, and energy transactions would start between the peers. Peer1 will get an e-mail notification indicating that the energy transfer has started. After the energy is transferred, the system will automatically disconnect the power supply based on the pre-set time between the peers. Peer1 will again receive an e-mail notification of payable energy showing time (in seconds) and energy consumption (in KWh). The UI of the sever gives the peers some other options such as ‘sell’, ‘refuse’, and ‘stop’. Peers willing to sell energy can also send the sell call. If the energy is not enough to be sold, the UI allows them just to tap the ‘Refuse’ button, and the other peer will receive an e-mail notification that energy is not available. In fig. 9, a ‘stop’ button is also shown, which allows the participants of the proposed P2P energy trading model to stop the transfer of energy instantly during any unwanted incident.

Fig. 11. Events shown in debug window

The system has been tested for various time intervals after connecting the load. All the trading sessions have been shown on the server and communicated to the peer (energy user) at the time energy transfer started and once the trading session was over. Fig.11 shows the start of the energy trading sessions, which also declares that the trading session is over by indicating the ‘event: stop’ notification with time stamps.

The server developed on the Node-Red IoT platform enables peers to trade energy freely according to their choice and without relying upon any utility company. All the trading sessions appear in the Node-Red debug window. At the same time, the energy consumer is notified about the energy trading session through e-mail notifications, as shown in fig. 12. All the information regarding energy trading would appear in the debug window on the server, and at the same time, all the trading events would be communicated through e-mail notifications.

Fig. 12 shows the e-mail notification from Node-Red regarding the trading session, which is the same as the information that appeared on the server itself. After the peer gets the information about the energy consumed, he/she will then pay for the energy consumed using the Ethereum blockchain. Details are presented in the next section.

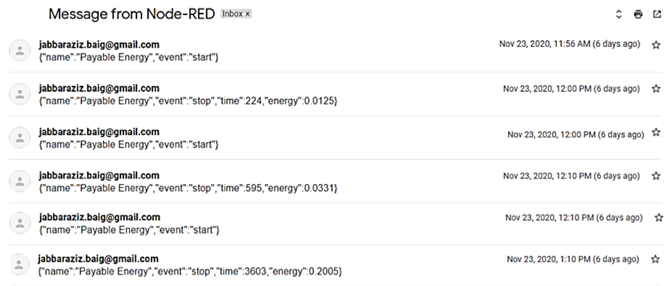

Fig. 12. P2P energy trading e-mail notification

c) *Payment Execution*

For payment execution, we use Ganache GUI, which provides the local network of Ethereum blockchain with 10 accounts. Each account is associated with public and private keys and a balance of 100 Ethers, which can be used to run tests. Ether is a cryptocurrency, and Ganache GUI allows financial transactions in Ethers.

After successful transactions, Ganache GUI creates real-time blocks. It also helps the participants to explore the blockchain, transactions and to deploy smart contracts. Peers can connect using RPC Server.

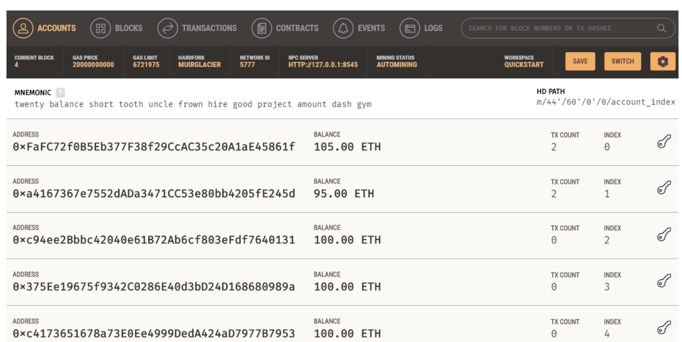

Fig. 13. Accounts with associated balance on server

Fig. 13 shows the created accounts for the testing purposes, the balance of 100 Ethers in each account except the accounts on INDEX 0 and INDEX 1 as we had performed transactions between these two accounts. The TX COUNT (Transaction count) represents that two transactions have been performed using the accounts at INDEX 0 and 1. For the rest of the accounts, the TX count is 0. The private key is hidden for all accounts. It is important to hide and secure the private key as it gives the peers the rights to funds with the associated address.

The TX COUNT in fig. 13 shows that 04 transactions have been performed using the address 0xFaFC72f0B5Eb377F38f29CcAC35c20A1aE45861f and 0xa4167367e7552dADa3471CC53e80bb4205fE245d, hence four blocks have been mined on the blockchain server the status of which is shown in fig. 14.

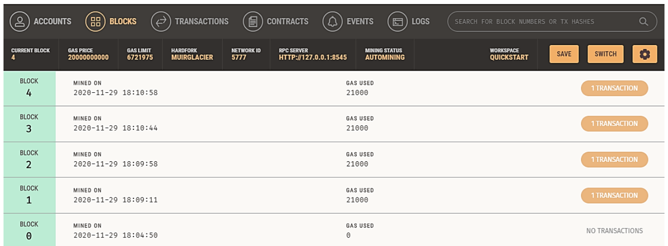

Fig. 14. Blockchain status on the server

It also shows the transaction details and the amount of GAS used. In cryptocurrency, the network charges a fee from the peers, which is called GAS. It only exists inside the Ethereum blockchain just to check the amount of work done. However, the transaction fee is charged based on the GAS price in the form of Ethers. If we explore the transaction in a block, it gives us important details of the addresses amongst which the transaction is performed, as well as Tx Hash (Transaction Hash), block hash and the time stamp.

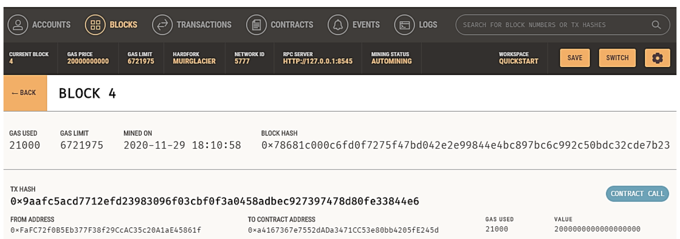

Fig. 15. Block details

The transaction Hash is a unique string of characters associated with each transaction. The details saved in block 4 regarding the transaction performed on the private Ethereum blockchain are shown in fig. 15.

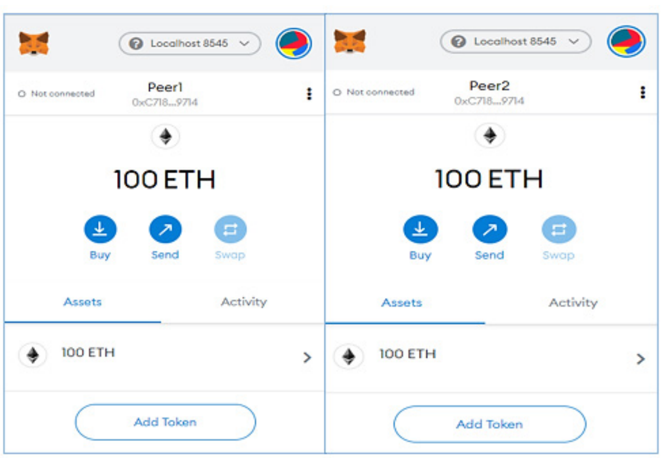

Fig. 16. MetaMask plugin

Fig. 16 shows the MetaMask plugin extension that is used to access the distributed applications of Ethereum as an add-on extension in Google Chrome. Ganache GUI can be accessed using MetaMask to perform transactions.

The balance of the accounts can be imported to MetaMask using the private keys of the accounts. To perform the transactions between peer1 and peer2, we have imported the balance using the private keys of the accounts into MetaMask. Once the private key is imported in the MetaMask, the balance associated with the private key appears, as shown in fig. 16. The balance associated with account 0xFaFC72f0B5Eb377F38f29CcAC35c20A1aE45861f for peer1 and account 0xa4167367e7552dADa3471CC53e80bb4205fE245d INDEXED at serial 1 for peer2 has been imported using the private keys, showing 100 Ethers for each account. Once the accounts are imported, the transactions can be performed by the peers, and the blocks are mined with timestamps following each transaction.

In this way, the participating peers of the P2P energy trading model are able to perform secured financial transaction on a private Ethereum blockchain using a unique private key that gives participant access to his ganache account and uses funds in a secured manner. While for the technical side, every participant has access to its own Node-red IoT server to monitor and transfer energy. The participants use e-mail notifications for communication, secured by built-in features of e-mail security like password and two-factor authentication.

VIII. Conclusion

The proposed P2P energy trading model has a unique and simple architecture. As compared to the existing P2P energy trading platforms, the proposed system is user-friendly, open-source, and may introduce increased efficiency and profitability. The existing P2P energy trading platforms mainly focus on software-based financial transactions to facilitate P2P trading. However, the proposed system in this work not only covers the financial side using the blockchain technology but also proposes hardware set up connecting with Node-Red for transfer of energy in real-time to get financial benefits as blockchain server provides a secure and transparent system for financial transactions. We have demonstrated that how an open-source platform can be utilized to achieve all the tasks in a P2P network. An interactive user interface has been developed to transfer energy. Ethereum blockchain is used for payments of the consumed energy. The proposed platform provides a complete open-source solution for energy transfer, metering, and fund transfer for P2P energy trading. Although the proposed P2P energy trading model has been tested in real-time for two peers only, this system is able to accommodate 10 peers at a time and can be extended at an inter-community level. This fully decentralized platform gives the opportunity to the peers to decide the price of energy they are producing. They can also control and manage their energy requirements. As such, this system yields financial benefits to the participants of P2P network. The peers can access the server remotely and start trading any time just by tapping on the UI. The proposed system is fully automated and eliminates the need of human intervention. In addition, peers can enjoy the distinct features of blockchain without relying on conventional financial institutions.

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