DESIGN AND IMPLEMENTATION OF PEER-TO-PEER ENERGY TRADING SYSTEM USING INTERNET OF THINGS AND BLOCKCHAIN

PhD Oral Defence

By

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Supervisory Committee

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Introduction-Background and Motivation

- The demand for electrical energy may rise by 20% over the next decade [1].
- All the countries around the world are focusing on renewable energy sources such as solar power and wind power to meet the electric demand and reduce greenhouse gas emissions [2].
- With the escalation of Distributed Energy Resources and advances in information and communication systems technology, a new market for electricity has emerged [3].
- As low-cost renewable energy technologies have gained popularity and electric energy demand has grown, there has been an increase in prosumers in the electric market [4].
- The proliferation of distributed energy sources has contributed to the growth of the prosumer in the energy sector [5].
- Recent years have seen the energy industry shift towards the decentralized model, driven by technological advances in information technology and distributed energy technologies [6].

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Introduction-Background and Motivation

- A conventional energy transmission and trading system is unidirectional in terms of both the flow of energy and cash.
- It is now imperative to have a state-of-the-art platform for energy trading to support this emerging concept of prosumers.
- The ability to set the optimal trading time, as well as complete trading autonomy, financial security, and pricing liberty is all provided by Peer-to-peer (P2P) trading platform.
- Peers can trade surplus energy through the use of peer-to-peer energy trading, which can be beneficial for both buyers and sellers [7].
- Generally, it is the national level that determines energy market prices. On the contrary, P2P energy trading allows participants to determine energy prices on their own.
- P2P energy trading has become a leading solution for energy management as it allows peers to contribute to the electricity market, either by reducing their demand or by selling excess energy [10].

Introduction-Background and Motivation

- As a result of blockchain technology, the prosumer can conduct financial transactions independently. However, smart devices, coupled with Internet-of-Things (IoT), provide a low-cost method of energy trading.
- Prosumers can trade energy like goods and services in peer-to-peer energy trading, which is a key component of energy trading over P2P.
- An entirely new market structure has been created for electricity due to blockchain technology and the internet of things.
- Renewable energy sources have undoubtedly had a significant influence on the conventional electricity market. Nevertheless, it has not yet completely captured the traditional electricity market.
- In this study, an energy trading platform based on blockchain and IoT is proposed. Featuring a decentralized structure, the proposed systems provide participants with access to the most recent solutions for energy trading, such as financial transactions, energy transfers, and energy metering.

Introduction-Research Objectives

- To select a remote site with no services and design a PV based DC microgrid.
- To design and implement an innovative P2P energy trading platform using open-source resources with real-time settlements, technical and economic efficiency.
- Design and implement a novel P2P energy trading platform by installing a decentralized web interface, Ethereum blockchain, and locally installed IoT server hosted on a local network. Since an open source, P2P energy trading network has never been seen before.
- Development and application of an open-source and low-cost, local server hosted on a private network for peer-to-peer energy trading, using a ganache command-line interface (CLI) private Ethereum blockchain and a raspberry Pi to host the server.
- To design and implement an optimal energy trading system for remote communities to achieve energy trading and monitoring independence without internet.

Introduction-Significance of Research

- The increasing demand for renewable energy sources to meet the energy requirement and the technological advancements have raised the number of prosumers in the electricity market.

- The emerging technologies like blockchain and the IoT have given a new trend to the electricity market.

- Blockchain technology has given financial liberty to the users and eliminated the need for third-party solutions for financial transactions. While the IoT excluded human interventions.

- This paradigm shift requires state-of-the-art energy trading solutions that can facilitate prosumers in monitoring generated energy, transfer of energy, energy metering, and freedom of financial transactions.

Introduction-Significance of Research

- This study identifies a straightforward and unique approach to designing and implementing an IoT and blockchain-based open-source platform for peer-to-peer trading of energy.

- As a result of the development of four platforms, the prosumers will be able to monitor and trade energy without the involvement of any central authority with fast and efficient financial settlements.

Design and Analysis of an Isolated dc-Microgrid-Site Description

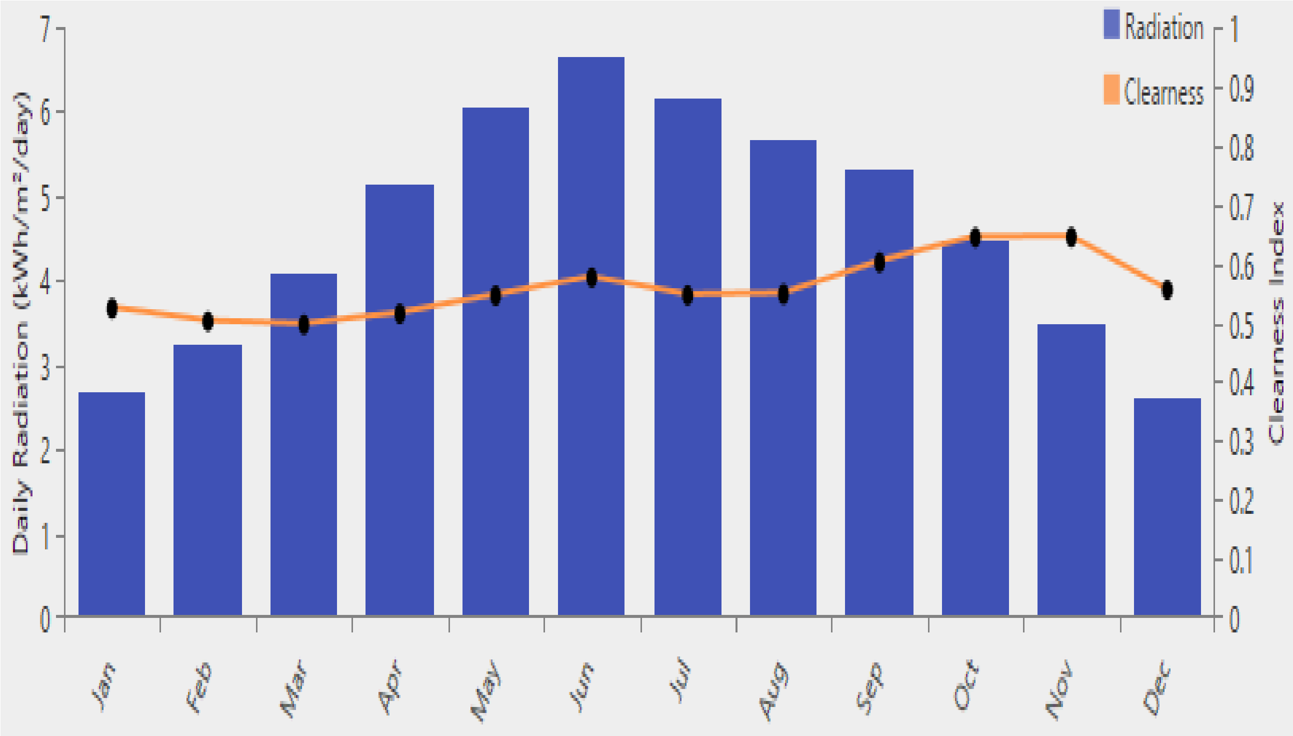
Aerial view of the proposed site

Proposed site

- There are no power lines and no road access to this community.
- The houses on the site are so close to each other that a Wi-Fi based private communication link to facilitate P2P energy trading can be setup.

Design and Analysis of an Isolated dc-Microgrid-Site Description

- The site selected for this study is in the Neelum valley, the Northern part of Azad Jammu and Kashmir, Pakistan encompassing the lower area of the Himalayas.
- By virtue of the location 34°49'06.6"N 74°13'06.5"E it receives daily average irradiance of 4.63 kWh/m2 /day.



Monthly Average Solar Global Horizontal Irradiance (GHI) data

Design and Analysis of an Isolated dc-Microgrid

System Design

- Ten houses from the community are selected for the proposed system design using HOMER Pro software.

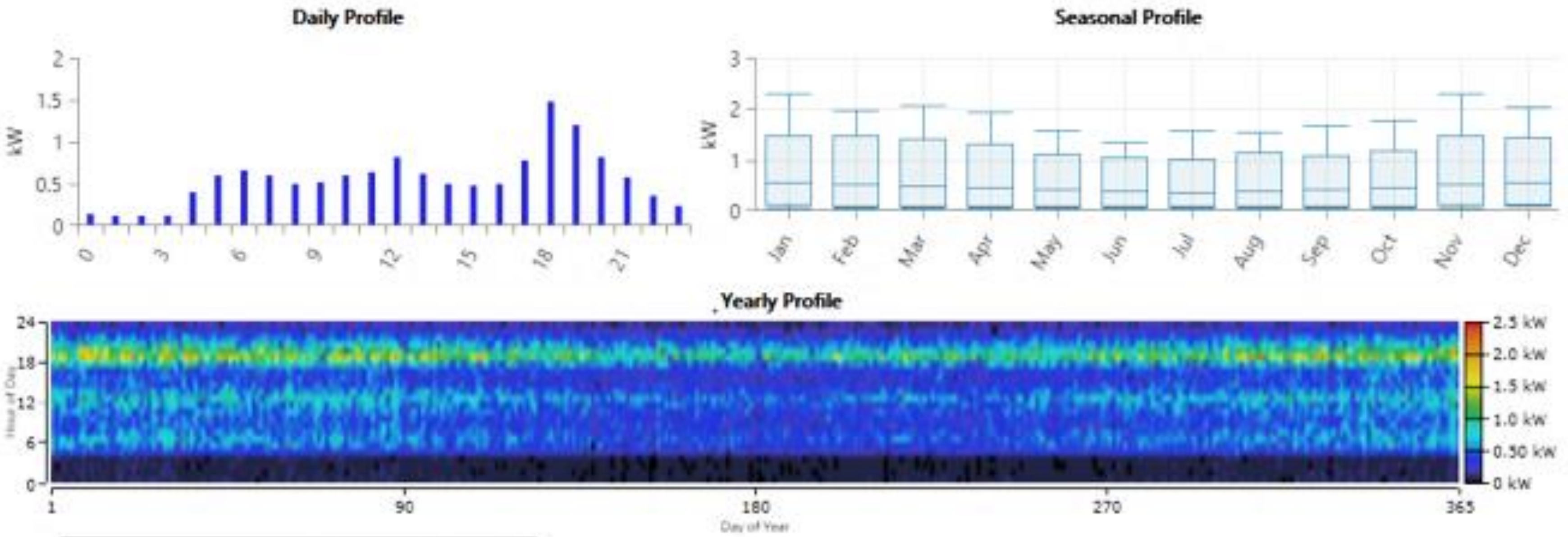
- A total of 2708 solutions were simulated, and the optimal design is selected.

- Load profile is developed for each house with load of a typical household as 1.68 kWh/day.

- The minimum load in community is 1.28 kWh/day and the maximum load as 2.00 kWh/day.

Design and Analysis of an Isolated dc-Microgrid

System Design



Metric	Baseline	Scaled
Average (kWh/day)	11.25	1.6
Average(kW)	.47	.07
Peak (kW)	2.32	.33
Load factor	.2	.2

Load Type: ○ AC ● DC

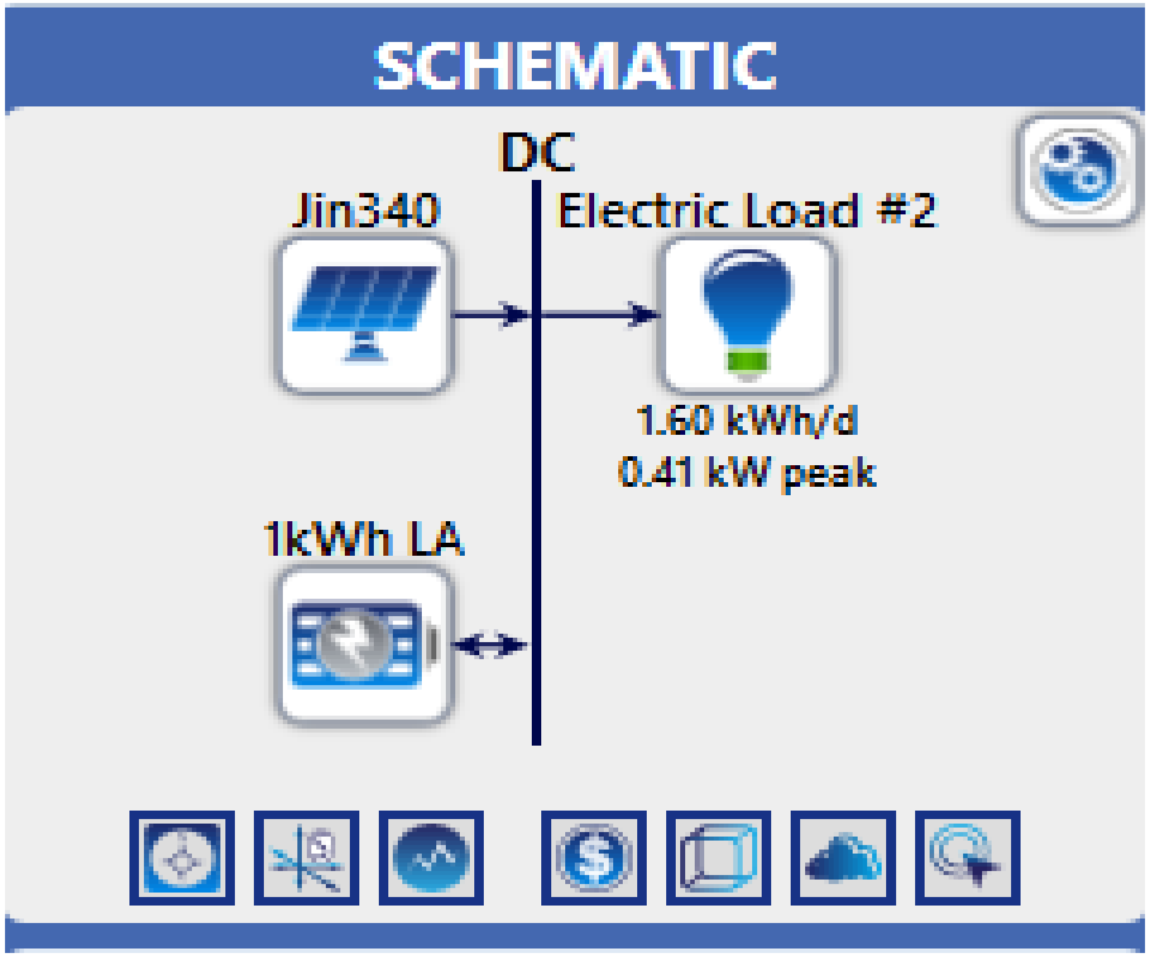
Daily, monthly, and yearly load profile of one house in the community

Design and Analysis of an Isolated dc-Microgrid-System Design

Sr. No.	Load Profile of connected Houses (kWh/day)	No. of PV panels (0.34kW each)	Initial capital Rs.	No. of Batteries (12V 85Ah each)	System Autonomy (Hrs.)
1	1.28	3	133,419	4	60
2	1.36	3	143,110	4	56.5
3	1.44	2	188,221	8	107
4	1.52	2	191,350	8	101
5	1.60	2	195,147	8	96.1
6	1.68	2	198,721	8	91.5
7	1.76	2	202,538	8	87.3
8	1.84	2	207,315	8	83.5
9	1.92	3	210,460	8	80.1
10	2.00	3	215,425	8	76.9

Design and Analysis of an Isolated dc-Microgrid

System Configuration and Components



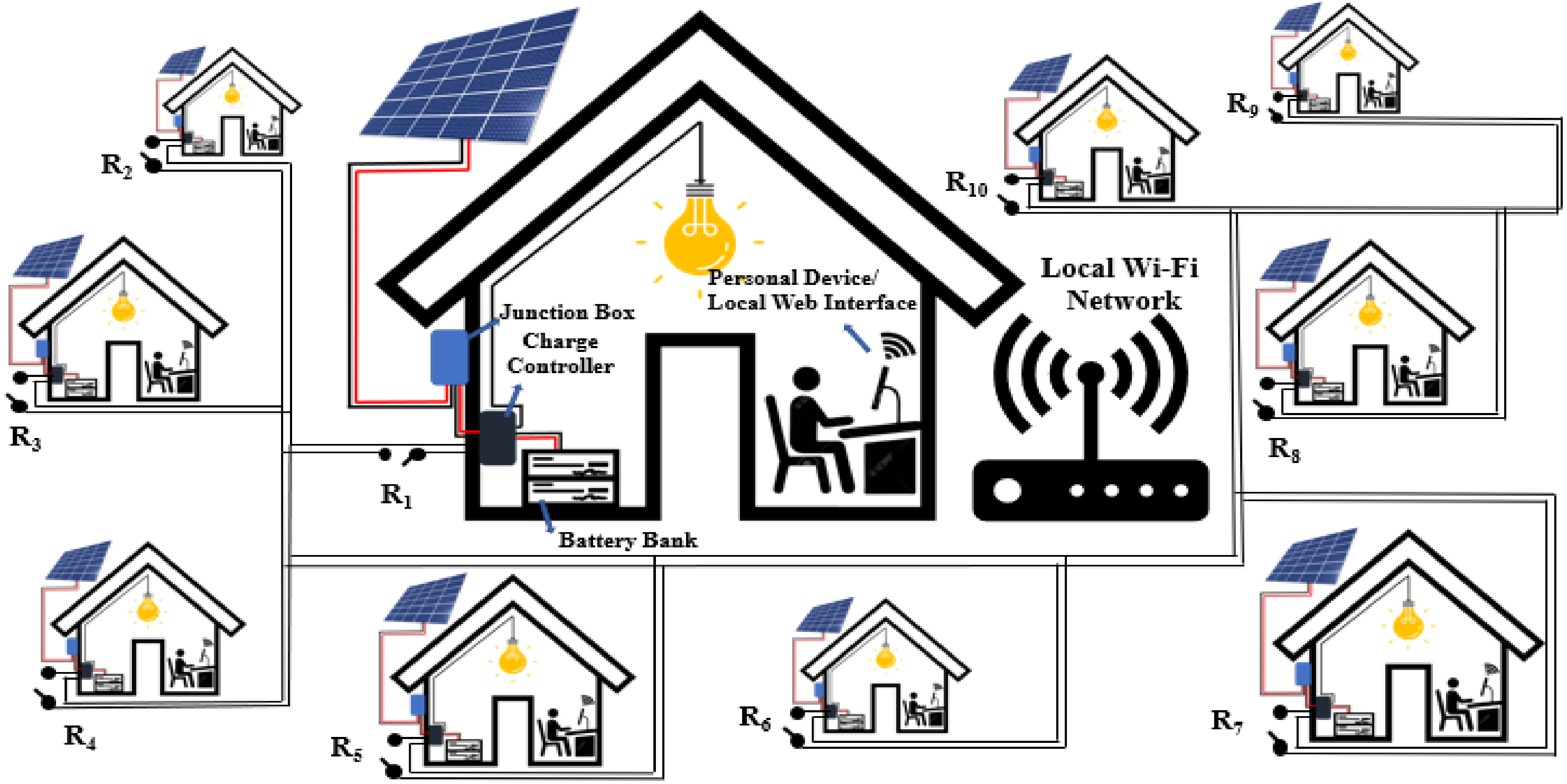
Optimal configuration of the proposed system

Design and Analysis of an Isolated dc-Microgrid
System Configuration and Components

- The system consists of PV module, load and a battery connected to a DC bus.
- The bus voltage selected for the proposed system is 48V.
- This system has a 25-year life expectancy with the initial capital cost of Rs. 133,419 for an average load of 1.28 kWh/day.
- The depth of discharge of the battery bank in the proposed system is 80%.
- The system autonomy of 4 to 8 days depending on the load profile.

Design and Analysis of an Isolated dc-Microgrid

Microgrid configuration and P2P Energy trading Scheme



Configuration of proposed microgrid with P2P energy trading scheme

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

System Description

- Consists of an IoT server with a user interface associated with a private Ethereum blockchain.

- The developed system enables the participating peers of the proposed P2P energy trading model to manage their energy needs either by selling or buying energy.

- A user interface (UI) is developed to facilitate energy trading sessions.
- The system is based on e-mail service.

- The Peers receives e-mail in response to buy or sell calls.
- The system uses a tamper proof private blockchain and MetaMask for financial settlements.

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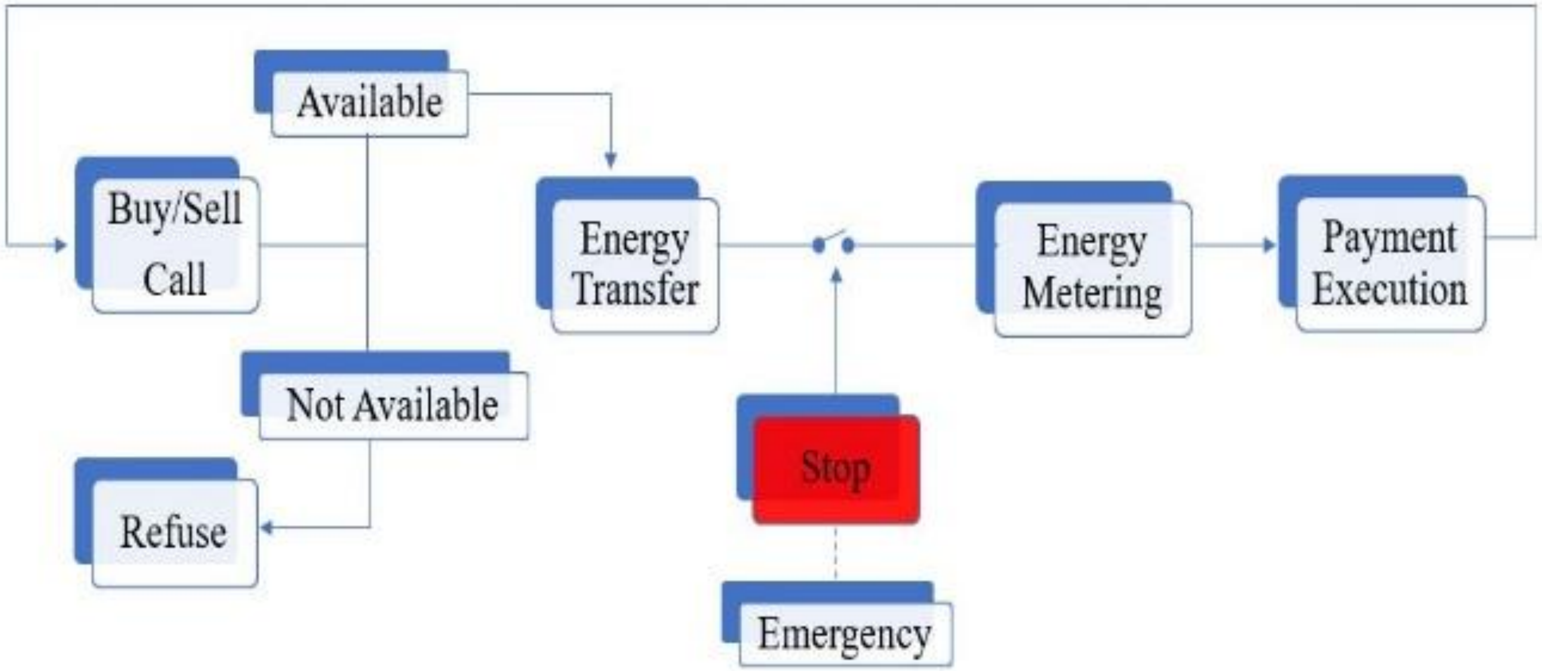
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

System Description



Block diagram of P2P energy trading

Experimental Setup and Results

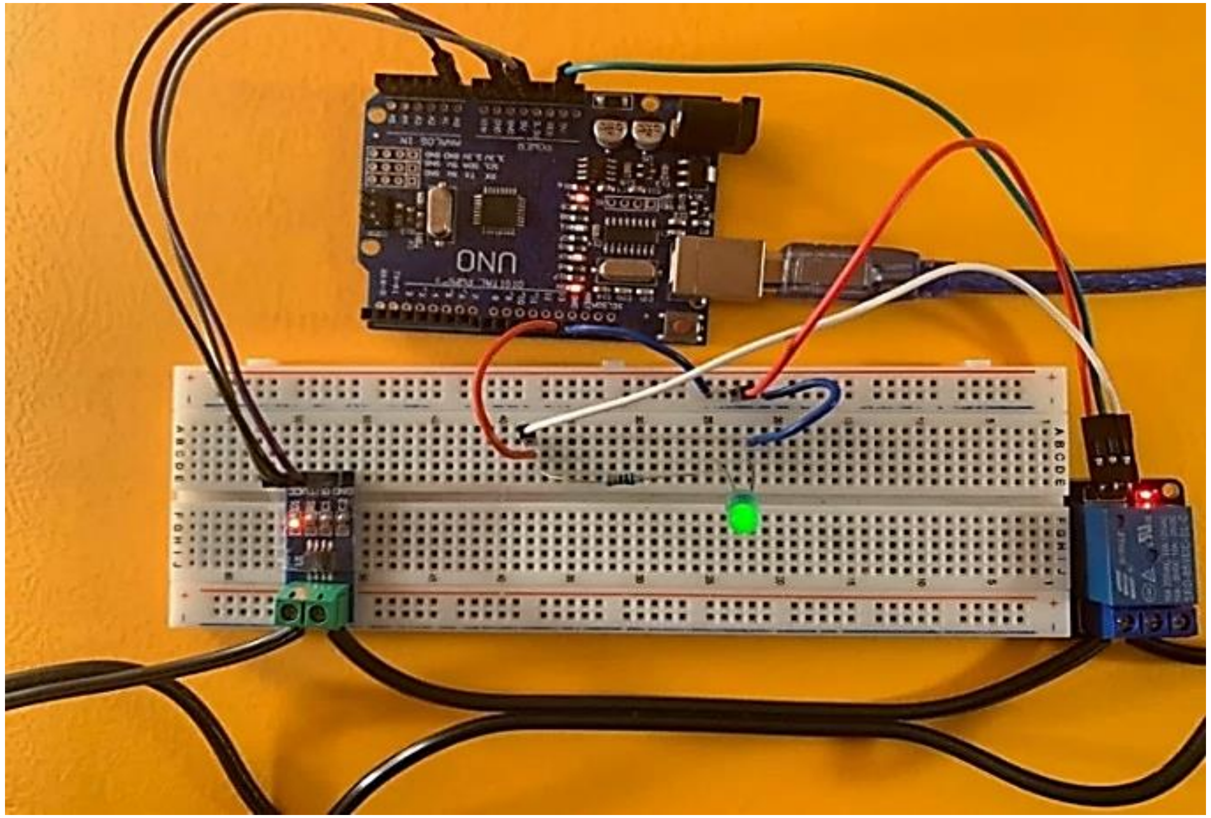
- The proposed P2P energy trading model has two main components:
- Hardware setup

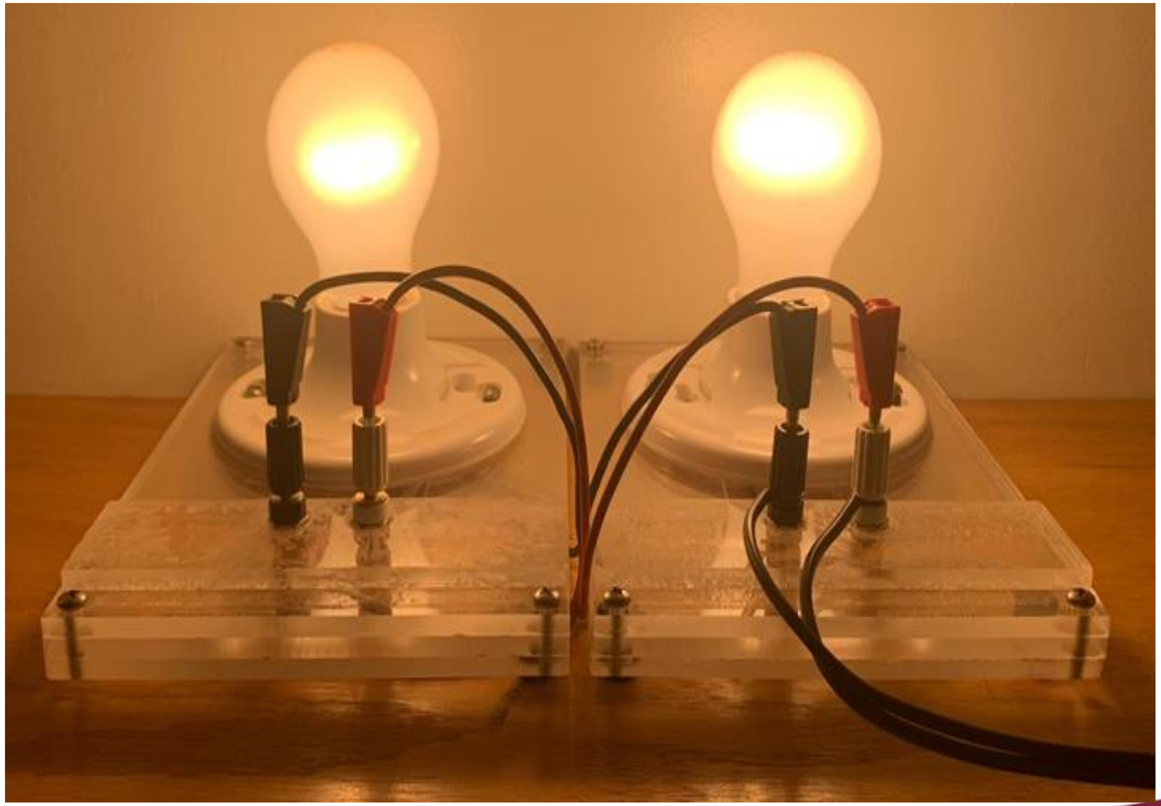
  and

- Software-based setup.

Peer-to-Peer Energy Trading using the IoT and Blockchain
Method 1

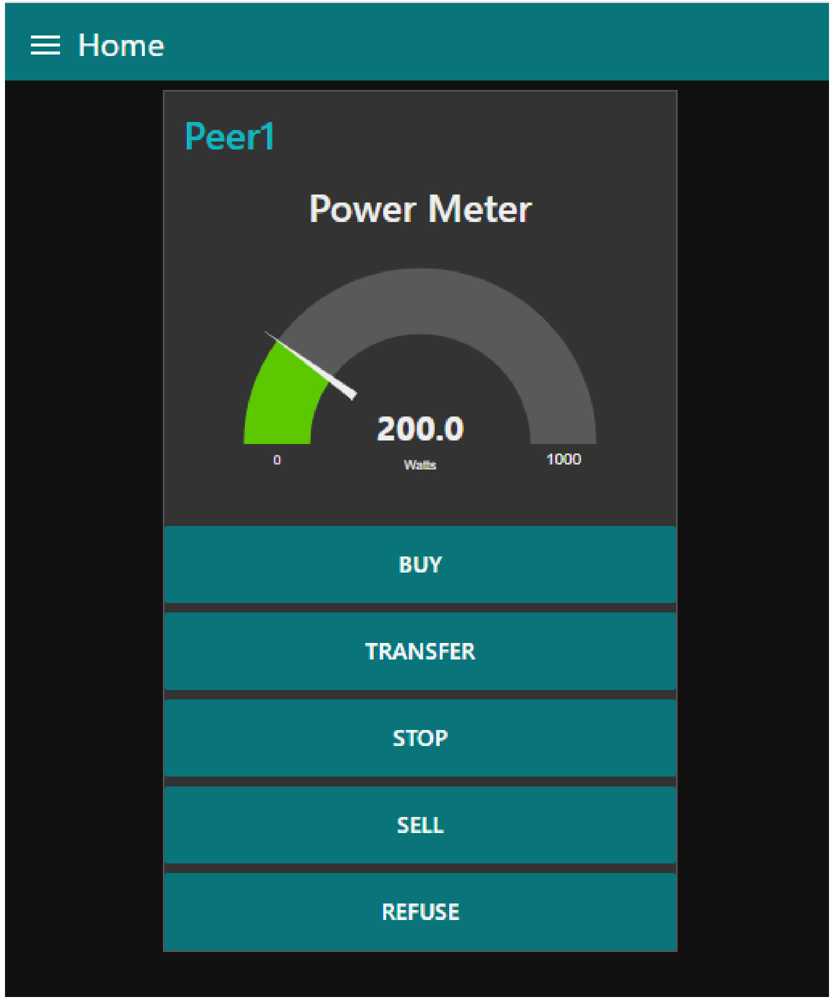
Hardware Setup



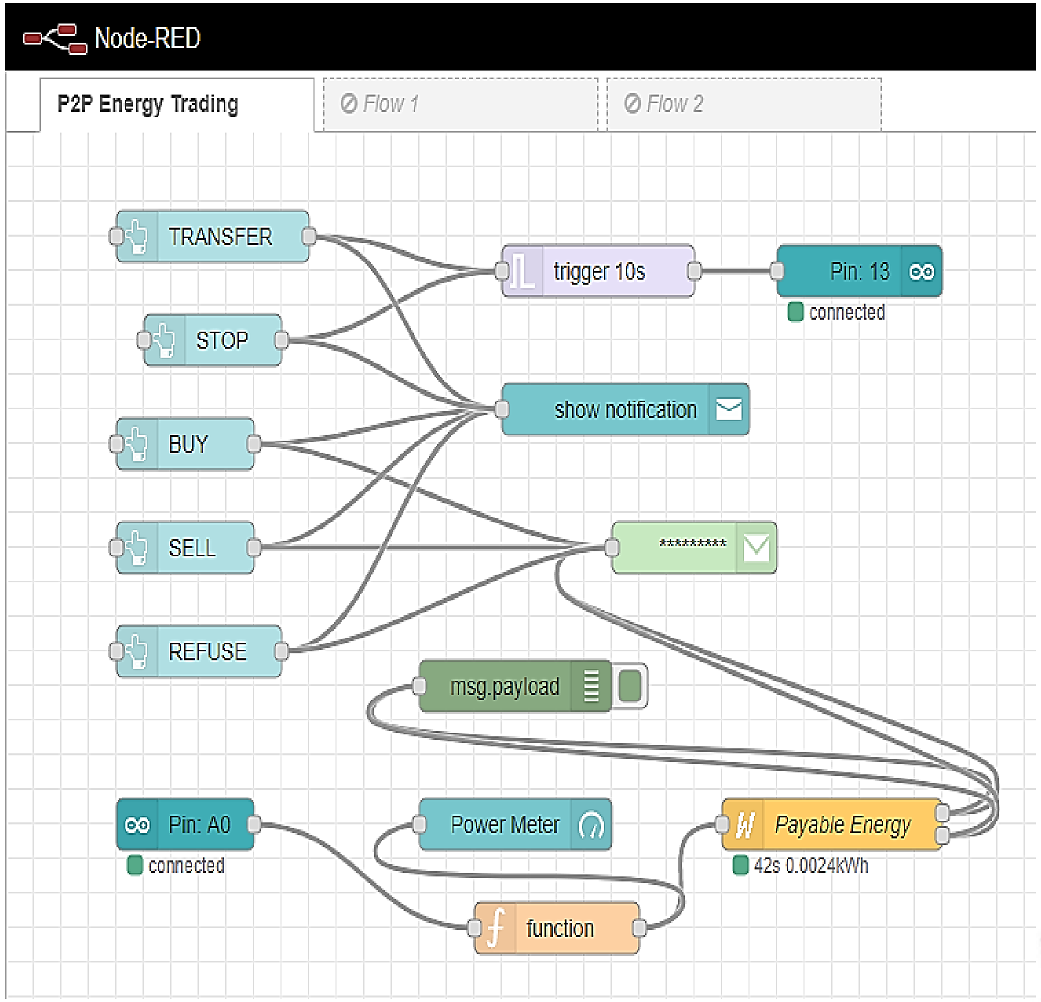


Hardware setup of P2P energy trading model

Software Setup



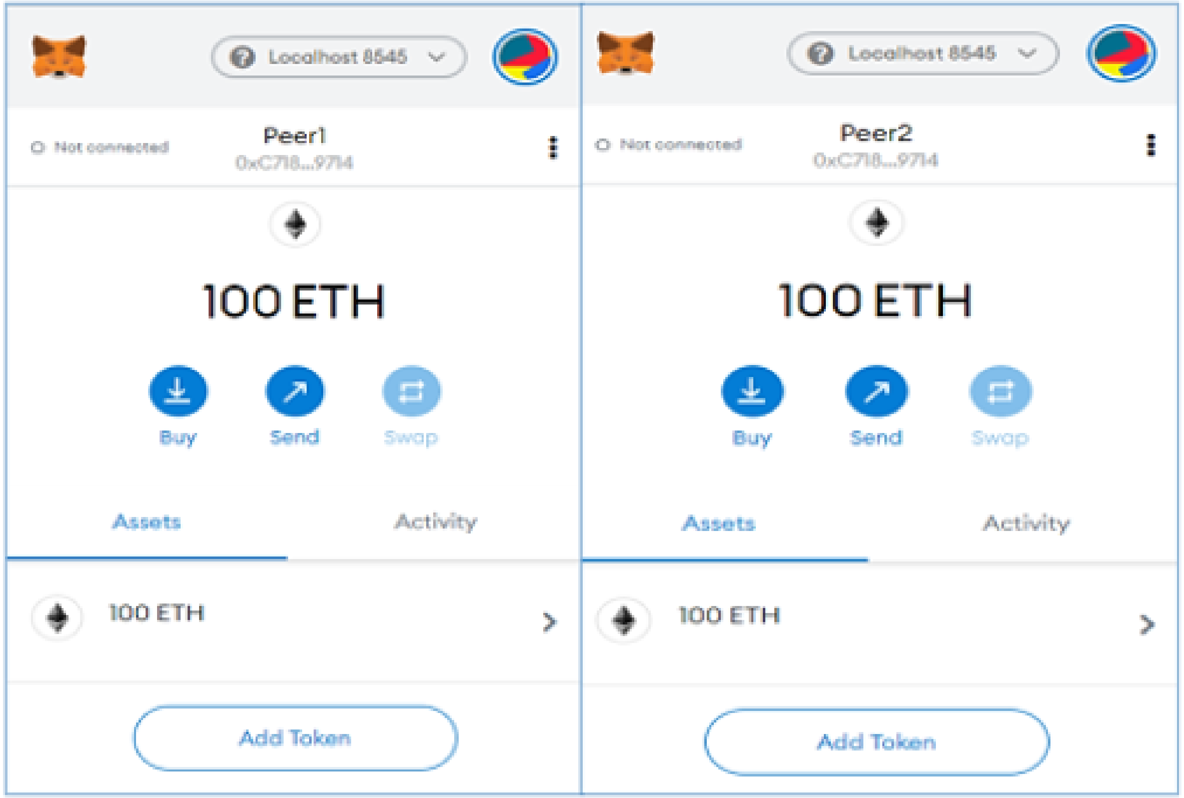
Node-Red User Interface



Node-Red Flow

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

Software Setup



MetaMask plugin

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

Results

E-mail buy energy

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

Software Setup

11/23/2020, 11:56:43 AM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "start" }

11/23/2020, 12:00:27 PM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "stop", time: 224, energy: 0.0125 }

11/23/2020, 12:00:27 PM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "start" }

11/23/2020, 12:10:22 PM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "stop", time: 595, energy: 0.0331 }

11/23/2020, 12:10:22 PM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "start" }

11/23/2020, 1:10:25 PM node: a214c30a.f2b92
msg.payload : Object
▸ { name: "Payable Energy", event: "stop", time: 3603, energy: 0.2005 }

Energy Trading events on Node-Red

Software Setup


Message from Node-RED Inbox x

jabbaraziz.baig@gmail.com Nov 23, 2020, 11:56 AM (6 days ago)
{"name":"Payable Energy","event":"start"}

jabbaraziz.baig@gmail.com Nov 23, 2020, 12:00 PM (6 days ago)
{"name":"Payable Energy","event":"stop","time":224,"energy":0.0125}

jabbaraziz.baig@gmail.com Nov 23, 2020, 12:00 PM (6 days ago)
{"name":"Payable Energy","event":"start"}

jabbaraziz.baig@gmail.com Nov 23, 2020, 12:10 PM (6 days ago)
{"name":"Payable Energy","event":"stop","time":595,"energy":0.0331}

jabbaraziz.baig@gmail.com Nov 23, 2020, 12:10 PM (6 days ago)
{"name":"Payable Energy","event":"start"}

jabbaraziz.baig@gmail.com Nov 23, 2020, 1:10 PM (6 days ago)
{"name":"Payable Energy","event":"stop","time":3603,"energy":0.2005}

P2P energy trading e-mail notification

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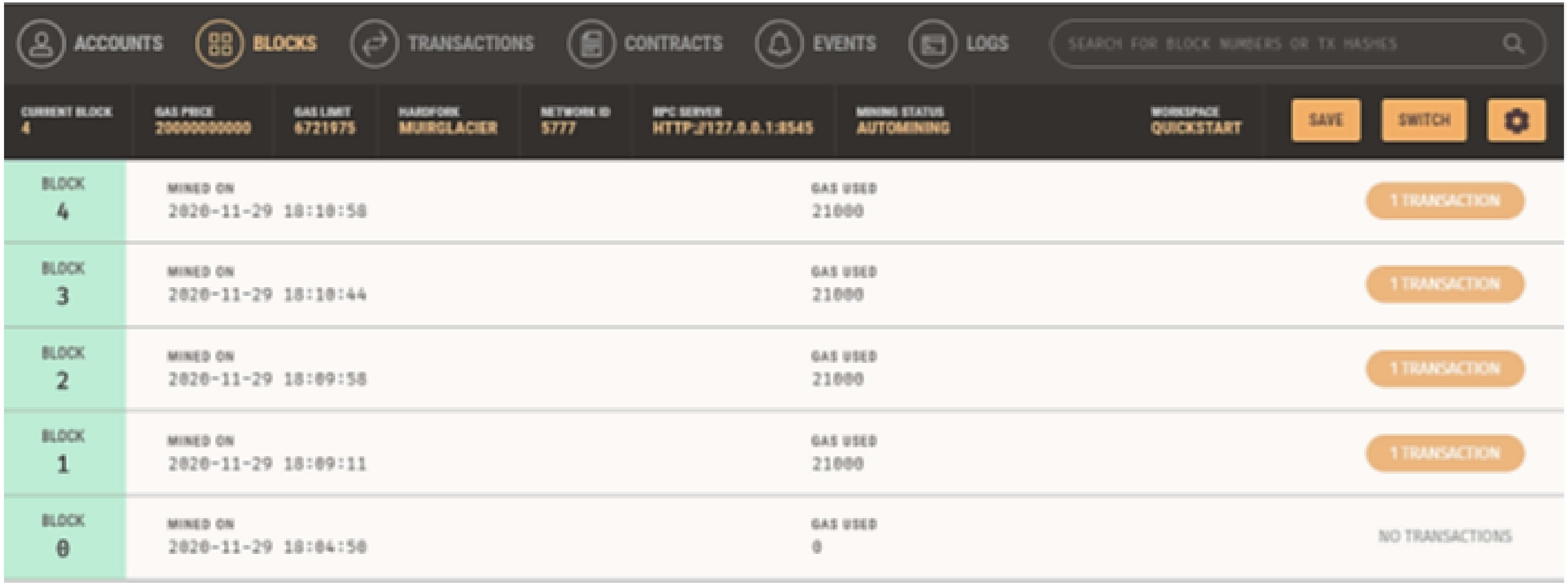
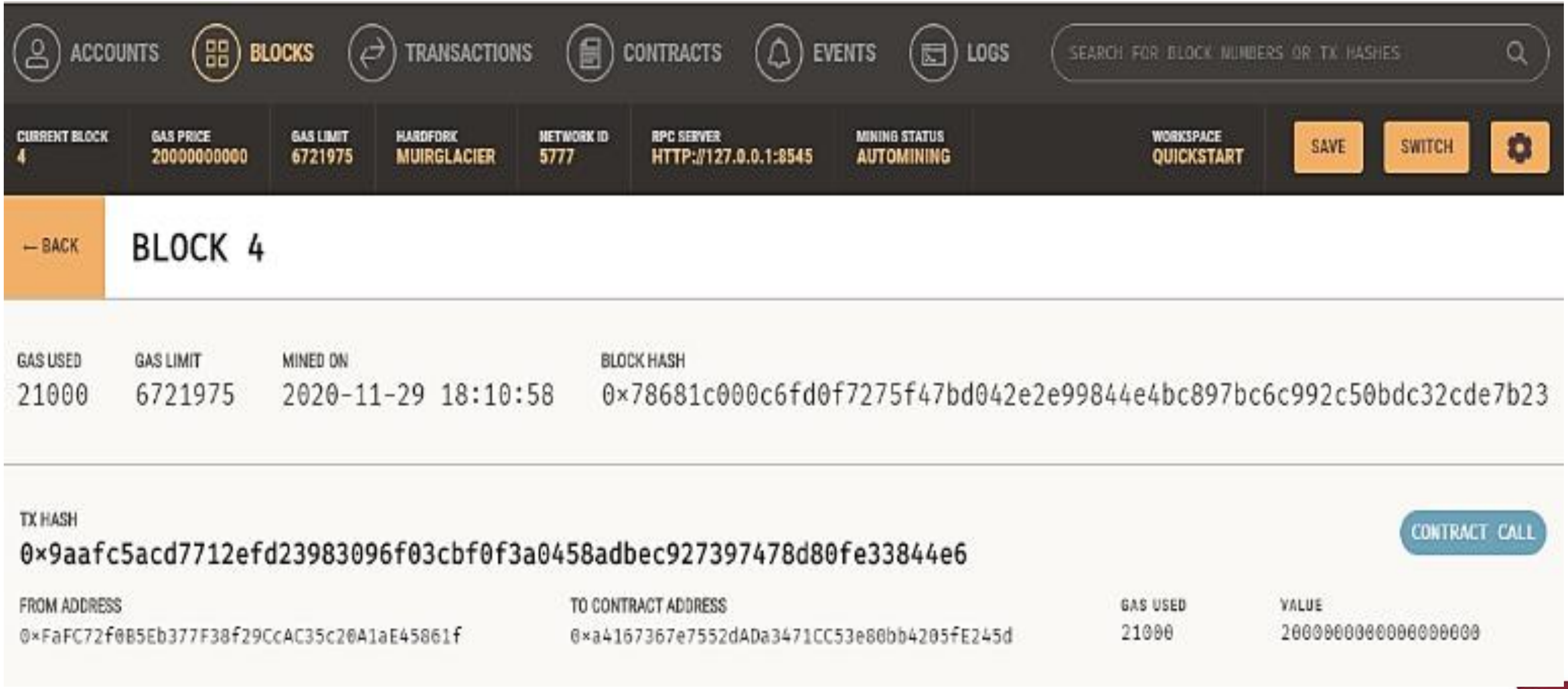
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1

Results



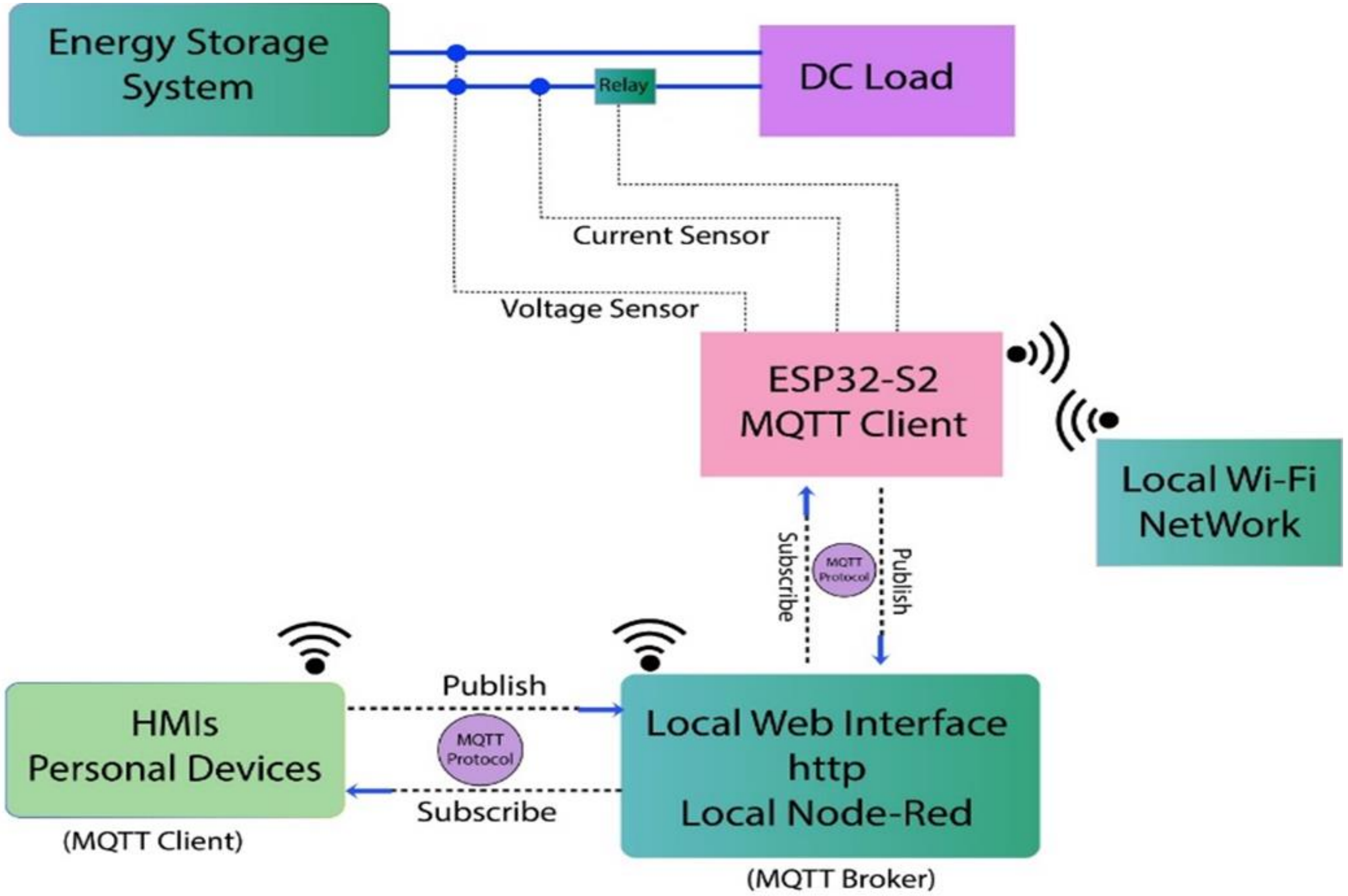
Blockchain status on the server

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 1- Results



Block Details

System Description



Proposed System Architecture

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Web Interface and Node-Red IoT server

- Node-RED is an open-source solution that was developed by IBM Emerging Technology.
- Node-RED runs locally on http://localhost:1880.
- Node-Red flow programmed using Node-Red visual programming language.

- The voltage, current, power and battery state of charge (SoC) data are transferred via MQTT protocol from the hardware components of the system and can be visualized on Node-Red user interface.

- For the automation of the P2P energy trading platform, we have implemented Hypertext Transfer Protocol (HTTP) request method.

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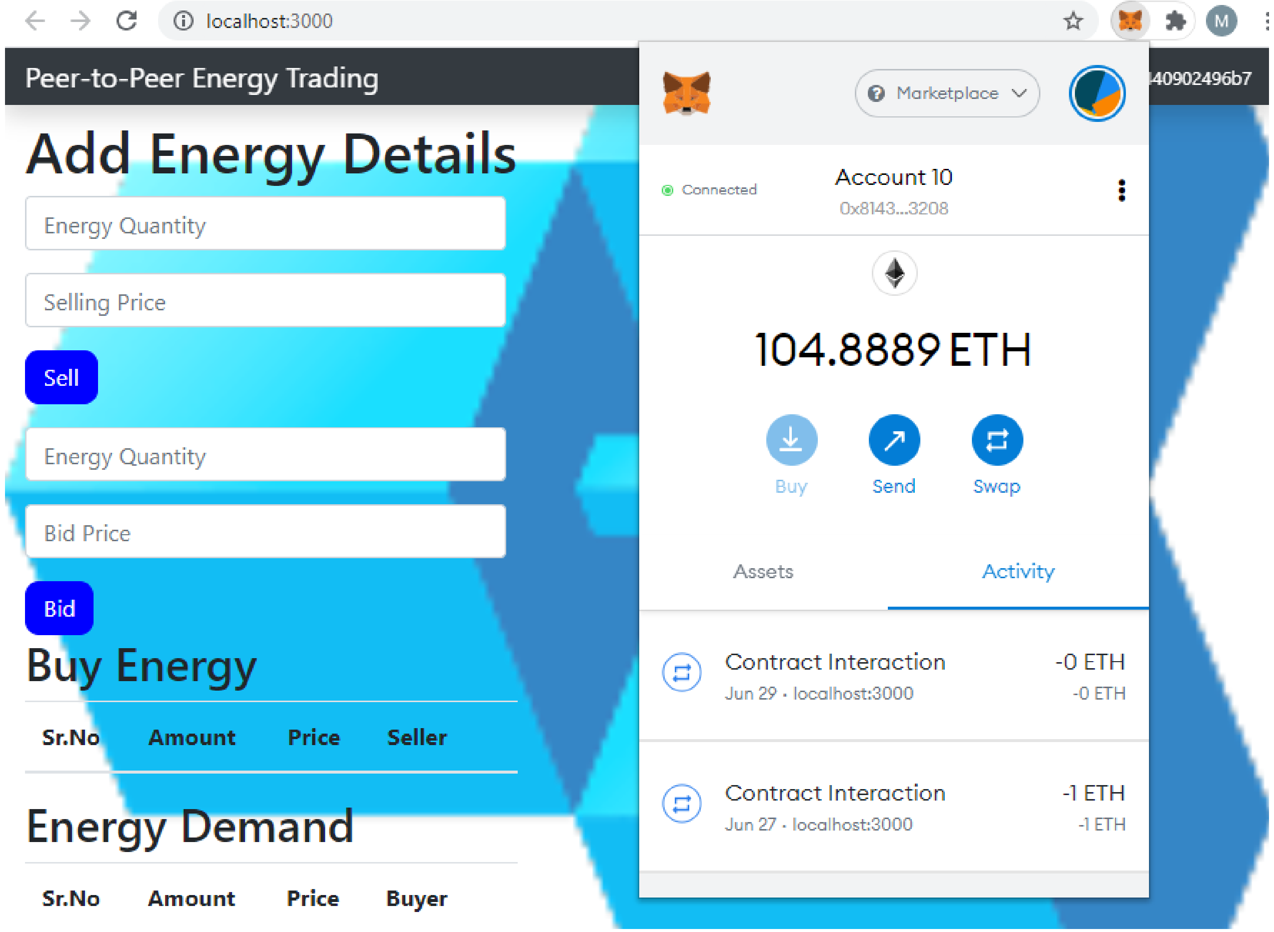
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Web Interface

- ❖ Web interface

  And

- ❖ MetaMask add on
- ❖ Localhost:3000



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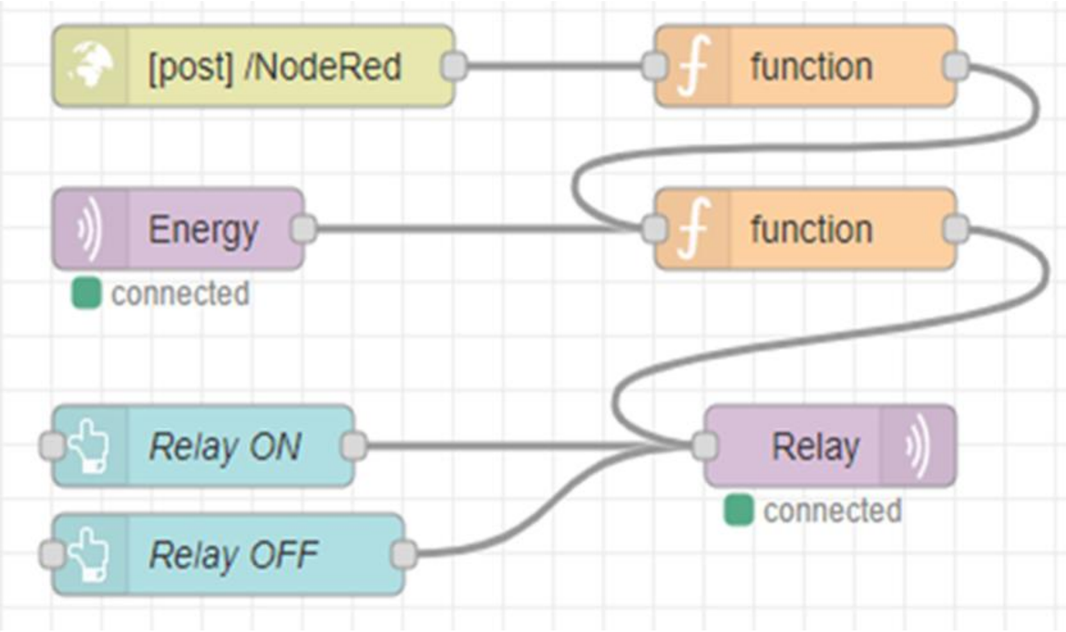
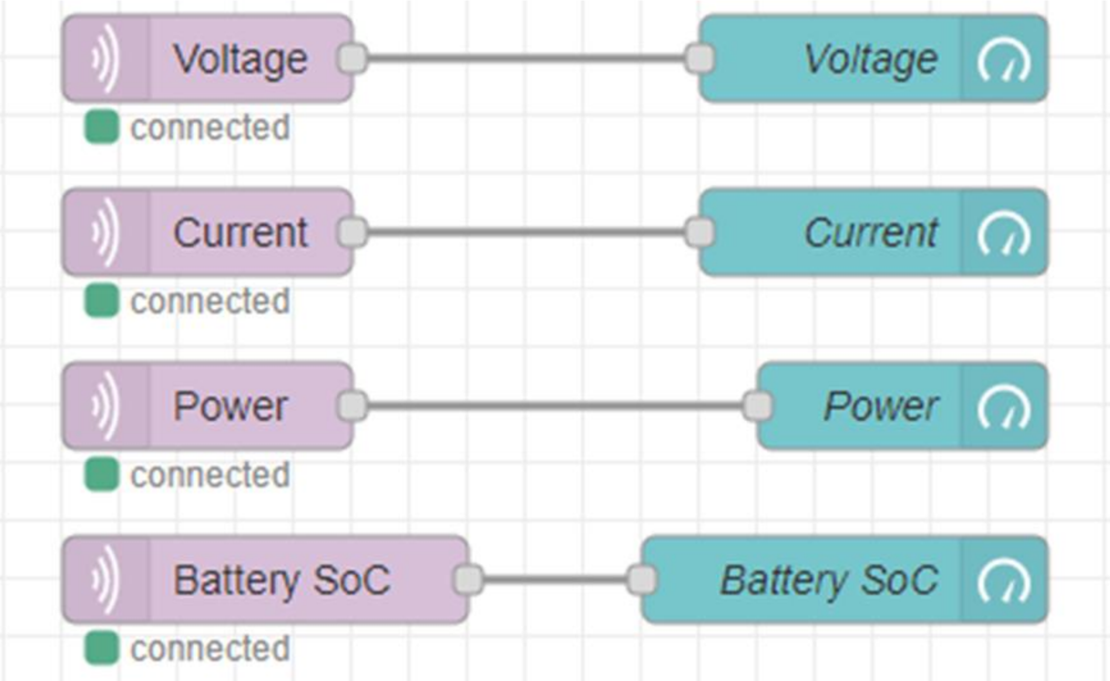
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2/C4

Web Interface and Node-Red IoT server



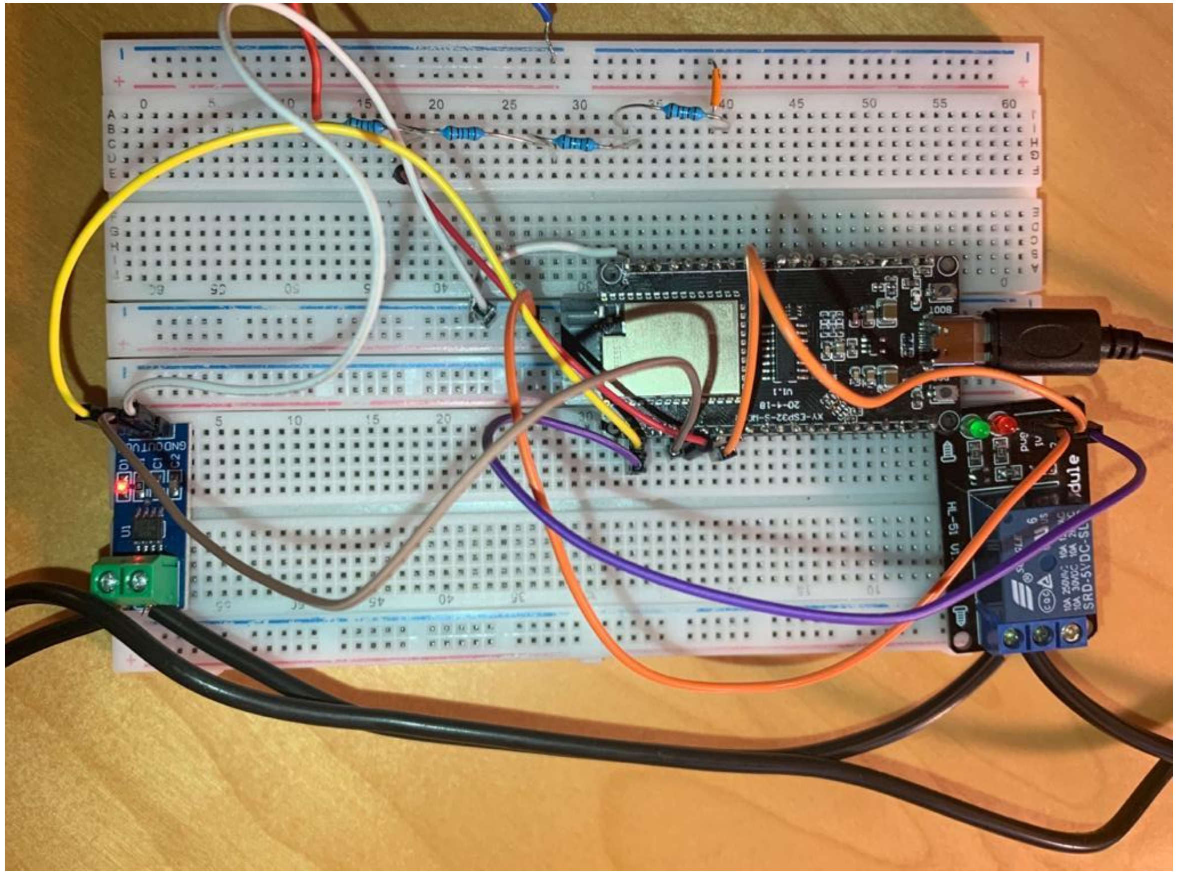
Node-Red flow to facilitate energy trading.



Node-Red flow for data acquisition

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Hardware Design and Implementation



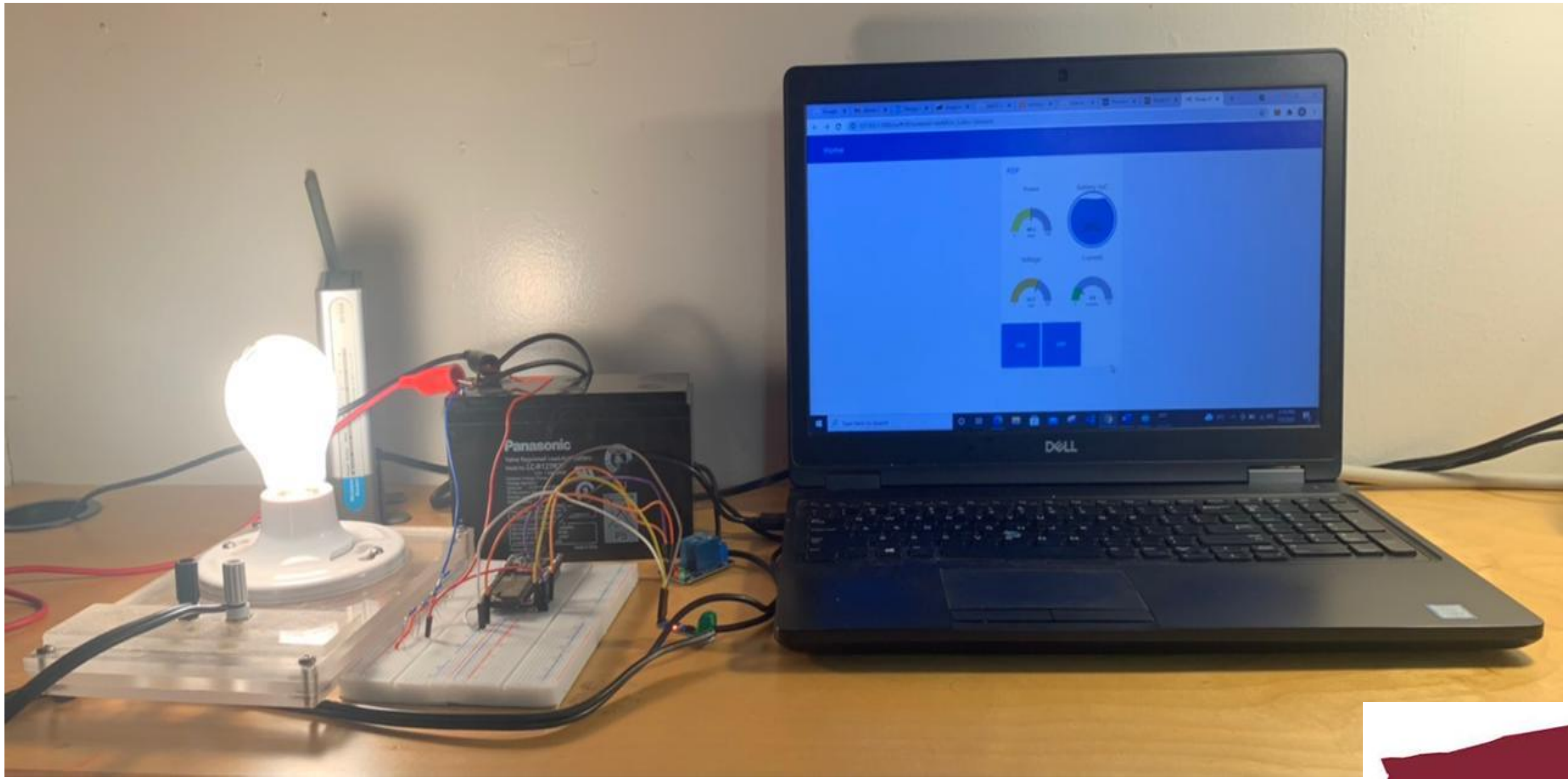
Hardware design

- ❖ESP-32 S2
- ❖Arduino IDE
- ❖Current Sensor
- ❖Voltage Sensor
- ❖Relay

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Experimental Setup

- Battery as Source Voltage
- Bulb as Load
- Wi-Fi Router as Communication Channel
- Relay for switching operations
- Voltage Sensor to to measure Voltage
- Current sensor to measure current



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Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Results

Energy Demand

Sr.No	Amount	Price	Buyer	
1	1 whr	1 Eth	0x81434b8aa49223d9D6D7249A64853425Dd2b3208	Purchased
2	3 Whr	2 Eth	0x139320128e32de57391682786cB8253b5aB3A480	Purchased
3	11 whr	6 Eth	0x81434b8aa49223d9D6D7249A64853425Dd2b3208	Purchased
4	1 whr	1 Eth	0x139320128e32de57391682786cB8253b5aB3A480	Sell Delete
5	2 Whr	3 Eth	0x81434b8aa49223d9D6D7249A64853425Dd2b3208	Sell Delete
6	2 Whr	4 Eth	0x27b62Dd1eD0394018B22c2D38b13E01C83e8b862	Sell Delete

❖ Energy demands by the buyers

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Results

❖ Available Energy posted by sellers

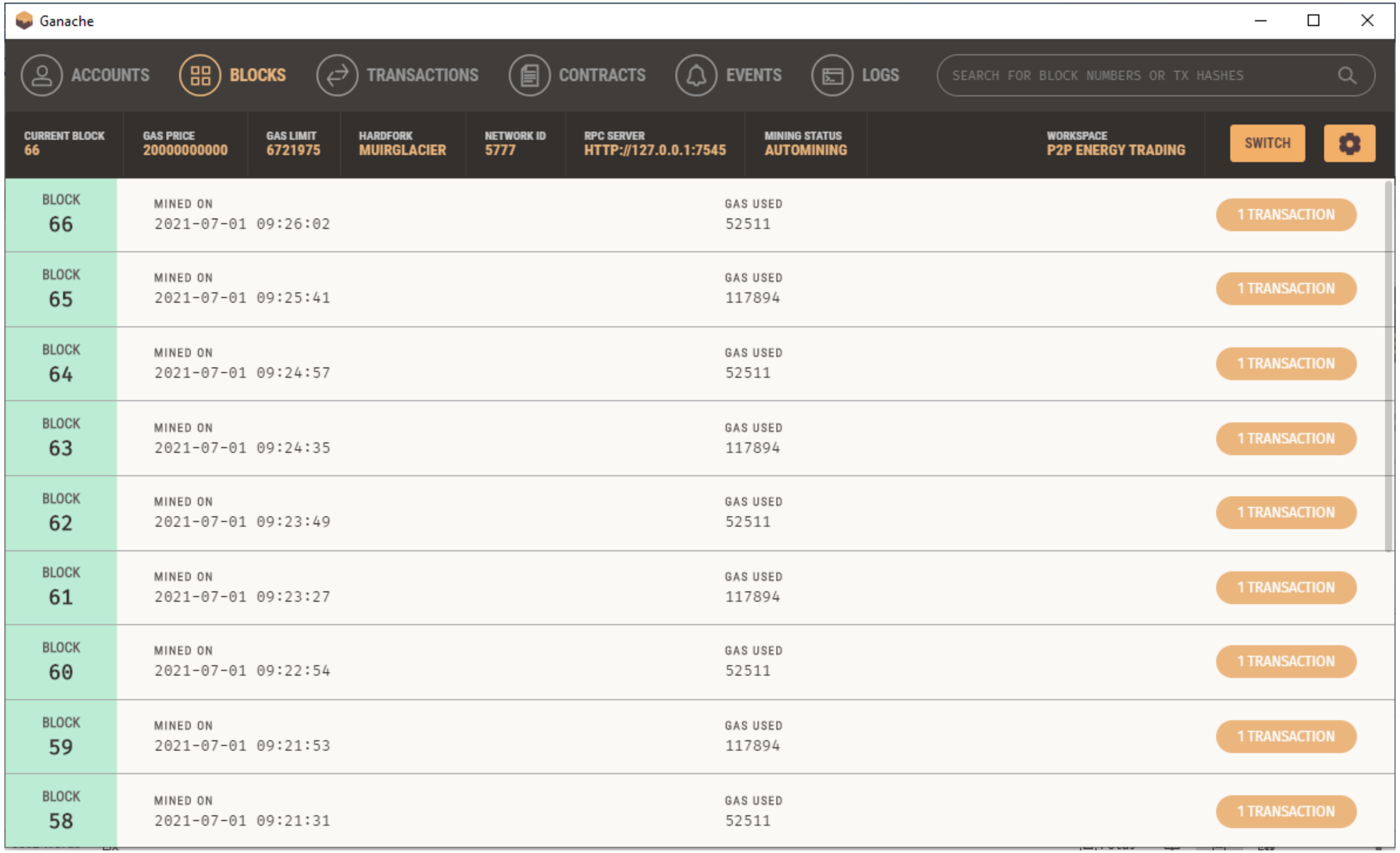
Buy Energy

Sr.No	Amount	Price	Seller	
9	5 Whr	1 Eth	0x81434b8aa49223d9D6D7249A64853425Dd2b3208	Purchased
10	5 Whr	1 Eth	0x139320128e32de57391682786cB8253b5aB3A480	Purchased
11	5 Whr	1 Eth	0x81434b8aa49223d9D6D7249A64853425Dd2b3208	Purchased
12	2 Whr	1 Eth	0x40234186eA4e23bb69258B7D8C21b8486ce66FD5	Buy Delete
13	2 Whr	2 Eth	0x710B2322b2aA5aD0f81C7b47af023B75ecec3Fdf	Buy Delete
14	2 Whr	5 Eth	0xcaF073257dDc8F00280710f0365D31CEE26345eC	Buy Delete

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Results

Blockchain status on server



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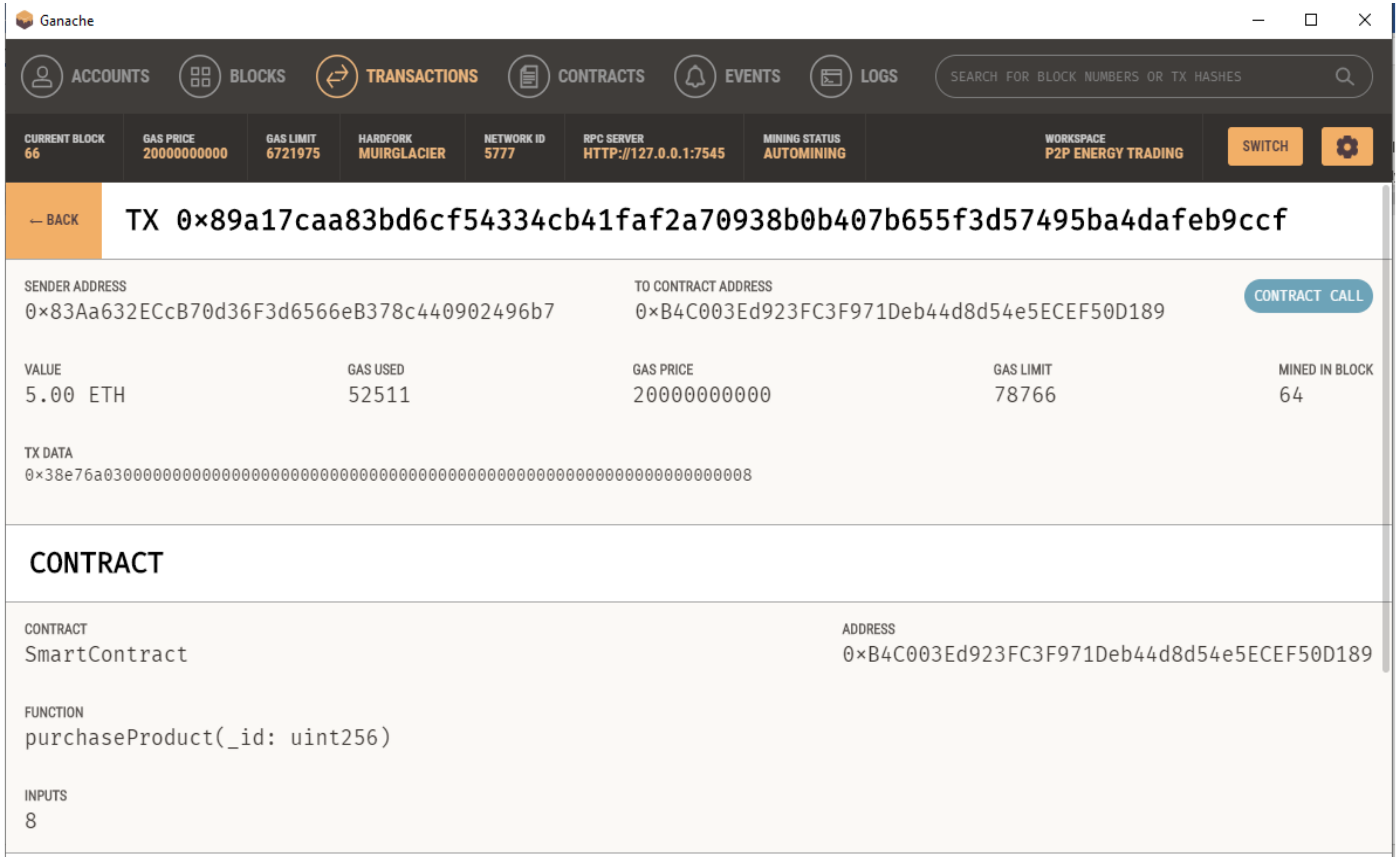
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Results



Details of block 64 on the blockchain server

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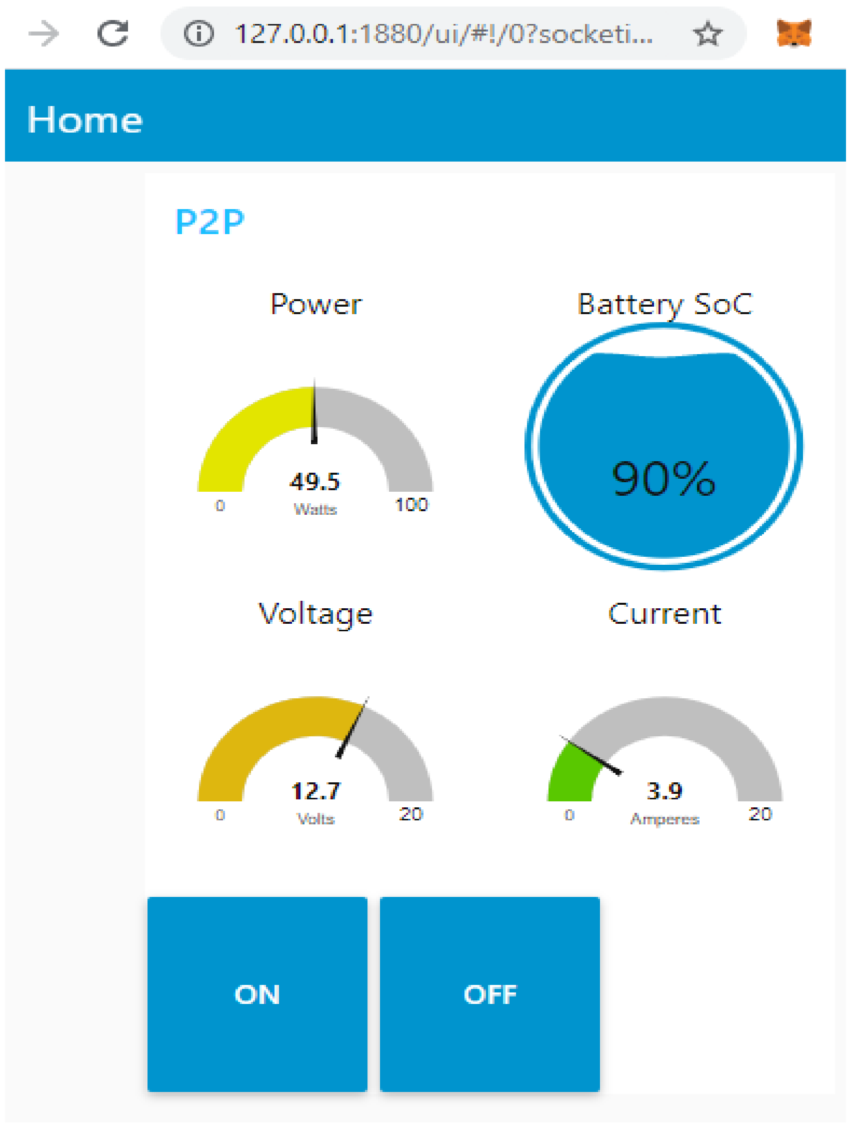
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 2

Results



- ❖ Node-Red dashboard
- ❖ http://localhost:1880/ui

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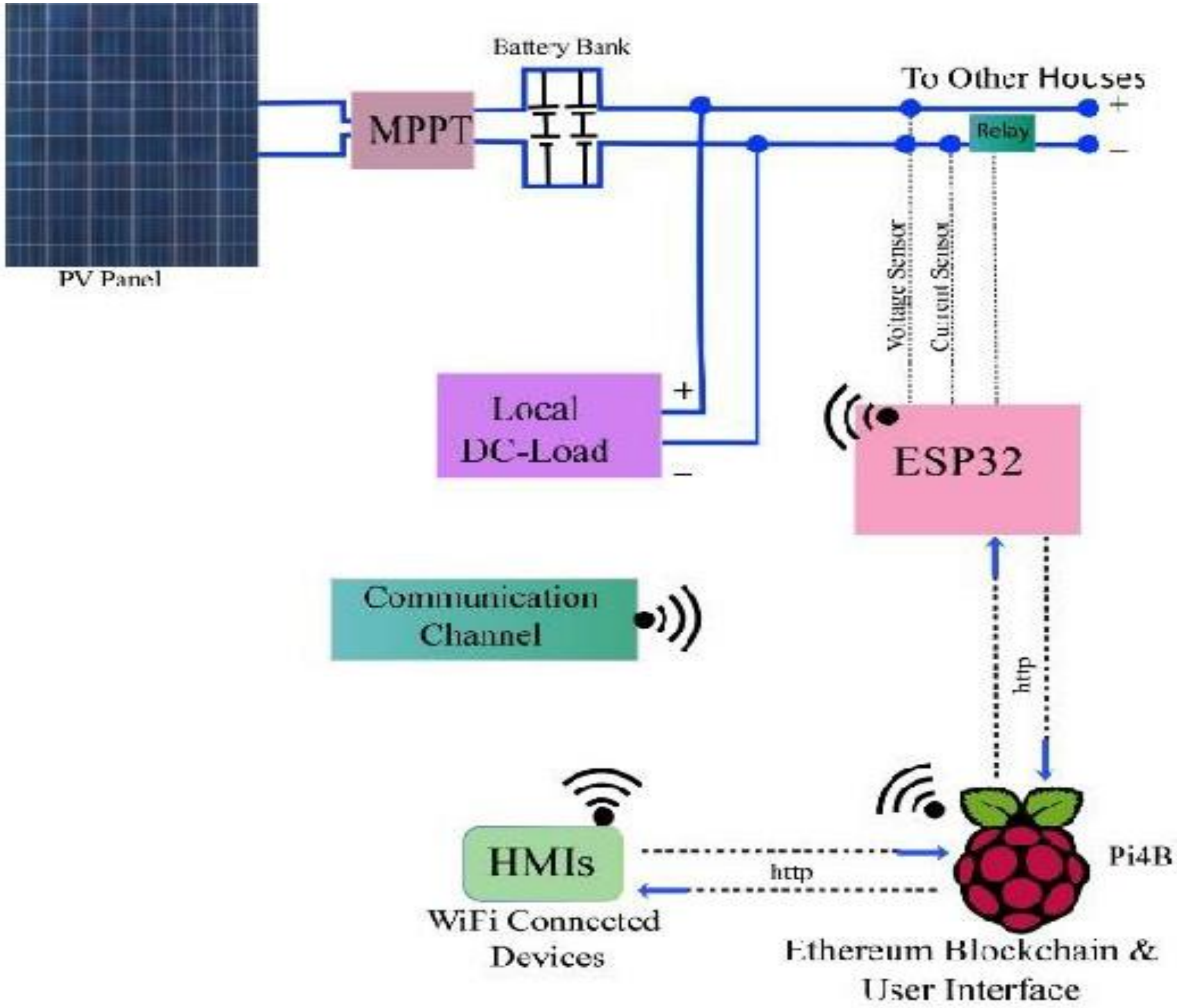
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

Site Description

Proposed Site

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

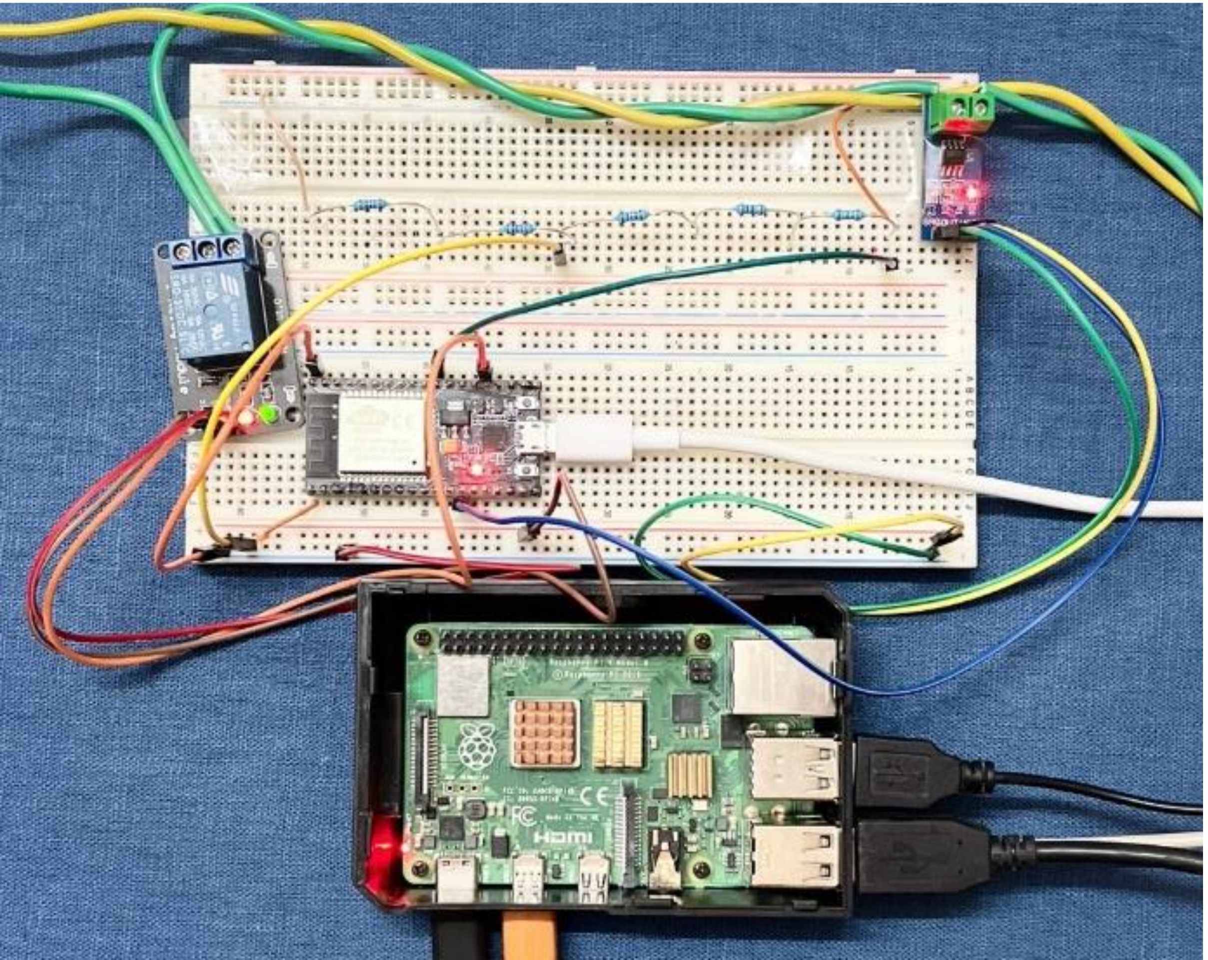
Hardware
and
Network Structure



- ❖ Low-Cost Server CAD$50
- ❖ Hosted on Local Network
- ❖ Raspberry Pi Model 4 B
- ❖ Private Blockchain
- ❖ HMIs Accessible

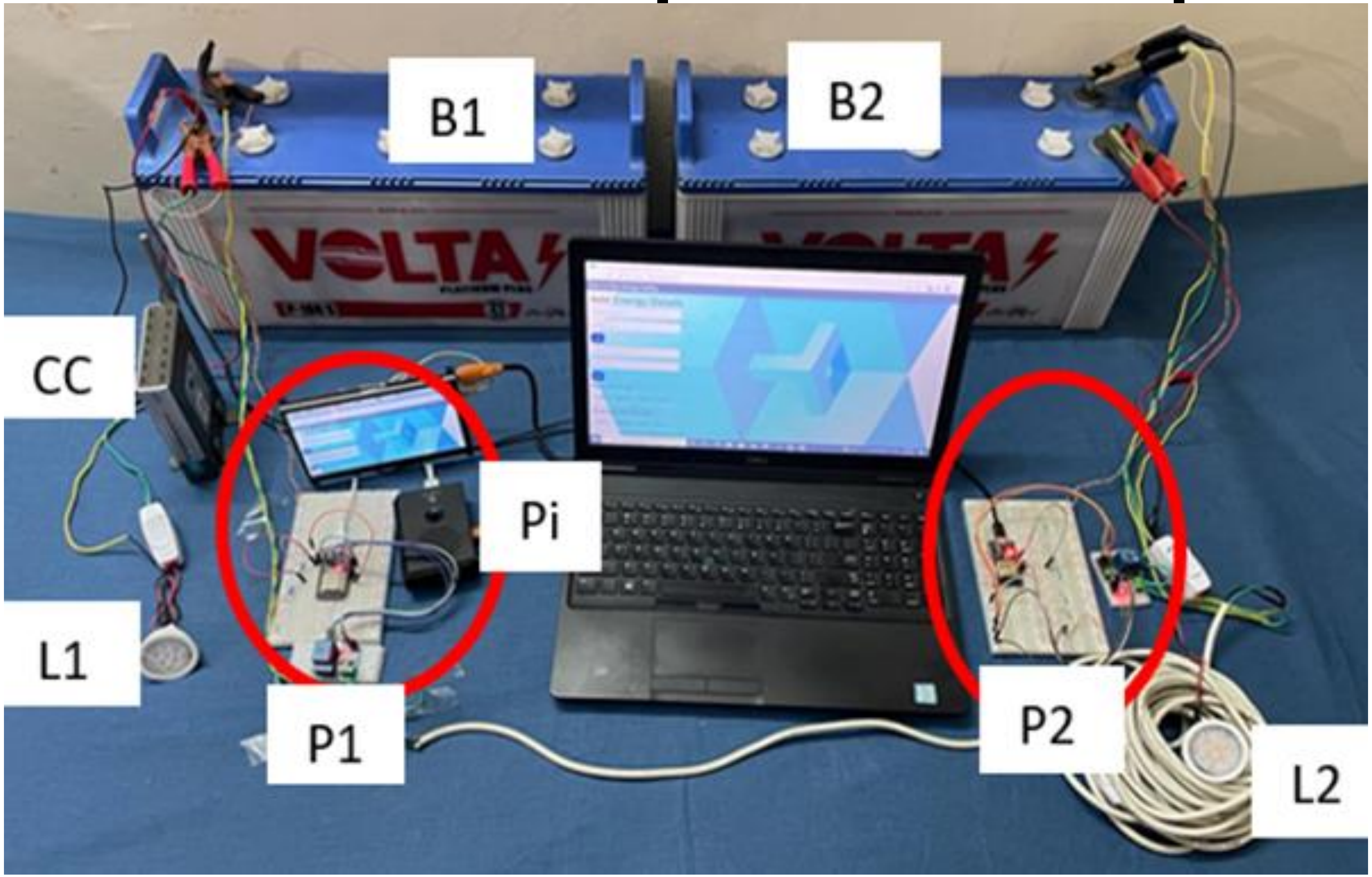
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

Prototype Design



- ❖Raspberry Pi as server
- ❖Relay as switching operations
- ❖ESP32 as IoT server
- ❖Current sensor for current measurement
- ❖Voltage sensor for voltage measurement

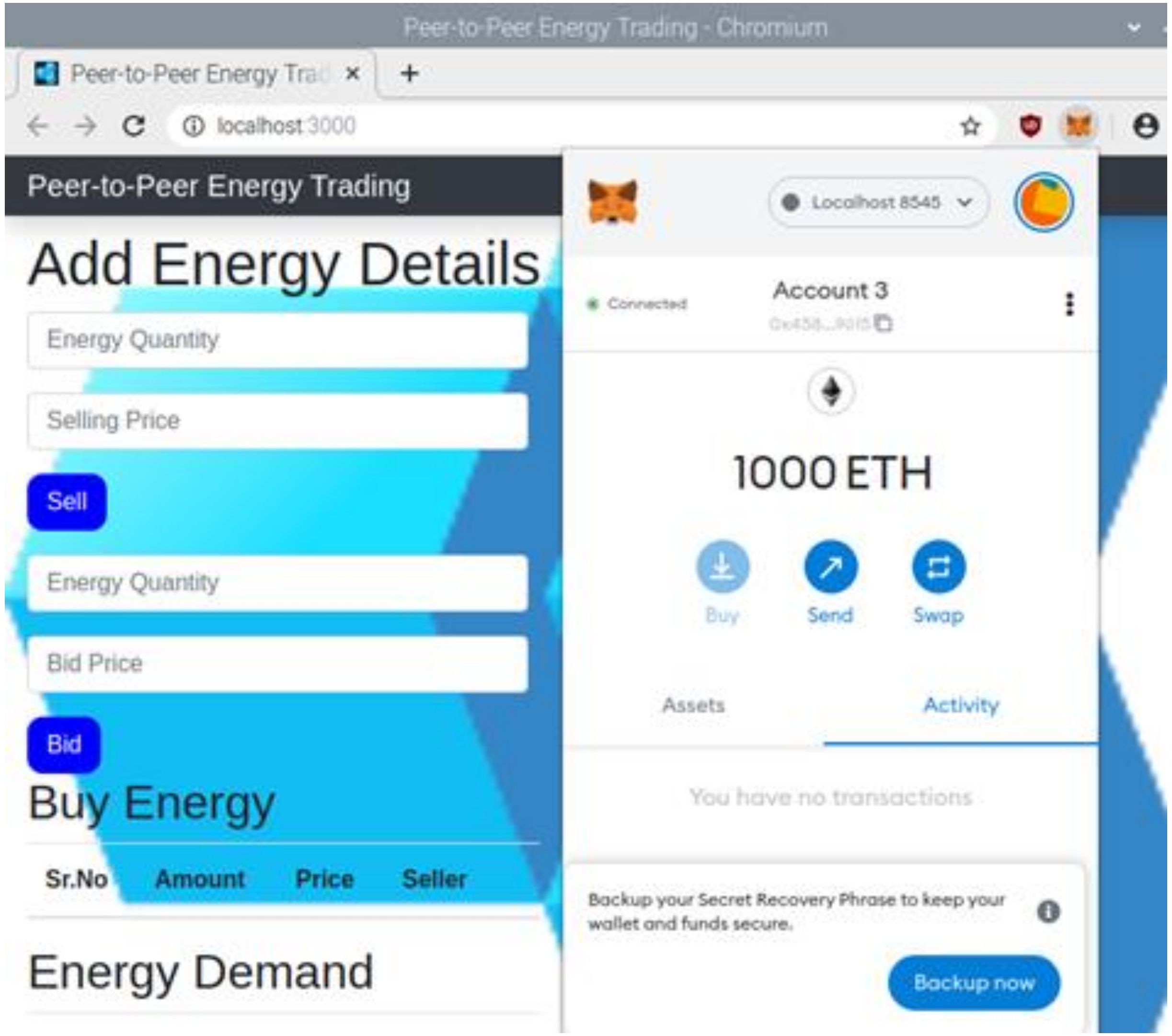
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3-Experimental Setup



Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

Results

❖User Interface



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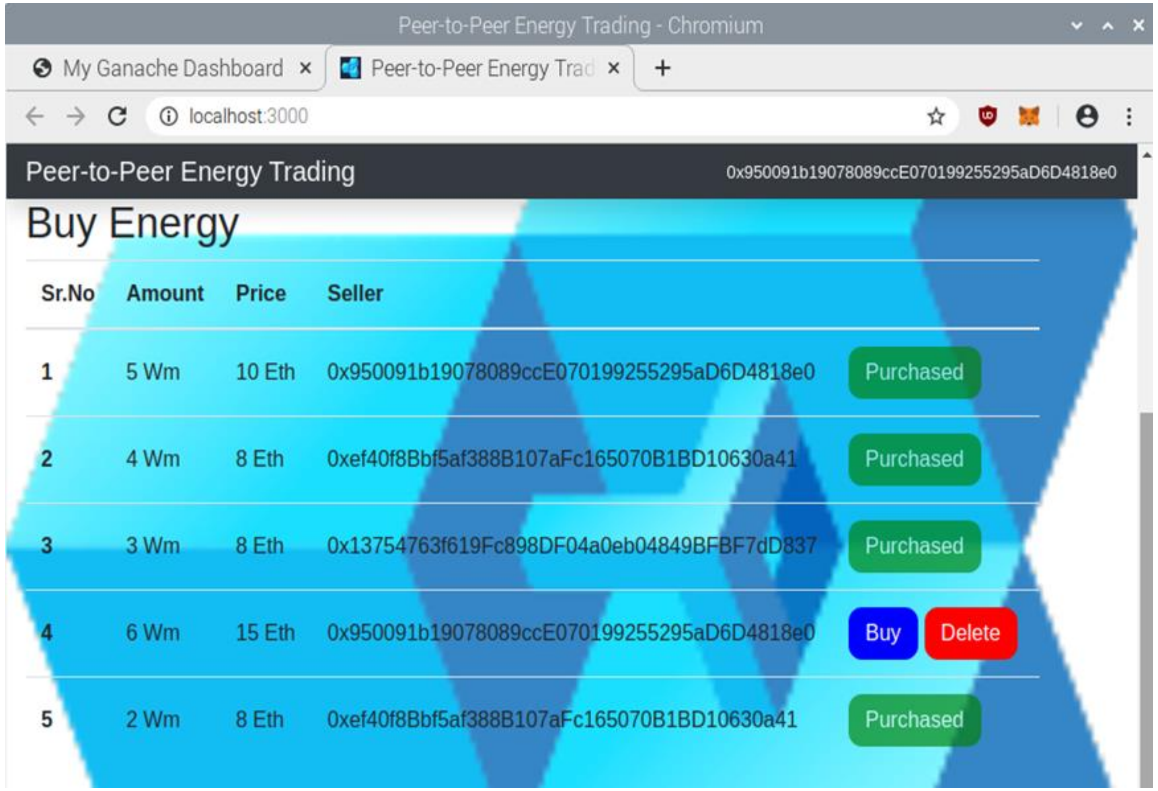
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

Results

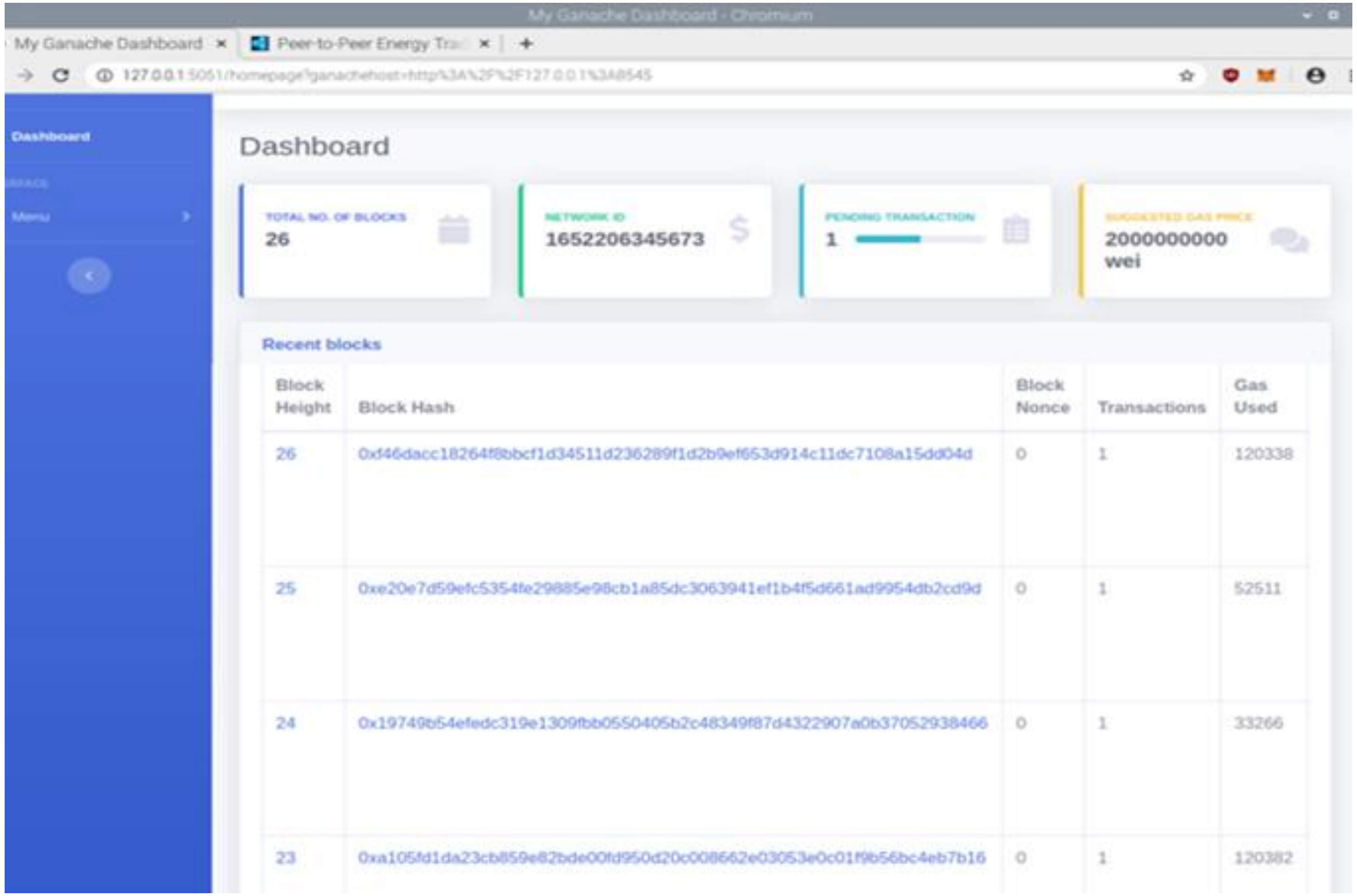


- ❖ Energy Offers

- ❖ Energy Demand

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

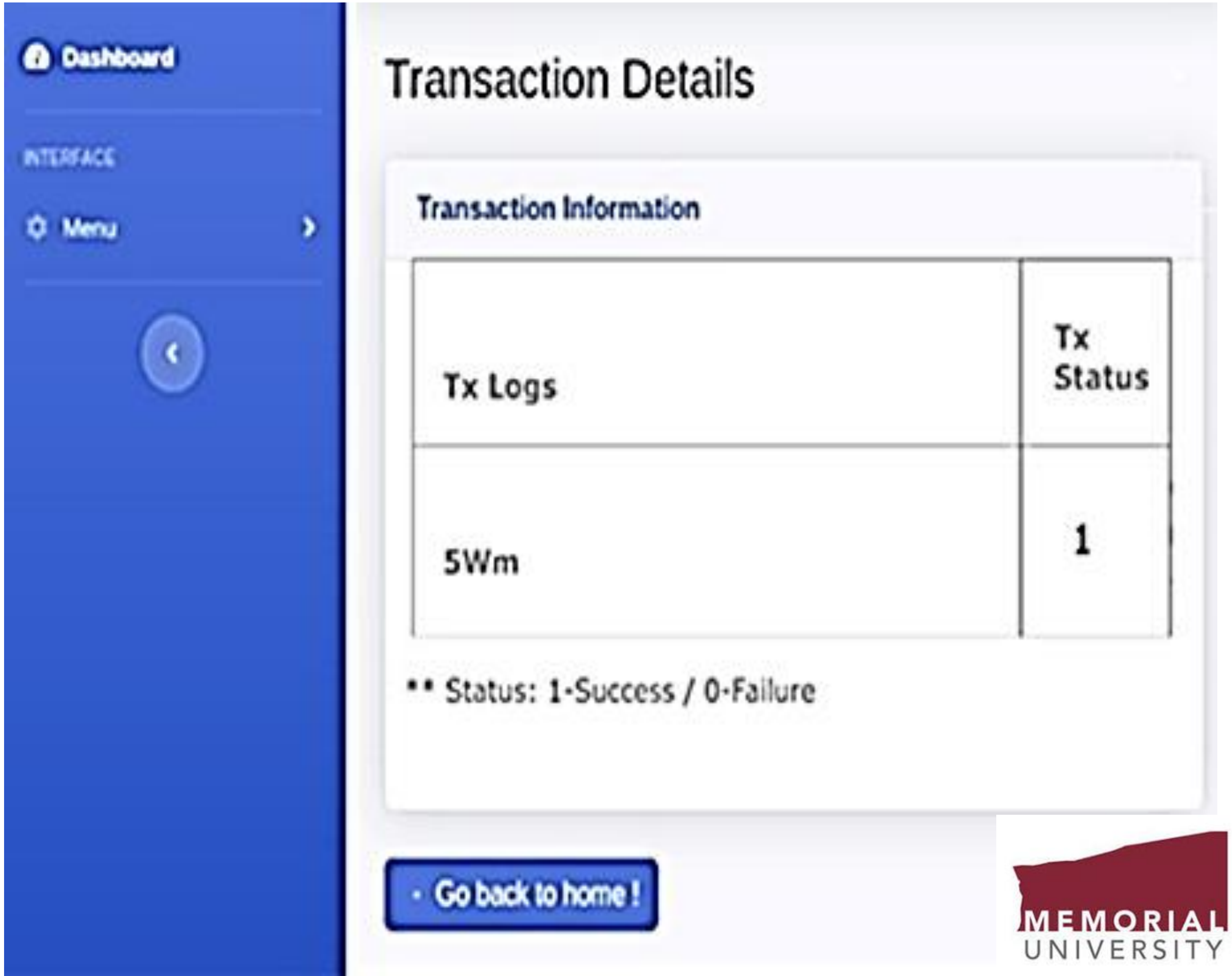
Results



- ❖ Blockchain Server
- ❖ Localhost:5051

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

Results



- ❖ Transaction details on the blockchain

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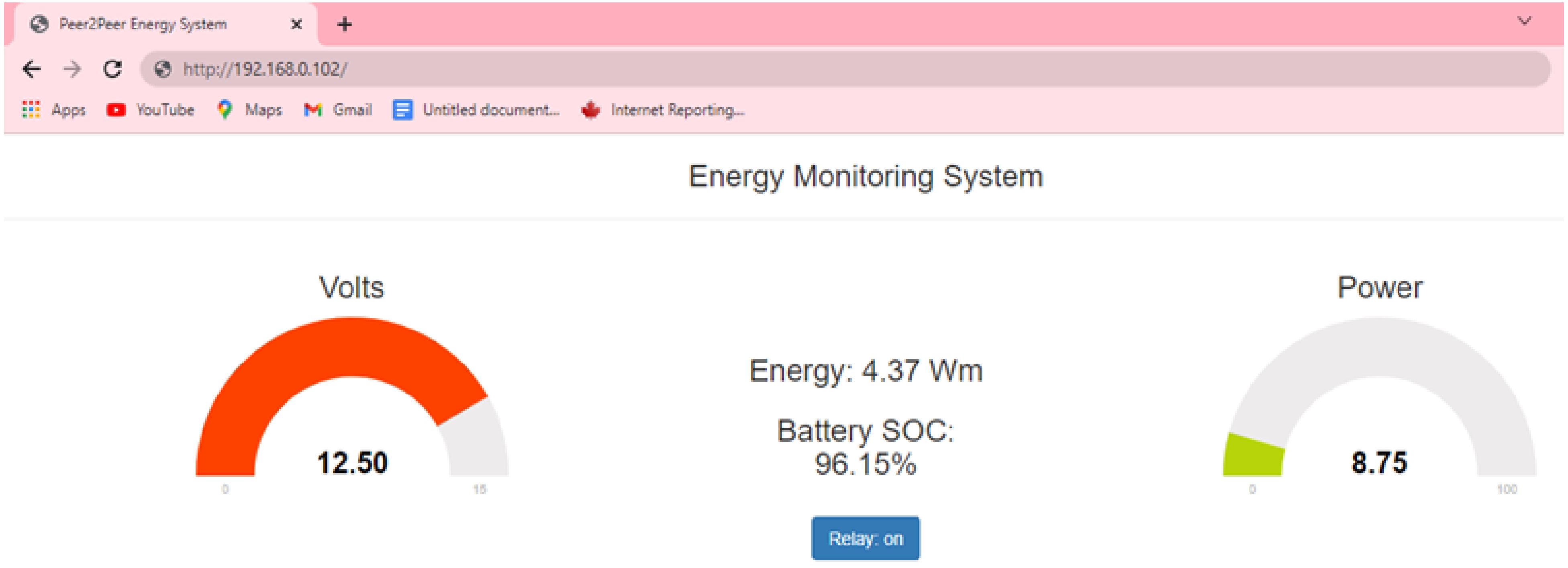
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 3

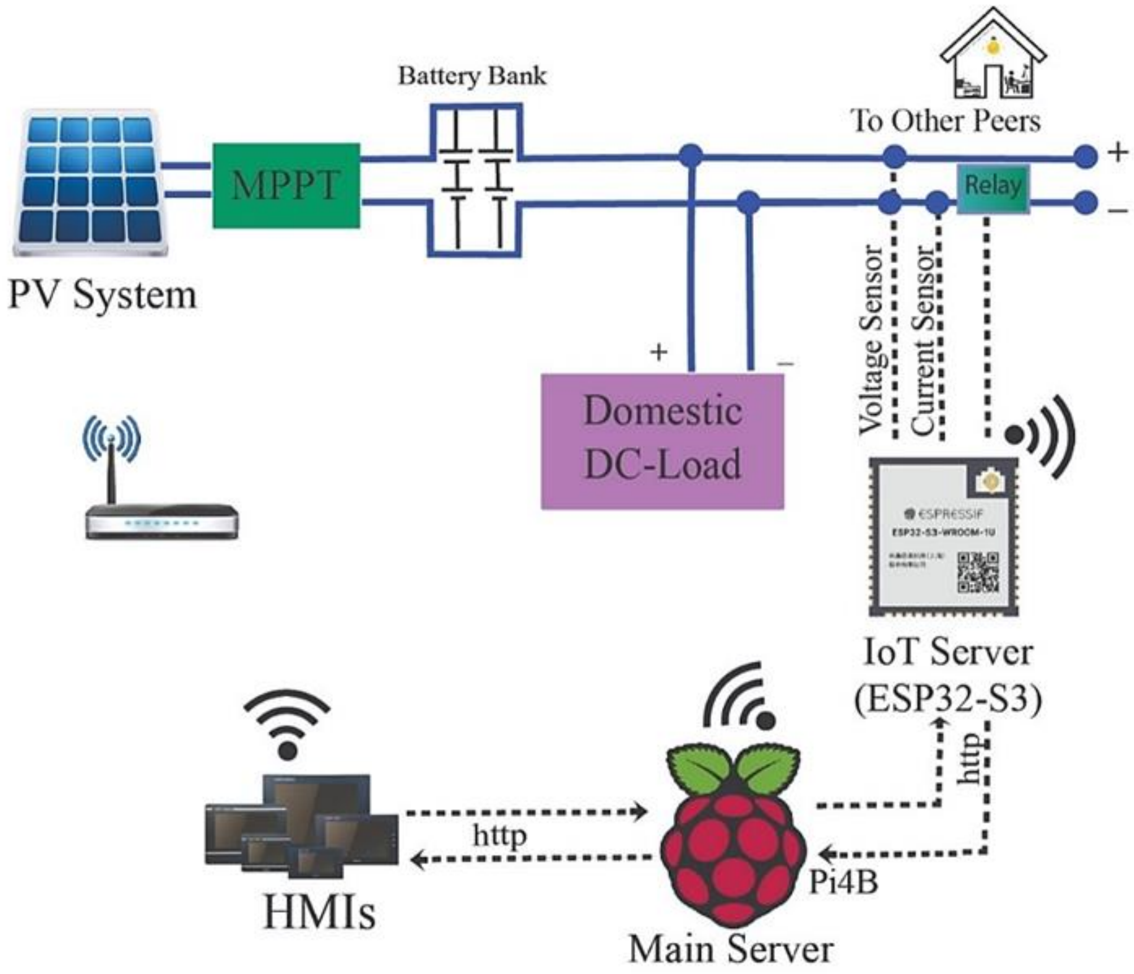
Results



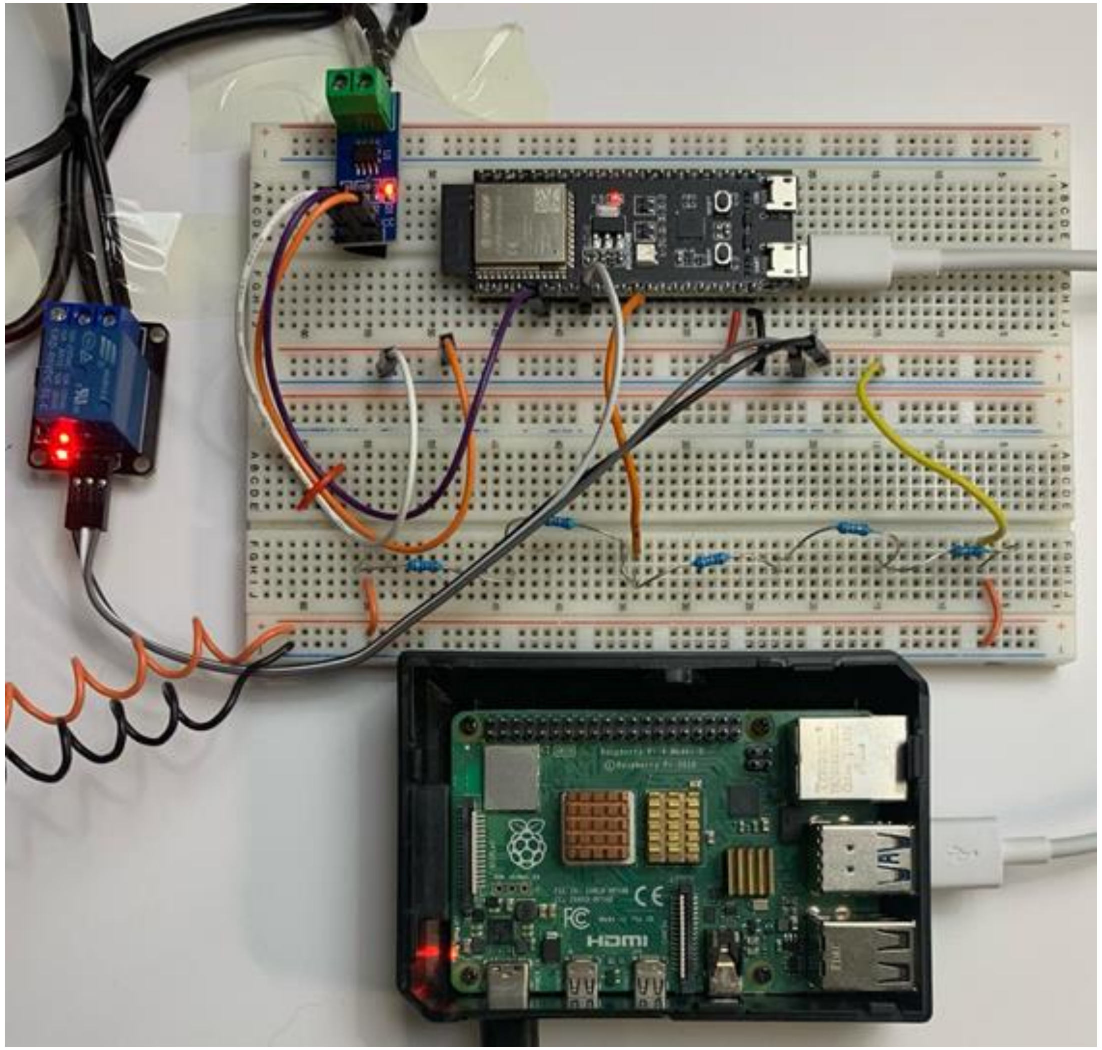
❖ IoT server status

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4
System Description

- ❖ Low-Cost Server CAD$15
- ❖ Hosted on Local Network
- ❖ Raspberry Pi Model 4 B
- ❖ Private Blockchain
- ❖ HMIs Accessible

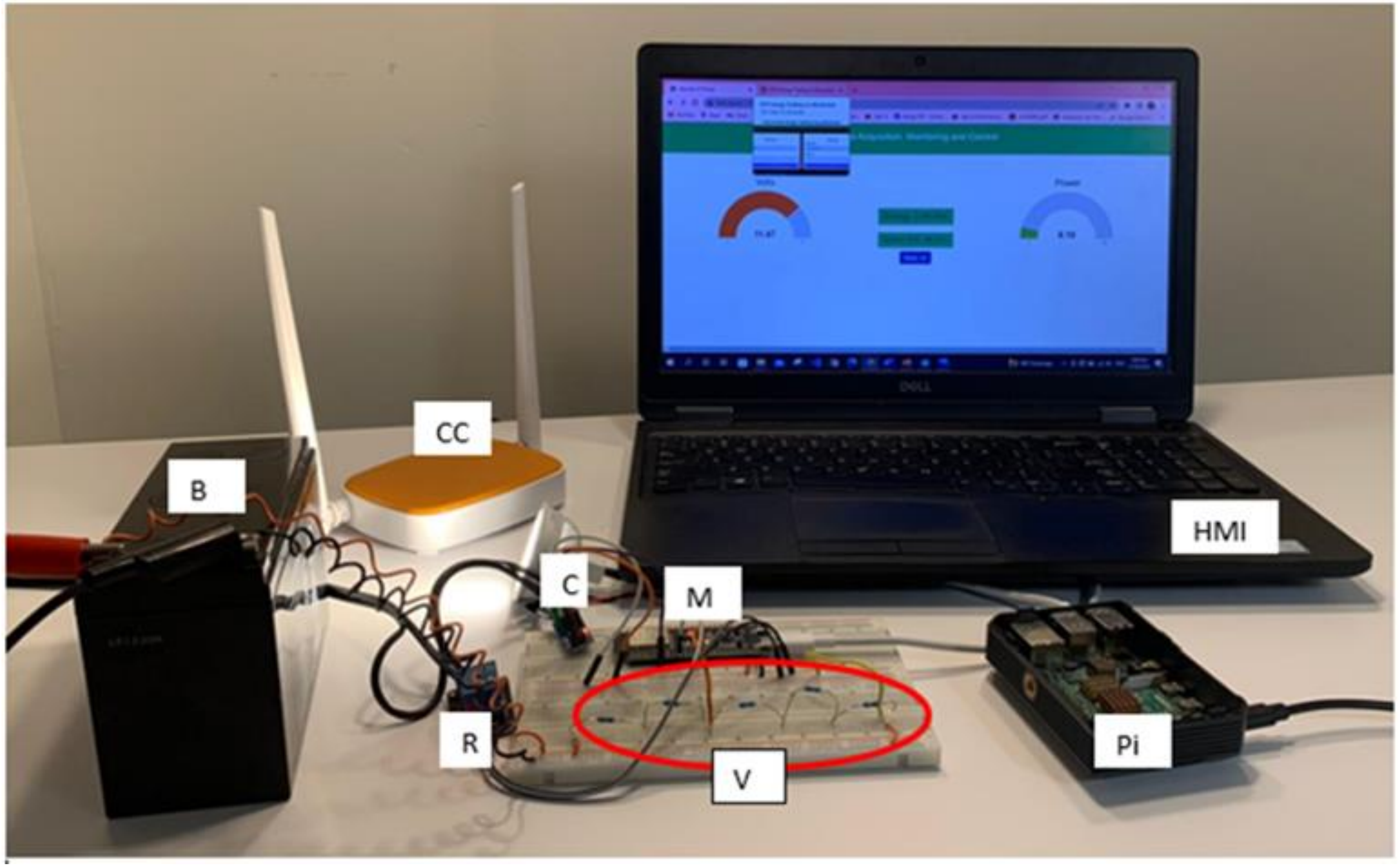


Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Prototype Design



- ❖ Raspberry Pi as server
- ❖ Relay as switching operations
- ❖ ESP32-S3 as IoT server
- ❖ Current sensor for current measurement
- ❖ Voltage sensor for voltage measurement

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Experimental Setup

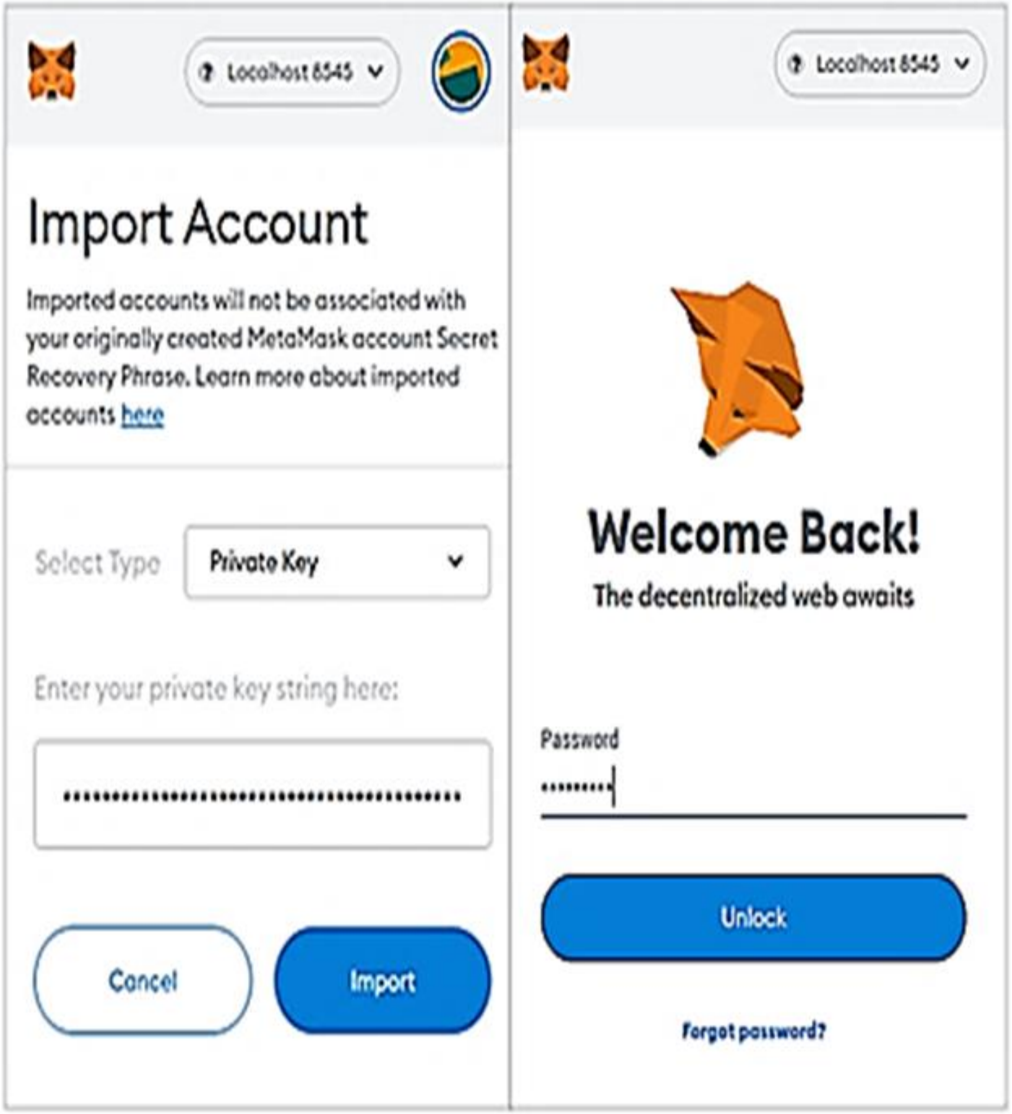


Experimental Setup

- ❖B= Battery voltage source
- ❖CC= Private Communication Chanel
- ❖M=ESP32-S3
- ❖C=Current Sensor
- ❖V=Voltage Source
- ❖Pi= Pi4B
- ❖HMI Device

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Implementation Methodology

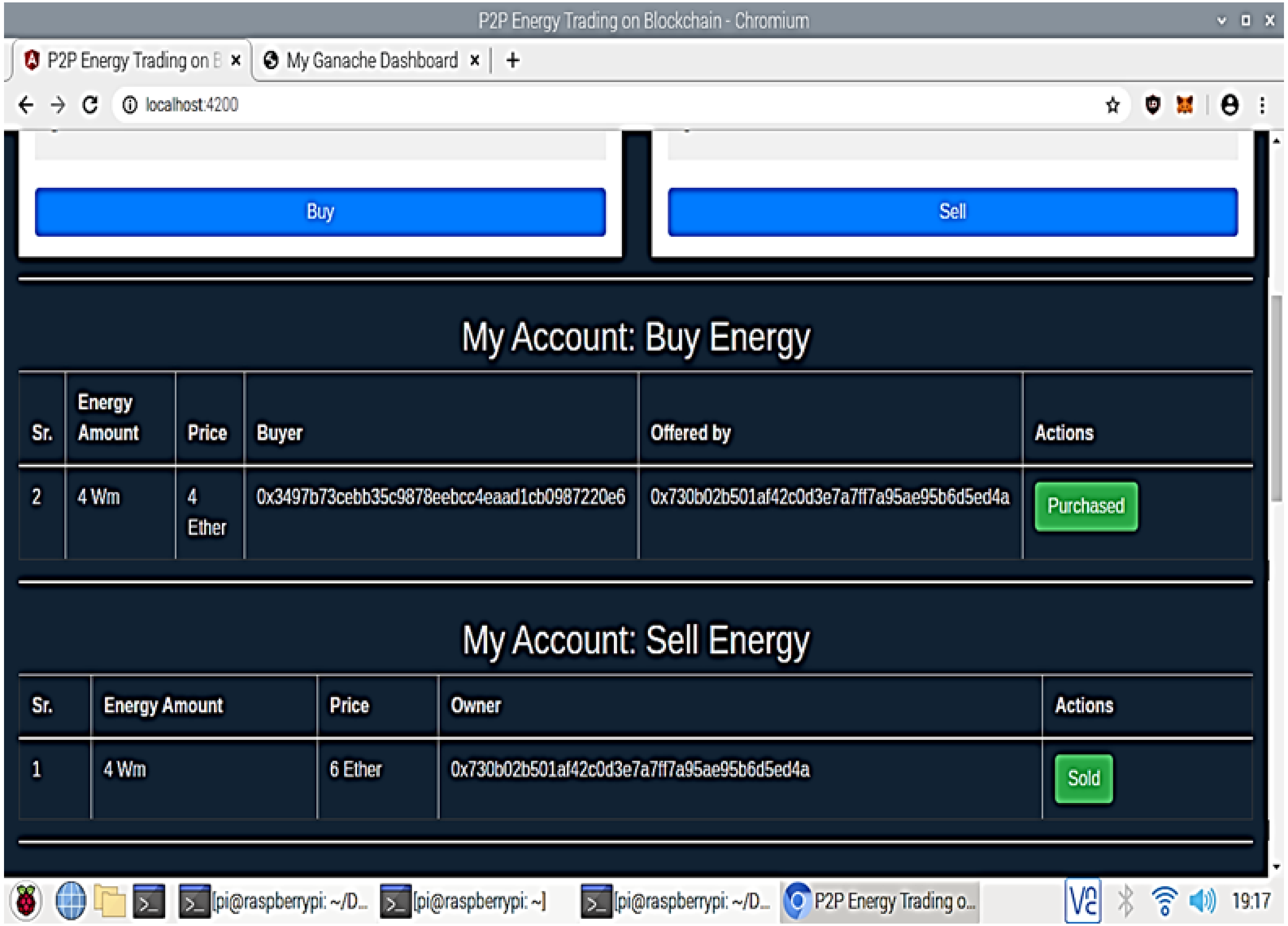
Accounts Import



User Authentication

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4

Testing and Results



- ❖ My Account Status on UI
- ❖ Localhost:4200

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Testing and Results

Buy Energy: Other Peers

Sr.	Energy Amount	Price	Owner	Actions
2	2 Wm	4 Ether	0x0e4ee1c7dab906bc621a2f4b64aa143a75cebd50	Purchased
3	3 Wm	2 Ether	0x0e4ee1c7dab906bc621a2f4b64aa143a75cebd50	Purchased
4	4 Wm	3 Ether	0x0e4ee1c7dab906bc621a2f4b64aa143a75cebd50	Buy
5	5 Wm	8 Ether	0x730b02b501af42c0d3e7a7ff7a95ae95b6d5ed4a	Buy

❖ Other Peers Buy Energy Status on UI

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4

Testing and Results

Sell Energy: Other Peers

Sr.	Energy Amount	Price	Demanded by	Actions
1	5 Wm	8 Ether	0x6adb823d3339b5873dd69cc40f1268203f7b6b4a	Sold
3	3 Wm	6 Ether	0x730b02b501af42c0d3e7a7ff7a95ae95b6d5ed4a	Request to Sell
4	10 Wm	6 Ether	0x6adb823d3339b5873dd69cc40f1268203f7b6b4a	Sold
5	8 Wm	10 Ether	0x0e4ee1c7dab906bc621a2f4b64aa143a75cebd50	Request to Sell
6	3 Wm	3 Ether	0x6adb823d3339b5873dd69cc40f1268203f7b6b4a	Requested for Sell
7	10 Wm	8 Ether	0x0e4ee1c7dab906bc621a2f4b64aa143a75cebd50	Request to Sell

❖ Other Peers Sell Energy Status

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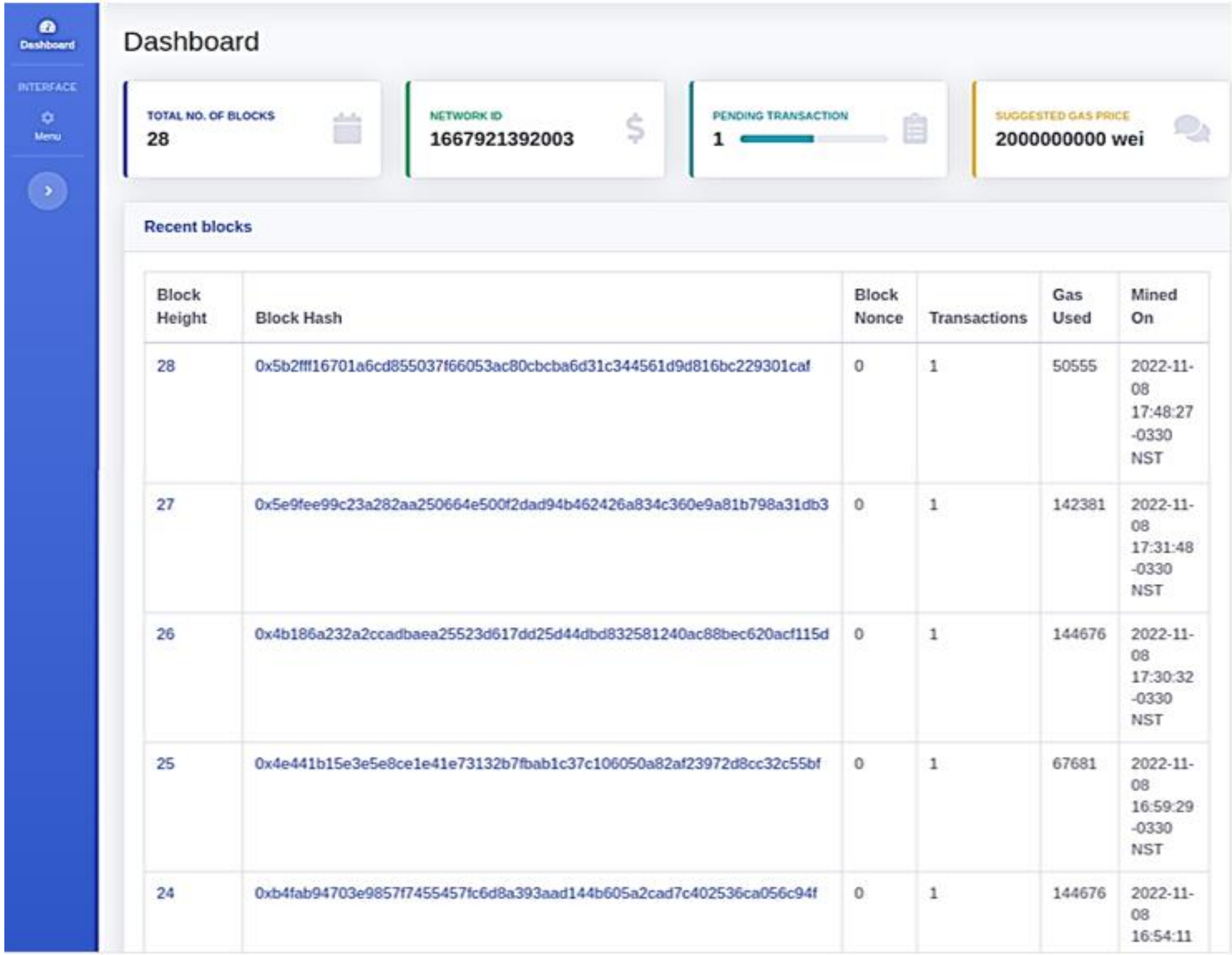
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Testing and Results



Block Height	Block Hash	Block Nonce	Transactions	Gas Used	Mined On
28	0x5b2fff16701a6cd855037f66053ac80cbcba6d31c344561d9d816bc229301caf	0	1	50555	2022-11-08 17:48:27 -0330 NST
27	0x5e9fee99c23a282aa250664e500f2dad94b462426a834c360e9a81b798a31db3	0	1	142381	2022-11-08 17:31:48 -0330 NST
26	0x4b186a232a2ccadbaea25523d617dd25d44dbd832581240ac88bec620acf115d	0	1	144676	2022-11-08 17:30:32 -0330 NST
25	0x4e441b15e3e5e8ce1e41e73132b7fbab1c37c106050a82af23972d8cc32c55bf	0	1	67681	2022-11-08 16:59:29 -0330 NST
24	0xb4fab94703e9857f7455457fc6d8a393aad144b605a2cad7c402536ca056c94f	0	1	144676	2022-11-08 16:54:11

- ❖ Local Blockchain Server
- ❖ http://localhost:5051/

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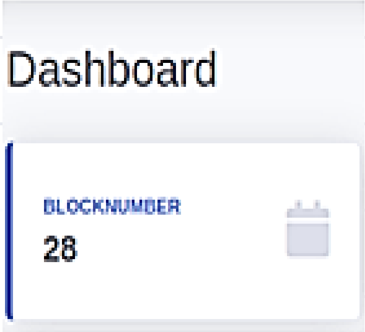
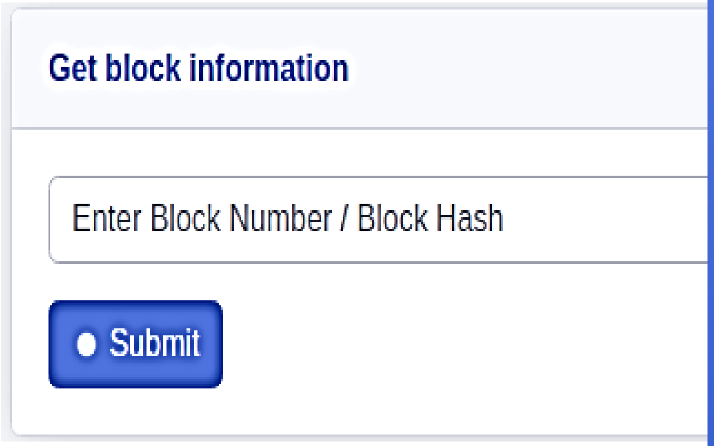
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Testing and Results

Overview	Comments
BlockHash	0x5b2fff16701a6cd855037f66053ac80cbcba6d31c344561d9d816bc229301caf
BlockNonce	0
Transactions	1
GasUsed	50555
MinedOn	2022-11-08 17:48:27 -0330 NST
Difficulty	1
Size	668.00 B
Gaslimit	30000000
ParentHash	0x5e9fee99c23a282aa250664e500f2dad94b462426a834c360e9a81b798a31db3

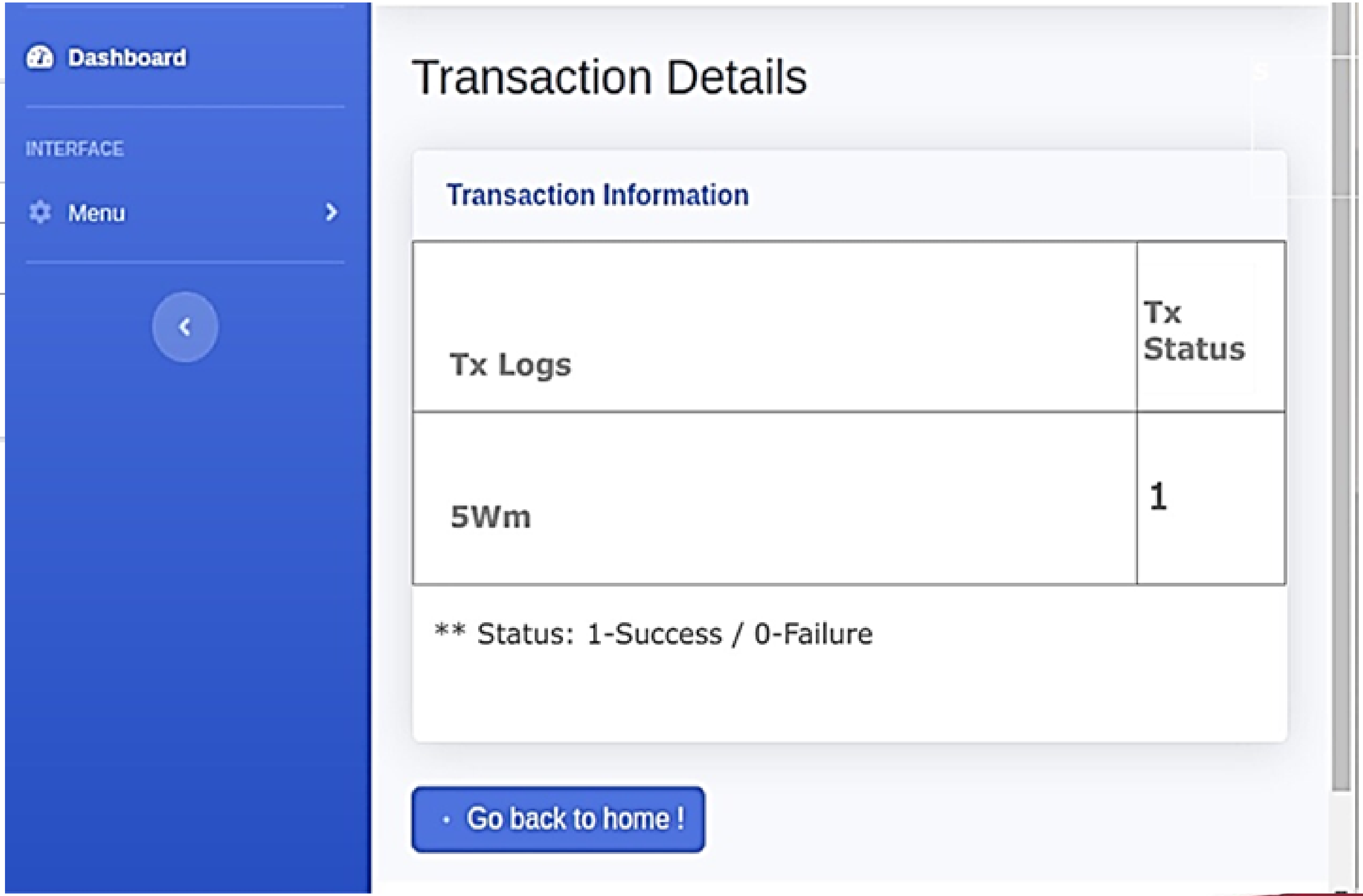


- ❖ Block Details

Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4 Testing and Results



❖Block Information



❖Details of Energy transaction

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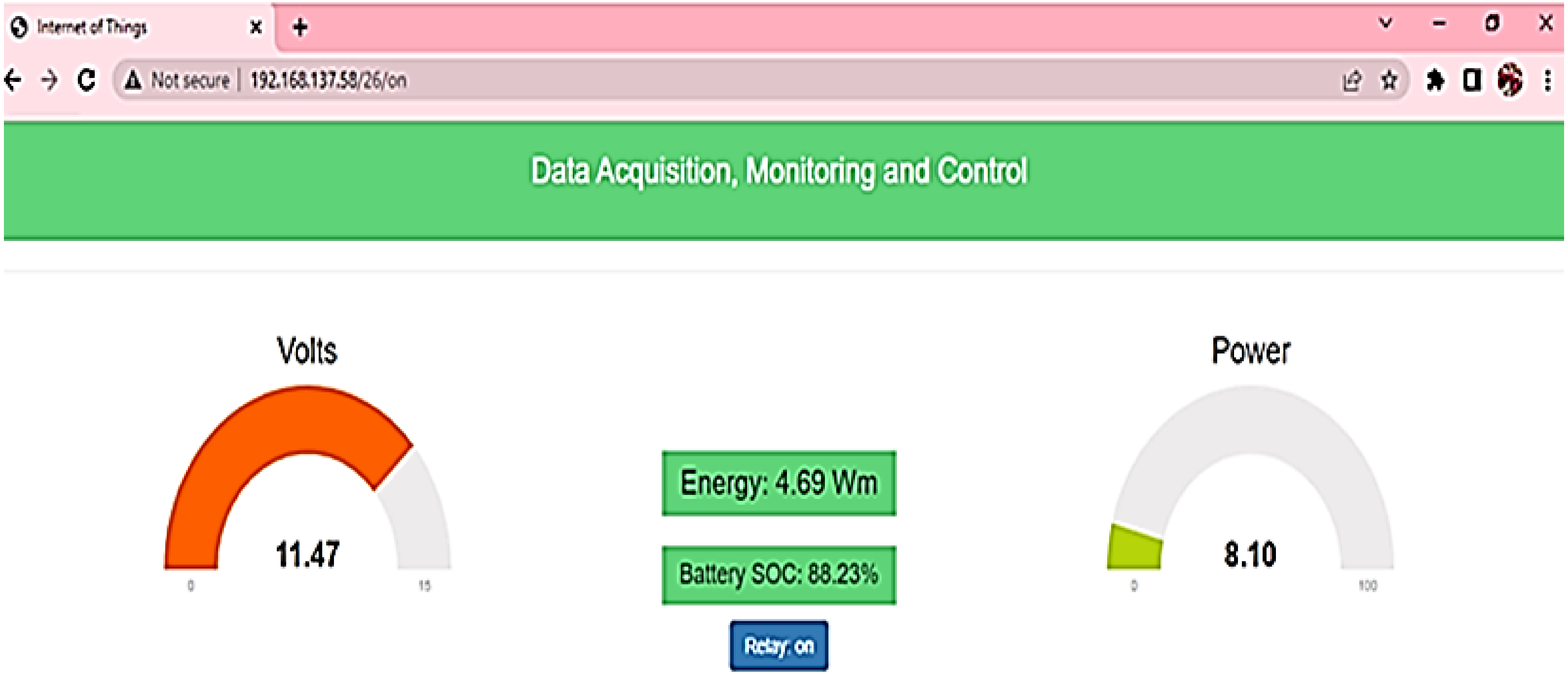
Peer-to-Peer Energy Trading using the IoT and Blockchain Method 4
Testing and Results



❖IoT server status

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Conclusion

Summary

- ❖ Optimal design of a Micro Grid is achieved for a remote community using Homer Pro.
- ❖ Technical information regarding P2P energy trading as well as connection details are also provided.
- ❖ Results indicate isolated DC-microgrids proved to be the most effective solution for un-electrified remote settlements.
- ❖ **First Method** Presents a Unique and simple architecture of P2P energy trading.
- ❖ The design proposes a hardware setup that connects with Node-Red for energy transfer in real-time in order to achieve financial benefits since blockchain servers provide a secure and transparent method of conducting financial transactions.
- ❖ In **second Method** both software and hardware implementations. Implementation of the software is carried out by installing a web interface hosted on a local machine by using React. JS library in conjunction with the Ganache GUI, a private Ethereum blockchain.

Conclusion

Summary

- As a result of the system's performance, all trading sessions are completed efficiently, and energy data is monitored accurately.
- **Method 3**, P2P energy trading system is implementation over a remote community is demonstrated.
- Design system is open source and low-cost of CAD$ 50 per house.
- Security measures such as authentication for MetaMask, private keys for each peer to access digital assets, firewalls, login credentials, and seed phrases are considered to be data security measures.
- The results demonstrated that the design system performs the desired functions of a P2P energy trading system, including Energy Transfer, Data Acquisition, Data Monitoring, Data Display, Networked Data Communication, and maintaining a Digital Ledger on a Local Blockchain Network.

Conclusion

Summary

- The **fourth method** uses an Angular-based user interface and IoT server.
- The system uses low-cost, low-power, open-source, and readily available components.
- System is experimentally tested and proven to be a low-cost and low power with all the desired functions of P2P energy trading.

Research Contributions

Design of Dc-microgrid: Optimal DC-microgrid design with the lowest net present cost for a remote community.

P2P Trading: A complete P2P energy trading setup is presented in this study, including technical and financial components as well as software and hardware implementation.

Node-Red based design: Design and implementation of a P2P energy trading platform using a local UI, Ethereum blockchain, and a locally installed Node-Red IoT server.

Conclusion

Research Contributions

React based design: The development and implementation of an open-source, low-cost, local server hosted on a private network to facilitate peer-to-peer energy trading using the Ganache command-line interface (CLI), React. J.S. and Ethereum private blockchain.

Angular based design: As part of the implementation of the proposed P2P energy trading system, Angular is configured, the framework on which many popular websites are built, such as Paypal, IBM, Weather, Samsung, etc. Additionally, an Angular-based UI is implemented on the Pi4B, closely coupled with both a local blockchain server as well as an IoT server running on the ESP32-S3.

Open-Source technology: The proposed system designs incorporate open-source technology.

System security: The design systems are protected by a number of security controls, such as SSIDs and passwords, firewalls, secret recovery phras MetaMask credentials, and a private key for accessing the Ethereum wallet.

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Conclusion

Future work

- ❖ Adding auto sale and purchase functions to the proposed system could be a future research direction.

- ❖ Increased security in the designed IoT and blockchain based P2P energy trading systems solution can be achieved through the development of reliable data encryption algorithms.

- ❖ Examine the possibility of expanding and implementing these systems in larger communities.

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List of publications

Journal Articles

1. M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Blockchain-Based Peer-to-Peer Energy Trading System Using Open-Source Angular Framework and Hypertext Transfer Protocol," *Electronics*, vol. 12, no. 2, p. 287, Jan. 2023, http://dx.doi.org/10.3390/electronics1202028.

2. M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "A Low-Cost, Open-Source Peer-to-Peer Energy Trading System for a Remote Community Using the Internet-of-Things, Blockchain, and Hypertext Transfer Protocol," *Energies*, vol. 15, no. 13, p. 4862, Jul. 2022,: http://dx.doi.org/10.3390/en1513486.

3. M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Design and implementation of an open-Source IoT and blockchain-based peer-to-peer energy trading platform using ESP32-S2, Node-Red and, MQTT protocol," *Energy Reports*, *vol. 7*, pp. 5733–5746, 2021, doi: https://doi.org/10.1016/j.egyr.2021.08.190.

4. M. J. A. Baig, M. T. Iqbal, M. Jamil, and J. Khan, "Peer-to-Peer Energy Trading in a Micro-grid Using Internet of Things and Blockchain," *Electronics*, *vol. 25, no. 2*, 2021, doi: https://doi.org/10.53314/ELS2125039B.

Refereed Conference Publications

1. M. J. Aziz Baig, M. T. Iqbal, M. Jamil and J. Khan, "Design and Analysis of an Isolated DC-Microgrid for a Remote Community in Pakistan," 2021 IEEE 12th Annual Ubiquitous Computing, Electronics & Mobile Communication Conference (UEMCON), 2021, pp. 0712-0716, doi: 10.1109/UEMCON53757.2021.9666665.

2. M. J. A. Baig, M. T. Iqbal, M. Jamil and J. Khan, "IoT and Blockchain Based Peer to Peer Energy Trading Pilot Platform," 2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2020, pp. 0402-0406, doi: 10.1109/IEMCON51383.2020.9284869.

List of publications

Other Category Publications

1. M. J. A. Baig, “Blockchain based Peer-to-Peer Energy Trading”, Accepted for fall 2023 Edition, IEEE Canadian Review Magazine.
2. S. A. Omidi, M. J. A. Baig, and M. T. Iqbal, “Design and Implementation of Node-Red Based Open-Source SCADA Architecture for a Hybrid Power System,” *Energies*, vol. 16, no. 5, p. 2092, Feb. 2023, doi: 10.3390/en16052092.
3. S. U. Uddin, M. J. A. Baig, and M. T. Iqbal, “Design and Implementation of an Open-Source SCADA System for a Community Solar-Powered Reverse Osmosis System,” *Sensors*, vol. 22, no. 24, p. 9631, Dec. 2022, doi: 10.3390/s22249631.
4. L. Ahsan, M. J. A. Baig, and M. T. Iqbal, “Low-Cost, Open-Source, Emoncms-Based SCADA System for a Large Grid-Connected PV System,” *Sensors*, vol. 22, no. 18, p. 6733, Sep. 2022, doi: 10.3390/s22186733.
5. M. J.A.Baig, M.T. Iqbal “Design and analysis of a rooftop PV system for a University Building in Pakistan,” 2019, [Online]. Available: http://research.library.mun.ca/id/eprint/14659.

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[1] J. Conti, P. Holtberg, J. Diefenderfer, A. LaRose, J. T. Turnure, and L. Westfall, “International energy outlook 2016 with projections to 2040,” USDOE Energy Information Administration (EIA), Washington, DC (United States), Tech. Rep., 2016

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[4] M. J. A. Baig, M. T. Iqbal, M. Jamil and J. Khan, “IoT and Blockchain Based Peer to Peer Energy Trading Pilot Platform,” 2020 11th IEEE Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON), 2020, pp. 0402-0406, doi: 10.1109/IEMCON51383.2020.9284869.

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[6] J. C. Ferreira and A. L. Martins, “Building a community of users for open market energy,” Energies, 2018, doi: 10.3390/en11092330.

[7] E. A. Soto, L. B. Bosman, E. Wollega, and W. D. Leon-Salas, “Peer-to-peer energy trading: A review of the literature,” Appl. Energy, vol. 283, p. 116268, Feb. 2021, doi: 10.1016/j.apenergy.2020.116268.

[10] W. Tushar, T. K. Saha, C. Yuen, D. Smith and H. V. Poor, "Peer-to-Peer Trading in Electricity Networks: An Overview," in IEEE Transactions on Smart Grid, vol. 11, no. 4, pp. 3185-3200, July 2020, doi: 10.1109/TSG.2020.2969657.