Design an Efficient Peer to Peer Energy Trading Algorithm for Microgrid

By

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Supervisor

Dr. Imtiaz Hussain

A dissertation submitted to

Pakistan Navy Engineering College

National University of Sciences and Technology (NUST), Islamabad

A thesis submitted in partial fulfillment of requirements for the degree of

Master of Science (MS) in Electrical (Controls) Engineering

August, 2023

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This thesis is dedicated to *my beloved parents*

Abstract

This thesis presents a novel peer-to-peer (P2P) energy trading and pricing algorithm designed to facilitate efficient and transparent energy exchange within a decentralized energy market. With the increasing adoption of renewable energy sources and the proliferation of distributed energy resources (DERs), there is a growing need for effective mechanisms to enable local energy trading among prosumers. Traditional centralized energy systems face challenges in accommodating these emerging trends, leading to an increased interest in decentralized P2P energy trading solutions.

To evaluate the effectiveness of the algorithm, a gaming based approach is employed. Real-world energy consumption and production data are used to create a realistic testbed, enabling the algorithm's performance to be analyzed under diverse scenarios. The simulation results demonstrate the algorithm's ability to efficiently match energy supply and demand, optimize energy allocation, and ensure equitable pricing in the P2P energy market.

Moreover, the algorithm's scalability and robustness are investigated to assess its feasibility for large-scale deployment. By considering network dynamics, computational efficiency, and communication overhead, the algorithm demonstrates promising scalability and resilience characteristics, paving the way for its potential implementation in real-world energy systems.

Overall, this thesis contributes to the emerging field of P2P energy trading by proposing an innovative algorithm that addresses the challenges associated with decentralized energy markets. The algorithm's ability to optimize energy trading and pricing fosters the development of more sustainable and resilient energy systems, empowering prosumers to actively participate in the energy transition

Key Words: *Peer to Peer energy trading, energy allocation and pricing algorithm, sellers and buyers*

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CHAPTER 1: INTRODUCTION

1.1 General

In recent years, the energy landscape has witnessed a significant transformation with the proliferation of renewable energy resources and advancements in information and communication technology (ICT) systems. This has paved the way for the emergence of innovative energy trading models, such as Peer-to-Peer (P2P) energy trading, which allows direct energy exchange between consumers and prosumers within local electricity distribution systems, optimal grouping can improve efficiency of the energy network by allowing the prosumers to trade locally, thereby reducing the non-commodity charges [1]. P2P energy trading holds the potential to revolutionize the traditional energy market by promoting decentralization, sustainability, and cost-effectiveness [2]. This thesis report aims to provide a comprehensive study of P2P energy trading, exploring its background, historical development, Energy trading and pricing Algorithm and implications for the energy sector.

Figure 1.1 P2P energy trading Potential benefits.

1.2 Background

Before delving into the history of P2P energy trading research, it is crucial to understand the concept of P2P energy trading and its origin. The term "P2P" stands for "Peer-to-Peer," which refers to a decentralized approach of directly connecting individuals or entities, known as peers, to engage in transactions without the need for intermediaries. P2P energy trading, therefore, involves the direct exchange of energy between energy consumers and prosumers, bypassing traditional centralized energy systems and utilities. The concept of P2P energy trading finds its roots in the broader P2P sharing economy, which emerged with the advent of digital technologies and the Internet. Pioneered by file-sharing platforms such as Airbnb and Uber, the P2P model facilitated direct transactions between individuals, enabling resource sharing and collaborative consumption.

However, A definition of P2P energy trading from the National Renewable Energy Laboratory (NREL) in the United States can be articulated as follows:

"P2P energy trading is an innovative approach to energy exchange, allowing individual energy producers and consumers to directly trade electricity within a local network. It leverages digital platforms and advanced technologies to facilitate secure and transparent transactions, enabling participants to optimize their energy usage, promote renewable energy integration, and contribute to a more resilient and sustainable energy system."

A significant aspect of energy markets deals with the decentralization and direct interaction between energy consumers and producers, which is the core principle of Peer-to-Peer (P2P) energy trading.

P2P energy trading markets can be categorized into three primary deployment methods, namely: i) Full P2P market, ii) Community-manager based P2P marketand iii) Hybrid P2P market

1.3 Problem Statement

The power sector is facing ongoing challenges due to the persistent imbalance between energy demand and supply. There is an increasing demand for electricity and a 40% increase is predicted by 2030 [3]. This imbalance has led to frequent power shortages and disruptions, often resulting in electric power cut-offs, commonly known as load-shedding. The significant gap between electricity demand and available supply puts immense stress on the power grid and negatively impacts the reliability and quality of electricity service.

The existing centralized energy system struggles to cope with this issue, resulting in limited electricity access and hindering economic progress. In addition to these challenges, the current reliance on long transmission lines contributes to significant energy losses during electricity transmission.
Hence, a plan to encounter this problem is required along with the pricing strategy to stabilize the energy market systems [4].

1.4 Proposed Solution & End Product

In order to ensure secure and efficient navigation of electrical energy, several Peer-to-Peer (P2P) energy allocation algorithms have been devised for both known and unknown environments. The utilization of advanced path planning algorithms in P2P energy trading promotes equitable energy allocation and contributes to the reduction of electricity bills. These algorithms optimize energy distribution among participants, ensuring equitable resource utilization. By dynamically adjusting energy flow paths, they minimize wastage and promote efficient consumption, resulting in cost savings for consumers. Integrating these algorithms into P2P energy trading systems fosters fairness, sustainability, and affordability. However, a few limitations including Scalability is a key concern [4], as the system must be able to handle a large number of participants and increased transaction volumes. Regulatory frameworks may not fully support P2P trading, creating barriers to its widespread adoption [5]. Technical integration of diverse energy sources and grid management systems poses challenges [6]. Market design complexities require careful consideration for fair pricing and transparent transactions.
Our main objective is to design an efficient Peer to Peer energy allocation and pricing Algorithm. The proposed approach handles two vital objectives i.e. energy allocation along with stability. This involves monitoring energy flows, load balancing, and managing fluctuations in supply and demand. By addressing stability concerns, the algorithm aims to ensure the reliable and uninterrupted operation of the P2P energy trading system. The proposed algorithm not only focuses on energy allocation and system stability but also tackles the challenge of high energy bills caused by pricing issues. Energy pricing plays a significant role in P2P energy trading, as it directly impacts participants' costs and financial sustainability [7].

Thus, we aim to implement an efficient Peer to Peer energy allocation and pricing Algorithm to deal with challenges in energy distribution, promote renewable energy integration, and optimize pricing mechanisms. [2].

1.5 Thesis Organization

The primary objective of this thesis has two aspects. Firstly, it aims to develop an algorithm for efficient peer-to-peer energy trading. Secondly, it aims to create a robust and efficient algorithm that simultaneously reduces customer bills and increases seller profits in peer-to-peer (P2P) energy trading, thereby enhancing system stability and overall performance.

The thesis will be structured as follows:

Chapter I will provide an overview of the history and background of peer-to-peer (P2P) energy markets, along with the inspiration for the thesis and its intended outcome.

Chapter II will extensively discuss the literature review.

Chapter III will delve into the concept of the distribution approach and the pricing strategy for energy.

Chapter IV will analyze the simulation results.

Chapter V will present the conclusions and suggestions for future research

CHAPTER 2: LITERATURE REVIEW

2.1 Literature Review on Peer to Peer (P2P) Energy markets

Peer to Peer Energy promotes a new revolutionary energy management paradigm of decentralized network environment for energy nodes, contrasting with the traditional hierarchical grid structure. In this network structure, all levels of energy generation and consumption can engage in communication and interaction with one another. As a result, the emergence of prosumers is becoming prominent, representing a novel category of consumers who possess Distributed Energy Resources (DERs) and have the ability to function as sellers or buyers depending on their surplus energy [8]. P2P energy trading markets can be categorized into three methods on the basis of customer interaction, namely: i) Full P2P market, ii) Community-manager based P2P market and iii) Hybrid P2P market

In the P2P energy trading market, the demand and supply dynamics can experience sudden changes due to the intermittent nature of renewable energy resources such as PV and wind turbines. Consequently, the energy market witnesses stochastic and dynamic fluctuations in pricing. Numerous studies have focused on achieving an optimal pricing balance among sellers. Broadly, the energy market can be categorized into two types: i) The auction-based model and ii) The bilateral-contract based model [8].

Hence, in the context of P2P trading, the term "**Energy Allocation**" refers to the process of efficiently directing the flow of energy between participants. It involves establishing a network framework where energy can be exchanged directly among peers, enabling a decentralized and efficient energy trading system.

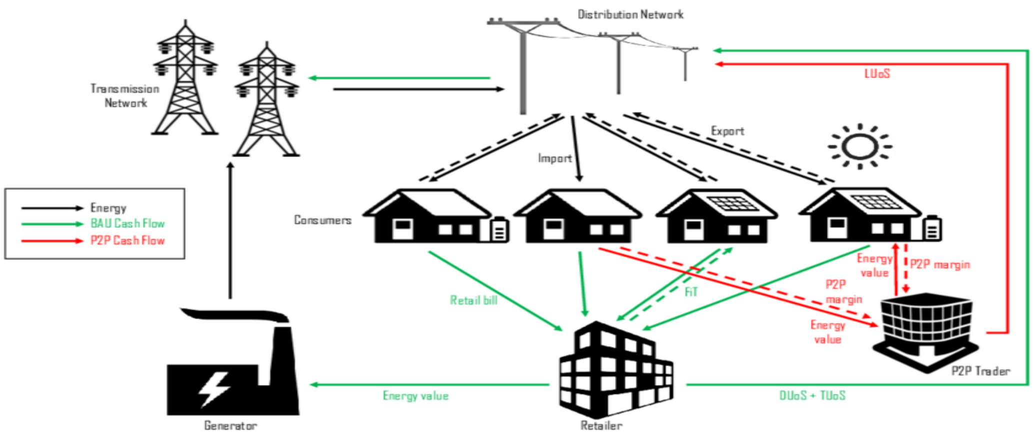

Figure 2.1Energy Allocation [2]

2.1.1 Classification of P2P energy market on the basis of Structure:

P2P energy markets offer a decentralized structure for energy trading, allowing direct interactions between energy producers and consumers. Within this structure, three main types of P2P energy markets have emerged: hybrid P2P, full P2P, and community-based P2P.

2.1.1.1 Full P2P market

In a fully decentralized P2P market architecture, participants, also known as peers, operate solely on a peer-to-peer basis, without the involvement of intermediaries or centralized entities. Energy producers can directly sell excess energy to consumers in their vicinity, resulting in greater efficiency and cost savings. This direct interaction promotes localized energy production and consumption, enhancing energy self-sufficiency and sustainability.

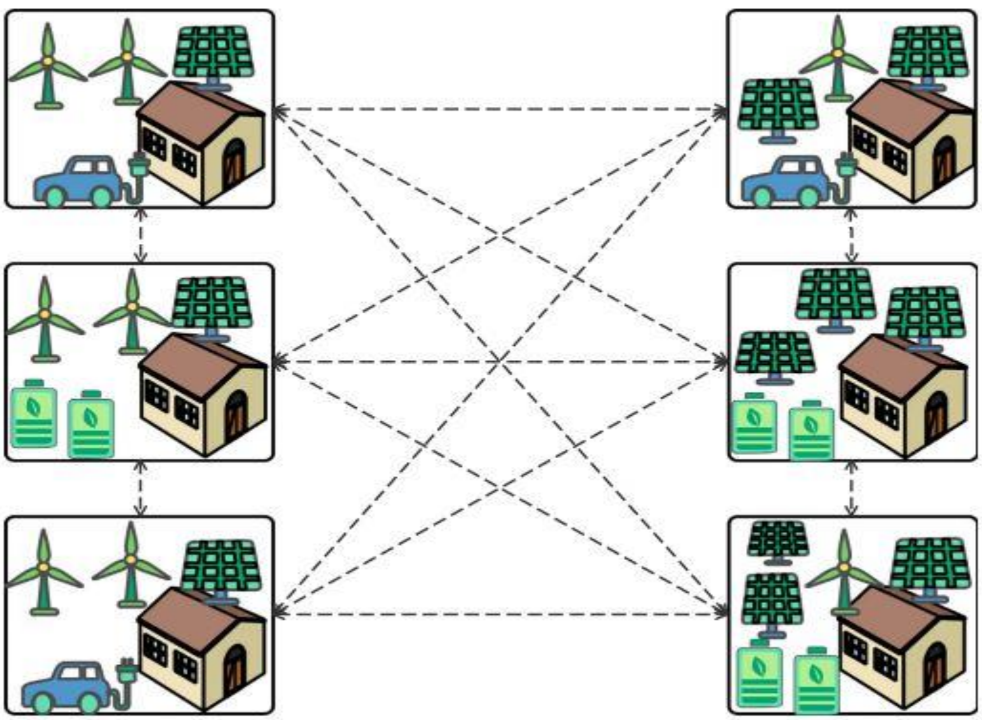

Figure 2.2 Full P2P Energy trading[3]

2.1.1.2 Community-Based P2P market

This market structure incorporates the role of a community manager (CM) who oversees and coordinates the energy trading activities within a specific community. The CM serves as an intermediary between peers within the community and the larger system, as depicted in **Error! Reference source not found.**. This community-based market architecture has b een widely explored in microgrid studies and has been implemented for energy trading among geographically proximate prosumers. These markets enable greater control over energy production and consumption, leading to increased resilience and community empowerment.

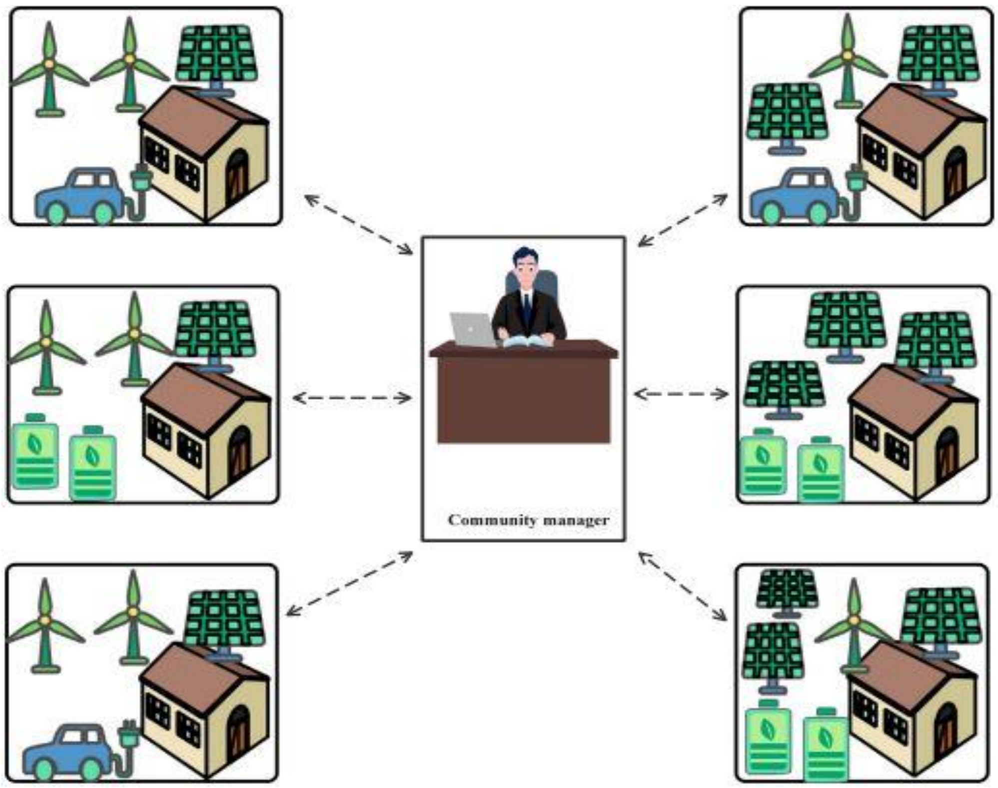

Figure 2.3 Community-based P2P Energy trading[3]

2.1.1.3 Hybrid P2P Market

Hybrid P2P markets combine elements of centralized and decentralized trading. They leverage both traditional grid infrastructure and peer-to-peer transactions, providing flexibility and scalability. Participants can engage in energy trading directly with other peers or through intermediaries, ensuring efficient energy allocation.

2.1.2 Classification of P2P energy market on the basis of Optimal pricing

Achieving an optimal pricing balance among prosumers is a crucial aspect of P2P energy trading. Various studies have been conducted to explore different pricing mechanisms that ensure fair and efficient energy exchange. The energy markets can be classified into two categories, namely: i) The auction-based model and ii) The bilateral-contract based model.

2.1.2.1 Auction Based Model

In the auction-based model, prosumers participate in competitive bidding processes where they submit their offers for buying or selling energy. The market clearing price is determined based on the intersection of the demand and supply curves, ensuring that the energy transactions are conducted at an equilibrium price. Auctions provide a transparent and dynamic platform for price discovery and can foster competition among prosumers.

2.1.2.2 Uniform Pricing-Based Model

In contrast, uniform pricing-based models distinguish themselves from auction-based models in that the bid price set by a single consumer is made accessible to all other consumers. While these models are recognized for their openness in P2P energy trading markets, they tend to prioritize the profitability of energy sellers, focusing primarily on their financial gain rather than considering the broader interests of all participants.

2.1.3 Principal of the Proposed Algorithm

The proposed algorithm aims to efficiently allocate electric energy while minimizing buyers' bills and maximizing sellers' profits. By employing a systematic approach, the algorithm optimizes the energy distribution process, taking into account various factors such as customer power consumption, comfort levels, and temperature. This algorithm holds potential for significant benefits in terms of cost savings and improved revenue generation.

The algorithm begins by calculating the comfortable index. This index represents the comfort level of each consumer. The algorithm also identifies the customer class based on their power consumption.

For each demand, the algorithm calculates a score by multiplying with multiple variables, each variable represents weights of each factor that contribute to the calculation of scores for each Players demand.

Then the pairs of buyers and sellers are made according to their scores. The scores basically determine the priority or preference in matching buyers and sellers.

If the total demand at a given time exceeds the total generation of sellers, the algorithm suggests taking the remaining energy from the grid.

On the other hand, if the total generation of sellers exceeds the total demand, the algorithm proposes that the buyer obtains energy from another seller with the highest price at that time.

In the case where the demand and generation of a pair are equal, the bill calculation simply includes the price of the seller.

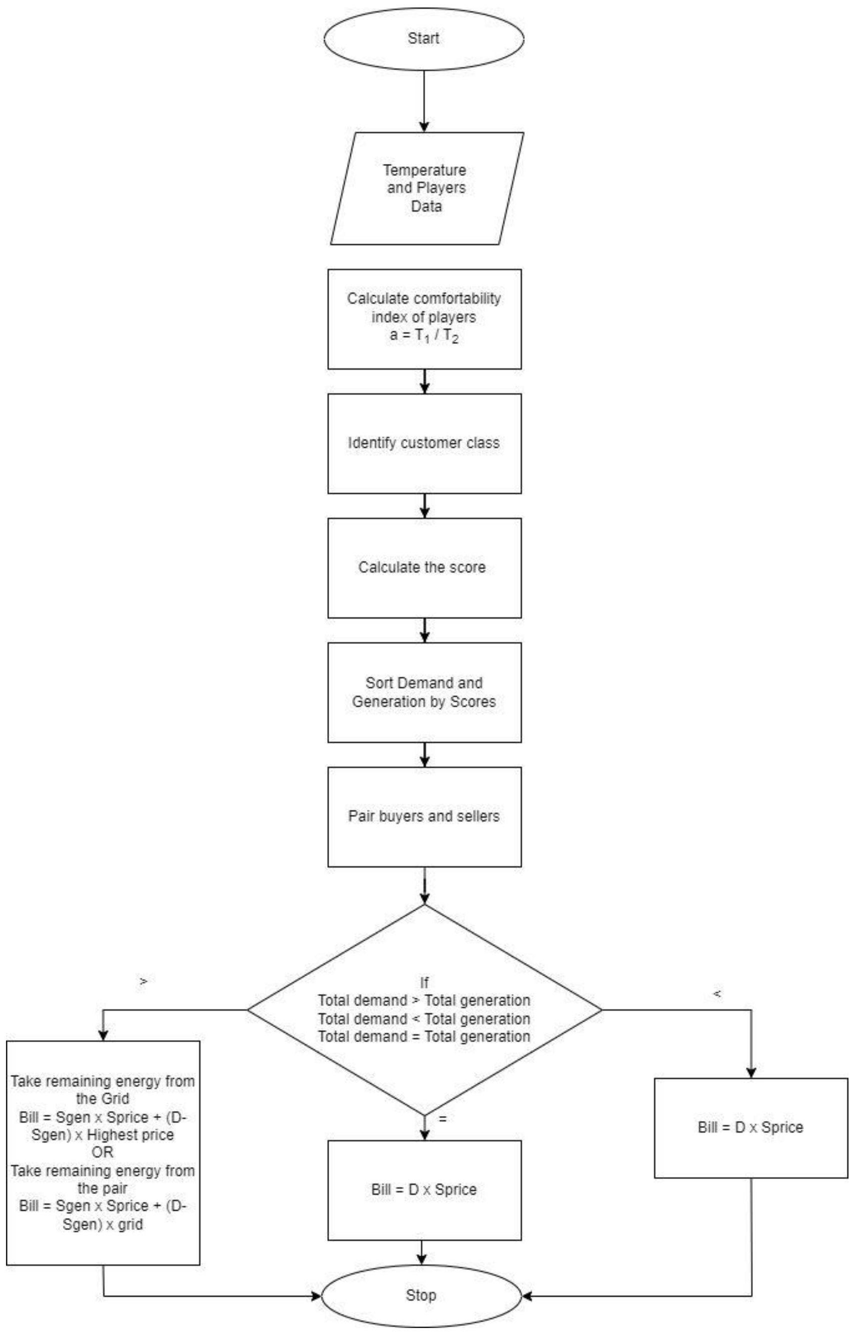

Figure 2.4 The Proposed Energy allocation Algorithm

The presented flowchart depicts a streamlined process for bill calculation, encompassing three distinct cases. Through its clear and concise layout, the flowchart enables billing administrators to navigate the decision-making process with ease. By following the sequential steps outlined in the flowchart, administrators can accurately determine the charges applicable to each case, ensuring fairness and accuracy in the billing system.

2.1.4 Challenges and Problems in the Current Energy System

The traditional energy system faces several challenges and limitations that makes the adoption of P2P energy trading necessary. First and foremost, the power sector often experiences imbalances between energy demand and supply, leading to issues such as power shortages and load shedding [9]. These supply-demand gaps can disrupt the stability and reliability of the grid, resulting in inconvenience for consumers.

Another significant problem is the extensive transmission and distribution losses that occur in the current long-distance electricity transmission networks. These losses not only waste valuable energy but also contribute to higher costs and inefficiencies in the system [10]. Additionally, the reliance on centralized power plants, particularly those fueled by fossil fuels, poses environmental concerns due to their high CO_2 emissions, which contribute to climate change and air pollution [11].

Furthermore, the lack of flexibility and responsiveness in the traditional energy market hinders optimal utilization of renewable energy resources. The intermittent nature of renewable sources, such as solar and wind, introduces fluctuations in energy generation, making it challenging to match supply with demand. This often leads to wastage of excess energy or inadequate supply during peak demand periods [12].

Moreover, traditional energy markets are characterized by centralized control and limited consumer participation. Consumers typically have limited choices and little control over the energy they consume and the prices they pay. This lack of transparency and consumer empowerment can result in unfair pricing practices and limited incentives for energy efficiency [13].

Addressing these challenges requires a paradigm shift towards a more decentralized and consumer-centric energy system. P2P energy trading emerges as a promising solution that enables direct energy exchange among consumers and promotes the use of renewable energy sources. Developing appropriate market designs and pricing mechanisms for P2P energy trading is crucial but complex. By facilitating the efficient allocation of energy, P2P trading can reduce energy wastage, optimize renewable energy utilization, and enable consumers to have greater control over their energy choices. Additionally, it offers opportunities for cost savings, improved energy access, and reduced environmental impact [14].

P2P energy trading tackles various pressing issues, including supply-demand imbalances, transmission losses, environmental impact, limited consumer participation, and inefficient utilization of renewable energy. By promoting decentralization, consumer empowerment, and the adoption of cleaner energy sources, P2P trading provides a pathway towards a more sustainable and resilient energy future.

CHAPTER 3: METHODOLOGY

3.1 P2P Energy Allocation and Pricing Procedure

To navigate electrical energy effectively, a testing platform is essential for conducting simulations. The efficiency of the proposed methodology is determined by the simulating algorithm. The primary requirement is to design an environment where prosumers can participate in energy allocation. Thus, MATLAB's platform was utilized to implement the proposed methodology.

A microgrid was created to replicate a distribution setup, where sellers are required to list their excess energy along with the unit price, and buyers must list their demand along with the bid price per unit. The Algorithm's design was evaluated in a familiar environment with the main objective of achieving efficient energy allocation. The algorithm was implemented to establish a balanced grid structure.

The generated code was given sellers surplus energy and its price per unit, buyers demand along with its bid price and the temperature data whereas the final pair were selected depending on the scores of each player's demands. Multiple simulations were conducted using the identical methodology, with the objective of achieving different energy allocation outcomes. These diverse cases resulting from the proposed algorithm will be thoroughly examined in the upcoming chapter.

3.2 Modeling & Pricing Methodology

The next section of this thesis focuses on optimizing the sellers' surplus margin also by considering the grid price, while simultaneously reducing consumers' bills. The mathematical model and the pricing strategy applied is discussed below.

3.2.1 Mathematical Model of P2P Energy allocation and pricing

The generated code has two sets of buyers and sellers at every 30 minutes of time interval which self-balances itself.

Here are the mathematical equations for the scenario with two sets of 22 players, which include 11 buyers and 11 sellers:

Let's denote the set of buyers as,

$$B = \{B_1, B_2, B_3, \dots., B_{11}\} \qquad \text{Eq. 3.1}$$

and the set of sellers as,

$$S = \{S_1, S_2, S_3, \dots., S_{11}\} \qquad \text{Eq. 3.2}$$

$$B \cap S = \emptyset \qquad \text{Eq. 3.3}$$

The above equation indicates that either a player can act as a buyer or a seller at each time slot.

To represent the temperature data taken at every 30-minute interval, we can use a discrete time series notation. Let's denote the temperature at each time interval as Temperature (t), where t represents the time index.

Let's denote the comfortable index of buyers as "I,"

the demand at the first time slot as "$B_{(i+2)j}$," and the demand at the second time slot as "B_{ij}." The mathematical equation for the comfortable index of buyers can be expressed as:

$$I = \frac{B_{(i+2)j}}{B_{ij}} \qquad \text{Eq. 3.4}$$

In this equation, the demand at the first time slot is divided by the demand at the second time slot to determine the ratio or index representing the comfort level of buyers.

Let P represent the power consumption of a customer in kilowatts (KW), and c represent the customer class identification.

$$\begin{cases} D \leq 2KW & c = low \\ 2K < D < 3KW & c = medium \\ D > 3KW & c = high \end{cases} \qquad \text{Eq. 3.5}$$

In above equation, the customer class identification (c) is determined based on the power consumption (P) of the customer. If the power consumption is less than or equal to 2 KW, the customer class is classified as "low." If the power consumption is between 2 KW and 3 KW, the customer class is classified as "medium." If the power consumption is greater than or equal to 3 KW, the customer class is classified as "high."

To calculate scores for every demand based on three variables that contribute to each customer's demand at intervals of 30 minutes, we can use the following equation:

$$\xi = \sum_{i,j,k}^{n} \varsigma_i\,(I) + \varsigma_j(c) + \varsigma_k(\tau) \qquad \text{Eq. 3.6}$$

In this equation, we have three variables:

ς_i (I): Represents the weightage of factor "I" in the customer's demand. This factor could be any relevant attribute or characteristic that influences the demand.

ς_j (c): Represents the weightage of factor "c" in the customer's demand. Similarly, this factor represents another attribute or characteristic impacting the demand.

ς_k (τ): Represents the weightage of the temperature as a factor affecting the customer's demand.

This factor accounts for the influence of temperature on the customer's demand behavior.

The resulting score represents the combined effect of these factors on the customer's demand at that particular interval of 30 minutes.

Let's assume we have "B" buyers and "S" sellers,
where each buyer i $(1 \leq i \leq B)$ is assigned a seller j $(1 \leq j \leq S)$ based on their demand score.
We can denote the demand score of buyer i as ξ_i,
and the assignment of buyer i to seller j as $A(i, j)$.

The mathematical equation can be expressed as:
$A(i, j) = 1$ if j is the seller assigned to buyer i
$A(i, j) = 0$ otherwise
The assignment equation assigns a value of 1 if buyer i is assigned to seller j and 0 otherwise.
The matching algorithm aims to maximize the overall compatibility between buyers and sellers based on their demand scores. Various algorithms can be employed, such as the Hungarian algorithm or the Gale-Shapley algorithm, depending on the specific requirements and constraints of the matching problem.
The specific implementation details and constraints may vary depending on the context and specific requirements of your buyer-seller matching problem.

Let's denote the total demand at time 't' as D,
The total generation of a seller at the same time as S_{Gen}.
The grid price is represented as G_{price},
The price of the seller is denoted as S_{Price}.
The highest price at time 't' from other sellers is denoted as H_{Price}.
The difference between the D and S_{Gen} is denoted by L.

The bill for the buyer, denoted as Bill, can be calculated based on the given conditions as follows:

If $D > S\_Gen$. (Total demand is greater than total generation of the seller):

$$\mathcal{B} = S_{Gen} * S_{Price} + (L) * H_{Price} + (D - L) * \mathcal{g} \quad \text{Eq. 3.7}$$

If $D < S_{Gen}$ (Total generation of the seller is greater than total demand):

$$\mathcal{B} = D * S_{Price} \quad \text{Eq. 3.8}$$

If $D = S_{Gen}$ (Demand and generation are equal):

$$\mathcal{B} = D * S_{price} \quad \text{Eq. 3.9}$$

The bill proposed by this algorithm benefits both buyers and sellers in the energy market. For buyers, the algorithm ensures that their energy demands are met efficiently and at the most cost-effective prices. When the total demand exceeds the total generation of a seller, the algorithm allows the buyer to acquire the remaining energy needed from the grid at the grid price, ensuring a consistent supply. This enables buyers to meet their energy requirements without any disruptions and minimizes the risk of energy shortages.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Simulation Results for P2P Energy Allocation and Pricing Algorithm for Microgrids

As previously stated, simulations were conducted in Matlab using initial demand, bid prices, seller's surplus energy, and temperature data to allocate energy and evaluate the algorithm's efficiency. In each simulation, a microgrid consisting of twenty-two participants is depicted at time 't', with varying demands and generation for each case. The table below presents the initial row data at time 't'.

Unsorted List at time ‘t’	**Demand at time ‘t’**	**Unsorted List at time ‘t’**	**Generation at time ‘t’**
Buyer 1	14.78219	*Seller 1*	2.120612
Buyer 2	11.99399	*Seller 2*	1.552483
Buyer 3	6.444139	*Seller 3*	3.83782
Buyer 4	0.775768	*Seller 4*	1.436005
Buyer 5	6.779486	*Seller 5*	2.977858
Buyer 6	5.245935	*Seller 6*	5.10033
Buyer 7	3.078067	*Seller 7*	8.506457
Buyer 8	0.851742	*Seller 8*	12.14512

Buyer 9	4.947312	*Seller 9*	0.766074
Buyer 10	3.956914	*Seller 10*	14.46632
Buyer 11	2.395729	*Seller 11*	4.788376

Table 4.1 Initial input Data

Using the data provided, the algorithmic pairing of buyers and sellers is carried out based on their Comfort Index (I), Consumer Class (c), and the temperature at that specific time (t). By considering these three factors, the algorithm aims to create optimal matches that result in enhanced satisfaction for both parties involved.

To calculate score of each buyer at time ‘t’,

Algorithm calculates the Comfortable index of ‘Buyer 2’,

$$I = \frac{B_{ij}}{B_{(i+1)j}} \qquad \text{Eq. 4.1}$$

$$I = 11.99399/12.256234$$

$$I = 0.978135$$

Similarly, Comfortable Index for all buyers are calculated,

Buyers	Comfortable index Calculation
Buyer 1	0.635205
Buyer 2	0.978135
Buyer 3	1
Buyer 4	1
Buyer 5	0.873158

Buyer 6	1
Buyer 7	1
Buyer 8	1
Buyer 9	0.850445
Buyer 10	1
Buyer 11	0.966159

Table 4.2 Calculation of I

Then the algorithm identifies the consumer class of each Buyer,

$$\begin{cases} P \leq 2KW & c = low \\ 2K < P < 3KW & c = medium \\ P > 3KW & c = high \end{cases} \qquad \textit{Eq. 4.2}$$

Value for low class consumer is '0.2'.
Value for medium class consumer is '0.3'
Value for high class consumer is '0.5'

e.g 'Buyer 2' demand at time 't' is '11.99399 KW' so it belongs to High consumer class (0.5).

Buyers	**Consumer Class identification**
Buyer 1	0.5
Buyer 2	0.5
Buyer 3	0.5
Buyer 4	0.2
Buyer 5	0.5
Buyer 6	0.5
Buyer 7	0.5

Buyer 8	0.2
Buyer 9	0.5
Buyer 10	0.5
Buyer 11	0.3

Table 4.3 Identification of consumer class

The algorithm further uses the temperature value at time 't' which is '12.25°C', to calculate the score of each buyer,

Eq. 4.3

$$\xi = \sum_{i,j,k}^{n} \varsigma_i (I) + \varsigma_j(c) + \varsigma_k(\tau)$$

To calculate the score, we multiply the value of each factor with its respective weightage:

The weightage of Comfortable index is represented by that is 0.4.

Similarly, the weightage of factor Consumer class is represented by y that is 0.3.

The weightage of factor Temperature is represented by z which is 0.3.

Calculation of Buyer 2 score,

$$\xi_{Buyer2} = 0.4(0.978135) + 0.3(0.5) + 0.3(12.25)$$

$$\xi_{Buyer2} = 4.216254$$

Buyers	Score
Buyer 1	4.079082
Buyer 2	4.216254
Buyer 3	4.225
Buyer 4	4.135

Buyer 5	4.174263
Buyer 6	4.225
Buyer 7	4.225
Buyer 8	4.135
Buyer 9	4.165178
Buyer 10	4.225
Buyer 11	4.151464

Table 4.4 Calculation of scores

The algorithm utilizes advanced analytical techniques to interpret the provided data and generate successful pairings that align with the preferences and requirements of buyers and sellers. Through this approach, the algorithm demonstrates its efficacy in facilitating well-matched buyer-seller relationships, ultimately leading to improved transaction outcomes.

Pairing at time 't'	**Satisfaction Index**
(S10, B1)	0.978632
(S4, B2)	0.119727
(S2, B5)	0.228997
(S9, B3)	0.118879
(S11, B6)	0.912778
(S3, B9)	0.775738
(S6, B10)	1
(S1, B7)	0.688943
(S5, B11)	1
(S7, B8)	9.98713
(S8, B4)	1

Table 4.5 Pairing and satisfaction index

After making the pairs, the algorithm now calculates the Bill of each buyer,

The bill for the buyer, denoted as Bill, can be calculated based on the given conditions as follows:

If $D > S\_Gen.$ (Total demand is greater than total generation of the seller):

$$\mathcal{B} = S_{Gen} * S_{Price} + (L) * H_{Price} + (D - L) * g \qquad \text{Eq. 4.4}$$

If $D < S_{Gen}$ (Total generation of the seller is greater than total demand):

$$\mathcal{B} = D * S_{Price} \qquad \text{Eq. 4.5}$$

If $D = S_{Gen}$ (Demand and generation are equal):

$$\mathcal{B} = D * S_{price} \qquad \text{Eq. 4.6}$$

E.g. the algorithm generated the pair of 'Buyer 1' with 'Seller 10' at time 't'.
The Demand of 'Buyer1' is 14.78219KW,
The Generation of 'Seller 10' is 14.46632KW at price '8.678602' unit per hour so it is case 1.

$$\mathcal{B} = S_{Gen} * S_{Price} + (L) * H_{Price} + (D - L) * g \qquad \text{Eq. 4.7}$$

$$\mathcal{B} = 14.46632 * 8.678602 + (0.31587) * g$$

$$\mathcal{B} = 126.8109$$

4.2 Comparison:

4.2.1. Comparison on the basis of the energy allocation:

In Figure 4.1, the results of two different algorithms are shown on consumers vs satisfaction index.
In the other method all the buyer's demand are first sorted and then the energy is supplied according to the ranking of the buyers. Buyers with the highest ranking will get the energy first and so on. While in

the proposed method the sorting of generation and demand is done according to the score, the pairs of buyers and seller are generated. Each pair will get the energy according to their score.

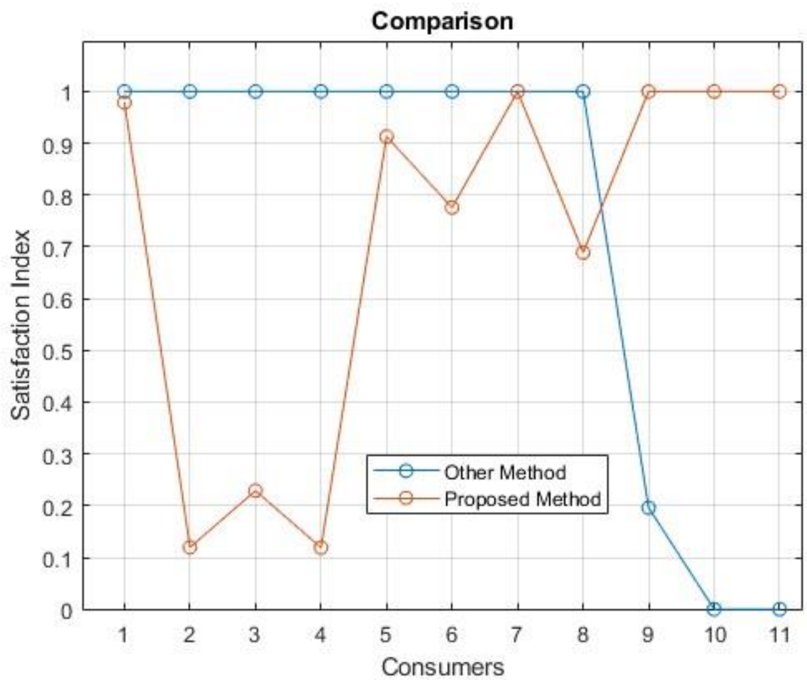

Figure 4.1 Comparison between Proposed method and other method

Proposed algorithm is more effective than the other one because, according to the graph not all the consumers will get the energy in the other method as shown in fig. Consumer will get the energy according to the highest ranking. But in the proposed method all the consumers will get the energy as in this method the consumers are in pairs of seller and buyers. According to the algorithm mentioned in fig 6 this is the distribution of the consumers and their satisfaction index.

4.2.2 Comparison on the basis of bills:

In the provided graph, we observe a comparison between two energy models. The first model entails buyers receiving energy at a fixed rate from sellers, while the method proposed introduces a more dynamic approach. In our method, buyers and sellers are paired based on their comfortable index, which accounts for their preferences and requirements. In situations where the demand cannot be fully met, buyers have the option to access energy from the grid. This proposed model aims to optimize energy allocation, improve customer satisfaction, and reduce wastage, thereby offering a more efficient and personalized energy distribution system.

Buyers ID	**Proposed Method**	**Grid Method**	**Percentage% Reduction**
Buyer 1	120.8109	118.2574865	2.159%
Buyer 2	51.62997	95.95193136	46.191%
Buyer 5	41.02822	54.2358856	24.352%
Buyer 3	32.28893	51.55310936	37.367%
Buyer 6	34.14313	41.9674828	18.643%
Buyer 9	19.22281	39.57849248	51.431%
Buyer 10	5.14202	31.65530976	83.756%
Buyer 7	32.61047	24.6245384	32.430%
Buyer 11	3.422561	19.16582936	82.142%
Buyer 8	20.74205	31.8139352	34.802%
Buyer 4	26.3071	29.20614	9.926%

Table 4.6 Comparison

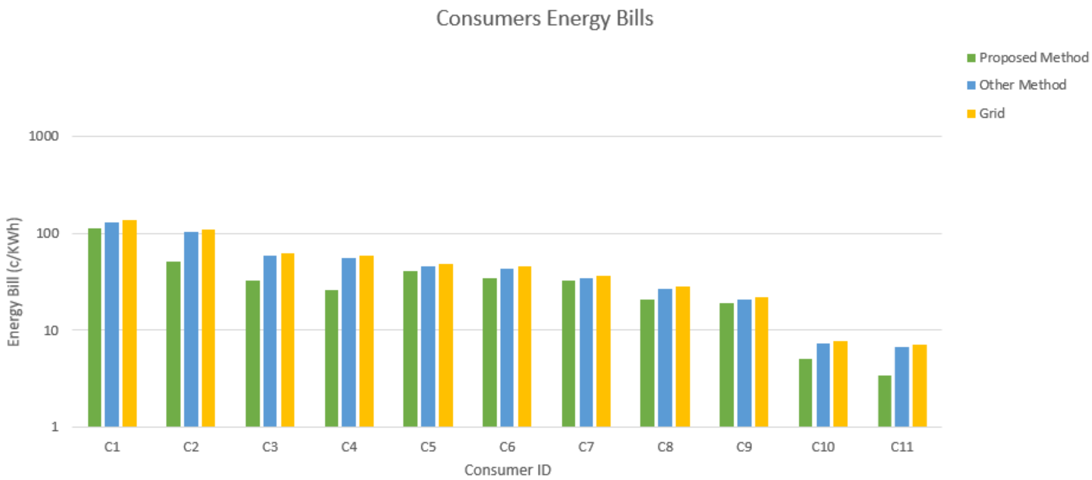

Figure 4.2 Comparison on the basis on bill

Based on the comparison graph presented above, it is evident that there is a substantial disparity in the bills incurred by each prosumer under the two examined methods. The conventional fixed-rate approach, where energy is obtained at a predetermined rate, proves to be inefficient and fails to cater to individual energy needs. In contrast, our proposed method offers a more efficient alternative, resulting in significant bill reductions for prosumers.

The proposed method takes into account the individual preferences and requirements of prosumers, ensuring a more tailored energy allocation. By pairing prosumers with compatible energy suppliers based on their comfortable index, our approach optimizes the utilization of available resources. This personalized matching not only reduces energy wastage but also leads to more accurate billing, eliminating the need for prosumers to pay for excess energy they do not utilize.

CHAPTER 5: CONCLUSION AND FUTURE DIRECION

5.1 Conclusion

In summary, this thesis has successfully accomplished two primary objectives. The first objective involved developing and simulating an energy allocation algorithm capable of efficiently managing energy distribution within a predetermined static environment. The second objective aimed to reduce consumers' electricity bills while generating profits for small-scale sellers.

This thesis report has presented a comprehensive study on peer-to-peer (P2P) energy trading and proposed an algorithm implemented in MATLAB for efficient energy allocation and pricing. The objective of this research was to address the challenges associated with centralized energy distribution systems and explore the potential benefits of decentralized energy trading.

Through an extensive literature review, the report has highlighted the advantages of P2P energy trading, including increased energy efficiency, reduced costs, enhanced reliability, and the promotion of renewable energy sources.

To tackle the complexities of energy allocation and pricing in P2P systems, the proposed algorithm in this report offers an innovative approach. By considering factors such as energy demand, supply, and user preferences, the algorithm optimizes the energy allocation process and determines fair and competitive prices for energy transactions. The implementation of this algorithm in MATLAB provides a valuable tool for simulation and analysis, enabling researchers and practitioners to evaluate its effectiveness in real-world scenarios.

The findings of this research contribute to the growing body of knowledge in P2P energy trading and offer insights into the potential of decentralized energy systems. The proposed algorithm presents a step forward in addressing the challenges of energy allocation and pricing, promoting a more efficient and sustainable energy ecosystem.

It is important to acknowledge that this research has some limitations. The algorithm's performance may vary depending on the specific characteristics of the energy market, the availability of data, and the scalability of the system. Further empirical studies and field trials are necessary to validate the algorithm's effectiveness and adaptability to different contexts.

In conclusion, this thesis report provides a valuable contribution to the field of P2P energy trading by proposing an algorithm for efficient energy allocation and pricing. It sets a foundation for future research and development in this area, ultimately paving the way for a more decentralized and sustainable energy future.

5.2 Future Work

In the realm of peer-to-peer energy allocation and trading, there are several exciting avenues for future exploration and development. One area of focus is the integration of blockchain technology, which can enhance security, transparency, and decentralization in energy transactions. Smart grid integration is another crucial aspect, enabling real-time monitoring and optimization of energy flows. Additionally, incorporating renewable energy sources and implementing advanced demand response strategies can promote sustainability and efficient energy management. Predictive analytics, regulatory frameworks, scalability, consumer engagement, data privacy, and international collaboration are other key areas that warrant attention for further advancements in this field.

Integration of block-chain technology for secure and transparent energy transactions. Smart grid integration for real-time monitoring and optimization. Incorporation of renewable energy sources into peer-to-peer systems. Development of advanced demand response strategies for efficient energy management. Utilization of predictive analytics and AI for optimized energy allocation.

Establishment of supportive regulatory frameworks for peer-to-peer energy models. Addressing scalability and interoperability challenge.

Promoting consumer engagement and education. Ensuring data privacy and security in energy transactions .Encouraging international collaboration and standardization efforts

APPENDIX A

Symbols	**Used for**
g	Grid Price
ξ	Buyers score
ς_i	Weightage of comfortable index
ς_j	Weightage of consumer class
ς_k	Weightage of temperature
τ	Temperature
I	Comfortable index
c	Consumer class

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