Peer to Peer Energy Trading for Microgrids

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A thesis submitted to The University of Lahore as partial fulfilment of Bachelor of Science in Electrical Engineering

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Certificate of Approval

This is to certify that the project/thesis work presented in this thesis, entitled "***Peer to Peer Energy Trading for Microgrids***" was conducted by Sheikh Muhammad Ibraheem, Muhammad Awais Khalid, Zunera Khalil, Hamza Awan, and Syed Zeeshan Haider under the supervision of Engr. Dr. Raheel Muzzammel.

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Dedication

To our supervisor, Engr. Dr. Raheel Muzzammel

Your guidance and support have been invaluable to us throughout this research project. We have learned so much from you, and We grateful for your mentorship. Your challenging questions and insights have helped us to think more deeply about our work, and your encouragement has kept us motivated. We truly fortunate to have you as my advisor.

We also dedicate this thesis to our family members and friends, who have always been there for us. Their love and support have meant the world to us and they offered us words of wisdom when we needed them most.

This thesis is the culmination of years of hard work and dedication. We are proud of what we have accomplished, and we could not have done it without the support of our supervisor, family members, and friends. We dedicate this work to them, with love and gratitude.

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We are grateful to our Creator, Allah Subhana-Watala, for leading us through this academic journey and for each new idea that entered our heads and propelled us forward. Following that, it gives us great pleasure and honor to convey our sincere gratitude to our supervisor, Engr. Dr. Raheel Muzzammel, who served as an excellent mentor throughout our studentship. His constant oversight and kind encouragement are crucial to the development of our academic skills as nonprofessional researchers. He assisted us in comprehending the complex ideas involved in engineering, mathematics, and thesis writing. We are thankful to Head of Department and other faculty members of Department of Electrical Engineering for providing us excellent guidance and academic environment throughout our bachelor studies.

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Table of Abbreviations

P2P:	Peer to Peer
MATLAB:	Matrix Laboratory
IEEE:	Institute of Electrical and Electronics Engineers
HVAC:	Heating, Ventilation, and Air Conditioning
KW:	Kilo Watt
LP:	Linear Programming
ET:	Energy Trading
AWG:	American Wire Gauge
SWG:	Standard Wire Gauge
DRs:	Distributed Resources
ICT:	Information and Communication Technology
RES:	Renewable Energy Source
IGBT:	Insulated Gate Bipolar Transistor
MPPT:	Maximum Power Point Tracking

Abstract

In answer to the limits of traditional centralized power infrastructure, the scientific and technological communities have turned their attention to the intriguing area of decentralized smart power systems, principally manifested through the intricate lattice of microgrid networks. The concept of peer-to-peer (P2P) energy trading is emerging as a revolutionary paradigm within this landscape, defying the established norms of the power sector by allowing end consumers to directly engage in the trading of electrical energy with their counterparts, bypassing the conventional intermediaries that have long facilitated such transactions, including utility companies. The importance of this ground-breaking notion becomes clearer in the context of microgrids, when its transformative potential is amplified. As a result, developing secure, efficient, and dependable means of selling energy across networked microgrids has become critical. This mechanism is particularly positioned to utilize the natural potential of renewable energy sources, with a particular emphasis on the symbiotic interplay of wind turbines and solar panels, both of which are harmoniously incorporated into the intricate fabric of a microgrid framework.

The very architecture of this endeavor is underpinned by meticulous planning and analysis, structured upon the venerable IEEE 9 bus bar system At the heart of this architectural tapestry is a tri-peer microgrid network, with each peer assuming the twin identities of consumer and producer, symbolizing the modern "prosumer" paradigm. The energy trading model is methodically developed from this comprehensive perspective, accounting for the oscillation between consumption and production inherent in the prosumer role. Furthermore, researchers and industry personnel are eager to use blockchain technologies to the energy sector. The peer-to-peer energy trading wireless communication network is based on Bluetooth technology and is intended to enable secure and safe energy transaction among peers. The procedure is done out through the use of an Android mobile device app.

Key Words: *Peer to peer, microgrids, renewable energy, decentralized energy systems, block chain, distributed ledger technology.*

Chapter 1.
Research Introduction

1.1. Introduction to the Research

A cutting-edge innovation with the potential to completely alter how we produce and consume energy is peer-to-peer (P2P) energy trading. Before it can be extensively used, there are a number of issues that must be resolved. P2P energy trading has the potential to improve the reliability, sustainability, and efficiency of our energy systems and energy trading systems if these obstacles can be solved. This chapter begins with basic background knowledge and the core ideas pertaining to the microgrid network and energy trading system. Moreover, the chapter unveils the major problems that are faced in this new type of technology and why we are motivated to do research on it.

1.2. Underlying Information on Microgrids

Small-scale power systems, or microgrids, can run separately or in conjunction with a bigger power grid. They are intended to provide a localized area, such as a community, university campus, military base, or an industrial park, with a dependable, resilient, and sustainable energy source. Different energy sources, such as sun, wind, biomass, fuel cells, and traditional fossil fuels, can be used to power microgrids, ensuring flexibility and environmental considerations. The three primary parts of a microgrid are generation, storage, and load. The energy sources used to generate power, such as solar panels and diesel generators, are included in the generation component [3]. Batteries or other energy storage devices that can store extra energy for later use make up the storage component. Lights, HVAC systems, laptops, and other electricity-consuming equipment are included in the load component. The ability of microgrids to function without the help of the larger electrical grid in the event of a blackout or other disruption is their primary advantage. As a result, essential facilities like hospitals, emergency rooms, and data centers can continue to function even when the main grid is down. Additionally, because they can match local demand with energy output, microgrids can be more effective than conventional power grids in terms of transmission and distribution. The figure 1.1 gives the generalized overview of microgrid [1].

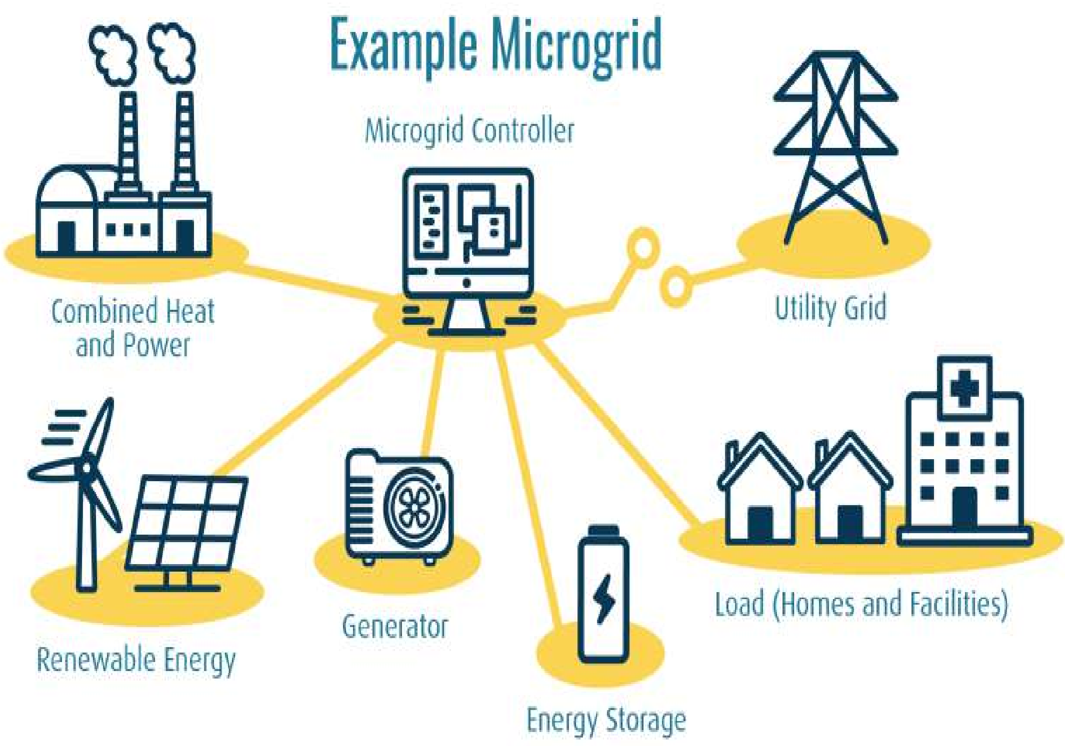

Figure 1.1. Microgrid Working Independently

A microgrid controller, which is in charge of maximizing the use of energy sources and storage systems to satisfy the energy demands of the load, usually oversees the operation of a microgrid. The controller can also manage fluctuations in energy output and demand by coordinating the flow of energy between the microgrid and the larger power grid.

1.3. Underlying Information on Energy Trading

In microgrids, energy trading refers to the buying and selling of energy within a small geographic region, frequently using a peer-to-peer (P2P) energy trading platform [4]. This enables microgrid participants to trade extra energy they've generated from their renewable energy sources, such solar panels or wind turbines, with other participants who might have larger energy demands. The fundamental idea behind energy trading in microgrids is that surplus energy is exchanged between participants to maximize energy efficiency and cut expenses. The trading platform may be controlled centrally by a utility or other independent system operator, or it may be a decentralized platform running on a blockchain network. A generalized energy trading model is shown in the figure 1.2, where four peers (households, consumers, or may be prosumers) are trading energy based on some energy trading contract [5]. Energy trading in microgrids can have several benefits, such as [6]:

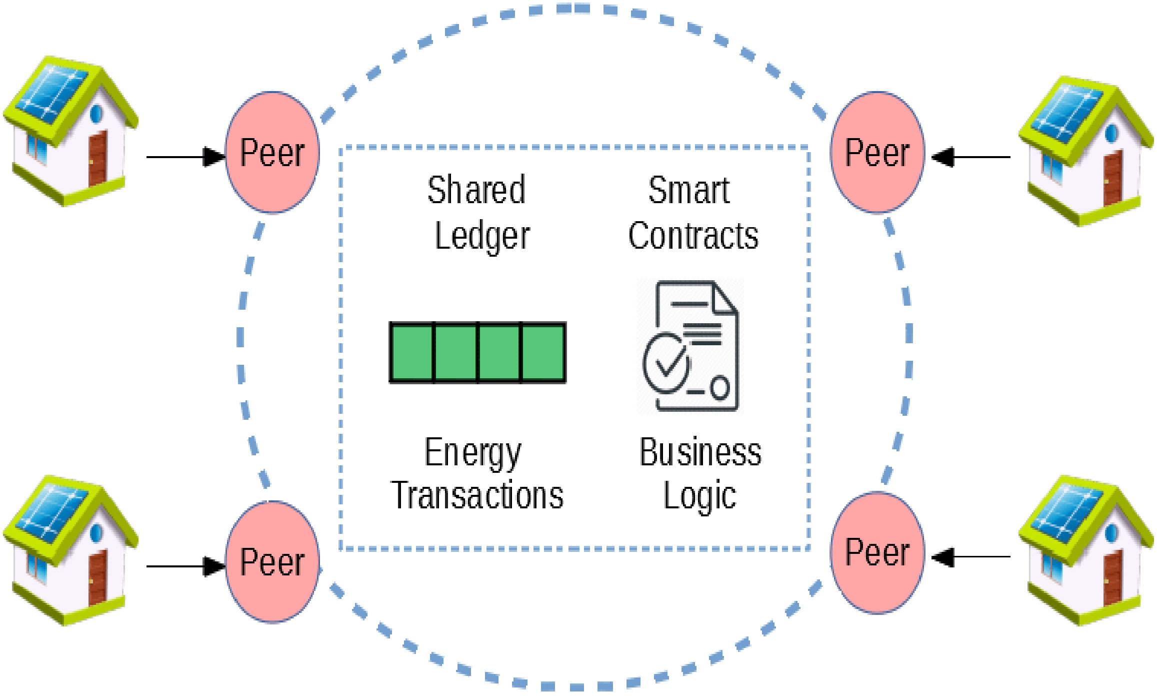

Figure 1.2. General Energy Trading Diagram

1. **Increased utilization of renewable energy sources:** Energy trading can incentivize participants to install and use more renewable energy sources, as they can earn money by selling excess energy to others in the microgrid.
2. **Reduced energy costs**: Energy trading can reduce the overall energy costs for participants in the microgrid by allowing them to purchase energy at a lower price from other participants, rather than from the larger power grid.
3. **Improved energy efficiency:** Energy trading can encourage participants to use energy more efficiently by providing financial incentives for reducing energy consumption during peak demand periods.
4. **Increased resilience:** Energy trading can increase the resilience of the microgrid by enabling participants to trade energy during power outages or other disruptions to the larger power grid.

1.4. Challenges Involved in Energy Trading

Energy trading in microgrids may have certain advantages, but there are a number of challenges that must be overcome before it can be a cost-effective and widespread solution.

There generally two types of challenges involved in P2P energy trading in microgrids[6].

1. **Technical difficulties:** Measuring and settling energy transactions between participants as well as controlling the decentralized distribution of energy present technical difficulties. This necessitates the creation of trustworthy and secure platforms that can manage numerous energy transactions.
2. **Energy measurement and settlement**: This essential aspect of peer-to-peer (P2P) energy trading involves carefully measuring and recording the exchange of energy between participants as well as timely and transparent payment settlement. The precision and reliability of energy measurement tools, as well as the requirement for safe and effective settlement systems, are, nevertheless, technical challenges.

1.5. Research Motivation

Working on a thesis may be a difficult but rewarding experience that gives us the chance to thoroughly research an issue we are interested in and advance the knowledge in a specific area. The research gap present in the peer to peer energy trading in microgrid related to the microgrid design for the peers and trading of energy at different hours of the day to keep the cost of the electrical unit at minimum price and utilizing the maximum amount of energy at the given time is what motivated us to select this topic as our research major in the bachelors of electrical engineering. Working on this thesis can also give us valuable research, analytical thinking, and communication skills and experience that we might use in other fields of study or job.

1.6. Research Objectives

The major objective of this thesis is to find and cover the research and design gap that exists in peer-to-peer energy trading in microgrids. To design and implement a solid solution for various peers to trade energy at different hour of the day easily on the basis of low unit charges and high use of the available energy either from the main grid, wind turbines, or solar power.

1.7. Thesis Outline

After introducing the concerned domain, motivations, problem statement, and research objectives in chapter 1, the necessary literature review concerning the history and previous methodologies related to the design and trading system are discussed in chapter 2. Starting from the basic characteristics and fundamental laws governing the energy trading system, microgrid utility, and its contribution to modern society.

Chapter 3 covers the depth analysis on the concept of peer to peer energy trading. Our research starts from chapter 4 where the research methodologies are designed to overcome the research gap. Chapter 5 covers the implementation and simulation analysis of IEEE 9 Bus Bar system based proposed model. Chapter 6 cover the hardware development based on the chapter 5 model. The remaining chapter will cover the impact of this research on society, climate change, and future research development.

Chapter 2.
Literature Review

2.1. Introduction

Recent years have seen a remarkable advancement in communication technology, with new inventions being introduced frequently. These developments have significantly changed how we communicate on a personal and professional level. The development of the internet has been one of communication technology's most important advances. These advancements have now made possible for people to transmit and receive data in seconds from thousands of kilometers [7][9].

These new systems have not just advanced the telecommunication systems but their involvement in power and energy systems have made possible for consumers to play an active role in the exchange of energy among themselves. This technology has made consumers the ultimate prosumer of selling and buying energy. These new trading members can use the two-way flow of information and energy to exchange information and energy with one another as well as with the national electric grid station. These new trading members can transact in energy locally by either buying from them when their supply is insufficient to meet their demand or selling their excess energy to other consumers or prosumers [8][9].

As the number of prosumers (consumers that are able to produce their own energy) are increased the challenges for the energy trading among them are also increased making it harder for the energy traders (eds) to trade energy with the local grid or independently in a microgrid. These challenges range from the mark design, cyber security, risk management, and pricing challenges [10][11].

This chapter on literature review covers the previous research gap involved in the design and implementation of peer-to-peer (P2P) energy trading model in the independent microgrid network for local community with problems associated such as renewable energy sources like solar power panels sources and wind turbines power sources. This chapter also discusses that peers traded energy before the implementation and invention of blockchain technology, what were the drawbacks of not using blockchain technology, and how energy trading with new techniques is much better choice.

2.1.1. Existing Energy Trading Models

Numerous models for Peer-to-Peer (P2P) energy trading with and without the integration of blockchain technology have been created in the published literature, which can be categorized into three main areas: Game theory models, auction models, and analytical models.

2.1.2. Game Theory Trading Model

A mathematical framework for modelling strategic interactions between two or more players is known as game theory [12] – [14] . In the context of peer-to-peer energy trading, game theory can be applied to describe the interactions of prosumers trading energy with one another. The Nash equilibrium is a popular game theory model for peer-to-peer energy trading. A Nash equilibrium in P2P energy trading is a condition in which no prosumer can enhance their profit by modifying the amount of energy they trade or the price they charge. The hierarchal structure of the entire model provided in figure 2.1 explains the working of the model in a nutshell [22].

The Stackelberg game is another popular game theory model for P2P energy trade. One player (the leader) has a first-mover advantage over the other players (the followers) in a Stackelberg game. The leader can choose their plan first, and then the followers, after watching the leader's method, can choose their own [21]. A Stackelberg game in the context of peer-to-peer energy trading would be a situation in which one prosumer (the leader) chooses the amount of energy they want to trade and the price they want to charge, and then the other prosumers choose the amount of energy they want to trade and the price they want to charge after observing the leader's strategy [20].

Here are some other game theory models that can be used for P2P energy trading:

1. **Prosumer cooperative game theory:** This model assumes that prosumers can work together to attain a common goal. This model can be used to simulate circumstances in which prosumers desire to cut their energy bills or increase grid dependability [23] [25].

2. **Non-cooperative game theory:** This model assumes that prosumers compete with one another and will not cooperate with one another. This model can be used to simulate situations in which prosumers are attempting to maximise revenues [23][24].

3. **Bayesian game theory:** This model implies that prosumers have varying levels of market knowledge. This model can be used to simulate scenarios in which prosumers are uncertain about the price of energy or the demand for energy [26].

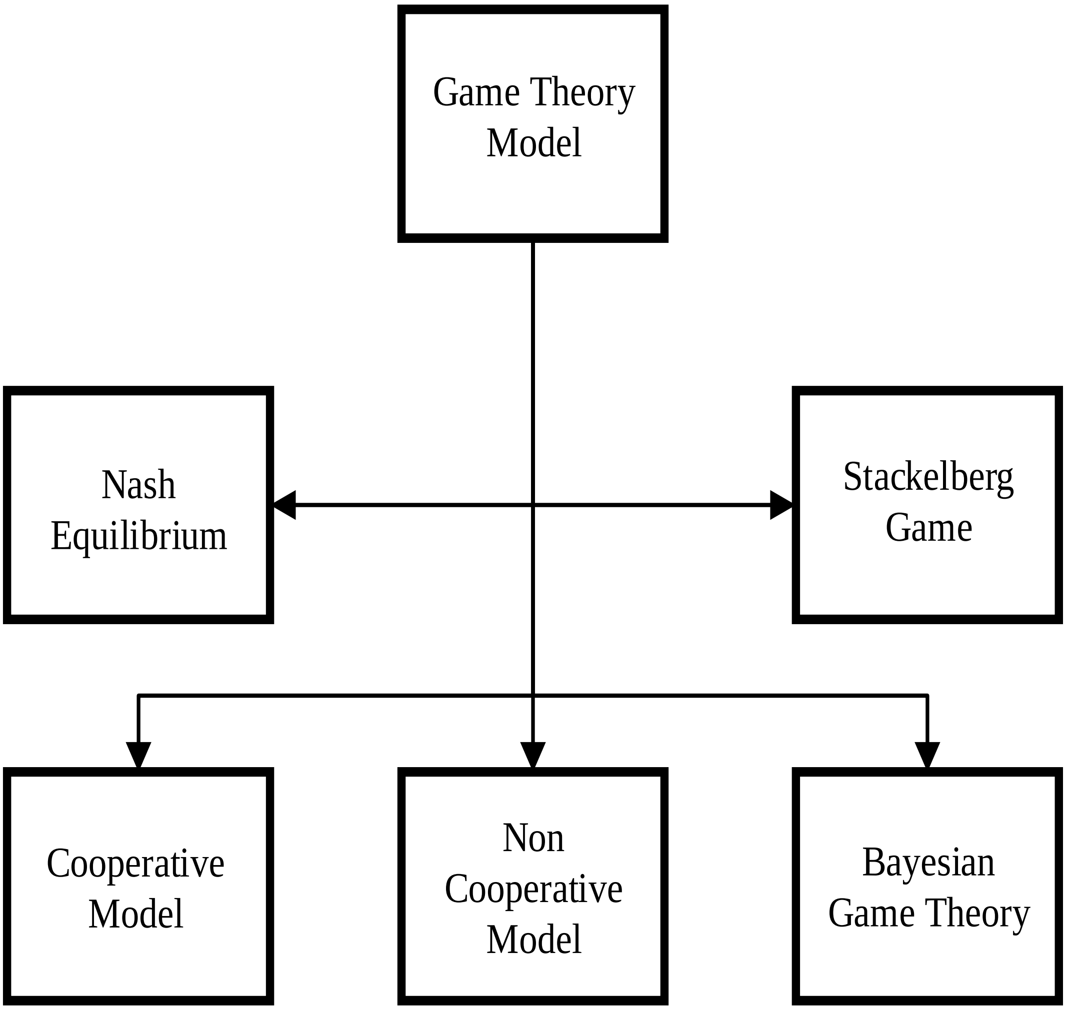

Figure 2.1. Hierarchal Structure of Game Theory Trading Model

Aside from the strategic exchanges amongst prosumers in peer to peer (p2p) energy trading. Models that are based on game theory can be extremely complex and challenging, especially when there are a significant number of prosumers available in the market. This can make solving the energy trading (ets) models and predicting how prosumers would behave even harder. Prosumers involved in many peer to peer (p2p) energy trading markets lack complete market information on how they can freely and beneficially trade energy. This can make the optimal decisions challenging for the energy traders in the market about how much energy to trade and at what price.

2.1.3. Auction Models for Energy Trading

Peer-to-peer (P2P) energy trading has seen the widespread adoption of auction models as a method, largely because of their success in effectively and fairly allocating energy supplies. Within this framework, prosumers participate by submitting bids that represent the amount of energy they would like to buy or sell. These bids are then carefully rated in descending order, with the prosumers who placed the highest bids receiving the energy they requested while also being required to pay the price that corresponds to their top bid. In the context of peer-to-peer energy trading, two distinctive variants of auction models stand out: sealed-bid auctions, where participants secretly submit their offers without knowing others' bids, and open-cry auctions, characterized by a more transparent and dynamic bidding process where participants can observe and react to each other's offers in real-time. Each of these variants is tailored to particular preferences and circumstances within the developing P2P energy trading landscape. [16] [17] [18].

1. **Sealed-bid auctions:** In a sealed-bid auction, prosumers submit their bids in secret, and the bids are not revealed to other prosumers until the auction is over. This type of auction is often used for P2P energy trading because it is less susceptible to strategic bidding.

2. **Open-cry auctions:** In an open-cry auction, prosumers bid for the energy they want in a public forum. The bids are announced to all prosumers, and prosumers can see how their bids compare to the bids of other prosumers. This type of auction is often used for P2P energy trading because it is more transparent and it allows prosumers to interact with each other.

Auction models are a popular approach for energy trading, but they have some challenges. One challenge is that they can be difficult to create and implement, which can make it hard for prosumers to understand the market and make informed decisions. For example, prosumers may not have access to all the relevant information about the auction, such as the bids of other participants or the current market price. This can make it difficult for them to bid strategically and get the best possible price for their energy. Another challenge is that prosumers may collude to manipulate the auction process. This can happen if prosumers agree to bid certain prices or quantities in order to drive up the price or drive down the quantity of energy traded. This can lead to higher prices and less efficient markets. Finally, auction methods may not always be able to allocate energy efficiently. Auction models, for example, may be unable to handle scenarios in which there are few prosumers or demand is fluctuating. This can result in energy shortages or surpluses, which can have a negative impact on the grid.

2.1.4. Analytical Models for Energy Trading

Analytical models are a type of mathematical model that can be used to analyze the behavior of peer to peer P2P energy trading markets. They can be used to predict how the market will perform under different conditions, such as different price levels, different levels of demand, and different levels of participation [19]. Analytical models can be used to achieve a number of different objectives for P2P energy trading, including:

1. **Predicting market performance:** Analytical models can be used to predict how the P2P energy trading market will perform under different conditions. This information can be used to make decisions about how to design and implement the market, such as what price levels to set and how to encourage participation.

2. **Identifying market inefficiencies:** Analytical models can be used to identify market inefficiencies, such as price volatility or market power. This information can be used to improve the design of the market and to make it more efficient.

3. **Evaluating market policies:** Analytical models can be used to evaluate the impact of different market policies, such as subsidies or taxes. This information can be used to make decisions about which policies and market strategies are most effective in achieving the desired outcomes.

Analytical models are a powerful tool that can be used to analyze the behavior of P2P energy trading markets. They can be used to predict market performance, identify market inefficiencies, and evaluate market policies [27]. This information can be used to improve the design and implementation of P2P energy trading markets and to make them more efficient.

Just like previous energy trading models the analytical models also face numerous challenges and these includes the complicated and difficult system and energy trading design. As a result, using them to make educated judgments on the design and implementation of peer to peer P2P energy trading marketplaces might be problematic. Assumptions regarding the behavior of prosumers and the market are difficult of maintain. These energy trading models are based on assumptions and these assumptions may not always be correct, resulting in erroneous forecasts. Despite of its drawbacks analytical models are still very effective in energy trading.

2.2. Linear Programming Energy Trading Model

A linear programming (LP) trading model is a mathematical model used to optimise energy trading in a peer-to-peer (P2P) energy trading market. The model is built on linear programming concepts, which is a mathematical optimisation technique for solving problems with a set of linear constraints [28]. The LP trading model in applications of decentralized storage energy markets is a useful tool for optimizing energy trading in a P2P energy trading market. It can be used to achieve a variety of goals, including cost reduction, profit maximisation, and supply and demand balance [29].

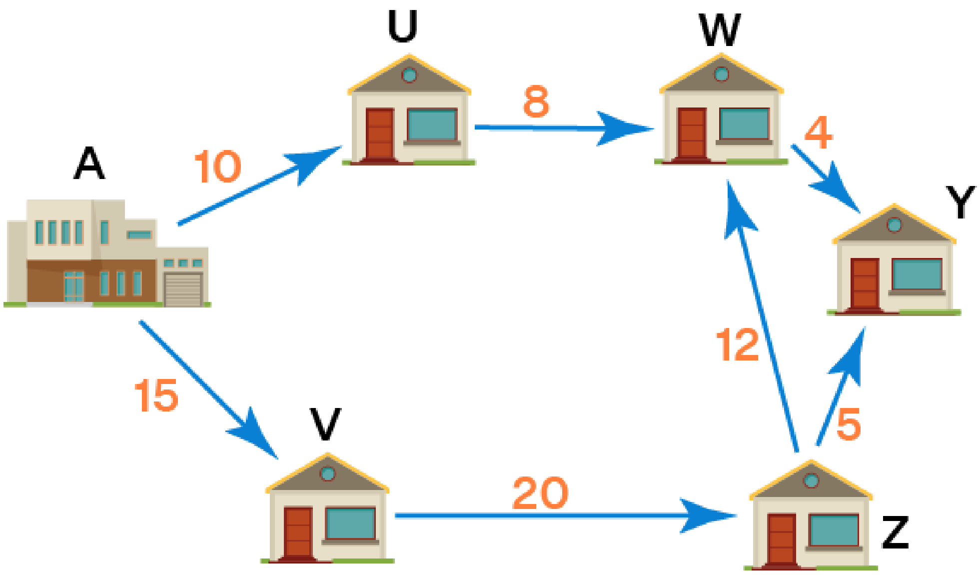

Figure 2.2. Concept Diagram of LP Trading Model

The figure 2.2 explains the working of LP in energy trading for P2P trading model. Let's say that A is the power source and U W Y Z and V are the various peers connected in a microgrid network. The numbers on the lines indicated the priority for the peer to buy the energy. For the most efficient way the power source will first do the trading with the peer lowest values on the line. As a result, the power source will compute several routes to all five destinations and then choose the quickest path. This method of determining the shortest path is known as linear programming. Linear programming (LP) trading model is no doubt minimizing the energy cost per peer and balances the supply and demand among the peers. Yet it is not an efficient method for trading energy.

2.3. Drawback of Existing ET Models

For a variety of reasons, the existing peer-to-peer (P2P) energy trading mechanisms are inefficient. For starters, it is frequently difficult for prosumers (producer-consumers) to discover each other and agree on an energy price. This is because P2P energy trading systems are frequently limited in breadth and reach, and they may lack the required capabilities to connect prosumers [30].

Second, the current P2P energy trading mechanisms are frequently slow and inefficient. This is due to the fact that most of them are based on a centralized system of clearinghouses and exchanges. These clearinghouses and exchanges can delay transaction processing and charge fees, making P2P energy trading less appealing to prosumers.

Third, the current peer-to-peer energy trading mechanisms are not always secure. This is due to the fact that they based on a digital platform that can be hacked or interrupted. This can result in financial losses for prosumers and harm the reputation of P2P energy trade. Finally, the current peer-to-peer energy trading mechanism are not necessarily scalable. This is due to the difficulty of adding new prosumers to the network. This has the potential to hinder the growth of peer-to-peer energy trading and prevent it from realising its full potential.

2.4. Conclusion

In this chapter a detailed overview on the existing energy trading model was provided how these models are currently implemented and what are the major drawbacks of using these models. However the successor of these models based on Blockchain is discussed in the later chapters.

Chapter 3.
Peer to Peer Energy Trading

3.1. Introduction to Energy Trading

Peer-to-peer (P2P) energy trading is a decentralized energy trading mechanism that enables power to be exchanged directly between energy producers and consumers without the use of a middleman. The energy grid might be decentralized using this paradigm, which would increase its dependability, efficiency, and sustainability.

In the traditional energy paradigm, electricity is generated at enormous centralized power plants, necessitating long-distance power transmission to reach end users. This conventional energy system is centralized and, in some ways, inefficient because it depends on a complicated and extensive infrastructure. Such centralized systems provide a number of difficulties, such as considerable energy losses during long-distance transmission, expensive upkeep of huge power grids, and a built-in susceptibility to disturbances. The system's propensity for single-point failures is a startling weakness, as problems at a single power plant could potentially lead to widespread blackouts that would affect the livelihoods and well-being of millions of people. This underscores the urgent need for more resilient, distributed systems [31][32].

By decentralizing the energy infrastructure, peer-to-peer energy trading can assist to address these issues. Consumers and producers can trade energy directly with each other in a P2P system, reducing the need for huge power plants and transmission lines. This can improve the efficiency and reliability of the energy system by reducing the amount of energy wasted during transmission. Furthermore, P2P energy trading can help to improve the penetration of renewable energy by allowing users to buy energy from local producers who use renewable sources.

Peer to peer P2P energy trading model has a lot of advantages. For starters, it can help consumers save money and time the plus advantage is that it can also prevent from uninterrupted power loss on energy. When consumers can buy energy directly from producers, they avoid the markup that energy retailers generally charge. Second, peer-to-peer energy trading can assist in improving the reliability of the electrical grid (microgrid or national gird). P2P energy trading can help to lessen the risk of outages by decentralizing the grid. Third, peer-to-peer energy trading can aid in increasing the use of renewable energy. When consumers can buy energy from local producers who use renewable sources, they are helping to establish a more sustainable energy system.

3.2. The Architecture of P2P Energy Trading

The architecture of the peer to peer energy trading is can vary depending on the implementation techniques, however every technique has these following elements[33] [34].

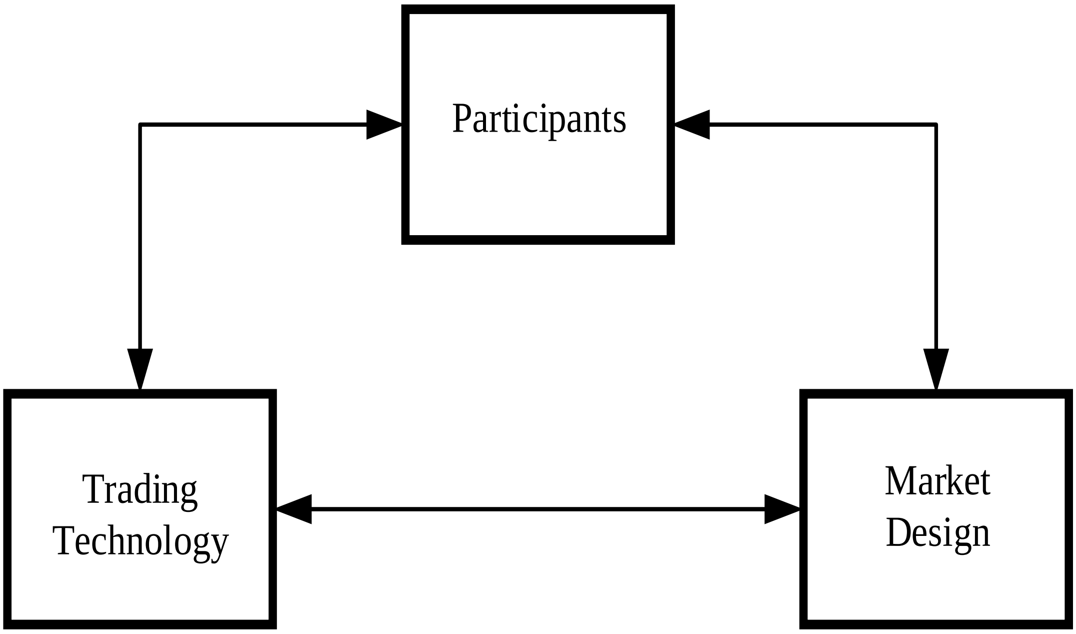

Figure 3.1 ET Architecture Elements

3.2.1. Trading Participants

The three main participants in a P2P energy trading system are consumers, producers, and a platform operator.

1. **Consumers**: Consumers are those who use energy. They can be individuals, businesses, or organizations. Consumers can participate in P2P energy trading by registering with a platform operator and providing information about their energy usage and demand.

2. **Producers:** Producers are those who generate energy. They can be individuals, businesses, or organizations that use renewable energy sources, such as solar or wind

power. Producers can participate in P2P energy trading by registering with a platform operator and providing information about their energy generation and availability.

3. **Platform operator:** The platform operator is the entity that facilitates the trading process. They provide the infrastructure for participants to connect with each other, match supply and demand, and execute trades. The platform operator can be a private company, a government entity, or a non-profit organization.

3.2.2. Trading Technology

P2P energy trading requires a number of technologies, including smart meters, communication networks, and a trading platform.

1. **Smart meters:** Smart meters are used to measure energy consumption and generation. They collect data about energy usage in real time, which is then transmitted to the platform operator. Smart meters are essential for P2P energy trading, as they provide the data that is needed to match supply and demand.

2. **Communication networks**: Communication networks are used to transmit data between participants. This data includes information about energy prices, availability, and demand. Communication networks are essential for P2P energy trading, as they allow participants to connect with each other and negotiate trades.

3. **Trading platform:** The trading platform is the software that facilitates the trading process. It matches supply and demand, executes trades, and tracks the settlement of payments. The trading platform is the heart of the P2P energy trading system, as it is responsible for bringing buyers and sellers together and making sure that trades are executed fairly and efficiently.

3.2.3. Market Design

The market design for P2P energy trading can be centralized or decentralized. This market design in still in its early stages of development. For now let’s understand the difference between centralized and decentralized models.

1. **Centralized market:** In a centralized market, the platform operator is responsible for matching supply and demand and executing trades. This means that the platform

operator has a lot of control over the market. Centralized markets are typically more efficient than decentralized markets, as they can aggregate demand and supply from a large number of participants. However, centralized markets can also be more vulnerable to fraud and manipulation.

2. **Decentralized market:** In a decentralized market, participants are responsible for finding each other and negotiating trades directly. This means that participants have more control over the market, but it can also be more complex and time-consuming to execute trades. Decentralized markets are typically more secure than centralized markets, as they are less vulnerable to fraud and manipulation. However, decentralized markets can also be less efficient, as they can be more difficult to scale.

The architecture of P2P energy trading is still evolving, but it has the potential to revolutionize the way we generate, distribute, and consume energy. By decentralizing the energy grid and giving consumers more control over their energy supply, P2P energy trading can help to make the energy system more efficient, reliable, and sustainable.

3.3. Economics of P2P Energy Trading

The economics of peer-to-peer energy trading appear to be promising. P2P energy trading has the potential to reduce electricity prices, boost energy efficiency, improve system resilience, and provide customers with more options for obtaining energy [36].

1. **Lower electricity prices:** P2P energy trading can help to reduce electricity prices by increasing competition in the energy market. When consumers and producers can trade directly with each other, they are more likely to get a better price for their energy. This is because they are not limited to the prices offered by the utility company.

2. **Increased energy efficiency:** P2P energy trading can help to increase energy efficiency by giving consumers more control over their energy use. When consumers can buy and sell energy from their neighbors, they are more likely to use energy more efficiently. This is because they can avoid wasting energy by over-producing or under-producing.

3. **Improved grid resilience:** P2P energy trading can help to improve grid resilience by reducing the reliance on the centralized grid. When consumers and producers can trade energy directly with each other, they can help to balance supply and demand on the

grid. This can make the grid more resilient to disruptions, such as power outages.

4. **Increased consumer choice:** P2P energy trading can give consumers more choice in how they get their energy. Consumers can choose to buy energy from their neighbors, from renewable energy producers, or from other sources. This gives them more control over their energy costs and their environmental impact.

3.4. Regulations of P2P Energy Trading

Peer-to-peer (P2P) energy trade regulation is still changing in many regions of the world. However, in order to facilitate the development of P2P energy trading marketplaces, a number of common regulatory obstacles must be solved.

One of the most important regulatory challenges is ensuring the security and dependability of the electrical grid. If not adequately controlled, peer-to-peer energy trading has the potential to disrupt the electricity grid. For example, if too much electricity is traded on a P2P network, the grid may become overloaded. Regulators will need to create rules to ensure that peer-to-peer energy trading does not jeopardize the security and dependability of the electricity grid.

Another critical regulatory concern is the requirement to protect consumers. If P2P energy trading platforms are not adequately regulated, they may take advantage of consumers. P2P energy trading platforms, for example, may charge consumers exorbitant fees or offer them low-quality energy. To safeguard consumers from unfair or misleading acts in P2P energy trading systems, regulators will need to adopt guidelines.

Finally, regulators must handle the taxation of peer-to-peer energy trading. In many places of the world, it is unclear how P2P energy trade will be taxed. To ensure fairness and transparency, regulators will need to create clear guidelines on how P2P energy trade will be taxed.

Overall, regulation of peer-to-peer energy trading is still evolving. However, in order to facilitate the development of P2P energy trading marketplaces, a number of common regulatory obstacles must be solved. To maintain the security, stability, and fairness of these marketplaces, regulators will need to collaborate to set clear and fair rules for P2P energy trading. Here are some specific examples of how P2P energy trading is being regulated in different parts of the world:

1. **United States:** In the United States, P2P energy trading is currently only allowed in some states. The Federal Energy Regulatory Commission (FERC) has issued a number of orders that clarify how P2P energy trading can be conducted in the United States. However, there is still some uncertainty about how P2P energy trading will be regulated in the future.

2. **European Union:** The European Union is currently developing a regulatory framework for P2P energy trading. The European Commission has published a number of proposals for how P2P energy trading should be regulated. These proposals are still being debated, and it is not yet clear when a final regulatory framework will be adopted.

3. **China:** China is one of the world leaders in P2P energy trading. The Chinese government has been supportive of P2P energy trading, and it has developed a number of regulations to govern this market. These regulations have helped to facilitate the development of P2P energy trading in China.

3.5. Introduction to Blockchain Technology

Blockchain is a decentralized, distributed digital ledger technology that allows for the secure and transparent recording and storage of transactions and data. It is essentially a chain of blocks containing information about transactions that are verified and recorded in an immutable and permanent manner. Each block in the chain is linked to the one before it, resulting in a continuous chain of blocks [37] [39].

The blockchain technology was invented in 2008 as the underlying technology for the cryptocurrency Bitcoin by an unknown person or group of people using the pseudonym Satoshi Nakamoto. Since then, blockchain technology has evolved and found applications outside of finance, such as supply chain management, voting systems, identity verification, and others. The working of the blockchain is shown in figure 3.2.

One of the most important characteristics of blockchain technology is its decentralized nature, which means it is not controlled by a single entity or organization. Instead, a network of nodes or computers communicates with one another to validate and add new transactions to the blockchain. This makes it difficult for a single party to tamper with the data on the blockchain without the majority of the network's approval.

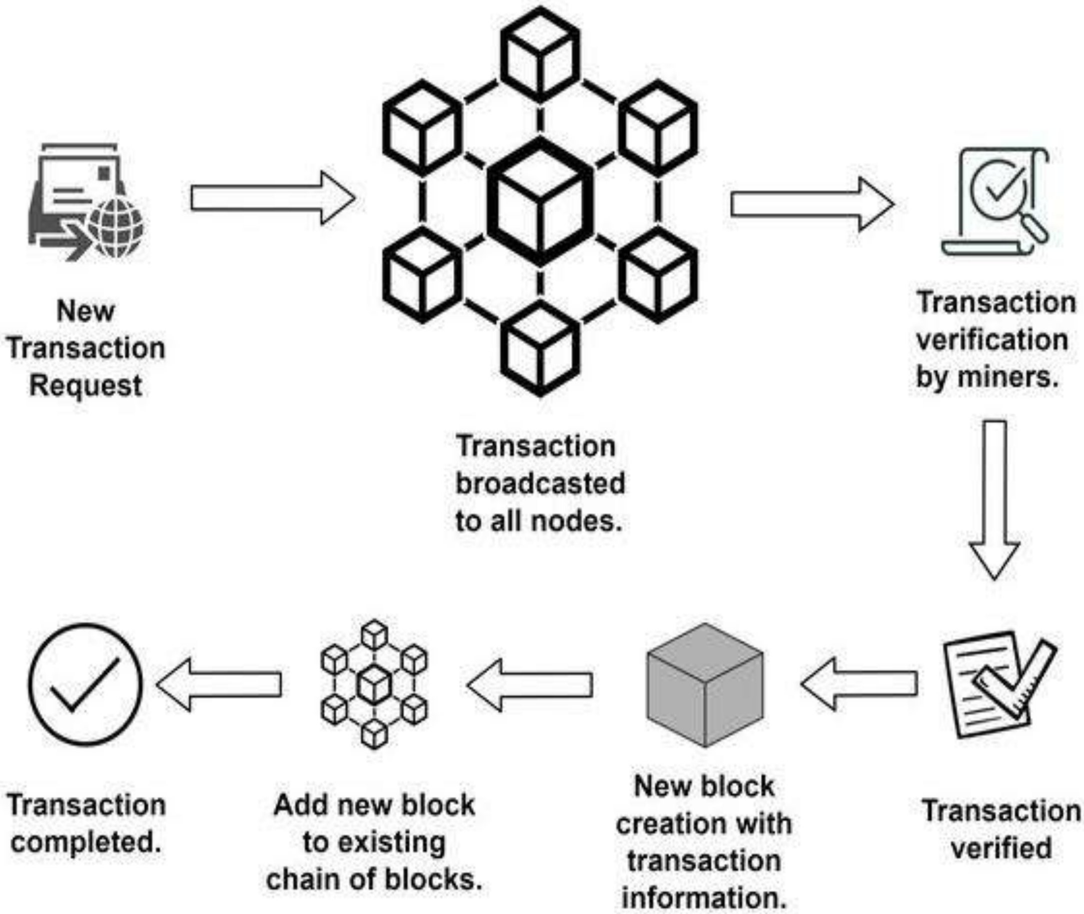

Figure 3.2. The Working of Blockchain Technology

Blockchain technology, however, is not without its difficulties. Scalability is a major issue because the number of transactions that can be processed on the blockchain is limited. Another issue is the amount of energy consumed during the validation process, which can be significant for certain types of blockchains.

Another crucial component of blockchain technology is immutability. It is impossible to modify or remove a transaction after it has been added to the blockchain, making it a trustworthy permanent record. Utilizing the cryptographic techniques that guarantee the accuracy of the data on the blockchain allowing for this.

To summarize, blockchain technology is a powerful and innovative technology with the potential to transform many industries by providing a secure and transparent method of recording transactions and storing data. While there are obstacles to overcome, the benefits of blockchain technology are clear, and it is expected to play a growing role in future.

3.6. Blockchain in P2P Energy Trading

Blockchain technology has the potential to revolutionize peer-to-peer energy trade. Blockchain is a decentralized ledger that securely and transparently records transactions. This makes it suitable for recording energy trading transactions, as it can assist participants create confidence and prevent fraud [40].

Aside from the benefits of openness and security, blockchain can also help to improve the efficiency of peer-to-peer energy trade. Blockchain technology has the potential to automate the energy trading process, saving participants time and money. This is due to the fact that blockchain can eliminate the need for third-party intermediaries like banks or energy suppliers.

Blockchain can potentially help to scale up peer-to-peer energy trade for the future purposes [41]. As the number of peer to peer energy market players expands further into the existence in the systems, blockchain can assist and ensure that the system can easily handle the increased and complex amount of transactions data made by the energy traders inside the peer to peer energy trading market, making it more reliable and secure for the future.

3.7. Future of P2P Energy Trading

Peer-to-peer (P2P) energy trade has a promising future. P2P energy trading is a decentralized approach to energy trading that allows users and producers to trade electricity directly with one another, eliminating the need for a middleman such as a utility company. This has the potential to result in a number of advantages.

3.8. Conclusion

In this chapter, a thorough examination of the peer-to-peer (P2P) energy trading landscape was meticulously presented, commencing with an exploration of the foundational concept of energy trading and progressing to delve into the fundamental architecture underpinning any energy trading model. Furthermore, an illuminating introduction to the world of blockchain technology was thoughtfully included to set the stage for forthcoming discussions. In the chapters, our focus will intensify on the integration of blockchain technology for the design of energy trading model.

Chapter 4.
Research Methodology

4.1. Introduction

This chapter covers how the peer to peer energy trading concept is implemented in the microgrid and how peers are doing the energy trading based on wireless technology while remaining in the blockchain. The research is based on two distinct part the software development of the design and the hardware development of the design.

4.2. Overview of the Research Methodology

As stated in the introduction, the research project is thoughtfully divided into two pivotal segments: simulation design and subsequent implementation using MATLAB in the software development facet, and hands-on practical realization of the design in the hardware development facet. Figure 4.1 illustrates the overarching process by giving a graphic perspective that captures the synergy between these two distinct yet interconnected phases, further explaining the research's holistic approach.

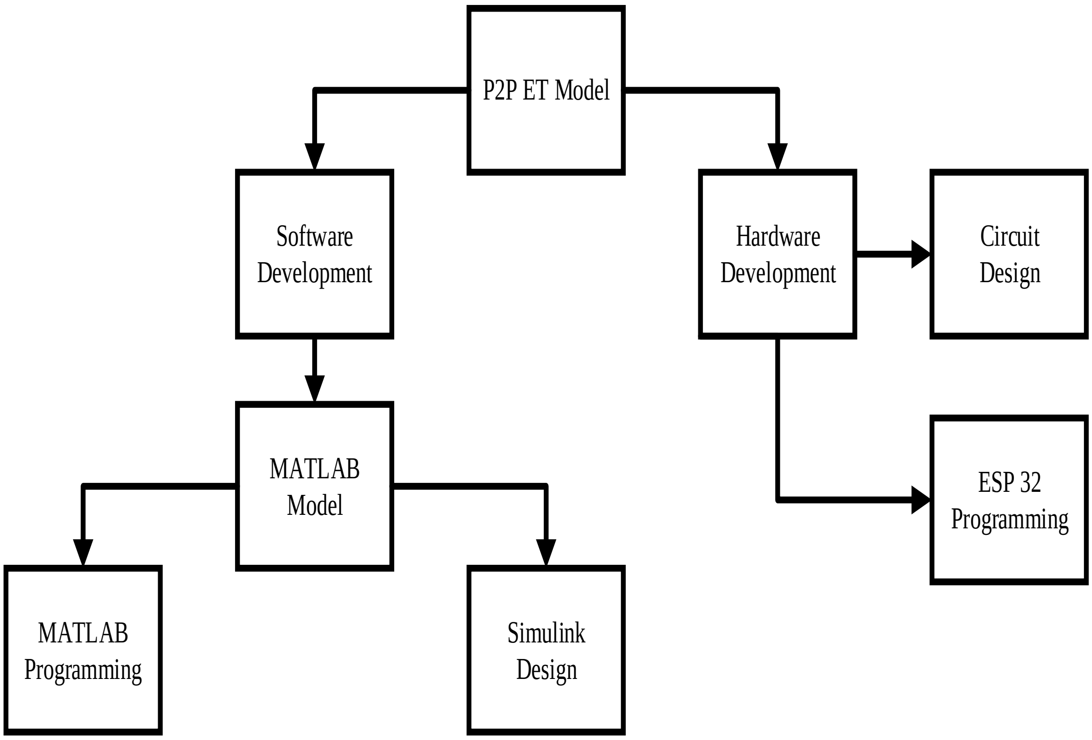

Figure 4.1. Overview of P2P ET Design

4.3. MATLAB Model Design

The MATLAB (Matrix Laboratory) model design is based on IEEE (Institute of Electrical and Electronics Engineers) 9 bus bar system in the MATLAB's Simulink design. The design is slightly modified in such a way that the general power sources are replaced with the renewable energy sources and the generator. The parameters of the blocks of the simulation design are set on the basis of the MATLAB m file.

4.4. Hardware Model Design

The hardware starts with the implementation of IEEE 9 bus bar system. Three microcontrollers called ESP 32 are used to make the design functional. ESP32s are programmed using Arduino IDE and the model then connects it with the mobile phones to perform trading.

4.5. Flowchart

The working of the entire design is shown in three different flowcharts. The first flowchart explains the design and trading concept on MATLAB Simulink and Script file and the second one shows the design and implementation of the system on hardware.

A trading mechanism based is also implemented in the MATLAB model as well as in the hardware model though the trading model is slightly different in case of MATLAB model and in hardware model but the end working of each model is same. A detailed explanation on how these models are working are explained in the chapter 5 and chapter 6.

4.5.1. MATLAB Flowchart

The elaborate flowchart in Figure 4.2 depicts the thorough design and deployment of the microgrid model, which is built on the IEEE 9 bus bar technology. This thorough graphic shows how conventional energy sources are thoughtfully replaced with sustainable and renewable alternatives such as wind turbines and solar power panels, matching with the necessity of lowering environmental effect. Similarly remarkable is the depiction of peers actively participating in the dynamic energy trading ecosystem, all while complying to the tight criteria governing peer to peer energy trading.

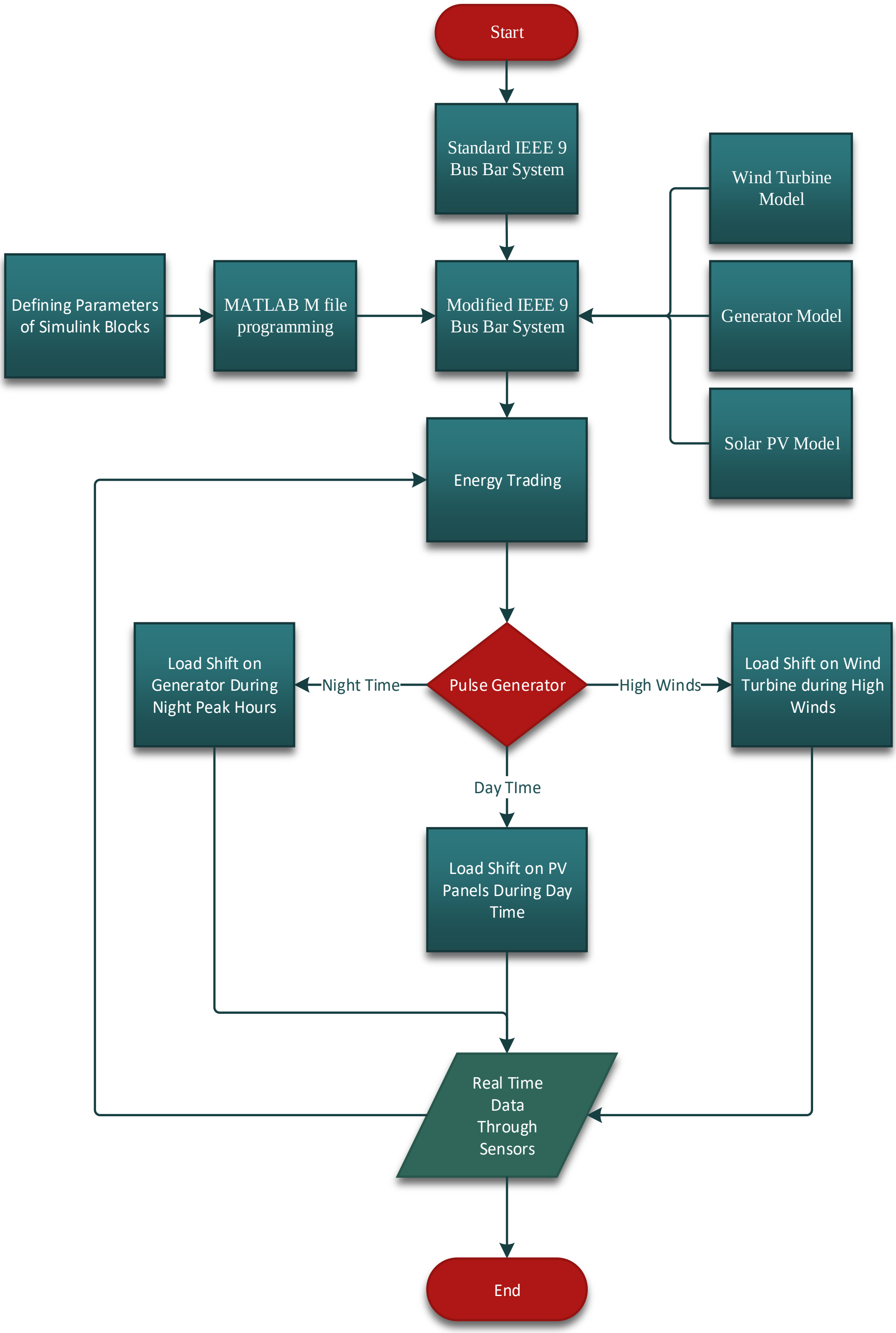

Figure 4.2. MATLAB Model Flowchart

4.5.2. Hardware Model Flowchart

The following flowchart shows the MATLAB Simulink model shown in the figure 4.2 is implemented in the figure 4.5 on the hardware physical model.

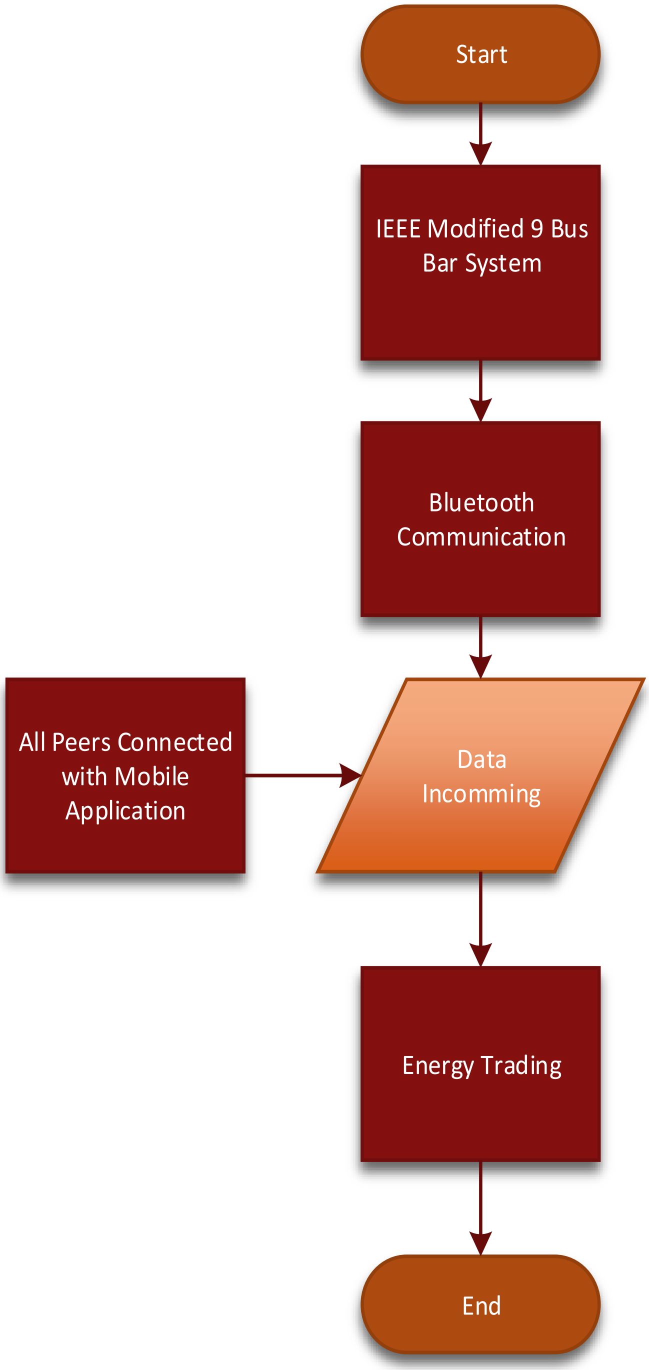

Figure 4.3. Hardware Simplified Flowchart

4.6. Conclusion

In this chapter a detailed overview of the research methodology was discussed, how the system will be designed and what will be its parameters. The flowcharts in this chapters are the simplified explanation of the project from the beginning till the end.

Chapter 5.
Implementation and Simulation Analysis

5.1. Introduction

In this chapter, the recommended methodology outlined in chapters 4 and the concept from the earlier chapters are implemented. This chapter goes through how the peer-to-peer P2P energy trading concept is implemented in the MATLAB Simulink and Script files in detail. To develop an efficient system based on the IEEE 9 bus bar system, it is necessary to first understand what the IEEE 9 bus bar system is and why it is used in our design.

5.2. IEEE 9 Bus Bar System

The IEEE 9-bus system is a well-known benchmark model for power system analysis and research. It represents a simplified version of a real-world power system, consisting of nine buses, three power sources, and three loads, interconnected by transmission lines. This model has been widely used for testing and evaluating new power system analysis techniques, as well as for teaching power system engineering. The figure 5.1 show the standard model of the system [42].

The nine buses in the system are numbered from 1 to 9, and each bus is assigned a type based on its characteristics. Bus 1 is designated as the slack bus, which means it has a fixed voltage magnitude and phase angle, and is used to control the overall system voltage level. Buses 2 and 3 are designated as PV buses, which means they have a fixed voltage magnitude and can control their active power output. The remaining buses (4 to 9) are designated as PQ buses, which means they have both active and reactive power injections,

Applications for power system analysis using the IEEE 9-bus system include load flow analysis, transient stability study, and optimization studies. It has also been used to gauge how well new power systems innovations like High Voltage Direct Current transmission and FACTS devices work. Overall, the IEEE 9 – bus system is expected to be used for many more years to come as a useful tool for power system study and research. Looking ahead, the IEEE 9-bus system is projected to remain a keystone in the study and research of power systems. Its versatility and historical significance assure that it will remain relevant for many years to come, making it an invaluable resource for engineers.

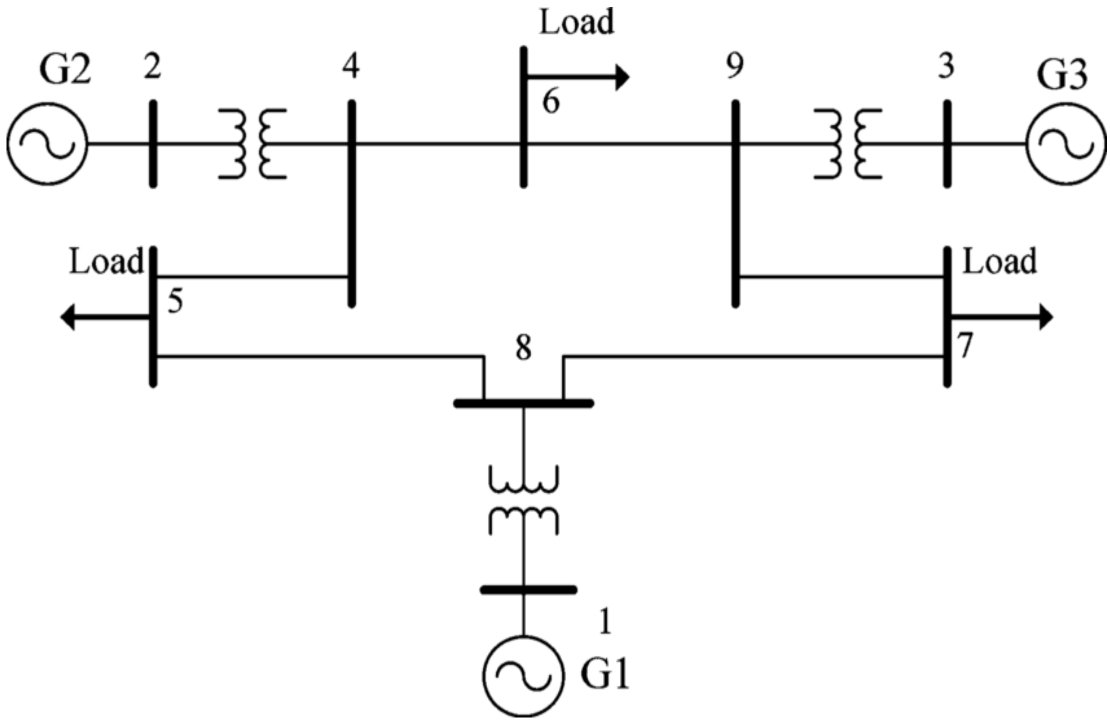

Figure 5.1. Standard IEEE 9 Bus Bar System

5.3. IEEE 9 Bus Bar System Based Microgrid Model

The IEEE 9-bus system and microgrid model are two commonly used models in power systems engineering for different purposes. The IEEE 9-bus system represents a simplified version of a large power system, whereas the microgrid model represents a small-scale power system that can operate independently or in parallel with the main grid.

Although there a number of various topologies and models are designed and explored by engineers and researchers respectively there are only a handful of microgrid designs that are based on the IEEE 9-bus bar system. The peer–to–peer energy trading in microgrid designed in IEEE 9 – bus bar system is a unique design of its own.

The design of our Microgrid based on IEEE 9-bus bar model is slightly modified version of the actual IEEE 9-bus bar system. The major changes are in the sources that are attached with the original IEEE 9-bus bar system and the consumer electrical load. The two generators are replaced with the two renewable energy sources i.e. solar power source and wind power source. The third power source is connected to the generator power source or national power grid or utility power grid. However, there are modifications in the loads attached to the system. The high loads are replaced with the 300W loads as the microgrid is designed for upto1KW of total power.

5.4. Simulation Software

Matrix Laboratory commonly known as MATLAB. It is a high-level programming language that is widely used for numerical computation, data analysis, and visualization. MATLAB provides a user-friendly interface for creating and executing code, making it a popular choice for researchers and engineers alike. It provides a wide range of built-in functions and toolboxes that can be used to perform complex mathematical operations, such as matrix operations, signal processing, and optimization [43].

On the other side, Simulink is a graphical simulation and modeling tool that works with MATLAB. By drawing block diagrams to depict the many parts of the system, users can construct complicated systems. These parts can be combined to build a simulation model that can be used to test and examine the system's behavior under various circumstances.

Simulink is commonly used to develop control systems, communication systems, and other systems having dynamic behavior. It offers a wide range of pre-built blocks and libraries that may be used to simulate many sorts of systems, allowing users to easily create complex models. Simulink is a powerful and versatile tool for system analysis and design because it allows users to easily integrate their MATLAB code into the simulation model.

5.5. Simulink Design

The "Peer to Peer Energy Trading Model in Microgrid" is built around a customized adaptation of the IEEE (Institute of Electrical and Electronics Engineers) 9-bus bar model and its smooth integration with the powerful execution software "MATLAB." The model we built closely resembles the IEEE nine-bus bar system, with intentional changes made to the power sources, electrical load, and transmission lines. Among these changes is the replacement of the original three power sources with two renewable sources, notably solar power source and wind turbine power source , as well as the addition of a regular diesel generator. This comprehensive system, precisely created within the MATLAB Simulink environment and MATLAB script programming. It operates at a voltage of 220V and can support a maximum electrical load of 1KW, signifying an innovative step forward in the investigation of microgrid energy trading.

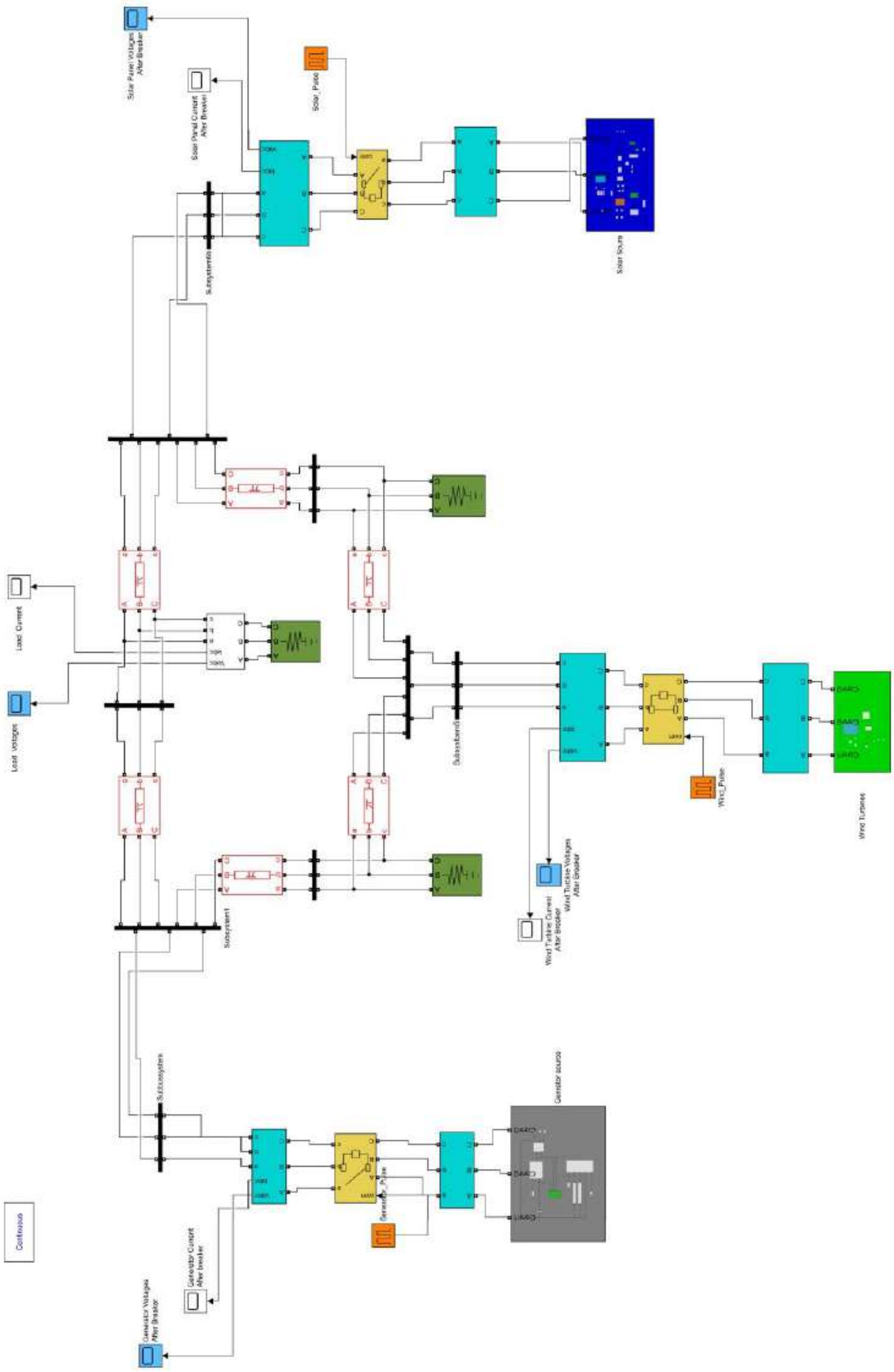

Figure 5.2. Microgrid Model Based on IEEE 9 Bus Bar System

The actual load of the entire system consists of 900W. Each power source either wind power, solar power, and electric generator is capable of supplying 220Vs enough to power up the entire electrical load at once. The figure 5.2 resembles more like three electric power sources connected in a grid through the IEEE 9 bus bar model.

5.5.1. Generator Model

One of our peers for this designed is based on the nonrenewable energy source i.e. the generator. The generator is used as it provided continuous energy without any interruption. The generator provided fix voltages at any conditions also it plays an important part in regulating the energy trade cost among peer. For its implementation in the system however there is no pre-installed generator model available in MATLAB library. So a pre designed model has been used for in this project design. The model is similar to the actual diesel generator with diesel generator governor, excitation branch and rotor. The figure 5.3 show the generator model.

5.5.2. Wind Turbine Model

Just as the generator model, wind turbine model is also not available in the MATLAB's library an external model is imported in the design and the paraments are then set. In the wind turbine model of MATLAB design, the external pins are controlling the input and output of the wind turbine. There is a perfect pitch angle where the turbine produces the most power for a given wind speed. The wind speed affects this ideal angle. This pitch

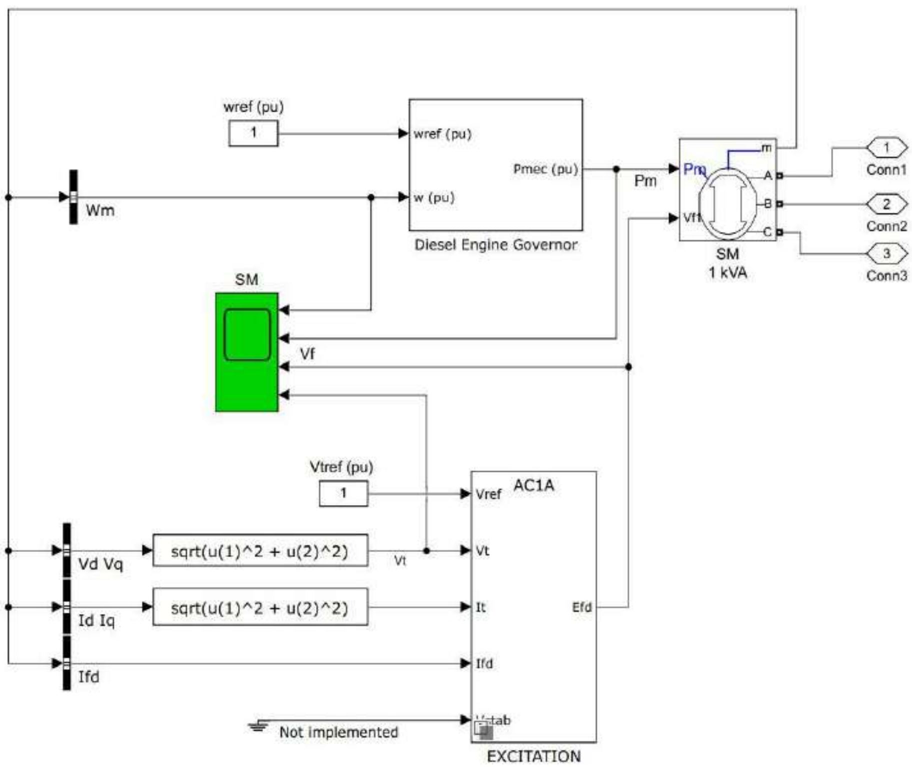

Figure 5.3. Generator Model

angle in our design is set to 45 after calculations. The figure 5.4 shows the wind turbine model.

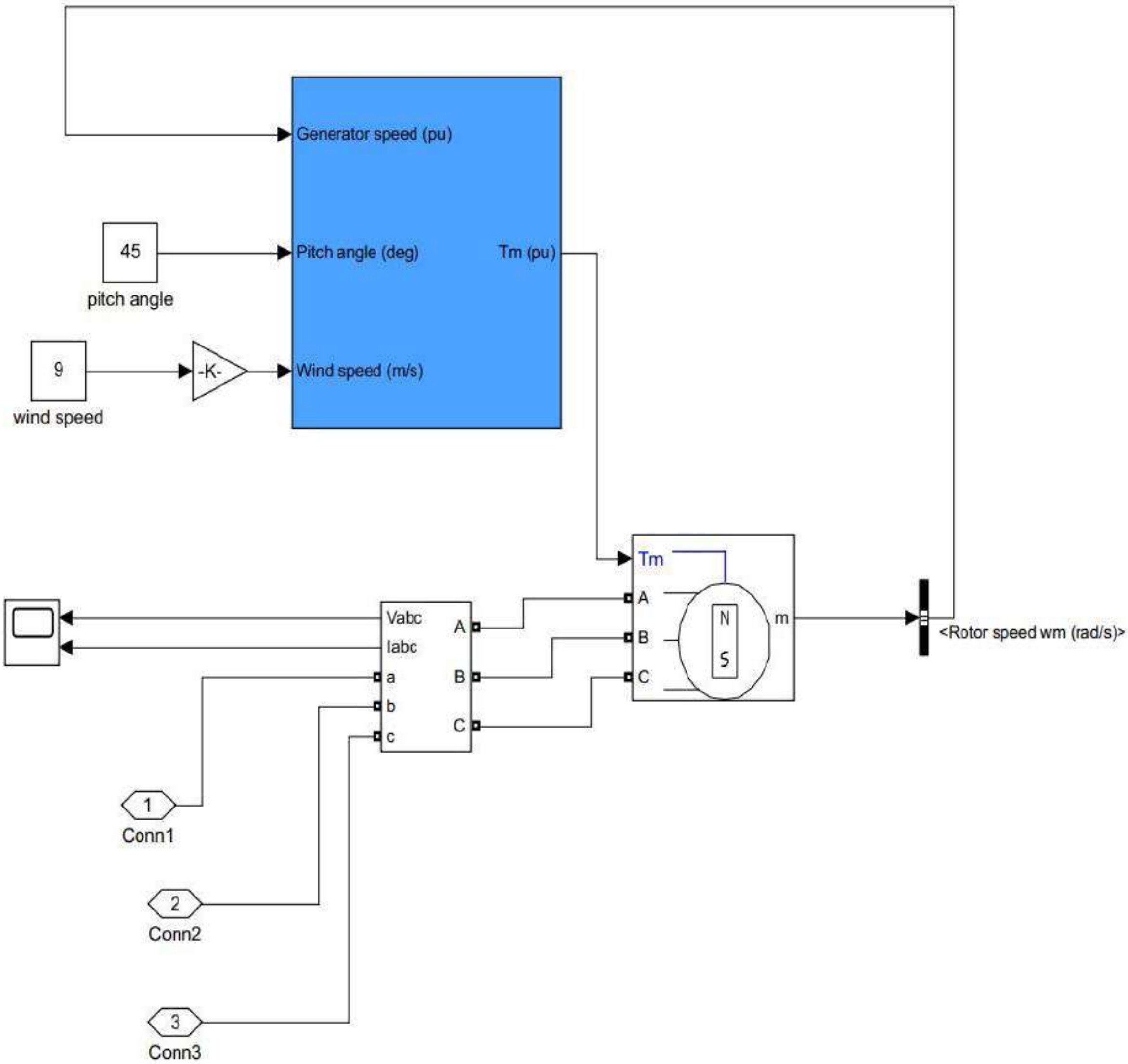

Figure 5.4. Wind Turbine Model

5.5.3. Photovoltaic Model

The solar power model in MATLAB is similar to actual solar power model. The irradiance provided from the MATLAB programming or .m file will be the main source that will decide how much energy will be produced along with the temperature of that particular time. The waveform of the solar panel output will be modified through the 3 Level IGBT Bridge and the inverter control will invert the DC into AC as final output. The figure 5.5 shows the solar panel or photovoltaic model.

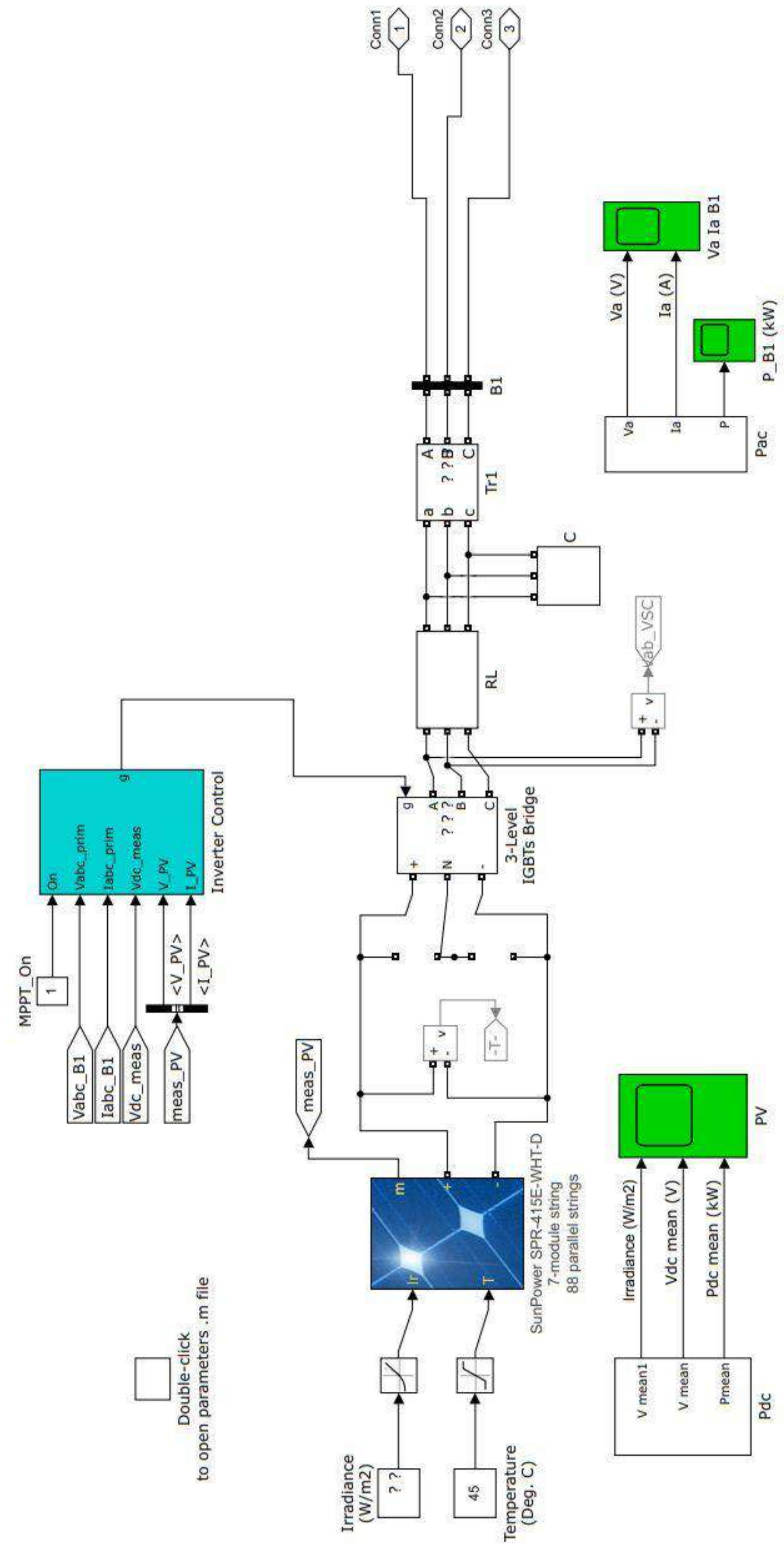

Figure 5.5. Solar Panel / Photovoltaic Model

5.6. Pulse Generator Model

The concept of peer to peer trading is introduced through the pulse generator connected with each power source circuit breaker. The Pulse Generator in MATLAB is a function that generates pulse signals based on user-defined parameters, which we can leverage to simulate energy trading transactions. The pulse generator works synchronously with the pulse generators of both generator and solar power source. In order for the pulse generators to works harmoniously in the grid its parameters are defined on real time values based on 24-hour system. This makes the system less complex and more energy efficient in day to day utilization. In figure 5.6 and figure 5.7 generator model with its output is shown.

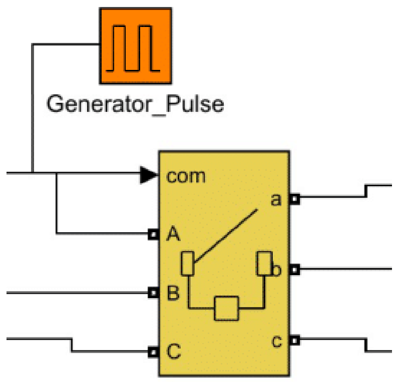

Figure 5.7. Pulse Generator Connected with CB

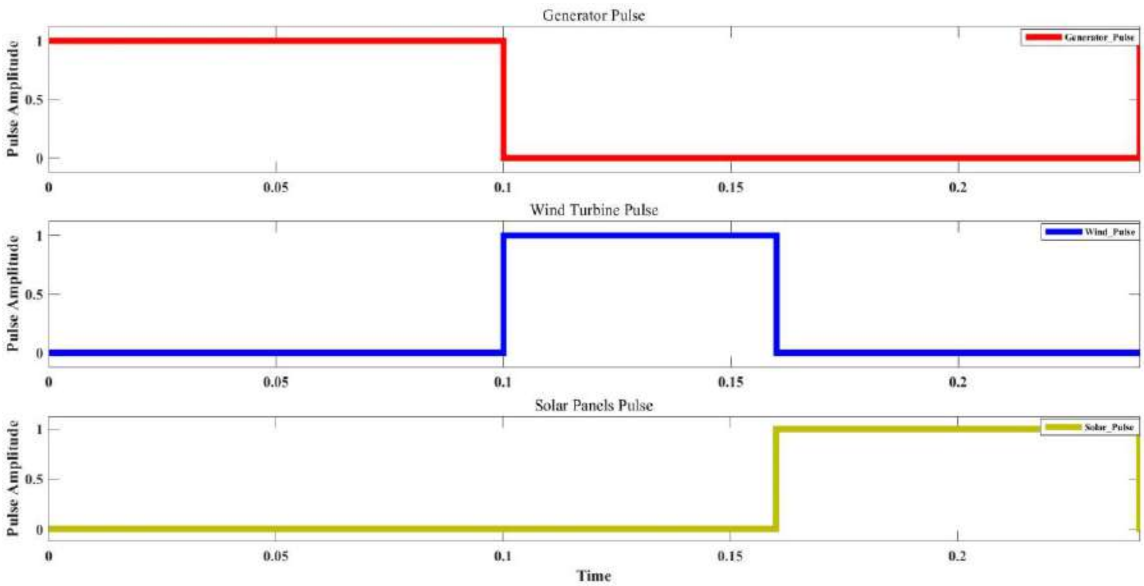

Figure 5.6. 24 Hours Working Pulse Generator Output

5.7. P2P Energy Trading Algorithm

The whole algorithm will be monitored and will work under blockchain as explained earlier. Suppose that a system works for 24 hours straight. This means that after 24 hours the time will repeat itself and so will the system. Let's assume some assumptions based on the goals of the research.

1. Fulfilment of Load Requirement.
2. Providing Clean Energy for Green Future.
3. Utilization of Power.
4. Cheap Power.

Now keeping these four goals in consideration the algorithm that is designed by us for 24 hours, will make certain decisions based on the real time conditions till its 24 hours are complete.

1. Assume that the solar power and the load connected to it is peer A, wind power and its load is peer B, and the generator with its load is peer C. The cheapest unit price is of peer A, then the peer B, and most expensive is the peer C.
2. During the day between 09:00 hours to the 16:hours the sunlight is available in abundance, the algorithm will receive the data from the sensors that will sense the lumens of the light intensity and if the conditions are correct like light intensity, cheapest unit price, and the load bearing capacity then the entire load will shift on peer A. This will make peer B and C the consumers and Peer A the producer.
3. Between 16:00 hours to 19:00 hours and 03:00 hours to 07:00 hours the winds are high then normal, during this time the energy from the wind power or the peer B will be cheapest if the peer B has enough capacity to bear the load of all other two peers then it will accept the conditions and the relays will trip the system accordingly. If the it does not fulfil the criteria then the power requirement will be fulfilled by the synchronization of any two available peers capable to bear the load.
4. During night the winds are low and there is no sunlight hence peer A and B cannot operate. If peer A and B has more than emergency backup then both peers will use that power, if the peers do not have this backup power then the energy to all the peers will be provided by peer C or the generator.

5. In all of this trading the uninterrupted power supply, low unit price, and efficient use of clean energy is the top priority.

This entire peer to peer P2P energy trading model will be under the blockchain which will make it a secure network as well as secure the energy transactions done by the energy traders or the peers inside the microgrid.

5.8. Standalone Working of Microgrid

The outcome is based on how much outcoming three phase sinusoidal voltages a peer with source is giving. As the system is set on 220V and the power sources are operating synchronously with one another with 50Hz frequency. For simple understanding lets discuss how the output waveform will be received when different sources will turn on and off. Keeping in mind the fact that these source in the following diagram are driving the load during specific intervals. The concept involved in the following diagram is crucial to avoid the intermixing of reading signals. The systems runs on 24 hour time scale and then repeats its self in MATLAB the simulation is scaled down to 0.24 seconds.

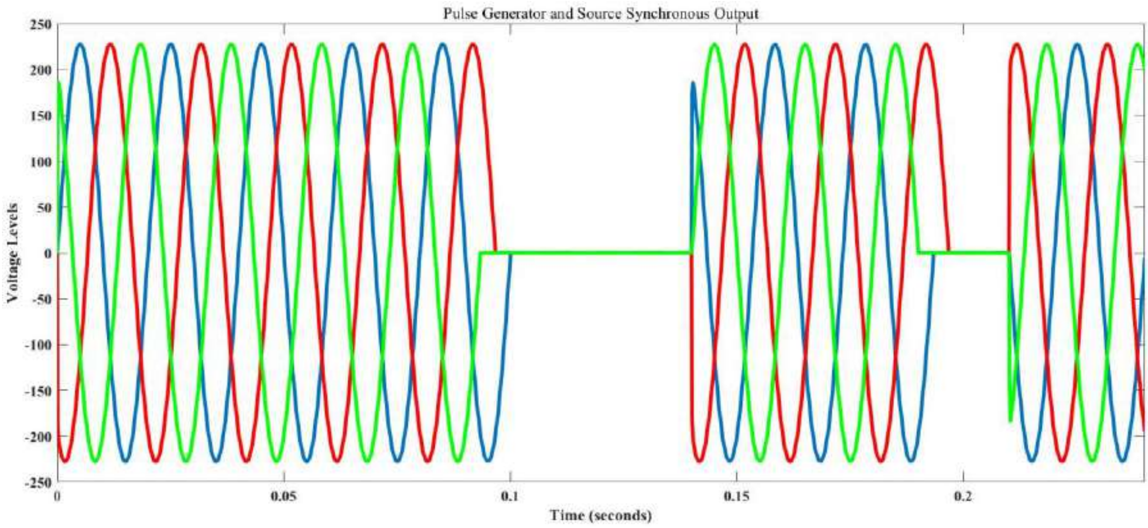

Figure 5.8. General Pulse Generator and Sources Synchronous Output

The figure 5.8 shows how all sources generator, solar panels and wind turbines are turning on and of and trading energy. In the above figure the first sinusoidal wave up to 0.1-time seconds is of generator then a gap is added in which no power source is on and all loads are turned on connected in microgrid network are off. Then from 0.13 seconds the wind turbine is operating and entire load either connected with the generator, solar panels, and wind turbines are shifted to the single power source and that is solar panel. Similarly, from 0.21 seconds the solar panels are in operation and the entire load is shifted on them.

In the actual trading there should be no interruption in figure 5.8 energy trading is in process but there is an interruption in which the consumers load is off. However in order to ensure the availability of the power 24 Hours there should be no interruption on any kind. To implement this the paragraph 5.7 explains the algorithm behind the energy trading and the code is available in appendix A on MATLAB script programming.

5.8.1. Standalone Generator

At night there is no sunlight and there little to no chance of the wind blowing. So in microgrid only one source is left to provide the energy to the load connected with all there peers. So during nighttime the generator will supply the power to the loads from 19:00 Hours to 04:00 Hours for total 12 hours. This is more elaborately explained in figure 5.9

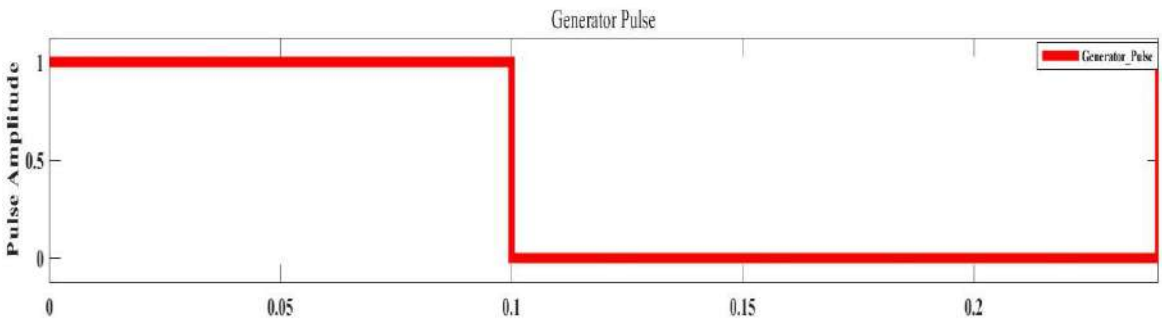

Figure 5.9. Generator Pulse

When the generator is high during this time only generator is the one supplying the load whereas the other solar and wind turbine sources should be off. This means no current will be generated by these sources. So in figure 5.10 when load is demanded from the generator only generator is providing the power while other sources remain off. The figure 5.11 shows the load voltages when only power is comping from generator.

The figure 5.12 shows the load current when the generator is on. As the load connected to every peer is of same power (WA) hence the total load on the microgrid is around 300 watts currently.

In the all of the following figures only generator power source is on and other sources like wind turbine power source and solar power panels source are off. So, for 11 hours of night the power to the loads of all sources connected in the microgrid network is only supplied by the generator.

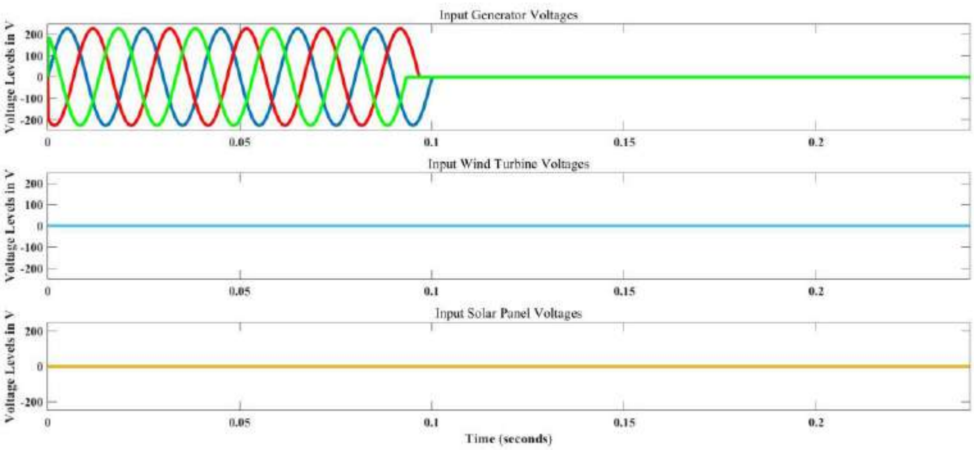

Figure 5.10. Input Generator Voltages

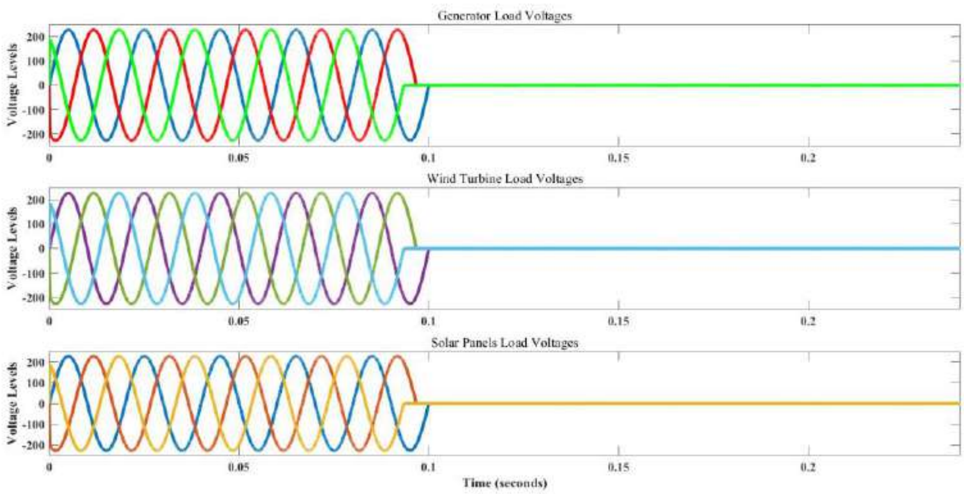

Figure 5.11 Load Voltages when input is Generator

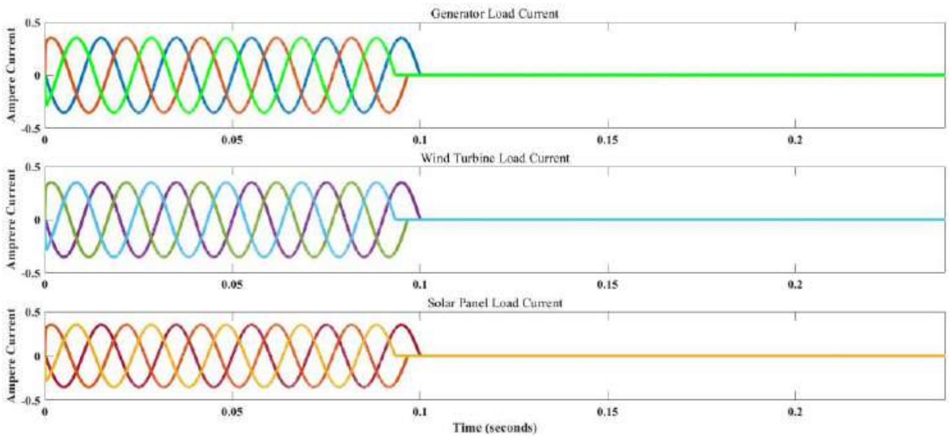

Figure 5.12. Load Current when input is Generator

5.8.2. Standalone Wind Turbine

Wind is usually high in early in the morning from 04:00 hours till 09:00 hours. During this time system will check whether the conditions for energy trading are suitable or not. If the conditions are suitable then the entire load will sift on the wind turbines. In the figure 5.13 shows the period for which wind turbine is on. Also wind turbine is only on for the period when there are high winds other then that wind turbine will remain off. This means that only the load that will only in this time and remains off in all other times. From time 0.1 to 0.16 for total 5 hours of stable wind the system is shifted to the wind turbine.

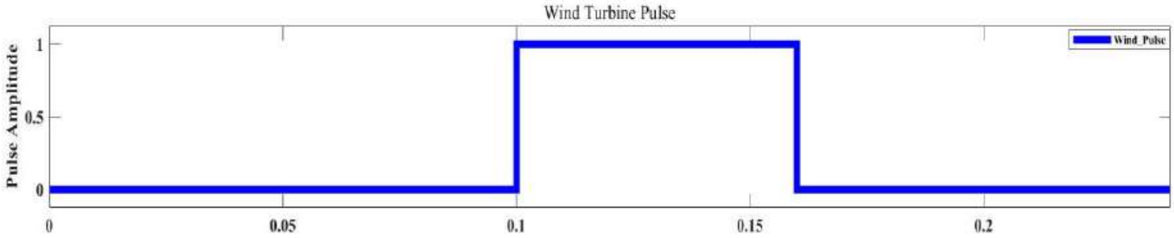

Figure 5.13 Pulse Generator for Wind Turbine

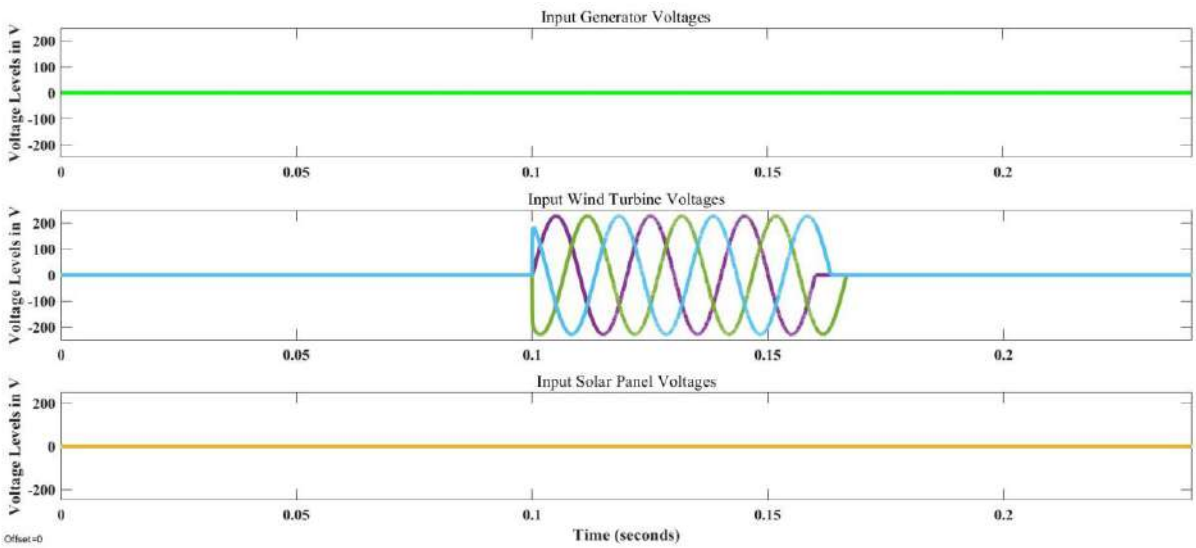

Figure 5.14. Input Wind Turbine Voltages

The figure 5.14 explains the input voltages generated from the wind turbine during the period when there are high wind and all the other sources are off because the load is shifted to the wind turbines after meeting the required conditions Now it is understood that only wind turbine is giving off power this surely means that the loads connected with the solar panels, generator, and wind turbine will turn on but for only the period in which the wind turbines are on and are off otherwise.

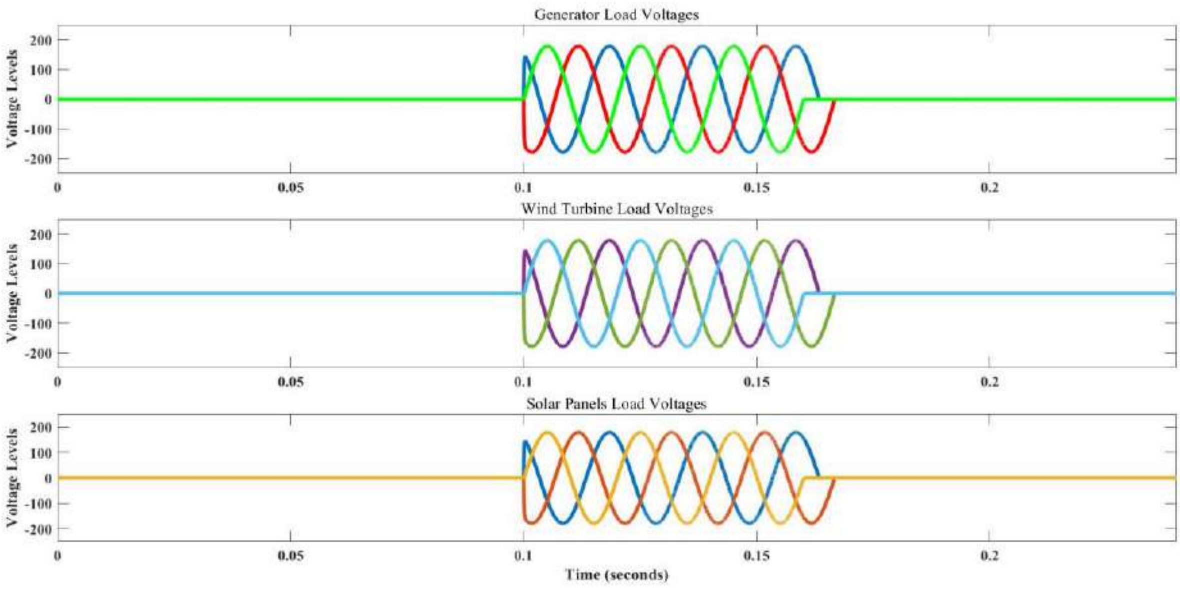

Figure 5.15. Load Voltages when input is Wind Turbine

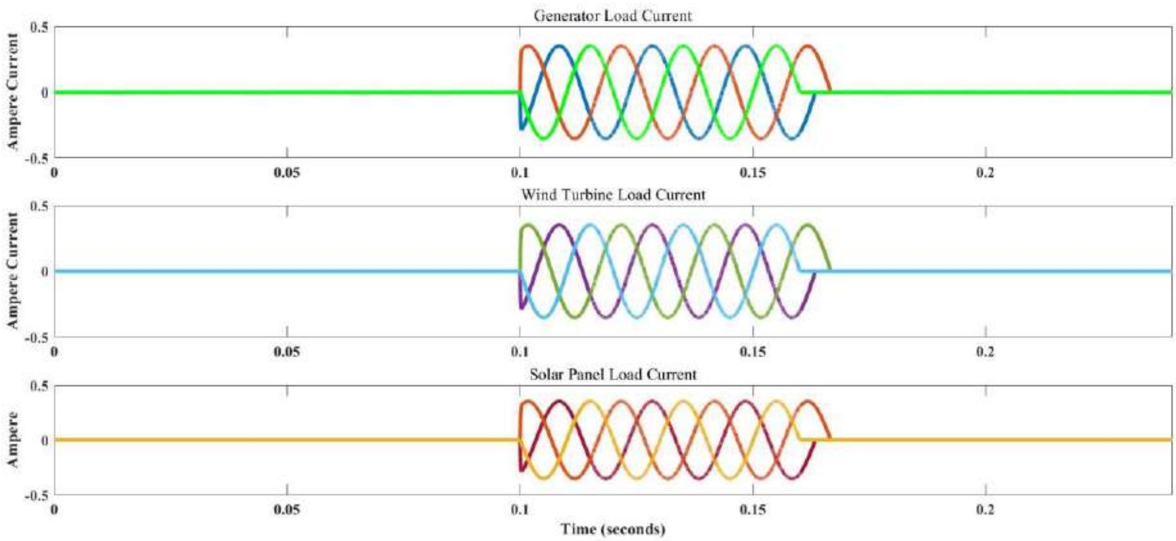

Figure 5.16. Load Current when input is Wind Turbine

The figures 5.15 and 5.16 shows the load voltages and currents respectively when the wind turbine power source are is in operation while all the other power sources e.g generator power and solar power panel sources are off.

5.8.3. Standalone Solar Panels

Now the sunlight is abundant in the daytime and the energy produced during this period will be the cheapest of all. The system will detect the availability of sunlight and check for its stability. Once the stability is assured the entire system will shift to the solar panel as the system is working in 24 Hours of time frame so between 09:00 Hours to 19:00 Hours the solar panel will operate and the pulse generator pulse during this period will remain high. From the figure 5.17 the pulse for solar panel is high showing that the solar panels will operate all day till evening and during this time power to the entire microgrid will be delivered by standalone solar panels.

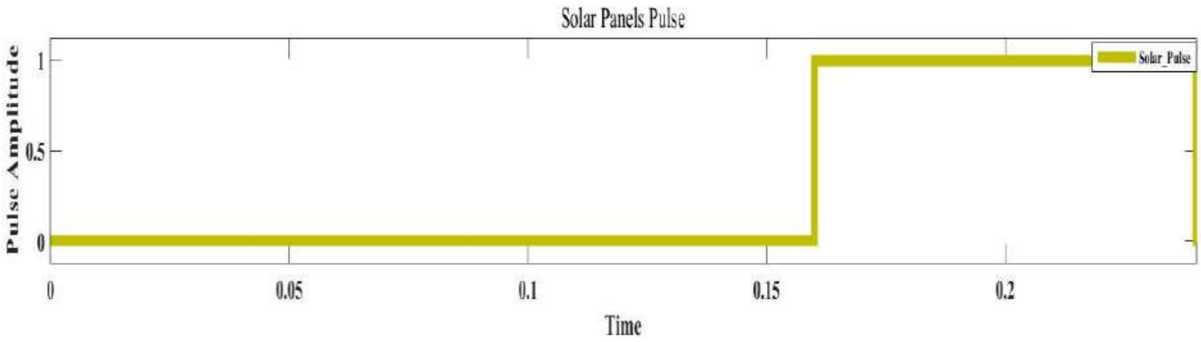

Figure 5.17. Pulse Generator for Solar Panels

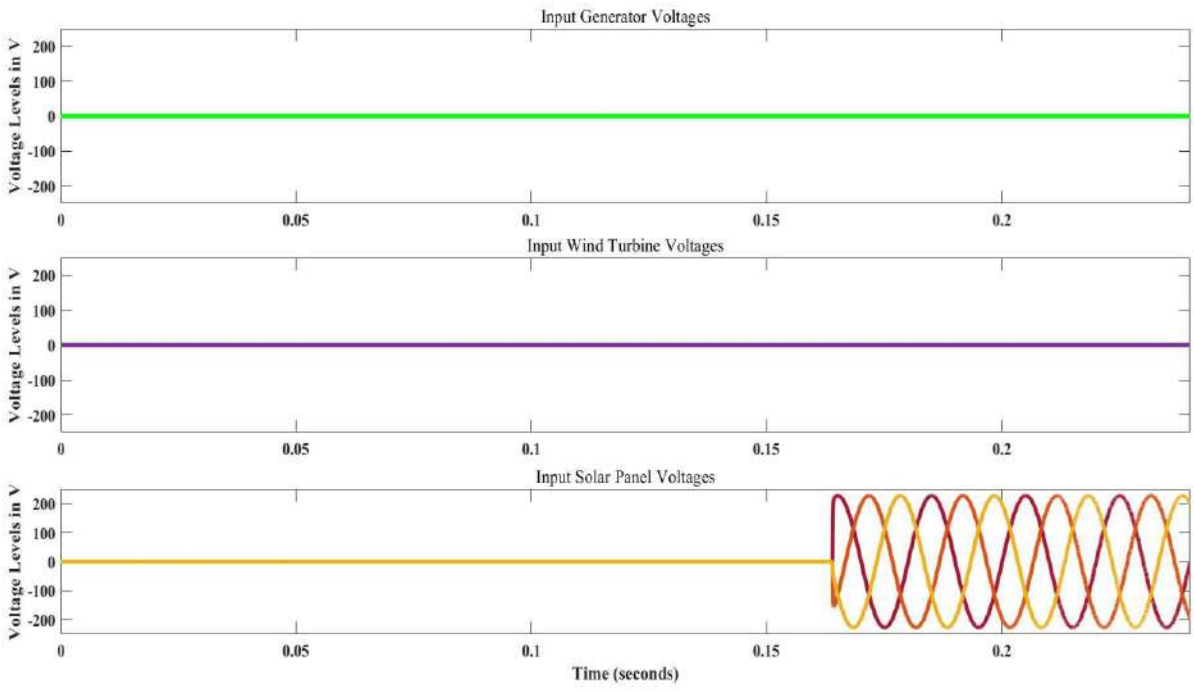

Figure 5.18. Input Solar Panel Voltages

The figure 5.18 shows that when the power requirement is shifted to the solar panels for the day time. Only solar panels will remain on and the other sources will remain off.

In the figure 5.19 and 5.20 the load voltages and currents are shown for all the loads attached in the microgrid. These load are only one when the solar panels are on , showing the dependency of the system on the solar panels.

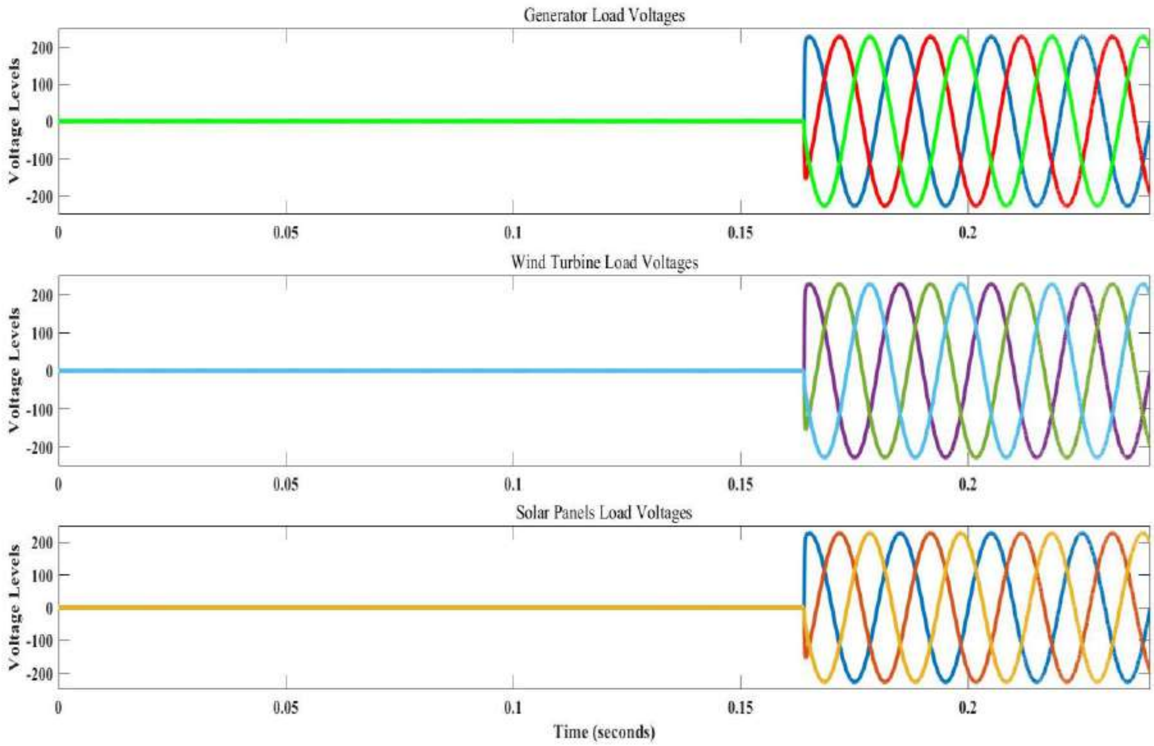

Figure 5.19. Load Voltages when input is solar panel

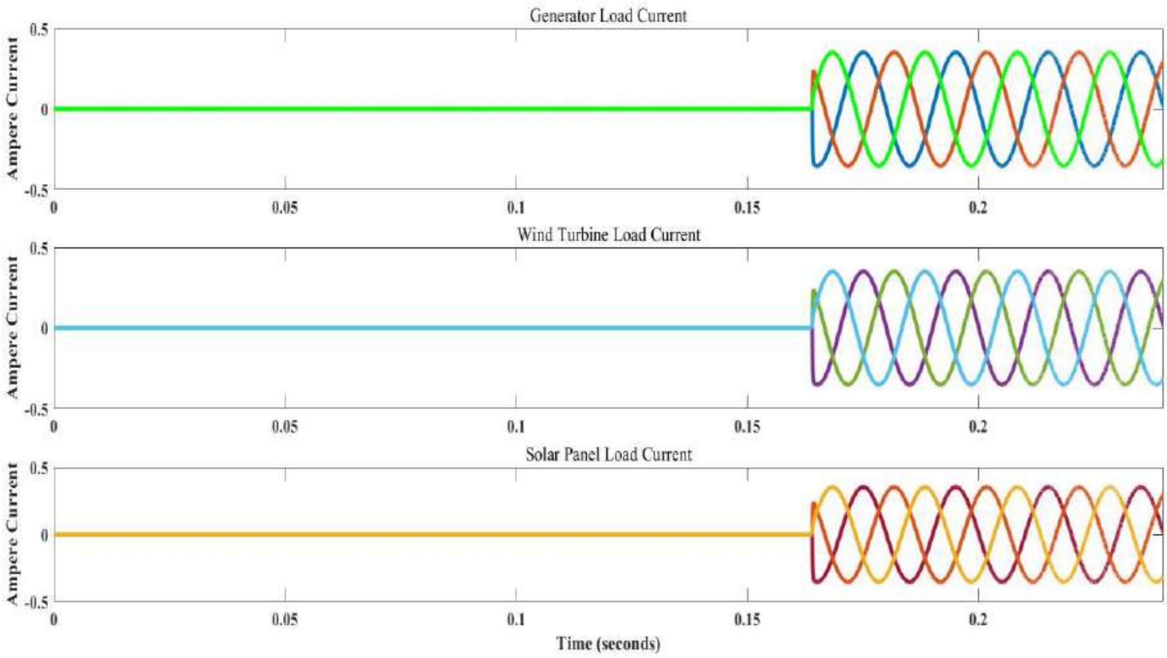

Figure 5.20. Load Current when input is Solar Panel

5.9. Synchronous Working of the Microgrid

Until now, the standalone or independent operation of the microgrid's connected sources and loads had been extensively investigated. However, the complete system operates synchronously and without interruption in the power supply. This means that when the necessary conditions for energy trading are met, the power sources will automatically switch. This will keep the system from getting into difficulty by making bids every time it runs out of energy.

Recall the figure 5.6 in which the 24 hours sources are shifting based on the energy trading set in MATLAB’s programming given in appendix A. The pulse generator’s value decides which power source should be on or off in the microgrid. But it does not depend on the load no matter what kind of power source is on the power will not be interrupted in any case. This makes the systems not just cost effective but more reliable and safe.

The figure 5.21 shows that how all power sources that are operating in their time frame. The figure clarifies the fact that no interruption is coming in or out or the system, when the power sources are switching automatically and all sources are working at 50Hz at 220Vs

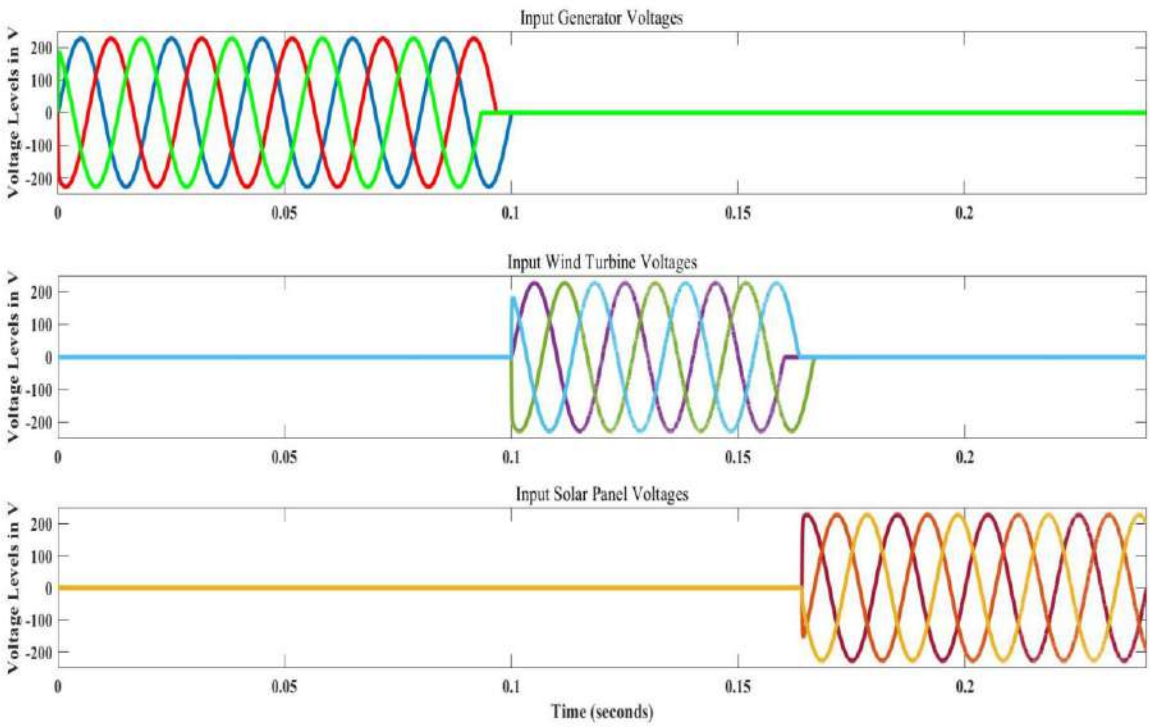

Figure 5.21. All Power Sources Voltages

In the figure 5.22 a single sinusoidal wave form is given showing that the power sources connected in the systems are running smoothly and there is no interruption of any kind. Plus it also shows how all energy sources are working at 220Vs harmoniously with one another.

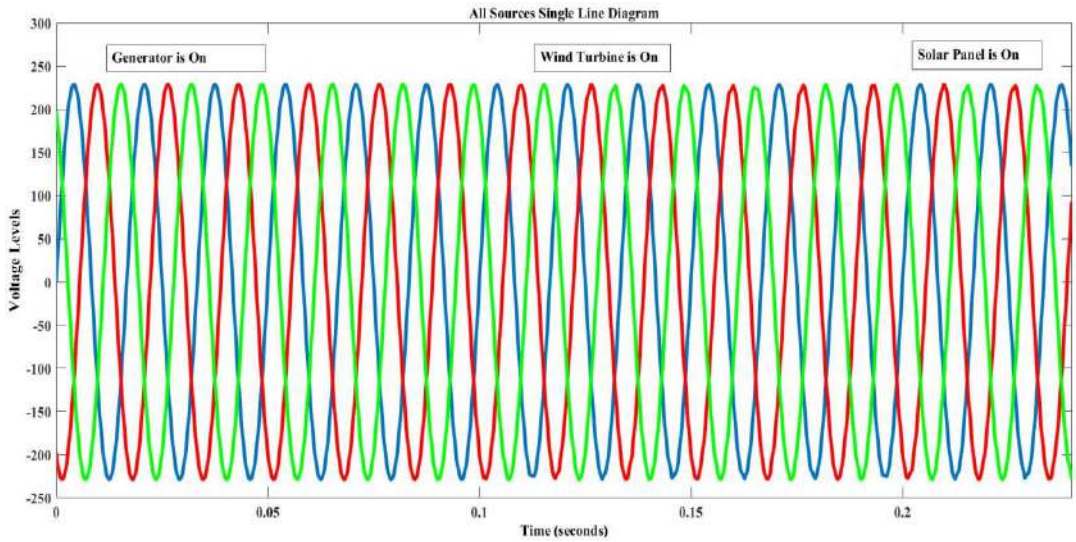

Figure 5.22. All Power Source Voltages in Single Diagram

In the following figure 5.23 all the loads voltages that are connected in the microgrid are shown. The figure clarifies that power is provided without any interruption and all the loads are working safely inside the microgrid.

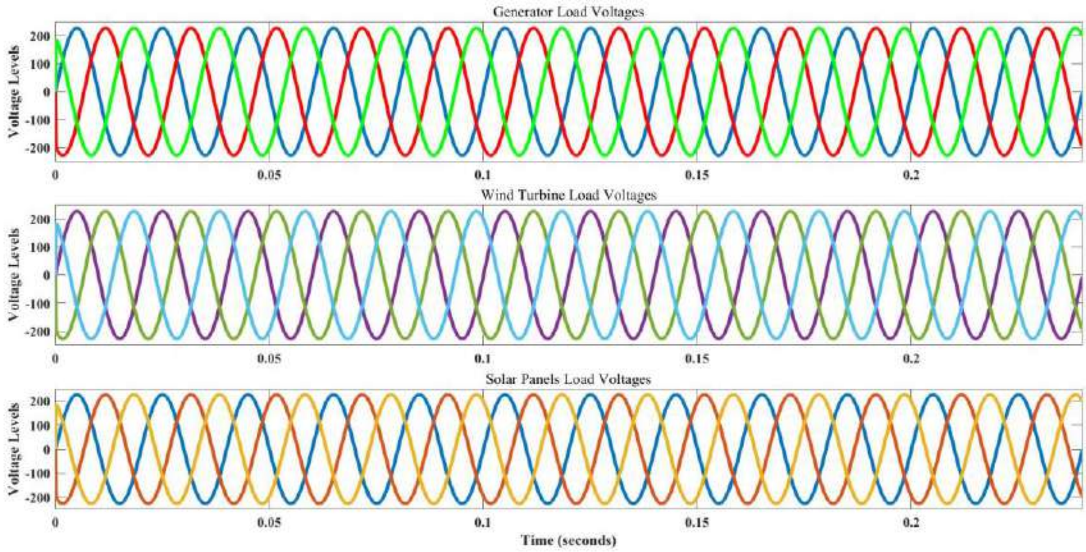

Figure 5.23. All Load Voltages

5.10. Conclusion

In this chapter a detailed explanation was provided in which how the system works if all the power sources are operating in standalone mode and in synchronous mode. It is extensively explained how peers are doing energy trade in the microgrid and to what extend the microgrid system based on IEEE 9 bus bar system is efficient.

Chapter 6.
Hardware Development

6.1. Introduction

In the previous chapter the MATLAB simulation and programming was implemented in this chapter a detailed overview on how the system is developed physically is explained. This chapter cover the implementation of IEEE modified 9 Bus Bar system on board and software written in C++ programming language for the driving the system. The system is controlled through a single board computer or microcontroller called ESP32. The other components involved in the design are four channel relay modules, electrical load, circuit breakers It is important to begin with the basics of the microcontroller.

6.2. Introduction to ESP 32

ESP 32 is a low-cost, low-power microcontroller. The microcontroller is developed by Espressif Systems, a Shanghai-based semiconductor company. The ESP series is known for its Wi-Fi capabilities, which make it an attractive choice for IoT projects that require wireless connectivity. The project is based on ESP 32 one of the microcontrollers of the ESP series [44].

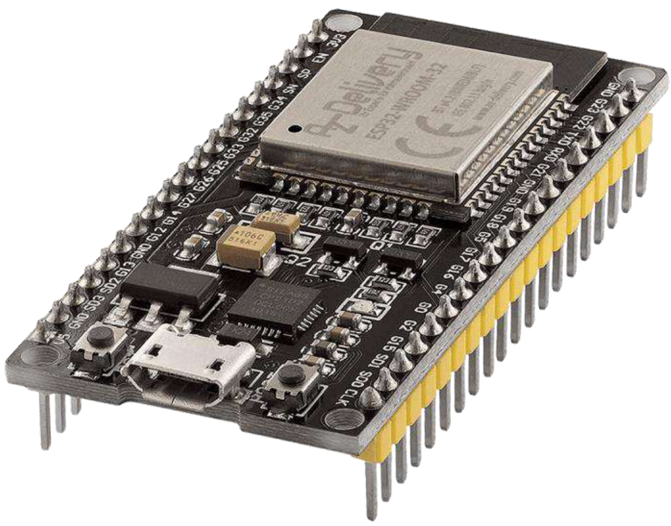

Figure 6.1. ESP 32 Microcontroller Board

A popular and potent system-on-a-chip (SoC) created for IoT (Internet of Things) applications is the ESP32. It is a modified model of the ESP8266, its predecessor. The

ESP32 is famous for its adaptability, affordability, and wealth of features, which make it popular in several projects and applications. The table 6.1 shows the useful features of ESP 32 microcontroller and it is used.

6.2.1. Key Features

1. **Dual-core Processor:** The ESP32 features two Tensilica Xtensa LX6 32-bit microprocessors, which can run at clock speeds of up to 240 MHz. Having dual cores allows for multitasking and more efficient handling of complex tasks [45].
2. **Wireless Connectivity:** One of the most significant advantages of the ESP32 is its built-in Wi-Fi and Bluetooth capabilities. It supports Wi-Fi 802.11 b/g/n/e/i with integrated TCP/IP protocol stack and Bluetooth v4.2 and BLE (Bluetooth Low Energy).
3. **Memory:** The ESP32 typically comes with various configurations of internal memory, including SRAM and Flash memory.
4. **GPIO (General Purpose Input/Output):** The ESP32 has a considerable number of GPIO pins, which allow it to interact with other peripherals and devices, making it suitable for a wide range of applications.
5. **Peripherals:** The ESP32 comes with a rich set of peripherals, including I2C, SPI, UART, ADC, DAC, PWM, and many more, making it adaptable to various sensor interfaces and communication protocols.
6. **Operating Voltage:** The ESP32 typically operates at a voltage range of 2.2V to 3.6V, making it compatible with a wide range of power sources.
7. **Low Power Capabilities:** The ESP32 has several power-saving modes, making it energy-efficient and well-suited for battery-powered applications.
8. **Security Features:** The ESP32 includes hardware accelerators for cryptographic functions, such as AES, RSA, SHA, and ECC, making it suitable for secure communication and data encryption.
9. **Development Environment:** The ESP32 can be programmed using various Integrated Development Environments (IDEs), such as the Arduino IDE, ESP-IDF (Espressif IoT Development Framework), or PlatformIO, making it accessible to developers with different preferences and backgrounds.
10. **Open-source Community:** The ESP32 has a large and active open-source community, which provides extensive documentation, sample codes, and libraries, making it easier for developers to get started and find support [45].

Table 6.1. Features of ESP 32 Microcontroller

Feature	Description
Microcontroller	Xtensa® Dual-Core 32-bit LX6 processor with clock speeds up to 240 MHz
Wi-Fi	Integrated 802.11 b/g/n 2.4 GHz Wi-Fi with support for station, softAP, and Wi-Fi Direct
Bluetooth	Bluetooth Classic (BR/EDR) and Bluetooth Low Energy (BLE) support
RAM	Up to 520 KB of SRAM
Flash Memory	Up to 16 MB of embedded Flash memory for program storage
GPIO Pins	34 programmable GPIO pins with support for GPIO, PWM, I2C, SPI, and more
Analog Inputs	18 ADC channels with 12-bit resolution
Digital Interfaces	UART, I2C, SPI, I2S, CAN, PWM, etc.
Security	Hardware accelerated encryption (AES, SHA-2, RSA, ECC), secure boot
Operating Voltage	2.2V to 3.6V
Power Consumption	Low-power modes for battery-operated applications
Co-Processor	Ultra-Low-Power for handling low-power tasks
Real-Time Clock (RTC)	Built-in RTC with sub-second accuracy and power management capabilities
Operating Temperature	Recommended operating temperature range: -40°C to +125°C

Feature	Description
Real-Time Clock (RTC)	Built-in RTC with sub-second accuracy and power management capabilities
Operating Temperature	Recommended operating temperature range: -40°C to +125°C
Peripherals	Capacitive touch sensors, temperature sensor, hall effect sensor, etc.
Development Framework	Supports Arduino IDE, ESP-IDF (ESP32 IoT Development Framework)
Wireless Protocols	Supports MQTT, CoAP, HTTP, WebSocket for IoT communication

6.2.2. ESP Series Comparison

The following table shows the series comparison of the ESP32 microcontrollers in terms of type of processor, installed flash and RAM, and the operating voltages. The Following table 6.2 shows the series comparison of the ESP32 with its different models.

Table 6.2. ESP 32 Series Comparison

Ordering Code	Core	Flash/PSRAM	Package	Voltages VDD
ESP32-D0WD-V3	Dual	-	QFN 5*5	3.3V
ESP32-D0WDR2-V3	Dual	2 MB PSRAM	QFN 5*5	3.3V
ESP32-U4WDH	Dual	4 MB flash	QFN 5*5	3.3V
ESP32-D0WDQ6-V3 (NRND)	Dual	-	QFN 6*6	3.3V
ESP32-D0WD (NRND)	Dual	-	QFN 5*5	3.3V
ESP32-D0WDQ6 (NRND)	Dual	-	QFN 6*6	3.3V
ESP32-S0WD (NRND)	Single	-	QFN 5*5	3.3V

6.2.3. Pin Layout Configuration

The following diagram shows the pin configuration of ESP 32 microcontroller's processor with the microcontroller board and its input / output pins.

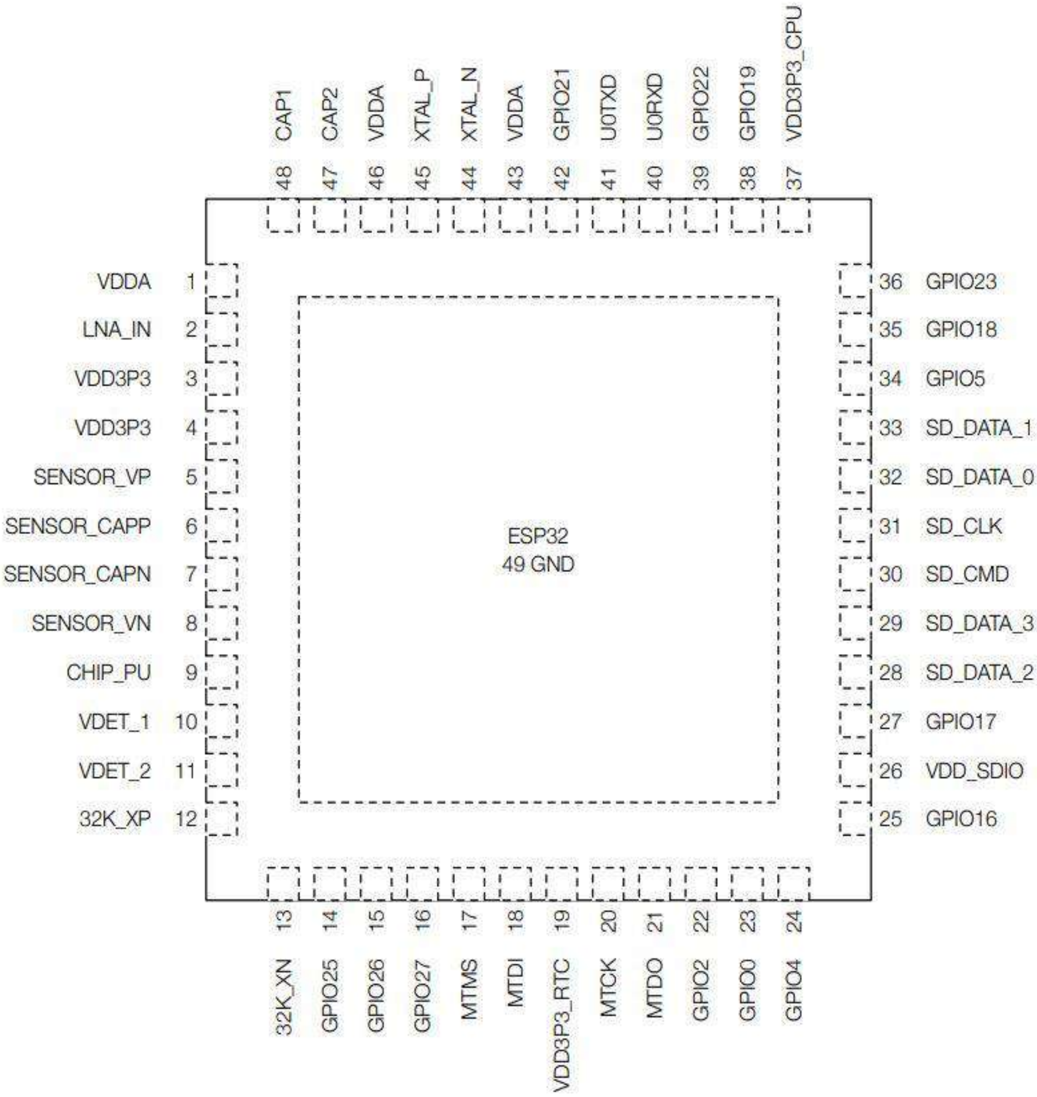

Figure 6.2. ESP32 Pin Layout (QFN 6*6, Top View)

6.2.4. Industrial Applications of ESP 32

The ESP32 is a strong and adaptable microcontroller that can be used in a variety of industrial applications. Here are some of the most typical industrial ESP32 applications:

1. **Industrial automation:** The ESP32 can be used to control and monitor industrial machinery and equipment. It can be used to control robots, conveyor belts, and other

machines, for example. It can also monitor sensors and actuators and give alarms when problems arise [46].

2. **Energy management:** The ESP32 can track energy consumption and control energy-saving devices. This can assist in lowering energy expenses and increasing energy efficiency.

3. **Environmental monitoring:** The ESP32 can detect environmental factors such as air quality, water quality, and noise levels. This information can be utilized to improve environmental compliance and safeguard public health.

6.3. Relay Modules

A four-channel relay module is a compact electronic board with four relays. Relays are low-power signals that control switches. This enables the 4 channel relay module to be utilized with a small microcontroller to operate high-current devices such as motors, lights, and solenoids. The following figure 6.3 shows the four channel relay module.

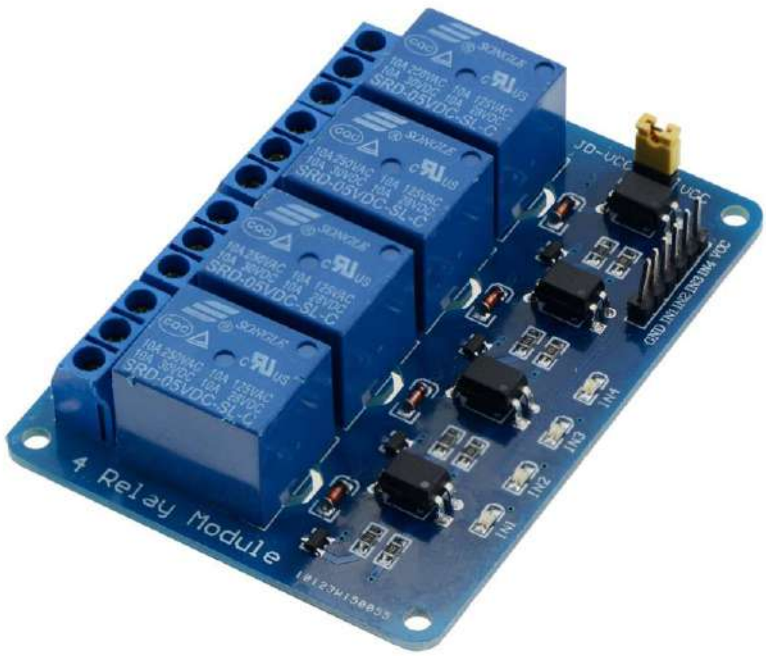

Figure 6.3. Four Channel Relay Module

For each relay, the 4 channel relay module normally has four screw terminals. COM, NO, and NC are the labels on the screw terminals. The common terminal is denoted by COM, the ordinarily open terminal by NO, and the normally closed terminal by NC. The COM and NO terminals are linked when the relay is not active. When the relay is turned on, the COM and NC terminals are linked.

A 5V or 3.3V power supply is generally used to power the 4 channel relay module. A microcontroller that outputs a digital signal can control the relay module. The microcontroller can be programmed to turn on or off the relays as needed.

Relay modules with four channels are a versatile and strong instrument for regulating high-current devices. They are simple to operate and can be programmed to control a wide range of devices. 4 channel relay modules are extensively used in applications such as industrial automation, home automation, and robotics.

6.4. Circuit Breakers

A circuit breaker is an electrical safety device used to safeguard an electrical circuit from overcurrent damage. Its primary role is to block current flow in order to protect equipment and reduce the risk of fire. Unlike a fuse, which can only be used once before needing to be replaced, a circuit breaker can be reset (manually or automatically) to continue regular operation. The figure 6.4 shows the miniature circuit breaker.

Figure 6.4. Miniature Circuit Breaker

6.5. Bluetooth Application

For the successful Bluetooth communication an pre-developed app available on the Google Play store developed by broxcode in August 06, 2015 and recent updated in May 24, 2023 is used in this project. Once a peer has installed this app on their mobile device they can connect with their respective microcontroller and to trade energy they can simply use the commands of 1,2, and 3.

- For generator microcontroller the command is 1.
- For solar panels microcontroller the command is 2.
- For wind turbine microcontroller the command is 3.

The app is also light weight and does not require much space in the mobile's device storage nor does it consumes too much battery's power. How Bluetooth app is working with the microcontrollers is explained in detail in the appendix B of ESP32 microcontroller programming in which the app parameters are integrated with the parameters of the microcontrollers.

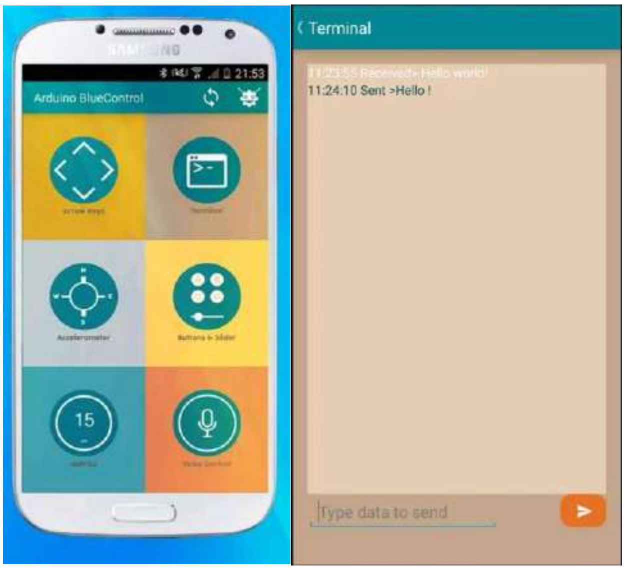

Figure 6.5. App User Interface

6.6. Project Circuitry

The project circuitry consists of the above explained microcontroller, relay modules, electrical load, and circuit breakers. The entire system is mounted on a wooden board with wiring done in 3/0.229 (AWG) wires. The figure 6.6 given below is a detailed diagram showing how the controllers are connected with one another and with their loads.

6.6.1. Microcontrollers

In total three microcontrollers are used in the project circuit for solar power source, generator power source, and wind turbine power source respectively. The microcontrollers are connected wirelessly with one another through Bluetooth communication. Each controller is connected with its load and the other loads.

6.6.2. Relays

Each peer or microcontroller has a total of eight relays or two four channel relays, four of which are used to operate the load of the corresponding peer and the other four of which are used to operate the load of other peers.

6.6.3. Circuit Breakers

Each peer in the microgrid network has its own dedicated circuit breaker that is accurately linked to the associated power sources. These circuit breakers play an important role in the energy distribution process, activating or deactivating their respective loads based on the predefined logic given by the relays.

6.6.4. Block Diagram

The figure 6.5 depicts an extensive block diagram created using Microsoft Visio 2019 that provides a deep look into the hardware design of the IEEE 9-bus bar system. This graphic depicts the energy flow inside the microgrid network, demonstrating how one peer can efficiently send energy to all other peers.

For example, when it's time for the generator to start, a synchronized dance of commands takes place. This performance is orchestrated by the microcontroller, which signals the generator relay to activate. In reaction, the circuit breaker connected to the generator quickly flips on, bringing the generator load online.

Simultaneously, the microprocessor controlling the generator interacts with the relays controlling the wind turbine and solar panels. These relays serve as gatekeepers, deactivating the circuit breakers associated with their respective sources. As a result, the load remains entrusted to the generator throughout this interval, displaying a complicated and dynamic interaction of power distribution and control inside the microgrid. This performance highlights the unique complexities of peer-to-peer energy transmission in the IEEE 9-bus bar system built for hardware applications.

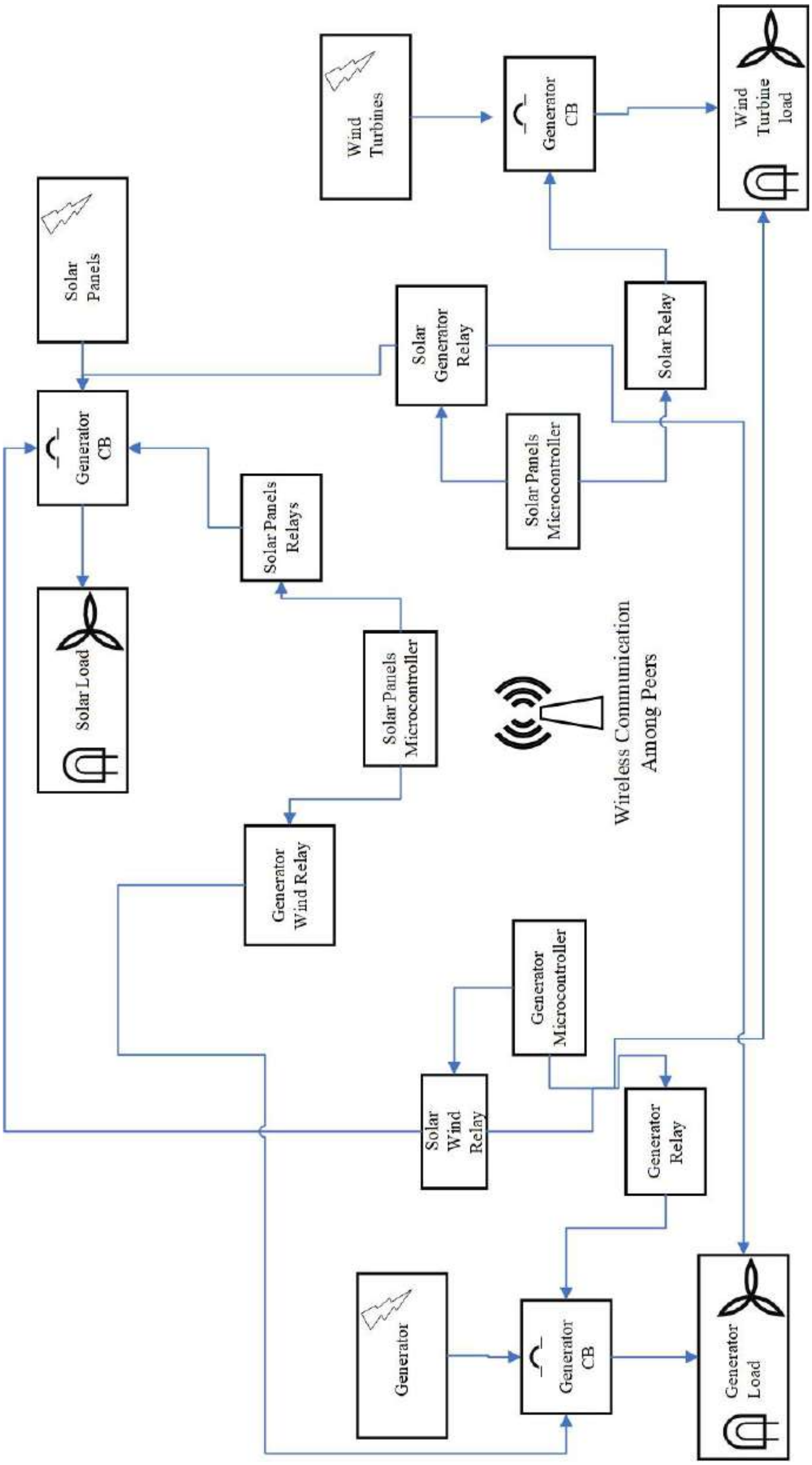

Figure 6.6. Block Diagram of Hardware Model

6.6.5. Project Working

- Assume that it is day time and solar energy is available. So according to the trading mechanism the solar peer will be active and the programming installed in the solar power microcontroller will active.
- Solar power microcontroller will send command to the solar panel relays and these relays will turn on the solar panel load.
- The microcontroller will also send command to the relays of wind turbine load and the generator load and the load will now shift on the solar panels.
- The programming of the controller will turn of the power of other peers for protection and the system will work smoothly.
- The system will work in the same manner for the other peers i.e. for wind turbine peer or the generator peer.
- In case of manual system the wireless Bluetooth communication among peers is controlled externally through Bluetooth devices or mobile phones with app installed in it.
- The app will generate command and the data will be shared will all the peers. For example for generator the command is 1 for solar the command is 2 and for the wind load the command is 3.
- If the generator provides the power to the all the other peers then the command shared on the Bluetooth devices will be 1 and this time the load will be shifted to the generator.
- In the case of solar panels the command will be 2 and in the case of wind turbines this command will be 3
- The system will work in the same manner for the other peers i.e. for wind turbine peer or the generator peer.

6.7. Project Assembly

The figure 6.7 shows a meticulously labeled diagram that shows the exact positioning and use of each component on the board. Meanwhile, Figure 6.8 depicts a complete perspective of the project assembly, including solar panels and wind turbines. This assembly demonstrates the intricate interconnection of peers within the microgrid network, following the blueprint of the IEEE 9-bus bar system, and provides a visual insight into the system's dynamic energy exchange and collaborative functioning. system.

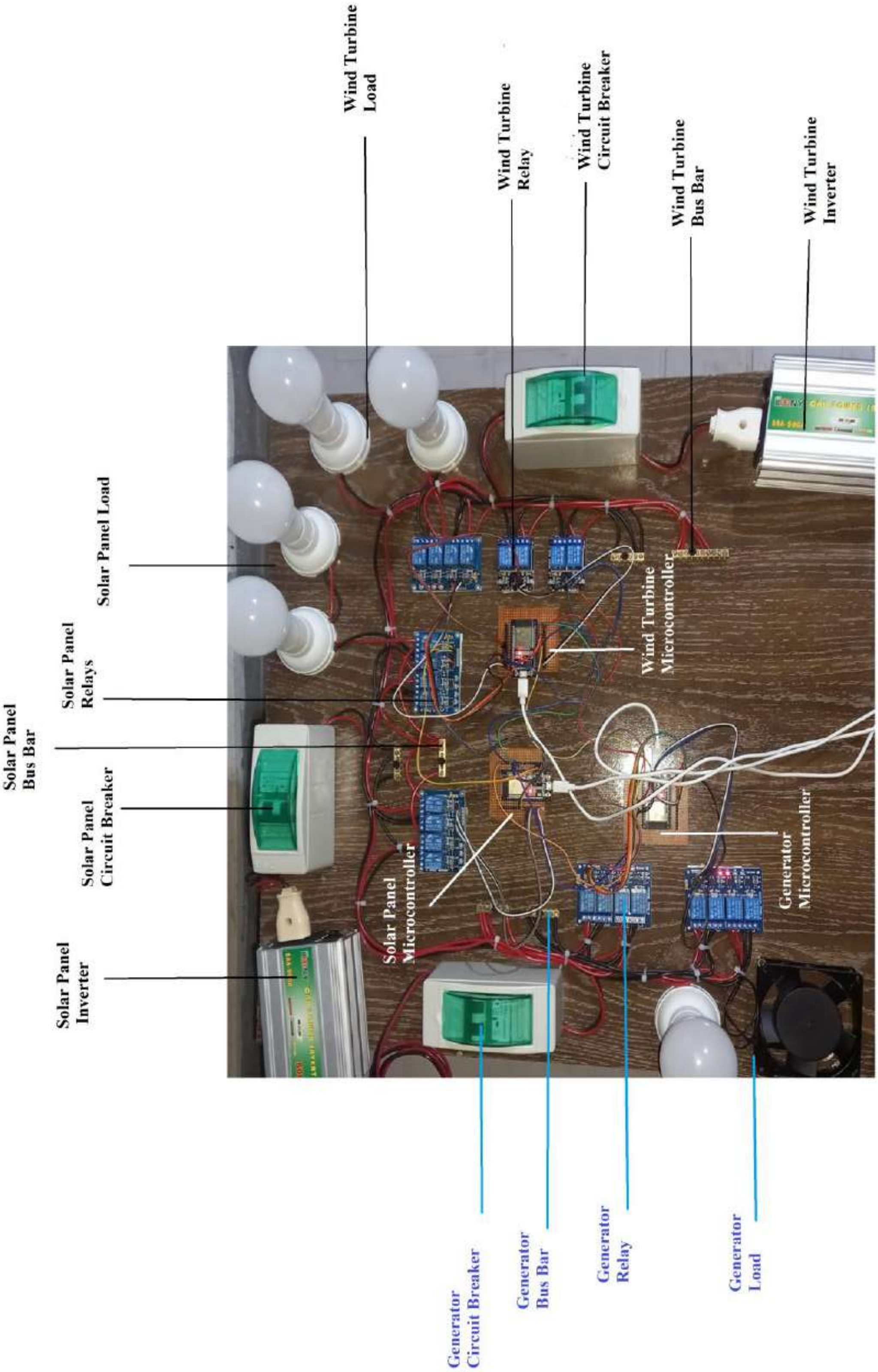

Figure 6.7. Hardware Labeled Model

Figure 6.8. Project Assembly

6.8. Conclusion

In this chapter we looked how peers are doing energy trading in the microgrid network with one another based on the wireless communication provided by the Bluetooth technology.

Chapter 7.
Environment and Sustainability

7.1. Introduction

The global concern for the environment and the need for sustainable energy practices has driven the development of new technologies and approaches to energy production, distribution, and consumption. One such approach is peer-to-peer (P2P) energy trading in microgrids, which has emerged as an innovative solution for achieving energy sustainability.

P2P energy trading involves the direct exchange of energy between producers and consumers, bypassing traditional energy providers. Microgrids, on the other hand, are local, self-contained power networks that can operate independently from the main grid, incorporating renewable energy sources [47] and energy storage systems. When combined, P2P energy trading in microgrids can offer numerous benefits, including reduced carbon emissions, increased energy efficiency, and greater energy independence for communities.

This chapter provides an overview of the environmental and sustainability considerations in P2P energy trading in microgrids, including the benefits and challenges associated with this approach.

7.2. Environmental Impact

Peer-to-peer (P2P) energy trading is a decentralized approach to energy trading that allows individuals and businesses to trade energy directly with each other, bypassing the traditional energy grid. This has the potential to significantly reduce the environmental impact of our energy system in a number of ways:

1. **Promoting the adoption of renewable energy sources**: P2P energy trading can make it easier for individuals and businesses to adopt renewable energy sources, such as solar and wind power. This is because P2P energy trading allows them to sell their excess renewable energy to their neighbors, rather than having to export it to the grid. This can help to reduce the demand for fossil fuels and increase the share of renewable energy in our energy mix.

2. **Improving overall efficiency:** P2P energy trading can help to improve the overall efficiency of our energy system by matching supply and demand more closely. This is because P2P energy trading allows individuals and businesses to trade energy in real time, based on their actual needs. This can help to reduce the amount of energy that is wasted.

3. **Supporting the integration of electric vehicles:** P2P energy trading can help to support the integration of electric vehicles (EVs) into our energy system. This is because P2P energy trading allows EV owners to sell their excess energy back to the grid, or to their neighbors, when their vehicles are not in use. This can help to reduce the need for new power plants to be built to meet the growing demand for electricity from EVs.

In addition to these environmental benefits, P2P energy trading can also have a number of other benefits, such as:

1. **Reduced energy costs:** P2P energy trading can help to reduce energy costs for individuals and businesses. This is because they can buy and sell energy directly with each other, without having to pay the markups that are charged by traditional energy suppliers.

2. **Increased grid resilience:** P2P energy trading can help to increase the resilience of our energy grid. This is because it allows individuals and businesses to generate and store their own energy, which they can then use during power outages or other disruptions to the grid.

3. **Increased social and economic benefits:** P2P energy trading can help to increase social and economic benefits by supporting local economies and creating new jobs. This is because it allows individuals and businesses to trade energy with each other in their local community, rather than having to rely on large, centralized energy suppliers.

Overall, P2P (Peer-to-Peer) energy trading has the promise of not just reducing our energy system's environmental imprint but also ushering in a slew of other notable benefits. P2P energy trading fosters improved energy efficiency and resilience by allowing individuals and communities to actively engage in energy generation and distribution. It enables consumers to make informed decisions about their energy sources.

7.3. Sustainability Considerations

While P2P energy trading in microgrids offers numerous environmental benefits, there are also various sustainability considerations that need to be taken into account. One of the main concerns is the integration of renewable energy sources, which can be intermittent and unpredictable, leading to energy fluctuations that can disrupt the stability of the microgrid [49].

To address this challenge, energy storage systems, such as batteries, can be incorporated into the microgrid to store excess energy during times of high production and release it during periods of low production. Additionally, demand-side management techniques can be employed to manage energy consumption during periods of low production, reducing the strain on the system.

Another sustainability consideration in P2P energy trading in microgrids is the need for effective governance and regulation. As P2P energy trading involves direct exchanges between producers and consumers, there is a need for transparent and efficient market mechanisms to ensure fair pricing and equitable distribution of benefits [48].

7.4. United Nations SDGs Involvement

The project is designed by keeping the SDGs in focus. Out of 17 goals of sustainable future two goals align in this project. Goal 07 on affordable and clean energy and goal 13 on climate action.

7.4.1. Affordable and Clean Energy

The whole motive of the p2p energy trading in microgrid to boost the renewable energy sources and their dependency in the society. Although the concept of p2p energy trading and microgrid is still new and is under development but in the near future this technology can help fight problems associated with fossil fuels depletion and carbon emissions.

7.4.2. Climate Action

Nowadays governments all across the world are taking serious actions against climate change chloro floro carbons (CFCs), ozone depletion, and other pollution causing substances. Governments are investing in renewable energy sources as they play major role in climate change. Microgrid in term can serve a clean and pollution free energy for the better future.

Figure 7.1. SDGS for P2P Energy Trading in Microgrids

7.5. Conclusion

In this chapter an overview on environmental impact of peer to peer energy trading in microgrid and how sustainable this system is for the present as well as for the future was provided. How United Nations sustainable developments are playing an important role in regulating the safety and protection conditions for this project.

Chapter 8.
Engineers and Society

8.1. Introduction

This chapter is linked with how peer to peer energy trading in microgrid will benefit the society and to the engineers. What engineering systems can be developed for the improvement of this technology and how this technology will solve the society's energy problems.

8.2. Role of Engineers

Engineers play a critical role in the development and deployment of P2P energy trading in microgrids. They are responsible for designing and building the physical infrastructure that enables energy production, storage, and distribution within the microgrid. They must also develop the software and communication protocols that enable participants to trade energy with one another.

Engineers must ensure that the physical infrastructure and software are designed with safety, reliability, and efficiency in mind. They must also consider the environmental impact of the technology, ensuring that the microgrid incorporates renewable energy sources and energy storage systems that minimize carbon emissions.

Additionally, engineers must consider the social and ethical implications of P2P energy trading in microgrids, ensuring that the technology is designed to promote equity, accessibility, and transparency for all participants.

8.3. Social Implications

The development of P2P energy trading in microgrids has significant social implications that must be considered by engineers and society. One of the main benefits of this technology is the potential to increase energy access and affordability for communities that have been traditionally underserved by the centralized energy system. However, there are also concerns that P2P energy trading in microgrids may exacerbate existing inequalities, with some of the participants benefiting more than others [50].

Engineers and society must work together to ensure that P2P energy trading in microgrids is designed in a way that promotes equitable access and distribution of benefits. This may require the development of regulatory frameworks and market mechanisms that ensure fair pricing and distribution of energy within the microgrid.

8.4. Ethical Implications

The development of P2P energy trading in microgrids also raises important ethical considerations. For example, there is a risk that the technology may be used to exploit vulnerable communities or exacerbate existing power imbalances. Additionally, there is a need to ensure that the technology is designed in a way that respects individual privacy and data security.

Engineers and society must work together to ensure that P2P energy trading in microgrids is developed and deployed in an ethical and responsible manner. This may require the development of ethical frameworks and codes of conduct that guide the behavior of engineers and other stakeholders involved in the development of the technology

8.5. Conclusion

P2P energy trading in microgrids has the potential to transform the way we generate, distribute, and consume energy. However, the development and deployment of this technology must be guided by ethical and social considerations that ensure that it promotes equitable access, transparency, and privacy. Engineers and society must work together to ensure that this technology is developed in a responsible and ethical manner, taking into account the interests of all stakeholders. By doing so, we can harness the potential of P2P energy trading in microgrids to promote a more sustainable and equitable energy future.

Chapter 9.
Conclusion with Future Research

9.1. Introduction

This chapter will provide an in-depth conclusion on how our system was created and what technology was employed to create it. Furthermore, this chapter discusses the ultimate future of energy trading and independent grids or microgrids, as well as whether or not this technology is the ultimate solution to the energy issue and climate change for a better future.

9.2. Conclusion of Our Research

Our journey on designing this system was an adventure. The design of microgrid and peer to peer energy trading was challenging for us to design. However we came up with a small solution in the sea full of problems related to the energy crisis and sustainable solution.

Peer-to-peer energy trading is a novel idea in current energy trading technologies. Our system was created using Chinese and American technology, as well as British electrical requirements. The motivation for this research project was to discover a solution associated with electrical energy and to make electricity available to end users at all times. Another key purpose of our study was to recognize the relevance of prosumers and how they may interact with one another in society to solve electrical energy challenges.

The IEEE 9 bus bar model is modified by connecting two renewable energy sources and a diesel generator. All of the project's users were also prosumers, and a wireless and automatic trading system based on daily energy requirements was built. The system was designed to handle up to 1KW of load, with a maximum load on the microgrid of 600 W at 220Vs.

9.3. Current Challenges Involved in this Technology

Before P2P energy trading can be extensively used, a number of hurdles must be overcome. These obstacles include legal difficulties, technical challenges, security and privacy issues, market design, and consumer and corporate acceptability.

1. **Regulatory impediments:** In many countries, peer-to-peer energy trading is not yet permitted. This is due to the fact that it necessitates adjustments to existing energy laws and regulations.

2. **Technical challenges:** To promote energy trading between individuals and enterprises, P2P energy trading necessitates the development of new technologies and infrastructure. Smart meters, energy trading platforms, and blockchain technology are examples of this.

3. **Concerns about security and privacy:** P2P energy trading entails the communication of sensitive data, such as energy use trends and financial data. This poses security and privacy concerns.

4. **Market design:** The market design for peer-to-peer energy trading is still in the works. There are several models that might be employed, and it is unclear which one is the best.

9.4. Future Research

Peer-to-peer (P2P) energy trading in microgrids has a promising future. P2P energy trade will become increasingly vital as the globe shifts to a more decentralized energy grid. Here are some of the reasons:

1. **Increased demand for renewable energy:** Peer-to-peer energy trading can make it easier for people and businesses to switch to renewable energy sources like solar and wind power. This is because peer-to-peer energy trading allows people to sell extra renewable energy to their neighbors rather than exporting it to the grid. This can assist to lessen our reliance on fossil fuels while increasing the proportion of renewable energy in our energy mix.

2. **Reduced emissions:** P2P energy trading can aid in the reduction of greenhouse gas emissions and other pollutants. This is due to the fact that it has the potential to reduce dependency on fossil fuels while increasing the usage of renewable energy sources.

3. **Increased resilience:** Peer-to-peer energy trading can aid in the resilience of our energy system. This is due to the fact that it enables individuals and organizations to generate

and store their own energy, which they may subsequently use during power shortages or other

grid interruptions.

4. **Increased social and economic advantages:** By supporting local economies and creating new jobs, peer-to-peer energy trading can help to increase social and economic benefits. This is because it enables individuals and companies in their local community to exchange energy with one another rather of relying on huge, centralized energy sources.

P2P energy trading is likely to grow more popular as these benefits become more widely acknowledged. In the future, peer-to-peer energy trading may become the rule rather than the exception. This would have a significant impact on how we generate, consume, and distribute energy. It would also contribute to the development of a more sustainable and fair energy system.

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Appendix A.
MATLAB Script File Programming

The models generator, wind turbine, and solar power panel all work through the C and C++ code written in (.m) file of MATLAB script editor. The code runs synchronously with the MATLAB Simulink model and generates output.

Microgrid Programming

Following is the code for the microgrid models in MATLAB making these models to work harmoniously with the Simulink and generate harmonious output.

```
% System frequency (Hz):
Fnom=50;
% Specialized Power Systems sample time (s):
Ts_Power=1/(33*Fnom)/100;
% Inverter Control system sample time (s):
Ts_Control=10*Ts_Power;


Pnom = 1000 ;      % Inverter nominal 3-phase power (VA)
Vnom_prim = 400;   % Nominal inverter primary line-to-line
voltage(Vrms)
Vnom_dc = 480;     % Nominal DC link voltage (V)

% Nominal inverter secondary line-to-line voltage (Vrms):
Vnom_sec= 0.85*Vnom_dc/2/sqrt(2)*sqrt(3);

% Transformer parameters:
% Nominal voltage in Vrms, Resistance in pu and Leakage
inductance in pu

Pnom_xfo=Pnom;       % Transformer nominal power (VA)
TotalLeakage=0.06;   % Transformer total leakage (pu)

W1_xfo=  [Vnom_prim TotalLeakage/25/2  TotalLeakage/2];  %
Winding 1 (Grid side)
W2_xfo=  [Vnom_sec  TotalLeakage/25/2  TotalLeakage/2];  %
Winding 2 (DC link side)

Rm_xfo=200;  % Magnetization resistance (pu)
Lm_xfo=200;  % Magnetization inductance (pu)

% Inverter choke RL [Rpu Lpu]
RLchoke=[ 0.15/100  0.15 ];  % in pu
Pbase_sec=Vnom_sec^2/Pnom;
```

```
RL(1)=RLchoke(1)*Pbase_sec;
RL(2)=RLchoke(2)*Pbase_sec/(2*pi*Fnom);

% Filter C Parameters
Qc=0.1*Pnom;      % Capacitive reactive power (var)
Pc=Qc/50;         % Active power (W)
% DC link energy for 3/4 cycle of Pnom
Ceq= 3/4 * (Pnom/Fnom*2/Vnom_dc^2);
Clink=Ceq*2;     % Cp & Cn (F)

% IGBT Bridge parameters

Rs=1e6;           % IGBT Snubber (Ohm)
Cs=inf;           % IGBT snubber (F)
Ron=1e-3;         % IGBT conduction resistance
Vf=0;             % IGBT Forward voltage
Vfd=0;            % Diode Forward voltage

% MPPT Control (Perturb & Observe Algorithm)

Increment_MPPT=  0.01;          %  Increment  value  used  to
increase/decrease Vdc_ref
Limits_MPPT= [ 583 357 ]; % Upper & Lower limit for Vdc_ref
(V)

% VDC regulator (VDCreg)

Kp_VDCreg=2;            % Proportional gain
Ki_VDCreg= 400;         % Integral gain
LimitU_VDCreg= 1.5;     % Output (Idref) Upper limit (pu)
LimitL_VDCreg= -1.5;    % Output (Idref) Lower limit (pu)
%
% Current regulator (Ireg)

RLff(1)=  W1_xfo(2)  +  W2_xfo(2)  +  RLchoke(1);  %  Feedforward
values
RLff(2)=  W1_xfo(3)  +  W2_xfo(3)  +  RLchoke(2);  %  Feedforward
values

Kp_Ireg= 0.3;           % Proportional gain
Ki_Ireg= 20;            % Integral gain
LimitU_Ireg= 1.5;       % Output (Vdq_conv) Upper limit (pu)
LimitL_Ireg= -1.5;      % Output (Vdq_conv) Lower limit (pu)

% PWM Modulator Parameters
Fc= 33 * Fnom ; % Carrier frequency (Hz)
```

Energy Trading Programming

In order to keep the model more simpler the P2P concept is implemented in the microgrid through the pulse generator controlling the individual circuit breaker connected to each power source This implementation automatically selects the right parameters for truncations, electricity cost and more transparently.

```
% The following communication code is for turning on different
circuit
% breakers in 24 hours time frame for utilizing every peer's
maximum
% capacity.
%--------------------------------------------------------------
-
% The system will also check that at which time the a peer
can provide
% cheap and reliable energy to the system.
%--------------------------------------------------------------
% The Wind Turbines best time is Between 04:00AM - 10:00 AM
(6 Hours)
% The Solar Panels best time is Between 10:00AM - 04:00 PM (6
Hours)
% The Generator best time is Between 04:00PM - 04:00 AM (12
Hours)

clc
clear all
% Setting Generator Parameters
set_param('Final_Project_Design/Generator_Pulse','Amplitude'
,'1')
set_param('Final_Project_Design/Generator_Pulse','Period','0
.24')
set_param('Final_Project_Design/Generator_Pulse','PulseWidth
','28')
set_param('Final_Project_Design/Generator_Pulse','PhaseDelay
','0.1')
%By settting these parameters Generator will work in night
when there is no
%wind source and solar source available

%Setting Solar Panels Parameters
set_param('Final_Project_Design/Solar_Pulse','Amplitude','1'
)
set_param('Final_Project_Design/Solar_Pulse','Period','0.24'
)
set_param('Final_Project_Design/Solar_Pulse','PulseWidth','3
3.33')
set_param('Final_Project_Design/Solar_Pulse','PhaseDelay','0
.164')

%Setting Wind Turbines Parameters
```

```
set_param('Final_Project_Design/Wind_Pulse','Amplitude','1')
set_param('Final_Project_Design/Wind_Pulse','Period','0.24')
set_param('Final_Project_Design/Wind_Pulse','PulseWidth','25
')
set_param('Final_Project_Design/Wind_Pulse','PhaseDelay','0.
1')
```

Appendix B.
ESP 32 Microcontroller Programming

Solar Panel Programming

```
#include <BluetoothSerial.h>
BluetoothSerial SerialBT; // Bluetooth Serial object
const int solar =         14; // Pin numbers for relays
const int solarg=         27;
const int wind =          26;
const int windg =         25;
const int wapda  =        13;
const int wapdag=         12;
const int load  =         19;
const int loadg =         21;
const int wind_signal_out=  5;
const int wapda_signal_out= 18;
const int wind_signal_in = 22;
const int wapda_signal_in= 23;

void setup()
 {
   Serial.begin(115200);
   SerialBT.begin("ESP32_SOLAR");
   pinMode(load,             OUTPUT);
   pinMode(loadg,            OUTPUT);
   pinMode(wapda,            OUTPUT);
   pinMode(wapdag,           OUTPUT);
   pinMode(wind,             OUTPUT);
   pinMode(windg,            OUTPUT);
   pinMode(solar,            OUTPUT);
   pinMode(solarg,           OUTPUT);
   pinMode(wind_signal_out,  OUTPUT);
   pinMode(wapda_signal_out, OUTPUT);
   pinMode(wind_signal_in,    INPUT);
   pinMode(wapda_signal_in,   INPUT);
   digitalWrite(solar,         HIGH);
   digitalWrite(solarg,        HIGH);
   digitalWrite(wind,          HIGH);
   digitalWrite(windg,         HIGH);
   digitalWrite(load,          HIGH);
   digitalWrite(loadg,         HIGH);
   digitalWrite(wapda,         HIGH);
   digitalWrite(wapdag,        HIGH);
   digitalWrite(wapda_signal_out, LOW);
   digitalWrite(wind_signal_out,  LOW);
}
   void loop() {
```

```
    int wind_signal_input = digitalRead(wind_signal_in);
    int wapda_signal_input = digitalRead(wapda_signal_in);
    if (SerialBT.available())
     {
    char command = SerialBT.read(); // Read incoming data
from Bluetooth

if((wapda_signal_input==LOW)&&(wind_signal_input==LOW)&&(com
mand=='1')){
     digitalWrite(wapda_signal_out, HIGH);
     digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_ON();
     delay(10);
     }
    else                                                    if
((wapda_signal_input==LOW)&&(wind_signal_input==LOW)&&
(command=='2')){
       digitalWrite(wapda_signal_out, LOW);
       digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_OFF();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
        }
    else                                                    if
((wind_signal_input==LOW)&&(wapda_signal_input==LOW)&&(comma
nd=='3')){
       digitalWrite(wind_signal_out, HIGH);
       digitalWrite(wapda_signal_out, LOW);
     WIND_ON();
     WAPDA_OFF();
     SOLAR_OFF();
     LOAD_ON();
     delay(10);
      }
       else                                                 if
((wind_signal_input==HIGH)&&(wapda_signal_input==LOW)&&(comm
and=='0')){
      digitalWrite(wapda_signal_out, LOW);
       digitalWrite(wind_signal_out,LOW);
     WIND_ON();
     WAPDA_OFF();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
     }
```

```
        else     if     ((wapda_signal_input==HIGH)     &&
(wind_signal_input==LOW) && (command=='0')){
        digitalWrite(wapda_signal_out, LOW);
      digitalWrite(wind_signal_out,LOW);
    WIND_OFF();
    WAPDA_ON();
    SOLAR_ON();
    LOAD_OFF();
    delay(10);
    }
   else      if      ((wapda_signal_input==HIGH)      &&
(wind_signal_input==HIGH) && (command=='0')){
           digitalWrite(wapda_signal_out, LOW);
      digitalWrite(wind_signal_out,LOW);
    WIND_ON();
    WAPDA_ON();
    SOLAR_ON();
    LOAD_OFF();
    delay(10);
    }
  else       if       ((wapda_signal_input==HIGH)       &&
(wind_signal_input==LOW)&& (command=='2')){
      digitalWrite(wapda_signal_out, LOW);
      digitalWrite(wind_signal_out,LOW);
    WIND_OFF();
    WAPDA_ON();
    SOLAR_ON();
    LOAD_ON();
    delay(10);
    }
       else     if     ((wapda_signal_input==LOW)     &&
(wind_signal_input==HIGH)&& (command=='2')){
          digitalWrite(wapda_signal_out, LOW);
      digitalWrite(wind_signal_out,LOW);
    WIND_ON();
    WAPDA_OFF();
    SOLAR_ON();
    LOAD_ON();
    delay(10);
    }}
        else         if         ((wind_signal_input==LOW)
&&(wapda_signal_input==HIGH)){
    digitalWrite(wapda_signal_out, LOW);
    digitalWrite(wind_signal_out,LOW);
    WIND_OFF();
    WAPDA_ON();
    SOLAR_ON();
    LOAD_OFF();
    delay(10);
    }
```

```
 else           if           ((wind_signal_input==HIGH)
&&(wapda_signal_input==LOW)){
  digitalWrite(wapda_signal_out, LOW);
  digitalWrite(wind_signal_out,LOW);
WIND_ON();
WAPDA_OFF();
SOLAR_ON();
LOAD_OFF();
delay(10);
}
 else           if           ((wind_signal_input==HIGH)
&&(wapda_signal_input==HIGH)){
  digitalWrite(wapda_signal_out, LOW);
  digitalWrite(wind_signal_out,LOW);
WIND_ON();
WAPDA_ON();
SOLAR_ON();
LOAD_OFF();
delay(10);
}
else            if            ((wind_signal_input==LOW)
&&(wapda_signal_input==LOW)){
  digitalWrite(wapda_signal_out, LOW);
  digitalWrite(wind_signal_out,LOW);
WIND_OFF();
WAPDA_OFF();
SOLAR_OFF();
LOAD_OFF();
delay(10);
}

}
 void WAPDA_ON ( )
  {
digitalWrite(wapda, LOW);
digitalWrite(wapdag, LOW);
}
     void WAPDA_OFF ( )
  {
digitalWrite(wapda, HIGH);
digitalWrite(wapdag, HIGH);
}
void WIND_ON ( ){
digitalWrite(wind, LOW);
digitalWrite(windg, LOW);
}
     void WIND_OFF ( ){
digitalWrite(wind, HIGH);
digitalWrite(windg, HIGH);
}
void SOLAR_ON()
```

```
    {
    digitalWrite(solar, LOW);
    digitalWrite(solarg, LOW);
    }
         void SOLAR_OFF()
    {
    digitalWrite(solar, HIGH);
    digitalWrite(solarg, HIGH);
    }
    void LOAD_OFF(){
    digitalWrite(load, HIGH);
    digitalWrite(loadg, HIGH);
      }
    void LOAD_ON(){
    digitalWrite(load, LOW);
    digitalWrite(loadg, LOW);
      }
```

Wind Turbines Programming

```
#include <BluetoothSerial.h>
BluetoothSerial SerialBT; // Bluetooth Serial object
const int solar =          14; // Pin numbers for relays
const int solarg=          27;
const int wind =           26;
const int windg =          25;
const int wapda  =         13;
const int wapdag=          12;
const int load  =          19;
const int loadg =          21;
const int wapda_signal_out=  5;
const int solar_signal_out= 18;
const int wapda_signal_in = 22;
const int solar_signal_in= 23;

void setup()
 {
   Serial.begin(115200);
   SerialBT.begin("ESP32_Wind");
   pinMode(load,             OUTPUT);
   pinMode(loadg,            OUTPUT);
   pinMode(wapda,            OUTPUT);
   pinMode(wapdag,           OUTPUT);
   pinMode(wind,             OUTPUT);
   pinMode(windg,            OUTPUT);
   pinMode(solar,            OUTPUT);
   pinMode(solarg,           OUTPUT);
   pinMode(wapda_signal_out,  OUTPUT);
   pinMode(solar_signal_out, OUTPUT);
   pinMode(wapda_signal_in,    INPUT);
   pinMode(solar_signal_in,   INPUT);
```

```
   digitalWrite(solar,         HIGH);
   digitalWrite(solarg,        HIGH);
   digitalWrite(wind,          HIGH);
   digitalWrite(windg,         HIGH);
   digitalWrite(load,          HIGH);
   digitalWrite(loadg,         HIGH);
   digitalWrite(wapda,         HIGH);
   digitalWrite(wapdag,        HIGH);
   digitalWrite(wapda_signal_out,     LOW);
   digitalWrite(solar_signal_out,     LOW);
}
   void loop() {
    int wapda_signal_input = digitalRead(wapda_signal_in);
    int solar_signal_input = digitalRead(solar_signal_in);
    if (SerialBT.available())
     {
    char command = SerialBT.read(); // Read incoming data
from Bluetooth


if((solar_signal_input==LOW)&&(wapda_signal_input==LOW)&&(co
mmand=='1')){
      digitalWrite(solar_signal_out, LOW);
       digitalWrite(wapda_signal_out, HIGH);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_ON();
     delay(10);
     }
     else                                                 if
((solar_signal_input==LOW)&&(wapda_signal_input==LOW)&&
(command=='2')){
       digitalWrite(solar_signal_out, HIGH);
       digitalWrite(wapda_signal_out, LOW);
     WIND_OFF();
     WAPDA_OFF();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
        }
     else                                                 if
((wapda_signal_input==LOW)&&(solar_signal_input==LOW)&&(comm
and=='3')){
       digitalWrite(wapda_signal_out, LOW);
       digitalWrite(solar_signal_out, LOW);
     WIND_ON();
     WAPDA_OFF();
     SOLAR_OFF();
     LOAD_ON();
     delay(10);
```

```
      }
     else                                                    if
((wapda_signal_input==HIGH)&&(solar_signal_input==LOW)&&(com
mand=='0')){
              digitalWrite(solar_signal_out,LOW);
       digitalWrite(wapda_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_OFF();
     delay(10);
     }
     else       if       ((solar_signal_input==HIGH)       &&
(wapda_signal_input==LOW) && (command=='0')){
              digitalWrite(solar_signal_out, LOW);
       digitalWrite(wapda_signal_out, LOW);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
     }
     else       if       ((solar_signal_input==HIGH)       &&
(wapda_signal_input==LOW)&& (command=='3')){
              digitalWrite(solar_signal_out, LOW);
       digitalWrite(wapda_signal_out, LOW);
     WIND_ON();
     WAPDA_OFF();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
     }
     else       if       ((solar_signal_input==HIGH)       &&
(wapda_signal_input==HIGH)&& (command=='3')){
            digitalWrite(solar_signal_out, LOW);
       digitalWrite(wapda_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
     }
    }
     else           if           ((wapda_signal_input==HIGH)
&&(solar_signal_input==HIGH)){
              digitalWrite(solar_signal_out, LOW);
       digitalWrite(wapda_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
```

```
delay(10);
}
else if ((wapda_signal_input==HIGH) &&(solar_signal_input==LOW)){
digitalWrite(solar_signal_out, LOW);
  digitalWrite(wapda_signal_out, LOW);
WIND_ON();
WAPDA_ON();
SOLAR_OFF();
LOAD_OFF();
delay(10);
}
else if ((wapda_signal_input==LOW) &&(solar_signal_input==HIGH) ){
digitalWrite(solar_signal_out, LOW);
  digitalWrite(wapda_signal_out, LOW);
WIND_ON();
WAPDA_OFF();
SOLAR_ON();
LOAD_OFF();
delay(10);
}
else if ((wapda_signal_input==LOW) &&(solar_signal_input==LOW) ){
digitalWrite(solar_signal_out, LOW);
  digitalWrite(wapda_signal_out, LOW);
WIND_OFF();
WAPDA_OFF();
SOLAR_OFF();
LOAD_OFF();
delay(10);
}
}
 void WAPDA_ON ( )
  {
digitalWrite(wapda, LOW);
digitalWrite(wapdag, LOW);
}
 void WAPDA_OFF ( )
  {
digitalWrite(wapda, HIGH);
digitalWrite(wapdag, HIGH);
}
void WIND_ON ( ){
digitalWrite(wind, LOW);
digitalWrite(windg, LOW);
}
    void WIND_OFF ( ){
digitalWrite(wind, HIGH);
digitalWrite(windg, HIGH);
}
```

```
void SOLAR_ON()
{
digitalWrite(solar, LOW);
digitalWrite(solarg, LOW);
}
     void SOLAR_OFF()
{
digitalWrite(solar, HIGH);
digitalWrite(solarg, HIGH);
}
void LOAD_OFF(){
digitalWrite(load, HIGH);
digitalWrite(loadg, HIGH);
  }
void LOAD_ON(){
digitalWrite(load, LOW);
digitalWrite(loadg, LOW);
  }
```

Generator Programming

```
#include <BluetoothSerial.h>
BluetoothSerial SerialBT; // Bluetooth Serial object
const int solar =          14; // Pin numbers for relays
const int solarg=          27;
const int wind =           26;
const int windg =          25;
const int wapda  =         13;
const int wapdag=          12;
const int load  =          19;
const int loadg =          21;
const int wind_signal_out=  5;
const int solar_signal_out= 18;
const int wind_signal_in = 22;
const int solar_signal_in= 23;

void setup()
 {
   Serial.begin(115200);
   SerialBT.begin("ESP32_Wapda");
   pinMode(load,             OUTPUT);
   pinMode(loadg,            OUTPUT);
   pinMode(wapda,            OUTPUT);
   pinMode(wapdag,           OUTPUT);
   pinMode(wind,             OUTPUT);
   pinMode(windg,            OUTPUT);
   pinMode(solar,            OUTPUT);
   pinMode(solarg,           OUTPUT);
   pinMode(wind_signal_out,  OUTPUT);
   pinMode(solar_signal_out, OUTPUT);
```

```
   pinMode(wind_signal_in,    INPUT);
   pinMode(solar_signal_in,   INPUT);
   digitalWrite(solar,         HIGH);
   digitalWrite(solarg,        HIGH);
   digitalWrite(wind,          HIGH);
   digitalWrite(windg,         HIGH);
   digitalWrite(load,          HIGH);
   digitalWrite(loadg,         HIGH);
   digitalWrite(wapda,         HIGH);
   digitalWrite(wapdag,        HIGH);
   digitalWrite(wind_signal_out,   LOW);
   digitalWrite(solar_signal_out,  LOW);
}
   void loop() {
    int wind_signal_input = digitalRead(wind_signal_in);
    int solar_signal_input = digitalRead(solar_signal_in);
    if (SerialBT.available())
     {
     char command = SerialBT.read(); // Read incoming data
from Bluetooth

if((solar_signal_input==LOW)&&(wind_signal_input==LOW)&&(com
mand=='1')){
     digitalWrite(solar_signal_out, LOW);
     digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_ON();
     delay(10);
     }
    else                                                  if
((solar_signal_input==LOW)&&(wind_signal_input==LOW)&&
(command=='2')){
     digitalWrite(solar_signal_out, HIGH);
     digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_OFF();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
        }
    else                                                  if
((wind_signal_input==LOW)&&(solar_signal_input==LOW)&&(comma
nd=='3')){
     digitalWrite(wind_signal_out, HIGH);
     digitalWrite(solar_signal_out, LOW);
     WIND_ON();
     WAPDA_OFF();
     SOLAR_OFF();
     LOAD_ON();
```

```
     delay(10);
      }
     else                                                  if
((wind_signal_input==HIGH)&&(solar_signal_input==LOW)&&(comm
and=='0')){
     digitalWrite(solar_signal_out, LOW);
     digitalWrite(wind_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_OFF();
     delay(10);
     }
     else      if      ((solar_signal_input==HIGH)       &&
(wind_signal_input==LOW) && (command=='0')){
      digitalWrite(solar_signal_out, LOW);
      digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
     }
     else          if           ((wind_signal_input==HIGH)
&&(solar_signal_input==HIGH) &&( command=='0')){
      digitalWrite(solar_signal_out, LOW);
       digitalWrite(wind_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
     }
   else       if       ((solar_signal_input==HIGH)       &&
(wind_signal_input==LOW)&& (command=='1')){
    digitalWrite(solar_signal_out, LOW);
    digitalWrite(wind_signal_out, LOW);
     WIND_OFF();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_ON();
     delay(10);
     }
    else           if           ((wind_signal_input==HIGH)
&&(solar_signal_input==HIGH) &&( command=='1')){
     digitalWrite(solar_signal_out,LOW);
     digitalWrite(wind_signal_out, LOW);
     WIND_ON();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_ON();
```

```
     delay(10);
     }
    }
      else           if           ((wind_signal_input==HIGH)
&&(solar_signal_input==HIGH)){
    digitalWrite(solar_signal_out, LOW);
    digitalWrite(wind_signal_out, LOW);
    WIND_ON();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
    }
    else            if            ((wind_signal_input==HIGH)
&&(solar_signal_input==LOW)){
     digitalWrite(solar_signal_out, LOW);
    digitalWrite(wind_signal_out, LOW);
    WIND_ON();
     WAPDA_ON();
     SOLAR_OFF();
     LOAD_OFF();
     delay(10);
    }
    else             if            ((wind_signal_input==LOW)
&&(solar_signal_input==HIGH)){
     digitalWrite(solar_signal_out, LOW);
    digitalWrite(wind_signal_out, LOW);
    WIND_OFF();
     WAPDA_ON();
     SOLAR_ON();
     LOAD_OFF();
     delay(10);
    }
    }
      void WAPDA_ON ( )
       {
     digitalWrite(wapda, LOW);
     digitalWrite(wapdag, LOW);
    }
          void WAPDA_OFF ( )
       {
     digitalWrite(wapda, HIGH);
     digitalWrite(wapdag, HIGH);
    }
     void WIND_ON ( ){
     digitalWrite(wind, LOW);
     digitalWrite(windg, LOW);
     }
          void WIND_OFF ( ){
     digitalWrite(wind, HIGH);
     digitalWrite(windg, HIGH);
```

```
}
void SOLAR_ON()
{
digitalWrite(solar, LOW);
digitalWrite(solarg, LOW);
}
     void SOLAR_OFF()
{
digitalWrite(solar, HIGH);
digitalWrite(solarg, HIGH);
}
void LOAD_OFF(){
digitalWrite(load, HIGH);
digitalWrite(loadg, HIGH);
  }
void LOAD_ON(){
digitalWrite(load, LOW);   digitalWrite(loadg, LOW); }
```