Design Of A Peer To Peer Energy Trading On A Micro Grid

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A Thesis submitted to

Pakistan Navy Engineering College (PNEC), Karachi

National University of Sciences and Technology (NUST), Islamabad

In partial fulfillment of requirements for the degree of

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

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I, *Muhammad Farhan Aslam* declare that thesis titled **"Design Of A Peer To Peer Energy Trading System For Micro Grid Application"**, the work published are my own and created by me according to my own research study.

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This thesis is dedicated to *my beloved parents, teachers, siblings and friends.*

Abstract

Power is among the major issues discussed these days. More than 25 percent of the world population lacks access to electricity. With the ever increasing cost of electricity, people prefer to have their own generation. This thesis presents an idea where people who can afford their own generation, trade electricity with others.

Peer-to-Peer (P2P) energy trading is an innovative model of power sharing system, where people who can afford to generate their own electricity can share the excess amount with others in a locality. This thesis proposes a novel peer-to-peer energy trading system between homes of a small community which will significantly reduce the impact of cost of power purchased from national grid, allowing more power to be available for the industries. Therefore, becoming economically beneficial for all the users involved.

All the users involved in Energy Trading on a micro grid are connected together using a communication network. The proposed system utilizes a bi-directional power meter and a Central Power Monitor which monitors and records the power exchange and at the end of the month performs bill calculations. In order for the proposed system to be economical a Day Time Algorithm is employed. It adjusts the load on generating sources based on time of the day by and the type of generating source available. At the end of month, Central Power Monitor calculates the monthly bills and transmits the information to each user individually. A private Block-Chain based payment method is employed among, where a secure and unforgeable transaction takes place and buyers pay sellers using crypto-currency.

Keywords: *Microgrid, Power Trading, Bills, Dynamic Rate, Central Power Monitor, Load Sharing, Blockchain*

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Abbreviations

P2P	Peer to Peer
ESS	Energy Storage System
HP2P	Hierarchical Peer-to-Peer
LAN	Local Area Network
UDDSR	User Dominated Demand Side Response
EMS	Energy Management Scheme
ICT	Information and Communications Technology
GUI	Graphical User Interface
kWh	Kilowatt Hour
IDE	Integrated Development Environment
TCP-IP	Transmission Control Protocol - Internet Protocol
RMS	Root Mean Square
BP	Buyer Power
SR	Seller Rate of energy
PoW	Proof of Work

Chapter 1

INTRODUCTION

1.1 PEER TO PEER ENERGY TRADING

P2P energy trading is an innovative method of power sharing among homes in a small community. It allows the end user who own a power generating source to become prosumers by selling the surplus amount of power to other consumers in need, as a result the prosumer functions as both energy producer and consumer. The excess electricity is exchanged with other consumers in the power grid at a cheaper rate than at the price available by the national grid. It is very much similar to the way people share data on Internet. Figure 1.1 gives an idea of Peer To Peer Energy Trading.

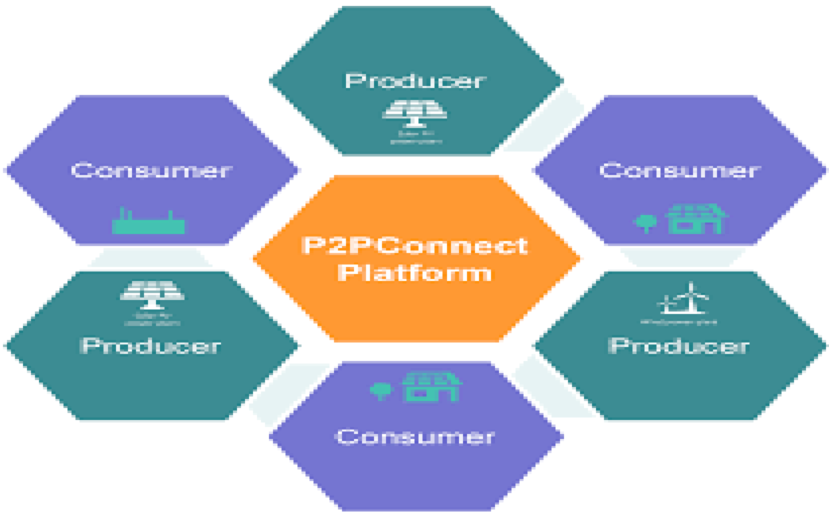


Figure 1.1: Peer To Peer Energy Trading

1.2 SOCIAL IMPACTS

P2P Energy trading could help us to overcome power crisis in our country as it will reduce power requirement of the power plants. More power will be available for industrial usage, hence it can help in industrial growth of Pakistan. Along with other advantages it allows the common households to benefit from this by selling surplus energy to their neighbors, and can become an extra source of income. For people buying power they can purchase cheap electricity, due to more usage of solar powered inverters for this application. Since most of the power plants are based on fossil fuels such as coal, gas and oil. Producing less power will result in lower greenhouse gases emission leading to a healthier and cleaner environment.

1.3 PROBLEM STATEMENT

With the advancement in technology and ever increasing demand of energy, the deficiency of electricity is one of the most serious concerns for the developing world. More than one-sixth of population of world does not have access to electricity [1].This is due to a number of reason which includes no infrastructure available or lack of power generating sources available in a country. Since electricity is the most useful form energy available, the lack of it creates a hurdle in delivering basic human needs to people such as health, education, communication etc.

Conventional power systems are designed for generating large amounts of power at a single remote location. The demand of electricity is always unreliable and unpredictable. The power load on existing power plants is increasing day by day. This creates a negative impact on the environment as more fuel needs to be burned to fulfill the power requirement. Moreover the load shedding is also increasing as power requirement of an industry needs to be fulfilled before the needs of a household can be looked for. To increase the generation, governments are forced to build new power plants along with its infrastructure. For developing nations, arranging financial resources for these projects is quite difficult. Also providing grid extensions to remote locations is quite expensive [2]. As a result, demand of solar powered inverters and diesel generators have increased [3]. Recently micro-grids have grasped the attention of developing nations, due to their relatively low cost of electricity achieved by aggregate generation [4]. By combining the advantages of Distributed Energy generation and Micro-Grid, a new power sharing market can be created where energy consumers can become prosumers, who can both generate and consume energy [5]. Prosumers who have more energy than required can supply power to others who require energy. This energy trading among prosumers is called Peer-to-Peer (P2P) energy trading [6].

1.4 GOAL OF THESIS

The goal of this thesis is to design a system which enables users on micro grid to trade electricity with one another using the method of Peer to Peer Energy trading, therefore allowing consumers to purchase power at cheaper rates than national grid. A complete solution is proposed with simulated results is presented which is implemented using a Centralized Power Monitor, which manages and controls the power transfer, creates monthly contracts between buyers and sellers, performs rate and bill calculation, imposes penalties, records all the power transactions and performs financial transactions between buyers and sellers using a secure private blockchain network. The proposed system provides an incentive to people who can afford power generating sources to invest more in this project.

The system designed for this thesis is a complete solution consisting composing of two parts, hardware and the software. The hardware part comprises of a Bi-Directional Smart Power Meter to measure the magnitude and direction of power from one house to another while the software part uses this data to record, monitor this flow and perform various decisions based on the input it receives. All the decisions taken by the system is independent of any human intervention. The users only decide their role as power producer or consumer along with generation type (solar or generator) and rates of power generation at the start of every month. After that Central Power Monitor creates a monthly contract and starts power sharing among the homes. At the end of the month, monthly bills are calculated send to each user on the micro grid.

1.5 THESIS OUTLINE

Thesis comprises of ten major chapters. Chapter one gives a brief introduction to the thesis. Chapter two provides literature review and past work done on this topic. Chapter three describes the concept of P2P Trading and micro-grid. Chapter four deals with an overview of Hardware Design along with network scheme employed. Chapter five describes the proposed P2P Model along with its working principle. Chapter six describes the Load Sharing feature and its advantages. Chapter seven describes the blockchain based payment method. Chapter eight gives detail explanation about the software created for this thesis, explaining its different features and properties. Chapter nine gives simulated results of the thesis and Chapter ten concludes the thesis.

Chapter 2

LITERATURE REVIEW

2.1 SCOPE AND OBJECTIVE OF THE CHAPTER

This chapter describes the previous research work done on P2P Energy trading and on-going projects throughout the world.

2.2 PREVIOUS RESEARCH WORK ON P2P ENERGY TRADING

The peer to peer (P2P) electricity trading mechanism is expected to grow because awareness about the shared economy has grown in recent years and the advantages of microgrid have risen. Furthermore, the research and development in area of renewable energy technology and the Internet technology will give a boost to implementation of the new system.

Since P2P electricity trading is still a new topic relatively and is at an early stage in business, studies are more attentive on what technology to use in this new area. Alvaro-Hermana [7] et al presented a peer-to-peer energy trading system between two sets of electric vehicles, which decreases the influence of the charging process on power system during business hours. The first set includes vehicles which complete all their daily trips with having a surplus of energy and second set includes vehicles which need to charge. An aggregator gathers all the available supply and demand information from the vehicles to calculate an optimum peer-to-peer price. Jiawen Kang et al [8] also proposed an idea of locally purchasing and selling of energy among Hybrid Electric Vehicles in smart grids using localized Peer-to-Peer (P2P) electricity trading model with Consortium Blockchain.

Inam et al. [9] presented architecture and provided an analysis for system of microgrids with P2P electricity sharing. The paper presented the types of microgrid which can be used, its hardware and software requirements along with results obtained using different methods. There are also an increasing number of researches going on to examine the social and economic impact of P2P electricity trading, with the anticipation that P2P electricity trading will steadily increase. Giotitsas et al. [10] deliberated the development of energy trading technologies and its impact on the global socio-economic structure. Aysajan Abidin et al. [11] suggested decentralized, secure protocols for localized energy trading and billing. This protocol used a bidding procedure centered on secure multiparty computations which allowed users to trade surplus electricity among themselves.

A fair energy trading system among a cluster of microgrids was proposed in [12] by Jadhav et al. The system assumes a cluster of power buying microgrid where a central buyer agent manages all the power and financial transactions, and a power selling microgrid where a central seller agent manages all the power and financial transactions. Based on power requirements of buyers, and grid buying and selling prices, buyer agent calculates the optimum bid price for purchase of energy.

Some hierarchical level of P2P trading was also introduced in [13] and [14]. Huang [13] et all proposed a hierarchical two-level electricity trading system, where at lower level a hierarchical coordination system is proposed for economic dispatch of energy within the country. At the higher level a parallel coordination system is proposed for international electricity exchange.

Paudel [14] et al also presented a hierarchical peer-to-peer (HP2P) energy trading structure which offered effective energy trading in the microgrid. A three-level hierarchy framework was proposed. P2P among the nanogrids within the community microgrid, P2P among the community microgrids in a multimicrogrid system and P2P among the various multi-microgrid system. The fundamental objective was to keep energy and power balance in each level and reduce the dependency of microgrid on the main grid.

Kang [15] et all presented a blockchain-based energy trading platform for smart homes. The paper presented an idea where every house involved in energy trading has a home miner. All nodes are connected to the Internet and has an ESS (Energy Storage

System) that can store purchased or produced energy monitoring energy usage. Home minor conducts energy trading based on pre-programmed smart contracts within private blockchain. Consumers purchase energy from prosumers which is charged to the energy storage device in the house.

Morstyn [16] et all proposed a bilateral contract networks as a new scalable market design for P2P energy trading. Energy contracts between fuel based generators, suppliers acting as intermediaries and prosumers with variable loads and renewable sources were created. For each type of agent, utility-maximizing preferences for real-time contracts and forward contracts were presented.

Zahou [17] et all proposed a Peer-to-Peer (P2P) local community energy pool and a User Dominated Demand Side Response (UDDSR) that allows for energy sharing with reduced bills for a smart community. The UDDSR enables users of a community to give flexible bids to Energy Management Scheme (EMS). Moreover, in order to allow an efficient usage of energy among the users, a local energy pool is also created which enables the energy trading among with the usage of surplus energy within the community. The price of pool energy is calculated by the real-time demand/supply ratio, and also maximum and minimum limit of price is configured to ensure that there is profitability for all the participants.

Hayes [18] et all expressed the potential effects of peer-to-peer energy trading on the control, operation and planning of the electrical distribution networks. He presented an approach for the co-simulation of power distribution networks and local peer-to-peer energy trading platforms. The distribution system model was combined with a peer-to-peer energy trading platform, which utilizes a blockchain based distributed double auction trading scheme. A framework was given for the co-simulation of three-phase unbalanced distribution networks and decentralized electricity trading methods. The analysis presented suggested that a reasonable level of peer-to-peer trading does not have major effect on network operational performance.

2.3 ONGOING PROJECTS ON P2P ENERGY TRADING

Many projects on P2P energy trading have appeared in recent years. Some of them have focused on business models and platform for energy markets similar to role of supplier role in utility sector, while others are more directed at the local control and ICT systems for Microgrids.

2.3.1 PICLO

Piclo was created in the United Kingdom [19]. It began its operation in October 2015 was a association between a technology company called Open Utility and a renewable energy supplier Good Energy. It allowed business consumers to buy electricity directly from the local renewable. It utilized the meter data, generator pricing and consumer preference information to match electricity demand and supply every half hour. Power producers have control and know about the buyers of electricity. Consumers are given freedom to select and prioritize from which generators to buy electricity. Piclo then matches generation and consumption data according to preferences and locality.

2.3.2 VANDEBRON

Vandebron's website allows users to buy electricity directly from independent power producers such as farmers who own wind turbines [20]. Existing utility companies do not participate in this transaction. Vandebron was created in 2013 and it opened a direct market for renewable energy.

2.3.3 PEER ENERGY CLOUD

Peer Energy Cloud was a project in Germany [21]. It was developed using cloud-based technologies for a local electronic trading platform for dealing with local surplus production. It was created to find new methods of recording and forecasting procedures for electricity consumption, to establish a virtual market for power exchange and develop value added services within a Microgrid.

2.3.4 SMART WATTS

Smart Watts was also a German venture. It gave new approaches for improving energy supply with the use of modern information and communication technologies (ICT). ICTs were developed and tested which achieved better cost effectiveness and security of supply. [22].

2.3.5 SONNENCOMMUNITY

The sonnenCommunity is developed by sonnenBatterie, which is a battery manufacturer in Germany. It is a community of sonnenBatterie owners who can share self-produced energy with others. Members can generate and consume their own energy needs on sunny days, also even generating a surplus power. This extra power is not fed into the power grid, but into a virtual energy pool that serves other members in times when they need it. Central software links up and monitors all members also maintaining a balancing between energy supply and demand. [23].

2.3.6 TRANSACTIVE GRID

TransActive Grid is combinations of software and hardware that allows members to purchse and sell energy from each other securely and automatically, with the help of smart contracts. It is located in Brooklyn, New York City. The consumers are given freedom to choose where to buy renewable energy from. Home energy producers can also sell their surplus power to their neighbors. [24].

2.3.7 ELECTRON

Electron is an innovative new platform for gas and electricity metering and billing systems, and is still under development. It will create a way for exciting and new consumer energy services. It is an entirely secure, transparent, decentralized platform that uses blockchain and provides an authentic metering, billing and switching services using Smart Contract. This platform will be open source and will be a benefit of all users. It will not be maintained or controlled by contractors or brokers [25].

Chapter 3

THE CONCEPT OF P2P ENERGY TRADING

3.1 SCOPE AND OBJECTIVE OF THE CHAPTER

The objective of this chapter is to deliver the idea behind Peer to Peer Energy Trading techonology. It explains the general working principle of Peer to Peer Energy Tradding, the benefits associated with this technology and challenges that come with this scheme of power trading.

3.2 WHAT IS PEER TO PEER ENERGY TRADING ?

In the traditional system, the power is mainly generated by large power plants. Electricity is usually transmitted from large-scale generators through the transmission grid on high voltage lines to consumers over long distances. Electricity is distributed to large consumers like industries or step down to medium and low voltages for distribution to smaller consumers using local grids. Conventional energy trading is mainly unidirectional in which the cash flows in the opposite way to the power flow. All the factors, which include generation costs, transmission losses etc. are taken into account in the bill of supplier.

In contrast, the P2P energy trading encourages multidirectional trading within a local geographical area. In a localized energy trading mechanism, the community members acting as producers and suppliers provide electricity to other members acting as consumers, which reduces the number of actors and also simplifies the model using an internal trading method.

Trials of energy trading which are based on the P2P economy concept are being carried out across the world, for example, Piclo in the UK, Vandebron in Netherlands, and sonnen Community in Germany.

Peer-to-peer energy trading is the purchase and selling of electricity between two or more grid-connected users. This is often performed for solar energy. Any surplus power can be transmitted and sold to other users using a secure energy trading platform. P2P energy trading allows the end user to become prosumer and function as both energy producer and consumer. The peers buy or sell energy directly with each other without involvement of any conventional energy suppliers as shown in Figure 3.1. P2P energy trading is normally enabled by Information and Communication Technologies (ICT)-based online services. It is very much similar to the way people share data on Internet, like BitTorrent and eBay for shopping and Airbnb which is used for accommodation. A fully established P2P energy trading systems removes the middleman and allows a transparent dealing between users, which is opposed for a user which acts a consumer for a corporation. In P2P Energy trading contracts or agreements are established between the buyers and sellers in order to regularize the flow of power and make system beneficial for all.

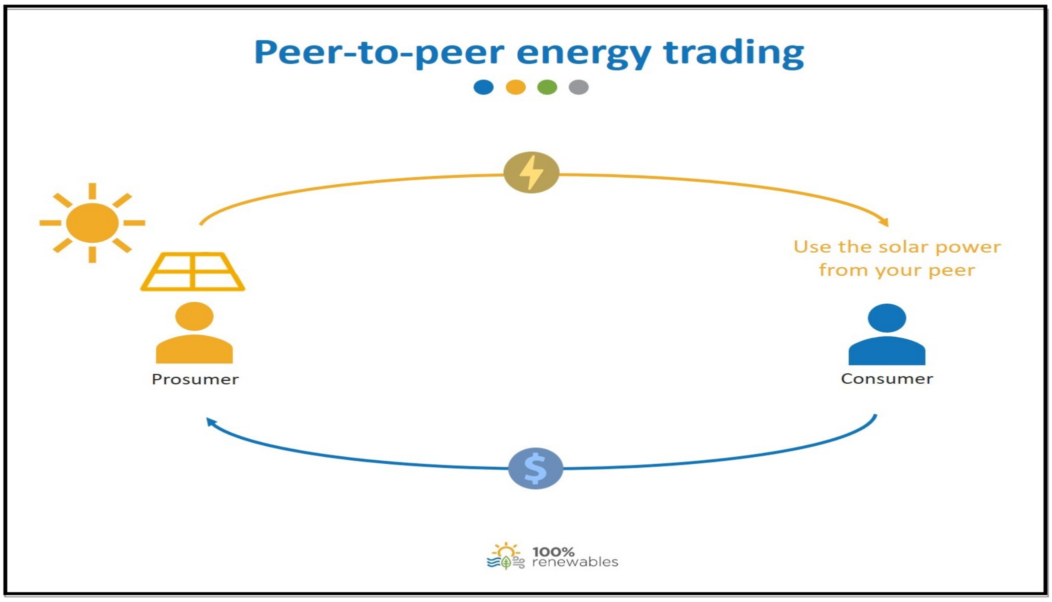


Figure 3.1: Buying and Selling of Power

The main idea behind P2P Energy trading is to transform a conventional power system into a Distributed Power System. The Figure 3.2 depicts this idea.

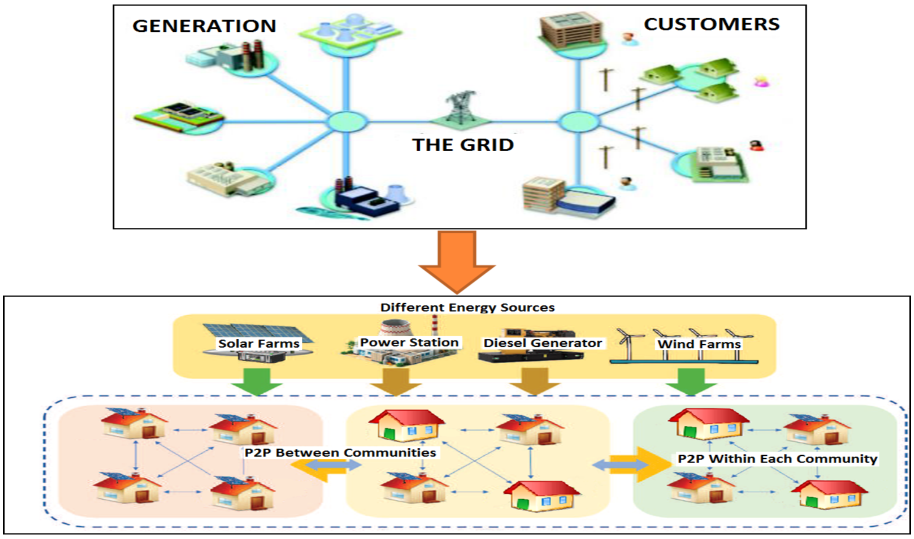


Figure 3.2: Transformation from Conventional to P2P Trading

3.3 THE ADVANTAGES OF PEER TO PEER ENERGY TRADING

Some of the Advantages associated with Peer To Peer Energy Trading are as follows:

- In a community people who do not own solar panels are still able to utilize renewable energy at a reasonable price from their neighbors. People selling their surplus power can sell at a price that is higher than the amount they would receive as a feed-in tariff from their retailer.
- Since energy is not being transmitted from centrally located power plants, this reduces electricity transmission costs and losses. According to Aurora Energy, 41.1 percent of electricity cost comes from managing and maintaining the infrastructures that transmits power from generating stations to end users.
- Energy can be produced or generated from renewable sources, which is beneficial for environment.

- Buyers in a community can buy energy a known source using a secure platform. The transfer of power and data is secure since contracts are established beforehand between buyers and sellers with their mutual consent.
- There is no middle man between buyers and sellers, providing a choice for dealing with other consumers.
- Using blockchain technology, all transactions can be made public and once data is on the blockchain it cannot be changed in any way, which creates full transparency.

3.4 CHALLENGES FACED BY PEER TO PEER ENERGY TRADING

At present P2P Energy Trading faces several challenges. It is currently not known when these challenges will be overcome so that consumers can start to participate and enjoy the benefits of renewable energy. Some of the main issues include:

- It is still not yet commercialized.
- The platforms present in market are still immature.
- People need to be convinced about the use and benefits associated with peer to peer energy trading.
- There also some regulatory barriers.

3.4.1 TECHNICAL CHALLENGES

There are two main challenges that need to be overcome. First, the billing process is a complex process. In a traditional system, all payments are gathered by the supplier and it is then distributed to the right actors. In a P2P system, the payments have to be collected and then distributed without the involement of supplier and must be done automatically.

The second challenge is that the community and traditional suppliers coexist. In order to avoid billing errors, there should be a clear distinction between the power supplied by the supplier and the power supplied by the community members. Figure 3.3 shows one possibility of billing process.

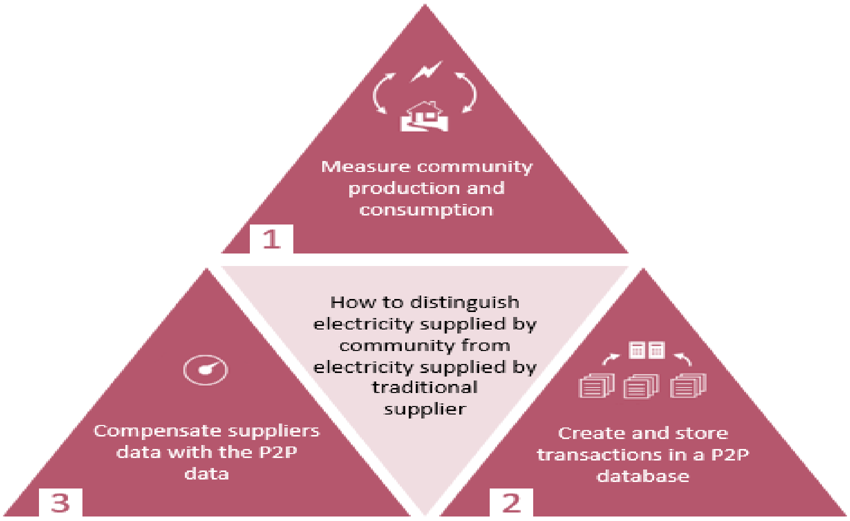


Figure 3.3: Billing Process

3.4.2 ORGANIZATIONAL CHALLENGES

For the community to be effective, rules and agreements between all members have to be developed. The electricity price must have a trade-off such that it remains a win-win situation for all parties involved. From a viewpoint of consumer, the P2P energy price has to be lower than the traditional price. From a viewpoint of prosumer, the P2P energy price has to be higher than the typical buy-back price for surplus electricity.

Secondly, entrance and the exit of new members within the community also have to be regulated. This can be linked to the installed production capacity or the average consumption.

Distribution rules needs to be established to handle situations in which supply does not match consumption. These rules will determine who benefits from the electricity community first.

3.5 WHAT IS A MICRO-GRID ?

A microgrid refers to distributed energy resources and loads that can be operated in a controlled, coordinated way; they can be connected to the main power grid, operate in islanded mode or be completely off-grid. Figure 3.4 shows a typical microgrid.

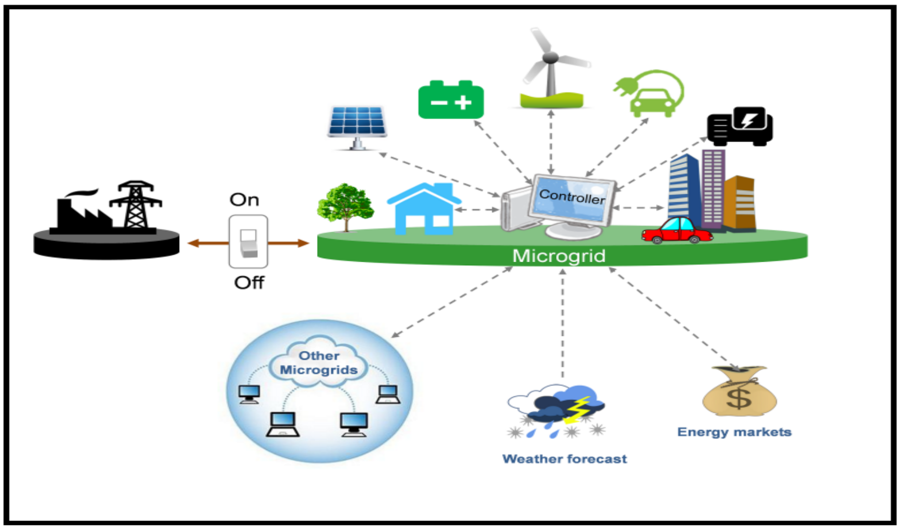


Figure 3.4: Typical Micro-Grid

Microgrids are low- or medium-voltage grids located at or near the consumption sites. They can generate power from both renewable and conventional sources and although they are mainly electrical systems, they can also incorporate a thermal energy component, such as combined heat and power. Microgrids are increasingly being equipped with energy storage systems, as batteries become more cost competitive. The system is controlled through a microgrid controller incorporating demand-response so that demand can be matched to available supply in the safest and most optimized manner. A flywheel or battery-based grid stabilizing system can be included to offer real and reactive power support.

The concept of a microgrid is not new: the earliest electricity networks were essentially microgrids before they were joined into regional and national grids. What is new is their changing and expanding role, in the face of rising power demands, the falling cost of renewable sources, and the increasing need for supply resilience and autonomy, both on and off-grid.

To understand how a microgrid works, we first have to understand how the grid works. The grid connects homes, businesses and other buildings to central power sources, which allow us to use appliances, heating/cooling systems and electronics. But this interconnectedness means that when part of the grid needs to be repaired, everyone is affected.

This is where a microgrid can help. A microgrid generally operates while connected to the grid, but importantly, it can break off and operate on its own using local energy generation in times of crisis like storms or power outages, or for other reasons.

A microgrid can be powered by distributed generators, batteries, and/or renewable resources like solar panels. Depending on how it is fueled and how its requirements are managed, a microgrid might run indefinitely.

Chapter 4

HARDWARE AND NETWORK SCHEME FOR PEER TO PEER ENERGY TRADING

4.1 SCOPE AND OBJECTIVE OF THE CHAPTER

The most important part of this Peer to Peer Energy Trading project is to acquire the data from real world and communicate it with the Central Power Monitor. Since the proposed system will be different from the existing system, to achieve the objective of effective measurement, a good hardware design is required which is reliable, robust and accurate in terms of measuring the electrical parameters. The hardware must be smart, capable of transferring the data to the new system in a form which is compatible. It must also be easy to use and can be installed easily without requiring any major changes in the existing system.

The only way the proposed Peer to Peer Energy Trading System can work effectively is to have a good and reliable communication system between users of the micro grid and the Central Power Monitor. Since data and commands will be continuously exchanged between users and Central Power Monitor, communication system plays a key role for effective transmission. The network must be controlled from a central source to avoid any traffic congestion in the network. Also the network must be robust, capable of withstanding any environmental changes that can affect the transmission of data.

Following are the main components of the Peer to Peer Energy Trading System described in this thesis. The purpose, design and the working principle of each component is described in detail:

- Power Network
- Communication Network
- Arduino Based Bi-Directional Power Meter
- Visual Studio
- Individual Data Monitor Workstations
- Central Power Monitor Workstation

4.2 THE POWER NETWORK

The Peer to Peer Energy Trading system designed for this thesis is based on a network of four houses connected in together in a micro grid, where they exchange power among them. For practical applications provision is available for more houses to be connected into this network in the future. The micro grid comprises of separate power lines connecting all the houses together for power sharing. Each house is connected to the micro grid using circuit breakers. These breakers are responsible for isolating the house from the micro grid. The micro grid is connected to the main grid via two separate circuit breakers which can be used for isolation of micro grid from main grid in case of any power fluctuation in main grid.

The houses in the micro grid can divided into two categories, power producing houses or sellers and power consuming houses or buyers. All the sellers have power generating sources that can be either fuel driven generators or solar powered invertors. These sources are capable of synchronizing itself with the main grid i.e. their frequency, voltage and phase matches with the main grid. Furthermore these sources can not only fulfill the power requirement of their own house load but also provide surplus to the micro grid. These sources can also adjust their power output as per the requirement of micro grid. Since the micro grid is synchronized with the main grid any additional requirement of power that micro grid will not be able to fulfill shall be supplied by the main grid. The system installed is intelligent enough to find out which house in the micro grid has used this additional power from main grid without requiring any separate power lines from main grid to individual houses. All the houses on the micro grid participating in energy trading have a Smart Bi-Directional Power Meter which is specially designed for this thesis. This power meter is installed between the House and micro-grid where it monitors the status of circuit breaker of houses connection to micro grid and measures the electrical parameters (voltage, current, frequency etc) along with magnitude and direction of power transfer between micro grid and house.

4.3 THE COMMUNICATION NETWORK

The communication or the transmission of data between houses and the Central Power Monitor is of key importance. Because of the data and commands exchanged the Central Power Monitor can perform various functions such as data recording, analyzing and making decisions. This communication network is a Local Area Network where as shown in the Figure 4.1. Each House participating in Energy Trading over micro grid has a network switch and a workstation, called Individual Data Monitor Workstation, installed in it. Fiber Optic cables are used to establish connectivity of each house with the Central Power Monitor. Each Individual Data Monitor Workstation is assigned a unique static IP Address with layer 192.168.100.XXX and mask address 255.255.255.0. This means a total of 255 houses can participate in this Peer to Peer Energy Trading System. The workstations are equipped with Firewall which means Internet cannot be accessed without proper authorization.

The network is designed in STAR topology where all the houses are only directly connected to Central Power Monitor. The network is Server / Client architecture, where houses behave as clients and Central Power Monitor is the Server. All the Houses in the micro-grid are only capable of communicating with the Central Power Monitor and not with each other. This means complete privacy is maintained for each house with respect to its power transaction with the micro grid. The Central Power Monitor receives data from all the houses by send a request to each house (data polling) and it can send commands to all the houses. The network of information flow is controlled by Central Power Monitor. Along with a unique IP Address, a unique House ID is also assigned to each Individual Data Monitor Workstation, which is used by the Central Power Monitor to communicate with individual houses.

The Individual Data Monitor Workstation receives data serially from the Bi-Directional Smart Power Meter. A USB to Serial cable is used to establish serial communication between Power Meter and the workstation. This data is used by Individual Data Monitor Workstation to display it on a Graphical User Interface (GUI) and also send it to Central Power Monitor over Local Area Network. The Central Power Monitor uses this data to perform various calculations and decision making.

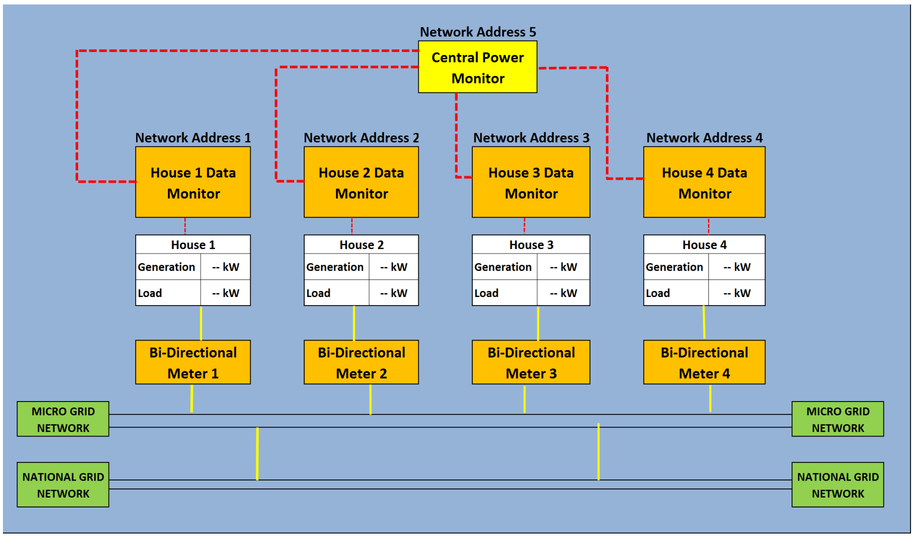


Figure 4.1: Power and Communication Network

4.4 ARDUINO BASED SMART BI-DIRECTIONAL POWER METER

The term bi-directional metering means that the meter can measure the flow of electricity in two directions. A Bi-directional meter measures how much the energy is being exported to the grid, kWh delivered. It also measures the amount of energy being imported from the grid, kWh received. It is the piece of equipment that allows you to receive feed-in tariffs or payments through the Renewable Energy Buyback Scheme.

As the generator system produces electricity, the kilowatt-hours are first utilized to fulfill the energy requirement of user such as lighting and appliances. If surplus energy is available from the system than the user requires, the additional kilowatt-hours are fed into the electric network of utility and which is then utilized by other customers. When the monthly electric bills are calculated, if the user has utilized more electrical energy than is generated from its own power source, the customer has to pay only for the net kilowatt-hours (kWh) utilized from the grid. If the customer has generated more electrical energy than what is used from the utility electrical network, the customer receives a kWh credit, which is adjusted in the future bills. In addition, the customer will be required to pay for any customer charges and minimum tax applicable under the utility rule of company.

A smart meter is a device that can be installed in switchboard to measure imported grid power, and exported power. The smart meter sends this import/export data back to the system via a data cable to be compared with the production data. The online monitoring platform provides real-time monitoring of the household electricity consumption, power production and the amount of excess power being exported to the grid.

The Bi-Directional Power Meter designed for this thesis is Arduino Based device, capable of measuring voltage, current, real power, reactive power, apparent power, power factor, frequency, phase angle and direction of power transfer. It is the only connection that the system has with the physical world. This meter also measures the power generated by the generator and the power exchanged with grid. The net difference is the load of the house. The auxiliary contact of the generator breakers and the grid tie connection breaker are also entered into this meter. This allows for real time monitoring of the generator and connection of grid to the house.

The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts. Arduino board designs use a variety of microprocessors and controllers. The boards are equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) or breadboards (For prototyping) and other circuits. The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs from personal computers. The microcontrollers can be programmed using C and C++ programming languages. In addition to using traditional compiler toolchains, the Arduino project provides an integrated development environment (IDE) based on the Processing language project.

Since houses connected on micro grid will either be supplying electricity to micro grid or accepting the power, it is essential to measure the power flow. This power flow will help the Central Power Monitor to check for the power transaction occurring. The Data from the Bi-Directional meter is fed into the Individual Data Monitor via a serial link, where the user can analyze the data for any abnormality. The same data is forwarded by the Individual Data Monitor to the Central Power Monitor using a TCP-IP connection. This data is of prime importance for this system as every calculation performed by the Central Power Monitor is based on the data provided by the Bi-Directional Power meter. Figure 4.2 shows main circuit design for measurement of electrical parameters.

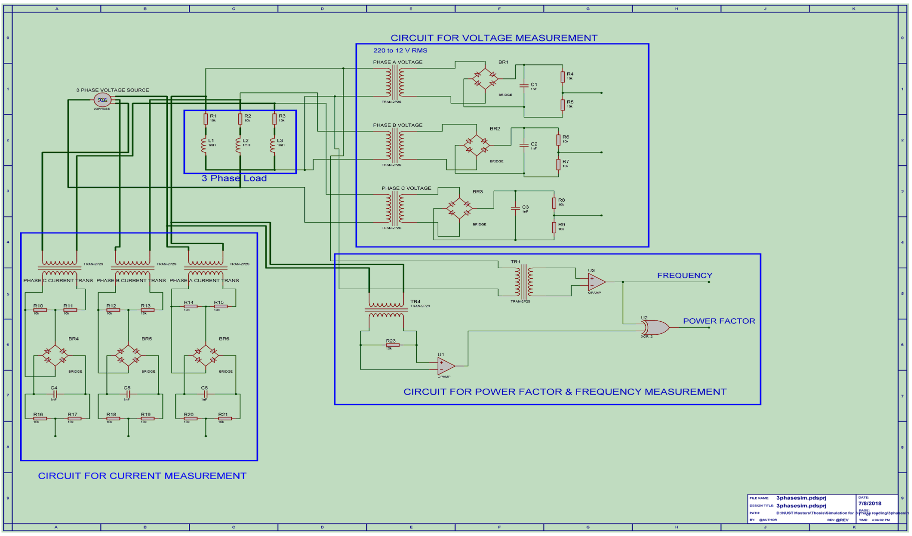


Figure 4.2: Hardware Circuit Design

4.4.1 VOLTAGE MEASUREMENT

The Arduino can only measure DC voltages between 0 to 5V. Since we are working on a 3 phase AC System, voltage levels have to be brought into acceptable levels for the microcontroller. To measure the AC RMS Voltage of each phase potential transformers are used for stepping down voltages to 12V AC RMS. This step down AC voltage is then converted into DC voltage using a Full Bridge Rectifier and filtered using a capacitor. This gives a DC voltage of 16.97V.

A voltage divider circuit is used after the Full Bridge Rectifier which gives a maximum peak voltage of 5V DC for corresponding maximum peak of single phase AC Voltage i.e. 311V. Arduino reads this DC voltage in the range of 0 to 1023 which corresponds to 0 to 5V respectively. Following formula is used by the microcontroller to calculate voltage:

$$\begin{aligned} VDC &= Vin \times (5.0 \div 1023.0) \\ VDC_{Max} &= VDC \times 3.425(VoltageDividerRatio) \\ VAC &= TR \times ((VDC_{Max} + 1.4) \times 0.707). \end{aligned} \tag{4.4.1}$$

where,

TR = transformer ratio 18.333

1.4 is the diode voltage drop

0.707 is the Peak to RMS conversion factor

The 5V DC measured is multiplied by the voltage divide ratio. This ratio is calculated by formula (R1+R2)/R1. This gives the DC voltage at the output of the Full Bridge Rectifier. The voltage drop of the diodes in the Full Bridge Rectifier is added (1.4V) to this DC voltage which then gives peak AC voltage at the output of the step down transformers. Using the value 0.707 as peak to RMS conversion factor, RMS value is obtained. Finally, the step down transformer ratio (220/12 = 18.333) is used to calculate the single phase RMS AC voltage.

4.4.2 CURRENT MEASUREMENT

To measure the current of flowing in each phase, a similar approach is used as voltage measurement. The current transformers are used to step down current to an acceptable level. A 1 Ω resistor of high power rating is used at the output of current transformer to convert the current into voltage as voltage drop across the resistor becomes equal to current flowing through it. The AC Voltage is transformed into DC Voltage using a Full Bridge Rectifier and filtered using a capacitor. A voltage divider circuit is then used after Full Bridge Rectifier to get a maximum peak voltage of 5V DC for corresponding maximum peak of AC Voltage. Arduino reads this voltage in the range of 0 to 1023 representing 0 to 5V respectively. Following formula is used to calculate current:

$$\begin{aligned} IDC &= Iin \times (5.0/1023.0) \\ IDC_{Max} &= IDC \times 5.405(VoltageDividerRatio) \\ IAC &= (IDC_{Max} + 1.4) \times 0.707. \end{aligned} \tag{4.4.2}$$

where,

1.4 is the diode voltage drop

0.707 is the Peak to RMS conversion factor

The 5V DC measured is multiplied by the voltage divider ratio. This ratio is calculated by formula (R1+R2)/R1. This gives the DC voltage at the output of the Full Bridge Rectifier. The voltage drop of the diodes in the Full Bridge Rectifier is added (1.4V) to this DC voltage which then gives peak AC voltage at the output of the current transformers. This AC voltage is equal to the AC current at output of current transformer because of 1 Ω resistor that has been used. Using the value 0.707 as peak to RMS conversion factor, RMS value is obtained. Finally, the current transformer ratio is used to calculate the single phase RMS AC current.

4.4.3 FREQUENCY MEASUREMENT

Arduino has the capability to measure time periods precisely. It uses a timer to measure the time a high signal (+5V) is received at one of its input. Using this feature of the microcontroller frequency is measured. A step down transformer is used first to step down the voltage to AC 12V RMS. This AC signal is converted into a square wave with the help of a comparator (op-amp). The op-amp compares the AC voltage with 0V. If the amplitude of AC signal is greater than 0V (i.e. positive), the comparator generates a +5V signal and if the amplitude of AC signal is less than 0V, the op-amp generates 0V signal. This Square wave is read by the Arduino to measure the On and Off times of the signal. Since frequency is inverse of time, by adding the On and Of times, time period of the square wave can be obtained. This time period is then used to calculate frequency. Following formula is used to calculate the frequency.

$$\begin{aligned} time_{period} &= high_{time} + low_{time} \\ time_{period} &= time_{period}/1000 \\ frequency &= 1000/time_{period}. \end{aligned} \tag{4.4.3}$$

4.4.4 POWER FACTOR CALCULATION

The power factor of an AC electrical power system is defined as the ratio of the real power absorbed by the load to the apparent power flowing in the circuit. Calculation of power factor is important because a load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost in the distribution system, and require larger wires and other equipment. Because of the costs of larger equipment and wasted energy, electrical utilities will usually charge a higher cost to industrial or commercial customers where there is a low power factor.

Power factor is calculated by first measuring the phase difference between voltage and current. If the phase difference between voltage and current is positive (i.e. voltage leads current) power factor will be lagging and if the phase difference is negative (i.e. current leads voltage) power factor will be leading. To measure this phase difference, square wave pulse obtained from the comparator used for frequency measurement is used as Voltage signal. Similarly using a current transformer and an additional op-amp current sine wave is converted into square wave to obtain a Current signal. These two square wave signals are compared using a XOR Gate IC. The property of XOR is to produce a high output when both of its input are different. Using this concept if the voltage and current are completely in phase, XOR output will be zero. If voltage and current are completely out of phase, XOR output will be high (Refer to figure). The duty cycle of the output wave of XOR will be directly proportional to phase difference. Greater the phase difference, higher the duty cycle of XOR output and thus representing a lower power factor. Using the power factor, phase angle is also measured which is used for power calculation. Following formula is used to calculate Power Factor.

$$
\begin{gathered}
time_{period} = high_{time} + low_{time} \\
duty_{cycle} = high_{time}/time_{period} \\
angle = duty_{cycle} \times 181.8 \\
power_{factor} = cos((angle \times 3.14)/180).
\end{gathered}
\tag{4.4.4}
$$

where,
181.8 is conversion factor, from duty cycle to angle

4.4.5 POWER MEASUREMENT

This Power Meter is capable to calculate active power, reactive power and apparent power values. The power which is actually consumed or utilized in an AC Circuit is called True power or Active Power or real power. It is measured in kilo watt (kW) or MW. The power which flows back and froth that mean it moves in both the direction in the circuit or react upon itself, is called Reactive Power. The reactive power is measured in kilo volt ampere reactive (kVAR) or MVAR. The product of root mean square (RMS) value of voltage and current is known as Apparent Power. This power is measured in kVA or MVA.

To calculate power values of voltage, current and power factor calculated previously are used. Active Power of a single phase is calculated by multiplying RMS values of voltages and current times the power factor (i.e. VRMS x IRMS x Power Factor). Apparent power is calculated by multiplying RMS voltage and RMS current (i.e. VRMS x IRMS). Reactive Power is calculated by subtracting Active Power square from Apparent Power square and then square root the result. Following formula is used to calculate the Power.

$$
\begin{gathered}
Active_{Power} = VRMS \times IRMS \times power_factor \\
App_{Power} = Vgen \times Igen \\
Reactive_{Power} = ((App_Power)^2 - (Active_Power)^2)^{1/2} \\
power_{factor} = cos((angle \times 3.14)/180).
\end{gathered}
\tag{4.4.5}
$$

4.4.6 POWER FLOW DIRECTION

After calculating the power exchanged between the house and the micro grid, it is essential to find out in which direction is the electricity actually flowing. If the generated power of a house is greater than the power consumed, surplus energy will flow to the micro grid. This is considered as Positive Power. If the generated power is less than the power consumed by the house, the extra power will be utilized from the grid. This is considered as Negative Power.

To find out the direction of power flow, the phase difference between voltage and current flowing through the Bi-Directional Meter is calculated. Since voltage is being measured with reference to the micro-grid (i.e. positive side is house and negative side is micro-grid), when the power will be positive, current will flow from house to the micro-grid. If voltage and current are in phase with each other (i.e. within acceptable limits), the surplus power generated is being delivered to the micro grid and power will be Positive. If current and voltage are out of phase with each other, then the flow of current is from micro-grid to house and power is being consumed from the micro grid. This power will be Negative.

Using this rule, the XOR output (which is used for power factor calculation) is continuously monitored. If the voltage and current will be in phase the duty cycle of the XOR output wave will be a low value. If the duty cycle is high, the current and voltage are out of phase with each other. Using multiple iteration method, it was found out that a duty cycle value higher than 88 percent represents that voltage and current are out of phase with each other and values of duty cycle lower than 88 percent means voltage and current are in phase.

4.5 VISUAL STUDIO

The Graphical User Interface for the Data Monitor Workstation and the Central Power Monitor is developed on Visual Basic.Net using Visual Studio Environment. Microsoft Visual Studio is an integrated development environment (IDE) from Microsoft. It is used to develop computer programs, as well as websites, web apps, web services and mobile apps. Visual Studio uses Microsoft software development platforms such as Windows API, Windows Forms, Windows Presentation Foundation, Windows Store and Microsoft Silverlight. It can produce both native code and managed code.

Visual Studio includes a code editor supporting IntelliSense (the code completion component) as well as code refactoring. The integrated debugger works both as a source-level debugger and a machine-level debugger. Other built-in tools include a code profiler, designer for building GUI applications, web designer, class designer, and database schema designer. It accepts plug-ins that enhance the functionality at almost every level including adding support for source control systems (like Subversion and Git) and adding new toolsets like editors and visual designers for domain-specific languages or toolsets for other aspects of the software development lifecycle (like the Azure DevOps client: Team Explorer).

Visual Studio supports 36 different programming languages and allows the code editor and debugger to support (to varying degrees) nearly any programming language, provided a language-specific service exists. Built-in languages include C, C++, C++/CLI, Visual Basic .NET, C Sharp, JavaScript, TypeScript, XML, XSLT, HTML, and CSS. Support for other languages such as Python, Ruby, Node.js, and M among others is available via plug-ins. Java were supported in the past.

4.6 DATA MONITOR WORKSTATION WITH GUI

Each house participating in P2P Energy trading is equipped with a Workstation which connects with the Bi-Directional Power Meter and Communication Network of the micro-grid. The workstation has a Graphical User Interface, developed on Visual Basic.NET, which allows a user to monitor the performance the house on the micro-grid. Using the workstation, the user can view the real time values of voltage, current, power factor and power being delivered or consumed from the micro grid. This workstation acquires data serially from Arduino Based Bi-Directional Power Meter and calculates energy in kWHr from the power. All these Data Monitor Workstation are connected to Central Power Monitor over TCP-IP LAN network. The Central Power Monitor receives the data from the Data Monitor Workstations which is used for further evaluation and calculation. The Data Monitor Workstation also receives several information from the Central Power Monitor, like end of month bills, payments, power raise and lower commands. Bills and Payments are shown in separate windows for the users and are available till new bills are not calculated at the end of next month. During the start of month, this workstation allows user to create new contract by choosing their role, seller or buyer, and entering specific parameters.

4.7 CENTRAL SERVER MONITOR

All houses participating in the Peer to Peer Energy Trading are connected to the Central Power Monitor through a Local Area Network. The Central Power Monitor is the central brain of the entire operation of the Peer to Peer Energy Trading System. The Central Power Monitor is a Workstation with a GUI interface created in Visual Basic.Net. All the programming to perform various calculations is done at the back end of the program.

It connects, sends and receive commands from other houses on the network using TCP-IP Sockets. The Central Power Monitor has multiple windows to control and view different parameters of the transaction going on micro grid. All the logical calculation is performed by Central Power Monitor.

The primary responsibility of the Central Power Monitor is to record the information received from all the House Individual Data Monitor in a database which is used for further evaluation and calculation. This database is made in MS Access which is linked with Visual Basic.Net for auto saving of the data. All the power transfer taking place between grid and individual houses is being recorded in the database. The Central Power Monitor calculates real time power rate according to real time generation of power, it calculates the power transfer between houses and any surplus power that has been consumed from the national grid. The Central Power Monitor continuously monitors the power transfer between houses and micro grid and controls the power transfer by sending commands to sellers to increase or decrease the power. The Central Power Monitor also initiates the monthly contract and keeps a record of this monthly contract. It imposes penalties if any house does not comply with their contracts by adding these penalties in their them into their monthly bill.

The secondary task of Central Power Monitor is to perform load sharing function between the sellers on the micro grid as per Day Time Algorithm. It sends the command to increase or decrease power to Individual Data Monitor Workstation which is then forwarded to the generation controller. The Central Power Monitor checks the load on all sellers and their source of generation. It will send an increase power command to solar powered source during the day and an increase power command to fuel driven generator during the night. In this way the whole system becomes more economical and environmental friendly.

Chapter 5

PROPOSED PEER TO PEER MODEL

5.1 SCOPE AND OBJECTIVE OF THE CHAPTER

This chapter describes in detail the proposed Peer to Peer Energy Trading system designed for this thesis. As discussed in chapter 4, the micro grid network comprises of four houses participating in energy trading with a Central Power Monitor controlling and monitoring the entire operation. Each house is equipped with a Bi-Directional Smart Power Meter and an Individual Data Monitor Workstation to communicate with the Central Power Monitor for exchanging commands and data. The Bi-Directional Power Meter reads the values of current and voltages and using it calculates the power transfer between houses and micro grid. The Data Monitor Workstation receives this data using serial communication. It calculates the Energy from the Power (which is exchanged with micro grid) and transfers all this information to Central Power Monitor. All the houses are connected together on a single LAN network in STAR topology with Central Power Monitor in center. The house cannot communicate with each other nor share any information. This allows complete privacy and security of the network. A unique IP layer is chooses for Peer to Peer Energy Trading communication and no other device is allowed to connect to this network.

Each house is assigned a unique ID and IP Address. This IP address and ID is defined in the Individual Data Monitor Workstation of the houses. The Central Power Monitor connects to each house using the IP address and identifies the house using the ID assigned to it. This allows the Central Power Monitor to exchange data and commands with each house. If a new user joins the network, a new IP and ID will be assigned to it. Figure 5.1 shows the flow chart of the whole process in steps. The complete process can be divided into 10 steps. Following are these 10 steps which are further discussed in detail.

- 1. Connecting to Server
- 2. Role Assignment
- 3. Setting up of parameters
- 4. Agreement Creation
- 5. Power Transfer
- 6. Dynamic Rate Calculation
- 7. Per minute based bill calculation
- 8. End of month bill calculation
- 9. Monthly Bill Summary Creation
- 10. Payment in cryptocurrency

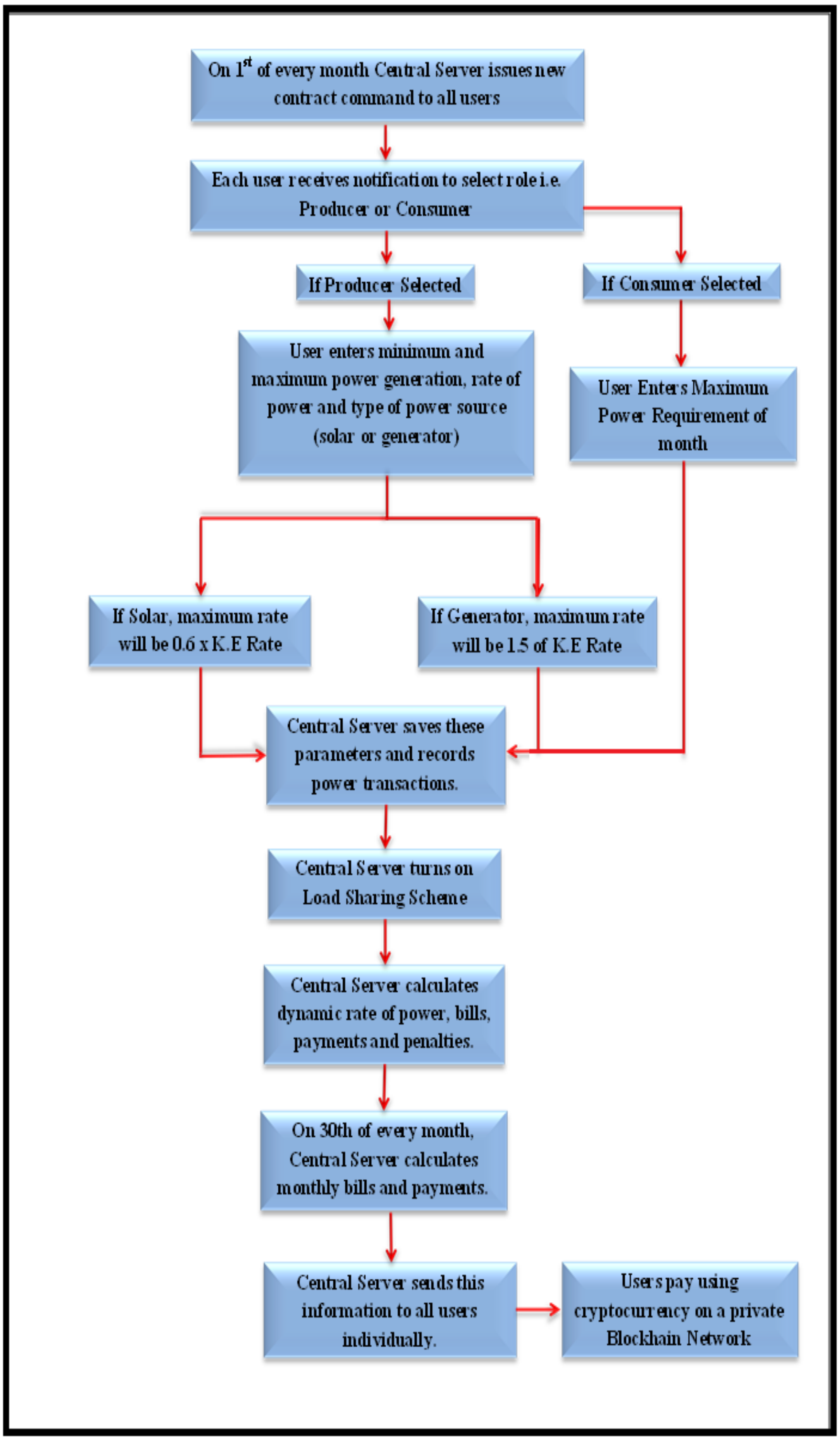


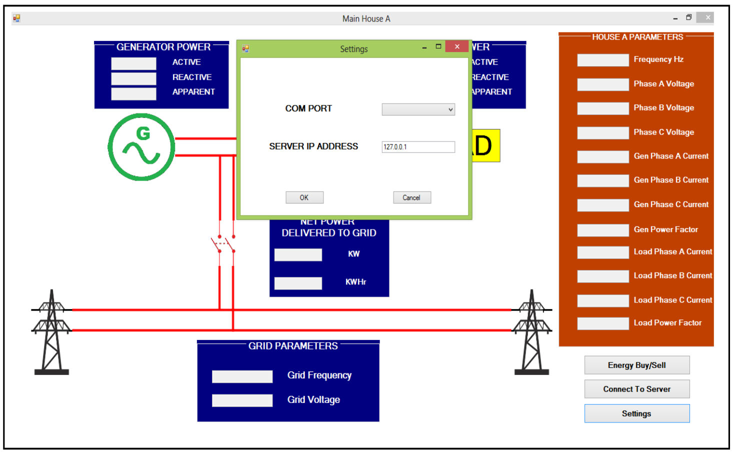
Figure 5.1: Flow Chart for P2P Energy Trading

5.2 CONNECTING TO SERVER

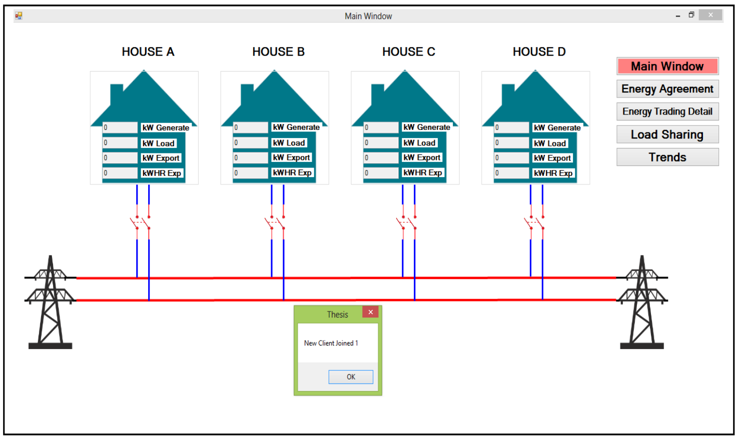
When a new user becomes part of the Peer to Peer Energy Trading Network, he is assigned a unique ID and IP address for his Individual Data Monitor Workstation. This ID and IP address is used by Central Power Monitor to recognize him and perform various data and commands transfer activities. Using the GUI of the Individual Data Monitor workstation, the user can connect to the Central Power Monitor. The Bi-Directional Smart Power Meter is also connected to the Individual Data Monitor Workstation using a USB cable for Serial data transfer. The connection to Central Power Monitor is two-step process.

The main display of the Individual Data Monitor GUI shows various parameters of the house. It will display the power generated, power consumed, power transferred, etc. At the bottom of the window there are three buttons for various purposes. Using the Settings button a new window will pop-up asking user to enter the COM-Port of Arduino Based Bi-Directional Smart Power Meter which is used for data acquisition from the Bi-Directional Meter. The user will also be asked to enter the IP Address of the Central Power Monitor for establishing communication with the network. This is will be only one-time activity, which is required to be performed during the initial setting of the Individual Data Monitor Workstation. This is the first step.

The second step involves pressing the second button Connect to Server on the main window of the Individual Data Monitor workstation. This will established the communication with the Central Power Monitor, and the user will then become part of the Peer to Peer Energy Trading Network. On Central Power Monitor main window, connection confirmation message will pop-up stating that a new user with ID No. xx has now connected to the system and is now part of the network. The Central Power Monitor now can exchange data and commands with the new user. Figure 5.2 shows the connection steps.



STEP 1



STEP 2

Figure 5.2: Connecting to P2P Network

5.3 ROLE ASSIGNMENT

Each user participating in Peer to Peer Energy Trading can either be Consumer (i.e. buyer of power) or he can be a Producer (i.e. seller of power). This platform allows a user to make his own choice based on its capacity of generation. At the beginning of every month, the Central Power Monitor broadcasts a Create Contract command over the entire network. The Individual Data Monitor Workstations upon receiving this command activates their create contract sequence.

The first step of this sequence is that a pop-up window will appear on the main window every House Individual Data Monitor Workstation, prompting the user to enter their role (i.e. producer or consumer) for the current month. Figure 5.3 shows decision window. The window will also display the name of month to clarify for which time duration this contract will be created. The user will then press his desired button, i.e. Producer or Consumer. As per the decision made by the user his role will be defined. The Individual Data Monitor Workstation will send this information to Central Power Monitor along with House ID, which will then be saved in the database Power Agreement Database.

The user is not allowed to change his role once the contract has been finalized. For entire month he will either be a Buyer or Seller in this Peer to Peer Energy Trading System. This role can only be changed at the beginning of the next month when a new contract will be formed. The information history regarding the contract formation of the previous months can later be viewed form the database. After role assignment task is finished another window pops-up asking user to enter certain parameters as per their role. This is the second step of contract formation.

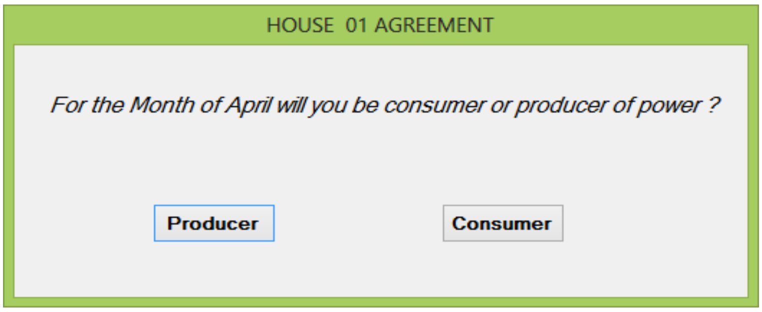


Figure 5.3: Role Assignment Message

5.4 SETTING UP OF PARAMETERS

The Second step of contract formation is to enter certain parameters which are specific to the roles user has decided. Once users have pressed his desired button in the Figure 5.3, a new window will appear asking to enter some more parameters. These parameters will them become the foundation of the agreement or contract for the Peer to Peer Energy Trading System. The parameters requested are different for producer and consumer. The data will be saved in the Central Power Monitor in the Power Agreement Database. They will be used as a basis for continues monitoring of power transaction going in the micro grid. Any violation of the contract will be dealt by a penalty imposed by

Central Power Monitor in the end of month bills.

If a user has decided to export surplus power to micro grid and presses the button Producer, a new window will appear asking him to enter to enter the maximum surplus power ($G_{\text{max i}}$) and the minimum surplus power ($G_{\text{min i}}$) he can provide to micro grid keeping in view of his own load and generating capacity. Figure 5.4 shows the Producer Parameters Window. Along with this information, he will also enter the source of power generation, i.e. solar powered invertor or fuel driven generator. The most important parameter that a user will enter is the rate of energy (SR_i) at which he would like to sell power to other buyers on the micro grid. For a user with solar power invertor generation source his rate cannot be higher than the rate of main grid.

If a user chooses to be a buy power from the available sellers on the micro grid, he should press the Consumer button in the Figure 5.3. In this way he will identified as a buyer in the database of Central Power Monitor. A new window will appear asking him to enter the maximum power he will consume in the coming month ($BP_{\text{max i}}$). Figure 5.5 shows the Consumer Parameters Window. All the calculation of bills and penalties will be performed according to the criteria set by buyer.

Finally Step 3 of the contract formation involves pressing the Set Parameters button. This will allow the Individual Data Monitor Workstation to send all the entered information to Central Power Monitor which will be saved in the database Power Agreement Database.

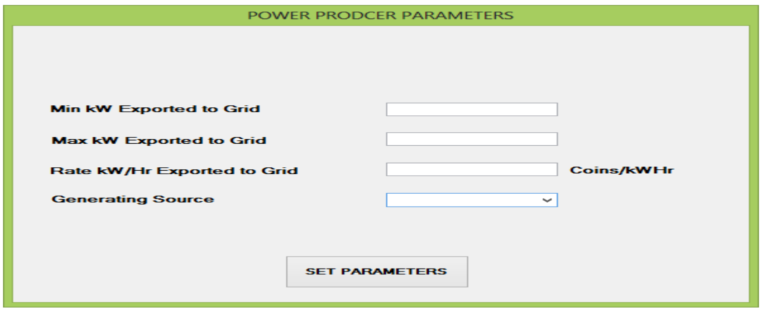


Figure 5.4: Producer Parameters

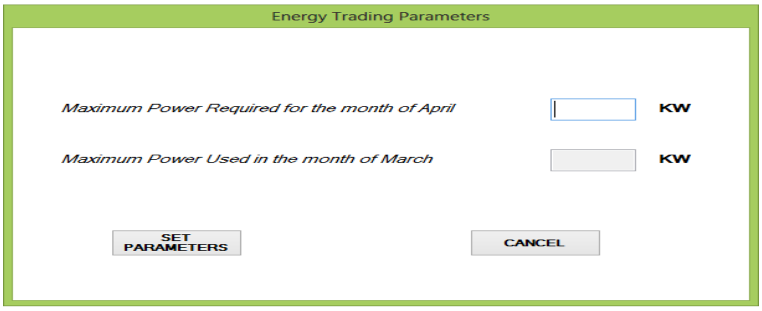


Figure 5.5: Consumer Parameters

5.5 AGREEMENT CREATION

Once all the houses on the micro grid have completed the previously define tasks of selecting their role and have entered their parameters, the Individual Data Monitor Workstations sent this information to the Central Power Monitor over the Local Area Network. The Central Power Monitor receives this information and saves it in the Power Agreement database along with House ID and name of the month. This information will then become the foundation of all the power transactions that take place between buyers and sellers. The Consumer house has to buy power from the Producer House on the micro grid at the rate set by the Producer House. The power producer is required to generated and export at any available time the minimum power agreed in the contract.

An important part of the contract is if the Central Power Monitor generates a power raise command to a particular power seller due any requirement, the seller house must increase its surplus power export up to maximum value defined in the contract. It is also a part of the contract that maximum available power to buyers at any time will be equal to the sum of maximum surplus power available from sellers divided by the number of buyers on the micro grid. Any additional power requirement for the buyers shall be fulfilled from the national grid at the rate of national grid.

The Central Power Monitor uses the information from Power Agreement database to calculate dynamic power rates, bills for buyers, payments for sellers and penalties. Using the same information the Central Power Monitor also performs the load sharing functions to change the power output of the sellers. This database also contains all the previous month contract information which can be viewed to check the past history. At the end of the month, the Central Power Monitor calculate bills which are based on the minimum and maximum power set the by producers and for consumers the maximum available power calculated. At the start of a new month, the Central Power Monitor will generate a request to all the houses for a new agreement creation. Figure 5.6 shows the information available in Power Agreement database.

ID	MONTH_AGR	A_TYPE	A_MAX_PWR_GEN	A_MIN_PWR_GEN	A_PWR_RATE	A_CONS_MAX_PWR	B_TYPE	B_MAX_PWR_GEN	B_MIN_PWR_GEN	B_PWR_RATE	B_CONS_MAX_PWR	C_TYPE	C_MAX_PWR_GEN	C_MIN_PWR_GEN	C_PWR_RATE	C_CONS_MAX_PWR	D_TYPE	D_MAX_PWR_GEN	D_MIN_PWR_GEN	D_PWR_RATE	D_CONS_MAX_PWR
1	August	Producer	60	50	10		Producer	120	150	15		Consumer	0	0	0		Consumer	0	0	0	
2	October	Consumer	0	0	0	35	Producer	16	15	10	0	Consumer	0	0	0	25	Producer	12	12	10	0

Figure 5.6: Power Agreement Database

5.6 POWER TRANSFER

After the completion and finalization of power agreement contract between sellers and buyers the Central Power Monitor gives the permission to exchange power between houses and micro grid. The Central Power Monitor calculates the maximum available power from the available sellers, the power available in power pool, current power being used by all the buyers.

Let S_i denote the i^{th} seller and B_j stands for the j^{th} buyer in the micro grid. N is the total number of sellers and M is the total number of buyers. Assume that P_i is the current power produced by S_i and Q_j is the current power consumed by B_j. The Central Power Monitor starts its operation by first calculating the maximum total available power (P_{max}) in micro grid which is available from surplus power producing houses. If any seller suddenly disconnects from the micro grid, its maximum available power is subtracted from the total available maximum power (P_{max}). Equation 5.6.1 represents the calculation for P_{max}.

The Central Power Monitor also calculates the total power being currently consumed by the buyers in the micro grid (Q_{curr}) by adding the current power consumption of buyers. Equation 5.6.2 represents this calculation. This helps to keep a track of surplus power available in the power pool. This pool power (P_{pool}) is calculated by subtracting the maximum available power (P_{max}) from the current consumption of the buyers (Q_{curr}). Pool Power is important because this allows the Central Power Monitor to continuously monitor the current loading of the buyers and calculate any excess power being consumed from the main grid.

If at any time the power consumption of the micro grid increases more than the maximum available power from the buyers, the excess power is utilized from the national grid. This is realized when the pool power either becomes equal or less than zero. The Central Power Monitor also keeps a track of power flow from the national gird to the micro grid and will charge this additional power in the bill or the payment of the houses which has consumed it in the form of a penalty.

Following are the Calculations performed by the Central Power Monitor to calculate the Current Power Export of the buyers:

$$P_{curr} = \sum(P_i) \qquad i \in N \tag{5.6.1}$$

And the total current power consumed by buyers is:

$$Q_{curr} = \sum(Q_j) \qquad j \in M \tag{5.6.2}$$

The maximum power available by sellers is given as:

$$P_{max} = \sum(G_{maxi} \times S_i) \qquad i \in N \tag{5.6.3}$$

where,
S_i is equal to 0 when seller is disconnected from the system.

The available power in pool is given as:

$$P_{pool} = P_{max} - Q_{curr} \tag{5.6.4}$$

These are some of the basic calculations which are performed by the Central Power Monitor to calculate some of the more complicated calculations for the power transactions occurring at micro grid. These complex calculations involve such as the calculation of current energy rate for the buyers, bills for buyers and payments for sellers respectively, any additional power consumed by main grid and which buyer has utilized this additional power.

Since no power rate agreement is made between the buyers and sellers as in other Peer to Peer projects, this model employs a method of Dynamic Rate Calculation. The Central Power Monitor calculates the current energy rate based on current power generation. The Central Power Monitor also has a Load Sharing Scheme to minimize the power rate and efficiently use the power source of seller. It changes the load as per day light hours by changing power output of solar powered sources and fuel driven generator sources. The Central Power Monitor also imposes penalties on any user who does not comply with the monthly contract. These penalties are added in the final bill calculation as a separate entry.

At the end of the month the Central Power Monitor will calculate power bills for buyers and payments for sellers. Using a private blockchain network and specially designed cryptocurrency for this project, called Power Coins, buyers can pay for their bills and sellers receive their payments.

5.7 DYNAMIC RATE CALCULATION

The establishment of contracts between buyers and sellers was the first step towards Peer to Peer Energy Trading System. Once the contract has been established, the Central Power Monitor initiates the power exchange between buyers and sellers on the micro grid. Meanwhile the Central Power Monitor performs some calculations as explained in the previous section. This Peer to Peer Energy Trading uses a dynamic method of bills calculations for the buyers. The rate of power purchased is not a fixed value but depends on the some continuously changing variables such as the surplus power exported by the sellers.

Meanwhile the transaction of power is being taking place between the buyers and sellers of the micro grid, the Central Power Monitor continuously calculates the real time rate of energy in the background. This rate of energy is used by the Central Power Monitor to calculate the bills for the buyers. The algorithm used for the calculation of real time rate of energy is called Dynamic Rate Calculation. It is based on current surplus power generation of the sellers. The Central Power Monitor uses this algorithm and the information about the individual surplus power generated (P_i) by the sellers along with the rate of energy (SR_i) set by sellers which were entered during the formation of initial monthly contracts. The real time rate of energy calculated by Central Power Monitor using the Dynamic Rate Calculation Algorithm is the sum of current surplus power produced by the seller houses (P_i) multiplied by their power rate (SR_i) divided by the total surplus power produced by all the seller houses on the micro grid (P_{curr}). Equation 5.7.1 gives the calculation for the current rate of energy being generated:

$$SR_{curr} = \sum(P_i \times SR_i)/P_{curr} \qquad i \in N \tag{5.7.1}$$

As it can be observed from the above equation the Dynamic Rate Calculation algorithm is largely dependent upon the current surplus power generated by the sellers of the micro grid. Therefor it is can be easily seen that a seller who is producing the most power or is providing a larger capacity of surplus energy to the micro grid will certainly have the highest influence on the real time rate of energy for the buyers. The Central Power Monitor will not allow the rate of power to rise too much such that the energy bought by buyers becomes more expensive than the supply of national grid.

In order to keep the rate as low as possible and make this Peer to Peer Energy Trading System more economical, the Central Power Monitor has a Load Sharing algorithm. The idea of Load Sharing Scheme is to control the rate of energy, by changing the power output of the sellers as per time of the day. The Central Power Monitor shall increase the surplus power on solar powered sellers during the day time and decrease power on fuel driven generator power sellers. This helps in reduction of rate of energy significantly.

By using a dynamic power rate, the consumers have to pay bills based on the amount of power produced by generating houses. The power produced may vary from time to time hence the rate will also vary.

5.7.1 CALCULATING MAIN GRID POWER

A feature of this Peer to Peer to Energy Trading System architecture is that the micro grid is connected to the main national grid. The micro grid power sources of sellers are synchronized with the main grid, i.e. their voltage and frequency matches. This scheme allows the micro grid to receive power from the national grid in case if the sellers of the micro grid cannot fulfill the energy requirement of the buyers. For example, if the power requirement of buyers exceeds the power produced by the sellers, the micro grid will accept power from the main grid to fulfill this deficit power. The power from the main grid is calculated by the Central Power Monitor by subtracting the total current power consumed by the buyers (Q_{curr}) of the micro grid from the total surplus power generated by the sellers (P_{curr}) of the micro grid. If the result is positive, this means that buyers are utilizing more energy than the available power from the sellers. Equation 5.7.2 gives additional power calculation:

$$P_{maingrid} = Q_{curr} - P_{curr} \tag{5.7.2}$$

The next job of the Central Power Monitor is to find out the reason behind this extra power is being used from the main grid. The Central Power Monitor will penalize the user responsible for the power used from the national gird. First the Central Power Monitor will try to minimize this power utilized from the main grid. This is because the micro grid should be able to fulfill its own power requirement and keep the power rate as minimum as possible. As per the calculation of the Central Power Monitor, if power is still available in power pool (P_{pool}) and extra energy is also being accepted from main grid ($P_{maingrid}$) the Central Power Monitor will make its first priority to find out which sellers (S_i) are operating under the maximum power ($P_i < G_{maxi}$) they have defined in the contract. The Central Power Monitor would generates a power raise command to all the sellers on the micro grid to increase their power. This command will be sent to Individual Data Monitor Workstation which will then send command to the generator power controller.

The power raise command from the Central Power Monitor will continue until the power from main grid becomes zero, i.e. no more power is being utilized from the national grid, or the pool power of the sellers becomes zero. The pool power can become zero in only two scenarios. In the first scenario, we assume that pool power has become zero and the sellers are operating at their maximum capacity. The Central Power Monitor then must find out which buyers in the micro grid are using this additional power from main grid.

Algorithm for Case 1 is given as:

$$\begin{gathered} If(P_{pool} <= 0 \; AND \; P_{maingrid} > 0) \quad then \quad \{ \\ For(k = 0; k <= M; k++) \qquad \{ \\ If(Q_j > BP_{maxj}) \quad then \quad \{ \\ Buyer(0, k) = Q_j - BP_{maxj} \\ Buyer(1, k) = B_j \quad \}\}\} \end{gathered} \tag{5.7.3}$$

The above mentioned algorithm for Case 1 defines that each buyer has already set its maximum power consumption in the contract (BP_{maxj}) at the start of month. These buyers are billed as per rate of main grid. When the pool power becomes zero and power from main grid is still positive, the algorithm finds out which buyers are responsible for it. The algorithm will compare the power consumption of each buyer (Q_j) to the maximum power (BP_{maxj}) that has been defined by the buyers. All buyers who are consuming more power than what has been allotted to them, their identity (B_j) and excess power consumed ($Q_j - BP_{maxj}$) are stored in an array (Buyer(x,x)). This information is stored in the database and retrieved later by the Central Power Monitor at the time of billing. When bills are calculated for he buyers, all the buyers which have utilized excess power are penalized at the rate of main grid for the excess power they have consumed.

Second scenario when pool power becomes zero and the power of main grid is being utilized by the micro grid, occurs when the Central Power Monitor sends a power increase command to all the sellers on the micro grid but due to some reason that seller could not increase its power export to the micro grid, while still operating under the maximum capacity, due to some issue in its generation. The Central Power Monitor will find out the sellers which could not increase their output. In this case the power utilized from main grid will be charged to those sellers which could not increase their generation at the rate of national gird. This penalized amount will be deducted from the payments made at the end of the month. Algorithm for Case 2 is given as:

$$\begin{gathered} If(P_{pool} > 0\ AND\ P_{maingrid} > 0) \quad then \quad \{ \\ For(k = 0; k <= N; k++) \qquad \{ \\ If(P_i < G_{maxi}\ AND\ Comm = pwr_{inc}) \quad then \quad \{ \\ DP_i = P_i - P_{maingrid}/N \\ Seller(0, k) = DP_i \\ Seller(1, k) = S_i \quad \}\}\} \end{gathered} \tag{5.7.4}$$

The Central Power Monitor uses the above algorithm to find the culprit sellers for not providing enough power output resulting in power being used from main grid. The algorithm compares the surplus power output of each seller (P_i) to the maximum power (G_{maxi}) they can provide to the micro grid. The algorithm also checks if a power raise command is given to the sellers ($Comm = pwr_{inc}$). If a seller is given the power raise command and is operating under maximum power, all such identity of sellers (S_i) and deficit power (DP_i) are stored in an array (Seller(x,x)). The deficit power is calculated by dividing the power of main grid by number of sellers which are not increasing power. The result is then subtracted by the current power output of these sellers. These sellers are penalized as per rate of main grid for the deficit power they are not providing to the micro grid.

5.8 PER MINUTE BASED BILL CALCULATION

Another very interesting feature of this Peer to Peer Energy System design is to calculate bills very accurately and as close as possible to the true value. In this case buyers feel they are not being overcharged and system is fair in charging only for the amount of energy they actually utilized. The Central Power Monitor uses a Dynamic Power Rate calculation method to calculate power rate. Since this power rate is not a fixed value and continuously changing because of varying surplus power delivered by sellers, energy bills for buyers simply cannot be calculated at the end of month by using total energy utilized by buyers and a fixed power rate. The Central Power Monitor is storing all the power transactions in the database at the sample rate of one data recording per minute. Since power does not change much within a minute that is why one-minute record time is selected. Using the same principle Central Power Monitor uses per minute based bill calculation method. Moreover, the penalties imposed on the sellers and buyers must also be a part of the bill.

The Central Power Monitor calculates the bills for the buyers and payments for the sellers very accurately using a per minute basis calculation method. All these one minute bills are stored in the database with ID of each buyer. At the end of the month when it is time to present bills, the Central Power Monitor sums all the one minute bills to calculate monthly bills. Bills are only calculated for the buyers including any additional power they have utilized from the main grid. The following equation is implemented inside Central Power Monitor to calculate per minute energy consumed by buyers:

$$Diff_{Ej0} = E_{j1} - E_{j0} \tag{5.8.1}$$

Let (E_{j0}) be the total energy consumed by a buyer (B_j) at time (T_0) and (E_{j1}) be the total energy consumed at time (T_1) (one minute later). The difference energy is calculated to find out the energy consumed within that one minute by a particular buyer. The current rate of energy is then multiplied with this difference energy ($Diff_{Ej0}$) to calculate the bill for that particular minute for each buyer. These one-minute bills are then stored in the database for time (T_0). Similarly, bills are calculated on per minute basis for the entire month. These are summed at end of the month which is given as:

$$B_{jBill} = \sum (Diff_{Ej0} \times SR_{curr}) \tag{5.8.2}$$

The payments to sellers are not calculated using the per minute method. Rather a much simpler approach is used. Since the payments for the sellers does not depend upon any continues changing power rate, the payment is calculated by simply multiplying the rate set by the seller (SR_i), in the contract for the month, and the total surplus energy exported by seller to the grid during whole month. Penalties, as defined previously, are subtracted from the payments. These are shown in a separate heading in the Individual Data House Monitor. All this information is communicated to respective users at the end of month.

5.8.1 CALCULATING PENALTIES

This Peer to Peer Energy Trading System is primarily based on the power agreement between the sellers and buyers of the micro grid. It is a part of the contract that users will pay the penalties which are imposed on them when they do not comply with the conditions of the contract of the current month. The Central Power Monitor has the information for the power transactions that are going about in the micro grid. The inherent programming of the Central Power Monitor is to make sure that power transactions occur within the rules as defined in the contract.

Different penalties are imposed on the sellers and buyers. For the sellers two different types of penalties are defined in the contract. They will be imposed by the Central Power Monitor and will be deducted from the end of payments to be made. These penalties are calculated in terms of power and will be charged at the rate of main grid. The first type of penalty will be imposed by the Central Power Monitor on a seller, if a seller is producing surplus power for the micro grid which less than the minimum power ($G_{min\ i}$) he has agreed in the contract of the current month. Each seller is bound to provide the minimum power he has agreed in the contract when parameters are entered during the initial phase. The algorithm for this penalty is given as:

$$\begin{gathered} If(P_i < G_{mini}) \quad then \quad \{ \\ P_{deffi} = G_{mini} - P_i \\ S_{iPenalty1} = P_{deffi} \times rate_{main} \quad \} \end{gathered} \tag{5.8.3}$$

The above defined algorithm states that the Central Power Monitor will continuously check the surplus power output of all the sellers on the micro grid. If there is any seller whose surplus power output to the micro grid falls below the minimum power defined, the deficit power ($P_{deff\ i}$) will be calculated. This deficit power is calculated by subtracting the current power output of the seller from the minimum power defined by the seller. This difference power is used to calculate the penalty which will be imposed at the rate of main grid ($rate_{main}$) by the Central Power Monitor.

The second type of penalty that could be imposed on a seller by the Central Power Monitor is that if any particular seller does not increase its surplus power output, while operating under the maximum power defined in the contract, when the power of main grid is being utilized in the micro grid and the Central Power Monitor has given a power raise command. The algorithm for this type of penalty was defined in the previous section in algorithm 5.7.4. The Central Power Monitor will impose this penalty at rate of main grid.

The Central Power Monitor only imposes one type of penalty on the buyers of the micro grid. Whenever the power of main grid is being utilized in the micro grid and all the sellers are operating at maximum capacity, the Central Power Monitor will look for those buyers which are using more power than what has been allotted for them. Complete algorithm for this type of penalty was explained in previous section. The Central Power Monitor will charge these buyers at the rate of national grid.

5.9 END OF MONTH BILL CALCULATION

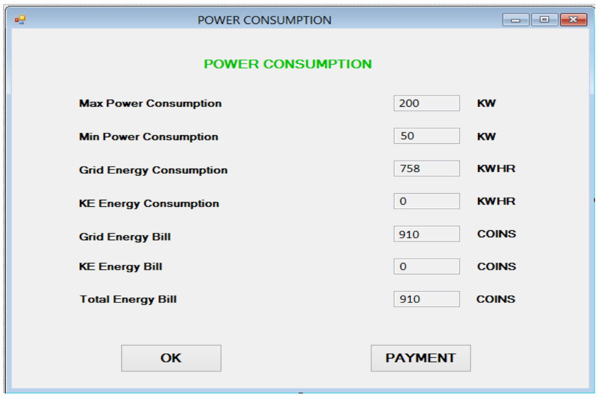
The Central Power Monitor records the per minute bill data, penalties, rate of power and other data continuously in the database. At the end of each month, Central Power Monitor will calculate the bill for each buyers and payments for each seller. The bills for the buyers are calculated by adding all the per minute bills calculated. Penalties are also calculated separately. For the sellers, the payments are simply calculated by the Central Power Monitor by using the total energy exported by the power rate set by the sellers. Penalties are calculated separately as described in the previous section.

The Central Power Monitor sends the information about the bills, payments and penalties to each Individual Data Monitor workstations separately. All this calculation is automatically performed and sent privately to each house, not broadcasted. This maintains privacy among the users on the micro grid. When this information reaches the Individual Data Monitor workstations, a separate window appears for the users. This window contains the complete detail about their power transaction history.

5.10 MONTHLY BILL SUMMARY CREATION

After the Central Power Monitor has performed its task of calculating bills and payments for each buyer and seller respectively on the micro grid, new window will pop-ups on the main window of each Individual House Data Monitor Workstation. This new window is called the Monthly Bill / Payment Summary Screen. It shows the monthly power consumption or surplus power production summary for each individual buyer and seller respectively. In case of the buyer, the report will show the maximum power that has been consumed, the minimum power utilized, the total energy that has been consumed from micro grid excluding energy from main grid, the total energy consumed from the national grid (which are the penalties), energy bill of national grid in terms of energy coins (at the rate of national grid), energy bill of micro grid in terms of energy coins (at the dynamic rate) and the total energy bill, which is the sum of micro grid bill and national grid bill.

For a seller on the micro grid, the same report will show different information which is specific for the seller. The report represents the maximum surplus power produced by the seller, the minimum surplus power exported to micro grid, the total energy that has been exported to the micro grid, the total energy that the seller consumed from national grid (which are the penalties), the bill of national grid in terms of energy coins (at the rate of national grid), the payment of micro grid to be received by the seller in terms of energy coins and the total payment which is the result after subtracting the penalties. Figure **??** shows the report for consumer and producer.



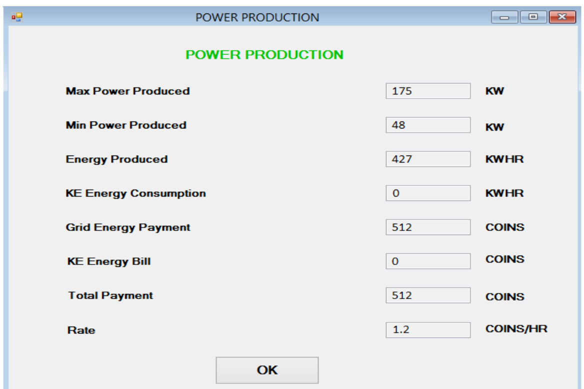


Figure 5.7: Monthly Bill Report

5.11 MONTHLY BILL SUMMARY CREATION

Once the bills have been calculated by the Central Power Monitor and the information is communicated to the Sellers and Buyers in the network, a private blockchain based payment process begins. All the sellers, buyers and Central Power Monitor are also connected together in a private blockchain network. Each user has a Power Coin Wallet with cryptocurrency Power Coin in it. When the bills summary is presented to the user, the buyer presses the button Payment button to start the payment process. The transfer of Power Coins from one user to another user takes place as per the energy transferred from the sellers to buyers. More of this process will be discussed in detail in chapter seven.

Chapter 6

LOAD SHARING OF POWER SOURCES

6.1 SCOPE AND OBJECTIVE OF THE CHAPTER

This chapter describes in detail one of the most important feature of this Peer to Peer Energy Trading System. The main purpose of the Peer to Peer Energy Trading system is to design a micro grid energy trading system which is self-sufficient, reliable and can provide electricity at a cheaper rate than the national grid. Moreover, the system should also be environmental friendly, as to not cause any harm to atmosphere of the earth. To do this, a system must utilize its renewable power generation sources to the maximum potential.

6.2 WHAT IS LOAD SHARING?

The load sharing feature designed for this Peer to Peer Energy Trading System is to increase the overall efficiency of the system and make it more economical. The load sharing feature allows the Central Power Monitor with the authority to alter the power outputs of the sellers so that load can be shared among the sources such that the rate of power becomes as low as possible. The micro grid for this thesis has sellers which produce power output based on both solar powered inverters and diesel generators as their power generation. This options of choosing the power generation source is done by sellers at time of contract formation at the beginning of the month. The Central Power Monitor uses this information to share load among the sellers. The algorithm behind the load sharing scheme is called the Day Time Algorithm which uses the time of the day to shift load between solar powered sources and the diesel driven generators.

6.3 WHY LOAD SHARING IS REQUIRED?

The renewable power generation sources utilize natural sources to generate power such as solar or wind. Unlike the fuel driven generators, these renewable power generation sources does not produce any waste gases which when released into atmosphere may cause damage to environment of earth. Moreover some renewable power sources also do not require frequent maintenance due to no moving parts required.

However, due to the high reliability of renewable generation power sources on the nature, their power output is usually not fixed or cannot fulfill a power demand of high capacity. For example, the output of solar powered invertor depends upon the time of the day and rays of sun falling on the solar cell. As time of day progresses, the output of invertor decreases as sun starts to set. Also during a cloudy season, the effectiveness of solar invertor may also drop significantly. The same case is also with wind turbine. They must be installed in a high velocity wind area. If the wind velocity decreases, the output of the wind generators also decreases. If a sudden demand of load arises, these sources take a larger time to adjust their output.

Because of these problems, renewable power generation source cannot be relied alone for the fulfillment of power load requirements. These renewable sources must operate in parallel with non-renewable power sources such as fuel driven generators to share the load. This scheme where two or more power generation source operate together to fulfill power requirement is called load sharing. During a stable operation, i.e. fixed power requirement, the renewable source can share most of the load. During a dynamic operation, i.e. load requirement is varying too much; the fuel driven generator can handle the transient operation and sudden high load demand.

6.4 WORKING OF LOAD SHARING ALGORITHM

The Day Time Algorithm employed in the Central Power Monitor has built in day light table. This table contains the start time and end time in which the sunlight is sufficient enough for the solar invertors to operate at maximum efficiency. These times are stored in the table with respect to the names of the month. Table 6.1 shows theses times against the months. For example during the month of June we can see from the table that the day light is effectively available for more than 13 hours in a day, making it the most effective month to use solar power. Since this is summer time and people tend to use more air-conditioning and refrigeration, the overall load also increases. Therefore using solar powered inverters would be an intelligent option to fulfill the power requirement. From the Table 6.1 it can be observed that the minimum day light is available in the month of December as compared to the whole year. The average time the daylight is available during the entire month is around 10 hours. Since during winters, the overall power demand is less than the summer power demand, the decreased effectiveness of solar inverters would not affect the overall power rate of the system.

Table 6.1: Day Light Times

Month	Start Time	End Time
January	07:30	17:45
February	07:20	18:10
March	07:00	18:30
April	06:45	18:45
May	06:15	19:05
June	05:50	19:20
July	06:05	19:10
August	06:15	18:50
September	06:25	18:20
October	06:40	17:50
November	07:00	17:45
December	07:15	17:40

The Day Time algorithm uses the data in the table 6.1 and compares the information with the current Windows system time and month of the Central Power Monitor Workstation. In this way the algorithm will determine if the current time is either day or night as per the table reference values. This allows Central Power Monitor to determine if the daylight still exits and is suitable to use solar powered inverters efficiently. Next the algorithm will calculate for each seller in the micro grid a ratio ($Load_i$) of the maximum power (G_{max-i}), that seller can provide to the system, with the current surplus power generation (P_i). This ratio gives information about the loading factor of the seller and how much more load can be added on it. After this the algorithm will check the generation type of the sellers, i.e. solar inverters or fuel driven generators.

Using the information about the generation type and the ratio ($Load_i$), the Central Power Monitor changes the surplus power output of sellers. If a seller has a solar powered source and it is day time as per the table, the Central Power Monitor will determine using the ratio ($Load_i$) to give a command for increasing the power and vice versa if its night time. Similarly if a seller has fuel driven generator and it is day time, the ratio will be used by the Central Power Monitor to decrease the power of the seller and vice versa if it is night time. Let (P_{solar}) and ($P_{generator}$) be a set of all solar powered sources and generators respectively in micro grid i.e. $P_{solar} = \{ i \in N \mid S_i \in solar \}$ and $P_{generator} = \{ i \in N \mid S_i \in generator \}$. The algorithm to adjust power is given as:

$$If(S_i \in P_{Solar}\ AND\ time = day\ AND\ P_{gen} \neq min\ AND\ Load_i < 0.9) \quad then \quad \{ \\ S_i = power_{inc} \quad \} \tag{6.4.1}$$

$$If(S_i \in P_{gen}\ AND\ time = day\ AND\ P_{solar} \neq min\ AND\ Load_i > 0.1) \quad then \quad \{ \\ S_i = power_{dec} \quad \} \tag{6.4.2}$$

The above mentioned Day Time Algorithm is implemented in the Central Power Monitor. It checks that if there is a seller having a solar powered generation source which is operating under 90 percent of its maximum capacity while it is day time in which daylight can be utilized effectively, and most importantly that there is one or more sellers having fuel driven generator sources ($P_{generator}$) which are operating at more than minimum capacity of generation(i.e. all ($Load_i$) <= 0.1), the Central Power Monitor will give a power raise command to that seller to increase its surplus power generation to the micro grid. Similarly if there is a seller having a fuel driven generator as power source and it is day time while it is operating at more than minimum capacity of generation, and also that there is any one or more sellers with solar powered sources (P_{solar}) which are not operating at maximum (i.e. all ($Load_i$) >= 0.9), the Central Power Monitor will give command to that seller to decrease its surplus power output to the micro grid. This power raise and lower command will continue to each solar powered sellers and fuel driven generator sellers respectively, until the load on each solar seller becomes equal or more than 90 percent capacity or the load on all generator power sellers decreases to less than or equal to 10 percent of the capacity.

During the night the algorithm performs a vice versa function to raise power on all fuel driven generator sources and decrease power on solar powered sources.

In this way Central Power Monitor shifts power from diesel powered sellers to solar powered sellers during the day and vice versa during night. Load sharing algorithm helps in making this P2P overall economical as more power is used during the day. It also gives an incentive to fuel driven generating sources to participate as they share more percentage of load during night.

Chapter 7

BLOCKCHAIN BASED PAYMENT

7.1 SCOPE AND OBJECTIVE OF THE CHAPTER

The main goal of this chapter is to explain in detail the working of payment process in terms on Power Coins from buyers to sellers. This chapter introduces the concept of blockchain, its working principle, the advantages of using this methodology for payment and how this technology of blockchain is adopted for this project. Although there are various blockchain based platform available online, like Etherium, which can be used for this project, a separate independent blockchain platform was created and embedded into the project which makes this research more interesting.

7.2 WHAT IS BLOCKCHAIN ?

Blockchain can be described as a data structure that holds transactional records and while ensuring security, transparency, and decentralization. Blockchain is the backbone Technology of Digital CryptoCurrency BitCoin. The blockchain is a distributed database of records of all transactions or digital event that have been executed and shared among participating parties. Each transaction verified by the majority of participants of the system. It contains every single record of each transaction. A blockchain is a distributed ledger that is completely open to any and everyone on the network. Once information is stored on a blockchain, it is extremely difficult to change or alter it. BitCoin is the most popular cryptocurrency an example of the blockchain.

Each transaction on a blockchain is secured with a digital signature that proves its authenticity. Due to the use of encryption and digital signatures, the data stored on the blockchain is tamper-proof and cannot be changed.

This revolutionary technology is impacting different industries miraculously and was introduced in the markets with its very first modern application Bitcoin. Bitcoin is nothing but a form of digital currency (cryptocurrency) which can be used in the place of fiat money for trading. Figure 7.1 summarizes the advantages of blockchain technology.

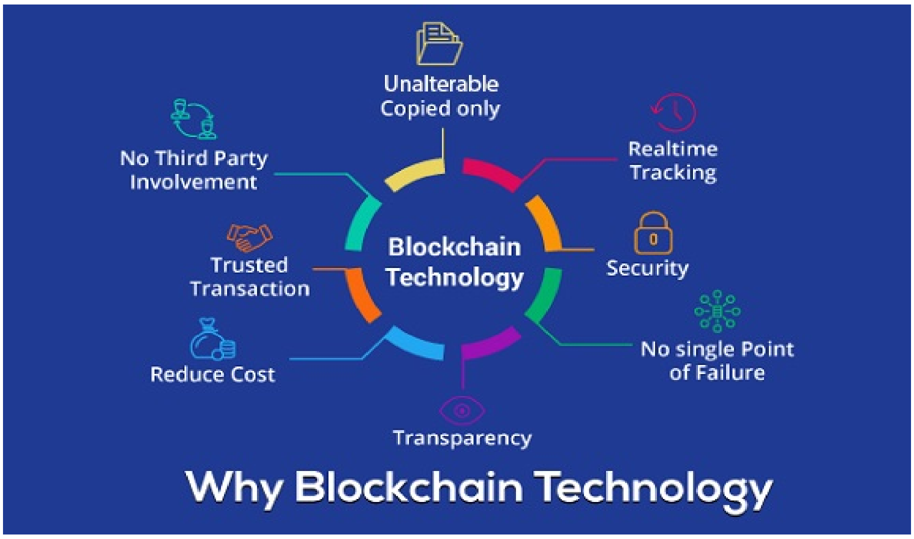


Figure 7.1: Advantages of Blockchain

7.3 HOW BLOCKCHAINS WORK ?

Each block in the BlockChain network consists of a hash pointer which acts as a reference to the previous block. It also contains the transaction data, a timestamp and a hash value. Each block includes the hash of the previous block in the Blockchain, linking the two as shown in Figure 7.2. Blockchains are very much resistant to modification of the data. Since the hash calculated for each block depends upon the data inside the block, by changing the block data hash value also changes. Since the next block contains hash of the previous block, this previous hash value must be changed. This leads to the modification of the entire chain which is theoretically not possible. A Blockchain functions as an open and distributed ledger that can store transactions between different two parties in a verifiable and permanent method.

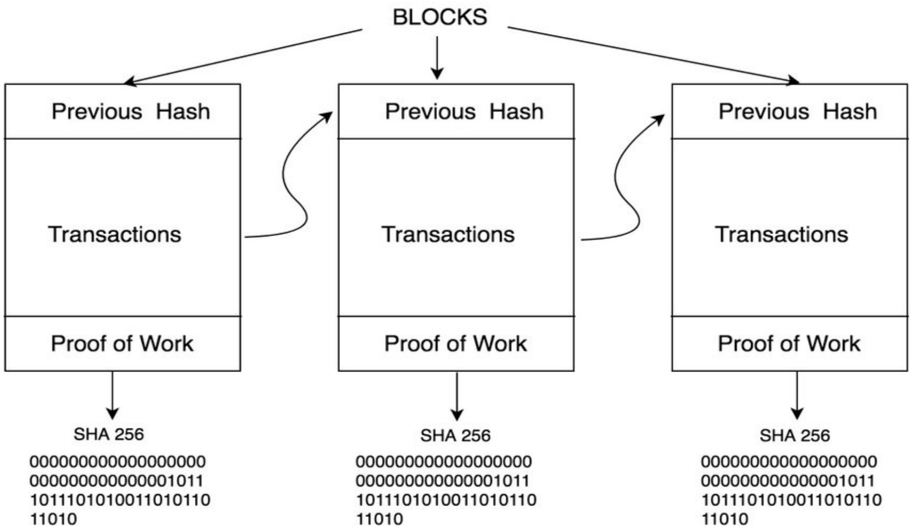


Figure 7.2: Blocks of Blockchain

As illustrated in Figure 7.3, a node that creates a transaction which is to be recorded in the blockchain network, it sends the transactions to all nodes within the blockchain network, i.e. the transaction is broadcasted. There are some specific nodes which are known as miners, collect this transactions try to solve a cryptographic puzzle named PoW (Proof of Work). The node that solves the puzzle first creates this new block and then broadcasts the block to all other nodes in the network. The nodes will only accept the block if all transactions in it are valid and then the block is connected to the previous block after block verification is completed.

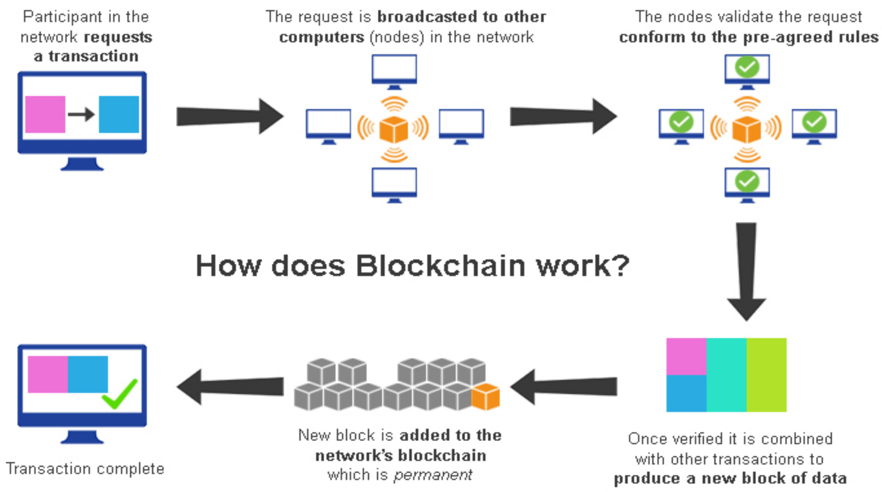


Figure 7.3: Working of Blockchain

There are two types of blockchain network: the public blockchain and the private blockchain. Public blockchain, allow new users to enter the network without any restrictions. On this type of network, all the transactions are verified and shared by all users on the network. Anyone can join the blockchain network, meaning that they can read, write, or participate with a public blockchain. Public blockchains are decentralised, no one has control over the network, and they are secure in that the data cannot be changed once validated on the blockchain.

On the contrary, the private blockchain allows only the designated participant nodes that can participate in reading, writing and consensus processes. In addition, specific nodes can be added or removed as required. Therefore, in a private blockchain network it is not fairly possible for any malicious nodes to enter the network. In private blockchains, the owner of the blockchain is a single entity or an enterprise which can override/delete commands on a blockchain if needed. That is why in its true sense it is not decentralized and hence can just be called a distributed ledger or database with cryptography to secure it.

7.4 PRIVATE BLOCKCHAIN NETWORK OF MICRO GRID

The microgrid of this thesis is a small-scale grid, which is constructed as a private blockchain network consisting of four houses and a Central Power Monitor. This means that besides the authorized nodes, no other user can enter the network and perform transactions. Each node in the network, including the Central Power Monitor, has the ability of creating blocks, i.e. they can perform financial transactions. Each node also acts as a miner for all the incoming data it receives from other nodes and outgoing information it sends to the network. The transactions are added to the block of the blockchain, which includes information about the payment which is to be transferred between the nodes. Then the node acts as a miner and works on searching a difficult PoW.

When the node is successful in finding PoW, the block is then added to the blockchain and the node will broadcasts this block to all the other nodes in the network. The other nodes will accept the block only if the transactions in it are valid. Once the validation process is complete, the transactions included in the block are never altered or modified.

7.5 THE PAYMENT PROCESS

Once the bills for the buyer nodes and payments for the seller nodes have been calculated by the Central Power Monitor, the information is communicated to the Sellers and Buyers in the network. After this using a private blockchain based payment process, the buyers pay sellers for the electricity they have utilized in the form Power Coins, a special cryptocurrency designed for this thesis. Each node has a Power Coin Wallet to store the cryptocurrency and only that node itself can access it. Following are steps associated with the payment process:

1. The Central Power Monitor communicates information about the bills and payments to each Buyer and Seller respectively, over the network. This information will not be broadcasted but sent to each user individually for privacy reasons. The Buyers validate this information and then proceed for payment.
2. As soon as the Bill information is received to the users, a new window pops up on the GUI Display of each Buyer displaying the amount of energy used by buyer from micro grid, national grid and the total amount which is to be paid for their consumption of power in terms of Power Coins.
3. This new window has the button Payment which allows user to proceed for payment. Once the user is satisfied with its bill, he presses the Payment Button on the GUI

window to which performs the transaction of Power Coins to the Central Power Monitor. The node generates a transaction block to pay the required Power Coins to the Central Power Monitor. The Block Data includes the sender ID, receiver ID and amount to be paid.

4. The Minor Node of Buyer determines if there is enough power coins available in the Energy Wallet of the user. If the amount is sufficient enough that payment can be made, the minor will generate a PoW using SH256 algorithm.

5. The Buyer Node will then broadcast this information about the block to all other nodes on the network and the information of the block will be updated in the Blockchain copies of all nodes. The block will be added to the Blockchain network.

6. The Central Power Monitor, along with all the other nodes, will receive this block. Since the block contains the receiver ID of Central Power Monitor, only the Central Power Monitor will validate the block by comparing the amount of Power Coin mentioned in the block with the amount to be paid in the bill.

7. If the block is confirmed by the Central Power Monitor to be valid, the amount of Power Coins as mentioned in the will be added in the Energy Wallet of the Central Power Monitor. The same amount will be deducted from the Energy Wallet of that particular Buyer.

8. The Central Power Monitor simultaneously will pay the Sellers if sufficient amount of Power Coins are available in its Energy Wallet, otherwise it will wait for buyers to process their payments and enough Power Coins are available so that payment to sellers can be executed.

9. If sufficient Power Coins are available in the Energy Wallet, the Central Power Monitor will generate a transaction block to pay the required Power Coins to Individual Sellers. The Block Data will include the sender ID, receiver ID and amount to be paid.

10. The Minor of Central Power Monitor will once again determine if enough power coins are available in the Energy Wallet. If the amount is sufficient it will generate PoW.

11. The Central Power Monitor will broadcast the information of the block to all other nodes and the information will be updated in the Blockchain.

12. The Seller node along with all other nodes will receive the block. It will validate the information inside the block by comparing the amount of Power Coin mentioned in the block and the actual amount that is required to be paid.

13. If the block is validated and confirmed by the seller to be correct, the required Power Coins will be added in the Energy Wallet of the Seller Node. The same amount will be subtracted from the Energy Wallet of the Central Power Monitor.

Once the bills are collected from all the Buyers and payments are made to all the Sellers by the Central Power Monitor, the Central Power Monitor will stop the payment process and create the contract of next month as per previously defined rules. This will continue the cycle of next month for Peer to Peer Energy trading process.

Chapter 8

OVERVIEW OF SOFTWARE AND ITS FEATURES

8.1 SCOPE AND OBJECTIVE OF THE CHAPTER

This section describes in detail about the software developed for this thesis. The software or the platform for Proposed Peer to Peer Energy Trading is developed using Visual Basic.Net. The Power Sharing record and Monthly contract is saved in a database is created using MS Access. Two separate software are created for Individual Data Monitor (Client) and Central Power Monitor (Server).

8.2 THE INDIVIDUAL DATA MONITOR

Individual Data Monitor collects data from the Arduino Based Bi-Directional Power Meter on serial port. The data is sent in a special packet with all the required data in it which includes value for voltage, current, active power, reactive power, etc. This data is decoded by the Individual Data Monitor and displayed on GUI. Using this data, the Individual Data Monitor also calculates the Total Energy consumed or supplied to micro grid using active power. The Clients and the Server are connected together using a single LAN network and are on same IP Layer. Each Client is assigned a unique static IP address and a House ID. The Clients and Server exchange data on LAN using TCP-IP Sockets.

The data of Each House is collected from their respective Bi-Directional Power

Meter is forwarded to Central Power Monitor by Individual Data Monitor. In exchange, the Central Power Monitor sends the respective monthly bill data to each house at the end of month. Figure 8.1 shows the GUI main page of Individual Data Monitor with its features.

The GUI of Individual Data Monitor displays all the required information which is important for a user to determine if the system is fully operational and healthy. The main screen shows the power generating source output active, reactive and apparent powers. The generator or invertor connection status with house load and its connection status with micro grid. The window also shows each phase voltage and current along with power factor and frequency. The most important parameter displayed by main window of Individual Data Monitor is the power and energy exchanged with grid. These values are of key importance as they are used for calculation of bills and penalties. A positive value will indicate power flowing from House to micro grid and a negative value will indicate power flowing from micro grid to house.

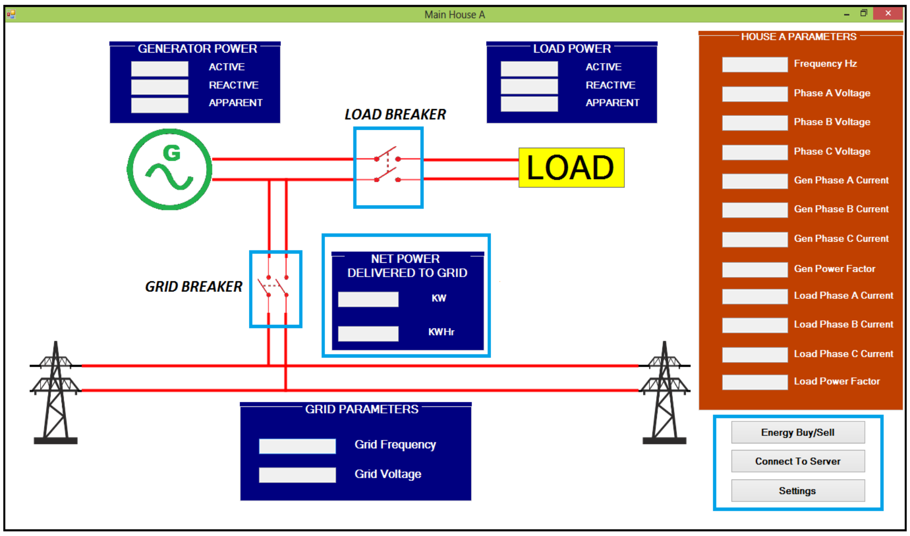


Figure 8.1: GUI for Individual Data Monitor

8.3 THE INDIVIDUAL DATA MONITOR

The Central Power Monitor polls each house to send its data. The data sent to Central Power Monitor is a single packet with all the required information. The data packed starts with House ID first and then subsequent values represent electrical parameters of the house such as voltage, current, power exchanged with grid etc. Each value is separated by commas, thus differentiating the values which they represent. The Central Power Monitor decodes this packet and displays the values also using it in its calculation. These values are also stored in the power database at the required field of each house.

Individual Data Monitor receives an Info command from Central Power Monitor at the start of every month. A new window pops up in Individual Data Monitor GUI asking user to enter their role (as a Consumer or Producer) and enter certain parameters as per their role. Once this activity is completed by all the users on micro grid, the role information of each user is sent to Central Power Monitor. The Central Power Monitor saves this information in a Power Agreement Database with the name of month. It also displays this information and uses it as a foundation of power transfer, bill calculation and penalties calculation.

When the load sharing function is active, the Central Power Monitor sends the Power Raise or Power Lower commands to the required Individual Data Monitors for increasing or decreasing their power output. The Individual Data Monitors sends this command to Arduino Based Bi-Directional Power Meter. The Power Meter relays this information to the Generator Controller (not in scope of this thesis) which then acts accordingly.

The Central Power Monitor is responsible for managing the entire P2P Energy Trading operation by collecting the required data from all the Individual Power Monitors and recording this data in a database. The Central Power Monitor records the data, performs power rate calculation, imposes penalties on users when they do not comply with contracts, creates and manages monthly contracts, perform load sharing function and most importantly has a GUI interface for displaying entire performance of micro grid. All these functions are performed autonomously by the Central Power Monitor without any human intervention involved in it. The GUI designed for Central Power Monitor has multiple windows for displaying different parameters of the micro grid. Following is the list of windows available in Central Power Monitor GUI:

1. The Main Window
2. Energy Agreement
3. Energy Trading Detail
4. Load Sharing

5. Trends

8.3.1 THE MAIN WINDOW

On starting the GUI of the Central Power Monitor, the first screen that is displayed is the Main Window. This screen displays the status of the micro grid and its users. The houses connected to the micro grid for power sharing are shown here. The real time status received from each house Individual Data Monitor Workstation is shown here which includes each houses breaker status connection with micro-grid, power generated or consumed by the houses (where positive power indicates power being delivered to micro grid and negative power indicates power being consumed from micro grid), load of the house, power and total energy exchanged with grid are displayed.

Since for this thesis, a test case of only four houses was developed to check the working of proposed Peer to Peer Energy Trading System, this window will only show four houses with their House ID (House A, House B, House C and House D). When more users will become part of this Energy Trading Network, their data can be displayed on the GUI. The required information for displaying is received from Individual House Data Monitor using TCP-IP. Figure 8.2 shows the main window. On the right side of the Main Window, several buttons are provided for changing the display windows to view other parameters of the micro grid.

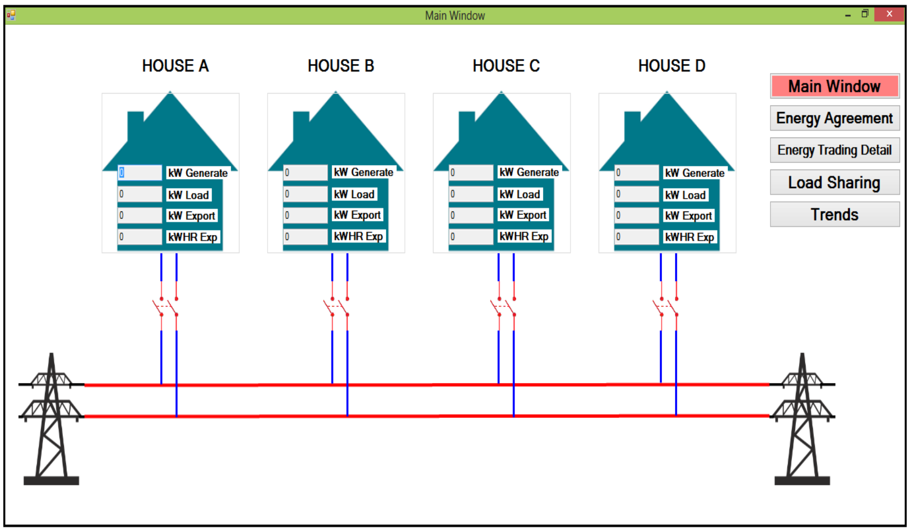


Figure 8.2: Main Window for Central Power Monitor

8.3.2 ENERGY AGREEMENT

The Central Power Monitor is responsible for creating monthly contracts for the users on the micro grid. The contract information for the current month is displayed in The Energy Agreement window. All the information displayed here is fetched from the database Power Agreement Database. The roles selected by all the four houses (Consumer or Producer) can be viewed in this screen. For a consumer this window shows the maximum power that consumer has been allotted to use from the micro grid. This value is equal to the total maximum power generated by producers divided by the number of consumers. Furthermore, this window also displays the total energy that a consumer has utilized from micro grid power sellers and the total energy consumed from main grid. Calculation for power utilized from main grid is explained in previous chapter.

For a power producing houses, this window displays the maximum and minimum power that the user has agreed to provide to the micro grid. If the power production decreases below the minimum power export agreed in contract, the Central Power Monitor imposes a penalty. The rate of energy supplied by sellers can also be seen here in terms of Coins/kWHr. This is the value agreed by producer in the creation of contract.

On the bottom of the window, the Total Maximum Power that can be generated is displayed. This value is the sum of the maximum power producing capacity of all the sellers on the micro grid. Moreover, the Total Power utilized by the consumers and net available power in pool is also shown. The Net Available Power is the difference of the Total Maximum Power and Total Power consumed. The current power rate is also displayed here which based on the current power generated by the producers and the rate set by sellers. This rate is used by Central Power Monitor for calculation of bills and payments for buyers and sellers respectively. The Power Rate of National grid is also displayed which is used for penalties calculation. Figure 8.3 shows the Energy Agreement screen.

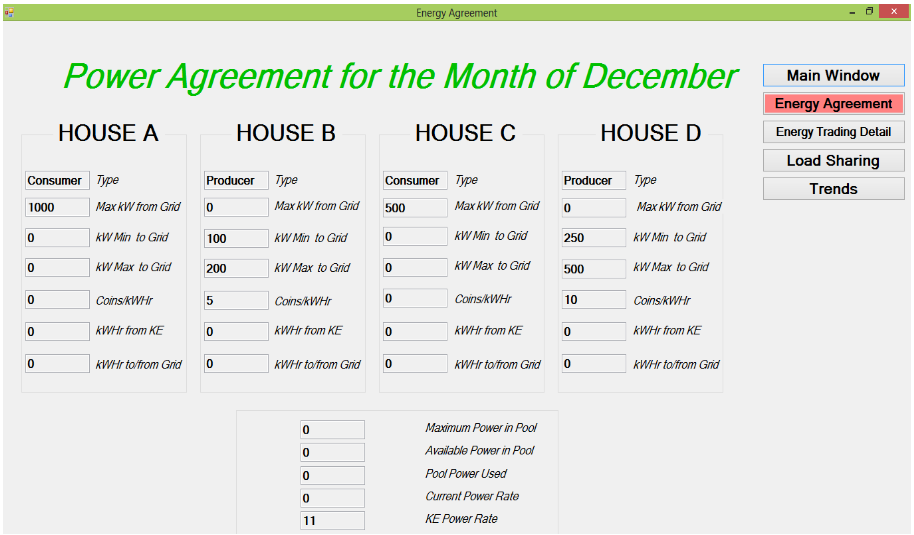


Figure 8.3: Energy Agreement Window

8.3.3 ENERGY TRADING DETAIL

The Energy Trading Detail window displays various parameters related to each individual house connected on the micro grid. Using the buttons on the bottom of this window, various parameters of each house can viewed. For each house some common parameters are displayed which include voltage, current frequency and power factor. But there are also some parameters which are only specific according to the role of the house.

For a consumer on the micro grid, this window shows the real time power consumed from producers and real time power consumed from the national grid. This distribution is done by the Central Power Monitor based on a rule that if a consumer utilizes more power than it has been allotted as maximum power, the excess power will be considered as utilized from the national grid. The excess power will be charged at the rate of national grid and will be added in the monthly bill of the consumer in a separate heading.

A house which has decided to act as a power seller, this window displays the real time power delivered to micro grid along with any excess power consumed by the producers from national grid. This excess power is calculated by the Central Power Monitor on the condition that if a producer produces power less than the minimum amount agreed in the monthly contract, than the difference amount is charged to producer, as a penalty, at the rate of national grid. Figure 8.4 shows the Energy Trading Detail window.

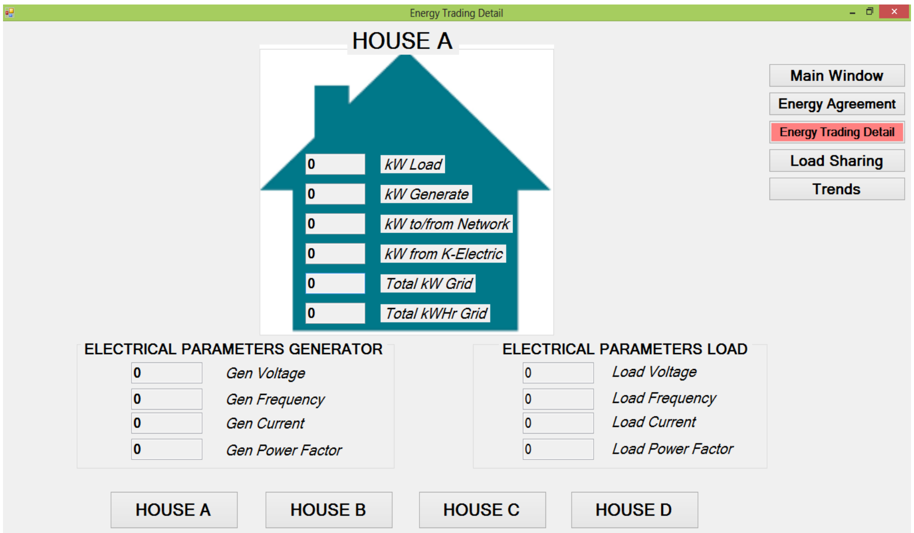


Figure 8.4: Energy Trading Detail Window

8.3.4 LOAD SHARING

The Load Sharing feature of this Peer to Peer Energy Trading was described in detail in Chapter 7 and the simulation results of this feature will be presented in Chapter 9. In this chapter only the graphical user interface of the Load Sharing window is explained.

The Load Sharing window displays the actual scenario of the houses undergoing power output changes when load sharing feature is turned on by the Central Power Monitor. The Load Sharing feature allows the Central Power Monitor to manipulate power output of sellers according to their power generating source, i.e. solar or fuel driven generator, and the current time of day. For a power consumer this window will only display the current power consumed by the House from the micro grid. It will also display the breaker status of the connection of house with micro grid.

For a power seller house, this window will display the current power generated by the house, the maximum and the minimum power capacity of the house that it can deliver to micro grid. Along with this information, this window also displays the type of power generating source of the seller, i.e. solar invertor or fuel driven generator, and the breaker status of the connection of house with the grid.

The algorithm behind the Load Sharing feature of this Peer to Peer Energy Trading System is called The Day-Time Algorithm. This algorithm is implemented in the Central Power Monitor. It uses the time of the day to determine if it is day time to use solar sources effectively or night time to utilize fuel driven generators. If it is day time, maximum load is shifted to the solar powered invertors and during the night most of the power requirement of the micro grid is fulfilled by the fuel driven generators. Figure 8.5 shows the load sharing window.

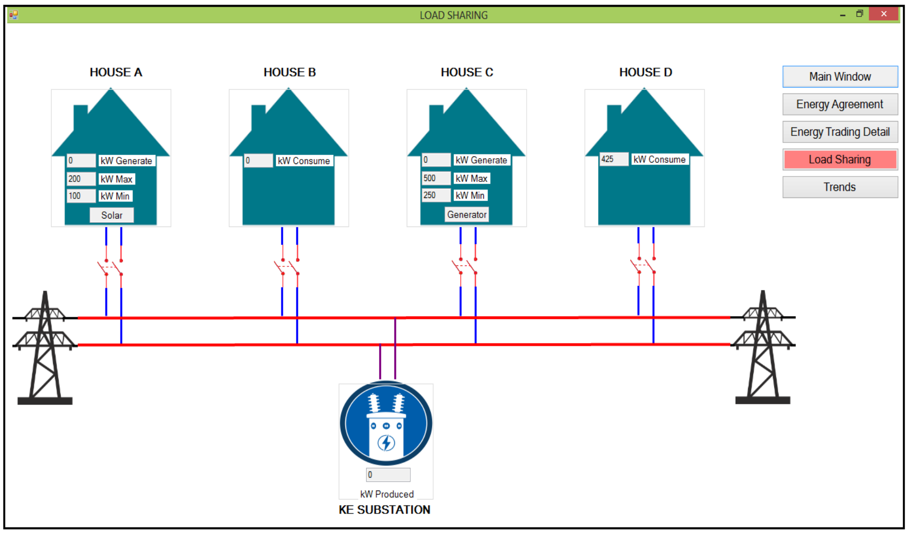


Figure 8.5: Load Sharing Window

8.3.5 TRENDS

For any electrical or control system, it is important for the users to see the historical or past values of power in order to make good decisions in the future. The graphical representation of the historical values provides more knowledge and insight of the past trends. This option to view past trends or the load profile of each house on micro grid is available in the Central Power Monitor GUI.

The Trends window allows the user to plot various graphs with desired start and end dates. The user can select start and end dates of the plot using the options provided. A calendar opens up when a user is selecting a date, allowing for easy selection of dates. This window allows a user to plot two graphs at with same reference dates. This window is very helpful when load profile of individual houses needs to be viewed or the load profile of entire micro grid needs to displayed. This window allows the user to plot following graphs:

- Individual House Generated Power
- Individual House Load

- Individual House Power Exported
- Total Load on Grid
- Total Power Exported to Grid
- Total Power Imported from Grid

The data for the plots is fetched from the Power Database. Each plot described above is assigned a special variable which is used by Central Power Monitor to fetch data from the database. The Central Power Monitor uses the user selected date and the plot chosen to filter out data from database. This data is then plotted in the designated plot area. Figure 8.6 shows the Trends window.

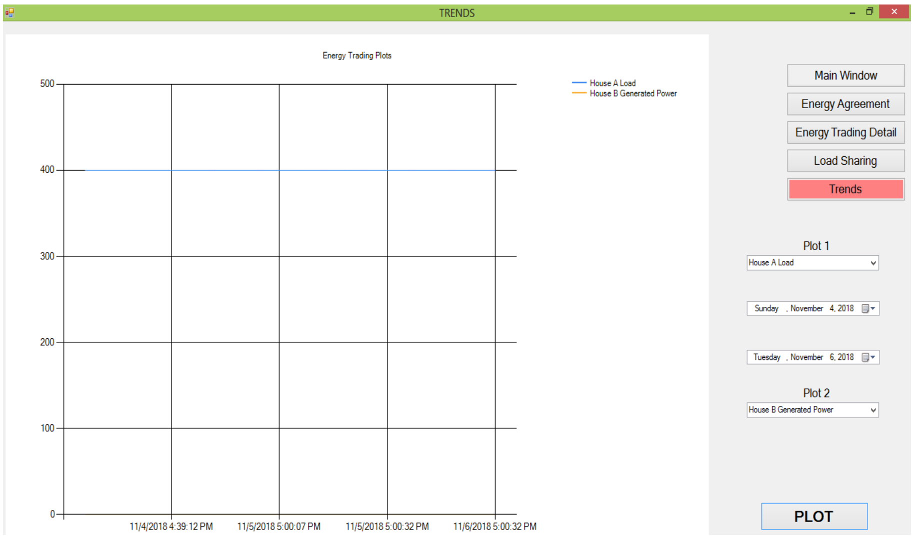


Figure 8.6: Trends Window

8.4 THE DATABASE

Data recording and retrieving is very important for any Peer to Peer Energy Trading system. For this project, the Central Power Monitor has a central database of all the power transactions occurring on the micro grid. The database allows Central Power Monitor for easy record retrieving and perform various calculations such as bills and payments. The advantage of using a database is to centralize the records which can be utilized in the future for any troubleshooting and making modifications in the system as per actual data available. There are two separate databases in Central Power Monitor. The Power Database and the Agreement Database. The databases are created on M/S Access.

The Power Database saves all the power transaction occurring on the micro grid. The Central Power Monitor receives data from Individual Data Monitor (Houses) of the power exchanged between micro grid and house. The Central Power Monitor performs various calculations on this value such as energy calculation, energy from main grid, bills etc. All this data is stored in the database with the current date and time and the ID of House. The sampling time selected for this data is one minute. This small interval allows precise calculations of bills based on current power rate. The date and time is very important part of this database. It helps in easy retrieval of data for the trends and also for the calculation of bills for the entire month.

The agreement database has the record for the contract of each month. During the start of the month, a contract is created between sellers and buyers of the micro grid. The Central Power Monitor receives information from each house and then stores this data in the Agreement Database. The data that is stored contains name of month, house ID, House role, rate of power, etc. The record from this database is used a reference to create monthly bills and impose penalties on the users of the micro grid. The agreement data of the current month is retrieved and can be viewed on the Energy Agreement Window.

Chapter 9

RESULTS USING A SIMULATED CASE

9.1 SCOPE AND OBJECTIVE OF THE CHAPTER

This chapter describes the tests and its simulated results which were performed on the Peer to Peer Energy Trading System designed in this project. The simulation is largely based on the Load Sharing Scheme implemented which was explained in the previous chapter. The test case involves four houses on a micro grid which are exchanging power with one another to fulfill their load requirement. The architecture of the micro grid and the distribution of the communication network among the houses and the Central Power Monitors are same as described in Chapter 4. Each house is assumed to have a Bi-Directional Smart Power Meter and an Individual Data Monitor Workstation installed in it. House A and House C are selected to act as power buyers in the trading scheme. House B is selected as seller with power generating source as solar powered invertor and House D is selected as seller with a fuel driven generator as a power source. It is also assumed that each seller house is capable to increase or decrease its surplus power output on the basis of the command issued by the Central Power Monitor. Using some data about the average power consumption of a typical Pakistani home, load profile for the buyers House A and House C were created.

9.2 CASE 1: BEFORE PEER TO PEER ENERGY TRADING

The average house in Pakistan consumes energy approximately 300 to 700 kWhr of electricity in a month. The daily average use of energy during a day time is around 6 to 18 kWhr of electricity and during night time the energy consumption drops to 4 to 9 kWhr. This information is used in order to test the system. A simulated case is developed to check if the proposed Peer To Peer Energy Trading Model in this thesis has any advantage over the conventional power system. The test is divided into two different cases. The first case is a conventional system which assumes that four houses are does not have any power generation source available and are utilizing electricity form the national grid without any Peer to Peer energy sharing among them as no house has any power generation of its own. They all are consuming power from the main grid. The daily electricity consumption of Each house is divided into 12 hour basis and has been simulated on random basis, day consumption is between 6 to 18 kWHR and night consumption is between 4 to 9 kWhr. Figure 9.1 shows the power (W) requirement of each house during day and night time. The rate of electricity as set by Karachi Electric (K.E) is 17 RS/kWhr for a monthly consumption between 300 to 700 kWhr. Table 9.1 shows the monthly bill for these four houses. As it can be seen from the table, the bills are between RS 5700 to Rs 11,000 if electricity is purely bought from the network of national grid.

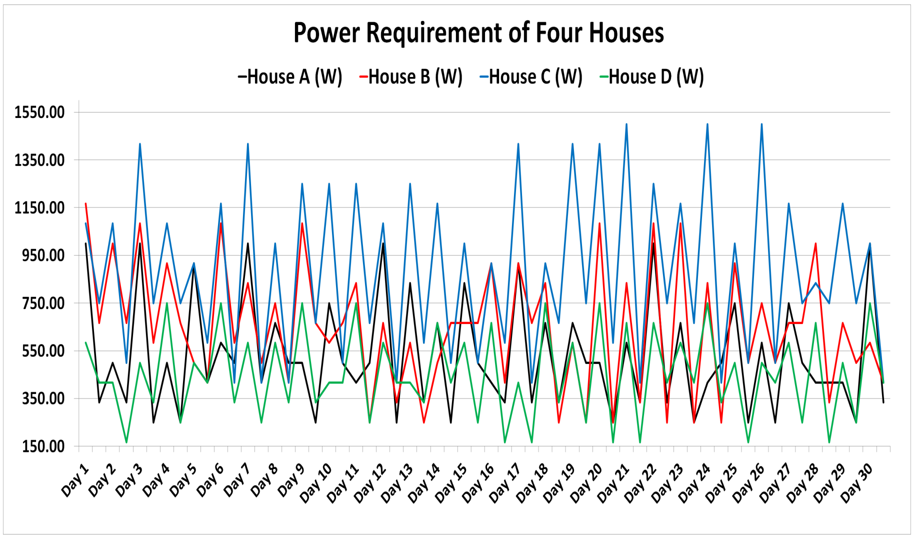


Figure 9.1: Power Consumption of Houses

Table 9.1: MONTHLY BILL BEFORE P2P MODEL IMPLEMENTATION

KE HOUSE A BILL	KE HOUSE B BILL	KE HOUSE C BILL	KE HOUSE D BILL
6688	8201.6	11176	5737.6

9.3 CASE 2: AFTER PEER TO PEER ENERGY TRADING

Second case employs that now the designed Peer To Peer Energy Trading System has been implemented to which will allow the exchange of power and share load among the four houses described in case one. The House B has now installed a solar inverter of capacity 4.0kW to fulfill its own power requirement and also to provide a surplus power with maximum output of 2.5kW and minimum output of 250W to micro grid at the rate of 8Rs/kWhr. House D is using a fuel driven generator which is of capacity 5.0kVA to fulfill its own load and also to provide a surplus power with maximum output of 2.5kW and minimum output of 250W to micro grid at 25Rs/kWhr. Load sharing scheme employed in the Central Power Monitor is enabled here to utilize maximum surplus power output (2.3kW) from solar inverters during the day time. Figure 9.2 shows the total power requirement of micro grid for buyer House A and House C. The power requirement during the day time is higher as compared to night time. As the load sharing scheme is utilized, it can be seen from Figure 9.3 that during the day most of the power requirement is fulfilled from the solar invertor (House B) as Central Power Monitor increases the power output of House B and decreases the load on House D simultaneously. During the night time maximum power is supplied from the fuel driven generator (House D) as Central Power Monitor issues a power raise command to House D. The energy bill rate is also being dynamically calculated as per the Dynamic Rate Calculation Algorithm on the basis of current power generation of House B and House D as shown in Figure 9.4. Because of dynamic rate method and load sharing scheme is can be observed from the Table 9.2 that there is a reduction in the bill for House A and House C of around 20 percent and 25 percent respectively as compared to the conventional method used in Case A. Moreover House B and House D have earned their payments for providing surplus power to the micro grid. Making the overall system more efficient and economical.

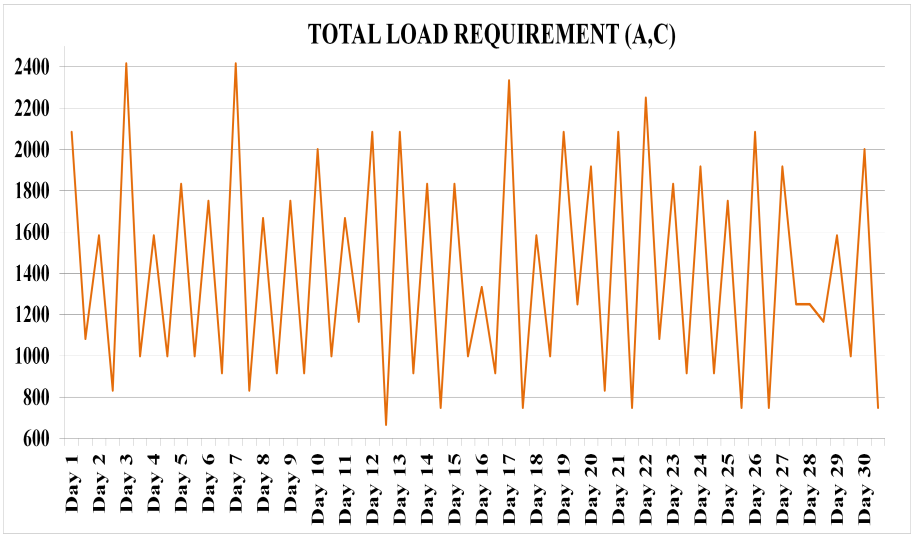


Figure 9.2: Total Power Requirement of House A and House C

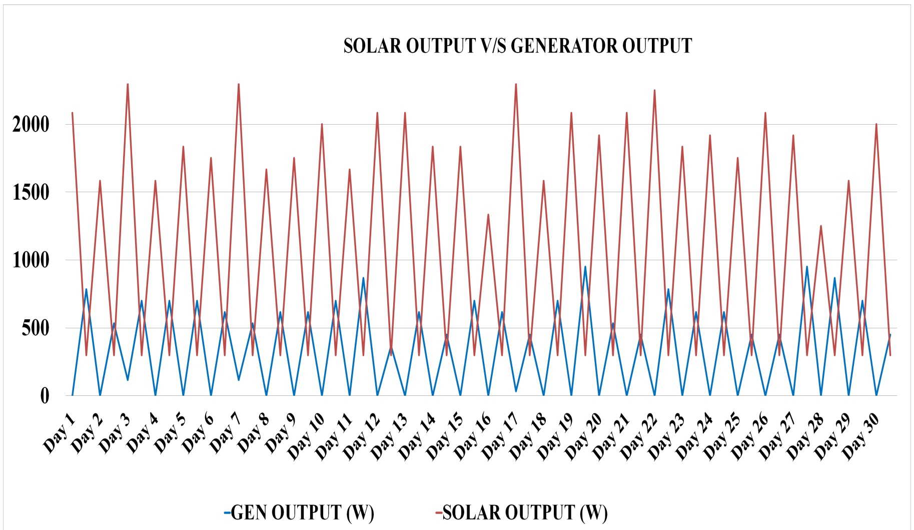


Figure 9.3: Solar and Generator output for Day and Night

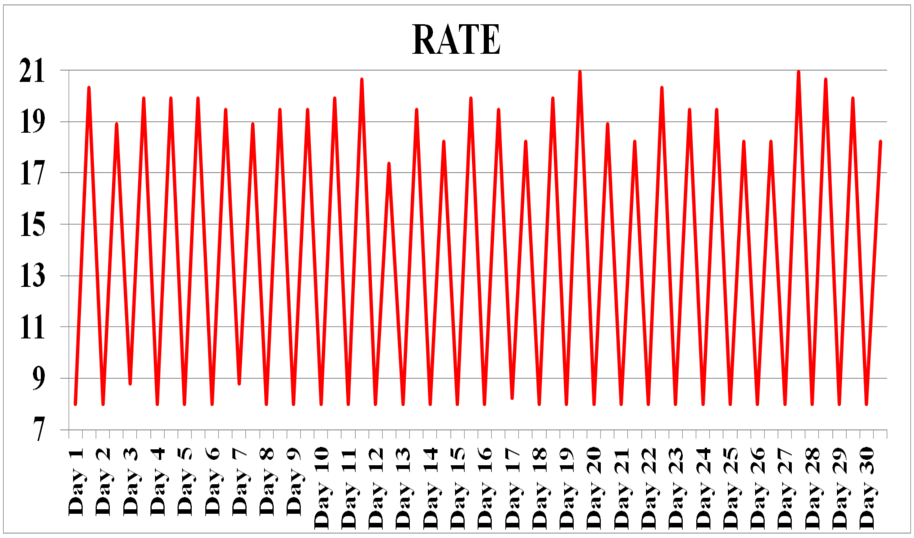


Figure 9.4: Dynamic Rate of Power for Generation

Table 9.2: MONTHLY BILL BEFORE P2P MODEL IMPLEMENTATION

HOUSE A BILL	4550.4
HOUSE C BILL	7517.0
HOUSE B SOLAR PAYMENT	6262.4
HOUSE B SOLAR PAYMENT	5805.0

Chapter 10

CONCLUSION AND FUTURE SUGGESTION

10.1 CONCLUSION

The Peer to Peer Energy Trading scheme presented in this thesis not only allows an effective and efficient utilization of distributed generation network of micro grid but also provides affordable electricity to all the users participating in the energy trading. The network topology presented involves a Central Power Monitor which monitors and controls all the energy transaction between consumers and producers. Each consumer and producer is equipped with an Individual Data Monitor Workstation and a Bi-Directional Smart Power Meter for measuring of power transfer between micro grid and house. The Dynamic Rate Calculation algorithm decreases the cost of electricity along as it only depends upon the current power generation. The load sharing methodology further enhances the efficiency of the system as it changes the power output of the sellers according to their power source and time of the day. This helps in effective utilization of solar powered invertors during the day time. Using the blockchain technology and the cryptocurrency, an effective bill payment methodology is utlized which allows consumers to pay the produces using Power Coins automatically. The software developed for the Central Power Monitor and Individual Workstation are easy and user friendly to use with a lot of different features as explained in previous chapters.

10.2 FUTURE SUGGESTION

The project can be greatly improve with some minor modifications and enhancement like implementing an autonomous load forecasting methodology which could predict the load requirement of the microgrid and create a load profile. This will greatly reduce the cost of power and sources can be utilized much more effectively. Also a method of Peer to Peer Load Sharing between microgrids can be used to share load on a larger scale. Using an improved security for the blockchain network, this system could solve energy problems throughout the world and could become an alternative source of income for the people.

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