DEVELOPMENT OF IoT BASED SMART ENERGY METERING SYSTEM

Dissertation submitted in partial fulfillment of the requirements for the award of the degree of

Master of Engineering

in

Power Systems

Submitted By

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DECLARATION

I hereby certify that the work which is being presented in the dissertation entitled, "**Development of IoT Based Smart Energy Metering System**" in the partial fulfilment of the requirement for the award of the Degree of **Master of Engineering** in **Power Systems**, submitted to **Electrical & Instrumentation Engineering Department** of **Thapar University, Patiala**, is an authentic record of my own work carried under the supervision of **Dr. Sanjay K. Jain**. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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Abstract

In recent years automation utilizing wireless communication has been evolving in major fields of societial life. The smart energy metering system (SEMS) is an innovative system that measures performance parameters of consumers on real time basis and communicates it to remote server. The traditional way of manually taking electricity meter readings and analyzing was a very cumbersome process; consumes lot of time and man power. Internet of Things (IoT) aims to connect multiple embedded systems to Internet, thus enabling an effective way of human-machine and machine to machine communication. This dissertation is an effort to develop an IoT based SEMS which introduces automation in the metering process and overcomes most of difficulties faced in traditional metering process. Proposed model uses two tier communication system in which a multiple smart energy meters communicates to one Data Concentrator Unit (DCU) via Radio frequency transceiver module *nRF24L01*. The Internet access to DCU can be provided either through Wi-Fi technology, Ethernet or mobile data. Publish/Subscribe messaging system is used to communicate between DCU and remote server. In order to perform all the tasks in easy and flexible way, a user friendly Graphical User Interface (GUI) has been developed. A complete working model of proposed system is implemented utilizing Atmega 328P microcontroller and Raspberry Pi 3 under Python. The developed system can also be used for report generation and sending bills directly to consumers through SMS and email. It can be operated in manual and auto mode. In manual the authorized person can request data at anytime whereas in auto the information is collected periodically with specified intervals.

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Abbreviations

AC	Alternating Current
API	Application Program Interface
ARM	Advanced RISC Machines
CPU	Central Processing Unit
CSI	Camera Serial Interface(CSI)
DCU	Data Concentrator Unit
DSI	Display Serial Interface
ETA	Equipment Type Approval
GPL	General Public License
GPRS	General Packet Radio Service
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HDMI	High Definition Multimedia Interface
HES	Head End System
I2C	Inter Integrated Circuit
IC	Integrated Circuit
IoT	Internet of Things
IS	Indian Standard
JSON	Java Script Object Notation
LCD	Liquid Crystal Display
LGPL	Lesser General Public License
M2M	Machine to Machine
NAN	Neighborhood Area Network
NFAP	National Frequency Allocation Plan
PLC	Power Line Communication
PLCC	Power Line Carrier Communication
RDBMS	Relational Database Management System

RF	Radio Frequency
RISC	Reduced Instruction Set Computer
RMS	Root Mean Square
RTC	Real Time Clock
SEMS	Smart Energy Metering System
SG	Smart Grid
SMN	Smart Meter Network
SMS	Short Messaging Service
SMTP	Simple Mail Transfer Protocol
SoC	System on Chip
SPI	Serial Peripheral Interface
SUN	Smart Utility Network
UART	Universal Asynchronous Receiver Transmitter
VM	Virtual Machine
WAN	Wide Area Network
WPC	Wireless Planning Coordination Wing

Overview

1.1 INTRODUCTION

In the era of Smart cities, *Manpower* which is a precious resource, should be used aptly and wisely. All of its efforts must be concentrated to automate every possible sector of society. The government is also paying lot of attention on the concept of smart city where major portion of the infrastructure, communication and power system is automated. Power sector is one of the most important sector of society and needs to be automated to full possible extent. This dissertation is an effort to automate the metering process of the power sector.

In the traditional energy metering system electricity board officials have to do a very tedious and time consuming task of obtaining each and every meter reading manually. Bills are calculated and forwarded to consumers manually. It is also very difficult to keep record of all consumers. Due to human dependency the traditional existing system suffers with lot of shortcomings:

- It consumes a lot of time and manpower which is one of costliest resource these days.
- Real time peak load monitoring is not possible.
- Time based tariff implementation is very difficult.
- It is very difficult and inefficient to keep track of power theft and meter tampering.
- Probability of error is high.

1.2 NEED OF SMART ENERGY METERING SYSTEM

In order to serve 1.2 billion individuals, a smart and cost efficient research should be the prime thought process. An advancement in this sector must be presented that overcomes the difficulties faced in traditional system, likely the idea of *Smart Energy Metering System (SEMS)* has been presented which in turn gives some additional features to eliminate the human dependency.

- It saves a lot of time and reduces labor cost drastically.

- It provides accurate consumer load profile information which is beneficial for utility as well as customer.
- Monitoring of peak load demand of customer and alert if more than sanctioned load.
- Effective and easy implementation of time based tariff.

The real time data obtained from a SEMS will help in improving the reliability and accuracy of load forecasting. The combination of this data with geography and weather can help to unhide some useful information to predict future power usage [19]. The effect of heat waves, humidity, cloud cover over the time of day on power consumption inferred from this data would make the peak power predictions more accurate. Consumer load profiling can be obtained which will help to identify abnormal patterns which can be due to faulty meter, fraud or human interaction. Electricity theft or losses can easily be identified by comparing the user data with measurements from transformer feeder [1].

Online payment gateway can be easily integrated with this smart system which makes it easier for customers to pay bills in time and utility can also manage data of its customers effectively. It can be easily configured to auto cut the supply of load in case of high outstanding dues. A web platform that tells the consumers of their usage pattern can help them to manage their electricity consumption .

1.3 LITERATURE REVIEW

Smart meters are being used in many countries across the world. The technology of electronic-metering has got many technological advancements since last few years. SEMS is an advanced system that measures, records and transfers energy consumed by the load as compared to a traditional energy meter. Various techniques, softwares and embedded devices have to be implemented for Smart energy meter integration into smart electricity grid. Design of a smart energy meter depends on various factors like requirements of the utility organization as well as the consumer, type of Internet connectivity available in that region etc [5].

Any smart metering system deals with acquisition of data, data transmission, processing, and its interpretation. Data acquisition means acquiring the load consumption data from a consumer end [1]. It requires a controller along with many sensors that fetches data and sends it to next station for further use. Different technologies can be used for this purpose. Atmel make microcontroller Atmega328P can be used along with sensors like voltage and current sensor and output device (LCD) for this purpose [6].

An extensive summary of the AMR innovations have been proposed up until now alongwith how future AMRs will receive profit of third generation (3G) communication technology has been presented in [7]. Communication protocols mainly used for transmission of collected data to server are either wired or wireless. Wired technology mainly includes Power Line Communication (PLC) and Telephone lines where as Radio frequency(RF), ZigBee communication(type of RF), Wi-Fi, Bluetooth are some of commonly used short range wireless communication protocols. Messaging over GSM (Global System for mobile communication) network and 3G wireless protocol can be used to transfer meter reading to remote device.These technologies and some of communication standards have been summarized very precisely in this paper [7].

The paper [6] summarized design and the execution assessment of a radio Frequency mesh based framework in the Neighborhood Area Network (NAN) for smart energy management related applications. The execution assessment depends on a topographical model of the arrangement situation and actualizes geographical routing joined with proper radio proliferation models. The outcomes demonstrate that the framework can deal with Smart Metering correspondence activity with a high probability if satisfactory number of repeater hub's are used in order to cover the whole area. The method proposed helps to identify the coverage gaps before deployment of network which can otherwise cause abnormalities in the framework, thus it supports a reliable and effective implementation and operation of the system.

Wireless GSM energy meter and its related web interface software is being used in some of existing smart meters for automatic billing system. It communicates the consumption units of load (kWh) via SMS (Short Messaging Service) periodically or on request by the remote server. It uses a main microcontroller that is interfaced to some energy metering IC that measures the energy consumed by load. Each meter is interfaced with GSM modem and the remote server is basically a PC with a GSM modem to receive the data [2, 8–13]. This increases the overall cost of the system to a large extent as GSM modem is very costly. Also the SMS communication media inefficient, costly and practically impossible to be used for real time data transfers.

A smart energy meter based on microcontroller PIC16F877A which uses energy metering IC MCP3905 is developed along with a billing software in .NET framework which generates the bill and forwards to the customer via e-mail and SMS in [8]. Other smart meters use GPRS

mobile data services mainly on 2G cellular network using GSM modem. Different models of GSM modems are available. They transmit data to a particular IP address of remote server on request [12–16]. The 2G network speed is limited to 115Kbps and mobile data is also costlier than broadband which makes it ineffective and economically non feasible for real time data transfers.
The Internet of Things (IoT) enables an effective and reliable way of wireless machine to machine communication over other technologies. It is basically a system of things which has an ability to collect the required input data and transmit the same data to a remote server via Internet without help of any individual. A thing, in the Internet of Things, can be a person with a heart rate monitor, a pet animal with a location transponder, a car that has sensors to notify the driver about tire pressure or any other natural or man-made device that has ability to transfer information to remote server via Internet. These sensors collect required information with help of various existing technologies and then communicate between different devices. IoT is a perfect platform for real time data transfers [4].

A remote energy measurement system using Raspberry pi board based on ARM11 processor along with various peripheral sensors was developed. Sensors fetch the information from user end, stores this data in Raspberry pi and transfers the required data to server over Wi-Fi technology. The remote server receives the data, stores it in database, interprets it for calculation of energy. The GUI was developed for data access using Qt Creator [17]. There is need to setup a new Wi-Fi tower that transmits the signal to server. Hence it adds up a huge cost to the system and also limits the distance between the meter and server.

Transfer of energy data from load end to database server can also be done using Power line carrier communication (PLCC) etc. There are two types of radio frequency technologies: Mesh technology and point to point technology. The mesh RF technology offers the large bandwidth, but suffers from long distance issues in case of remote areas. On the other hand, Point to Point RF technology offers larger bandwidth, can communicate directly with each endpoint, and covers longer distances but it is difficult to interface with Automation devices. PLCC reduces capital cost for rural transmission lines, and makes it easier to work in remote area or over long distances. It suffers from a disadvantage that data transmitting time is larger than wireless and higher overall cost in cities [3].

1.4 SCOPE OF WORK

After the brief review of the literature in section 1.3 on smart energy meters, communication technologies the scope of work is framed. The one of the major aim must be cost effectiveness as large pool of consumers are associated with power sector. The GSM modem interfaced with each SEM increases the overall cost of system. In order to lower the cost a two stage communication model is designed using the low cost RF transceiver module *nRF24L01* which is approx. $1/5$ cost to the ZigBee module for 1st stage. Publish Subscribe messaging scheme for 2nd stage of communication which is suitable for real time data transfers.

1.5 OBJECTIVE OF THE WORK

The objectives of the work are summarized as follows:

- Develop the SEMS utilizing two way communication and cost effective.
- Develop the SEMS suited for real time communication and supporting existing infrastructure.
- Develop the Interface that is user friendly and supporting billing/report generation.

1.6 ORGANIZATION OF THE DISSERTATION

The work carried out in this dissertation has been organized in 6 chapters.
Chapter 1 comprises of introduction and recent developments. This chapter also summarizes the need of smart system, objective of the work and organization of dissertation.
Chapter 2 describes the different types of energy metering system and comparison of proposed system with different types of system.
Chapter 3 describes the technology of Internet of Things and different communication models available.
Chapter 4 summarizes the description of different components used in system and hardware implementation of the proposed system.
Chapter 5 summarizes the results and discussions.
Chapter 6 summarizes major conclusions and future scope of the work.

Developments in Energy Metering System

2.1 ENERGY METER

Watt hour meter or Energy meter is an instrument which measures quantity of electrical energy utilized by the customers. Utilities introduce these instruments at each consumer place like homes, businesses, associations to charge the power utilization by loads, for example, lights, fans and different appliances. The basic unit of power is watts. The energy consumed is measured in kWh (Kilo Watt Hour), it means that if one kilo Watt load runs for one hour than it will consume 1 kWh of electricity. Basic types of energy meters are explained in next section. In the initial years these meters measured only the electricity consumption units, later the measurement was extended to all parameters of electricity. The advance meters measure parameters such as Voltage, Current, Real Power, Power Factor, Reactive Power, Apparent Power in addition to consumption units on real time basis. The smart meters have the ability to communicate these parameters to remote server. The instantaneous power is incorporated over a period which gives the vitality used over that era.

2.1.1 *Types of Energy Meter*

There are mainly three different categories of energy meters:

a. **Electromechanical induction type Energy meter**

   The electro-mechanical induction type meter works by checking the rotation of a non-magnetic, however electrically conductive, metal disc revolves at a speed which is directly proportional to power consumed by the load. A gear arrangement is coupled to this metal disc that displays the reading in a series of dials and indicates total energy consumed in kWh. This kind of meter is basic in development and precision is slightly less because of creeping and other field interference. A noteworthy issue with these sorts of meters is that they are easy to tamper. In the initial years these were very commonly in residential and industrial applications.

b. **Electronic Energy meters**

These types of meters have higher accuracy, precision and reliability when contrasted with regular mechanical meters. It devours less power and starts measuring with no delay when associated with load. These meters are of two types: Analog and Digital type.

(i) *Analog Electronic Energy Meters*

In analog type electronic meters, instantaneous values of voltage and current are acquired by voltage divider and current transformers separately which are connected to load. ADC (Analog to Digital Converter) changes these analog values to equivalent digital sample. This is then converted to equivalent pulses which in turn drives a gear based counter arrangement. The torque that drives the counter is directly proportional to total power consumed by load. Hence the counter displays overall power consumed in kWh units.

(ii) *Digital Electronic Energy Meters*

Digital signal processor or high end microcontrollers are utilized in this type of meters. The power is straightforwardly measured by micro-controller. The micro-controller senses the instantaneous voltage and current using potential divider circuit and current transformers respectively. The other load parameters such as RMS voltage and current, real power, apparent power, reactive power and Power factor are calculated with help of these instantaneous values. It interfaces Real time clock (RTC) for figuring out time for power combination and date and time stamps for specific parameters. Moreover, it interfaces liquid crystal display(LCD) to display parameters on real time basis, specialized communication protocol and other sensors required for its operation. A small cell type battery is accommodated for RTC and other noteworthy peripherals for power backup.

c. **Smart Energy Meters**

It is an advanced metering technology which includes installing smart meters to acquire, process and communicate data to a remote end device. It measures load data, remotely handles the supply of consumer, tracks tampering and monitors peak load along with some other extra features. Any Smart system deals with data acquisition, recording, interpretation and its analysis. These meters incorporate the capability of Automatic meter reading which removes the necessity of visiting the customer premises for reading collection thus saving a huge man power. They are equipped with devices required for conveying information in both directions i.e. from load end to utility and vice versa. The Smart meter is an important part of SG. Different types of wired and wireless communication protocols are available for data transfer from energy meter to remote device.

2.2 INTRODUCTORY ENERGY METERING SYSTEM

In general Energy Metering System refers to a process of acquiring energy meter reading, processing, calculating bills, forwarding it to the customer and monitoring payment dues. The Fig. 2.1 shows basic structure of Energy metering system.

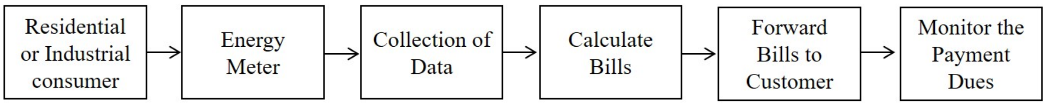

Fig. 2.1: Schematic of basic Energy Metering System

As the technology advanced and following the shortcomings of electromagnetic type meters, they were replaced by analog and digital electronic type meters. Although this improved the accuracy and reliability but this metering process requires a large manpower and consumes a lot of time. It is also very difficult to track power theft, meter tampering and keep record of all consumers. The real time data of load parameters and load outage is not available which reduces the reliability of the system. The Fig. 2.2 shows a basic structure of Traditional Metering System.

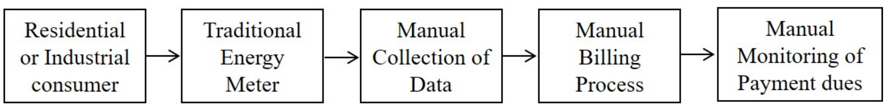

Fig. 2.2: Traditional Energy Metering System Schematic

2.3 SMART ENERGY METERING SYSTEM (SEMS)

It refers to a highly scalable energy metering system which is automated to full possible extent that increases reliability and reduces human effort. Smart energy meter is installed at each consumer premises which acquires the load parameter data and communicates it to remote server either periodically or on request. The bills are calculated automatically and forwarded to customer via email or SMS. The system can be integrated with online payment gateway which enables easy monitoring of dues. The supply of customer can be handled remotely if required. The Fig. 2.2 shows a basic structure for any Smart Energy Meter.

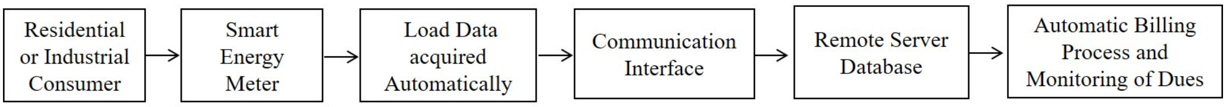

Fig. 2.3: Smart Energy Metering System Schematic

2.4 STANDARDS IN SMART METERING

The taking off of SG deployment pilots which depend intensely on information/data for conveying the intended capacities has moved the concentration to different information, its availability, information trade, security, interoperability and utilization among partners.

The AMI will be a required sub arrangement of any SG project. It is an information/data transportation network enveloping the source and destination stations. It is the combination of different functional elements mainly HES, WAN, SMN and DCU. SMN is Smart Meter Network which is a collection of SEMs. It is designed to exchange information, utility messages and commands on real time basis. In addition to the support of supplier-customer contract and acquire necessary data for billing purpose, it serves as a very valuable source of information which helps in improving efficiency and reliability of operation of SG.

Smart metering systems must be adaptable to different communication media without creating any data incompatibilities for the supported applications. The SEMs are a combination of simple static energy meter, communication protocol and load switching element. It is interfaced with a RTC that tells real time to the meter. It perform functions like acquisition of data, calculations, event tracking, communication, storing and control.

This standard has utilized on the different arrangements of Indian metering benchmarks that are as of now set up, the overhauls in embraced IEC models, chose IEEE benchmarks. The blend of these standard make this SEM spell out the principles for outline, advancement and testing of SEMs The arrangements of this standard will empower design of outside DCUs. The standards related to Smart metering system are basically divided mainly into four classes:

a. **Metering Requirements**

   It is the foremost requirement of SEMs. Metering requirement is governed by standards IS 13779 & IS 15884. These standards governs the requirements of static watthour meters of accuracy class 1 and 2 used for the measurement of AC electrical power of frequency range 45Hz-55Hz for single as well as three phase unbalanced and balanced loads.

IS 13779 specifies different current and voltage ratings, general constructional requirements, markings, display, insulation requirements, accuracy and test specifications for energy meters. IS 13779 also applies to netmeters and multirate tariff meters. IS 15884 specifies the influence of supply voltage, Short -Time Overcurrents, Self heating on energy meters and its electromagnetic compatibility.

b. **Load Switch Requirement**

The SEM must be interfaced with a switching device to remotely control the supply of electricity to consumer. For Single Phase meters load switch must be installed in phase and neutral and in each of three phase in case of three phase meters. The switches must be designed to carry maximum rated current continuously in normal conditions and must withstand the switching transients. The performance requirements of load switch are specified in IS 15884.

c. **Data Exchange Protocol**

The requirements for data exchange protocols are defined by IS 15959.

d. **Communication Requirement**

The SEM must be interfaced with communication module to provide bidirectional data transfer with DCU or HES as per requirement of application. The communication protocols may be RF, PLCC , WAN or any other cellular technologies.

The standard IEEE 802.15.4g Physical layer defines the support for different International as well as regional ISM band frequencies which are allocated for communication by utility in different countries. SEMs that support communication based on IEEE-802.15.4g over low power RF of sub Ghz and Ghz in license free band spectrum must follow the frequency bands defined by NFAP (National Frequency Allocation Plan). This standard is sometimes referred to as Smart Utility Network (SUN) PHY layer.

The 2.4 Ghz band frequency is defined in NFAP-2011 as international license free band and sub Ghz(865MHz-867MHz) band is defined as license free band for India in NFAP-2011. The SEMs that use low power RF communication using 2.4Ghz may adopt the PHY layer and frequency band as defined in IEEE-802.15.4g. Wireless technologies must be according to specifications as defined by the Indian WPC (Wireless Planning Co-ordination wing) [20].

2.5 SEMS Functions: A proposal by Central Electricity Authority of India

SEMS is referred as Advanced Metering Infrastructure (AMI) by CEA in India. The foremost purpose of AMI is to enable a bidirectional communication between SEM and Remote server to enable monitoring, remote reading and control of energy meters. The data obtained can be utilized for other utility functions for advanced analysis and billing purposes.

Smart Energy Meter for customers can be based either on Radio Frequency (RF), PLCC, GPRS/3G/4G or any other WAN communication technology as certified by competent authority. A combination of these technologies may be used as per region requirement. The radio frequency must be in license free band. The data communication to remote server can be either directly from SEM to remote server using 3G/GPRS/4G technology or via an in between hub called Data Concentrator Unit (DCU). The SEM data will be acquired by DCU via PlCC or RF mesh and communicated to Head End System (HES) i.e remote server through Wireless Area Network (WAN). CEA defines some of the minimum functions that a AMI system developed in India must have. Some of these functions are:

- It must be capable of communicating its data to remote server at configurable interval or on request.
- Easy implementation of time based tariff.
- Bill generation and forward to customer via electronic media such as e-mail and SMS.
- Pre-paid bill facility.
- Remote handling connection/disconnection of Load.
- Effective Event detection and reporting to the remote server.
- Remote firmware upgrade.
- Easy integration with other existing systems like collection software, IVRS & Billing.
- Incorporate security features to prevent access of system to unauthorized person [21].

2.6 PROPOSED IoT BASED SEMS

Existing Smart systems mainly use a main micro-controller unit which receives input from energy metering IC. The energy metering IC measures instantaneous voltage and current and input these values to micro-controller. It then calculates other parameters and displays it on a LCD as well as communicate it to the remote server on real time basis. Different wireless communication technologies like GSM, GPRS, Wi-Fi, ZigBee, Bluetooth and IoT are available for data transfer to remote server.

The Meters which are interfaced with a GSM modem either uses SMS or GPRS for communication to remote server. They transfer the total consumption units of load via SMS once in a bill cycle or on request by the remote server. The remote server also incorporates the GSM modem which decodes the SMS sent by each meter and interprets it accordingly. Those using GPRS, send data to particular IP address of GSM modem that is interfaced to remote server. Data transfer on real time basis is not practically possible in case SMS technology is used and very inefficient and costly in case GPRS or 3G/4G i.e. mobile data is used. The data transfer is limited by very low speed of GPRS in this case.

ZigBee is the Radio frequency transceiver module that enables effective short length data transfer. A two stage communication system is used in some of the existing systems which involves a Data Concentrator Unit (DCU) interfaced with GSM modem and DCU communicates data to remote server. Another short range wireless communication technology is Wi-Fi. It is preferable for Wireless metropolitan cities where the infrastructure for Wi-Fi is already installed.

The proposed IoT based SEMS is based on a two tier communication system which consists of three stations: Smart Energy meter(SEM), Data Concentrator Unit (DCU) and Remote Server. SEM measures the load performance parameter of each consumer load, displays them on LCD unit interfaced with it and has communication module to transfer the data to DCU via RF transceiver module *nRF24L01*. The collection of neighboring SEMs is referred to as Neighborhood Area Network (NAN). One DCU receives data from NAN and communicates the data to remote server. The basic schematic of SEMS is shown in Fig. 2.4. The detailed schematic will be discussed in Chapter 4.

The proposed system works in two modes: Manual mode and Auto mode. In manual mode an authorized person can request the required data by sending a command to each SEM while in the second mode every SEM transmits its data to remote server at configurable intervals of time via DCU. The working mode, time interval and request for data can be updated with a single click through GUI. The SEM uses Atmega328P micro-controller along with other required sensors like voltage and current sensor for its operations and the DCU is based on a microcomputer Raspberry Pi 3 which works on a Linux based operating system *Raspbian*. The Internet access to DCU can be provided either through Broadband, Wi-Fi technology, wired Ethernet cable or mobile data as per easy availability in region. Publish/Subscribe messaging system is used to communicate between DCU and remote server.

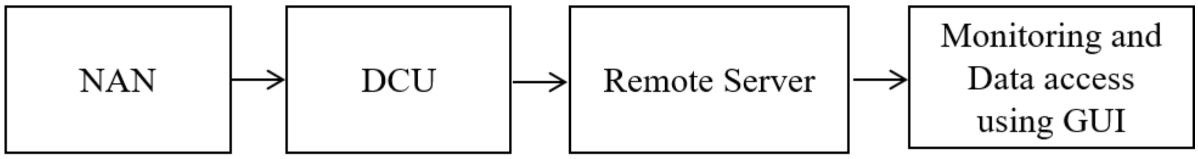

Fig. 2.4: Basic Schematic of SEMS

2.6.1 *Comparison between different metering systems*

In the traditional system only the total energy consumption units (kWh) of each consumer is taken manually by the utility officials on their periodic visits to the premises. This system requires huge manpower, consumes lot of time and is very inefficient.

SEMS on the other hand minimizes the human intervention in this process. It supports Automatic Meter Reading(AMR), billing system, tracks power theft and meter tampering etc. The system provides the facility of remote handling of electricity supply to load if needed. It enables easy implementation of time based tariff and monitoring of customer peak load. Table 2.1 and Table 2.2 depicts the comparison of proposed IoT based SEMS Vs Traditional metering system and proposed IoT based SEMS Vs Existing SEMS respectively.

Table 2.1: A Comparison of Proposed System Vs Traditional Metering System

S.No.	**Features**	**Traditional Energy Metering System**	**Proposed IoT Based SEMS**
1	Load parameters Acquisition	Manually consumption Units (kWh) are noted down once in a bill cycle	All load performance parameters are communicated to remote server on real time basis
2	Accuracy in recording meter reading	Chances of error are high	Chances of error are minimized
3	Electricity Bill Generation	Manual Process	Auto bill generated and forwarded to consumer via email and SMS
4	Remote Connection Handling	Not Possible	Auto as well as remote shut off facility
5	Tracking of Meter Tampering	Very difficult	Easy tracking
6	Consumer Peak load Monitoring	Not possible	Easy monitoring
7	Load Outage Information	No notification of particular load outage	Notification in case of load outage
8	Implementation of Time based tariff	Not possible	Easy and effective implementation

Table 2.2: A Comparison of Proposed IoT based SEMS Vs Existing SEMS

Features	**GSM Based Smart Meter**	**GPRS Based Smart Meter**	**GSM and ZigBee Based system**	**Proposed IoT Based SEMS**	**Advantages**
Meter Reading Acquisition	Only Energy consumption Units (kWh) are sent via SMS periodically (once or twice in bill cycle) or on request to a particular remote GSM modem.	It uses mainly 2G mobile data to transfer load performance parameters to a remote GSM modem having static IP address.	One GSM based DCU uses mainly 2G mobile data to transfer performance parameters of multiple loads to a remote GSM modem having static IP address.	One Raspberry pi based DCU requires Internet access which can be given either through Wi-Fi, broadband, Ethernet or USB mobile data dongle to communicate load performance parameters on real time basis. Publish/Subscribe messaging system is used for communication.	1. Lower cost. 2. High speed Internet connection. 3. Publish/Subscribe messaging system is very efficient and is poised as perfect platform for real time applications.
Real Time Data Transfer	Not practically feasible through SMS.	It is possible through 2G GPRS but is very expensive and is limited by low speed of 2G network.		Easy, effective, reliable and less costly Internet access can be given through Wi-Fi or Ethernet.	1. Publish/Subscribe messaging system is easy, effective and reliable for real time applications. 2. Internet through Broadband is cheaper than mobile data.
Database Used	RDMS	RDMS	RDBMS	*MongoDB*: A NoSQL database.	1. Light weight database. 2. Suitable for storing unstructured real time data.

Continuation of Table 2.2

Features	**GSM Based Smart Meter**	**GPRS Based Smart Meter**	**GSM and ZigBee Based system**	**Proposed IoT Based SEMS**	**Advantages**
Modification of server side IP address	All Smart energy meters have to be re configured.		All DCU's needs to be reconfigured.	Only server side needs to be reconfigured.	1. Easy adaptability. 2. Easy Infrastructure expansion.
Cost	Each meter is equipped with GSM modem which makes it very expensive.		Two Tier Communication system is Used: Multiple meters communicate with one GSM based DCU (Through ZigBee RF Transceiver) that sends data to single remote server.	Two Tier Communication system is Used: Multiple meters communicate with one Raspberry pi based DCU (Through nRF24L01 RF Transceiver) that has internet access and communicates data to Remote server.	1. Only one Internet connected station for multiple smart meters which makes it very low cost in comparison to GSM based meters. 2. ZigBee RF Transceiver cost is approx. 4-5 times of nRF24L01 RF Transceiver. 3. High speed internet using Broadband is relatively very cheap as compared to 3G/4G technology.

End of Table

Internet of Things (IoT)

3.1 WHAT IS IoT

Internet of Things (IoT) is a network of connected gadgets that can be accessed over the Internet. The Thing in IoT refers to any object that have been assigned a particular IP address and is able to sense information and communicate it over network without help of human. It could be anything like an endangered species with a GPS tag, an automobile with different sensors, a smart jar with ability to communicate its real time quantity etc [4].

In the factitious world if we had we had some PCs that knew everything about things, using data they caught with no assistance from humans. It will have the ability to monitor and track everything which would significantly reduce wastage, lower cost and losses. Reminders will be generated automatically when things need overhauling, maintenance, replacement or reviewing. We need to draw in PCs with their own specific strategies for machine to machine communication , so they can see, hear and see the world for themselves, in all its unpredictable grandness. This is absolutely what IoT platform accomplishes for us. It empowers gadgets/items to watch, recognize and comprehend a circumstance or the surroundings without being reliant on human offer assistance.

Internet of Things can associate gadgets/devices embedded in different frameworks to the web. Whenever gadgets/devices can digitally represent themselves, they can be controlled from anyplace through Internet. The real time communication then helps us catch more information from more places, guaranteeing more methods for enhancing efficiency, reliability and IoT security.

IoT is a transformational constrain that can help organizations enhance execution through IoT analysis and IoT Security to convey better outcomes. Organizations in the utilities, oil and gas, protection, producing, transportation, foundation and retail segments can receive the rewards of IoT by settling more informed choices, helped by the value-based information available to them.

The emergence of different innovations and changing market trends has made it possible to interconnect several number of objects effectively through M2M communication protocols:

- *Universal Connectivity*
  Lowcost, highspeed, universal connectivity , mainly through authorized and unauthorized wireless innovations have connected each and everything through Internet.

- *Boundless acceptance of IP - based networking*
  IP have become a worldwide standard for networking that provides a well-defined and broadly implemented framework of tools and software that can be interfaced with wide number of gadgets effectively and reasonably.

- *Miniaturization of things*
  Innovations in manfacturing sector allows the incorporation of communication and computing technologies into smaller objects. Coupled with several prominent computing analytics, this has energized the growth of little and cheaper sensor gadgets that drives several applications related to IoT.

- *Advancement of Cloud Computing*
  Cloud computing have empowered the network computing and remote resources, to handle, store, and manage information that enables the control abilities of smaller and geographically distributed objects which helps them to communicate with intense back-end system.

- *Advancements in Data Analytics*
  New principles and swift advancements increments in enumerating data storage, power and cloud applications allows the collection, relationship, and analysis of huge amounts of information.

3.2 IoT COMMUNICATION MODELS

From the operational outlook, it is valuable to know how IoT gadgets connect and transfer data in different specialized communication models. The IAB (Internet Architecture Board) defines the architecture for networking smart devices. It summarizes the communication models utilized for networking IoT devices in mainly four types. The discourse underneath presents key attributes of each model in the system.

3.2.1 *Device-to-Device Communications*

This model represents a network in which at least two devices are directly connected and communicating with each other instead of communicating via an intermediate server. These objects connect over several types of networks including IP or Internet. Usually these are interconnected through short range communicating technologies like Bluetooth, Wi-Fi, ZigBee as shown in Fig. 3.1. This type of network enables the devices to exchange messages via particular communication protocol to perform their function. This model is mainly used in home automation where less data is to be transferred at relatively lower data rate.

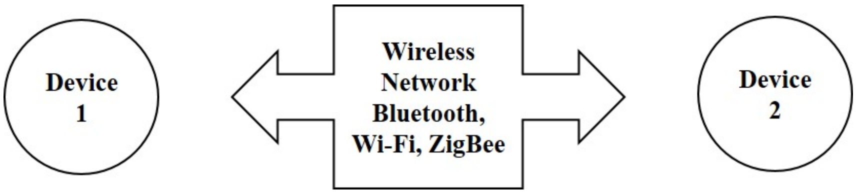

Fig. 3.1: Layout of Device-to-Device IoT Communication Model

3.2.2 *Device-to-Cloud Communications*

In this model, the IoT object is directly connected to an Internet cloud service like an application service provider organization to exchange information and control message activity. This approach oftentimes utilizes existing communication protocols like conventional wired Ethernet or Wi-Fi to interconnect device and IP network, which finally connects the device to Internet cloud service. Basic structure of this model is shown in Fig. 3.2.

This type of communication model is utilized in applications where real time data has to be communicated like real time energy consumption of a house. The connection of device to cloud service allows the user to remotely control the device. The data obtained can be analyzed to achieve different objectives. This models adds additional features to the device which originally were not a part of it. In any case, interoperability difficulties can emerge when endeavoring to coordinate devices of different make. Much of the time, the gadget and cloud administration are from the same vendor.

Fig. 3.2: Layout of Device-to-Cloud IoT Communication Model

3.2.3 *Device-to-Gateway Communications*

In this model the device connects through an intermediate device to reach the Internet cloud server. The devices are connected to intermediate device via some short range communication protocol like Wi-Fi, ZigBee, Bluetooth or other Radio frequency modules. The Fig. 3.3 shows basic structure for this model. In many case the intermediate device may be smart phone connected to device and communicating its data to cloud service. For example, the personal fitness bands use this type of communication model. These devices do not have the ability to directly connect to cloud service so they use smart phone as an intermediate gateway to reach the cloud. Another form of this model is that multiple devices communicate with a single DCU to connect to cloud service. The DCU can be called as a hub device.

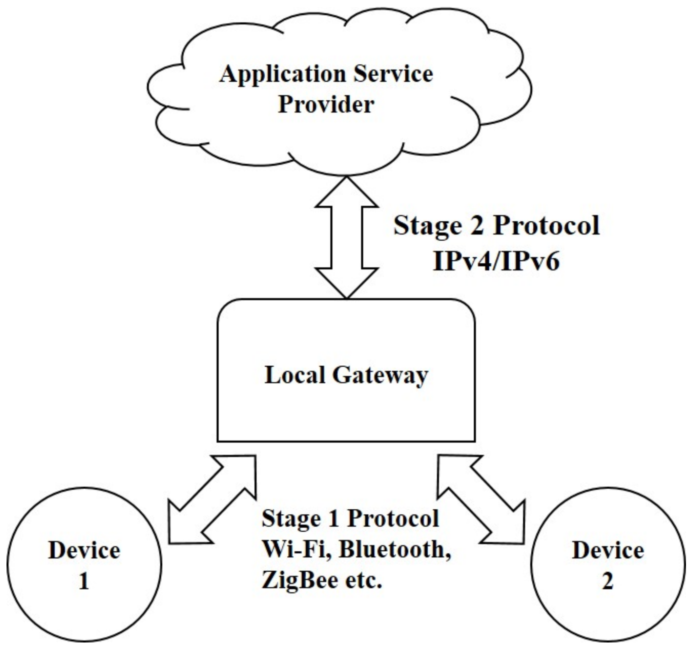

Fig. 3.3: Layout of Device-to-Gateway IoT Communication Model

3.2.4 *Back-End Data-Sharing Model*

This model is extension of device to cloud model in which a single device is connected to cloud service. It allows the users to analyze the data of any smart object in combination with data from other cloud services. This model supports the facility of granting data access of any device to other third parties. The back end application aggregates the data from different sources and the data can be analyzed. This model is used in applications where the user is interested in consolidating and analyzing data from different IoT sensors. A advanced and effective back-end architecture will enable the organizations to easily retrieve and analyze the data of several IoT devices. Application Programmer Interfaces(APIs) are required for easy interconnection of multiple smart devices. The Fig. 3.4 shows the basic structure of this model [22].

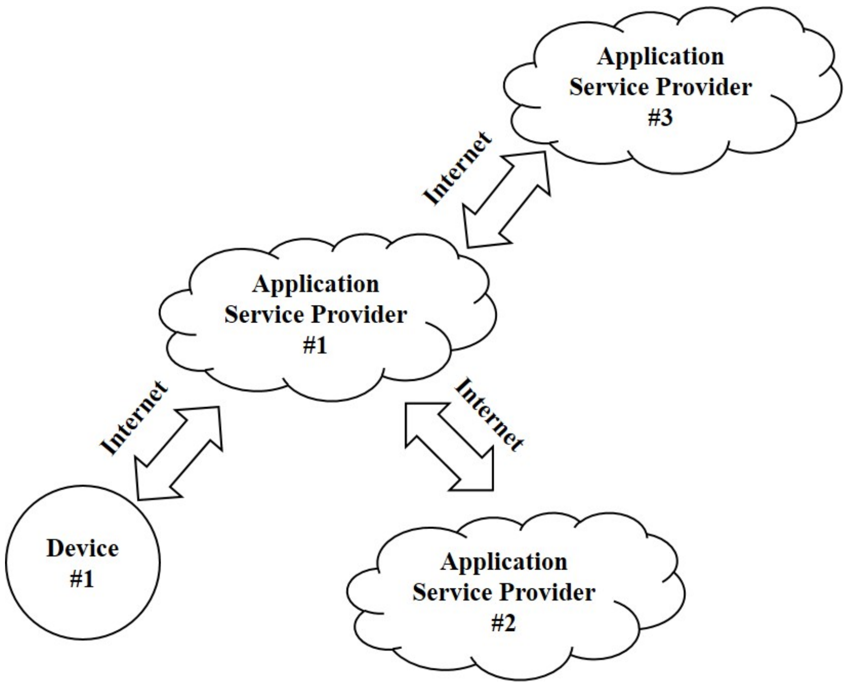

Fig. 3.4: Layout of Back-End Data-Sharing IoT Communication Model

Schematic and Implementation of Proposed System

The proposed system is based on Device to Gateway type of IoT communication model that was discussed in previous chapter. So it uses a two tier communication system that consists of three stations: Smart Energy Meter, DCU and Remote Server.

A Smart System having two Smart Energy Meters, one Raspberry Pi 3 based DCU and Laptop PC as Remote Server is implemented. The Internet access to DCU can be provided using Wi-Fi, Ethernet Port or 3G/4G USB dongle in case mobile data is to be used. Smart Energy Meter programming is done in Embedded C and script for DCU and remote server is written in Python programming language. A Graphical User Interface is made using Tkinter. Tkinter is only Python package in standard library package for developing Graphical User Interface (GUI).

The working of this system can be effectively explained by its implementation in any Residential area. Any residential area is divided into different lanes with number of houses in each lane. Energy meter of each house measures its electricity consumption which is taken down manually by utility official once in bill cycle in traditional metering system. In this smart system a SEM is installed for each house and all the SEMs which are in the area of 80-100 meters will communicate their respective data to one DCU installed at appropriate location.

The combination of these neighboring SEMs is referred to as Neighborhood Area Network (NAN). The communication between NAN and DCU is through short range RF transceiver module nRF24L01. Now different DCU's will be there for different lanes which will communicate data to one remote server. The Internet access to DCU can be given through different options as per availability in region. The cost of all hardware components used in this work is mentioned in Appendix. The Fig. 4.1 depicts the Schematic of Proposed system and Fig. 4.2 shows the sequence of data transfer from energy meter to remote server.

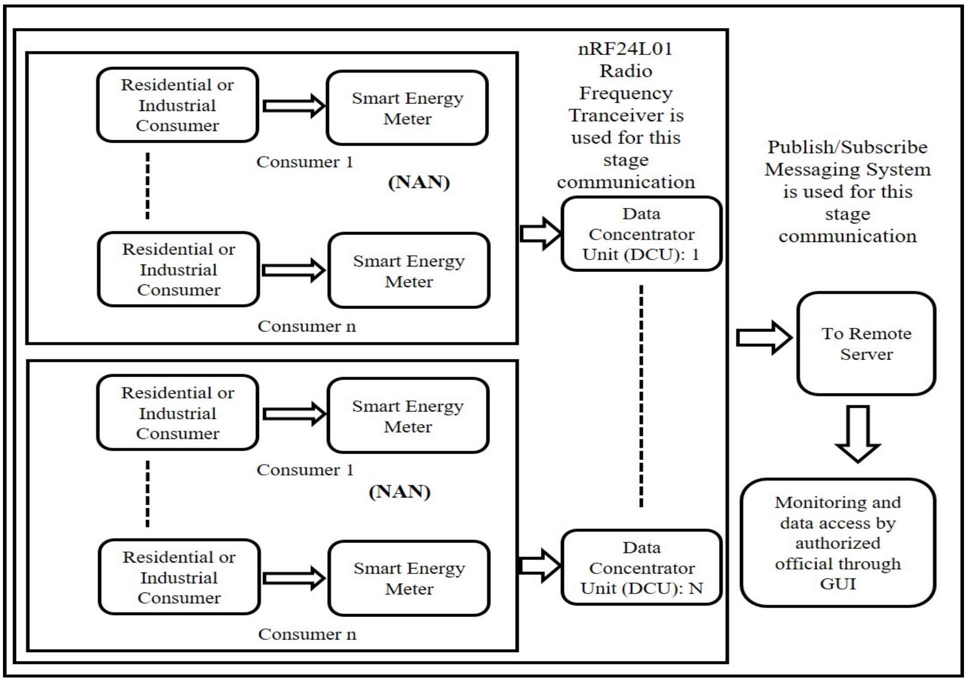

Fig. 4.1: Schematic of IoT based SEMS

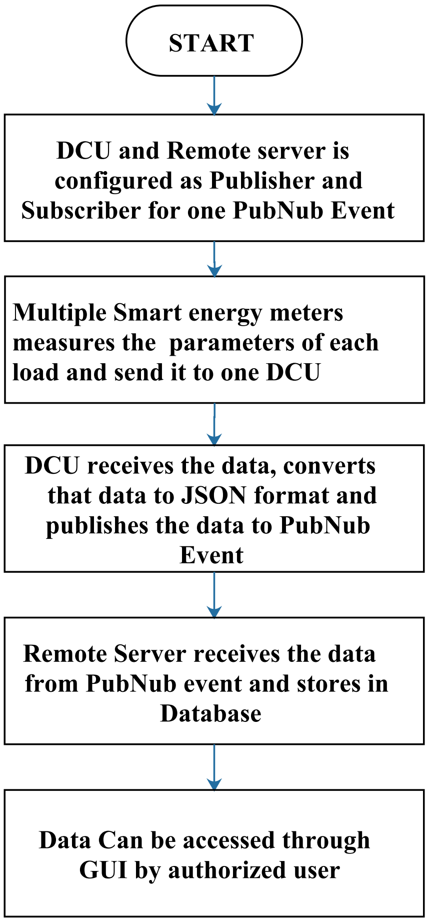

Fig. 4.2: Sequence of Data Transfer from Energy meter to Remote Server

4.1 SELECTION OF HARDWARE COMPONENTS

Power is one of the major and biggest sector in today's world. Nobody can expect a life without electricity these days. Huge amount of customers are engaged with power sector, so the cost involved in up-gradation of traditional Power Grid to smart grid is very high. So one of the major aim in a developing some equipment related to smart grid must be to achieve good results at minimum possible cost.

All efforts are to automate the metering and billing process of power industry at minimum possible cost. To achieve this the main requirements of the hardware that were considered in selection of main hardware components are as follows:

- Easy availability
- Low cost
- Open source
- Wide knowledge base must be available
- Easy interfacing with most of the electronic components
- Softwares used can be free and open source which will further reduce the cost of the system
- Micro controller used can be programmed through simple and easy understandable programming languages
- It must be old enough so that its accuracy and reliability has been thoroughly tested
- Size must be compact and small which allows easy portability

Main components that are needed in building up the system are:

I. Main Micro controller: Atmega 328P

It is main controller which will be used in smart energy meter. It would measure the instantaneous values of input supply parameters such as voltage and load current with help of voltage sensor and current sensor. With help of these values it will calculate other parameters such as Real power, Power factor, Apparent power, Reactive power etc. It will display these parameters on LCD as well as communicate the data to remote server on real time basis through stage 1 communication protocol. Relay will be used to handle the electricity supply to load.

Atmel make AVR based micro controller Atmega328P is used as main micro controller It is programmed using open source Arduino framework. Arduino offers of free and open source Integrated Development Environment (IDE). It's less cost, easy availability and effortless functions makes it favorable for this application. Due to its cheaper cost, open source nature and widespread acceptance, a huge knowledge base is available which verify its reliability in performing different tasks. Any of I/O pens can be configured as input or output as required in the application on like other microcontrollers which have specified inputs and outputs. In addition to this it allows easy interfacing with different external module with the help of I/O buses like I2C, SPI, UART.

II. Stage One Communication Protocol: nRF24L01 RF Transceiver

In order to reduce the cost of overall system a two stage communication system is used. The first stage is between SEM and DCU and can be effectively done with a short range communication protocol. Some of the short range Communication protocols available are Radio frequency communication, Bluetooth and WiFi. Bluetooth has very low range limited only to 5 to 10 m and Wi-Fi is preferable for wireless Metropolitan cities where Wi-Fi infrastructure is already available. RF communication in license free frequency band i.e 2.4Ghz is suitable for this application as it offers a free low range communication up to 150 meters depending on which module is used. A very commonly used RF transceiver for short range communication is ZigBee that works on 2.4 Ghz is easily available in India and is also being used in some existing SEMS but is very costly. A commercial module of ZigBee costs approximately around Rs 1500 which has to be interfaced with each SEM and DCU. This makes the whole system very costly.

On researching upon the alternatives for ZigBee, a recently developed RF transceiver module nRF24L01 of make nordic semiconductors was found and tested. On testing satisfactory results were achieved. Its commercial grade module costs around Rs 150 (without antenna) and Rs 300 (with antenna). As the cost difference between ZigBee and nRF24L01 is very large, it will reduce the cost of system drastically and reviews of later module are also fine so the module with antenna is used for stage 1 communication that offers a range up to 150 meters.

III. Data Concentrator Unit: Raspberry Pi

The main function of DCU is to receive data from multiple SEMs and send this data to a web cloud platform. For this it must have Internet connectivity which can be provided in different ways like WiFi, Ethernet or 3G/4G USB dongle as per easy availability in region. Many IoT hardware platforms are available for realizing this system like Arduino Yun, ESP8266, NodeMCU, Raspberry Pi, Beaglebone black, Arduino Ethernet Shield and Netduino etc.

ESP8266 is basically a Wi-Fi module that can interfaced to any microcontroller through UART to provide internet connectivity. Arduino's different shields for ethernet and Wi-Fi are available which can provide Internet connectivity to microcontroller. USB ports have to externally interfaced with microcontroller if this type of structure is used. All these features are available in single microcomputers such as Raspberry Pi and Beaglebone Black. The specifications of both of these are comparable but the cost of Beaglebone black is approximate 1.5 times as that of Raspberry Pi 3. Its main features which makes it favorable for this application are:

- Lesser cost.
- Its small credit card sized allows it's easy portability.
- Easy availability in India.
- Wide knowledge base is available.
- Continuous improvement by manufacturer since its launch in 2012. Now 3rd Generation Raspberry Pi is available with many extra features as compared to its initial version.
- Many external add ons are available for Raspberry Pi.
- It operates on Linux based operating system developed exclusively for Raspberry Pi which is provided for free by the manufacturer.

4.2 DESCRIPTION OF SMART ENERGY METER (SEM)

SEM is the energy meter installed at consumer end to fetch the performance parameters of load. It uses Atmega328P microcontroller along with other required sensors for performing the desired task. It requires 5V DC power supply to operate. The controller is programmed in Embedded C programming language using open source software Arduino IDE. Other peripherals which are interfaced are Voltage and Current sensor, *nRF24L01* RF Transceiver, Relay, Limit switch, LCD, RTC (Real time clock) etc. It transfers data to DCU via Radio frequency transceiver module nRF24L01. Transceiver means that same module can be used as transmitter as well as receiver. All parameters are displayed on lcd as well. The load is connected to supply through Relay which can be controlled by micro controller. The Fig. 4.3 shows the schematic of the smart energy meter. The Fig. 4.4 shows the flow chart for operations of Smart energy meter and Fig. 4.5 shows all the components of the implemented the smart energy meter. Main components of SEM are briefed through:

- Arduino Uno
- Power Supply
- Voltage Sensor
- Current Sensor
- RF Transceiver *nRF24L01*
- Relay
- 16x2 LCD(Liquid Crystal Display)
- Tampering Sensor
- Real Time Clock(RTC)

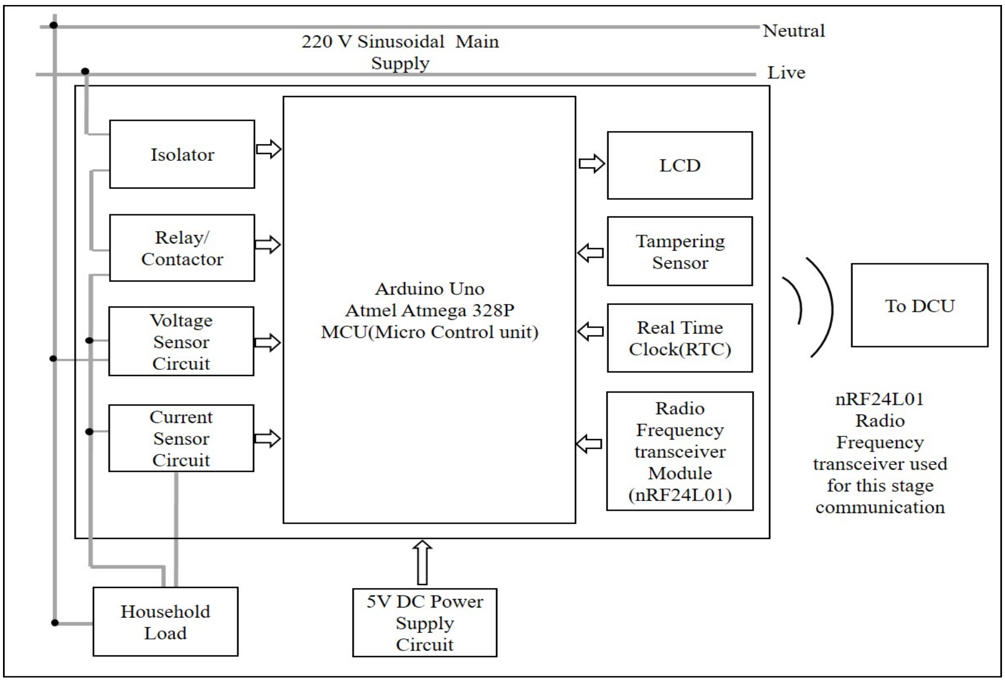

Fig. 4.3: Schematic of Smart Energy meter

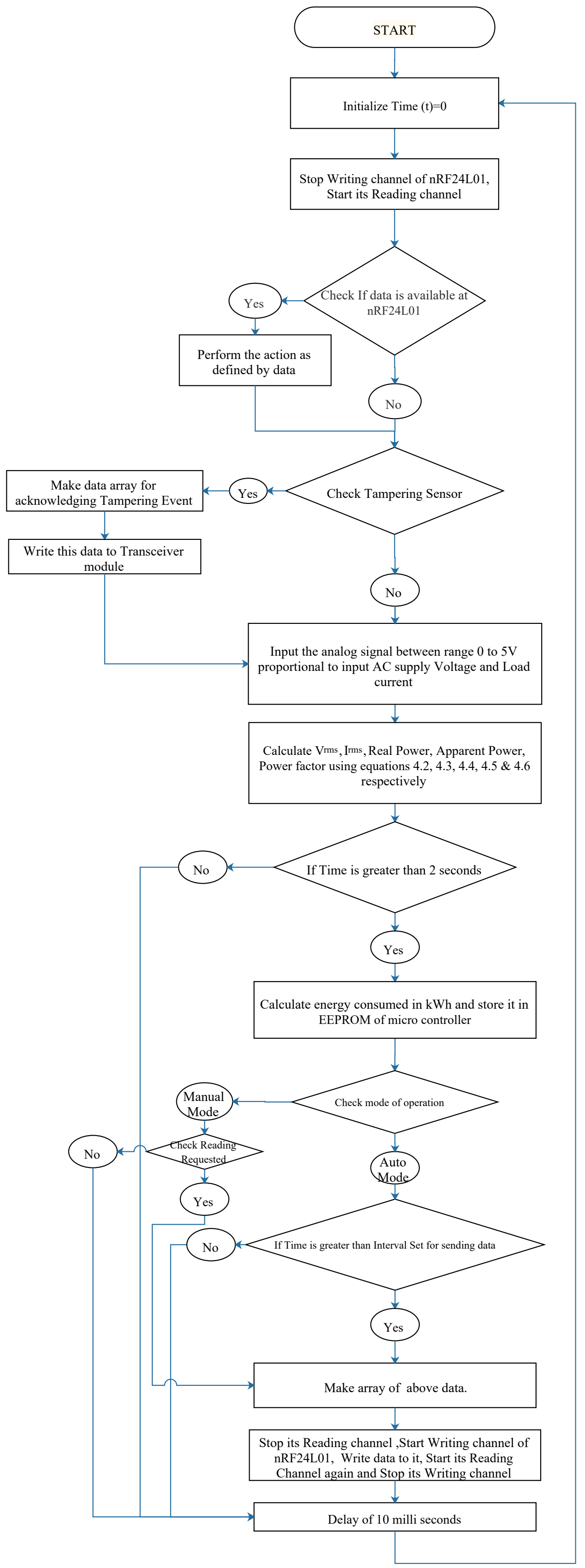

Fig. 4.4: Flowchart of operations to implement Smart energy meter

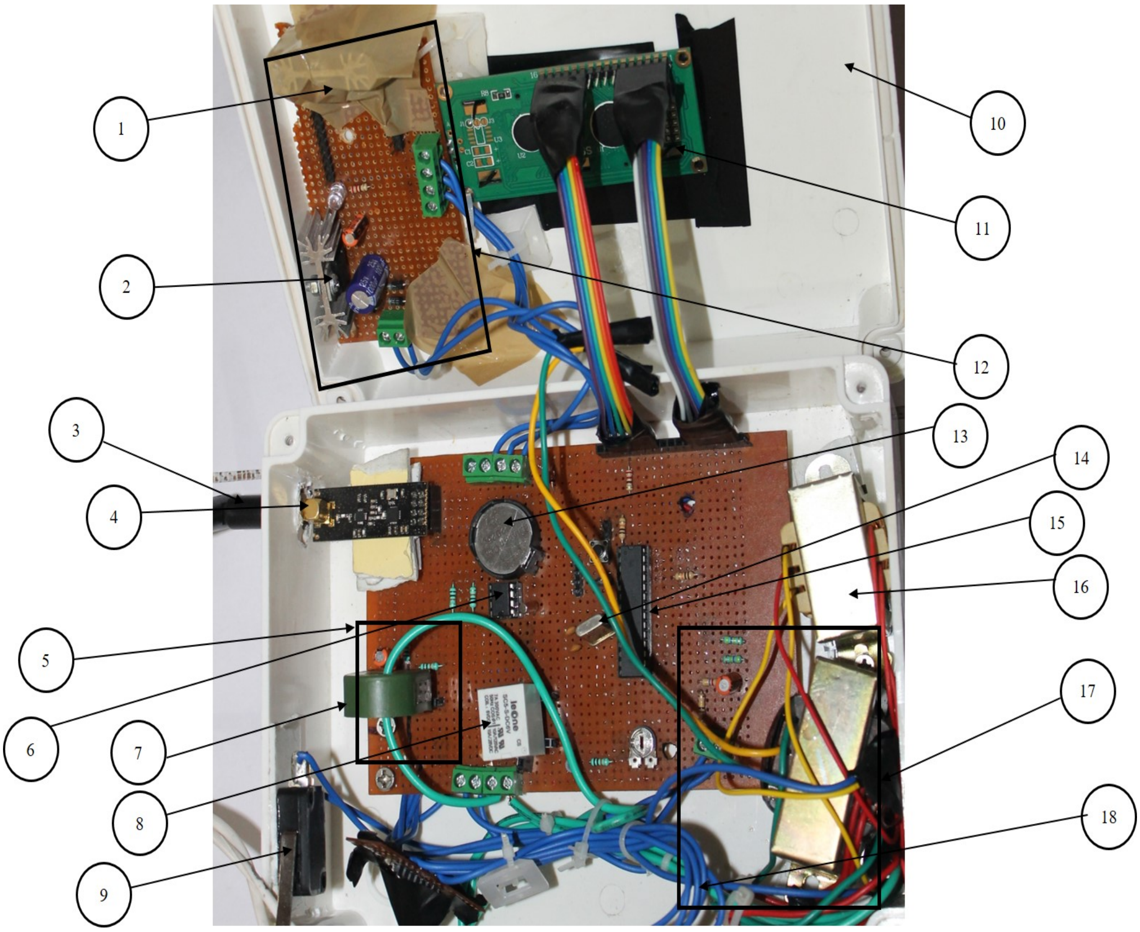

Fig. 4.5: List of main Components of Smart energy meter

Table 4.1: List of main Components of Smart energy meter

S. No.	Component	S. No.	Component
1	LM 1117 IC	10	IP55 compliant enclosure
2	7805 IC	11	16x2 LCD
3	Antennae	12	Power Supply
4	nRF24L01	13	3V Coin Cell
5	Current Sensor	14	16Mhz Crystal
6	DS1302 RTC	15	At mega 328P microcontroller
7	Current Transformer	16	Step Down Transformer
8	Relay	17	Voltage Sensor
9	Tampering Sensor	18	Connecting Wires

4.2.1 *Arduino Uno*

Arduino is an open source and free framework used for building gadgets intelligent items and digital embedded devices that can sense and control devices in the physical world. Arduino incorporates both microcontroller and software which is called IDE (Integrated Development Environment). The IDE is used to to program the microcontroller through computer. Arduino Boards based on different microcontrollers are availablee. Depending on the micro-controller the board have different sets of analog and digital inputs/outputs (I/O). The boards highlight Universal Serial Bus (USB) including serial communication interfaces on a few models. The arduino uses simple version of C++ programming language to program microcontrollers. As per requirements of digital and analog inputs/outputs for the system, Atmel make microcontroller *Atmega328P* microcontroller is selected. Arduino Uno is the board that uses ATmega328P micro-controller. The Fig. 4.6 shows the circuit diagram of Arduino Uno board.

ATmega328P is 8-bit AVR based microcontroller. It has a total of 14 digital I/O pins out of which 6 I/O pins can be used as PWM output (whose output varies between 0-5V), Six analog inputs. It works on 5V DC power which can be given through a power supply. A reset button and ICSP pin headers are provided for easy connections. The board contains all things required for easy interface of microcontroller and computer. The ATmega328 microcontroller incorporates 32 KB of flash memory in addition to it posses 1 KB of EEPROM and 2 KB of SRAM. The Fig. 4.7 shows the pin configuration of Atmega328p microcontroller.

The microcontroller pin number 7,20 and 21 (Refer Fig. 4.7) which are VCC,AREF and AVCC respectively are given 5V regulated DC power supply. The AVCC pin gives power to ADC module & AREF pin acts as a reference for ADC module. Its reset pin is pulled up with a resistor of value *10k* ohms as it of active low type and is connected to ground through a switch to provide a facility of hardware reset to microcontroller. To filter the voltage spikes, decoupling capacitor of ceramic type of value 0.01F are connected between VCC and GND. The decoupling capacitor prevents the sudden rise and fall of voltage across microcontroller. The Fig. 4.8 shows the circuit of Atmega328P microcontroller.

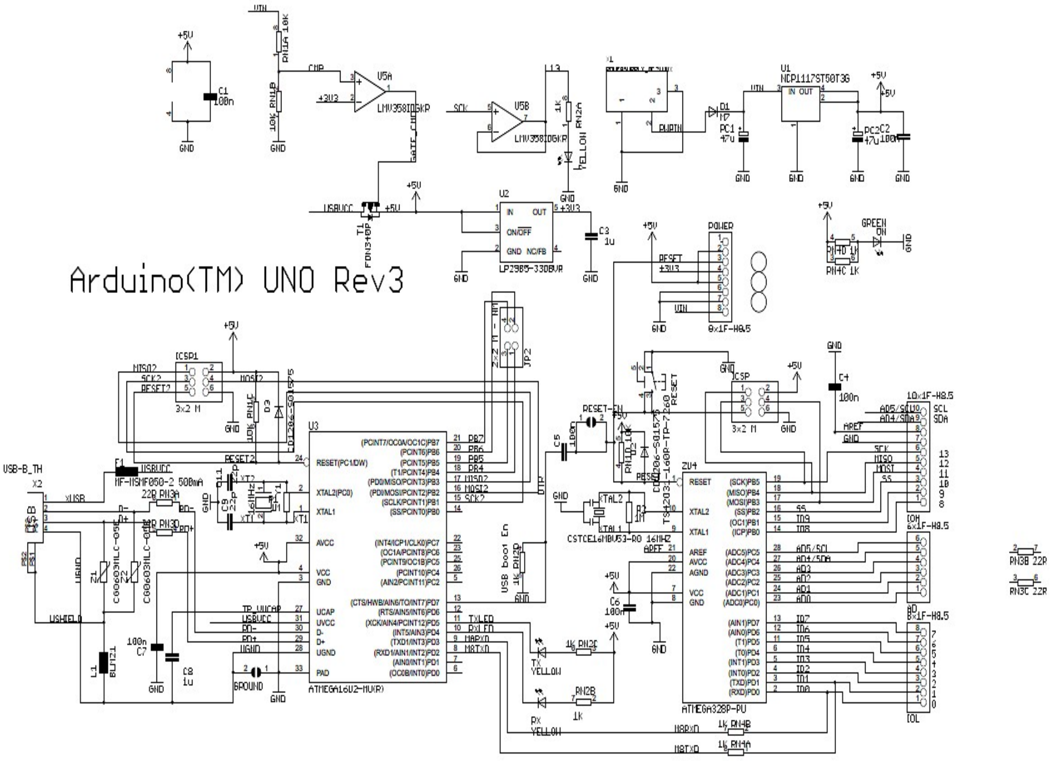

Fig. 4.6: Circuit diagram of Arduino Uno board [23]

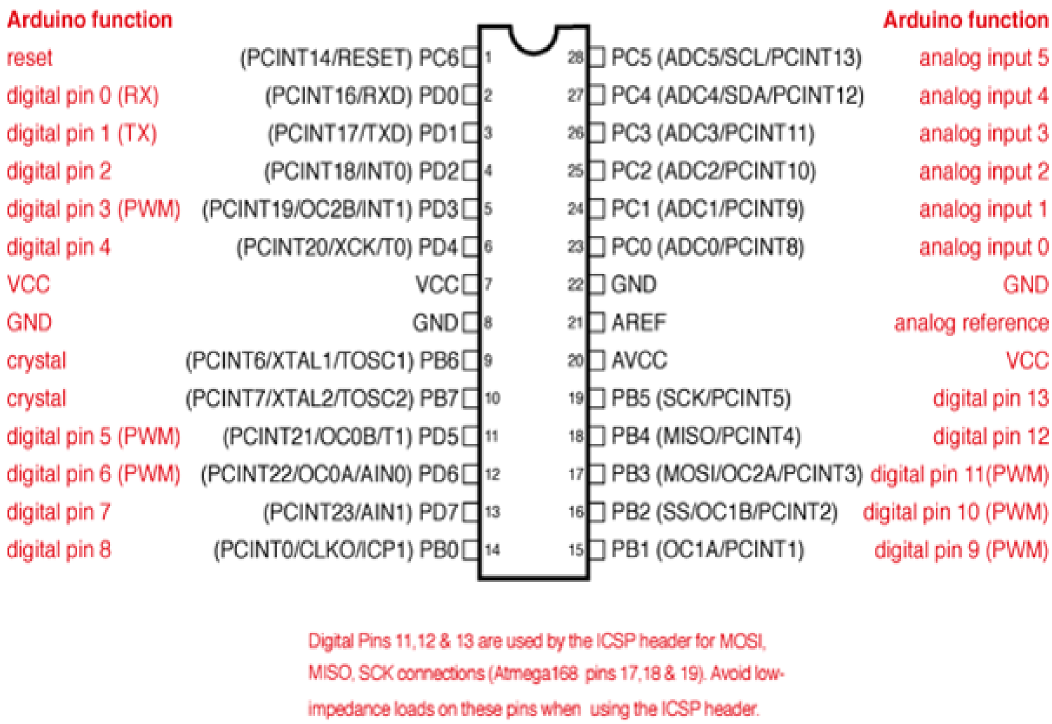

Fig. 4.7: Pin Configuration of Atmega328P [24]

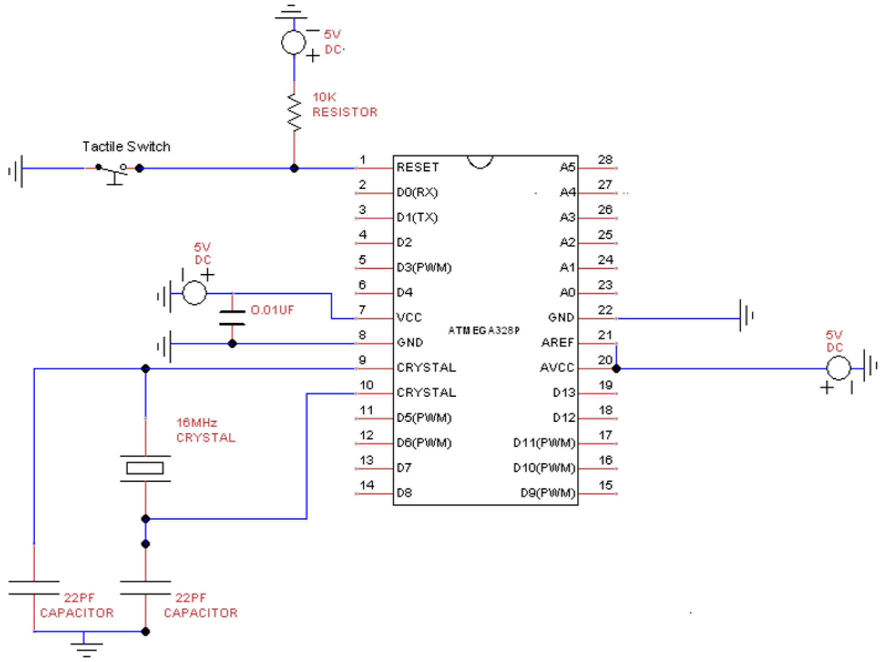

Fig. 4.8: Basic circuit diagram to operate Atmega328P

4.2.2 *Power Supply*

The circuit operates on 5V DC supply. This has to be obtained from input 220V AC supply using a suitable circuit. The 220V AC is first step down to 9V AC through step down transformer. This input is fed to bridge rectifier which converts it to pulsating DC signal. This has to be passed through a filter circuit before input to the voltage regulator. The voltage regulator IC *LM7805* is used in order to obtain a constant voltage. The Fig. 4.9 shows the circuit of Power supply.

The 78xx IC series are fixed linear voltage regulator integrated circuits. Those applications that require regulated power supply use these series of ICs. It is perfect for this application due to its low cost, easy availability and ease-of-use. The xx in 78xx represents the output voltage of the IC i.e. 7805 means its regulated output voltage will be 5V regulated. These ICs have inbuilt over current, overheating and short circuit protection This feature not only protects itself but also other components of circuit. This IC along with an appropriate heat sink can deliver current more than 1A. Fig. 4.10 shows the pinout of LM7805 IC.

The RF transceiver module nRF24L01 operates on 3.3 V which is obtained using 3.3V voltage regulator IC *LM1117-3.3V*. The 5V output from previous circuit is fed to this IC. Fig. 4.11 shows the pin out of *LM1117* IC.

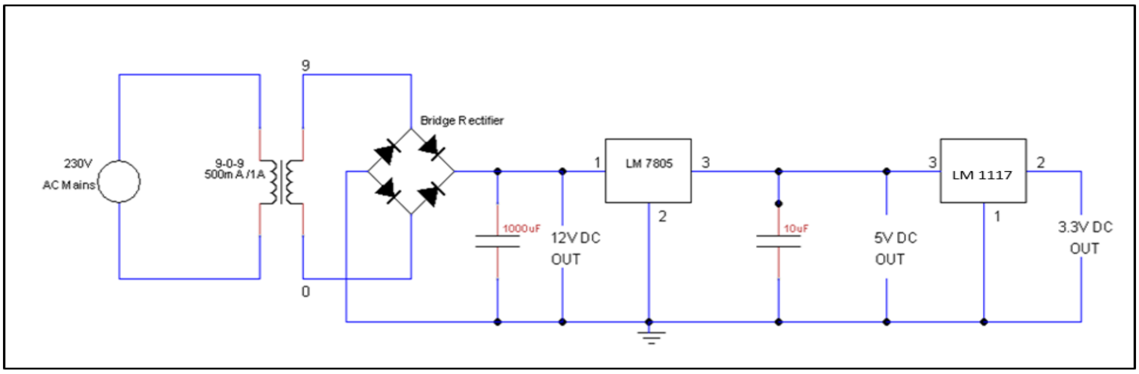

Fig. 4.9: Circuit diagram to convert 230 V AC supply to 5V DC

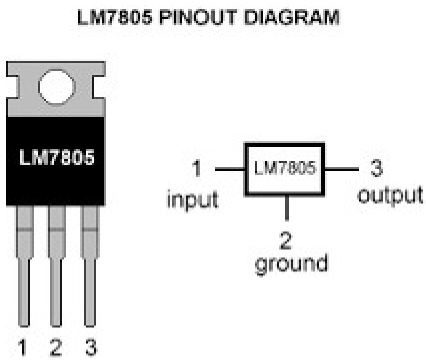

Fig. 4.10: Pin Configuration of 5V Voltage Regulator IC LM7805 [25]

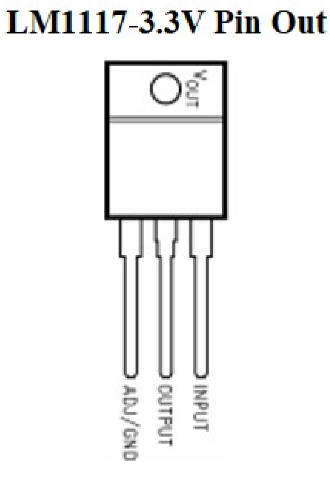

Fig. 4.11: Pin Configuration of 3.3V Voltage Regulator IC LM1117

4.2.3 *Voltage Sensor*

The sinusoidal input voltage signal of magnitude 220 V is stepped down to 9V using a step down transformer. The output voltage has RMS value of 9V so the positive and negative voltage peak will be 12.7V and -12.7V respectively. The output voltage level of the transformer is directly proportional to the input voltage. The Voltage input to microcontroller should be proportional to AC input voltage and must be between 0V and 5V. Hence for this purpose, the input 220V AC signal is stepped down to 9V which is further scaled down using a potential divider circuit to bring the signal between -2.5V and 2.5V. To bring the magnitude between 0V to 5V an offset signal of 2.5V is added. The resulting signal is applied to one of analog input of controller. This input value is measured and back calculated to get the instantaneous input AC source voltage. The RMS value of Voltage is calculated using equation 4.3. The Fig. 4.12 represents the circuit diagram and corresponding voltage waveforms : [26].

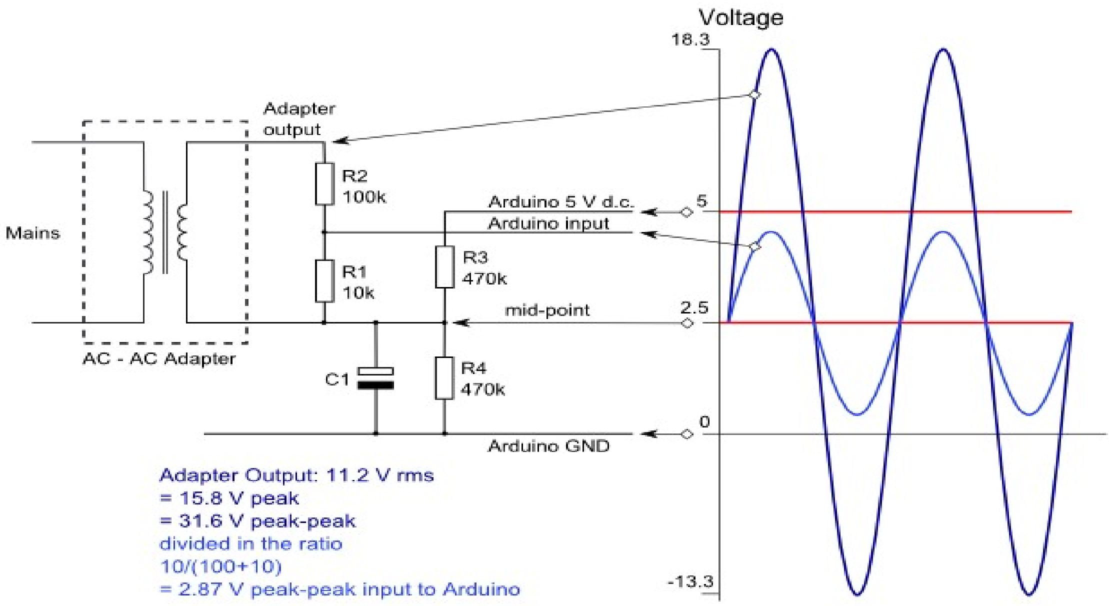

Fig. 4.12: Circuit diagram of Voltage Sensor [26]

4.2.4 *Current Sensor*

It measures the instantaneous load current with help of Current transformer and other peripherals. Current transformers (CTs) are basically step up transformers which are used for measuring alternating current. Similar to other transformers, a current transformer also has a primary winding, a magnetic core, and a secondary winding. The primary winding of the CT is one turn winding which is the current carrying conductor whose current is to be measured. The secondary winding has number of turns made up of fine wire.

$$I_2 = A \times I_1 \quad (4.1)$$

Where:

I_1: Primary Winding current

I_2: Secondary Winding current

A=Turn ratio of CT = No of primary turns / No of secondary turns

The secondary current has to be converted to equivalent voltage across a burden resistor which should be directly proportional to the current drawn from load. The Voltage input to microcontroller should be proportional to load current and must be between 0V and 5V. To bring the magnitude between 0V to 5V an offset signal of 2.5V is added. The resulting signal is applied to one of analog input of controller. This input value is measured and back calculated to get the instantaneous input AC load current. The RMS value of load current can be calculated using eq. 4.4.

A Current transformer should never be open-circuited if its primary winding is energized. As a CT is basically step up transformer so if primary winding is energized with secondary side open circuited, a very high voltage is developed across secondary which is potentially very dangerous for operating personnel. The value of burden resistor can calculated using eq. 4.2 [27, 28]. The Fig. 4.13 represents the concerned circuit diagram and corresponding waveforms.

$$Idealburdenresistance = \frac{(\frac{AREF}{2})}{Secondarypeakcurrent} \quad (4.2)$$

Now as we have obtained the equivalent digital values of instantaneous voltage and current, therefore static power parameters such as RMS voltage and current, Real Power, Apparent Power and Power Factor can be calculated as follows [15]:

Let N samples of voltages (V_1,V_2,V_3....V_N)and current (I_1,I_2,I_3....I_N) are acquired during a period.

- Root Mean Square(RMS) Values

$$V_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_i^2} \quad (4.3)$$

$$I_{rms} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} I_i^2} \tag{4.4}$$

- Power

$$RealPower = \sqrt{\frac{1}{N}\sum_{i=1}^{N} V_i I_i} \tag{4.5}$$

$$ApparentPower = V_{rms} \times I_{rms} \tag{4.6}$$

$$PowerFactor = \frac{RealPower}{ApparentPower} \tag{4.7}$$

$$ReactivePower = \sqrt{(ApparentPower)^2 - (RealPower)^2} \tag{4.8}$$

Where:

N are the total number of samples taken over a period

V_i represents the i_{th} sampled voltage

I_i represents the i_{th} sampled current

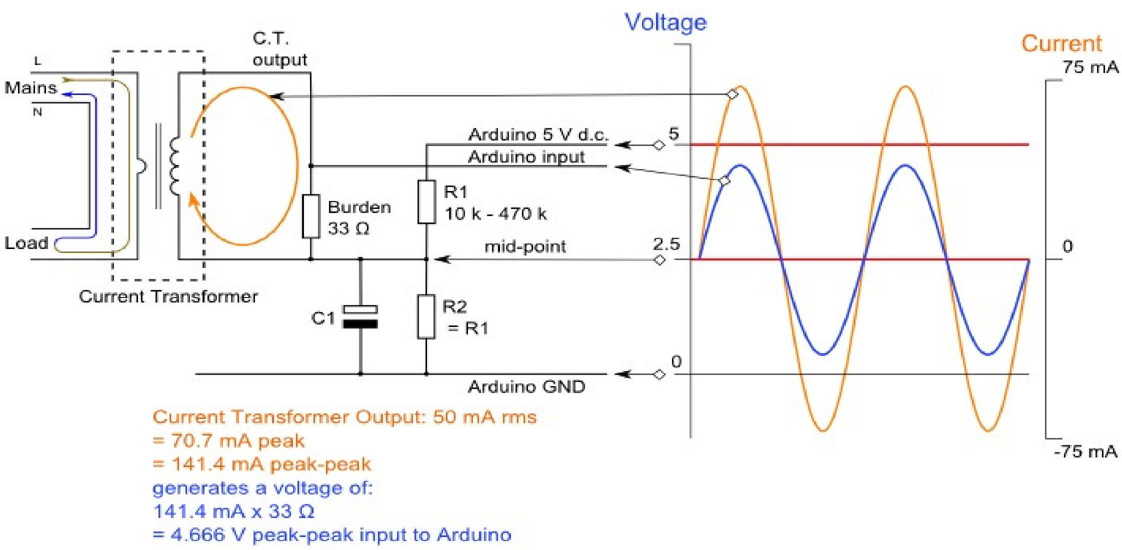

Fig. 4.13: Circuit diagram of Current Sensor [27]

4.2.5 *RF Tranceiver nRF24L01*

The Nordic Semiconductors make module nRF24L01 is basically a 2.4 GHz Radio frequency based transceiver used for communication over short distances. The 2.4Ghz is an International license free frequency band as defined in NFAP-2011. Transceiver is a single unit which can be used for transmitting as well as receiving of data. The module has integrated transceiver along with other peripherals such as Radio frequency synthesizer, baseband logic. It doesnt requires any external loop filter but only resonators, or varactor diodes can serve the purpose. It requires a less expensive crystal, interfacing circuit, and antenna. It has lower peak RX/TX currents (Less than 14mA) and works on power supply ranging between 1.9 to 3.6V. This module offers ultra-low power solution which enables up to years of battery life from a simple coin cell [29]. Fig. 4.14 shows the pin configuration of nRF24L01 module & Fig. 4.15 shows the circuit to interface this module with micro-controller.

Fig. 4.14: Pin configuration of nRF24L01 module

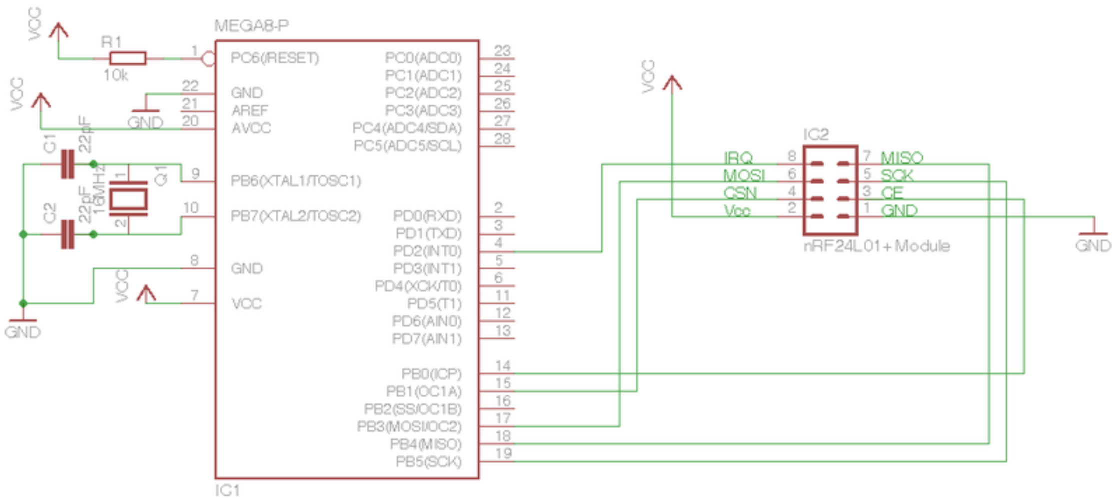

Fig. 4.15: Circuit diagram to interface RF module: nRF24L01 with microcontroller [30]

4.2.6 *Relay*

A relay is an electronically operated electromechanical switch. It consists of an electromagnet which is coupled to a mechanical switch. The mechanical switch operates when the electromagnet is energized. The electromagnet is called coil of relay. Relays are used whenever it is necessary to operate high power application using a low power electronic circuitry. It offers a complete electrical isolation between low and high power circuits. In our application relay is used to connect the input supply to load, so that the load connection can be controlled by microcontroller. Fig. 4.16 shows the circuit to interface relay with micro-controller.

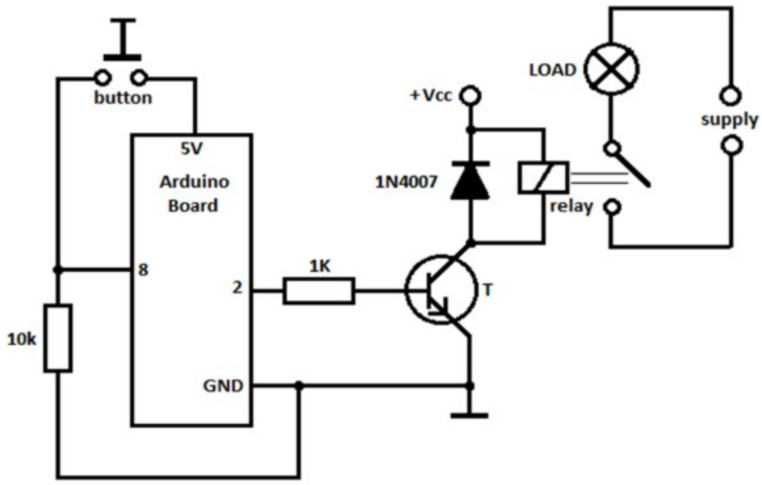

Fig. 4.16: Circuit diagram to interface Relay with microcontroller [31]

4.2.7 *16x2 LCD (Liquid Crystal Display)*

Liquid Crystal Display(LCD) is an electronic output device. Due to its simple interface and easy compatibility with a lot of controllers it is used in wide range of applications. A 16x2 LCD screen is very basic type of display device and is also easily available. 16x2 means that it can display 16 characters in one line and a total of two such lines are there. It can display all characters including special characters and also custom characters which is not possible in seven segment displays. A 16x2 LCD is interfaced with microcontroller to display performance parameters of load on real time basis [32]. Fig. 4.17 shows the circuit to interface 16x2 LCD with micro-controller.

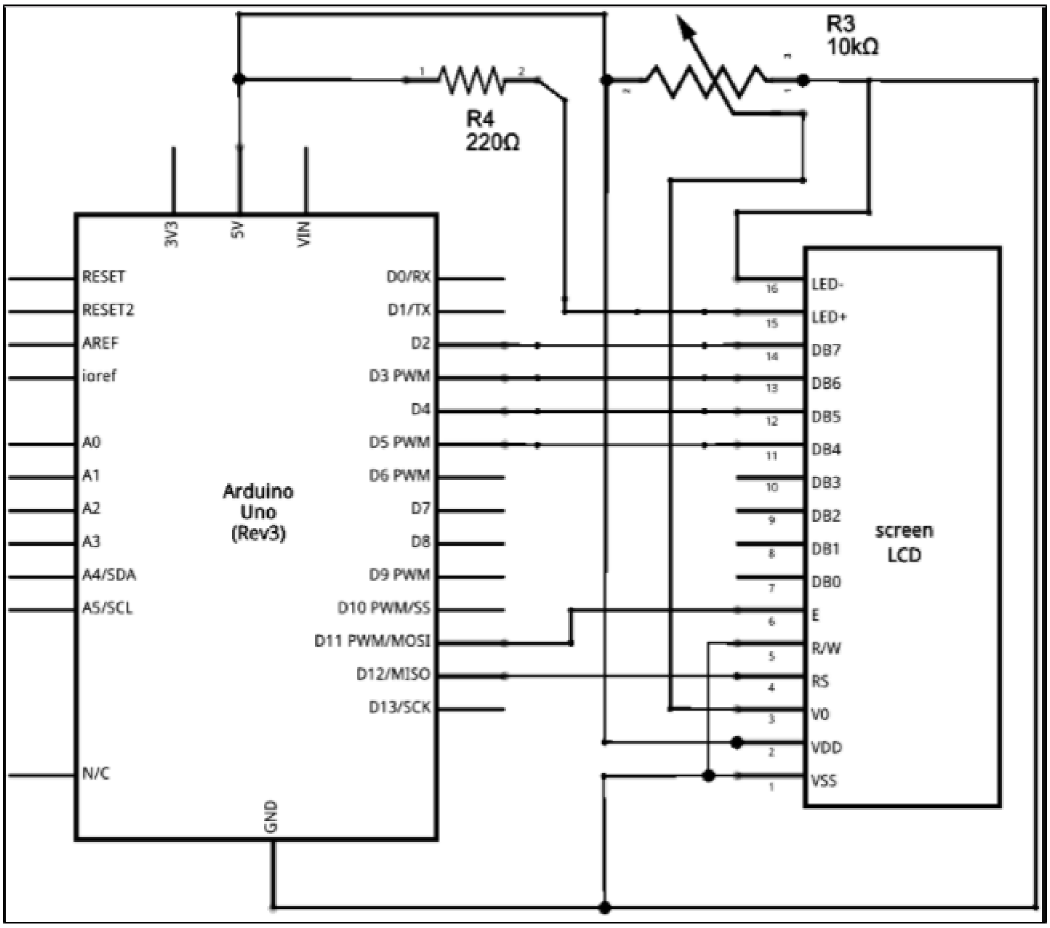

Fig. 4.17: Circuit diagram to interface 16x2 LCD with microcontroller [33]

4.2.8 *Tampering Sensor*

A small Limit switch is used as tampering sensor, whenever someone will try to open the box this limit switch will be operated and microcontroller will detect the event. The Fig. 4.18 shows the circuit to interface a limit switch type tampering sensor with micro-controller [34].

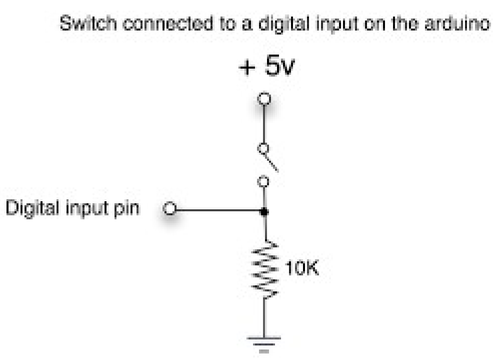

Fig. 4.18: Circuit diagram to interface Tampering Sensor with microcontroller

4.2.9 *Real Time Clock (RTC)*

As the name suggests the module tells the real clock time to the microcontroller. A number of RTCs are available for use. In this project the RTC IC DS1302 is used. The controller can be programmed so that it wakes up between particular time intervals for performing a task and then goes into sleep mode for rest of time as energy saving measure. This can only be done with help of RTC. The DS1302 IC contains a real-time clock and 31 bytes of SRAM. Its easy communication with most of micro controllers using a serial communication interface makes it favorable for our application.

The RTC provides seconds, minutes, hours, day, date, month, and year information to the microcontroller. The RTC operates in two modes, the 24-hour mode or 12-hour mode with an AM/PM indication. The DS1302 operates on 32.768 kHz crystal and consumes low power. It can retain data and clock information for a long time using a simple 3.3V coin cell. Its pins no. 1 and 2 are connected to 32.768 kHz crystal which helps in keeping track of time. Coin cell battery of 3.3V which is usually CR2032 is connected to 3 and 4 pins to retain time even when there is no power. It communicates with ATmega328P through I2C (Inter Integrated Circuit) protocol [35]. Fig. 4.19 shows the circuit to interface DS1302 RTC with micro-controller.

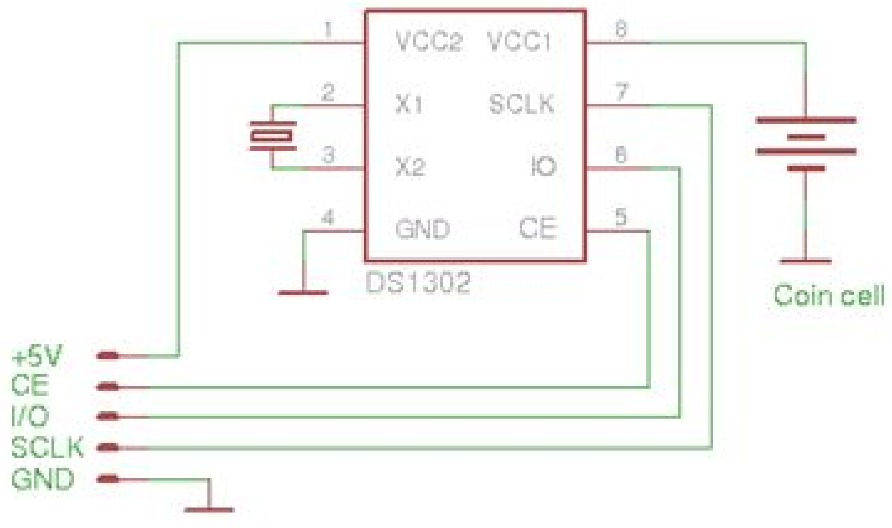

Fig. 4.19: Circuit diagram to interface DS1302 RTC with microcontroller [35]

The Fig. 4.20 and Fig. 4.21 shows the implemented two Smart Energy meters with unique Meter Id and Fig. 4.22 shows the load used for testing purposes.

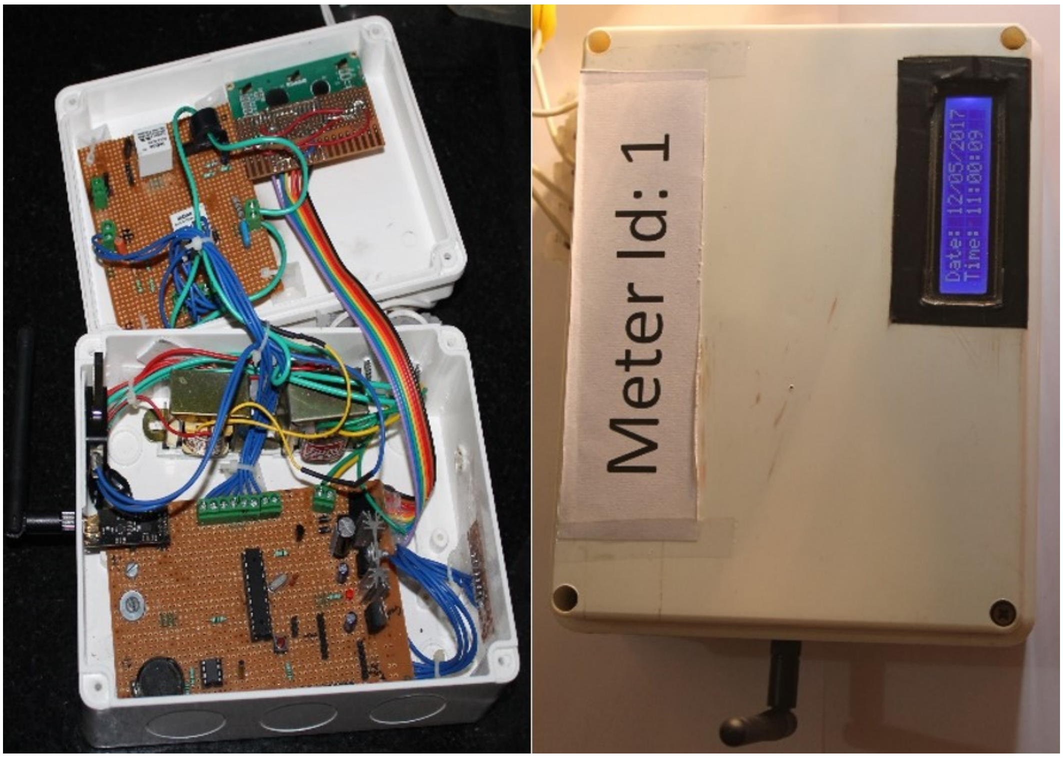

Fig. 4.20: Implemented Smart Energy meter: 1

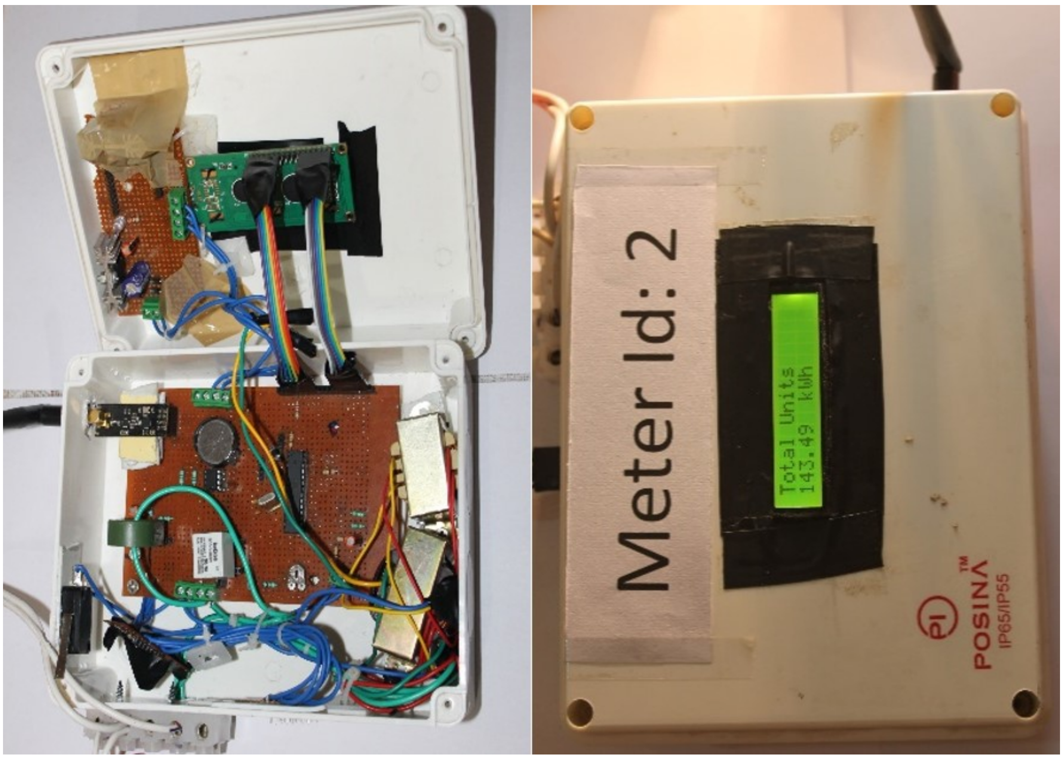

Fig. 4.21: Implemented Smart Energy meter: 2

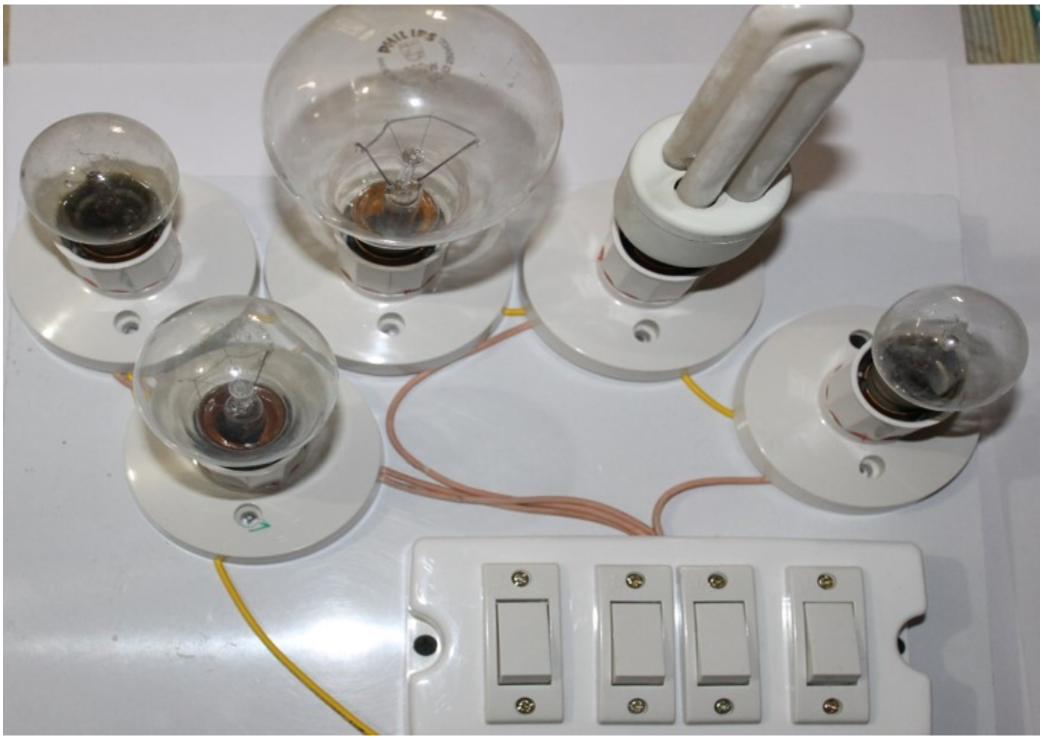

Fig. 4.22: Load Used for Testing purpose

4.3 DESCRIPTION OF DATA CONCENTRATOR UNIT (DCU)

It receives data from multiple SEM's via Radio frequency module *nRF24L01* and transfers it to Remote Server on real time basis.Fig. 4.24 shows the circuit to interface RF module with Raspberry Pi. It comprises of ARM based microcomputer Raspberry pi 3 to perform its operations. It runs on Linux based operating system (Raspbian). Publish/Subscribe messaging system is used for communication between DCU and remote server. It needs active Internet access for data transfer which can be provided either through broadband, Wi-Fi, Ethernet or mobile data as per easy availability in region. In case mobile data is to be used USB 3G/4G dongle can be used. A software based RTC is incorporated in DCU which updates itself as soon as it is connected to Internet. Schematic and flowchart of operations to implement this station is shown in Fig. 4.23 and Fig. 4.25 respectively.

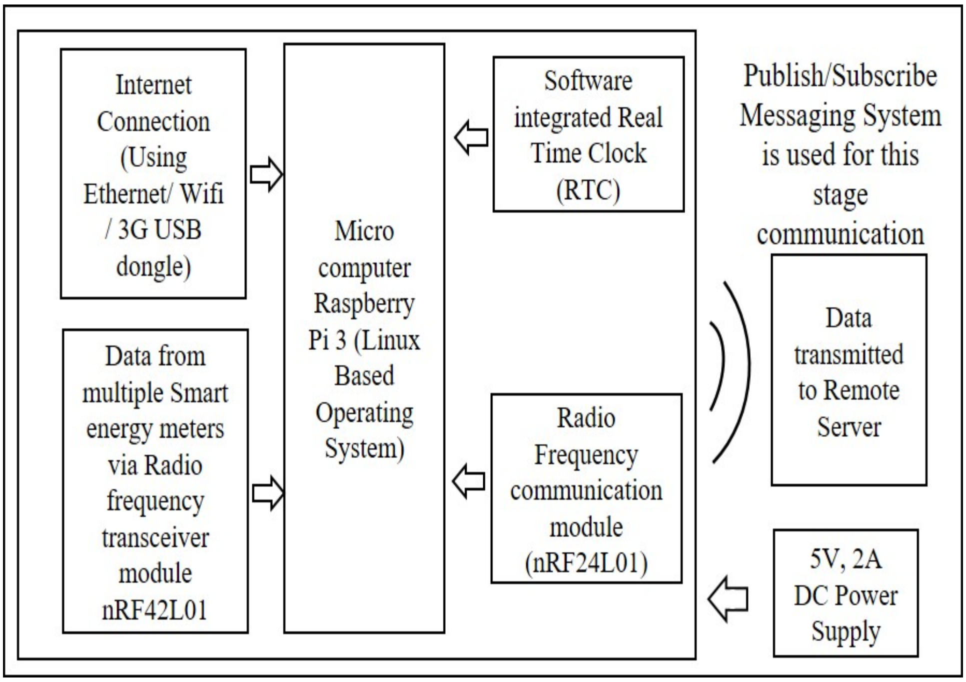

Fig. 4.23: Schematic of DCU

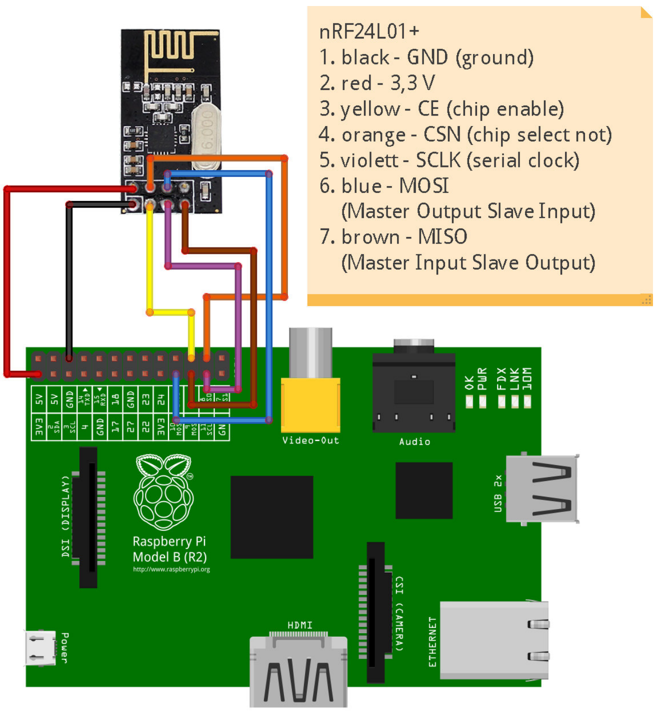

Fig. 4.24: Circuit to interface RF module: nRF24L01 with Raspberry Pi 3 [36]

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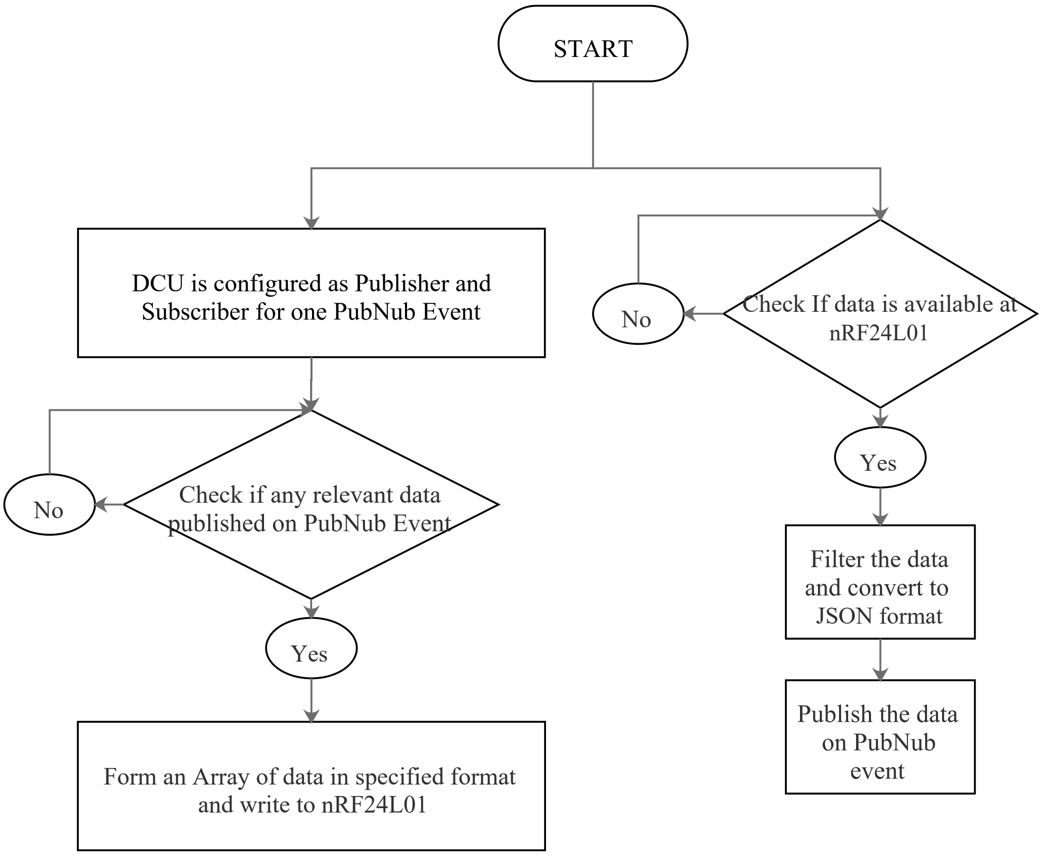

Fig. 4.25: Flowchart of operations to implement DCU

4.3.1 *Raspberry Pi 3*

The Raspberry Pi is small microcomputer of credit cart size. Different series of this single-board computer has been developed till now. It is developed by Raspberry Pi foundation in United Kingdom. Now a days third generation of Raspberry Pi is available. Raspberry Pi 3 includes ARM based quad core CPU (ARM Cortex-A53, 1.2GHz), a Broadcom BCM2837 SoC (System on a chip). It operates on Linux based Operating System *Raspbian* and incorporates Broadcom Video Core IV as on chip graphics processing unit (GPU). The Foundation encourages scratch and python as main programming language. In addition to this, it provides easy compatibility and support with many other languages. The foundation offers Linux based operating system: Raspbian, a Debian-for download. In addition to above it has following features:

- It offers Bluetooth Low Energy.
- It has 1Gb of 900MHz LPDDR2 RAM.
- It offers Networking using 2.4GHz 802.11n Wireless as well as Ethernet.

- External Micro SD card can be used as storage device.
- It has 40 GPIO pins.
- Ports available are: 4 USB 2.0, 3.5mm analogue audio-video jack, Display Serial Interface (DSI), HDMI, Camera Serial Interface(CSI) [37].

The Fig. 4.26 shows detailed description of Raspberry Pi 3, Model B and Fig. 4.27 shows the implemented DCU based on Raspberry Pi 3 and interfaced with *nRF24L01* RF Transceiver

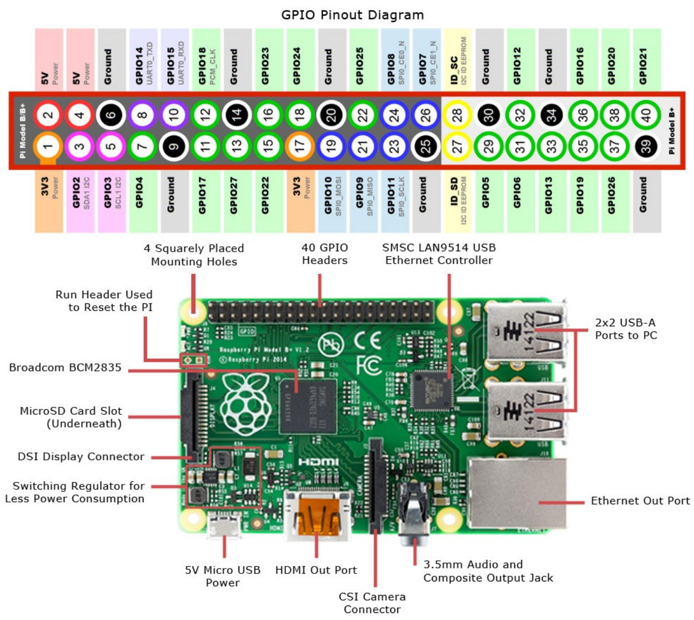

Fig. 4.26: Description of Raspberry Pi 3 [38]

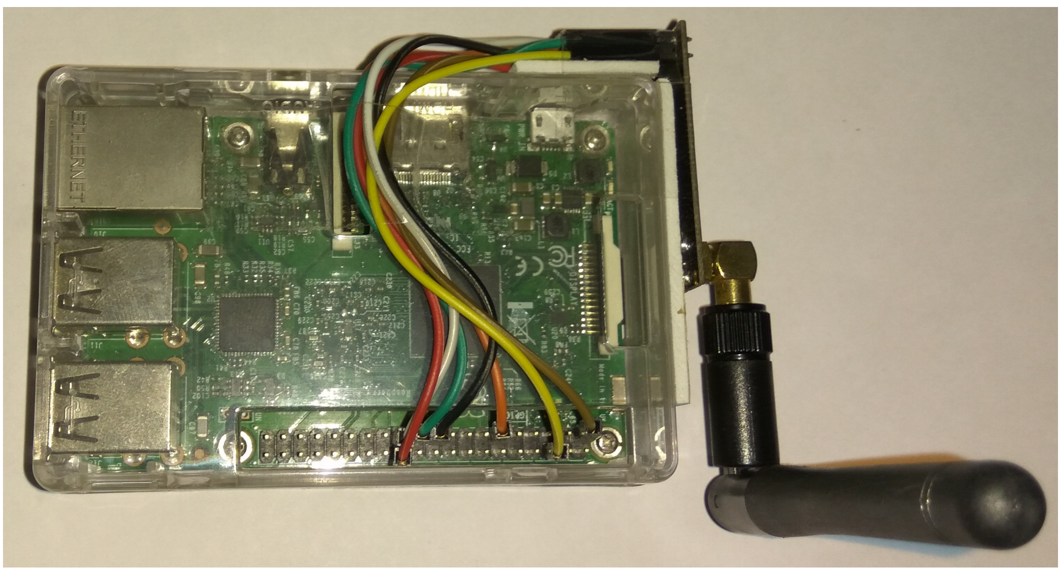

Fig. 4.27: Implemented Raspberry Pi based DCU

4.4 REMOTE SERVER

It is simply a computer machine which is capturing the data from cloud platform and storing it in a database. It may be of virtual machine type. In computing, a virtual machine (VM) mimics a computer system that provides the functionality of a physical computer and are based on computer architectures. It can be Linux or windows operating system based as per the choice of the user that can be configured to perform specific task. In the implemented system a Laptop is used as Remote Server. In the real world system these virtual machine services can be hosted on servers which are provided by many leading companies such as Amazon, Google etc. on chargeable basis. Graphical User Interface (GUI) is made for easy monitoring and data access by an authorized person.

The remote server side script is written in Python programming language. NoSQL type of database: MongoDB is used in this work. MongoDB is very light weight database that is perfect for storing unstructured and real time data. MongoDB database server must be installed. Other Python Libraries which needs to be configured before use are PubNub publish/subscribe API library, Twilio, API, PyMongo, Matplotlib, Tkinter. Tkinter is only package for developing Graphical User Interface (GUI) that is available in Python standard library package and is free for use. PubNubs real time data streaming based on Publish/Subscribe messaging model is used to communicate between Server and DCUs. The brief description of interfaces used is given in next section.

4.4.1 *Description of Interfaces*

The remote server has to capture the data from number of DCUs through a common cloud framework. A Publish/Subscribe messaging system is used for this purpose. The Publish/Subscribe system realized by PubNub is used in this work which is described below. This data is stored in NoSQL type database: *MongoDB*.

I. Publish/Subscribe Messaging System

Publish Subscribe is an expression used to portray an application system in which provider of a information (Publisher) is decoupled from the customers of that information (Subscriber). It is an is an asynchronous messaging system. Publishers do not send the data to a particular receiver. Rather, the published messages are separated into events, unmindful of the subscribers.

Subscribers express enthusiasm for at least one event, and just get messages that are of their interest, with no consciousness of the sender. All the subscribers which are subscribed to event of interest will receive the message sent by any sender to that event [39].

A wireless sensor can be configured as Subscriber, Publisher or both for multiple events. Communication entities are decoupled in time as well as space in this model. Space decoupling means that communication entities are unknown to each other. Time decoupling means that both need not to active at same time [40]. We have used PubNub real-time data streaming which utilizes Publish/Subscribe messaging system for this purpose.

The main components that build a data stream are API Keys, Messages, and Channels. It includes built in AES encryption and optional TLS/SSL encryption. In this model channels are handled in a lightweight manner. Application Programming Interface (API) is basically an interface that helps any user to access any third party application within its own program. It is a set of different commands and data built by the application provider and is specific for each programming language. Keep in mind that an API is a portrayal of how to advise another application to get things done for the third party and trade information programmatically. While a site or an application might give you a chance to give commands and get information related to that site.

PubNub provides APIs in 70 different programming languages for accessing its real time data streaming network which utilizes Publisher/Subscriber messaging System. API keys are unique keys for configuring a client as Publisher and Subscriber. If a client is configured only as Subscriber then the client has to initialize only with subscriber key and if it is configured as Publisher it has to initialize with both subscriber as well as publisher key. Unlimited number of channels can be created for one set of API keys.

A message comprises of a channel, and its related information payload. A sender customer distributes messages to a given channel, and a subscribing customer gets just the messages related with the channels its subscribed to. PubNub. Message payloads can contain any JSON information including Booleans, Strings, Numbers, Arrays, and Objects. All messages are related to some channels. A Channel is basically an event or a Topic to which multiple clients are connected. The sender and receiver in this system doesn't know each other and are connected through this channel. For a particular API key each channel must have unique name. Two types of channel designs are possible:

a. Unicast (One to One Communication) In this design there can be a unique channel for one to one communication. Each subscriber only listens to the channel of its interest so it receives only the relevant data, hence the need of filtering out data is eliminated in this design. So the processing rate reduces and network usage is minimized. Fig. 4.28 shows the basic structure of this design pattern.

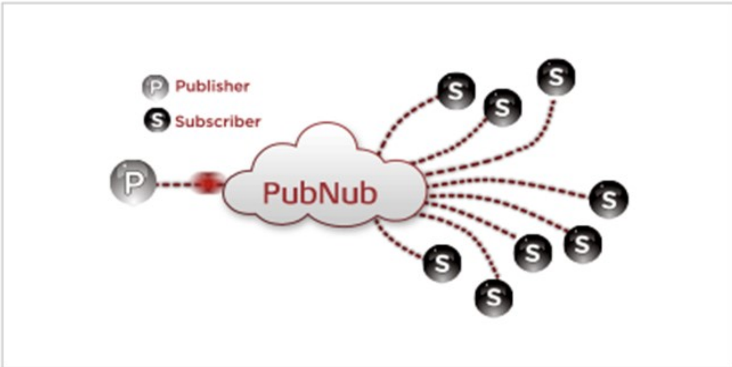

Fig. 4.28: Basic scheme of Unicast Design of PubNub Communication Channel [41]

b. Multicast (One to Many Communication) In this design pattern the channel is used for global communications with multiple clients. Each subscriber receives the messages published by any sender, so the message has to be filtered out by each client before processing. This type of channel is normally referred as public channel. Fig. 4.29 shows the basic structure of this design pattern.

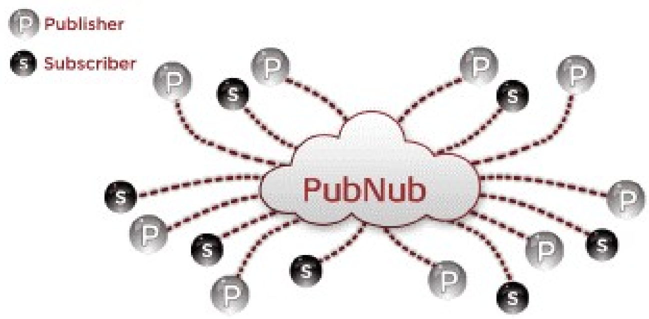

Fig. 4.29: Basic scheme of Multicast Design of PubNub communication channel [41]

In the Proposed system the DCU and the remote server both are configured as Publisher as well as Subscriber for same channel/event service as shown in Fig. 4.30. This is required in order to enable bi-directional communication between smart meter and utility. The steps for Message delivery to receiver in PubNub is as follows:

a. The client requests the publisher to publish some data to PubNub event.

b. It transfers the published message to all subscribers of that particular event.

c. Subscribers which are active listeners receive the published message in their client application. [41]

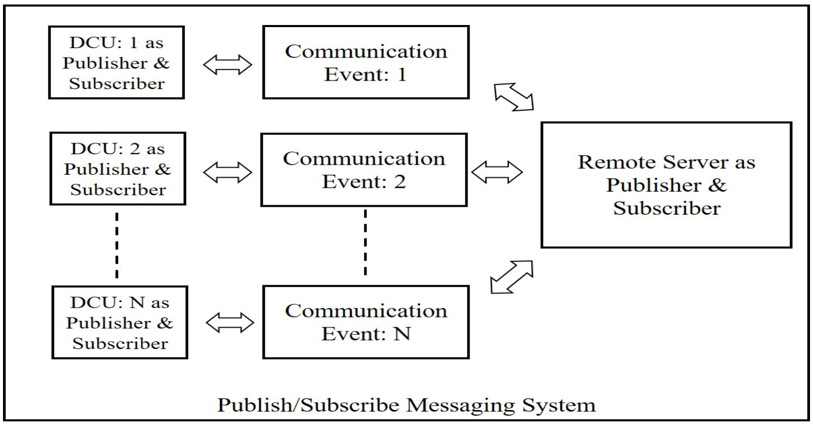

Fig. 4.30: Basic structure of Publish/Subscribe messaging system

II. MongoDB- No SQL Database

MongoDB is a free and open source No SQL database which is written in C++ programing language. It is a cross-stage, document oriented database that gives, high execution, high accessibility, and simple versatility. It deals with idea of collection and document It stores data in BSON format. BSON, stands for Binary JavaScript Object Notation. BSON is basically a binary JSON (Javascript Object Notation) that includes ordered lists and provides some additional data types.JSON format is simple document format with dynamic schema. It is a lightweight text based specially designed for easy human reading. MongoDB makes integration of data very simple, easier and faster. This database system is developed by a company called 10gen [42]. A single MongoDB server has many databases and each of these databases have its own set of files located on the file system and contain multiple collections. Each collection consists of multiple documents and is analogous to a table in RDBMS which shown in table A.1.

MongoDB has an added popularity because of its support for secondary indexing and rich queries. This implies that the creation of indexing and querying of indexed fields is much faster and easier. Complex queries can also be created using MongoDB but these queries may not be as complex as made with JOINs in SQL databases. It is not useful for transaction-based projects. In a transactional database, if a single operation fails then the entire transaction will fail. But this does not happen in the case of MongoDB. All the operations are taken up independently by MongoDB. So, if one of the operations fails, the rest of the operation will continue as it is [43].

Table 4.2: Comparison of RDBMS and MongoDB

RDBMS	**MongoDB**
Database	Database
Row	Document
Table	Collection
Column	Field
Database server: mysqld	Database server: mongod
Table Joins	Embedded Documents
Database client: mysql	Database client: Mongo

Database

Database is a physical holder for different collections. Every database gets its own particular arrangement of documents on the document framework. A solitary MongoDB server ordinarily has various databases.

Collection

Collection is a gathering of different MongoDB documents. It is basically an equivalent to table in Relational databases. Different collections exist inside a specific database. Ordinarily, all documents in a particular collection are of comparative or related reason.

Document

A document is an arrangement of key-value sets. Documents will include dynamic schema. Any record in MongoDB is referred to as document which contains multiple field-value pairs. The data is stored in JSON format and when a new document is inserted, a unique id is assigned to the document and then it is stored in the database. This unique id is called object id and its field name is _id. This id is a 12-byte hexadecimal number. It works without the usage of JOINs to relate the documents as in the traditional relational databases. All the data is stored in a single document and if it is required to store the data in different documents, then these documents can be related using reference fields. Dynamic schema implies that documents in a similar collection don't need a similar set of fields or structure, and basic fields in a collection's document may hold distinctive sorts of information. This format is basically JSON. A simple example of data in JSON format is given below:

{"Personal data": {"name": "Kapil", "age":27, "education": "Post graduate", "home town": "Patiala"}, "Higher secondary": "Non-Medical", "graduation": "B.E", "post-graduation": "M.E"}

The advantages of MongoDB over MySQL Database are summarized as follows:

- It is a schema less database, so, the fields for different documents within a collection may be different.
- It is easily scalable and also has the ability of horizontal scalability which is done by using the method of sharding. Sharding is the process of partitioning a large database into smaller, quicker and much easier to manage parts which are called data shards.
- It is useful as it does not consist of any complex joins.
- It has the ability for deep query i.e. it supports dynamic queries on the documents making it as robust as SQL databases.
- It makes use of the internal memory to store the working set which allows quicker access of the data.
- The conversion of the application objects to the database objects is not required because the JSON format data is being used throughout.

MongoDB can likewise be scaled inside and over various dispersed server data centers, giving new levels of accessibility and adaptability. As the arrangements develop in volume, MongoDB scales effortlessly with no downtime and without changing your application.

4.4.2 *Graphical User Interface (GUI)*

A Graphical User Interface (GUI) has been developed for easy Real Time Monitoring and data access.User has to enter a password in order to access it. The GUI is divided into six sections for easy access of different operations as shown in Fig. 4.31. GUI is made using Tkinter toolkit. Tkinter is used for developing functional professional GUI for python applications. It is the only GUI development package available in python standard library package by default. It is very simple and lightweight toolkit for development of GUI. Tk operates in a loop which is transparent to the developers. It includes themed Tk widgets that gives consistent look to all GUI elements. Widget means a label, button, check box, radio button, text box or progress bar etc. There are different commands for configuring each widget as per user requirement.

The layout managers helps in placement of widgets in different frames and windows. Tkinter provides three types of layout geometry managers : absolute, pack and grid.Real time graphs can be made using Matplotlib graphs in Tkinter window. User have to install Matplotlib library package before using as it is not a part of standard python library. It is basically a graph plotting library for python language and provides API for embedding graphs into python GUI packages such as Tkinter,Qt etc. Its advantage is that it is free to use. Fig. 4.32 shows the steps for implementing different operations through Graphical User Interface (GUI):

- Set mode of operation of system between auto and Manual.
- Configure the time interval of data transfer in auto mode.
- Request data from each meter separately in manual mode.
- Monitor the load parameters in numerical as well as graphical form.
- Know live status of load.
- Remotely handle supply of electricity to load.
- Access the stored data in Microsoft excel document.
- Generate Electricity bill and sends to customer through e-mail and SMS.

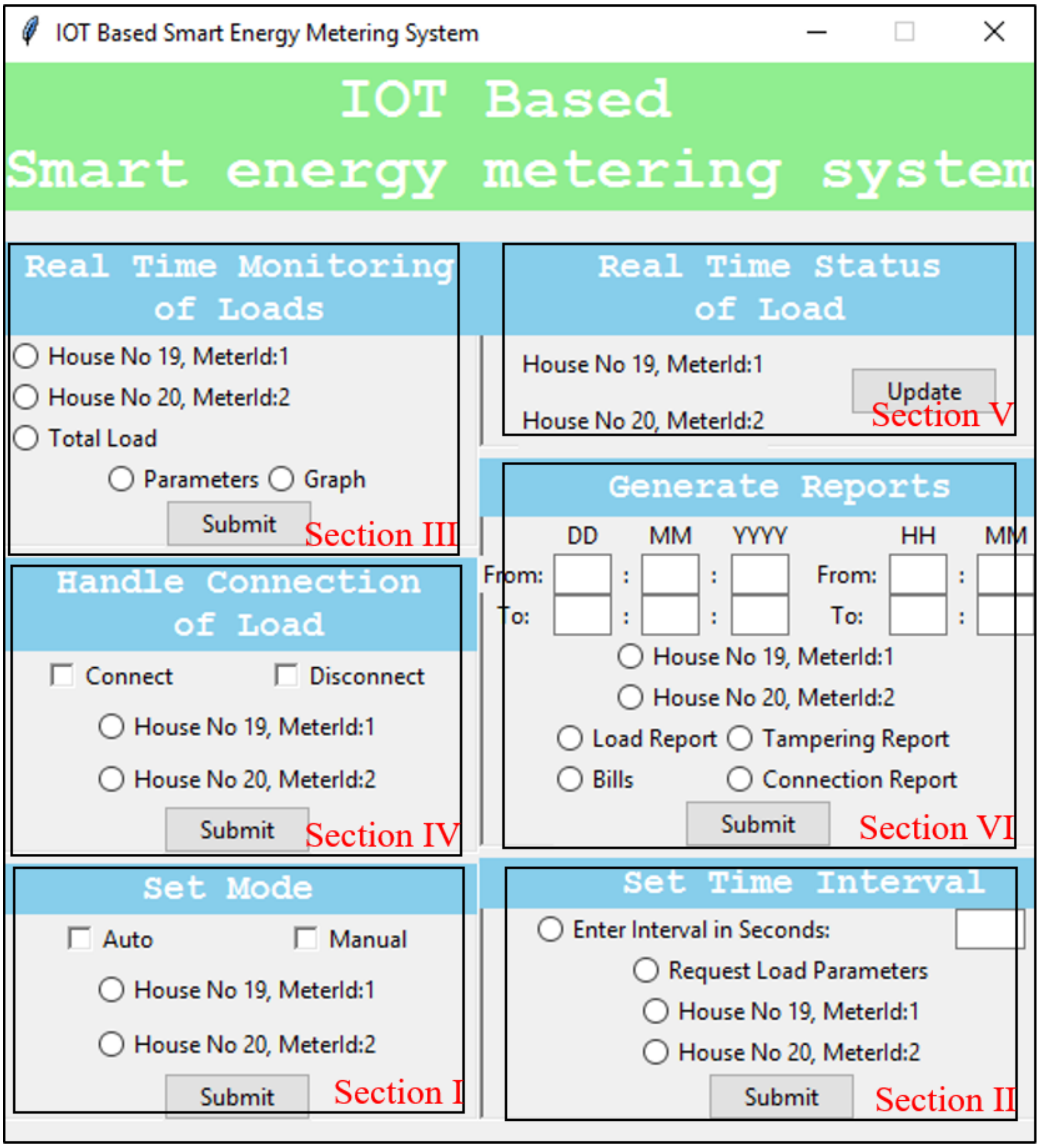

Fig. 4.31: Developed Graphical User Interface (GUI)

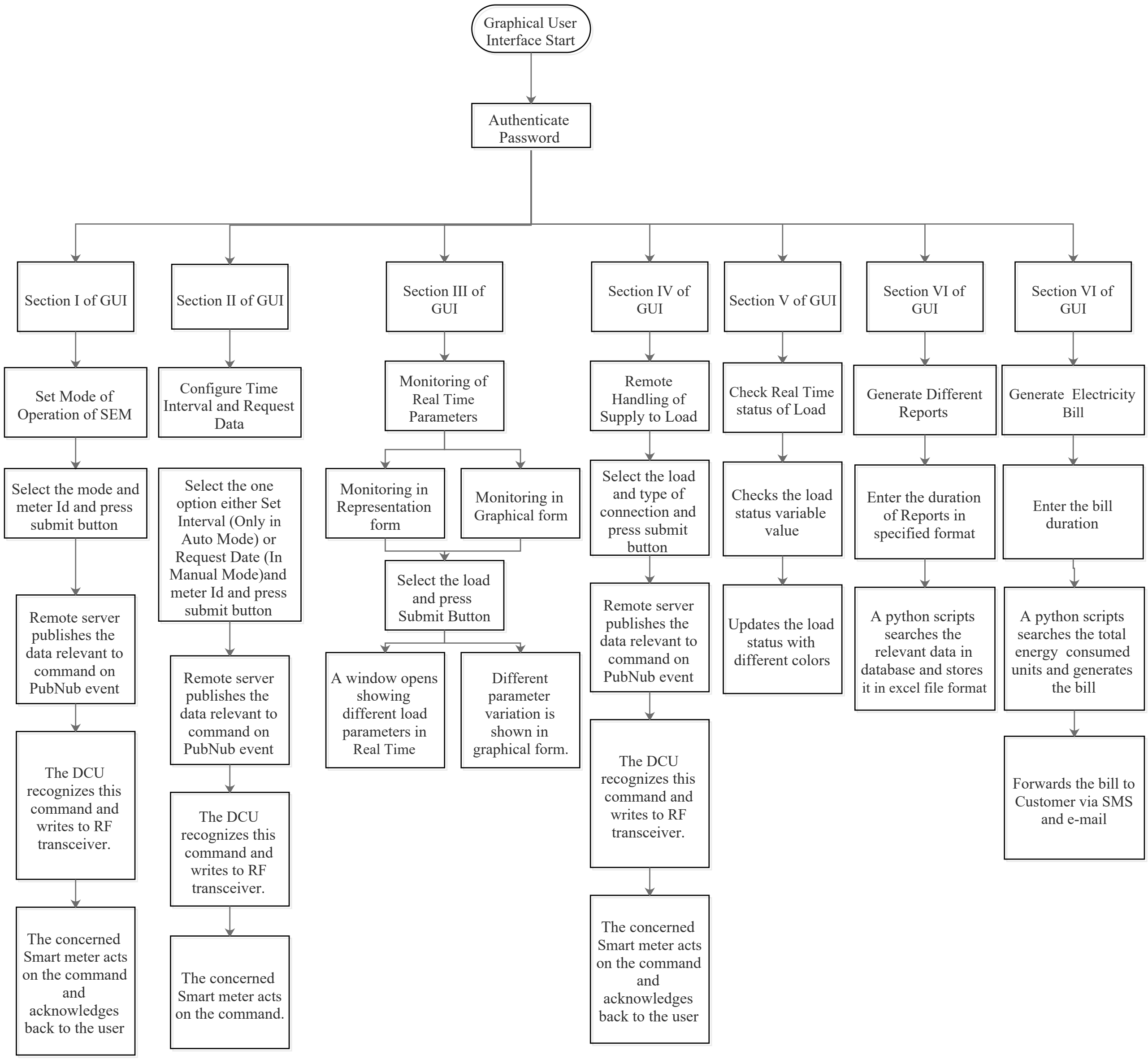

Fig. 4.32: Steps for implementing different operations using GUI

Results and Discussion

The implemented IoT based SEMS measures, displays and communicates the load performance parameters such as Voltage, Current, Real Power, Apparent Power and Power Factor via DCU to remote server on real time basis. Each data packet includes the unique meterId along with other parameters. In this section detailed results have been shown.

Section 5.1 discusses the backend for data transfer from SEM to remote server where it is stored in No SQL type database and second section 5.2 discusses the operations that can be done through GUI in detail. The GUI is mainly divided into six sub sections as shown in Fig. 4.31:

I. Set mode of operation of system

II. Request data and configure time interval

III. Real Time Load Parameter Monitoring

IV. Remote handling of Load supply

V. Real Time Status of Load

VI. Reports and Bill Generation

5.1 DATA TRANSFER FROM SOURCE TO REMOTE SERVER

SEM sends an array of data via nRF24L01 RF transceiver to the DCU which further publishes it to the PubNub event. The array of data contains the unique meter Id, voltage (V), current (A), apparent power (VA), real power (Watts) and consumption units in kWh. The maximum size of data that can be transferred at one time through nRF24L01 module is 32KB. So the whole data is send in two packets one after another. The data packet made for sending parameters is in form of Array that is described below:

1^{st} Data Packet: *[Meter Id, 1, Voltage (V), Current (A), Total Consumption Units (kWh)]*

2^{nd} Data Packet: *[Meter Id, 2, Real Power (Watts), Apparent Power (VA), Power Factor]*

The RF module nRF24L01 has six writing & reading pipes. A pipe basically describes the path of communication by defining pipe address. The pipe address must be same for transmitter as well as receiver. This means that one module can receive data from six transmitters or write data to six receivers. The module can be configured as receiver or transmitter at one time. A mesh network can be realized by using different stages of communication. As soon as the DCU receives these arrays of data it converts it into JSON format and publishes it to the PubNub event. The Fig. 5.1 shows the Python Shell of DCU that depicts the received data arrays from SEM and the JSON object that is published. The highlighted data in Fig. 5.1, 5.2 and 5.3 shows the sample readings:

Parameter	**Value**
Meter Id	1
Voltage	258.52 V
Current	1.31 A
Real Power	327.76 W
Apparent Power	339.34 VA
Power Factor	0.97
Total Consumption Units	49.94 kWh
Date	07/06/2017
Time	14:44:47

The JSON object of the above data that is designed is as below: {“power”: “327.76”, “kva”: “339.34” , “kwh”:“49.93”, “request”: “parameter”, “current”: “1.31”, “pf”: “0.97”, “voltage”: “258.52”, “time”: “144447”, “date”: “20170607”}

There is a string named *request* (refer Fig. 5.1) in this JSON data packet that depicts what type of data is contained. For this type of data its value is set to “parameter ”. The value of this string is different for different types of data packet. Additional strings may be added in other data packets as per requirements.

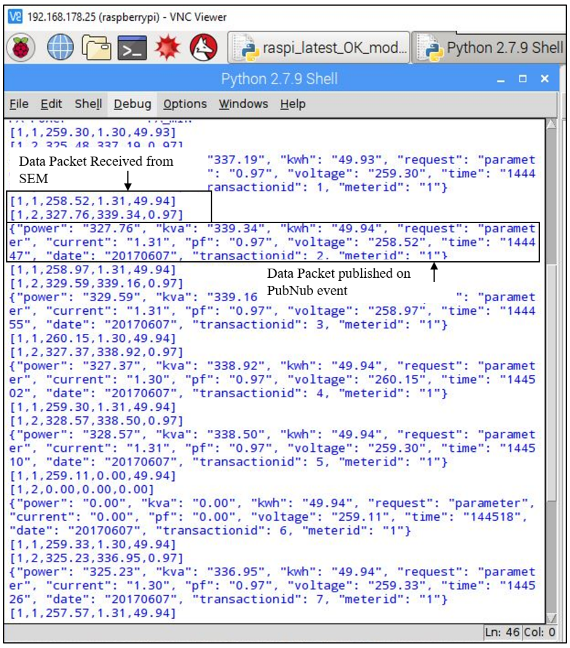

Fig. 5.1: Raspberry Pi Python Shell depicting data received and published on PubNub event

The remote server is configured as Subcriber as well as Publisher to the same PubNub event to which the above data is published. As soon as the data is published, remote server receives that data and stores it in database MongoDB in same JSON format. A Laptop as remote server is used in implemented system in order to test the system. In real world a virtual machine can be hosted to serve the purpose. The Fig. 5.2 depicts the python shell of Laptop showing the data received from PubNub event.

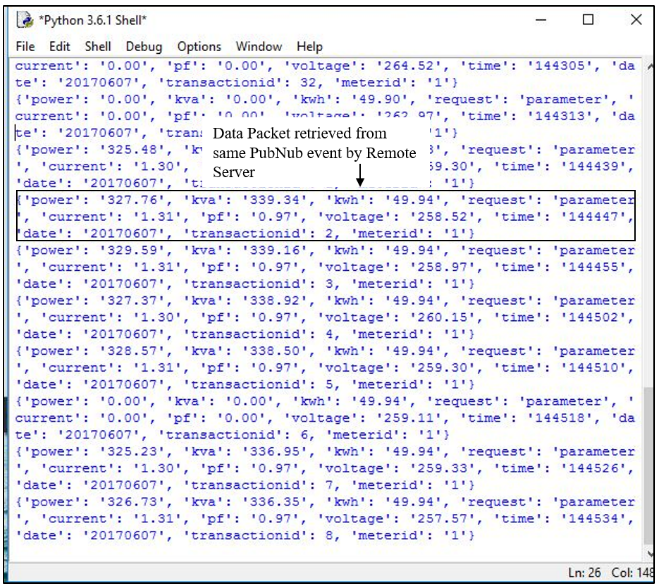

Fig. 5.2: Python Shell of Remote Server depicting the data retrieved from PubNub event

The data is stored in specific collection of particular database. Each entry is stored as a document. The MongoDB library for python language is PyMongo which has to be installed separately as it is not included in standard Python library. The database adds an unique ObjectID to the received JSON object before storing it. The Fig. 5.3 shows the JSON data object that is stored in database.

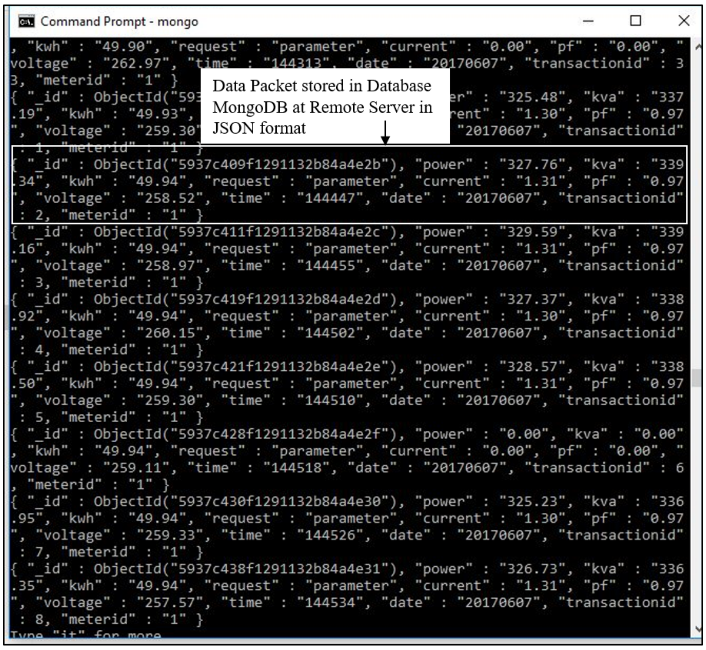

Fig. 5.3: Screen depicting data stored in MongoDB database at Remote server

5.2 OPERATIONS USING GRAPHICAL USER INTERFACE

The Graphical User Interface helps the user to easily monitor the system and access the stored data whenever required. It allows the user to remotely handle the electricity supply to the load and generate as well as forward the electricity bill to customer via e-mail and SMS. Different operations which can be carried out using GUI are presented below:

I. **Set mode of operation of the system**

   The implemented system works in two modes: Manual mode and Auto mode. In manual mode an authorized person can request the required data by sending a command to each SEM while in the second mode every SEM transmits its data to remote server at configurable intervals of time via DCU. The working mode of each SEM separately can be updated with a single click from section I of GUI . As soon as the button is pressed the remote server generates a JSON array for updating the mode of the SEM and publishes it on PubNub event. The DCU receives this data from PubNub event and transmits it to all SEMs via nRF24L01 module after converting it into relevant array. As meter Id is included in the array only the specific meter acts on this command. Thereafter it acknowledges back to remote server the updated mode status via DCU. The Fig. 5.4 shows the acknowledgment received after updating the mode status to Auto and Manual mode.

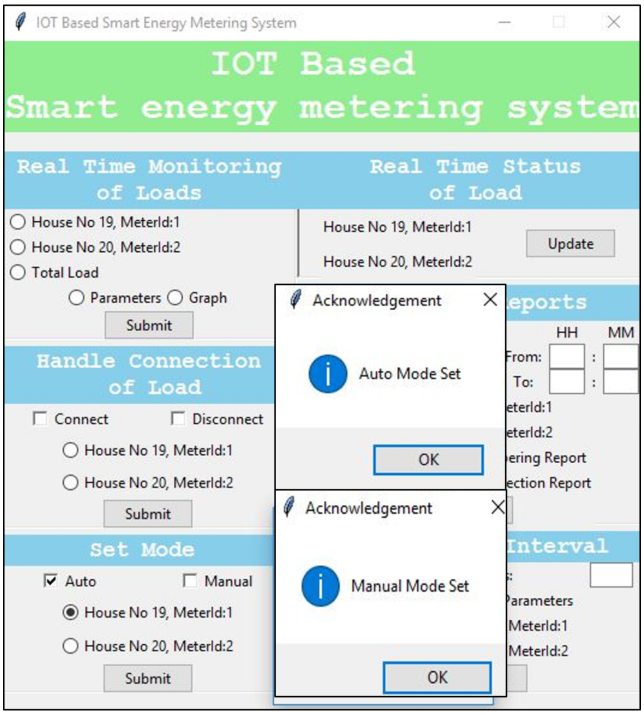

Fig. 5.4: Set mode of operation of any SEM through GUI

II. **Request data and configure time interval**

In Manual mode of operation the user has to request the parameter reading from a specific SEM. It can be done from section II in GUI as shown in Fig. 5.5. The remote server publishes a data corresponding to this on the PubNub event which is transmitted to SEM via DCU. The SEM in return sends the parameter data once which contains total electricity consumption units till now.

The time interval for sending data to remote server by any SEM can be configured though this section of GUI as visible in 5.5. A data packet corresponding to this command is published on event which contains the time interval in seconds. The Fig. 5.6 verifies the time interval between two consecutive data packets is 8 seconds before the command and 30 seconds after submitting the command to update the time interval.

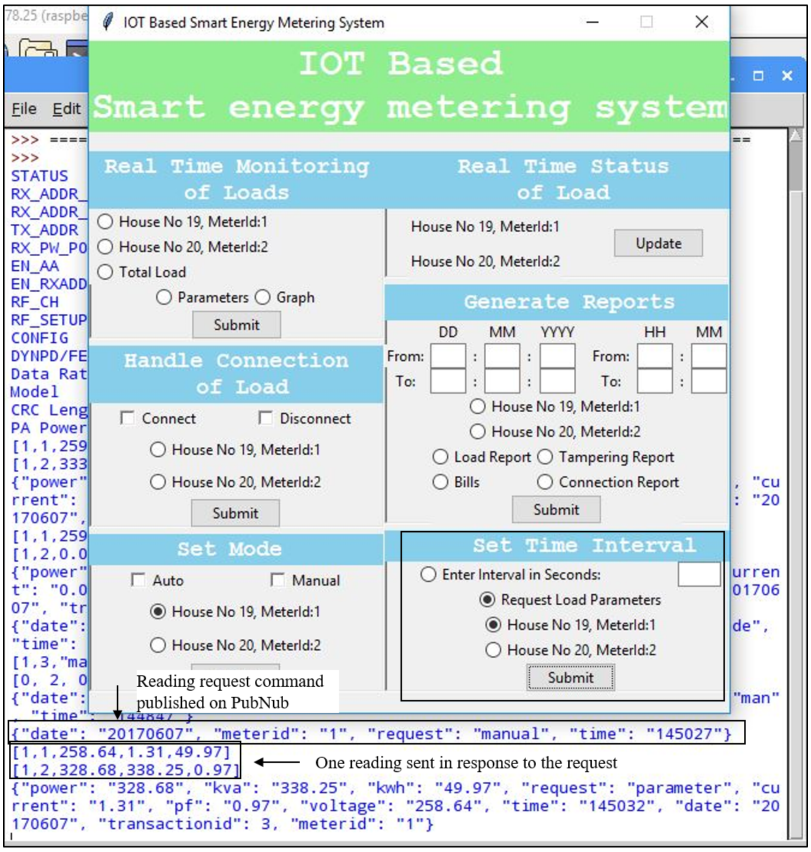

Fig. 5.5: Request parameter data in Manual mode from SEM through GUI

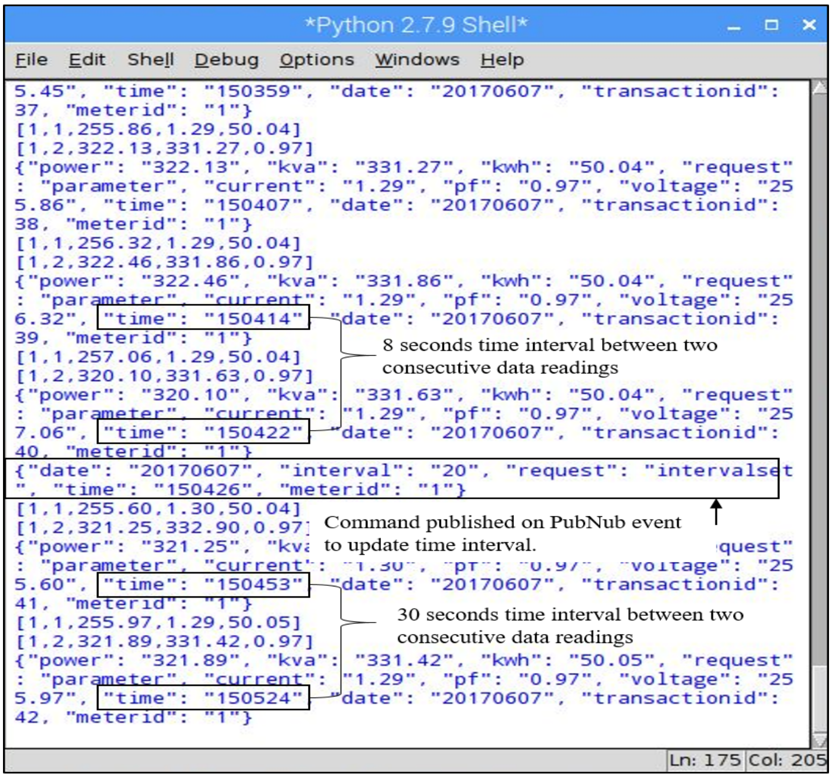

Fig. 5.6: Set Time Interval of consecutive data readings from Remote server using GUI

III. **Real Time Load Parameter Monitoring**

All the real time parameters of each load can be visualized separately in a numerical as well as Graphical form as desired by the user from section III of GUI. As soon as the submit button is pressed after selecting the desired options of parameter, a new window opens showing parameter real time values as shown in Fig. 5.7. The user can monitor the variations of different parameters simultaneously such as Voltage, Current, Real Power and Power factor graphically with time as shown in Fig. 5.8.

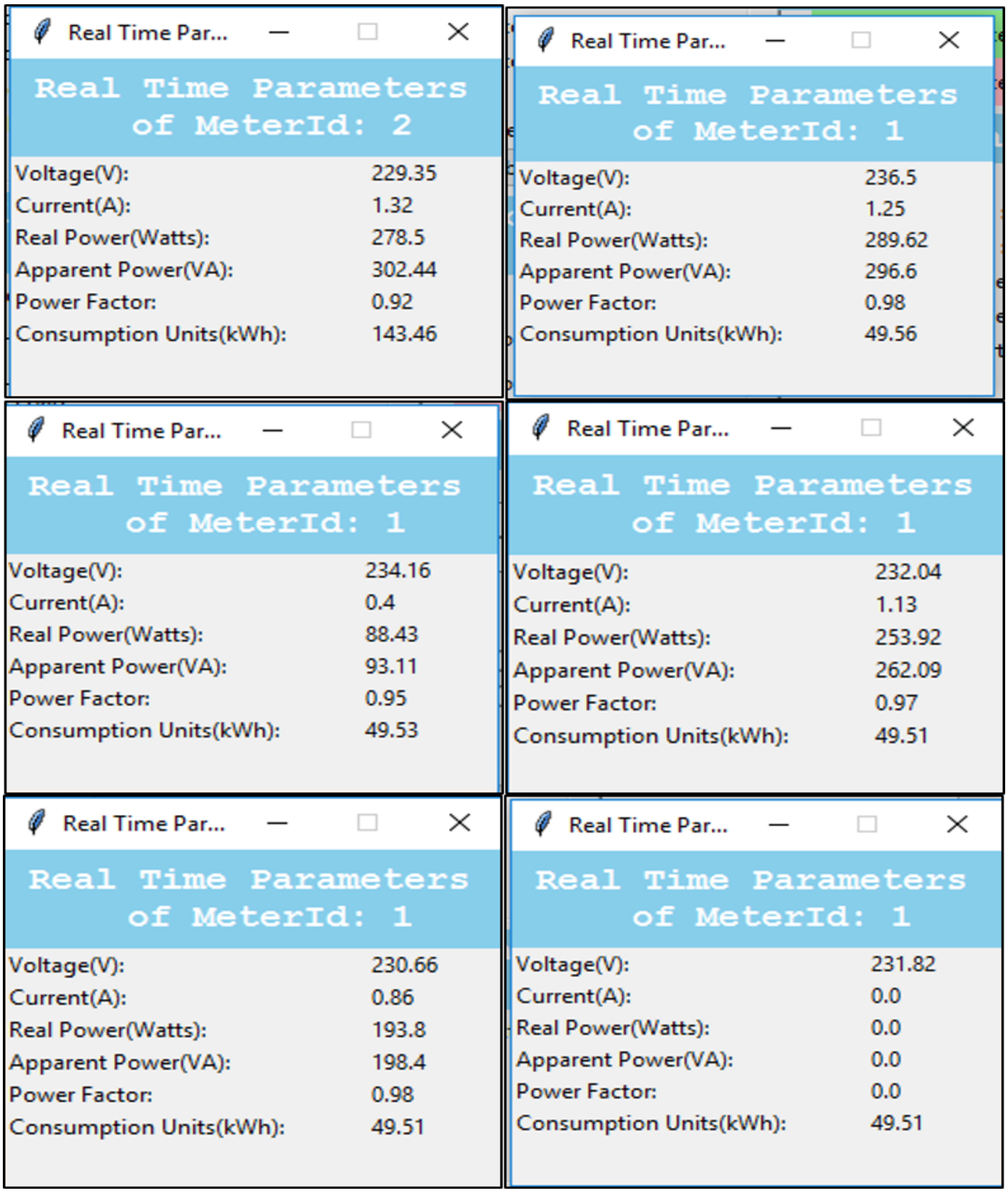

Fig. 5.7: Monitoring of Real Time Load Parameters through GUI

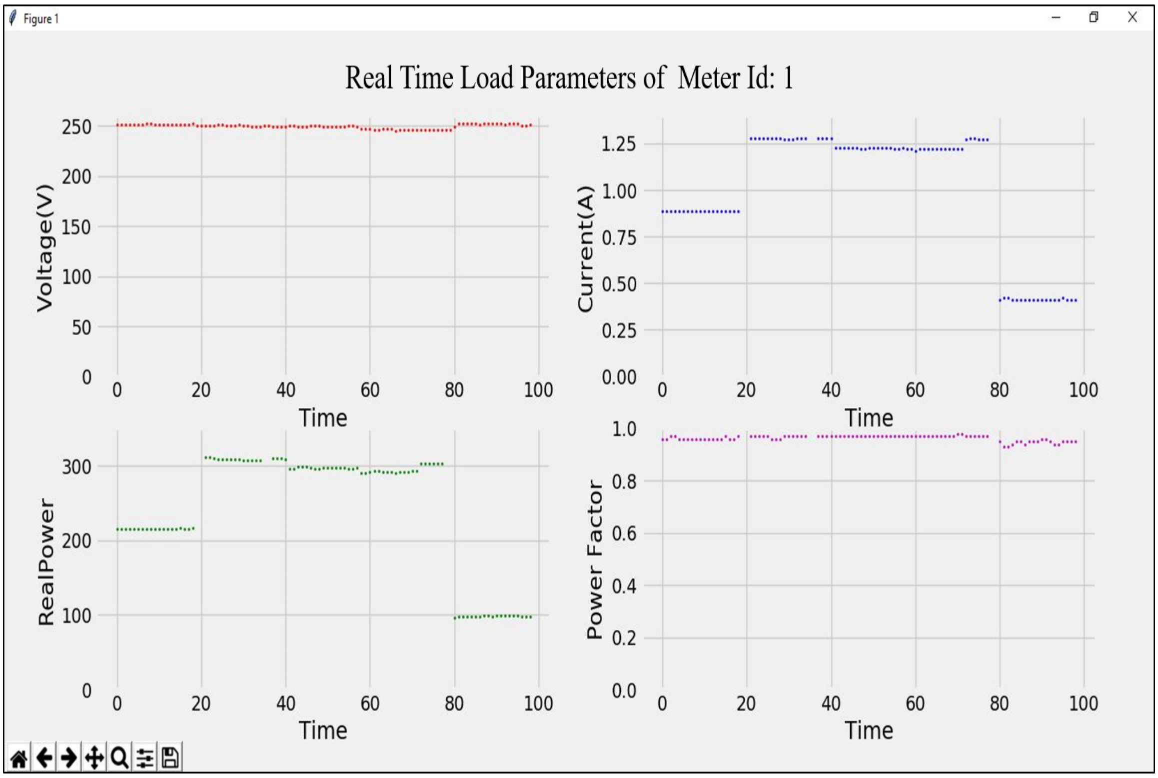

Fig. 5.8: Graphical variation of load parameters of meter 1 through GUI

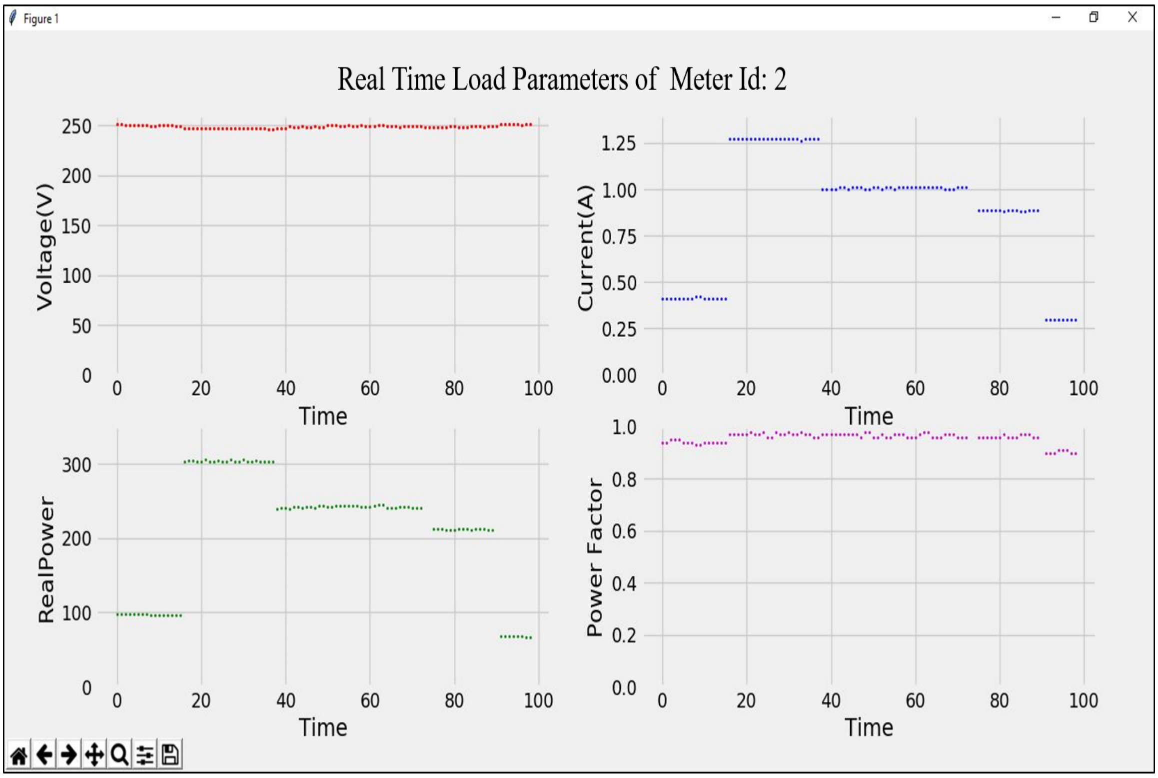

Fig. 5.9: Graphical variation of load parameters of meter 3 through GUI

IV. **Remote handling of Load supply**

The system gives the facility to authorized user to remotely handle the electricity supply to the load through section IV of GUI. The user can connect or disconnect the load in case of high outstanding dues or any other issue with the customer. The system updates the connection of customer and acknowledges back the updated status of connection as shown in Fig. 5.10. When the system is integrated with the online payment gateway, the system can be easily re-configured to auto-cut the supply in case timely payment of bill is not done.

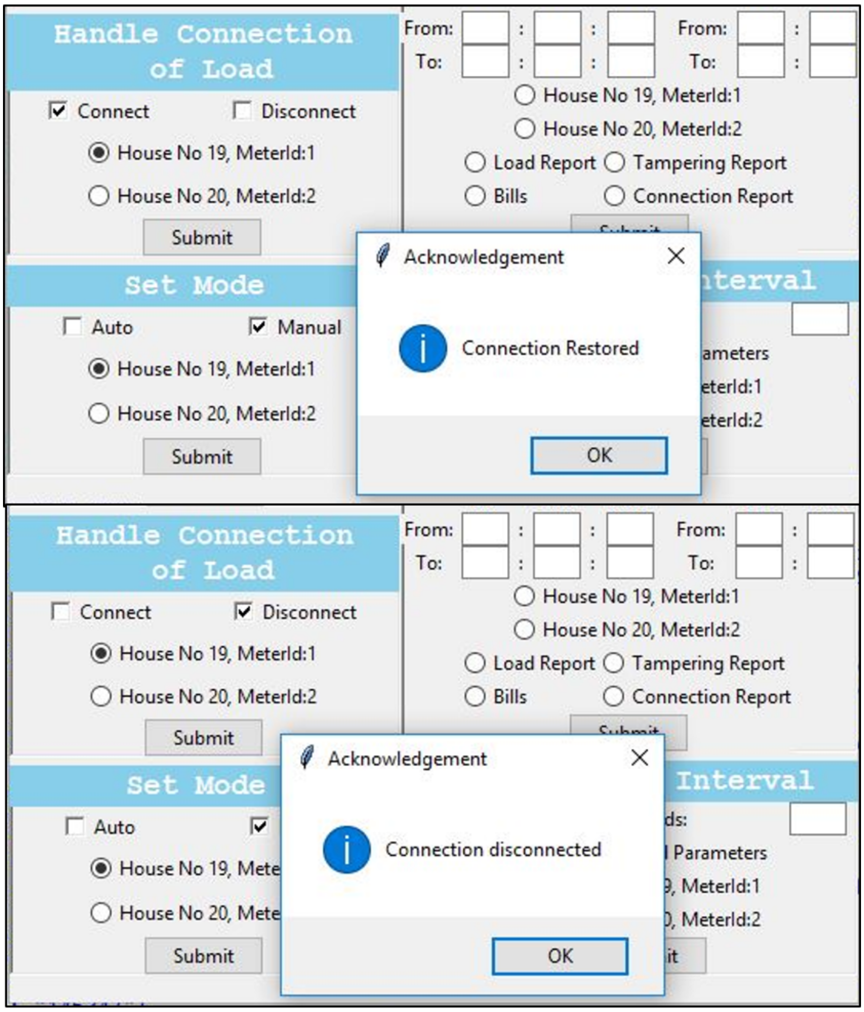

Fig. 5.10: Remote handling of electricity supply to load through GUI

V. **Real Time Status of Load**

Real time load status can be detect by clicking update button in section V of GUI. The remote server checks the current status of communication with different SEMs and updates the status. Different types of load status is represented in form of different colors to help the user to easily identify the load status as shown in Fig. 5.11 . It notifies with a pop up in case of particular Line outage. It detects this condition if all the meters of that line are not communicating with remote server. Color representation is follows:

- Green: Normal healthy condition
- Pink : Load is not available/communicating
- Red : Load is disconnected in lieu of some issue with customer
- Yellow :Line is down

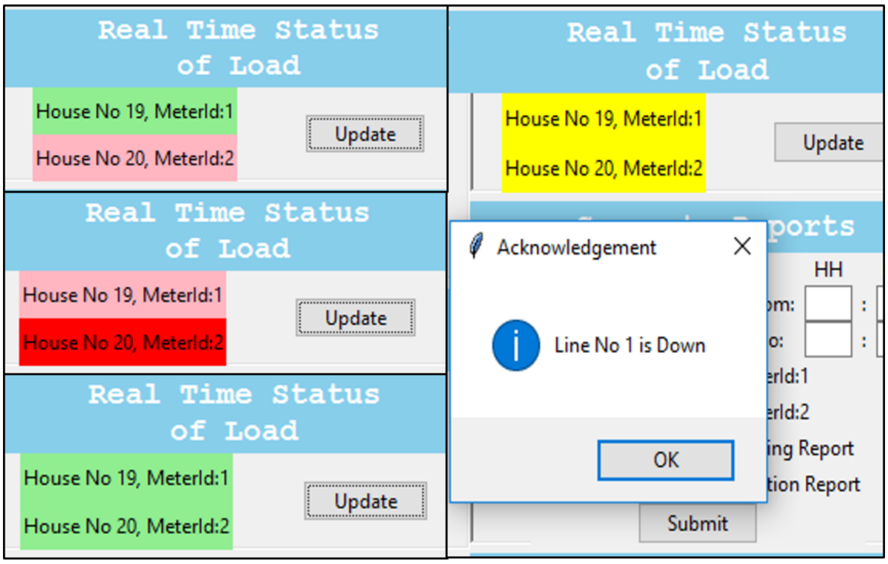

Fig. 5.11: View real time status of Load through GUI

VI. **Reports and Bill Generation**

One of the main aim of developing this system is to obtain the stored real time parameters which can be further analyzed and used for other purposes like Load forecasting etc. The GUI enables the user to retrieve the stored data from database in an Excel format and generate as well as forward the bill to customer via e-mail and SMS. The user have to enter the time period in specified format for which the required data is needed. The database can be searched for required data with help of queries in python language which are provided by the manufacturer. Different types of reports that can be generated are described below:

(a) Three types of reports can be generated Load report, Connection Report and Tampering Report.

Load report

It contains the detailed instant wise load performance parameter report as shown in. Table 5.1. The database is searched for all the relevant documents which lie in the entered time period and all the relevant documents are transferred to excel file in pre specified format. As described in section 5.1 all documents with *request* value equal to *parameter* lie in this category.

Table 5.1: Report of Load Parameters at different instants of Time

S. No	**Date**	**Time**	**Meter Id**	**Current**	**Voltage**	**Real Power**	**kVA**	**Power Factor**
1	31/03/2017	4:07:54 PM	1	0	238.76	0	0	0
2	31/03/2017	4:09:11 PM	1	0	236.63	0	0	0
3	31/03/2017	4:10:27 PM	1	0	233.72	0	0	0
4	31/03/2017	4:13:01 PM	1	0	238.19	0	0	0
5	31/03/2017	6:00:05 PM	1	0.85	247.31	204.8	209.96	0.98
6	31/03/2017	6:12:40 PM	1	0.84	241.67	198.07	202.94	0.98
7	31/03/2017	6:13:57 PM	1	0.84	242.39	196.03	202.69	0.97
8	31/03/2017	6:15:13 PM	1	0.84	242.95	198.27	204.45	0.97
9	12/05/2017	1:00:51 AM	1	0	240.51	0	0	0
10	12/05/2017	1:00:59 AM	1	0	240.86	0	0	0
11	12/05/2017	1:01:07 AM	1	0.88	238.02	203.17	208.35	0.98
12	12/05/2017	1:01:30 AM	1	1.15	239.88	268.71	275.65	0.97
13	12/05/2017	1:01:38 AM	1	1.14	239.22	266.66	273.53	0.97
14	12/05/2017	1:01:46 AM	1	1.14	238.56	265.05	273.14	0.97
15	12/05/2017	1:01:54 AM	1	1.14	237.02	262.52	269.39	0.97
16	12/05/2017	1:02:33 AM	1	1.19	236.18	271.87	279.95	0.97
17	12/05/2017	1:02:40 AM	1	1.25	235.43	287.19	295.3	0.97
18	07/06/2017	2:44:39 PM	1	1.30	259.30	325.48	337.19	0.97
19	07/06/2017	2:44:47 PM	1	1.31	258.52	327.76	339.34	0.97
20	07/06/2017	2:44:55 PM	1	1.31	258.97	329.59	339.16	0.97
21	07/06/2017	2:45:02 PM	1	1.30	260.15	327.37	338.92	0.97

Connection report

It tells the detailed instants at which the load connection status is updated as shown in Table 5.2.

Table 5.2: Report of status of load connection

S. No	Date	Time	Meter Id	Connection Status
1	31/03/2017	2:13:57 PM	1	Disconnected
2	31/03/2017	2:15:00 PM	2	Not available
3	31/03/2017	2:15:27 PM	1	Connected
4	31/03/2017	3:06:53 PM	2	Not available
5	31/03/2017	4:15:34 PM	2	Not available
6	31/03/2017	5:57:01 PM	1	Disconnected
7	31/03/2017	5:59:11 PM	1	Connected
8	31/03/2017	6:00:04 PM	2	Not available
9	31/03/2017	6:00:25 PM	1	Disconnected

Meter Tampering report

It summarizes all the instant at which someone has tried to tamper a particular meter as shown in Table 5.3.

Table 5.3: Report of Meter Tampering events

S .No	Date	Time	Meter Id
1	31/03/2017	2:28:33 PM	1
2	31/03/2017	2:32:09 PM	1
3	31/03/2017	2:37:53 PM	1
4	31/03/2017	2:40:11 PM	1
5	31/03/2017	2:49:28 PM	1
6	31/03/2017	3:26:51 PM	1
7	01/04/2017	4:30:24 AM	1
8	12/05/2017	1:18:55 AM	2

(b) **Electricity Bill**

It can be generated easily by entering required details that is auto forwarded to the customer via e-mail and SMS as shown in Fig. 5.12. Twilio is a company that provides a cloud communication platform which helps the software developers to send SMS and make phone calls. It provides web API's in all major programming languages including Python to use its platform for sending SMS and making phone calls. Twilio services are billed on basis of usage and are free for trial purposes. In trial part SMS to all verified phone numbers is free of cost and this makes it ideal for our application.

SMTP is a communication protocol that handles the sending and routing of e-mails between different mail servers. A smtplib module is available in Python standard library which allows the user to send e-mails to any email address by defining a SMTP client session object. It can be configured to send e-mail to any Internet machine with SMTP listener daemon.

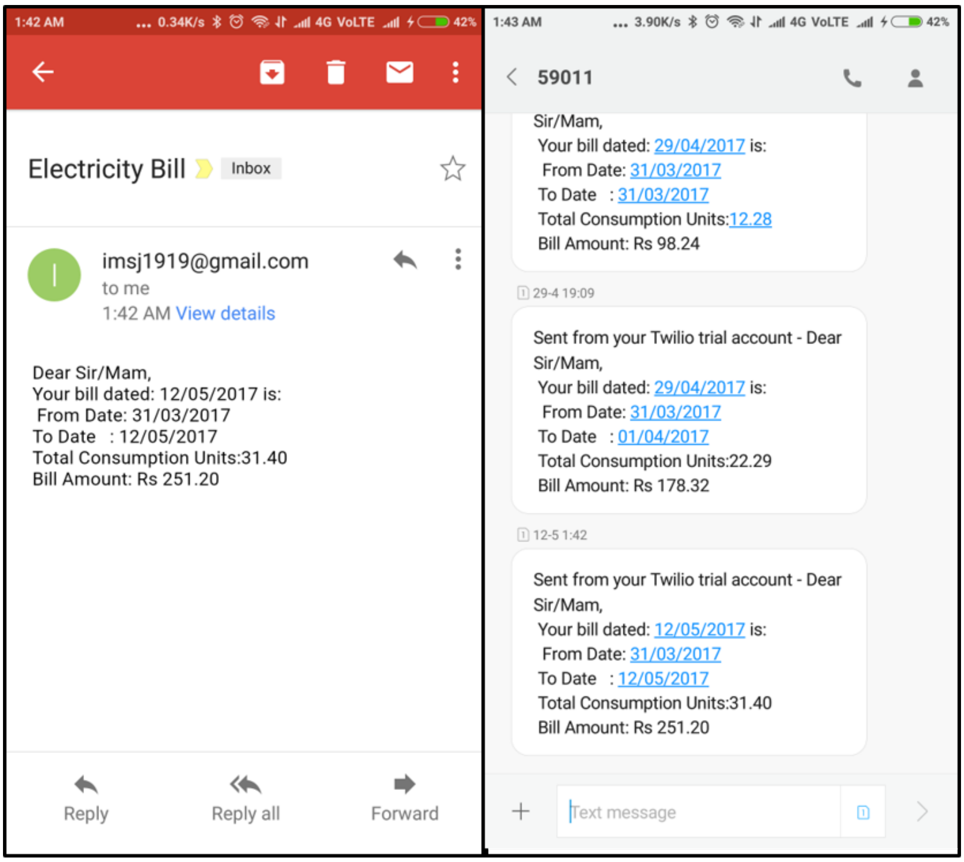

Fig. 5.12: Screenshot of Electricity Bill that is send to Customer via e-mail and SMS

VII. **Meter Tampering Alert**

The implemented system tracks the tampering of all meters and notifies the utility at the instant someone tried to tamper the meter as shown in Fig. 5.13. The event is also captured and stored in database, whose report can be generated any time through section VI of GUI. A small limit switch is used in each SEM as Tampering Sensor. Whenever anyone tries to open the outer box of SEM the limit switch operates which allows the microcontroller to detect the event and sends info to the remote server. Other type of electricity theft or losses can easily be identified by comparing the user data with measurements from transformer feeder. Consumer load profiling can be judged with detailed data obtained which will help to identify abnormal patterns which can be due to faulty meter, fraud or human interaction.

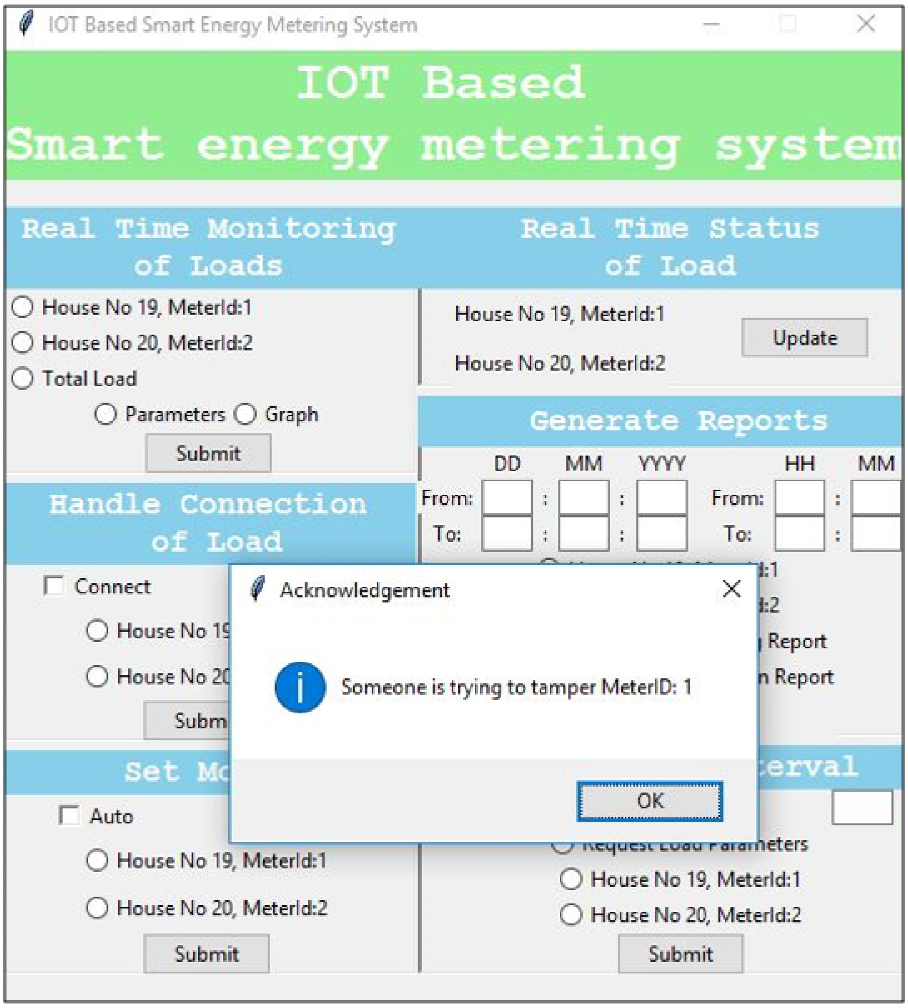

Fig. 5.13: Meter Tampering event Alert in GUI

Conclusions and Future Scope of the Work

6.1 CONCLUSIONS

An IoT based Smart Energy Meter Metering system has been developed. The complete work can be concluded as follows:

- A SEMS provides the facility of Automatic meter Reading, Real time load parameter data, Remote handling of supply of customer, easy monitoring of peak load, easy implementation of time based tariff.
- A user friendly GUI has been developed in order to perform all the tasks in easy and flexible way and access the data.
- The developed SEMS is IoT based and requires internet for communication. Internet facility can be given through broadband Ethernet connection (preferably), Wi-Fi or mobile data using USB dongle.
- A two stage communication system is used in order to reduce the cost. Most of the existing Smart systems that use two stage communication utilize *ZigBee* module for short range whereas in the developed system a RF transceiver *nRF24L01* is used which is $1/5$ cost to ZigBee module and yielding satisfactory results.

6.2 FUTURE SCOPE OF THE WORK

According to Forbes Research, spending on IoT will reach $267 billion by 2020 and revenue generated will be more than $1 Trillion. This gives the great potential of integrating more features to the implemented system so as to enhance the system:

- The present work has been implemented on power sector monitoring and billing section and also can be successfully implemented on other similar sectors as well like Water and Natural gas supply sector.
- Online payment gateway can be interfaced easily with the model which will help to provide facility of auto power cut in case of high outstanding dues.
- The data obtained can be integrated with real time weather forecasting data and other events which effect the load for improved analysis of load forecasting.
- A web platform for customers can be developed that shows their daily consumption which can help them to manage their usage.
- Prepaid metering system can be integrated. It is referred as pay-as-you-go model, which is convenient way for people to reduce costs of power consumption. It is analogous to prepaid mobile recharge. User can use their E-wallets or any other payment methods for purchasing power.

List of Publications

- I.S. Juneja and S.K. Jain,"An IoT Based Smart Energy Metering System Using Publish/Subscribe Messaging", communicated to *IEEE Internet of Things Journal*

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Appendix

a. **Requirement of Hardware Components**

Table A.1: List of hardware Components Used in each Smart Energy Meter

S.No.	Component	Type	Quantity	Cost (Rupees)
1	Microcontroller	Atmega328P	1	120
2	5V Regulator	LM 7805	1	05
3	3.3V Regulator	LM 1117	1	20
4	Step down T/F	220/9V	2	120
5	RTC	DS 1302	1	30
6	Crystal	16MHz	1	10
7	Crystal	32.768MHz	1	10
8	Coin cell	3.3V	1	20
9	RF module	nRF24L01	1	300
10	LCD	16x2	1	100
11	PCB	Zero PCB	1	50
12	Outer Box	IP55 Compliant	1	200
12	Miscellaneous	Miscellaneous	15	50

Table A.2: List of hardware Components Used in DCU

S.No.	Component	Type	Quantity	Cost (Rupees)
1	DCU	Raspberry Pi 3	1	3000
2	RF Module	nRF24L01	1	300
3	Power Supply	5V, 2A DC	1	150