

# DEVELOPMENT OF SMART ENERGY METER WITH PARAMETER EXTRACTION AND CLUSTERING

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**2016**

# DEPARTMENT OF ELECTRICAL ENGINEERING

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### CERTIFICATE

I, ARUNESH GAUTAM, Roll No. 2K14C&I19 student of M. Tech. (CONTROL AND INSTRUMENTATION), hereby declare that the dissertation/project titled “**Development of Smart Energy Meter with parameter extraction and clustering**” under the supervision of Dr. Madan Mohan Tripathi, Associate Professor, Electrical Engineering Department, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: Delhi

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Date: 28.07.2016

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## **ABSTRACT**

Electricity is one of the most versatile and widely used type of energy and its global demand is growing continuously. Smart Energy Meters with respect to present developments in power sector after introduction of concept of smart cities have gained a significant importance. The smart grids can be considered to an evolved power grid system that manages demand of electricity in viable, reliable, economical and efficient manner by an advanced infrastructure so as to keep every involved integration in perfect tuning. Thus the smart meters in this context form an integral part of this system.

Smart Energy meters unlike traditional electricity meters can extract more than one parameters like current, voltage, power, frequency, phase etc. and can have two way connectivity to the consumer end as well as provider end by a significant communication infrastructure. The careful analysis of these parameters can provide the useful information like operational status, power consumption profiling and even can help in identification of consumer's peculiar activities and behaviour. This can further help the providers to take several technical, management and security decisions in Smart Grid.

The energy meters with parameter extraction features are available in the market but in order to process them in real time they need to be taken out through some communication channel. Additionally enabling this meter to take some actions on the basis of these processed parameters further add to the smartness of the meter. The various works on parameter analysis so as to enhance security in a smart grid are already available but implementing them for real time parameters is another task. Further the meter can also be made smarter if it can compensate some more features like online accessibility to it, dynamic pricing on the basis of supply and demand chain and load forecasting data, alerts via SMS channel and various other features from ICT infrastructure.

The work is divided into two phases. First phase deals with parameter extraction from a digital electricity meter and then transferring them to a micro controller based setup which will use concept of Internet of Things (IoT) and thus resulting in availability of these parameters along with real time pricing over the dedicated internet portal. The second phase suggests an approach to establish clustering of users on the basis of average power consumption and also compensating the suggested other works in the relevant area too. The dynamic pricing is subjected to an open end based as it is operating on power consumption only but future scope is that it can also have inputs from load forecasting centre.

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## **ABBREVIATIONS**

ICT	Information and Communication Technology
IoT	Internet of Things
EISA	Energy Independence & Securities Act
AMI	Advance Metering Infrastructure
AMR	Automatic Meter Readings
SoC	System on Chip
DIP	Dual in Package
SMS	Short Message Service
ZC	Zero Consumption
MC	Medium Consumption
HC	High Consumption
GLC	General Low Consumption
VLC	Very Low Consumption

# CHAPTER 1

## INTRODUCTION

The world's first alternating current (AC) power grid was installed in 1886 in Great Barrington region of Massachusetts in United States of America (USA). This grid was a centralized and followed unidirectional system for transmission of electricity, distribution of electricity, and its control was based on demand only [1].

For economic as well as reliability reasons all emerging grids were interconnected eventually by the 20<sup>th</sup> century. By the late 1960s, the power grids of developed countries developed into a very large and highly interconnected infrastructure, with extremely large number of 'central' power generation stations providing power to major load centers through power lines having high capacity, which were branched and divided to provide power to different industrial as well as domestic users over the entire supply area.

Metering of power consumption became necessity on the per-user basis so as to allow proper billing in accordance to the level of consumption of different users. But due to limited data collection and processing capabilities during the growth period of the grid, tariff arrangements of fixed nature were used.

The problems started emerging between the periods of 1970s to the 1990s, when the growing demand led to increase in numbers of power stations. The demand in some areas raised to a level that it started resulting in poor quality of power including blackouts, frequent power cuts and brownouts. By the end of the 20th century, as a solution to all these problems electricity demand patterns were established. The opportunities for taking advantage of developments in electronics and communication technology to decide the limitations and costs of the electrical grid have become apparent.

Thus with advent of time, energy infrastructure perhaps has emerged as the single supreme feature in any city. Integration of parallel developed technologies in the field of electronics and communication and Information Technology (IT) has tremendously enhanced the capabilities of grid and has helped in addressing many of the

related problems. The need of adequate physical infrastructure remains necessary, but Information and communications technologies (ICT) and virtual social networks are must to guarantee the best kind of services in energy sector and thus the smart grid comes into picture [2].

A smart grid has 3 basic features [3]. First, it modernizes the systems through self-restorative designs, mechanization and computerization, remote monitoring and control, and micro-grid establishments. Second, it enlightens and informs consumers about their usage of energy, expenses and substitute options, to enable them to make decisions on their own about how and when to use electricity. Third, it provides safe, secure and unswerving integration of distributed and non-conventional energy resources. All these add up to an infrastructure which is more reliable, more efficient, more sustainable and more robust. Thus, a smart grid can be considered to be the heart of a smart city, which cannot even exist without it.

## **1.1 Smart Grid**

The first official definition of Smart Grid was proposed by the Energy Independence and Security Act of 2007 (EISA-2007), which was ratified by the US Congress in 2007 [4]. According to the provisions of this act a definition for Smart Grid can be considered with the following ten characteristics:

- (1) Augmented use of digital information and communications technology to enhance reliability, security, and efficiency of the grid.
- (2) Optimization of grid operations dynamically, with cyber-security.
- (3) Integration of distributed energy resources and generation, including non-conventional resources.
- (4) Incorporation of demand response, resources on demand side, and resources that can ensure energy-efficiency.
- (5) Arrangement of `smart' technologies (based on real-time, computerized, interactive technologies that improve the physical operation at consumer end) for metering purposes, communications concerning energy grid operations and status, and distribution mechanization and automation.
- (6) Incorporation of `smart' appliances and consumer devices.

- (7) Incorporation of peak-shaving and advanced electricity storage technologies, including hybrid electric vehicles, and air conditioning based thermal storage.
- (8) Facility to consumers of well-timed information and control opportunities.
- (9) Development of communication standards and interoperability of utilizations connected to the grid, along with the infrastructure meant for serving the grid.
- (10) Identification and reduction of unnecessary hurdles to adoption of smart grid technologies, practices, and services.

Smart grid can be considered to a modern version of the pre-existing electrical grid infrastructure that uses analog as well as digital information and communication technology (ICT) to amass and act on the data about the behaviors of providers and users in an automated manner so as to improve the efficiency, economics, practicability, sustainability and reliability of the production and distribution system [5].

## **1.2 Smart Energy Meters**

A smart energy meter is an electronic device that registers usage of electrical energy in intervals of very short duration like an hour or less and transfers that information in real time to the utility for monitoring, managing, billing and taking further improvement and corrective actions if required. Smart energy meters facilitate two-way communication between the meter and the centralized system, thus making advanced metering infrastructure (AMI) different from conventional automatic meter reading (AMR) [6].

Since the beginning of electricity deregulation and market-compelled pricing throughout the world, providers have been considering all the means to match consumption with production. A smart energy meter sends readings from meter in automated fashion directly and securely to the energy supplier as well as users, resulting in accurate bills, transparent billing system and also puts an end to approximate and energy meter readings taken manually. It has all the features of the already existing metering devices but the additional features add up to its value. The more advanced devices in this domain can even incorporate benefits related to load forecasting, power profiling, Short Message Service (SMS) based alerts related to dynamic pricing and real time monitoring and optimization of the system.

The future perspective with reference to Internet of Things (IoT) can even lead to integration of sensing and actuation systems, allied to the Internet, is which will certainly help in optimization of energy consumption as a whole [7]. It is anticipated that IoT based energy metering devices will be assimilated into all types of energy consuming devices (bulbs, televisions, etc.) and enabling it to communicate to the supplier company in direction of effectively balancing power generation and energy consumption. Such devices would also give the prospectus to users to remotely control their devices, or manage them with a cloud interface, and can also enable advanced features like scheduling (e.g., remotely powering on or off air conditioners, controlling ovens, changing lighting patterns etc.).

### **1.3 Power Profiling and Clustering**

The information related to the consumer's behaviour is attaining prominence in an energy grid. By having the knowledge related to load profiles of users, the already existing electricity distribution firms can plan to have better market strategies and it will help them in taking the advantages of new liberalized market of energy [8]. The significant knowledge about the electricity demand curve and profile of the users rejuvenates suppliers to develop and design new pool of tariffs in accordance to the particular type of user. The newly developed tariffs may also take account of the time based pricing methodology which will be dynamic in nature done over a day. In case of pricing main aspect is to diminish the deviations of the anticipated to the actual consumed energy among different distributors.

Calculation in deviation for large number of eligible consumers or their group of suppliers can be easily obtained as they are well-found with suitable metering equipment, which leads to tracking of consumption in real time. In a similar manner the deviations can be easily allocated to the level headed distributor if it is the only one who is responsible for all the users connected to the particular substation, which is carried out with the help of supply meters present at the substation. Contrary to this, work can be quite difficult if users are not equipped with appropriate energy metering devices and with presence of more than one suppliers providing electricity to the consumers. A solution based on load profile can act as a better standby of costly installations of time-interval meters and it guarantees a "fair" as well as true billing system with additional



access to the retail market. Furthermore, the load profiles can also be extremely helpful in load management, planning of distribution system, state estimation and distribution transformer loss or distribution system restoration [9]. Load profiling can be solution in direction of protecting the smart grid form cyber-attacks. Cyber-attacks related to grid in form of data injection, load alteration may be spotted and checked if one has used the appropriate technology and policies in smart grid on the basis of data obtained from load profiling [10]. The obtained information is helpful in establishment of load diagrams of a particular region or a consumer group [11]. The planning related to grid capacity and generation of accurate consumption forecasts can be done by power profiles. [12].

## **CHAPTER 2**

### **LITERATURE SURVEY**

Since we are interested in design of smart energy meter with some advanced features and thus enabling power profiling too, it becomes important to know and study the basic concepts of related to the all the hardware and software components and tools relevant to the work .

#### **2.1 Types of Electricity Meter**

Electricity providers use electricity meters installed at users' terminal to know the electrical energy supplied to their users for the purpose of billing. The most commonly used unit is kilowatt hour [kWh]. They are generally taken once in a period of billing. The various types of electricity meters are being available in the market according to the needs and usages [13].

##### **2.1.1. Electromechanical Meter**

Electromechanical meters has a non-magnetic metallic disc internally attached to it which performs rotation on the basis of power passing through it. So the fast rotation of disc is indicative of high power consumption and slow rotation of disc is indicative of low power consumption. Thus the reading on the meter is decided by the rotation of the disc. Lower the number of rotation, lower is the reading and vice-versa. The rotation of disc itself involved some of the energy for its rotations, hence consuming some part of energy being measured for itself. It is estimated that around 2 Watts power is wasted in its rotation and this power is not added up in the meter readings.

Electromechanical meters are still common in most of the developing economies of the world. They still are being used in the rural areas due to less penetration of modern technology as compared to urban areas.

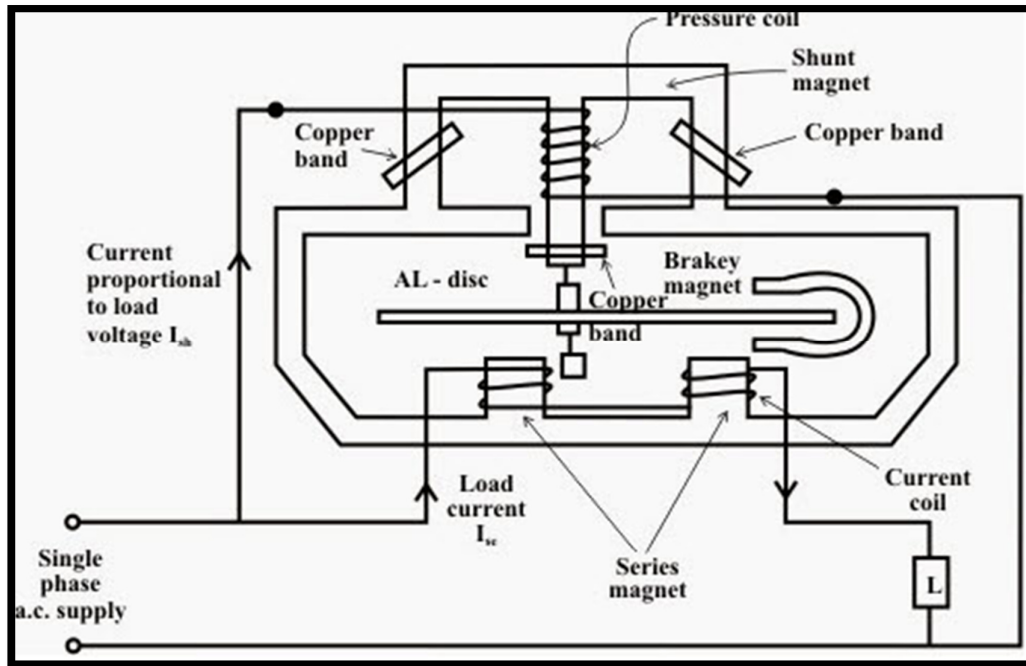


Fig 2.1 Internal Structure of Electromechanical meter

### 2.1.2. Electronic Meter

Electronics meters have very high rate of accuracy and precision and can be considered to be reliable measuring instrument as compared to traditional mechanical meters. The power consumed is less and it starts measuring instantaneously as soon as connected to load. The meters can be either analog or digital. In case of analog meters, energy is converted to relational frequency or pulse rate and then it is integrated by counters present inside it. In case of digital meter energy is measured directly by using high end processor.

### 2.1.3. Smart Meter

It is a metering technology of modern era which involves placement of intelligent meters for reading, processing and also with feedback facility of the data to users. It can measure consumption of energy, can remotely switch the supply to users and can also control the maximum electricity consumption remotely [14]. It uses the advanced metering infrastructure (AMI) system technology for improved performance.

They are capable of dual way communication. They have facility of transmission of the data to the suppliers like power usage, relevant parameters, alerts etc. and also can get information from suppliers such as automated reading of system, instructions regarding reconnect/disconnect, up gradation of energy meter software's and other important messages.

#### **2.1.4. Trinity NF-29 Smart Energy Meter**

The NF29 is a versatile power meter, having all the important features required for implementation of a robust electrical measurement [15]. It can be configured to observe basic electrical parameters like current, voltage, power, frequency, phase etc.

The meter has the following characteristics which can help in the implementation of the proposed work:

- (1) It is a micro-controller based energy meter.
- (2) It can measure all important parameters.
- (3) Measurement of parameters with very high accuracy.
- (4) Attached display with customized LCD.
- (5) All the individual currents and voltages for all the three phases (R-Y-B).
- (6) All the individual powers-KW, KVA and KVAR.
- (7) Individual PF as well as system PF with lead (-) and lag (+).
- (8) Relevant Frequency (Hz) measurement.

The NF29 is a versatile power meter, having all the important features required for implementation of a robust electrical measurement. It can be configured to observe basic electrical parameters like current, voltage, power, frequency, phase etc.

The technical specification of the meter are given in the table below.

Table 2.1 Technical Specifications of NF-29

SR. NO	PARAMETERS & OPTIONS	STATISTICS	
1	Volts R-N	Direct Voltage Input	: 20 to 300V L-N
2	Volts Y-N	Burden	: 0.5VA
3	Volts B-N		
4	Volts RY	Direct Voltage Input	: Up to 500V L-L
5	Volts YB	Burden	: 0.5VA
6	Volts BR		
7	Current R	Secondary Current Input : 5A or 1A (To be specified at the time of Ordering)	
8	Current Y	CT Primary	: Site Selectable
		Range of Reading	: 5 – 5000A
		Burden	: < 1.0VA
9	Current B	Overload(Through CT)	: 5A CT = 6A RMS Continuous 1A CT = 1.2A RMS Continuous
		(Whole Current)	: 120% of I <sub>max</sub> continuous.
10	Frequency	45 to 55 Hz, Accuracy	: 0.3% of Reading
11	KWh	Range of Reading	: 0 to 9999999.0 KWh
		Accuracy	: 1.0S as per IS13779.
12	KVARh	Range of Reading	: 0 to 9999999.0 KVARh
		Accuracy	: 1.5% of Reading (Between 0.5 Lag to 0.8 Lead)
13	KVAh	Range of Reading	: 0 to 9999999.0 KVAh
		Accuracy	: 1.0% of Reading
14	System PF	Accuracy	: 1% of Reading (IPFI <sub>≥</sub> 0.5)
		Range of Reading	: 0.05 to 1.00 Lag/Lead
15	System KVA	Accuracy	: 1.0% of Reading
16	System KW	Accuracy	: 1.0% of Reading (Between 0.5 Lag to 0.8 Lead)
17	System KVAR	Accuracy	: 1.5% of Reading (Between 0.5 Lag to 0.8 Lead)
18	DISPLAY	61X57 mm.	
20	Bezel	96x96 mm	DIN enclosure
21	Depth	55 mm	

## **2.2 Microcontroller**

It is a small computer (SoC) on a single platform preferably integrated circuit(IC) having a processor, memory, input and output peripherals. The microcontrollers are used mostly in embedded technologies, such as automobiles, telephones, and peripherals for computers. There are several microcontroller architectures and vendors including Intel, Atmel, Freescale, Motorola etc. By careful analysis and considering all the requirements, Atmel's Atmega-32, which is low power 8bit CMOS based microcontroller is best suited for the work.

### **2.2.1. Atmega-328**

The Atmel's AVR ATmega-32 is a low-power CMOS based 8-bit microcontroller [16]. It is based on AVR enhanced Reduced Instruction Set Computing (RISC) architecture. It has the following features:

- (1) It is low power, high performance and 8 bit microcontroller.
- (2) It has advanced RISC architecture which contains 32 x 8 registers for general purpose.
- (3) It has 32Kbytes self-programmable flash programmable memory, 1024Bytes of EEPROM and 2Kbytes of internal SRAM.
- (4) It has two 8-bit Timer/Counter and one 16-bit Timer/Counter.
- (5) It has four PWM channels and 8-channel 10-bit ADC.
- (6) It has programmable serial USART and on chip analog comparator.
- (7) It has some special features like internally calibrated RC oscillator and power-on Reset.
- (8) It has facility of internal as well as external interrupts.
- (9) It has 32 Programmable input/output (I/O) lines.

The above features make it a very powerful microcontroller and all these will supplement the work with a very high end performance. It is commonly available in the market in form of 40 pin dual-in line (DIP) package and is supported by full suite of program and tools for system development by the manufacturer.

### 2.2.2. Arduino

It is an open-source prototyping platform which is based on flexible, easy-to-use software and hardware. The circuit board has a microprocessor and input/output (I/O) pins for communication purpose and controlling the physical objects like LED, servos, buttons, etc. The board is powered by USB or an external power supply which allows it to provide power to other hardware and sensors.

It also has an open-source software section which is similar to C++ language. The integrated development environment (IDE) of Arduino allows to code writing, compilation, and then uploading to Arduino for stand-alone use in projects [17]-18]. It comprises two major components: the Arduino board, which is a hardware used to build objects; and the Arduino IDE, the software which is run on computer.

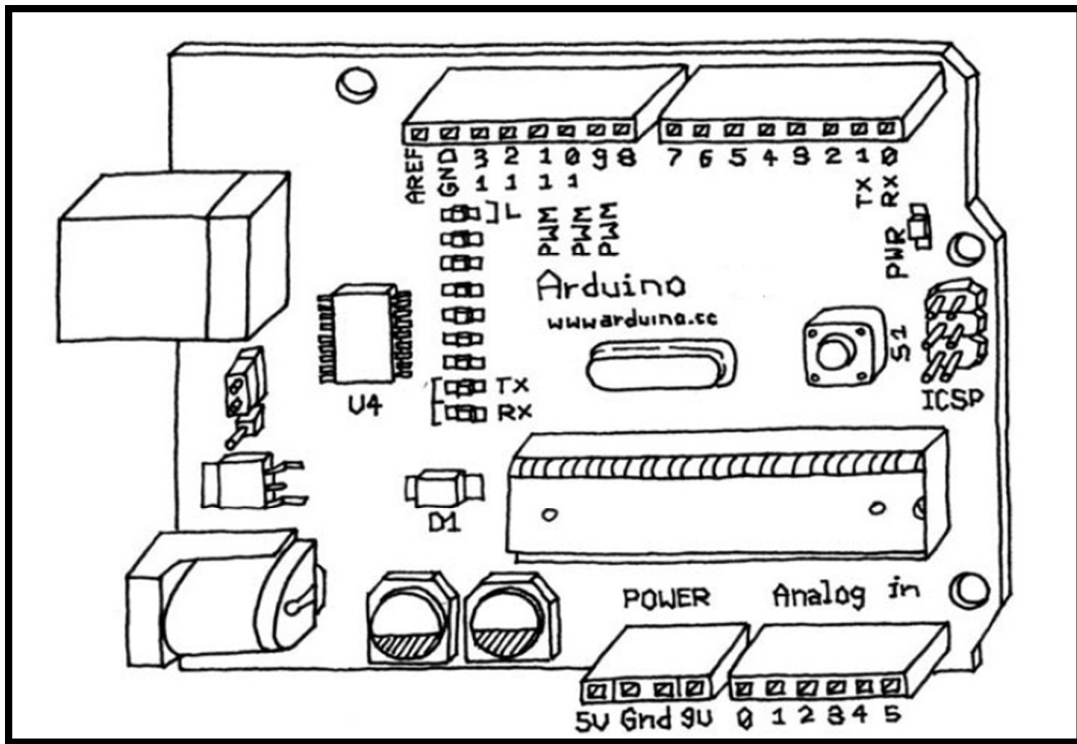


Fig 2.2 Arduino Atmega-32 board

The hardware is easily accessible in the market whereas the relevant software can be downloaded from the official website of Arduino.

## 2.3 Serial Communication

It is process of sending the data bit by bit in a sequential manner over a communication channel. It was generally preferred for long haul communication but with improved technologies in this domain has allowed it to be used even for shorter distances. It is able to provide signal integrity at higher data rates and thus replacing parallel communication methodologies.

The term "serial" generally refers to the RS232 port which is present on the back of original IBM manufactured PC, often called "the" serial port, and complementary "the" serial cable was designed to plug into it, and other many devices were designed to be compatible with it.

### 2.3.1 Modbus RTU

It is a serial (RS-232 or RS-485) and open protocol based on the Master/Slave architecture. This protocol has got wide acceptance due to its simplicity in use and reliability [19]. It is widely used in Industrial Automation Systems (IAS) and Building Management Systems (BMS).

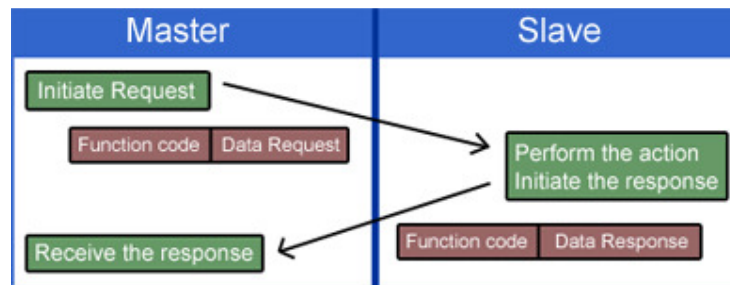


Fig 2.3 Overview of Modbus RTU Protocol

The messages of Modbus-RTU are a simple 16-bit CRC (Cyclic-Redundant Checksum). The simplicity ensures the reliability. The basic 16-bit MODBUS RTU register structure can be used in floating point, tables, ASCII text, queues, and other unrelated data. Messages on serial connections sent in frames which gives receivers convenient way for detection of beginning and end of the message.



Table 2.2 Modbus message structure

Field	Description
<b>Device address</b>	Address of the receiver
<b>Function code</b>	Code defining message type
<b>Data</b>	Data block with additional information
<b>Error check</b>	Numeric check value to test for communication errors

### 2.3.2 Max-232

It is an integrated circuit (IC) which can convert signals from a TIA-232 (RS-232) serial port to the signals suited for use in TTL digital logic circuits. It is a dual driver/receiver and usually converts the signals related to communication like Receiver (RX), Transmitter (TX), Clear to send (CTS) and Ready to Send (RTS).

Table 2.3 RS-232 voltage levels

TIA-232 line type and logic level	TIA-232 voltage	TTL voltage to/from MAX232
Data transmission (Rx/Tx) logic 0	+3 V to +15 V	0 V
Data transmission (Rx/Tx) logic 1	-3 V to -15 V	5 V
Control signals (RTS/CTS/DTR/DSR) logic 0	-3 V to -15 V	5 V
Control signals (RTS/CTS/DTR/DSR) logic 1	+3 V to +15 V	0 V

### 2.3.3 Sunrom RS-485

It is used to create virtual serial port on PC and it also allows communication to RS-485(2-Wire) & RS-422(4-Wire) with an option of auto switching between transmit/receive. It is an isolated version and a popular product in an industrial environment.



Fig 2.4 RS485 2 wire connection

### 2.3.4 RS-485 module for Arduino (MAX-485)

It can be used to send serial data from Arduino over long distances up to 1 Km, using RS485 signals. Below figure shows the example of RS485 Network Diagram.

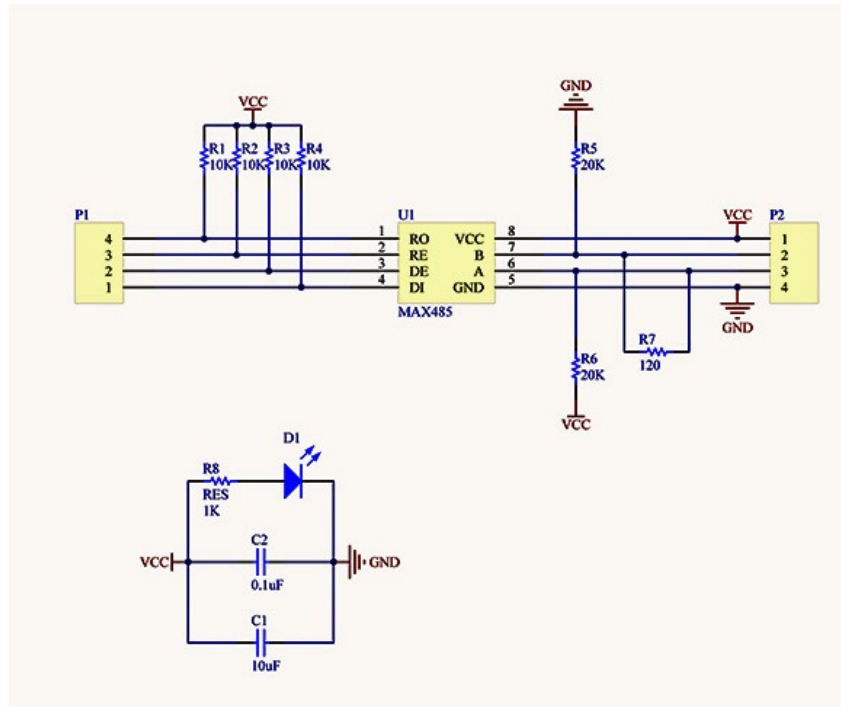


Fig 2.5 RS-485 module diagram

The network has resistors equivalent to 120 ohm at every END. For using more than one module it is required to remove the 120 ohm resistors (R7). The resistors having value equal to 20K hold a known signal when no one is doing transmission.

## 2.4 Concept of Internet of Things (IoT)

It is an interconnected network of physical equipment, buildings, vehicles, and other items such as embedded with electronics, sensors, software, and a network that can enable these physical objects to amass and exchange data. The integration of these things with the Internet means that devices have to be assigned an IP address to be used as a unique identifier [20].

### 2.4.1 Internet of things in energy sector

The Internet of Things (IoT) is considered one of the emerging and very promising technologies in the implementation of Smart Grid [21]. It can be used in almost every phase of Smart Grid, including generation, transmission, substation, distribution, utilization and dispatch. The Table 2.3 shows applications of IoT in smart grids [10].

Table 2.4 Applications of IoT in Smart Grid

Smart Grid	Things in Smart Grid
Generation	Generation facilities monitoring, Pollutant and gas discharge monitoring, Natural environment monitoring and forecasting for new energy, Generation equipment controlling
Transmission	State monitoring of power transmission lines, such as meteorological environment, ice covering, temperature, sag, and etc.
Substation	Substation equipment operation and control State monitoring of substation equipment and environment safety
Distribution	Power distribution automation
Utilization	Utilization information collection, Power load control, Advanced Metering Infrastructure (AMI), Smart Home
Dispatch	SCADA(Supervisory Control And Data Acquisition)

The future perspective with reference to Internet of Things (IoT) can even lead to integration of sensing and actuation systems, allied to the Internet, is which will certainly help in optimization of energy consumption as a whole. It is anticipated that IoT based energy metering devices will be assimilated into all types of energy consuming devices and enabling it to communicate to the supplier company in direction of effectively balancing power generation and energy consumption [22]. Such devices would also give the prospectus to users to remotely control their devices, or manage them with a cloud interface, and can also enable various advanced features [23]. The generic network topology is shown in the figure 2.6 below.

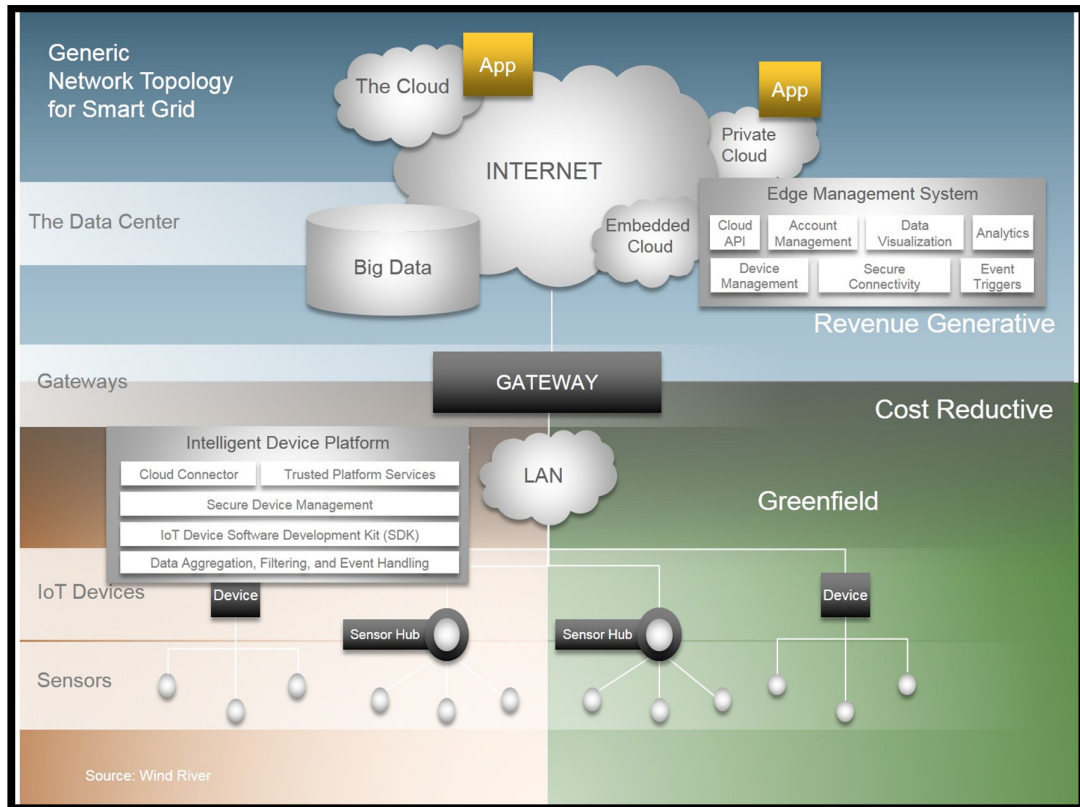


Fig 2.6 Generic Network Topology for Smart Grid

## 2.4.2 GPRS

General Packet Radio Service (GPRS) [24] is a technology based on packet-switching that helps data transfer on cellular networks. It can be used in connectivity of the physical devices over the internet and can actually help in the implementation of concept of Internet of Things (IoT). It can be implemented by use of simple module i.e. SIM-900.

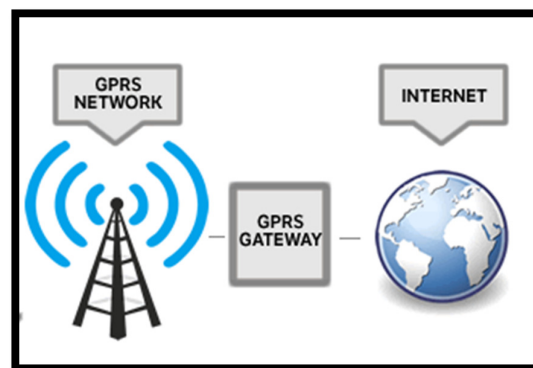


Fig 2.7 GPRS and Internet

## 2.5 SIM 900 GPRS/GSM Module

SIM 900 is an ultra-compact and very reliable wireless module with software power on and reset support [25].

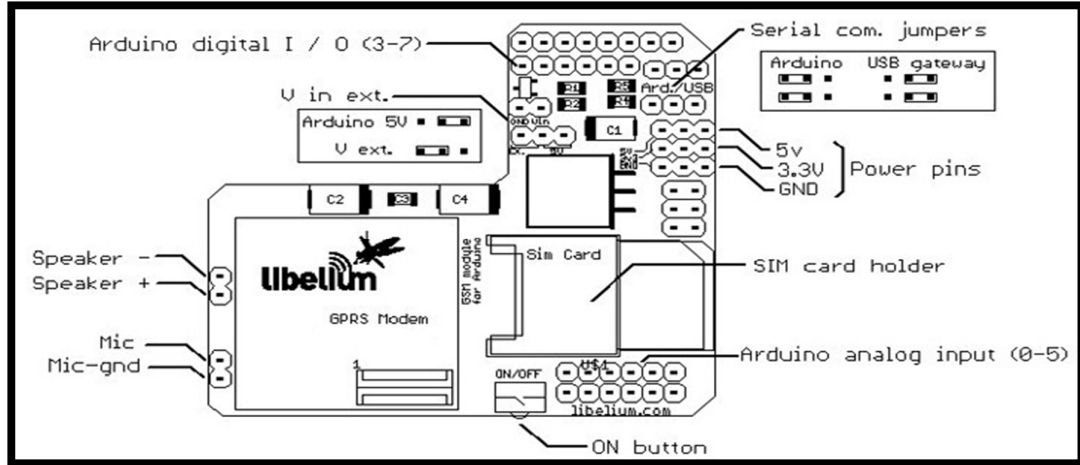


Fig 2.8 SIM 900 module

It can be interfaced to any microcontroller unit and thus enabling the unit to have internet connectivity via cellular network. The main advantage of this module lie in its simplicity of use and can be configured for various modes like GPRS connectivity, SMS service, voice call etc.

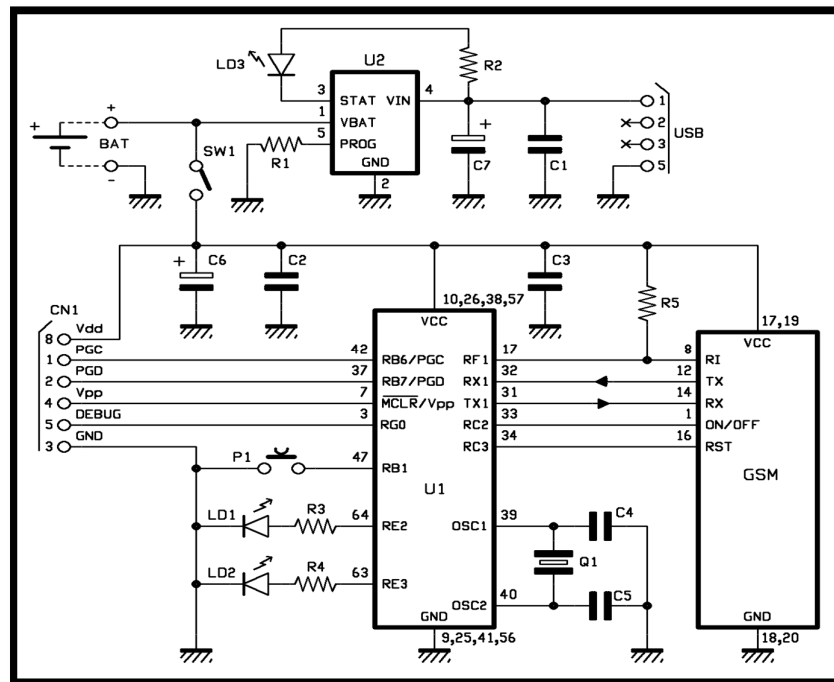


Fig 2.9 SIM 900 with Microcontroller

## 2.6 Thingspeak.com

It is an Internet of Things (IoT) online platform that enables to collect and store data from sensors in the cloud and thus supporting development of IoT applications [26]. It provides applications that help in analyzing and visualizing data in MATLAB, and thus operation on the data. It provides accessibility to a broad range of web services and embedded devices like Arduino, Raspberry Pi etc.

The principal element of its activity is the channel, which has data fields, status field, and a location fields. After creation of ThingSpeak channel, the data can be written to the channel, process and it can be viewed with MATLAB code, and reaction to the data in form of tweets and other alerts. The usual ThingSpeak workflow enables:

- 1) Creation of a Channel and data collection.
- 2) Analysis and Visualization of the data
- 3) Processing of the data using several Apps.

Here are some keywords that are used in the API:

- **Channel** - The name on which data can be placed in or taken out within the ThingSpeak API, and is recognized by a numerical Channel ID
- **Field** - It can store numeric data collected from sensors or alphanumeric strings from RFID readers or serial devices.
- **Status** – It is a short status message to supplement the data stored in a channel.
- **Location** - The latitude, longitude, and elevation of where data is being sent from
- **Feed** - The collective name for the data placed inside a channel, which can be any combination of field data, location info and status updates.
- **Write API Key** – A 16 digit code which allows an application to write data to a channel.
- **Read API Key** – A 16 digit code which allows an application to read the data stored in a channel.

## CHAPTER 3

### DEVELOPMENT OF SMART ENERGY METER

#### 3.1 Modified NF-29 energy meter

The modified energy meter extends the scope of pre-existing metering device by incorporating the real time extraction and transmission of the parameters to the microcontroller unit and the online portal which is accessible to the user as well as the consumer. The block diagram of whole setup can be seen in fig 3.1

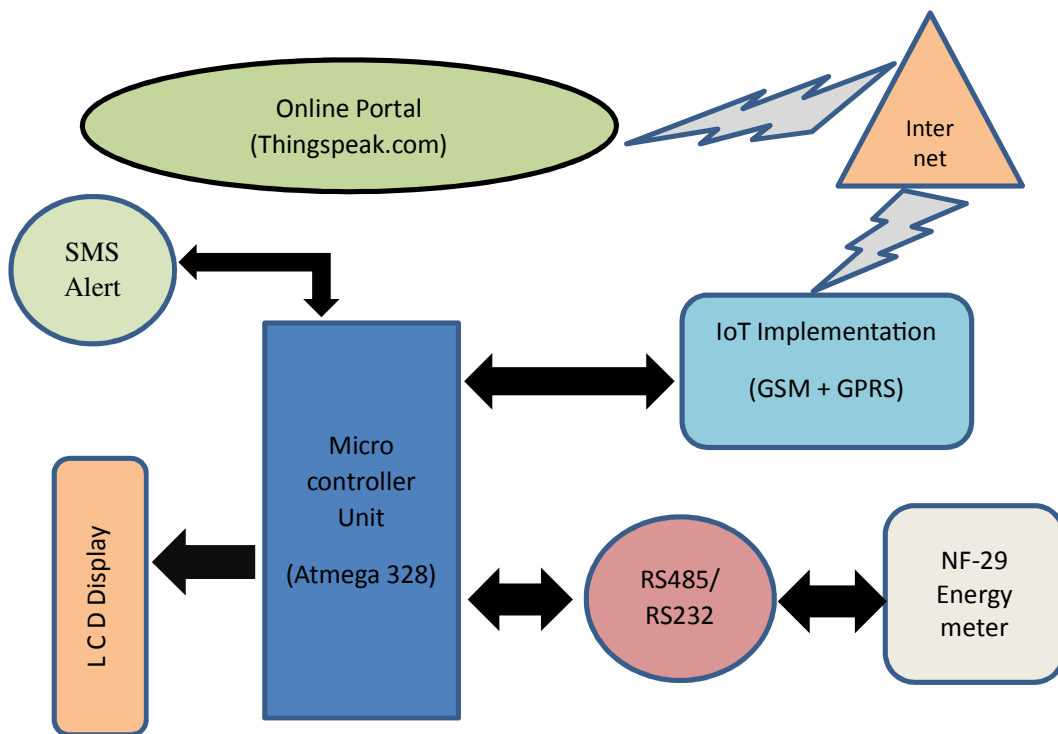


Fig 3.1 Block diagram of the modified energy meter

The major blocks include microcontroller unit, display unit, serial communication unit, IoT implementation unit, online portal and energy meter unit. The real challenge lies in identification of suitable and compatible hardware components for

the development purpose. It is followed by suitable interfacing components and relevant compatible software support.

### **3.1.1. How is it Different for Existing Meters**

The designed modified energy meter is modification of existing NF-29 meter. The new energy meter has the following features.

- I. Parameter extraction: - The parameters like current (i), voltage (v), real power (kW), apparent power (kVA), phase ( $\phi$ ), and frequency (f) are extracted from the meter and available at microcontroller unit as well as online portal.
- II. Real Time operations: - All the parameters extracted are transmitted in the real time which makes whole operation transparent and more reliable.
- III. MATLAB based support at online portal: - The online portal is equipped with various apps and components of MATLAB which allows processing of data so as to enable better management and secure operations.
- IV. SMS alert for change in pricing: - The user can know about the status of pricing by requesting price alerts on his mobile phone.
- V. Data Collection at cloud: - The data collected at the online portal is accessible in various formats and it can be further used for the processing of clustering which is even demonstrated in the next chapter.

## **3.2 Circuit diagram**

The block diagram is already shown in figure 3.1. To give a practical shape to the block diagram the previous chapter well describes about all the technical components and knowledge required for the development.

The hardware components include Trinity NF-29 energy meter, SIM-900 module, MAX 232 IC, Arduino board, Atmega 328 microcontroller and connecting wires. The software requirements include Arduino 1.6.9 platform for programming purposes. All the components are connected to each other using Zero PCB board which



provides flexibility to alter the physical components as per the needs. The use of SIM-900 significantly reduces the need of soldering process. The detailed circuit diagram is shown in fig 3.2(a) with all the components:

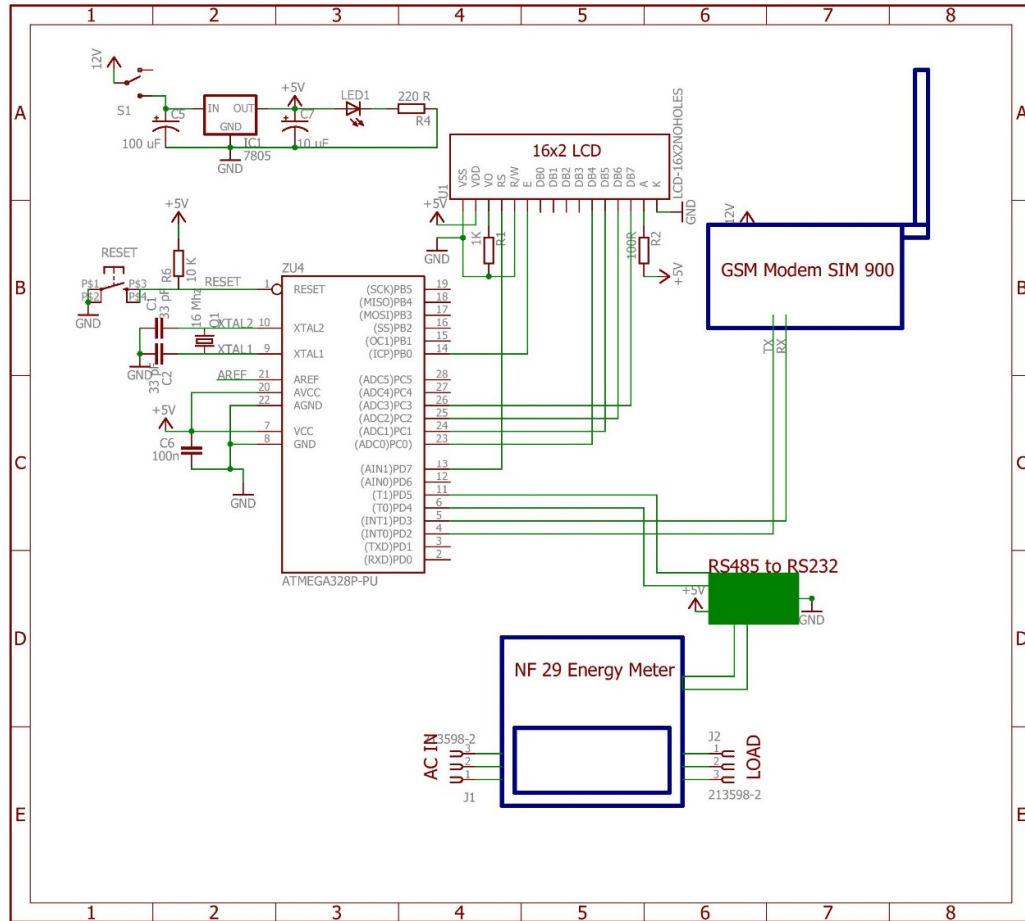


Figure 3.2 Circuit diagram for energy meter

### 3.3 Steps of operation

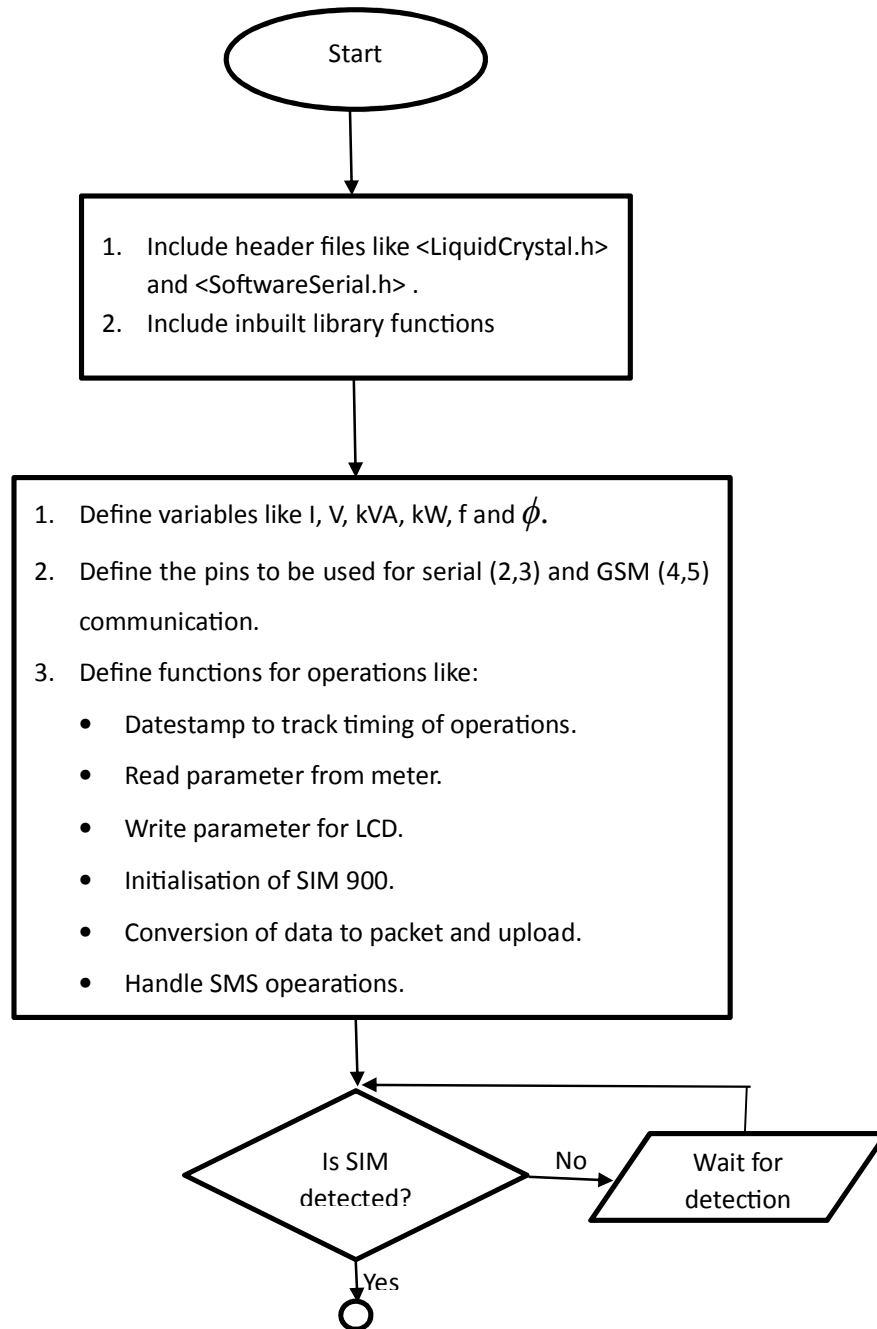
The whole process can be understood with the help of steps discussed below. These steps are used as a base to write the code for the system.

- Step 1) Include the header files and library functions like 'liquidcrystal' and 'softwareserial'.
- Step 2) Define all the variables like current (I), voltage (V), Apparent power (kVA), Real Power (kW), frequency (f) and phase ( $\phi$ ).
- Step 3) Define the pins to be used for GSM (2=Rx, 3=Tx), serial communication (4=Rx, 5=Tx), for LCD (7,8, A0, A1, A2, A3) and 'previousmills' as a timestamp.

- Step 4) Define the packet format to be used for uploading the data on thigsspeak.com which will include API key, post http command and data length.
- Step 5) Check for SIM in the system required for establishing an internet connection for uploading the data to the server. If detected then send an alert to user “SYSTEM STARTED” and display “GSM DETECTED” on the LCD display.
- Step 6) By enabling and disabling the pin no. 6 at microcontroller, send a request to the energy meter for acquiring the parameters over a serial communication channel established.
- Step 7) Process the parameters to convert them to string so as to display on the LCD, two parameters are displayed at once.
- Step 8) Create a function to enable the GSM module and establish an internet connection to the server.
- Step 9) Process the data in suitable format and convert in the packet format to be send to the server with IP address =‘184.106.153.149’ and port address =‘80’.
- Step 10) The API key will enable the data to be uploaded at dedicated portal only after a fixed interval of time and thus restricting the unauthorized access.
- Step 11) All the parameters are displayed in the form of graphs and it is also being collected in excel files which can be used for processing.
- Step 12) The user can also request the info regarding the pricing status by send a SMS <PRICE> from the mobile number which is associated with each metering device, in this case we have ‘9990004640’ as user number.

The NF-29 meter works on RS-485 protocol but microcontroller has RS-232, so to overcome this problem an intermediate interface is also required. This issue is addressed by using MAX-232 IC which converts the voltage levels of RS-485 to the levels of RS-232 and thus enabling the communication between meter and microcontroller. The code according to the setup is written in C language using Arduino 1.6.9 platform which contains all the library functions and elements to support the required operation. The code is transferred to the microcontroller by placing the microcontroller on Arduino uno board and Arduino 1.6.9 has one step function to transfer the hex code into it.

The complete programming is done using C language as per the flowchart shown in fig 3.3. It gives an idea about all the necessary header files and the functions to be created and incorporated for development of an efficient code. Another flowchart for showing the sequence of operations is shown in fig 3.4. The programming can be done using other languages too, with a condition that it may result in hex code which needs to be transferred to microcontroller.



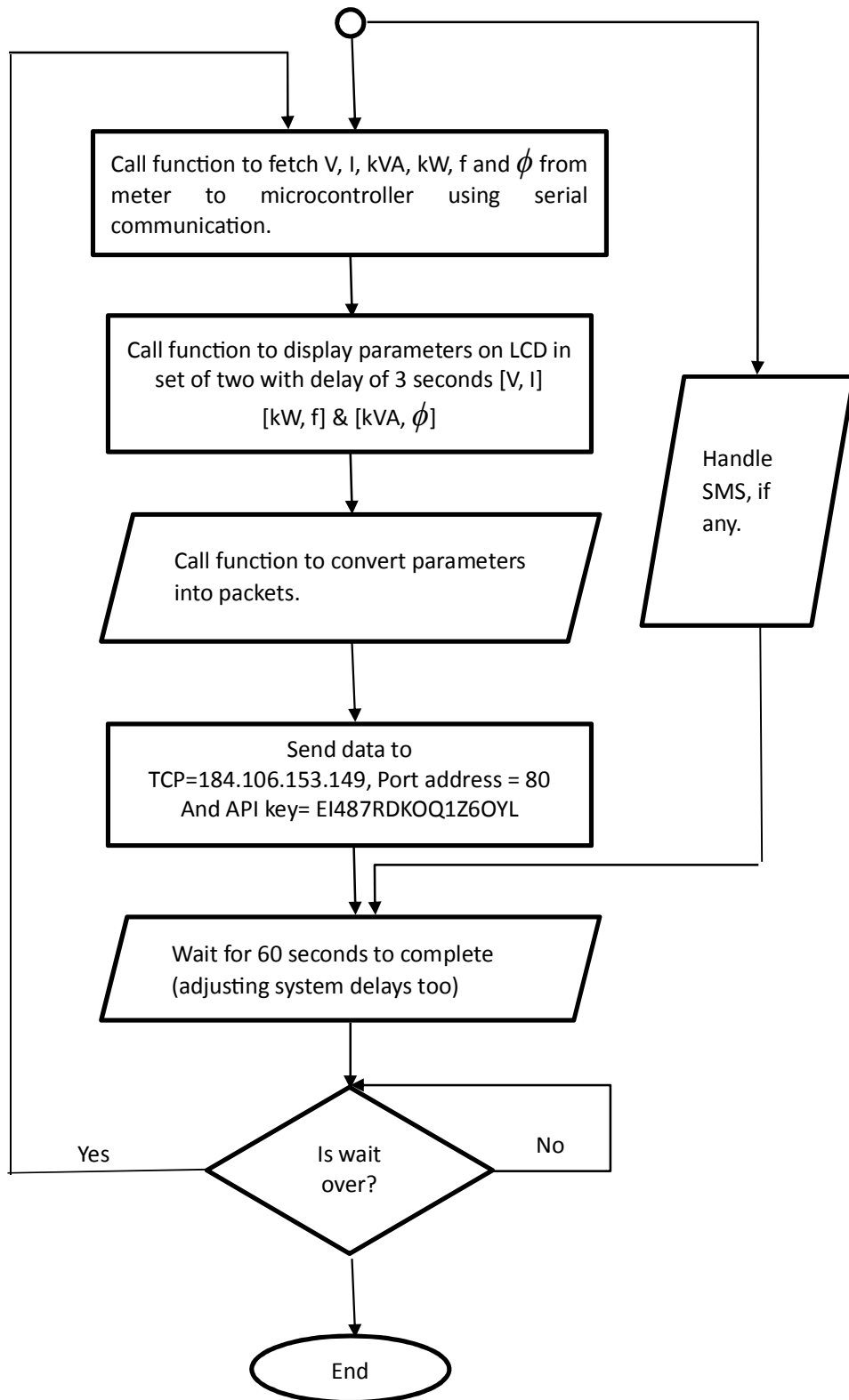


Figure3.3 Flow chart for programming

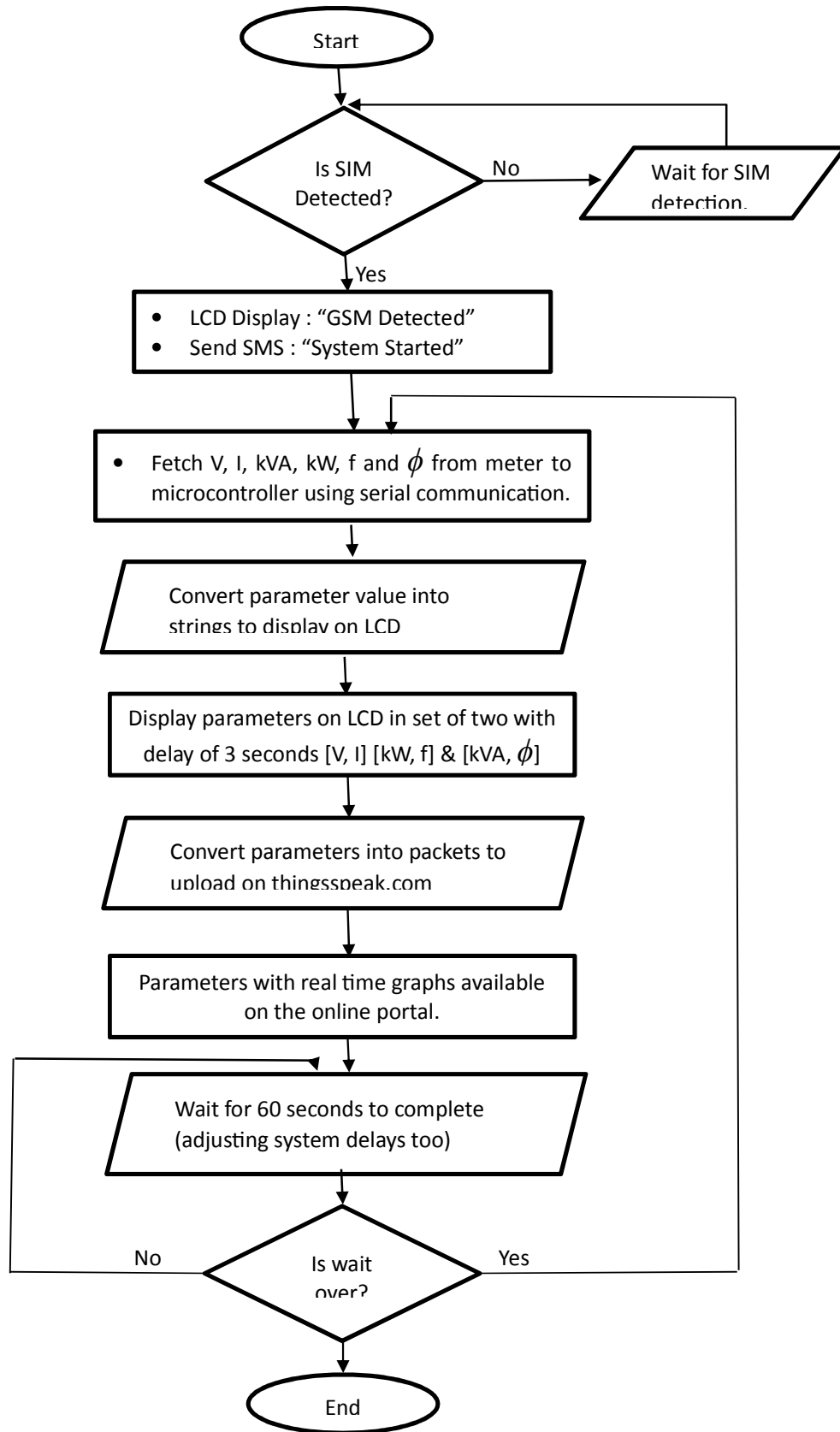


Figure3.4 Flow chart for working of energy meter

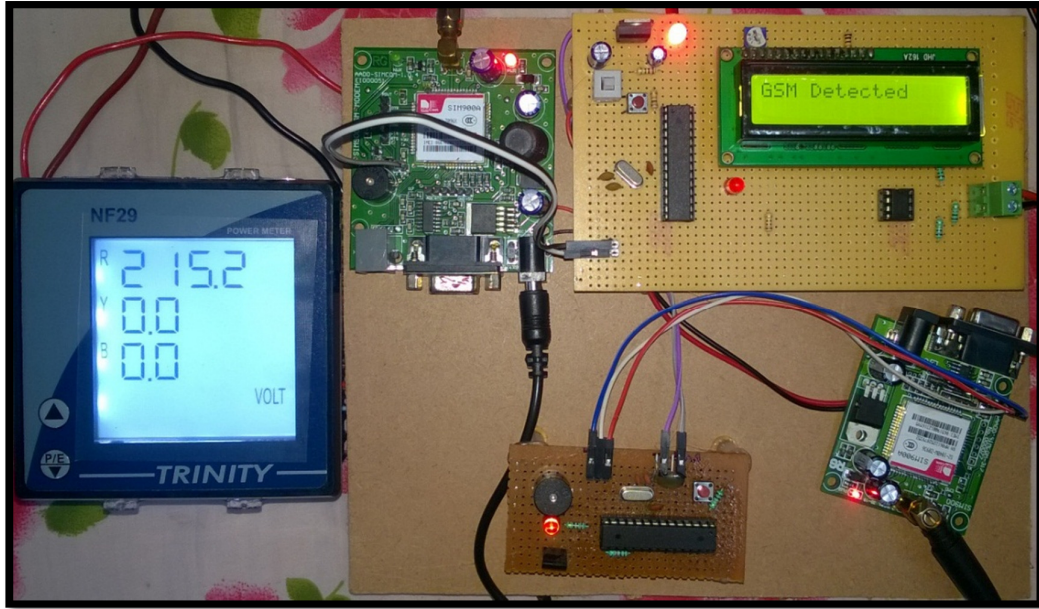


Figure 3.5 Hardware setup for energy meter

There are some open ended operations which are incorporated in the device for demonstration purpose like SMS alerts about price increase, but due to non-availability of direct access to the data from the load forecasting center. By doing some minor programming changes in the microcontroller the meter can be enhanced and upgraded to communicate and adjust the prices as per the load forecast and then automatic alert can be send to the end user.

The meter used to pull out data can also be configured to be used as three phase meter also. So the meter can be also be upgraded for three phase measurements also by making some wired connections. So overall meter has lot of scope of further modifications scope to upgrade the functionalities to a newer and higher level.

### 3.4 Results and Discussion

The data is collected at an interval of one minute and updated simultaneously on the online portal. To ensure the reliability, the data which is send to the server is displayed first on the LCD screen attached to the microcontroller and it is send in packet form to the server. For this purpose also a message is displayed on the LCD.

As soon as the system starts a SMS is send from the system to the end user on registered mobile number as in fig 3.6. If the user want to know the pricing status the user can send SMS on the system's number in format <PRICE> and system reverts back the message as shown in fig 3.6.

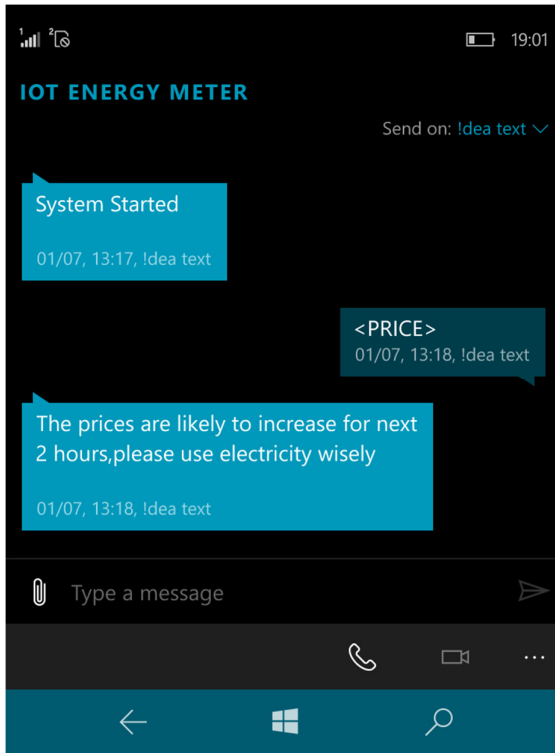


Figure 3.6 SMS alerts by the system

The system starts only when a SIM card is detected as it is one of the most vital link for communication purpose, a message is displayed as shown in fig 3.7(b). The message related to acquiring of IP address is displayed as in fig 3.7(a). The message related to the establishment of connectivity is displayed as in fig 3.7(c).

The alerts creates a certain amount of delays in the operation and processing, thus more and more alerts may induce delays and can cause error in timing, so only optimum number of alerts are generated by the system. The LCD can only display 16 x 2 characters, thus a temporal display of information is adopted for display of parameter related information.



Figure 3.7(a) System alert if IP address is acquired



Figure 3.7(b) System alert on detection of GSM

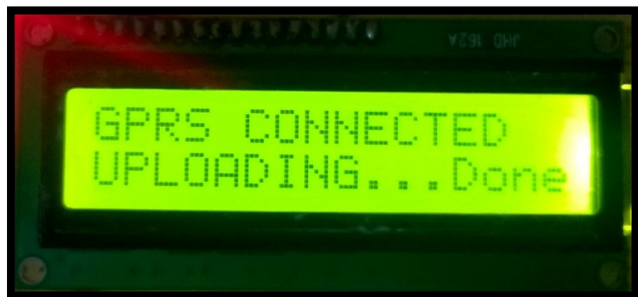


Figure 3.7(c) System Alert for GPRS connection

Figure 3.7 Various types of status signals displayed on the LCD Display

The measurement readings are considered for two different conditions, one is without load and other readings by connecting load. The parameters on LCD are displayed in group of two i.e. (V, I), (F, kW) and (kVA,  $\phi$ ). Each set is displayed for the duration of three seconds and at the end a delays of forty seconds is added intentionally so that data can be processed and uploaded to the online server too. This process is indicated by a message displayed at LCD which shows the upload process. The data at an interval of one minute is available in graphical and tabular form on the online portal which is accessible to the end user as well as supplier.





Figure 3.8(a) Voltage and Current measurement



Figure 3.8(b) Frequency and Real Power measurement

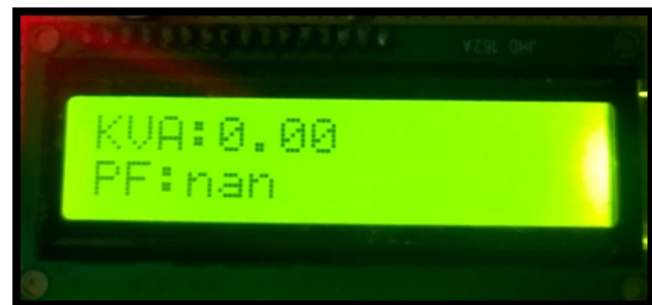


Figure 3.8(c) Apparent Power and Power Factor measurement

Figure 3.8 Display of all the parameters on LCD Display without any load

As the information on LCD screen shows the value of all the parameters except voltage to be zero which is indicative of no load condition and corresponding graphs are also available at the online portal which are shown by fig 3.9(a) to fig 3.9(f). One of the most prominent feature which can be observed from the graphs is the level of accuracy in the measurement, that it is even able to capture the very smaller variations too which can help in power quality management too.

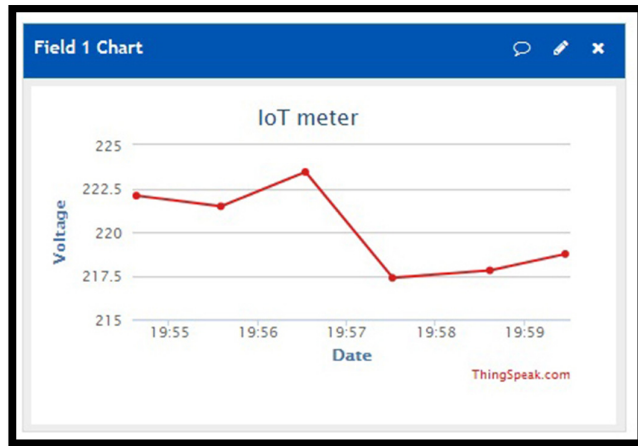


Figure 3.9(a) Voltage

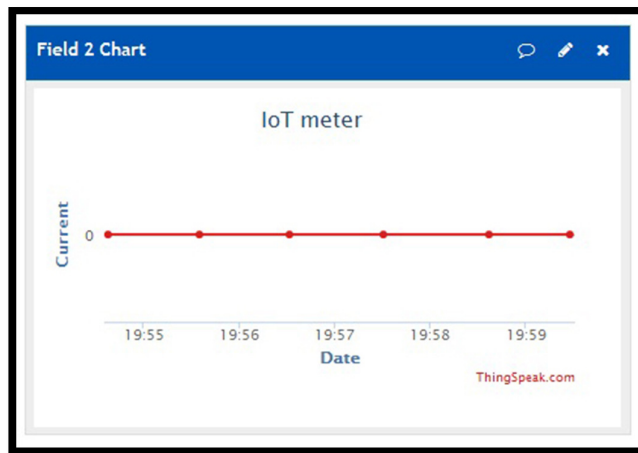


Figure 3.9(b) Current

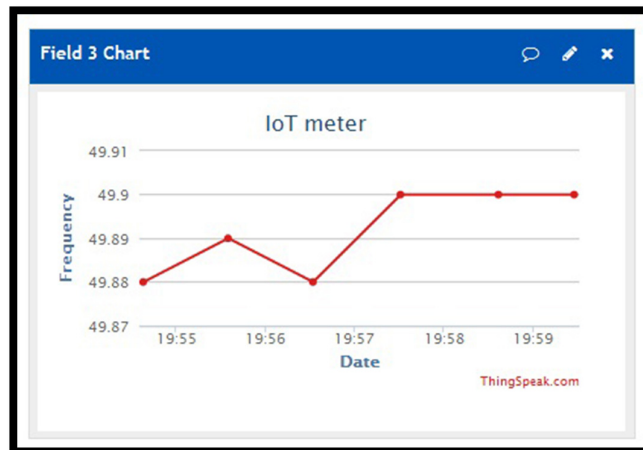


Figure 3.9(c) Frequency

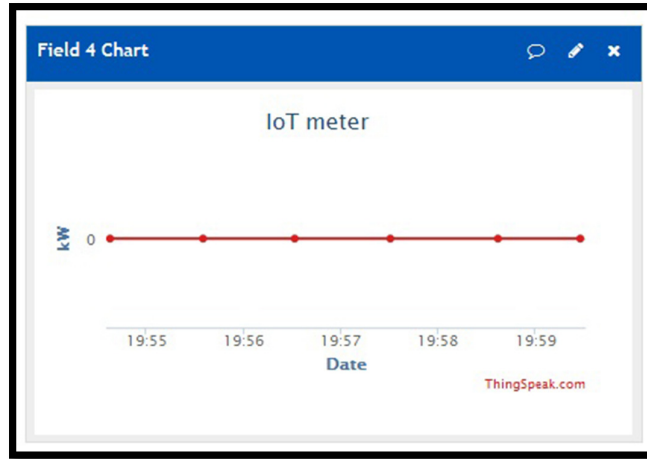


Figure 3.9(d) Real Power

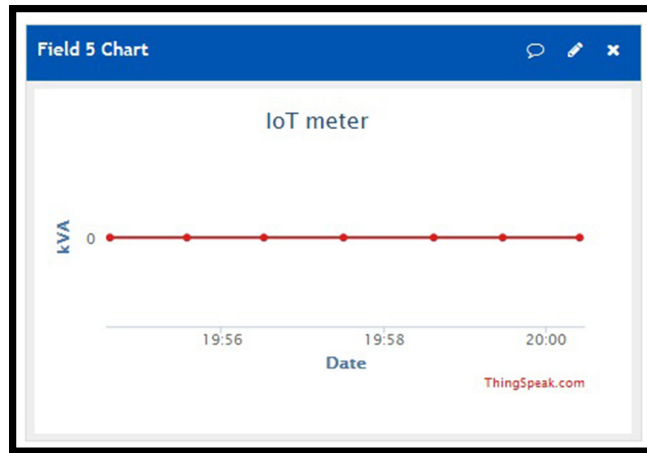


Figure 3.9(e) Apparent power

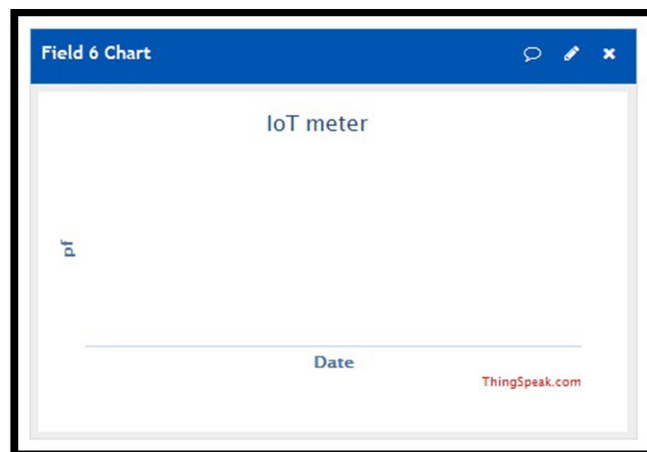


Figure 3.9(f) Phase

Figure 3.9 Updating of all the parameters on the portal and plotting of graphs in real time for no load

Another set of measurements is done by connecting a load to the meter, for which the readings are displayed on the LCD screen as shown in the fig 3.10. The readings turn to a non-zero value as soon as load is connected. The variations in the graph at online portal is clearly visible by the emergence of slope in all the parameters, which was earlier a straight horizontal line in previous case. The graphs corresponding to these reading will be updated on the portal as in fig 3.11(a) to fig 3.11(f).



Figure 3.10(a) Voltage and Current measurement



Figure 3.10(b) Frequency and real power measurement



Figure 3.10(c) Apparent power and phase measurement

Figure 3.10 Display of all the parameters on LCD Display with load

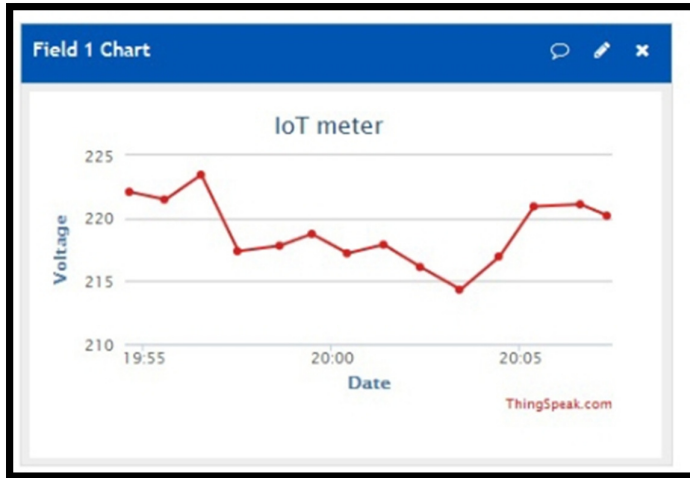


Figure 3.11(a) Voltage

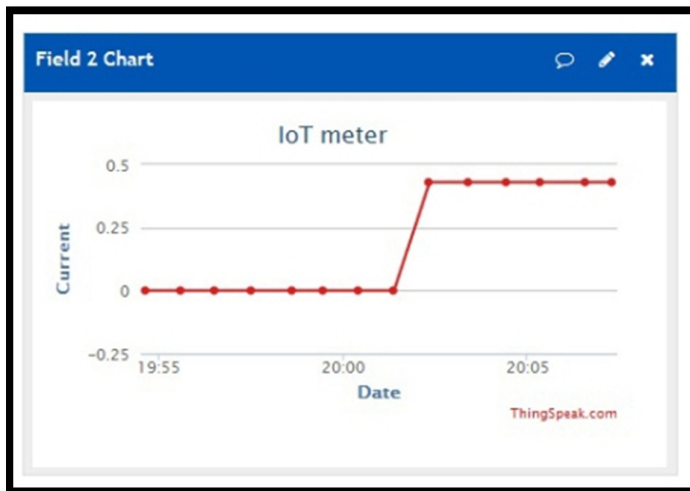


Figure 3.11(b) Current

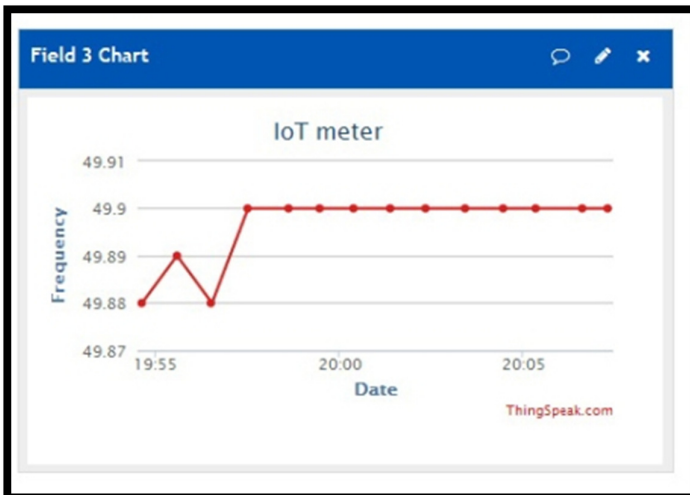


Figure 3.11(c) Frequency

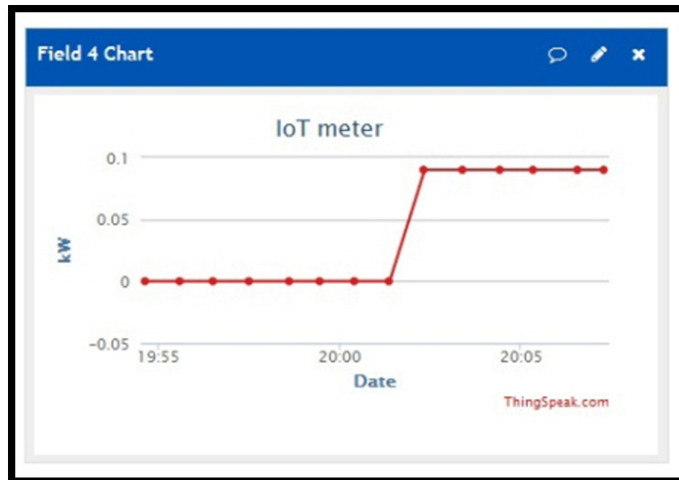


Figure 3.11(d) Real power

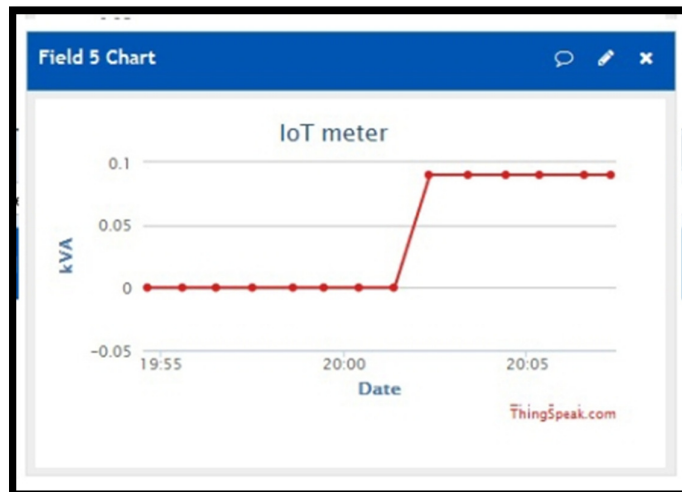


Figure 3.11(e) Apparent power

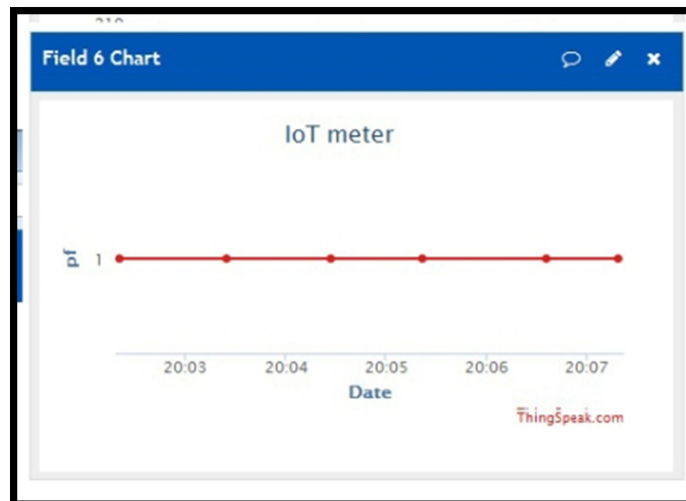


Figure 3.11(f) Phase

Figure 3.11 Updating of all the parameters on the portal and plotting of graphs in real time with load connected

The graphs obtained in fig3.11 (a)-(f) shows the variation in the curve as soon as load is changed. Earlier there was no reading in the phase graph but the resistive load connected to the meter is able to show the relevant value on the LCD display as well as the portal. It is to be notes that the horizontal axis on the graphs takes the time as variable as is not having any fixed parameter. It represents the variable on this axis as per the available data. For an instance if data is available for few minutes, it will consider minutes as variable and similarly if data is available for few days it will consider the day as variable on this axis. The data accumulated on the portal can be cleared by a function already available on the portal thus helping in management of cloud storage of data.

The data accumulated is extracted in form of excel sheets which is going to be used for the process of clustering and profiling in the next chapter which will ultimately address the issues with efficient management of the grid.

## CHAPTER 4

### LOAD PROFILE DETERMINATION OF A CONSUMER IN A SMART GRID USING MATRIX BASED APPROACH

#### 4.1 Introduction

The deviation from predicted and actual consumption of energy among different energy suppliers for eligible consumers can be easily obtained as they are well-found with suitable energy metering device, which will result in tracking of consumption in real time. The task of data collection is comparatively easy if there is single supplier for a particular area whereas it may be a challenging job if the suppliers are more than one and the metering devices are not also present for every user.

A load profile determination can be a better substitute of costly metering device installations as they can be extremely powerful tool in management of load, distribution and planning system, state estimation etc. [27]. It can be extremely helpful in protecting smart grid from cyber-attacks too. Cyber-attacks in form of injection of anonymous data and load altering commands may be sensed and a check can be put with use of suitable technology and policy [28].

The previous chapter successfully demonstrated the method to obtain the important electrical parameters like power, voltage, current, phase etc. which will can be used for power profiling. But due to hardware limitation the data collected is for single user only, whereas the profiling will require the data from multiple residences. To overcome this limitation the dummy data is being used for the clustering process here. The data obtained from the methodology suggested and the used in clustering is in the exactly similar format. The data collection from all the users in the smart grid and then transforming it into a matrix based dataset will enable all the tools being used for matrix operations to be implemented directly on the dataset obtained for the load profiling.



## 4.2 Profiling of power consumption measurements

The dataset is analyzed with different methods to obtain proper and well defined clusters. Beginning with raw measurement analysis to the matrix based analysis towards the end of this chapter.

### 4.2.1 Dataset from raw power measurement

The data used for work for creation of the matrix based dataset is taken from the Smart\* project [29]-[30], which consists anonymized average power consumption measurements in the arrangement of a series which is in continuous time domain from 148 residential buildings in western Massachusetts region of USA. The measurements were taken at the intervals of one minute which is similar to our measurements obtained in the previous chapter. There are total of 1440 measurements in a day i.e. equal to number of minutes in a day, from a single residence. Thus there are total N number of datasets where N is equal to 148, and it simply represents the number of users in a particular area which under consideration.

On merging all series of data from all the residences matrix B is obtained as given in eq. 1 having dimensions  $i=1440$  and  $j=N$ , where N represents the number of houses. From the very large dataset ,initially only 148 homes are considered, thus making the  $j=N=148$ .It is to be distinguished intervals of one minute measurements will always result in fixed value which will be equal to 1440 and thus leaving the only variable to be i which will change according to number of users considered :

$$B = \begin{pmatrix} A_{1\ 1} & A_{1\ 2} & \dots\dots\dots & A_{1\ 148} \\ : & & & : \\ : & & & : \\ : & & & : \\ A_{1440\ 1} & A_{1440\ 2} & \dots\dots\dots & A_{1440\ 148} \end{pmatrix} \quad (4.1)$$

In the above matrix  $B_{1440\ 1}$ , shows consumption of user 1 at 1440th instant of a day. Fig. 4.1 illustrates the 3D waterfall plot of matrix B. The obtained plot shows an extremely complex view of the measurements. The complexity of graph will certainly increase as

we keep on increasing the number of considered users. Individual analysis for each user can be a solution but it will require huge amount of processing space as data will be extremely high. Thus it is required to defragment dataset and obtain certain parameters for more appropriate analysis.

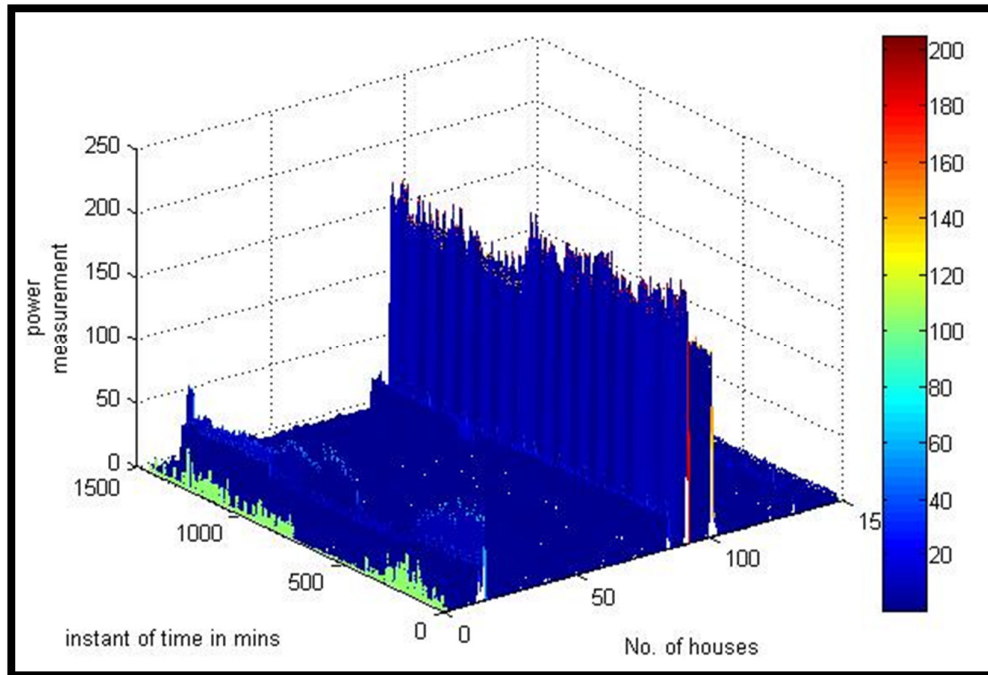


Fig 4.1 Graphical representation of raw measurements

#### 4.2.2 Operation on dataset

The analysis by graphical means and by using various mathematical functions on the data set can fetch some significant parameters such as the maximum value, minimum non-zero value, average value, bound values, so as to define the ranges for different clusters in which users are to be placed in accordance to their respective consumption patterns.

The clustering can be done in four groups i.e. Zero Consumption (ZC), Low Consumption (LC), Medium Consumption (MC) and High Consumption (HC). As the graph illustrates that most of the users lie in low consumption (LC) cluster which can result in it overcrowding. To avoid this problem we can go for further clustering of LC cluster into General Low Consumption (GLC) and a Very Low Consumption (VLC) clusters. The other method to avoid this overcrowding of cluster is by reducing the upper limit of the LC that will result in shifting of some of the users to the other clusters i.e. MC cluster and similar process can also be used if problem of overcrowding occurs in

MC cluster too. The use of iterative methods with suitable boundary value of clusters will result in effective boundary values.

It is to be well-known that the matrix having the average values with one column and the matrix A will contain same value of j which will refer to the user number. After getting the average values it is required to move to the matrix A and an appropriate value in between the average value and the maximum value of each residence need to be allotted as threshold value of consumption for each user. The key objective in assigning the threshold value is to have check on irregularities in the consumption.

Due to a large data set, analysis of each dataset independently may lead to errors and complexity. Time and frequency approach shown in [31] is unable to pull out the zero power consumption users into single cluster. There is a need to have a comparatively less complex and more efficient dataset processing methods with the purpose of merging of information from all series together and the essential information related to operation of grid can be administered and acquired simultaneously to obtain the different power consumption clusters together with zero power consumption.

### 4.3 Profiling of clusters

The profiling of clusters can be done by the method presented in the previous section and which is presented below. The flow chart of the program used is shown in fig. 3.

Let us denote the dataset matrix with B having its elements as  $A_{i,j}$ , then

$$B = \begin{pmatrix} A_{1,1} & A_{1,2} & \dots\dots\dots & A_{1,148} \\ A_{2,1} & A_{2,2} & \dots\dots\dots & A_{2,148} \\ : & & & : \\ : & & & : \\ A_{1440,1} & A_{1440,2} & \dots\dots\dots & A_{1440,148} \end{pmatrix} \quad (4.2)$$

Any measurement at certain instant of time is denoted by  $A_{i,j}$ , where

$$i = i^{\text{th}} \text{ residence and } 01 < i < 148$$

and  $j = j^{\text{th}}$  instant of time (in minutes) and  $0 < j < 1440$

### 4.3.1 Mean( $C = \text{mean}(B)$ )

Let us represent the mean value of each user by  $C_i$  which holds average values of the users.

$$C[i] = \{ C1, C2, C3, C4, \dots \dots \dots \dots \dots \dots \dots C147, C148 \} \quad (4.3)$$

$$\text{Average power, } P_{\text{avg}} = \text{Mean} \{ C_i \}$$

By use of prevailing tools and methods we have obtained the average value of all the measurements throughout a day for all users under consideration and a two dimensional plot is shown in Fig. 4.2. From the graph it is quite visible that most of the users have low power consumption and results improper classification into different clusters. But another aspect gives an idea for the limits to define the range for the different clusters by consideration of the minimum non-zero value and maximum value. Zero can also be considered to be a minimum but we desire to place the zero consumption houses to another cluster which compel us consider a non-zero value to be a minimum. All the steps which are being followed will be represented by a flowchart towards the end of this chapter.

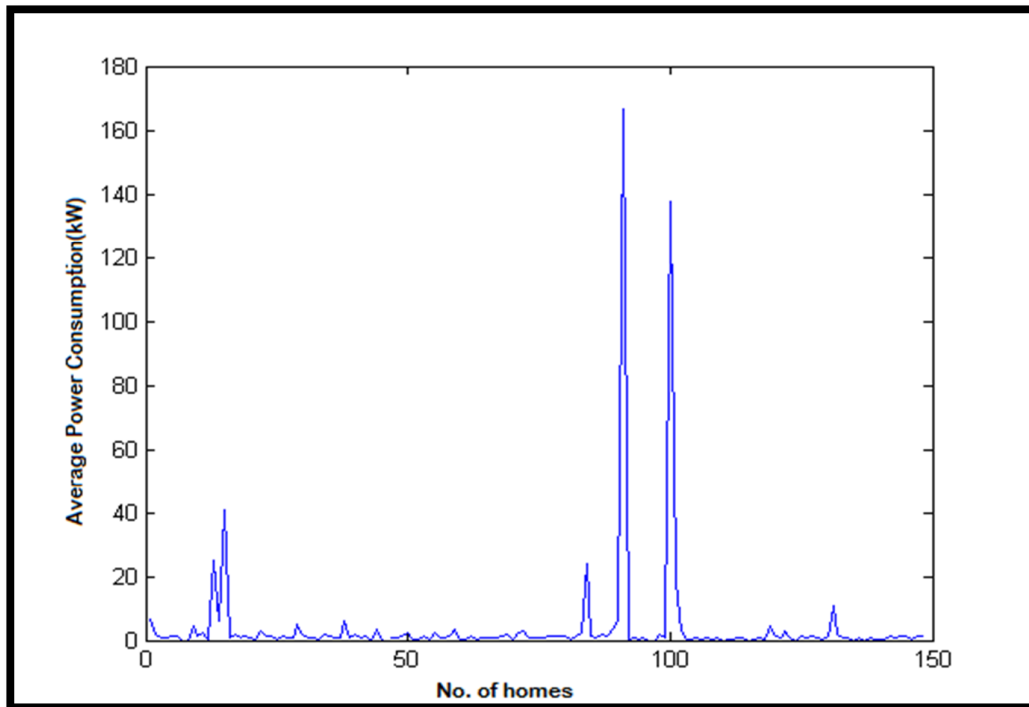


Fig 4.2 Graphical representation of average measurements

### 4.3.2 Min, Max and Boundary values

To obtain the maximum (max) value from the dataset C, the graphical or analytical method can be used. In our case, the max value obtained is:

$$D = \text{Max}(C) \quad (4.4)$$

$$D=166.3984 \text{ kW}$$

The recognizable minimum from the graph is zero which we don't want to use as minimum, thus a positive and non-zero minimum denoted by E.

$$E = \text{Min}(C(C>0)) \quad (4.5)$$

$$E=0.03357806077=0.0336 \text{ (approx.)}$$

The D and E are max and min values. It is required to obtain boundary values to classify the houses into different clusters as per their average power consumption. By the means of graphical and iterative inspection the obtained values of the boundary are:

$$F = 0.015 * D = 2.4960 \quad (4.6)$$

$$G = 0.006 * D = 0.9984 \quad (4.7)$$

The boundary values are:

$$\begin{aligned} \text{HC : } & \text{HC\_UL} = D & // \text{ LL : Lower Limit} \\ & \text{HC\_LL} = F & // \text{ UL : Upper Limit} \end{aligned}$$

$$\begin{aligned} \text{MC : } & \text{MC\_UL} = F \\ & \text{MC\_LL} = G \end{aligned}$$

$$\begin{aligned} \text{LC : } & \text{LC\_UL} = G \\ & \text{LC\_LL} = E \end{aligned}$$

$$\text{ZC : } \text{ZC\_UL} = \text{ZC\_LL} = 0$$

The next aim is to identify the users in accordance to the above criteria. The subsequent method will place the houses into clusters and will help in the process of power profiling.

$$\text{ZC}=\text{find}(C=0)$$

$$k=\text{numel}(\text{ZC}) \quad //\text{Matlab command to count elements}$$

LC=find((C>E)&(C<G))

l=numel(LC)

MC=find((C>G)&(C<F))

m=numel(MC)

HC=find((C>F)&(C<D))

n=numel(HC)

where, ZC= houses with zero consumption

LC = houses with low consumption

MC= houses with medium consumption

HC = houses with high consumption

and k = no. of houses in ZC

l = no. of houses in LC

m = no. of houses in MC

n = no. of houses in HC

The detailed information about the clusters is as follows and the process is shown by flowchart in fig 4.3

#### **4.3.2.1 Zero Consumption (ZC)**

It contains the houses with zero consumption all over the day. It directs that the houses may be in locked condition or there can be a chance of someone hacking the network and sending null or zero values value as Direct Load commands to the administrator network. In the analysis of 148 houses, the 11 houses are grouped in ZC cluster i.e. 7, 8, 43, 45, 96, 97, 110, 115, 124, 135 and 137. The policy formulation can be done by the electricity suppliers for costumers to inform if they are not available for using the electricity. It adds one more variable in load forecasting and thus enabling better management of the available resources.

#### **4.3.2.2 High Consumption (HC)**

This cluster contains the users with higher usages from all the 148 houses. The upper bound is fixed to the maximum value and lower limit is fixed to the 1.5% of the maximum value from the set of average consumption values. The main reason for very large range

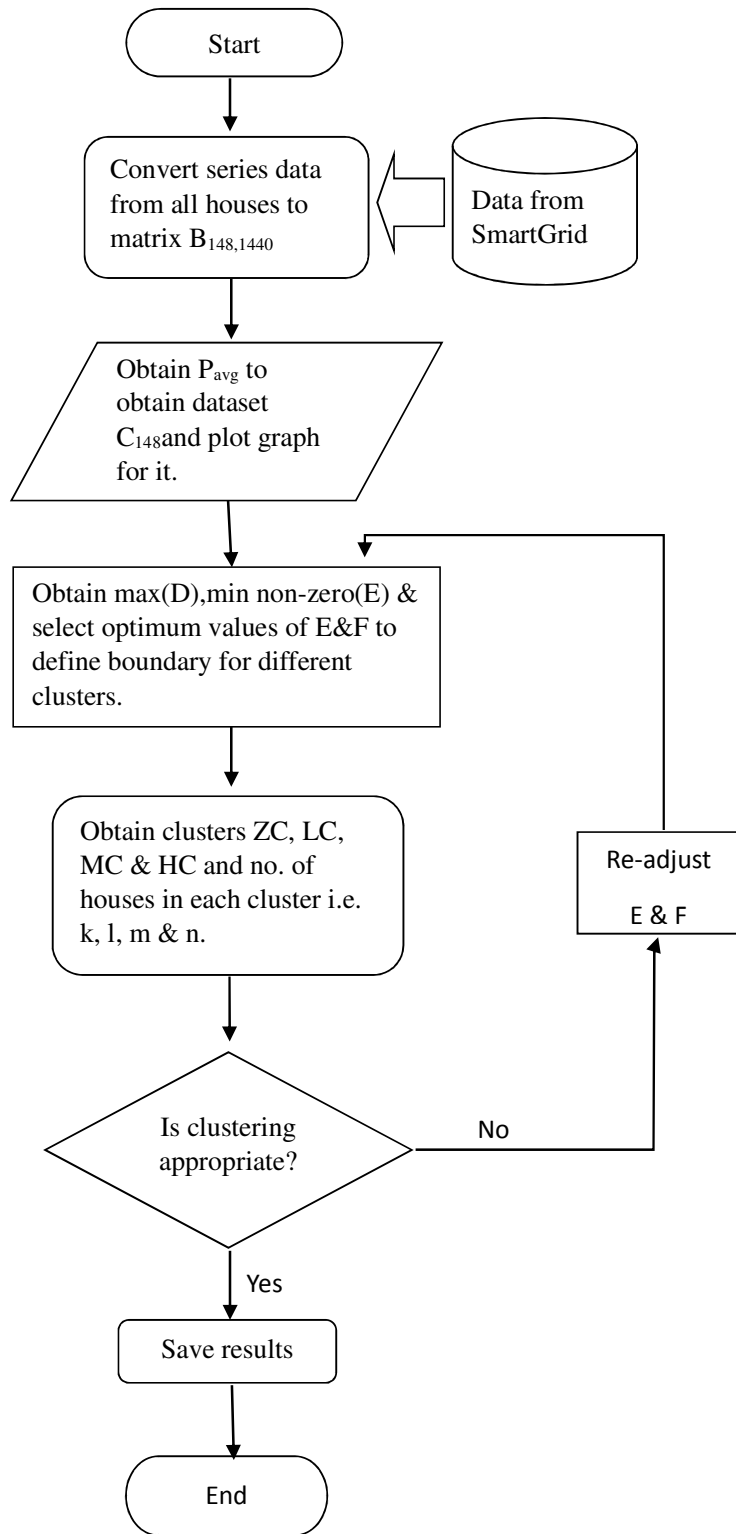


Fig 4.3 Graphical representation of average measurements

of this particular cluster is that, it is clear from graph that very few users are lying in this cluster .If its lower bound is raised up then the situation may arise that cluster may end up having very less number of houses and it will ultimately lead to overcrowding of other clusters. On sorting 22 houses are placed in this category. The houses are 1, 9, 13, 14, 15, 23, 29, 38, 44, 55, 59, 72, 84, 89, 90, 91, 100, 101, 102, 119, 122 and 131. But house no. 90 and 91 have extremely high usage i.e. 166kW and 137kW which gives rise to suspicion. It is required to check if it is actually a usage or a sign of malicious behavior arising out of hack or insertion of direct load commands in the network.

#### **4.3.2.3 Medium Consumption (MC)**

This cluster have all the users with intermediary average value of the usage. The upper bound is taken as 1.5% of the max value and lower bound is 0.6% of the max value for cluster. On applying the bounds ,46 users are placed under this cluster i.e. 2, 5, 6, 10, 11, 17, 18, 19, 22, 23, 24, 26, 31, 35, 36, 37, 40, 42, 49, 50, 53, 58, 62, 68, 69, 71, 75, 77, 78, 79, 80, 82, 83, 85, 87, 88, 98, 120, 125, 127, 130, 132, 142, 144, 145, 147 and 148. Each and every user in this cluster have tendency to shift in the HC cluster if there is increase in the consumption and it can also go to LC cluster if there is reduction its consumption, and this feature can allow users enjoy the differential tariff rates for clusters.

#### **4.3.2.4 Low Consumption (LC)**

The last cluster in classification of users is this LC cluster. It consists of all the users with low and very low consumption. From the preliminary graph it was clear that most of the users were having low average value of usage so assumption can be made that this cluster is going to be congested even with best efforts. There two ways can be followed to develop this cluster. First way is by simply classifying by the use of bounds that we have used for the previous cases. The upper bound is 0.6% of the max value which is equal to the min value of the MC cluster and the lower bound is non-zero minimum value from the average values of all the users. The other easy way of obtaining this cluster is to place all the left out users which are not placed in any cluster. So by either of the mode we are having 68 houses in this cluster i.e. 3, 4, 12, 16, 20, 21, 25, 27, 28, 31, 32, 33, 36, 39, 41, 46, 47, 48, 51, 52, 54, 56, 57, 60, 63, 64, 65, 66, 67, 70, 73, 74, 76, 81, 84, 86, 92, 93, 94, 95, 99, 103, 104, 105, 106, 107, 108, 111, 112, 113, 114, 116, 117, 118, 121, 123, 126, 128, 129, 131, 133, 134, 136, 138,140, 141,143 and 146. The results indicates 40%



to be present in this cluster from the dataset of 148 users which is indicative of requirement of further clustering of this grouping.

#### 4.4 Results and discussions

The table 1 shows the summarized results and pie chart is represented by fig 4. The table 1 displays 147 houses but for analysis 148 users were considered. On careful inspection it is revealed that house no. 23 is present in both in MC and HC cluster which is likely to be possible due to the usage value of this user equal to the value at the margin of cluster regions. The approach of has provided a distinctive separation of all the users into different clusters.

Cluster	No. of houses	Houses no's
ZC	k=11	7, 8, 43, 45, 96, 97, 110, 115, 124, 135, 137
HC	l=22	1, 9, 13, 14, 15, 23, 29, 38, 44, 55, 59, 72, 84, 89, 90, 91, 100, 101, 102, 119, 122, 131
MC	m=46	2, 5, 6, 10, 11, 17, 18, 19, 22, 23, 24, 26, 31, 35, 36, 37, 40, 42, 49, 50, 53, 58, 62, 68, 69, 71, 75, 77, 78, 79, 80, 82, 83, 85, 87, 88, 98, 120, 125, 127, 130, 132, 142, 144, 145, 147, 148
LC	n=68	3, 4, 12, 16, 20, 21, 25, 27, 28, 31, 32, 33, 36, 39, 41, 46, 47, 48, 51, 52, 54, 56, 57, 60, 63, 64, 65, 66, 67, 70, 73, 74, 76, 81, 84, 86, 92, 93, 94, 95, 99, 103, 104, 105, 106, 107, 108, 111, 112, 113, 114, 116, 117, 118, 121, 123, 126, 128, 129, 131, 133, 134, 136, 138, 140, 141, 143 ,146
Total	147	

Table 4.1 Division of users in different clusters

Overall, the results of this clustering approach demonstrates that the power consumption profiles can be recognized on the basis of average power consumption and dataset in appropriate matrix form. Usage profiles on the basis of low, medium, high and

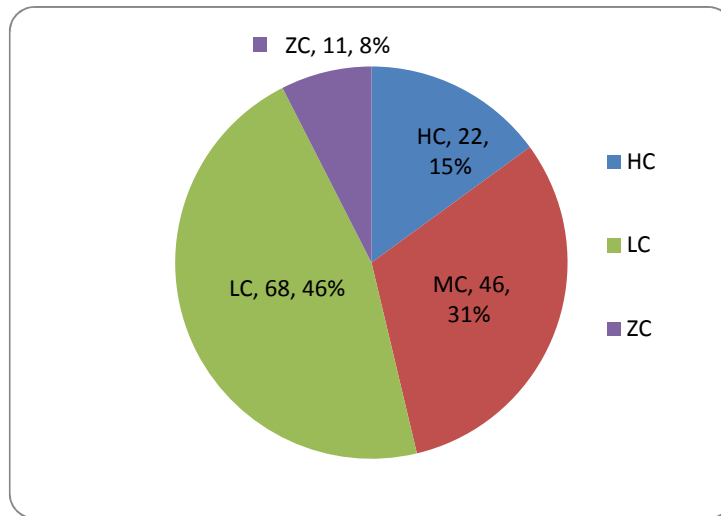


Fig. 4.4 No. of houses in different clusters after classification

zero consumption can be distinguished easily by average power consumption. The limitation of this approach is its incapability to place users with usage values equivalent to the margin value into a distinctive cluster.

## **CHAPTER 5**

### **CONCLUSION**

The project, had the purpose to design and develop a new energy metering device that can have some smart parameter extracting features which can be later used for the purpose of power profiling by creation of clusters. The development of smart energy meter concluded with the hardware design, software support and the also the integration of internet based and cellular based components. The results of the power profiling are obtained by the MATLAB and related graphs showed the grouping in proper format as per their energy consumptions. Both the phases of work are in complete accordance and supplementary to each other to produce an efficient smart metering and clustering mechanism.

The designing of hardware related setup required an exhaustive work of identifying the compatible hardware elements and then use of relevant software along with online support. The result are obtained in form of real time graphs of all the parameters and display of information on the LCD screen too. All the graphs were obtained with different value of loads being connected to the meter and variation was clearly visible. The values shown in graphs at online portal were verified and cross checked by the measuring them at actual meter terminal too.

The clustering of users on the basis of power consumption could be very useful in taking many techno-managerial decisions required for secure and unflinching operation of a smart grid. The main advantage of this method is that it can classify the residences with zero consumption into a separate cluster while earlier approaches were not able to do so. But a shortcoming of this approach is regarding the non-stationary values and for every new system it will require different set points for margins. The artificial intelligence based techniques like artificial neural networks and fuzzy can be used for defining the cluster boundaries and clustering methods.

Results obtained from both the phases of work schemes have been encouraging and many open ended terminals are present to further take this work to a new level. All the targets which were present before the commencement of work have been successfully achieved with efficient utilization of available information and resources. Few additional modifications can be made to further improve the performance.

## **CHAPTER 6**

### **FUTURE SCOPE**

The work can be taken to the completely different level by implementing some more features like online tracking and controlling of the individual appliances of the residence. The information about repair and maintenance of the appliances can be transmitted to the meter or the online portal via IoT. The device can have best of its utility if the benefits from the load forecasting methods can be integrated and meter is enabled to automatically inform the user about dynamic price in the real time.

The artificial intelligence techniques like fuzzy and artificial neural networks can be applied to define the cluster boundaries and clustering methods. The extracted parameters can be used to develop more efficient techniques for the concept of power profiling. Various works are available which suggest the use these parameters for purpose of the same. With more technological advancements the work has forward as well as backward linkages and will definitely prove to be a breakthrough when it will be implemented by use of actual IoT chips.

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# **PUBLICATIONS**

## **Published**

- [1] Arunesh Gautam and M. M. Tripathi, “Load profile determination of consumer in a smart grid by using matrix based approach,” in IEEE India Conference (INDICON): New Delhi, December 2015.

## Appendix

### Sample code for programming:

```
#include <LiquidCrystal.h>
#include <SoftwareSerial.h>
#include <MemoryFree.h>

#define VOLT 1
#define CURRENT 2
#define FREQ 3
#define KW 4
#define KVA 5
#define PF 6

SoftwareSerial GSerial(2,3); // RX, TX // GSM
SoftwareSerial mySerial(4,5); // RX, TX // RS485 Energy Meter

LiquidCrystal lcd(7,8, A0, A1, A2, A3);
int rs485_tx_en=6;
unsigned long previousMillis;

const char arr1[] = {0x06,0x03,0x0B,0xDF,0x00,0x02,0xF6,0x62}; //Voltage R
const char arr2[] = {0x06,0x03,0x0B,0xE1,0x00,0x02,0x97,0xAE}; //Current R
const char arr3[] = {0x06,0x03,0x0B,0xDB,0x00,0x02,0xB7,0xA3}; //Frequency Hz
const char arr4[] = {0x06,0x03,0x0B,0xB9,0x00,0x02,0x16,0x7D}; //KW
const char arr5[] = {0x06,0x03,0x0B,0xB7,0x00,0x02,0x77,0xBE}; //KVA
const char arr6[] = {0x06,0x03,0x0B,0xBD,0x00,0x02,0x57,0xBC}; //PF

float voltr=225.05,currentr=1.01,freq=49.90,kw=25,kva=25,pf=1;

int flag=0;
```

```
char lin1[500]="POST /update HTTP/1.1\nHost: api.thingspeak.com\nConnection:  
close\nX-THINGSPEAKAPIKEY: IW5SARBDYO4UM9GV\nContent-Type:  
application/x-www-form-urlencoded\nContent-Length: ";
```

```
char lin2[200];
```

```
char str_arr[15];
```

```
int len1;
```

```
int len2;
```

```
char buffer[10];
```

```
char aux_str[15];
```

```
/**  
*****
```

```
void read_parameter(int parameter)
```

```
{
```

```
int mul;
```

```
unsigned long currentMillis;
```

```
char temp[50];
```

```
int count=0,i;
```

```
long no=0;
```

```
float value=0;
```

```
mySerial.listen();
```

```
while (mySerial.available()>0) // Read any previous data
```

```
{
```

```
mySerial.read();
```

```
}
```

```
count=0;
```

```
delay(100);
```

```
digitalWrite(rs485_tx_en, HIGH);
```

```
delay(100);
```

```
//Send data according to parameters
```

```

if(parameter==VOLT) //Process voltage
{
  for(i=0;i<=7;i++)
  {
    mySerial.print(arr1[i]);
  }
}
if(parameter==CURRENT) //Process current
{
  for(i=0;i<=7;i++)
  {
    mySerial.print(arr2[i]);
  }
}
if(parameter==FREQ) //Process Frequency
{
  for(i=0;i<=7;i++)
  {
    mySerial.print(arr3[i]);
  }
}
if(parameter==KW) //Process KW wattage
{
  for(i=0;i<=7;i++)
  {
    mySerial.print(arr4[i]);
  }
}
if(parameter==KVA) //Process KW wattage
{
  for(i=0;i<=7;i++)

```

```

    {
        mySerial.print(arr5[i]);
    }
}
if(parameter==PF) //Process KW wattage
{
    for(i=0;i<=7;i++)
    {
        mySerial.print(arr6[i]);
    }
}
//*****
digitalWrite(rs485_tx_en, LOW);
previousMillis = millis();
while(currentMillis - previousMillis < 500)
{
    if (mySerial.available()>0)
    {
        temp[count]=mySerial.read();
        count++;
    }
    currentMillis = millis();
}
temp[count]='\0';
//
// A valid value is received
if(count>5)
{
    for(i=3;i<=6;i++)
    {
        no=no<<8;

```

```

no=no+temp[i];
}
value=no;
if(parameter==VOLT) //Process voltage
{
    lcd.setCursor(0, 0);
    lcd.print("V:  ");
    value=value/100;
    lcd.setCursor(2, 0);
    lcd.print(value,2);
    voltr=value;
}
if(parameter==CURRENT) //Process Current
{
    lcd.setCursor(0, 1);
    lcd.print("I:  ");
    value=value/100;
    lcd.setCursor(2, 1);
    lcd.print(value,2);
    currentr=value;
}
if(parameter==FREQ) //Process Frequency HZ
{
    lcd.setCursor(0, 0);
    lcd.print("F:  ");
    value=value/100;
    lcd.setCursor(2, 0);
    lcd.print(value,2);
    freq=value;
}
if(parameter==KW) //Process KW

```

```

{
    lcd.setCursor(0, 1);
    lcd.print("KW:  ");
    value=value/100;
    lcd.setCursor(3, 1);
    lcd.print(value,2);
    kw=value;
}
if(parameter==KVA) //Process KVA
{
    lcd.setCursor(0, 0);
    lcd.print("KVA:  ");
    value=value/100;
    lcd.setCursor(4, 0);
    lcd.print(value,2);
    kva=value;
}
if(parameter==PF) //Process PF
{
    lcd.setCursor(0, 1);
    lcd.print("PF:  ");
    value=value/1000;
    if(value>1)
    {
        value = value-1;
    }
    lcd.setCursor(3, 1);
    lcd.print(value,2);
    pf=value;
}
}

```

```

}

//*****

int8_t sendATcommand2(char* ATcommand, char* expected_answer1, char*
expected_answer2, unsigned int timeout) //This function sends command to the GSM
Modem and wait for reply according to arguments
{

    uint8_t x=0, answer=0;
    char response[300];
    unsigned long previous;

    memset(response, '\0', 100); // Initialize the string

    delay(100);

    while( GSerial.available() > 0) GSerial.read(); // Clean the input buffer

    GSerial.println(ATcommand); // Send the AT command

    x = 0;
    previous = millis();

    // this loop waits for the answer
    do{
        // if there are data in the UART input buffer, reads it and checks for the answer
        if(GSerial.available() != 0){
            response[x] = GSerial.read();
            x++;
            // check if the desired answer 1 is in the response of the module
            if (strstr(response, expected_answer1) != NULL)

```



```

    {
        answer = 1;
    }
    // check if the desired answer 2 is in the response of the module
    else if (strstr(response, expected_answer2) != NULL)
    {
        answer = 2;
    }
}
}
// Waits for the answer with time out
while((answer == 0) && ((millis() - previous) < timeout));

return answer;
}
//*****
int initialize_gsm900()
{
    int ret1=0;

    delay(1000); //Recent Change

    ret1 = sendATcommand2("AT", "OK", "OK", 2000); //Recent Change // Send AT
    command and test for any response from GSM
    //ret1 = sendATcommand2("AT", "OK", "OK", 2000);
    if(ret1==1 || ret1==2)
    {
        lcd.setCursor(0, 0);lcd.print("GSM Detected ");
        //---digitalWrite(led1, HIGH); //GSM Modem Detected
        flag=1; //First LED is On
    }
}
else

```

```

{
  lcd.setCursor(0, 0);lcd.print("GSM Not Detected");
  while(1);
}
delay(2000);

sendATcommand2("AT+CIPSHUT", "OK", "ERROR", 10000); //Close any previous
TCP socket connection

delay(5000);

while( sendATcommand2("AT+CREG?", "+CREG: 0,1", "+CREG: 0,5", 4000)== 0 );
// If registered to home network or roaming

// Selects Single-connection mode
if (sendATcommand2("AT+CIPMUX=0", "OK", "ERROR", 1000) == 1)
{
  // Waits for status IP INITIAL
  while(sendATcommand2("AT+CIPSTATUS", "INITIAL", "", 500) == 0 );
  delay(5000);

  // Sets the APN, user name and password
  if (sendATcommand2("AT+CSTT=\\"www\\",\\"\\",\\"\\", "OK", "ERROR", 30000)
== 1)
  {
    // Waits for status IP START
    while(sendATcommand2("AT+CIPSTATUS", "START", "", 500) == 0 );
    delay(5000);

    // Brings Up Wireless Connection
    if (sendATcommand2("AT+CIICR", "OK", "ERROR", 30000) == 1)
    {
      // Waits for status IP GPRSACT
      while(sendATcommand2("AT+CIPSTATUS", "GPRSACT", "", 500) == 0 );
      delay(5000);
    }
  }
}

```

```

// Gets Local IP Address
if (sendATcommand2("AT+CIFSR", ".", "ERROR", 10000) == 1)
{
// Waits for status IP STATUS
while(sendATcommand2("AT+CIPSTATUS", "IP STATUS", "", 500) == 0
);

delay(5000);
//Serial.println("Openning TCP");
flag=2;
lcd.setCursor(0, 0);lcd.print("IP ACQUIRED ");
delay(2000);
//digitalWrite(led2, HIGH); //GSM GPRS Active and IP assigned, now
send data // Second LED turned on
return 0;

}
else
{
lcd.setCursor(0, 0);lcd.print("IP NOT ACQUIRED ");
delay(2000);
//Serial.println("Error getting the IP address");
}
}
else
{
//Serial.println("Error bring up wireless connection");
}
}
else
{

```

```

        //Serial.println("Error setting the APN");
    }
}
else
{
    //Serial.println("Error setting the single connection");
}

    sendATcommand2("AT+CIPSHUT", "OK", "ERROR", 10000); //Shutdown GPRS
connection
    delay(10000);
    return 1;
}

//*****
*****

void setup()
{
    lcd.begin(16, 2);
    lcd.setCursor(0, 0);
    lcd.print("Welcome!");

    Serial.begin(9600); //UART for testing data on terminal
    Serial.println("System Begin");
    Serial.print("freeMemory(=)");
    Serial.println(freeMemory());
    delay(100);

    mySerial.begin(9600);
    pinMode(rs485_tx_en, OUTPUT);
    delay(100);

```

```

GSerial.begin(9600);    //UART for GSM Modem
delay(100);

GSerial.listen();
delay(2000);
lcd.clear();
initialize_gsm900();  //Initialize GSM modem
}
//*****
*****

void loop()
{
mySerial.listen();

lcd.clear();
read_parameter(VOLT);
delay(250);
read_parameter(CURRENT);
delay(3000);

lcd.clear();
read_parameter(FREQ);
delay(250);
read_parameter(KW);
delay(3000);

lcd.clear();
read_parameter(KVA);
delay(250);
read_parameter(PF);
delay(3000);
}

```

```

//Uploading on Server Starts
GSerial.listen();

if (sendATcommand2("AT+CIPSTART=\"TCP\",184.106.153.149\",80\"",
//Start TCP socket connection to thingspeak server
    "CONNECT OK", "CONNECT FAIL", 30000) == 1)
{
    lcd.clear();
    lcd.setCursor(0, 0);
    lcd.print("GPRS CONNECTED");
    lcd.setCursor(0, 1);
    lcd.print("UPLOADING");

    delay(2000);

    strcpy(lin2,"field1=");
    dtostrf(voltr,4,2,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);

    strcat(lin2,"&field2=");
    dtostrf(currentr,4,2,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);

    strcat(lin2,"&field3=");
    dtostrf(freq,4,2,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);
}

```

```

    strcat(lin2,"&field4=");
    dtostrf(kw,4,3,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);

    strcat(lin2,"&field5=");
    dtostrf(kva,4,2,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);

    strcat(lin2,"&field6=");
    dtostrf(pf,4,2,str_arr);
    strcat(str_arr,"\0");
    strcat(lin2,str_arr);

    sprintf(buffer,"%d",strlen(lin2));

    strcat(lin1,buffer);
    strcat(lin1,"\n\n");
    strcat(lin1,lin2);
    strcat(lin1,"\n\n");
    strcat(lin1,"\0");

    sprintf(aux_str,"AT+CIPSEND=%d", strlen(lin1));
    if (sendATcommand2(aux_str, ">", "ERROR", 10000) == 1) //Actually here data
is sent to thingspeak server
    {
        sendATcommand2(lin1, "SEND OK", "ERROR", 100);
        lcd.print("...Done");
    }
else

```

```
{
  lcd.print("...Fail");
}
delay(5000);
}
else
{
  lcd.setCursor(0, 0);
  lcd.print("GPRS NOT CONNECT");
}
//Uploading on Server Stops

}
//*****
*****
```