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Smart Energy Meter with Advanced Features and Billing System

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Abstract: The paper presents designing, implementation of the cost effective Energy Meter having demand side load management with flexible tariff plan. Smart Energy Meter with the enabling feature of Automatic Meter Reading (AMR) and storing data in SD card, communication of billing information with the consumer and utility through GSM network, tampering detection and notify both consumer and utility through Short Massaging Service (SMS). Advanced feature of this meter is demand side load management during peak and off-peak hours. Using load management customer can go into daily cost reduction process. In load management, consumer load limit is flexibly reduced during peak hours and by increasing this limit SEM automatically cut off the load. In case of any fault SEM also automatically disconnect the complete load through relay operation..

Keywords: Smart Energy Meter (SEM); Automatic Meter Reading (AMR); Global System for Mobile (GSM); Short Message Service (SMS); Secure Digital (SD; Liquid Crystal Display (LCD); General Packet Radio Service (GPRS); Giga Bites (GB).

I. INTRODUCTION

The traditional meters such as electromechanical and electronic are not suitable for utility company and consumer because of monitoring, controlling and automatic meter reading is not possible by these metering system. Different approaches like Power Line Carrier (PLC) communication, ZigBee, Wi-Fi and Bluetooth have been used to provide the reliable and effective solution to the remote metering system [1, 2, 3, 4]. Meter operation on PLC has reliability issues due to noise in the transmission line and weather condition. Because of this whole power system may be damaged.

In convectional billing there are many errors and flaws. Some of the common observations in the conventional billing are:

- Process is a time consuming.
- Extra human effort is required.
- Chances of physical error when noting reading by manual method.
- No method of check and balance in this type of meter reading.
- More chances of tampering the meter are present.
- No updates of usage to the customers.

Energy meter is a device that records the consumption of electricity consumed by homes, industries or an electrically powered device. SEM is an electric device which has energy meter chip that records the consumption of electric energy, wireless system for communicating with data (like GSM network) and devices for the purpose of security, displaying data(LCD) and controlling equipment's like relays etc. Energy meters [5] can be integrated with embedded micro-controllers like GSM network which transmit the data to users mobile. This data will then be integrated with the energy monitoring and management centers.

Wireless energy meters are energy meters which are used to measure power and monitor the different parameters of it and communicating the useful information like billing by using some wireless technology. This eliminates the use of manpower for noting meter reading by going door to door. The electricity consumption meter facilitates the billing of energy meter and using wireless GSM technology we can control load using. In current situation, all customers are using manual communication [6, 7]. In order to overcome human errors in manual reading we need automated system which monitors all the functioning and parameters of the consumer. Moreover, Utilities will be able to connect or to disconnect the customers remotely, detect outages, executing the sophisticated demand-response programs and to perform other customer services using intelligent smart meters [8, 9].

AMR system involves Smart meter sending information wirelessly to service. There are different means available for communication like ZigBee, X-Bee, Local Area Network (LAN), Wireless Local Area Network (WLAN) and Global System for Mobile (GSM), General Packet Radio Service (GPRS) and Power Line Communication (PLC) [10, 11]. Arduino UNO is the heart of this Smart Energy Meter which processes the analog values getting from voltages and current sensors. The Hall Effect sensor ACS-712 (30 A) using for the sensing of current and its output fed to analog pin of ARDUINO UNO. The Step-down voltage transformer 230/6V used for voltage measurement, there is a resistive voltage divider series circuit consists of 1000 ohm and 2800 ohms' resistors. The output is rectified using fill wave rectifier and a capacitor of 1000μF for smoothing the voltage waveforms along

with Zener diode. The transmitting ways of data information here is GSM which is low cost and most feasible solution among all the solutions available, so SIM900 module was used which supports GPRS connectivity as well. The load load management is done by using the 8-channel relay module, microcontroller sends signal to relay module which energizes the relay coils and trip load if energy exceeds to threshold value. Time of use pricing or metering is a process in which a consumer is charged with respect to its time of consumption of electrical energy or using electrical appliances. The Time of use pricing includes off peak pricing, peak pricing, real time pricing and load reduction credits [10]. A smart metering approach is presented in [12] which would overcome or reduces the traditional metering system and this approach is based on GSM module network to wirelessly transmit the reading data. In case of any miss happening, utility can shut down the load.

II. Proposed Smart Energy Meter

The specific feature of SEM is their ability to communicate the meter's reading to the supplier via communication network. For quick and efficient means of data collection GSM network is preferred in this proposed system for communication purposes between the consumer and utility service because it offers many facilities to mobile phones such as text messaging and internet even at low speed. Due to large network coverage, low cost and with negligible maintenance, sending the data through SMS becomes a useful and handy tool.

An Arduino based smart metering system comprising of a smart energy meter and a mobile phone acting as a central server receiving all the data sent by the energy meter. The proposed SEM sends all the measuring parameters to the utility company such as voltage, current, power, power factor, kilo watt-hour and billing. It also limits the energy consumer from exceeding the maximum demand during peak hours. Tamper alert feature has also been implemented to prevent any unauthorized and illegal activity. The data stored in SD card as a backup storage.

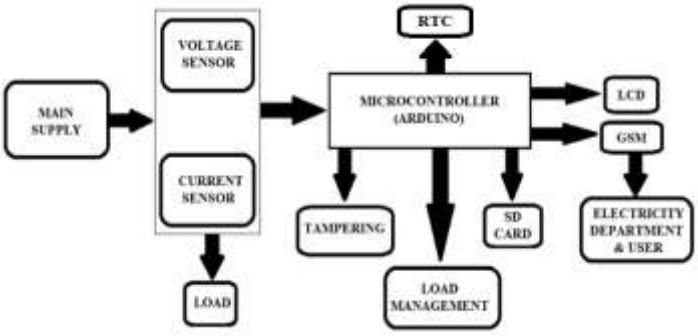

Fig. 1. Block Diagram of Proposed SEM

Proposed Smart Energy Meter can be divided into several main components. Their introduction and purposes are introducing as follows.

Arduino MEGA 2560

The Arduino mega 2560 is microcontroller board based on ATMEGA 2560. It has total 54 pins. Among these 54 I/O pins, 16 pins are analog input/output data pins and 4 pins are for UART serial communication. The advantage of Arduino Mega over other microcontroller like Arduino Nano or UNO is that it has high sketch memory and High RAM which make him a fast processing controller.

GSM Module SIM900A

The SIM 900A is a dual band (900/1800 MHz) GSM/GPRS module. It communicates with controllers using AT commands. The reason for selecting module is its slim and compact size which fits in almost every requirement of the user. Main features of this module are:

- Dual Band 900/1800 MHz controller
- Control via AT Commands.
- Low power usage (1.5mA in sleep mode).
- Different LED blinking rate for Different purposes.

Relay

Relay is simply an electrically controlled switch. In this, relay is controlled by Arduino. It operates at 5V which is given through Arduino 5V pin. The SRD-05VDC-SL-C relay has three terminals i.e. one common, one NC (normally close) and one NO (normally open) that are connected to high voltage devices to whom we are controlling.

Liquid Crystal Display (LCD)

A 20x4 LCD has been used in this project. In this, there are four display lines and each line has the capability to display 20 characters in a line. The parameters that are displayed on the LCD include voltage, current, power, power factor, energy, billing.

SD Card Module

Micro SD card module is used to store the values so that meter readings are not lost when meter is turned off. Also, the SD card also serves the purpose of meter reading verification because as the reading are sent to the utility through GSM the utility company can verify the values being sent to them by comparing it with the SD card values.

For this, an SD card module has been used to transfer the data to the card. We use SD card of 8 GB.

Real Time Clock (RTC)

The RTC module DS3231 used in this project is a low cost and an accurate module that provides hours, minutes, seconds, date, day, month, and year information. The date of the month ending with less than 31 days is automatically adjusted including the leap year.

Current Transformer (CT)

CT is used for measuring the AC current consumed by the load. Different current transformers are available in the market but we chose the split core type. The advantage of this CT is that we don't need to break the wire for measuring the current of the load but we simply clamp the CT over live or neutral wire (at any part of wire) of the load from which current is flowing.

Miniature Snap Action Switch

The snap action is a switch which operates at very small external force or pressure, it has three terminals which are normally open (NO), normally close (NC) and common (C). It has a level which is pressed downward to open or close the switch depending upon the connections made.

III. METHODOLOGY

There are two main measurement blocks. One is voltage measurement block and the other is the current measurement block. In voltage measurement, main power supply is connected to the primary of a 230-4.5 V step down transformer while secondary of the transformer is connected to a voltage divider circuit which consists of a two resistors of values 100k and 10k which divides the secondary voltage of the transformer into a ratio of 10:1.

The value of voltage across the low value resistor is taken to be fed to the analog pin of the Arduino but this AC signal contains both the positive and negative values. As Arduino can read only the positive values, so to convert the negative values of the incoming signal into positive values, a DC voltage shift is given to the incoming signal. For this purpose, a 5V DC is supplied to the voltage divider circuit consisting of two 470k resistors dividing the voltage equally. This DC shift is added to the incoming voltage level so that the negative portion of the signal may be converted into positive since the Arduino can read only the positive values. The voltage that has been now converted into the compatible range of the Arduino is given to the analog pin of Arduino.

Similarly, the current of the load is measured by the CT and is stepped down by the ratio of 60:1. If input current is 60 A output of CT will be 1V ac signal.the negative part of current signal is converted into positive part by using DC voltage shift of 5V as in voltage circuit.

When measuring current by CT we see some fluctuations in the output. For this reason and to overcome it we used current sensor. It simply connects in series with the load and its output signal pin is fed directly to the Arduino mega. It gives accurate values of current. The values of voltage and current (measured by CT) are processed by the Arduino such that the relative time difference is measured between the voltage and current waveform. The voltage waveform is taken as the reference and the amount of the angle or time by which the current waveform lags behind the voltage waveforms calculated by detecting the zero crossing of the voltage and current waveforms. The time period of sine wave is 20msec for 50Hz system. The maximum time difference that can exist is 5msec, so time difference gives us the information about power factor. For a resistive load, the power factor is one because there is no time difference between the two waves.

The voltages, current and real power consumed, power factor, energy, billing information are displayed on the 20 x 4 LCD. The LCD is connected to the Arduino. The energy is measured by multiplying the real power consumed by the load with the time. All the values are constantly stored in the SD card. The snap action switch has been used for tampering alert if unauthorized person tries to open the meter casing and this tampering information is stored in SD card. The GSM module is connected to the Arduino through the serial communication pins TX and RX of the module with the pins 9 and 10 of the Arduino. The 5V supply to the GSM module is separately provided by the Arduino. The GSM module is operated through AT commands. These commands are basically the instructions that are used for controlling and communicating with the GSM/GPRS modem. The reason why these commands are called the AT commands because each command starts with the word 'AT'. Some of the SMS related AT commands are:

- AT + CMGS for SMS sending
- AT + CMSS for sending SMS from storage
- AT + CMGL for listing all the SMS
- AT + CMGR for reading SMS

AT in the start of the line only give information about the GSM modem about the beginning of the next command line. For example, the real command in the line "AT + CMGR" is "+CMGR". Thus, by executing these commands messages are sent to the number that has been saved in the code. The readings of the meter are also stored in the SD card.

III. SOFTWARE SIMULATION

For simulating electronic circuits Proteus is the best simulation software. We have simulated our proposed scheme of Smart Energy Meter in Proteus 8.0 software. First, we need to add the Arduino library in Proteus software because software does not support Arduino boards by default. The .hex file of code is uploaded in Arduino boards in Proteus. For serial communication baud rate is set to 9600. The simulation of Smart Energy Meter consists of following parts.

- Voltage Measurement Circuit
- Current Measurement Circuit
- Load Management Circuit

After uploading the Arduino code results can be seen

on LCD as shown in the figure 2.

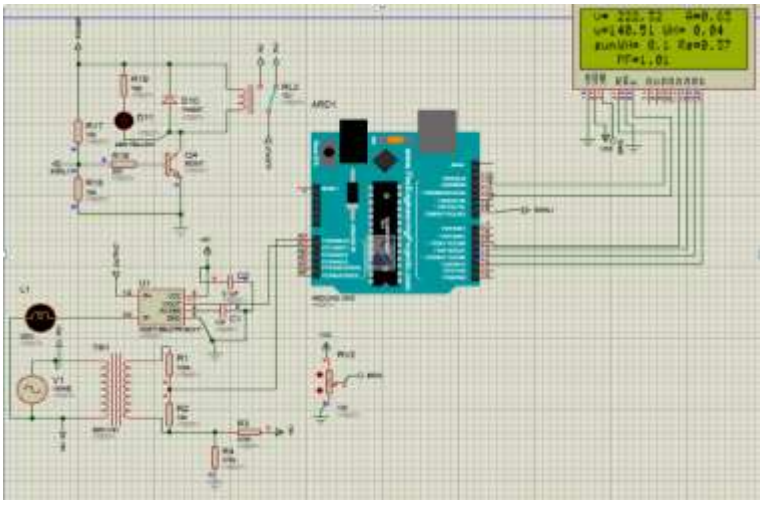

Fig. 2 Schematic Simulation of Proposed Smart Energy Meter

IV. RESULTS AND DISCUSSION

During the implementation of proposed Smart Energy Meter, we tested the meter by connected it with different loads including resistive and inductive and it gives accurate results. Table I shows the percentage error of SEM readings to that of wattmeter readings.

Table I. Observation Table of Power Calculation

	Observation Table		
Load (W)	***Smart Energy Meter Power Values (W)***	***Analog Wattmeter Values (W)***	***Percentage Error Values***
100	109.3	108.4	0.83
200	208.4	207.3	0.53
300	303.9	302.8	0.363

It is clearly seen that maximum error is at light load but as we starts increasing the load the percentage error will start decreasing.

A. When load is turned ON during Off-Peak Hours

When load is switched ON LCD displays all the parameters which include Voltage, Current, Power Factor, Power and Energy as shown in Fig 3.

Fig. 3 Parameters measured by Smart Energy Meter

B. When load exceeds the Max Demand during Peak Hours

When consumer load exceeds the maximum demand during peak hours, meter sheds the load and alert message is displayed on the LCD as shown in the Fig 4.

Fig. 4 Load is cut-off due to maximum demand

C. When Meter is Tampered

When meter casing is being lifted, tampering alert message is displayed on LCD as shown in Fig 5.

Fig. 5 Tampering Alert

D. SD Card File Result

Fig 6 shows the values stored in the SD Card. Different parameters like Voltage, Current, Power, Energy and Billing values are being stored including date and time .

Fig. 6 Different parameters stored in SD Card

E. GSM Result

GSM sends the energy and billing information after fixed interval of time. Different GSM messages received on mobile are:

Fig. 7 Smart Energy Meter readings received via SMS

V. CONCLUSION

This manuscript describes the designing and fabrication of the smart energy meter. This is a new concept in the under developing countries and it is successfully being implemented in the various countries. It calculates the energy consumption in very short interval of time and transmits it to the utility through GSM system. It eliminates the need of utility person to visit the customer meter and to read the readings. The billing of the energy is also calculated and is transmitted to both utility and consumer through GSM method. The feature of meter tampering is also included if someone tries to tampered or try to illegal use of electricity meter. Many future enhancement and improvement could be made in this project, few of them are listed below:

- Single phase smart energy meter could be upgraded for three phase system.
- Online billing system could be implemented in this.
- Mobile app could be developed which links the meters and user could view all the details and parameters on the app.
- We can upgrade GSM network into 3G and 4G technology.
- User profile could be created on the web portal which displays parameters like Voltage, Current, Energy, Power Factor, Billing information, Tampering information.
- All smart meters could be linked together through a central networking hub such that the accumulative incoming and outgoing power consumption could be tracked down.

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