Design of IoT Enabled Smart Energy Meter (IoTeSEM) Reading and Billing System using Arduino

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Abstract— Technology stemming from web of things is home automation. World's main focus is to make a smart home to take advantage in providing comfort for human life. Energy monitoring and conservation holds prime importance in today's world because of the imbalance between power generation and demand, there are very accurate electronic energy monitoring systems available in the market. Most of these monitor the power consumed in a domestic household, in case of residential applications. Many a times, consumers are dissatisfied with the power bill as it does not show the power consumed at the device level. This paper presents the design and implementation of an energy meter using Arduino microcontroller which can be used to measure the power consumed by any individual electrical appliance. Internet of Things (IoT) is an emerging field and IoT based devices have created a revolution in electronics and IT. The main intention of the proposed energy meter is to monitor the power consumption at the device level, upload it to the server and establish remote control of any appliance. The energy monitoring system precisely calculates the power consumed by various electrical devices and displays it through a home energy monitoring website. The advantage of this device is that a user can understand the power consumed by any electrical appliance from the website and can take further steps to control them and thus help in energy conservation. Further on, the users can monitor the power consumption as well as the bill on daily basis.

Key words: Internet of Things (IoT), Arduino Nano, ESP8266, Current Sensor SCT-013-030, HEMS (Home Energy Monitoring System)

I. INTRODUCTION

Energy monitoring is an important tool for determining the energy efficiency of various devices. This paper implements an energy monitoring system which displays the power consumed by individual or multiple devices. This can help a user to detect any errors in the electricity bill. Many a times the domestic electricity bill shows excess amount which causes consumer dissatisfaction and complaints. A smart energy monitoring system can help a user to analyse the energy consumption data at device level and manage it rather than assuming it to be a fixed monthly expenditure. Also, it helps a user to replace the regular appliances by energy efficient ones. Importantly, the monitoring system can alert the user on unexpected excess consumption caused by equipment malfunctions, lack of proper maintenance and the like. Further, proper energy management can make proper budgeting possible.

Internet of things (IoT) has opened up a plethora of applications in numerous fields such as medical and healthcare systems, smart home automation and environmental monitoring. IoT is expected to bring about large amount of change in the field of ubiquitous computing. IoT based energy management system can contribute a lot into conservation of energy.

Energy bills are generated on monthly basis and the user has the option of analyzing the consumption details every month. The energy meter installed in the residential buildings show the energy consumed by the household. Very often, devices which operate in standby mode consume a significant amount of power about which the end customer is unaware of. So, there is a strong need for a novel energy monitoring system which can show the energy consumption of different devices in normal as well as standby mode and also alert the user on unexpected rise in the energy consumption on daily basis.

II. LITERATURE REVIEW

A survey of the already existing literature on energy meters show that a lot of developments have been reported in implementation of meters which record and display the domestic power consumption [1,2].

[1] presents the implementation of an energy meter which is based on non-invasive current sensing. Noninvasive current sensing has the advantage that it can be placed at any point where the power is to be measured. The energy consumption details in this case are displayed on a smart phone. ENC28J60 Ethernet module was used to send data over the internet. S.H Ju et.al [3] have devised an automatic meter reading device (AMR) based on power line communication (PLCC). PLCC involves sending data over. the electrical wiring cables. This possibility requires appropriate modification in the domestic wiring of house. Moreover, it uses invasive technique to sense the current from the mains. The disadvantage with this kind of a system is that the user cannot measure the power consumed by an individual device.

[4] Explains the implementation of a wireless automatic meter reading system (WAMRS) which incorporates the widely used GSM/GPRS network. The system includes a microcontroller, which periodically transmits power consumption values calculated from the sensed voltage and current values via an existing GSM/GPRS network, to a master station. The main disadvantage of this technology is distance factor. A strong GPRS or a GSM network coverage at long distances may not be available whereas the other disadvantage might be speed of operation.

Considering the inputs provided from various literature, this paper proposes a portable energy meter using noninvasive technique for sensing the current using a split core current transformer [5,6]. The internet connectivity is established through Wi Fi module ESP8266 [7]. Real time acquisition of energy and its remote monitoring can be implemented by adopting the concept of IoT. This idea allows customers to analyse load wise energy usage and avoid peak pricing.

III. IMPLEMENTATION

This paper proposes a novel smart home energy system which senses the current values on real time basis, computes the instantaneous power and uploads the values to the cloud [8] using the Wi-Fi module. The block diagram of this system is as shown in Fig1.

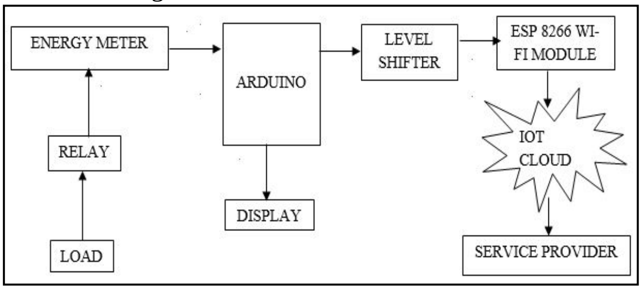

Fig. 1: Block diagram of Home Energy Monitoring System

The current sensor SCT-013-030 is the main part of the circuit. The current values are sensed on real time basis and are transmitted wirelessly to the server through the Wi-Fi module ESP 8266 which is connected to Arduino Nano. The user display is implemented display module and Real Time Clock (RTC) module.

The Split Core Current Transformer sensor SCT-013-030 [5] has a capacity to sense a maximum current of 30A and gives an output voltage of 1V peak to peak for this current. The output voltage thus produced is then given to the microcontroller Arduino Nano through the Analog to Digital Converter (ADC) input. This voltage waveform is shifted upwards by 2.5V dc with the help of the circuit shown in Fig 2. The rms value of the output signal is computed and the power is calculated in the program.

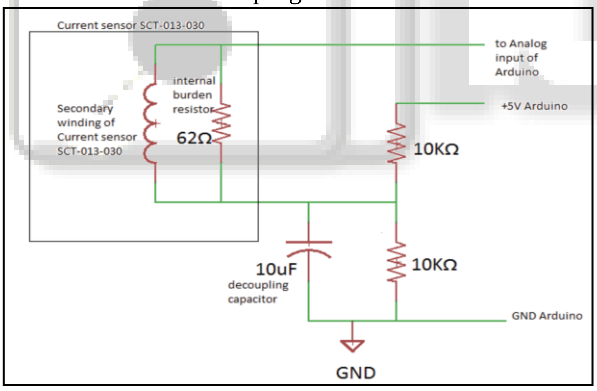

Fig. 2: Circuit for current sensing

This shifted voltage signal is then sampled at 3kHz. Sensing of this signal happens at every 20ms (1/50Hz). Thus the extraction and calibration of rms value of current [6] is done in the following ways.

An AC voltage signal, proportional to the current sensed by current sensor, which is sensed varies between 2.5V to 5V. Samples are filtered, blocking low frequency values thereby blocking noise. $V_{filtered}$ in (1) refers to the previously computed V_{filter} value, sample is the present sample value while prev. sample is the previous sample value. Here k is the constant which was found out to be 0.995. The rms of the input voltage signal is computed using (2).

$$V_{filter} = k*(V_{filtered} + sample - prev\_sample) \quad (1)$$

$$V_{rms} = \sqrt{\frac{V_{filter}^2}{\text{Number of Samples}}} \quad (2)$$

$$I_{ratio} = \frac{CT\_TURNS}{CT_{Burden\ Resistor} * 5 * (\text{Numbers of samples})} \quad (3)$$

The ratio which converts Vrms to Irms is given by eqn. (4).

$$I_{rms} = I_{ratio}\sqrt{V_{rms}} \quad (4)$$

Where CT_TURNS represents the number of turns of secondary coil of CT which is 1800 and internal burden resistor of SCT-013-030, i.e. CT Burden resistor = 62ohm. Here Number of samples =1024, as Arduino nano is being used which is having 10bit ADC, i.e. having 1024 (2^{10}) samples. Rms value of the current sensed by the current sensor is computed using (4). Finally the power consumed is calculated by

$$P = 230.\ Irms \quad (5)$$

Any real time monitoring system has its timer as a critical part of the circuit. RTC DS3231 (Real Time Clock) is used to keep the track of time. This module has internal oscillator and it uses I2C port to communicate with Arduino Nano. Keeping track of the monthly power consumption is accomplished by this module. Subsequently, it resets the value of power consumed in units (kwh), which is to be displayed to zero, on monthly basis.

The display module displays the power consumed by the load in Kilo Watt hours. Further the WiFi module requires 3.3V to power up, so a 9V to 3.3V buck is required for smooth functioning of WiFi module. The information of power consumed is transferred from WiFi module to dedicated website which keeps track of all device power consumptions etc. The purpose of using RTC is to keep track of time even if it is not powered so that even if the electricity is down, a proper track of time is taken.

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Fig. 3 depicts the work flow at the server end. The ESP module sends the instantaneous power values after every 20 seconds over the internet (cloud). Webpage for this project was developed in three different stages. First stage includes the display of power values (on real time basis), the units consumed so far as well as the estimated electric bill so far. The second stage involves the graphical representation of data on a monthly or daily basis, thus providing a statistical data to the user and third includes control of devices at home over the internet.

The webpage was designed using HTML, PHP, CSS and JavaScript. HTML was used for designing the webpage which includes positioning the objects on the screen which includes text. Font, style, color and formatting of the text was done using CSS which is very handy as compared to HTML as far as formatting is concerned. Fig 3 illustrates the implementation of IOT based energy monitoring. PHP script is used for importing data from cloud & reverse process i.e. sending ON/OFF commands to cloud is also done by same. JavaScript is used to represent the data graphically.

User can switch the operation mode of a device by choosing ON or OFF respectively on a webpage. ESP module polls for the change in the status i.e. from ON to OFF and vice versa. After sensing the change it actuates the relay, with the help of Arduino to turn ON or turn OFF the device, depending upon the current status. Login page was also created so as to provide secured environment to the user thereby providing secured access of data from the webpage.

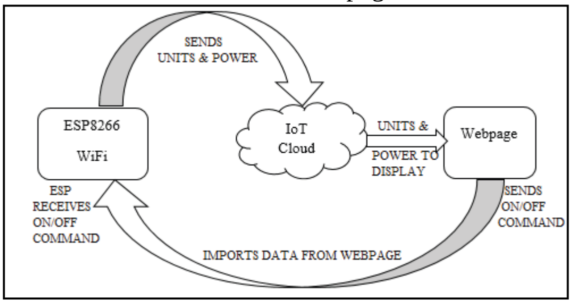

Fig. 3: Implementation of IoT based energy monitoring

IV. Hardware Testing and Results

The details of design and hardware implementation of portable IoT based energy meter is presented in this section. Fig. 4 shows the hardware prototype of the system on a general purpose PCB.

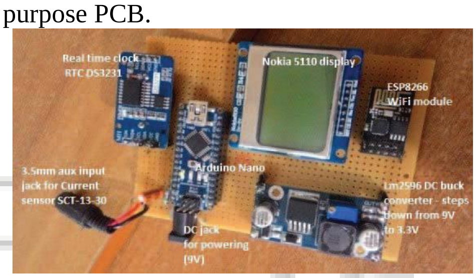

Fig. 4: Hardware prototype with all the modules

Fig 5(a) and 5(b) shows the energy monitoring meter connected to the main supply board for monitoring the energy in a particular room or of the whole house. This system can show the power consumption of the whole household or for any particular room also.

Fig. 6 shows the implementation of the portable device which can display the powers of individual appliances. The device under consideration can be connected to the device and the LCD display shows the power consumed. This device is very useful to the customers as they can understand the power levels for various appliances in any mode of operation which otherwise they are unaware of.

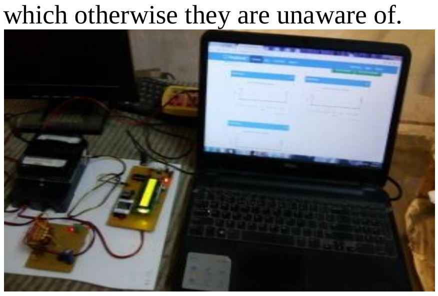

Fig. 5(a)

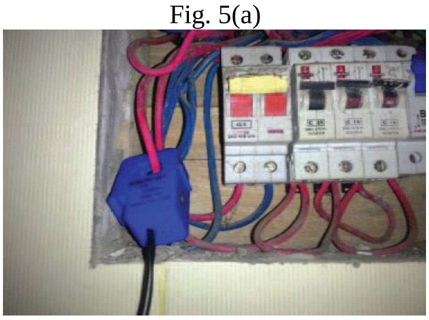

Fig. 5(b)

Fig. 6: Energy meter which displays the power consumed by a device

To validate the readings obtained with the implemented energy meter, testing was done on a variable resistive load. A variable lamp load was considered and power measurements were done using the energy meter as well as using a Power and Harmonics Analyzer (MECO Instruments make). Power measurements were done for three different loads and the results are as shown in Table 1power is measured. The readings are shown in Table I.

Loads (in Watts)	Power Reading in the energy meter(in Watts)	Power Reading in PHA 5850A
60	53	57
100	91	97
200	160	168

Table 1: PHA and Device readings

Thus, average accuracy of the device found out to be 92.6% which is low. As the wattage of the load increases, the accuracy is found to improve. The current sensor used in this device is SCT-013-030 which can measure currents in the range of 0-30 A. As per the datasheet, this current sensor gives 1V output for 30A current sensed. As the current value is lower, the CT output accuracy also falls. The second reason for the lesser accuracy obtained is that in this device design, power calculation is done assuming the voltage to be 230V. The current sensor values are multiplied by constant value of 230. The voltage readings in the power analyser showed fluctuations from 228V to 235V. Hence this also has caused a reduction in accuracy. Hence, it can be concluded that if voltage sensing is also done, then the accuracy of the readings will improve.

Power readings of some common domestic loads were also tested using the energy meter. Fig. 7(a) and 7(b). Shows the power consumed by a 42" LED television set (Samsung) in standby mode as well as in normal working mode.

Table II shows the power consumption of some of the household devices in different operating conditions. Most of the domestic consumption of power though the devices are not fully operating.

It can be easily seen that LED TV consumes significant power in standby mode (around 11W). Also it is observed that given a choice, the user must opt for a capacitive regulator than the resistive regulator since the latter consumes the same amount of power in all the speeds which is not the case as with the capacitor regulator which consumes variable power depending upon the speed of the fan. In case of capacitor regulator the power consumed is directly proportional to the speed of the fan. Similarly, lower reading was observed when the refrigerator was ON with its compressor OFF as compared to the refrigerator with its compressor ON (during the initial cooling process). A 42”

LED TV was also tested using the device shown in Fig. 6, whereas the rest of the devices were tested using energy monitoring system shown in Fig. 5


Fig. 7(a) Fig. 7(b)

Electrical Appliances	**Power Consumed (Watts)**
42" LED TV Standby mode & Normal mode	9-11 & 68-70
CFL 32W	31
1 Ton Window AC (when switched ON)	956

Table 2: Power consumption readings of household devices

The power consumption details are sent to cloud with the help of WiFi module which will be then updated on the website. Fig 9 shows the screenshot of the website through which the users can monitor daily/monthly power consumed.

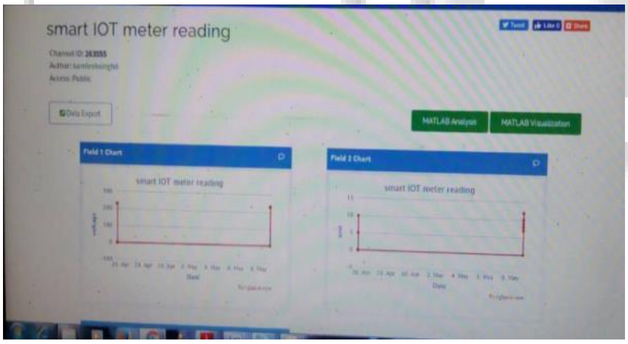

Fig. 9: Screenshot of Home Energy Monitoring and Controlling System

D3.js script was used for displaying power (kwh) and cost (Rs.) in graphical form thereby providing a statistical analysis. D3.js is a JavaScript library which was imported for encompassing bar chart in the webpage as shown in Fig 10. The X-axis shows the days of a particular month, in figure the readings are of April month. The green colour bar indicates the daily power consumption (in kwh) and the orange bar shows the power bill calculated on cumulative basis (in Indian rupees) from the first day of month onwards. The user can observe the readings corresponding to each bar by just hovering the mouse cursor over it. Also the user is given freedom to choose the interval (like daily basis, every alternate day etc) in the month over which he/she wishes to see the comprehensive bar chart.

Remote control of household devices can also be done by the user. For controlling a device from webpage, ON/OFF interface was created as shown in Fig 11.

Fig. 10: Graphical representation of power consumed and estimated bill day wise

For experimental purpose a 32W CFL bulb was switched ON/OFF with the help of this interface. Interface will indicate the status of device whether it is ON/OFF based upon the previous selection of the user i.e., if previously user made the device ON by hitting "change status" tab, the display shows 'ON'. In case, from the daily power usage graph the user finds an alarming rise, any load which consumes more power can be remotely controlled.

Fig. 11: Dashboard for controlling devices at home

V. CONCLUSION

Minimal power consumption is the main design aspect of any appliance. A survey into the power consumed by common domestic loads provides awareness to the common customers which helps further in energy conservation. This paper presents the implementation of a portable energy meter which can monitor the power consumption at device level as well as for a residence. The energy device which is currently implemented assumes the voltage to be 230Vrms and subsequently computes the power consumed by means of current sensing only. Including voltage sensing into the hardware as well as processing it to calculate power can improve the accuracy of this device.

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