International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-9 Issue-1, May 2020

Design and Implementation of Cost-Effective IoT Energy Meter to Monitor Energy Flow in Smart Grids

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Abstract: This paper presents a device that uses the evolving IoT technology to design and implement an internet-based energy meter. This meters, being cheap and easy-to-implement solution, enables consumers to monitor the daily usage of electric power easily. This work primarily concerns the energy-monitoring aspect of IoT, along with discussing other advantages of this meter, such as its ability to overcome human errors and reducing dependency on manual labor, besides reducing costs in energy consumption. The proposed design in case 1,and case2 which are comprises a low-cost wireless network for smart energy along with an android application capable of automatically reading the unit and then sending the data automatically provides great advantages to users by allowing them to keep a track of their meter reading. This system will help users by allowing them to not only take steps to reduce power wastage but also bring down costs of consumption, along with minimizing the threat of power theft, which is incurs great losses to power companies. Experimental results of this study show that the proposed IoT meter works efficiently and has proven its potential in practical applications at substantially reduced costs.

Keywords : Sensing systems, Smart Energy Meter, Cost Saving, Data Privacy, IoT

I. INTRODUCTION

Electricity, which is the driving force behind the development of any country, is currently a global concern in the form of energy crisis. Although an increase in energy production might seem like the answer to this problem, the actual remedy lies in the effective use of available energy. This might be made possible by a system that can effectively control and monitor power usage. One of the ideal approaches to addressing this current energy crisis is through reduced power usage at the household level. Efficient energy monitoring is required for achieving this reduction in power usage. Even in this digital age, consumers are not aware of their real-time energy consumption until the electricity bills are issued, and even in these technologically advanced times, labor-intensive work still continues. Analogue energy meters, which were used decades back, are insensitive to minute power changes, and the values generated by them are not exactly accurate, leading to inaccurate reading and hence to the imprecise generation of bills. Although digital watt meters, which sample the voltage and current thousand times a second, have helped resolve these issues, an employee of the electricity board still has to make a monthly visit to each house to note down the power reading and to accordingly calculate the bill amount. To carry out this procedure, at least one member of the household should be present at home when the person arrives, which is bothersome for consumers because running errands or going about their personal and professional works get affected since one cannot predict the arrival of the electricity board personnel. Moreover, an unknown person entering the house for power-reading purposes might also act like an invasion of one's privacy. In India, electricity bills are generally issued either monthly or bimonthly. Even in this digital era, consumers remain generally unaware about their energy consumption and do not take the pain to check the meter reading and compare it with the previous reading to obtain a fair idea about their consumption patterns. Moreover, this entire procedure needs to be repeated several times a month to efficiently monitor and control energy usage, which becomes pretty cumbersome. However, if consumers were instead given the means to check their energy consumption using their mobile phones or laptops, it would not only become quick and efficient but also indicate a great advancement in the field of energy management. Since most people are usually online almost 24*7 nowadays, allowing them to monitor their energy consumption online from anywhere will be quite helpful.

II. MOTIVATION AND RELATED WORK

B. S. Koay [1] proposed a design of a Bluetooth-enabled energy meter that can read energy meters wirelessly. Two features were proposed, namely, the automatic meter reading (AMR) and the automatic polling mechanism (APM), that will help retrieve the meter reading with little human intervention, and these were implemented in the targeted applications. The design is based on the CSR Bluetooth module as well as the analog device ADE7756 energy meter. Brasek C. *et al*., [2] proposed a new AMR scheme using WiFi technology and an ARM-based PMWCM scheme.

Manuscript received on April 02, 2020.
Revised Manuscript received on April 15, 2020.
Manuscript published on May 30, 2020.
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They suggested both economical and effective ways of implementing an AMR system, which helped save costs in not just pre-building communication network but also in cable maintenance. This leads to sharing of broadband wireless network resources along with remote real-time management of the user's power data, helping save resource costs.

Qiang Fu *et al.*, [3] discussed microgrids, which are currently receiving quite some attention, due to the ever-increasing need to enable distributed generation, ensure power quality, and provide energy surety with regard to the critical load. Hence, they analyzed a high renewable-energy penetrated micro-grid.

Qazi Mamoon Ashraf *et al.*, [4] implemented a prototype capable of acquiring energy-related data after a few seconds that allows the study of energy consumption patterns. The device was termed the ELIVE device. The ATMEGA328 microcontroller worked in harmony with an ESP8266 WiFi system-on-chip (SoC) module, an AC transformer, as well as current transducers. The ESP8266 allowed easy connection to the Internet for the microprocessor with the use of an established WiFi connection based on serial interfacing requirements. Arduino Integrated Development Environment (IDE) was used to program the microcontroller that obtained energy measurements using an analog to digital converter (ADC).

Li Li, Xiaoguan Hu, Jian Huang, and Rosario Morello, [5-6] proposed a new scheme, which combines WiFi and WIMAX with current various communication forms of AMR, based on analyzing the differences of specific environments. This scheme, which aids the development of AMR, provides a good solution and a meaningful exploration.

Dakka. Obulesu1, K. S. V. Phani Kumar et al [7] proposed a Wireless communication technology has made the exchange of information fast, secure and accurate. With the help of this technology, many of the industrial aspects of energy management can be automated, which will ultimately lead to the reduced usage of manpower.

Mismanagement of electrical energy is a prevalent problem in today's world. The only way to overcome this crippling drawback in electricity distribution is to develop an effective monitoring system. This paper proposes an integrated hardware and software solution that enables wireless monitoring of energy consumption to make it more convenient for the end user.

This paper provides a way out of these above-mentioned difficulties caused by the previous mechanisms of measuring power.the proposed design considered in two cases, which comprises a low-cost wireless network and protocol for smart energy – along with a web application capable of automatically reading the unit and then sending the data automatically – provides great advantages to users by allowing them to keep a track of their meter reading. This system will help users by allowing them to not only take steps to reduce power wastage but also bring down costs of consumption, along with minimizing the threat of power theft, which has incurred great losses to power companies. The system has three components, namely, the digital energy meter, the ESP8266 WiFi module, and web application. The ESP8266 WiFi module is embedded into the meter, and the TCP/IP protocol is employed to allow seamless communication between the meter and the web application.

III. HARDWARE DESIGN

The block diagram of the hardware design of independent modules is represented in Fig.1.

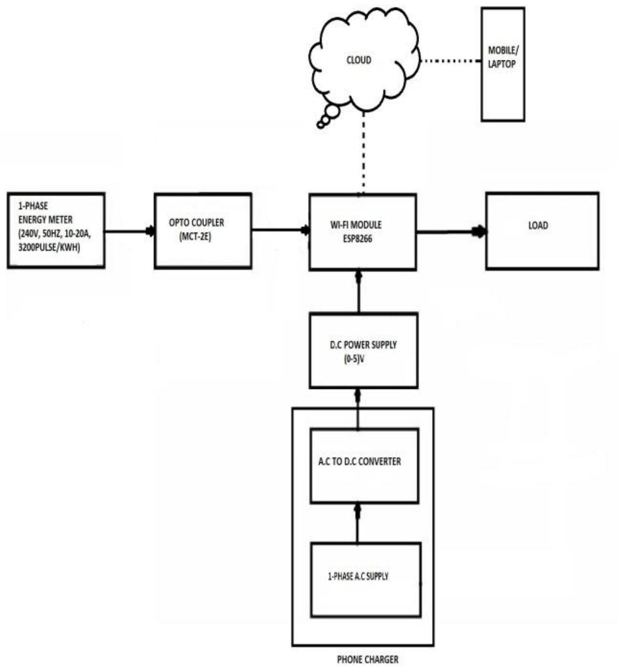

Fig. 1.Block diagram of the IoT Energy Meter.

The primary blocks of this hardware are the WiFi module (ESP8266), the Opto coupler (MCT-2E), the single-phase energy meter, an LED, an AC to DC converter, a single-phase AC supply, regulated power supply, and load. The ESP8266 WiFi module is a self-contained SOC possessing an integrated TCP/IP protocol stack. The ESP8266, which is a small WiFi module built around the ESP8266 chip that can wirelessly connect a microcontroller to the Internet, can provide any microcontroller access to a WiFi network at minimal cost. The rapidly growing popularity of ESP8266, launched in 2014, can be proven from the fact that even though there is only one ESP8266 processor, it is found on many different breakout boards, which differ in terms of both which pins are exposed and in the size of the flash memory. Over time, these breakout boards have also evolved rapidly, proving themselves ideal in this IoT era. The ESP8266 – a low-cost WiFi module that can be integrated easily into IoT devices – features powerful on-board processing and storage capability that allows it to be integrated with the sensors and other application-specific devices by means of its general purpose input/output (GPIO) with minimal upfront development and loading during runtime. Its high degree of on-chip integration leads to its minimal external circuitry, including the front-end module, which is designed in such a way that it occupies a very small PCB area. The ESP8266 supports automatic power save delivery (APSD) for voice over IP (VoIP) applications along with Bluetooth coexistence interfaces. Its self-calibrated RF, which allows it to work under all operating conditions, makes it possible to mitigate the need for any external RF parts.

The ESP8266 module – powered by a 3.3V regulated power supply – has a maximum voltage input rating of 3.3V, and thus voltages greater than 3.7V would damage the module, making it important to be extremely cautions regarding the same. When connecting the ESP8266 to the power supply, the Vcc and ground pins should be connected to the power supply lines and the power supply's ground line needs to be connected to the Arduino's ground pin. Because the Arduino is powered via USB connection to the laptop, a common ground needs to be created for common reference to compare voltages and thereby interpret digital high and low signals. Second, it is important to connect the output of a resistor voltage-divider circuit to the receive (RX) line for the ESP8266 module so as to transit the serial communication logic level (the highs and lows of the digital signals that make up the serial communications) from a logic high of 5 volts on the Arduino to a logic high of 3.3V on the ESP8266 module. Since the ESP8266 has a maximum voltage input rating of 3.3V, connecting the module's receive line directly to Arduino's transmit line might result in critical damage. However, since the module's 3.3V logic high is high enough to also register as a logic high on Arduino, the ESP8266's transmit line levels do not need shifting. After completing all the hardware connections, the program should be uploaded to Arduino. The program will copy commands typed into the serial monitor and will send them to ESP8266. The responses from the ESP8266 will be displayed in the serial monitor window.

IV. RESULTS AND DISCUSSIONS

A. EXPERIMENTAL RESULTS CASE-I

This paper Case –I present an overview of the wireless energy meter, which is very efficient for power measurement because inaccuracy is greatly reduced. The developed energy meter was tested using an electric light bulb of 60 watts and a water heater of 2000 watts, driven by a supply voltage of 230V, which draws a current up to amperes as shown in Fig. 2. The energy consumption was calculated, and the information was uploaded to the web page using it. The WiFi helps transmit the energy consumption information to a web page. The energy consumption data are then sent to a web page by uploading the web server code. On a WiFi ESP 8266 serial monitor, the unit and cost of energy consumed are shown in Fig.3.Consumers have the ease of obtaining energy consumption information just by filling in the login details online, anytime and anywhere, made possible by using WiFi communication technology called IoT. This information could be viewed by both consumers and utility. Fig. 3 shows the web information regarding unit and cost of electrical energy consumption.

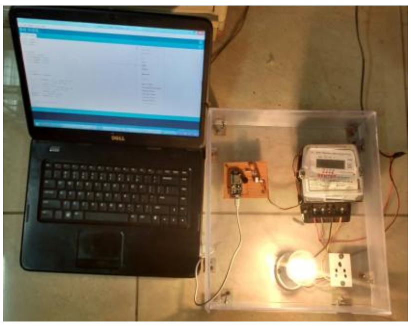

Fig. 2 Output when supply is given

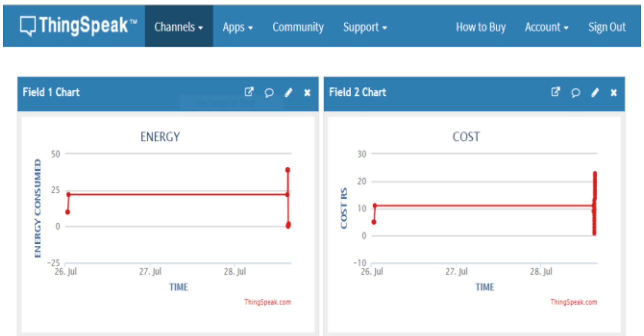

Fig. 3 Web information regarding unit and cost of electrical energy consumption

B. EXPERIMENTAL RESULTS CASE-II

In this Case-II The hardware considered for testing the system, shown in Figure-4 consists of three energy meters (single phase 1600pulses/Kwh), assumed to be serving three households. Each house is equipped with three loads. Each energy meter is connected to a microcontroller (atmega328p) with a Wi-Fi module (esp8266) connected. There is a separate power supply (SMPS – 12V, 2A) for powering the microcontroller and the Wi-Fi module. A Digital Signal Oscilloscope (DSO) (TBS- 1072B series) is used for capturing the signals going to the controller for analysis shown in Figure-7. For demonstration, Load-1 in house-1 is switched ON. Now, energy meter starts measuring the energy consumed, and displayed as LED blinks. Since the circuitry and functioning of meter is not to be intruded, LED blink samples are collected by means of an optocoupler and amplified. This information is sent to microcontroller and also connected to a DSO for analysis. The sample measurement recorded is presented in Figure -5. The spikes in the graph correspond to the blinking of the LED. Since the load is constant, the spikes are placed equidistant to each other. The microcontroller also receives this information.

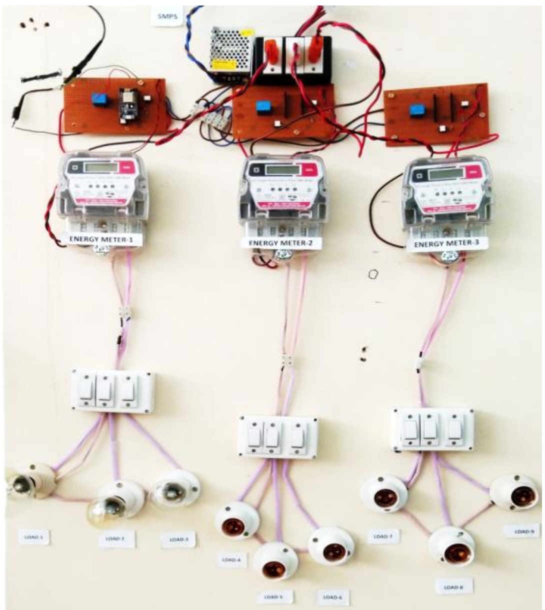

Fig. 4: Energy meters set up

" A counter is updated each time a spike event occurs. This counter value helps in evaluating what is the amount of energy consumed per hour or for an interval of time. The sample calculation can be shownas:

i) If 1Kw of load is switched ON for 1hr, then total blinks = 1600.
ii) In one hour, if total blinks are 96, then the load connected is 60W.
iii) In five min, if total blinks are 8, then the load connected is 60W.

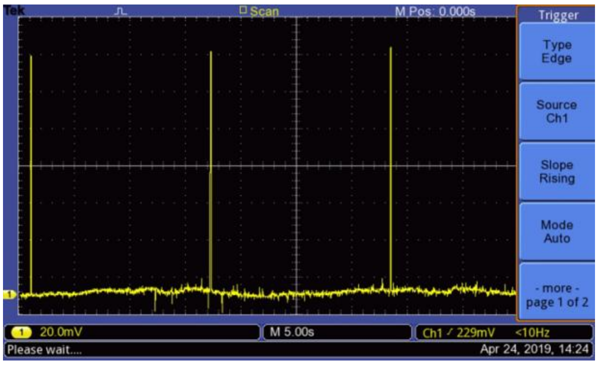

Fig – 5: LED status when Load-1 is switched ON

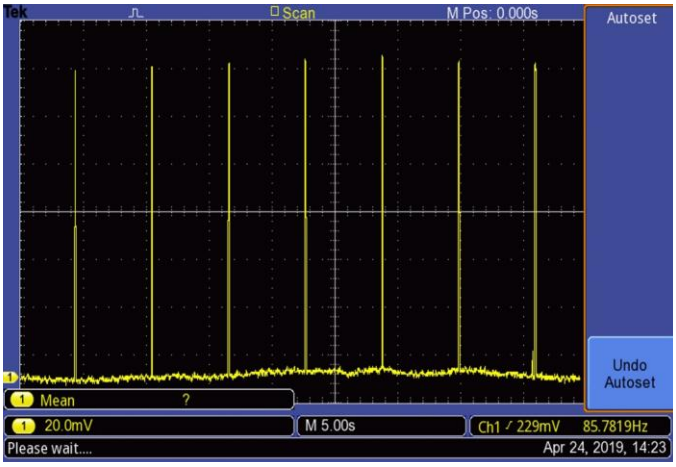

Fig – 6: LED status when Load-2 is switched ON

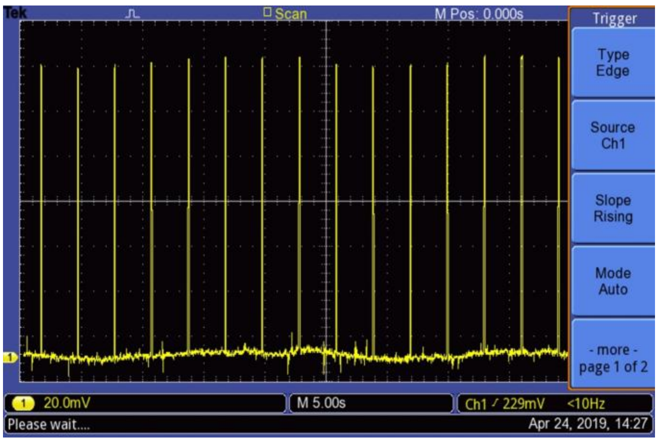

Fig – 7: LED status when Load-3 is switched ON

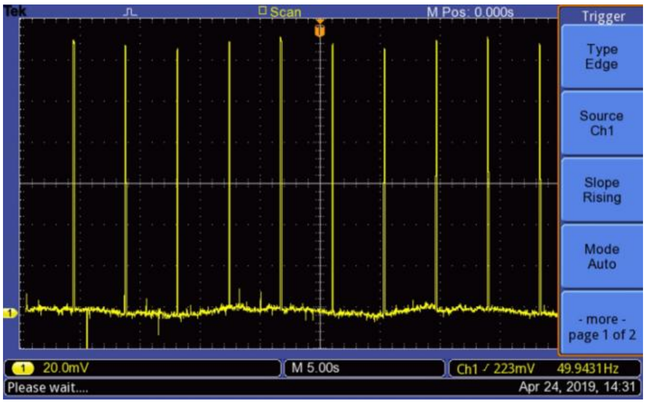

Fig – 8: LED status when the total load value is increased

One day's analysis is shown in the paper. Load-1 is Kept in ON state for the entire day. The amount of energy consumed, and the cost incurred on the owner of the house is shown in figure 6 and 7.

Load-2 is added in the house, at 6th hour. Hence more energy is being consumed and the frequency of blinks starts to increase. This can be shown in figure – 6. Keeping load 1 and 2 ON, after six hours, Load-3 is switched on. The sample LED blinks are recorded in DSO and shown in Figure 4. And finally at 18th hour of the day, the capacity of the load is increased and hence the frequency of blinks increases, while the total energy consumption by the house also increases. In figure 9 and 10 it can be observed that the slope of the graph from hours 1 to 6 is less compared to that of slope of the graph from hours 6 to 12, and so on.

As the load is connected to the house, the counter value keeps increasing and hence, the user must pay an amount to the supplier of power proportionately based on the tariff. The tariff considered in this paper is 3.24Rs/kWh.

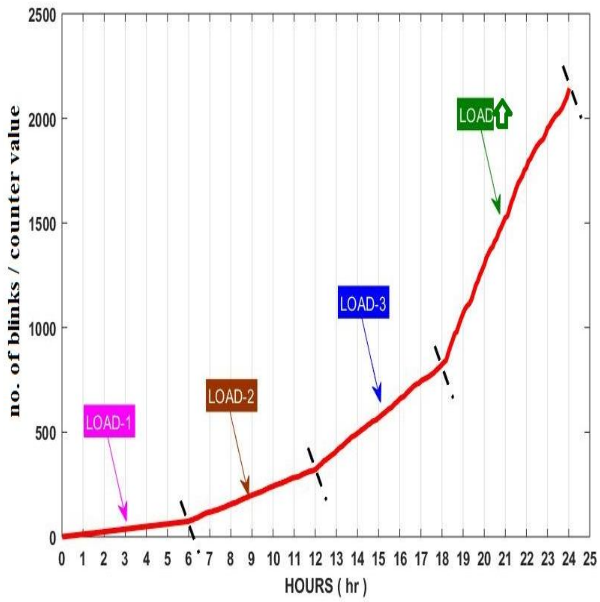

Fig – 9: Counter value recorded by the microcontroller

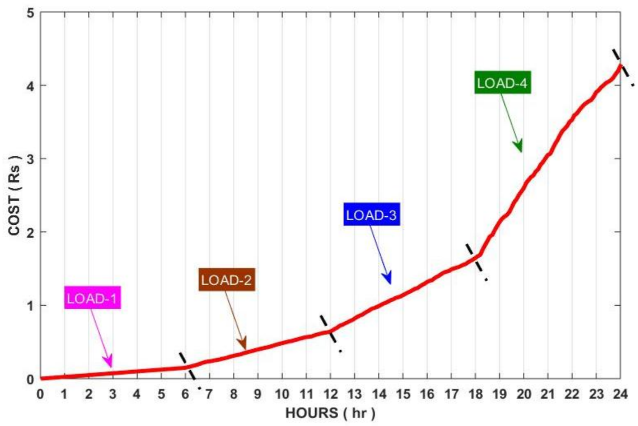

Fig – 10: Billing value estimated by the microcontroller

V.CONCLUSION

This paper presented an overview of the smart energy meter for IoT along with a low-cost implementation process, which is very efficient and accurate in energy measurement. The proposed energy meter set up in case 1: three energy meters (single phase 1600pulses/Kwh each), assumed to be serving three households can overcome challenges associated with the efficient management of energy. Our developed meter allows one to read its parameters – load profile, demand value, and the total energy consumption – correctly and reliably. For IoT implementation, the WiFi module ESP 8266 works reliably, which sends information to be displayed on the website throughout the existing server. This not only reduces human involvement, but also provides a capable meter reading and mitigates billing mistakes that can arise because of human intervention. The paper aims to propose a possible solution to the issues concerning the sensing and measurement aspects by discussing the potentialities of the proposed three energy meters.In case one single energy meter was also tested using electric appliances such as a light bulbs of 60 watts,100watts and 200 watts are driven by a supply voltage of 230V. The energy consumption was calculated, after which the information was uploaded to the web page using IoT.

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