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Design and Implementation of IoT Energy Meter to Monitor Energy Flow at the Consumer End

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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 meter, 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, 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 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: **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 from 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. RELATED RESEARCH AND MOTIVATION

The work by Win Hlaing and Somachai (2017) deals with wired home automation systems. Some studies have even proposed a system that uses a remote to control water temperature through transmission control protocol and internet protocol (TCP/IP). Although this has a lower hardware cost, it ends up affecting both the build and maintenance costs.

Brasek C. *et al.*, [1] proposed a new AMR scheme using WiFi technology and an ARM-based PMWCM scheme. 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.

B. S. Koay [2] 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.

Li Li, Xiaoguan Hu, Jian Huang, and Ketai [3] 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.

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).

Qiang Fu *et al.*, [5] 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 critical load. Hence, they analyzed a high renewable-energy penetrated micro-grid.

This paper provides a way out of these above-mentioned difficulties caused by the previous mechanisms of measuring power. 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.

In this paper, the proposed design, 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 is incurs 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 MODEL

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

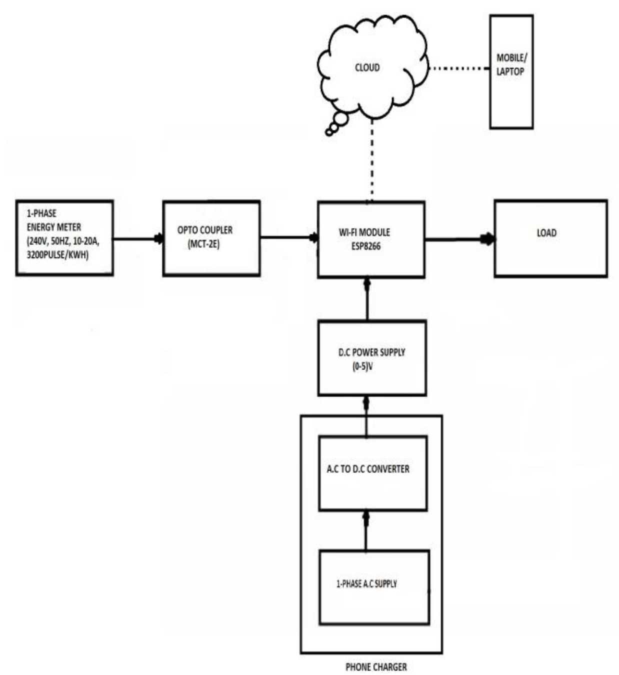

Fig. 1 Block diagram of the IoT Energy Meter

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 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.

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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

This paper presents 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 webpage using IoT.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.

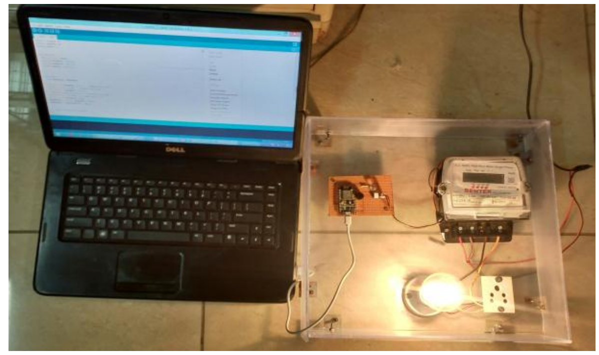

Fig. 2 Output when supply is given

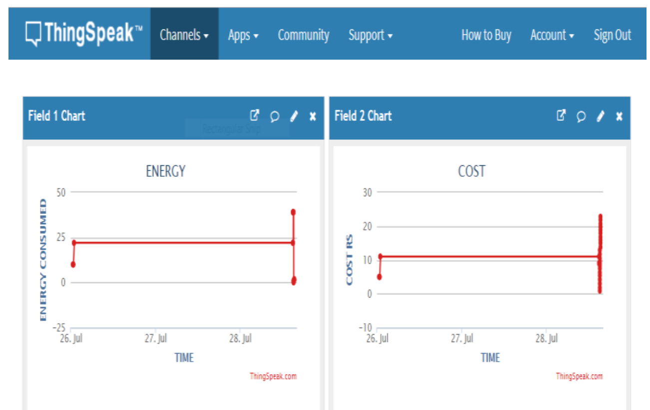

Fig. 3 Web information regarding unit and cost of electrical energy consumption

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 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 capable meter reading and mitigates billing mistakes that can arise because of human intervention. The energy meter was tested using electric appliances such as a light bulb of 60 watts, driven by a supply voltage of 230V. The energy consumption was calculated, after which the information was uploaded to the webpage using IoT.

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