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Real time monitoring of AMR enabled energy meter for AMI in Smart City - An IoT Application

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***Abstract*—Smart meters are promising towards increase in energy efficiency, but their installation needs significant infrastructure change, ranging from installation of new hardware units at individual households – a time consuming task, to creation of data servers to store the data available from these smart meters. The cost and time issue involved in this task has motivated us to devise a cost effective and portable hardware, capable of adding functionality of smart meters into traditional meters. This paper describes the method for measuring active power registered by traditional meters in real time. Considering the worst case as, cases when traditional meter registers less than 10 watt, the proposed system can provide its users with active power consumption data in 101.25 seconds as against monthly billing cycle of traditional meters. The proposed system uses LDR for sensing the frequency of LED present on the meter, which blinks at a frequency proportional to the active power registered by traditional meters. It also uses ESP8266-12e to compute the active power of load connected across traditional meter, from sensed value of blinking frequency of LED and store it in an online data server.**

***Keywords*—Smart meter, AMR, AMI, ESP8266 application.**

I. Introduction

In India, residential electricity demand has shown a continuous increase and the reasons for this can be attributed mainly to population explosion and rapid economic and technology development. In 2015-16, 13% of total energy demand was in the form of electricity which is 1001.191 TWh of electricity. Of the total electricity demand 24% of electricity is used only in residential/domestic sector [1]. Various work has suggested the efficacy of smart meters in increasing energy efficiency, by providing real time feedback of energy consumption [2, 3].

Automatic Meter Reading (AMR) is a technology that automatically collects energy consumption data from an energy meter, located at customer premises and send this data to utility for billing purpose. Here, in this paper AMR meter has been considered as a traditional meter. Data from these traditional meters are typically gathered once in a month or at most daily with the help of a hand-held unit by human operators [4]. It is a touch-based system, where a meter reader carries this unit to individual houses and data is automatically collected by touching or placing it over the touchpad. After AMR, a new technology was introduced, known as advanced metering infrastructure (AMI). The term and technology behind AMI began evolving from the foundations of AMR. AMI is typically more automated and allows real-time monitoring of energy consumption. This AMI technology not only measures how much electricity is consumed, but also at what times during the day. It also transmits pricing and energy information from the utility company to the consumer to analyse usage and to manage consumption [4]. Smart meters implement this AMI technology where the involvement of these human operators is completely removed.

In case of traditional energy meters which are generally situated inside house premise, the electricity billing system is highly dependent on human operator. Operator needs to visit every customer's house to record meter readings. This needs significant time and is a manpower dependent task. Moreover, data in such system do not provide any useful feedback for increasing energy efficiency, as consumers do not remember their actions during period of past month and as a result no corrections can be done to them. Thus, to overcome all these issues regarding manual billing system of AMR meters, and to reduce electricity consumption, implementation of AMI technology has become a necessity.

In India, millions of traditional meters are already installed, and it will include a huge amount of cost and time to replace all these meters with smart meters [5]. Thus, by looking into this matter, this paper proposes an economical solution, in which consumers don't need to install new meters, rather by putting a small portable device over their existing meters they can convert their traditional meters into a smart one. The proposed system uses Wi-Fi network to continuously upload active power readings registered by traditional meters on internet. The proposed device will help the consumers to manage their consumption by providing them a tool using which consumers can visualize their electrical energy consumption in real time, thus enabling them to become energy literate.

The paper is organized in following sections. Section II briefly discusses about similar work present in existing literature. Section III describes the methodology for active power calculation from LED of AMR based energy meter and assimilating the energy information to users. The proposed methodology was experimentally validated by developing a lab level infrastructure as detailed in section IV for emulating the field environment and the results presented in section V shows the efficacy of the method. Finally, section VI provides conclusion.

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II. LITERATURE SURVEY AND RELATED WORKS

For measuring electricity consumption from an electronic energy meter, lots of systems had been proposed which used Bluetooth [6], Global System for Mobile Communication (GSM) [7] and Ethernet [8]. Range of Bluetooth is not suitable for long distance communication between consumer and utility. In case of GSM based system, there are chances of missing SMS, which reduces the reliability of the system. Though [7] has claimed to solve this issue but they haven't given sufficient details to support their claims. Reference [8] has suggested to implement Ethernet for a reliable two-way communication. Ethernet will need an infrastructure change and initial installation cost and moreover, as the proposed system does not need a two-way communication so the use of Ethernet as communication medium was avoided. Reference [9] has given detailed description for upgrading electromechanical energy meters by counting the number of rotations of the disk. But implementation in [9] needed to tamper the original meter by making a small hole in the disk of the meter which was not desirable in the proposed work. So this method was also ruled out in this work. In this work, a portable externally attachable Wi-Fi enabled device is developed to upgrade an electronic meter having a LED, without tampering it.

III. METHODOLOGY

This paper describes the method to monitor the electrical power consumption registered by AMR enabled energy meter in real time using Light Dependent Resistor (LDR) sensor. The electricity meter is owned by the utility company and so must not be modified/tampered. Every AMR enabled energy meter have a pulse LED which blinks at frequency proportional to energy consumption registered by it. The proposed method utilizes LDR to measure the frequency of blinking LED to compute the power consumption. Further, the computed power consumption data is uploaded on internet via standard HTTP request over TCP/IP to access the data remotely. The details are provided in following sub-sections.

A. Computation of Power Consumption using LDR Sensor

LDR is a semiconductor material which changes its electrical resistance from several thousand ohms at near zero Lux to only few hundred ohms when light falls upon it. This property of linear dependence of resistance of LDR on intensity of incident light (turn on and off of LED) has been exploited to sense the blinking of LED.

Every AMR enabled energy meter has a fixed meter constant which defines the number of pulses generated by blinking LED for unit energy registered by them. Let, the meter constant be 3200 imp/kWh. For p kW of active power registered by energy meter for duration of one hour will generate N pulses in one hour as in (1)

$$N = 3200 * p \quad (1)$$

Thus using (1), the frequency of blinking of LED, f (in Hz) can be expressed as in (2)

$$f = (N) / 3600 \text{ Hz} \quad (2)$$

Since the time latency of LDR i.e. response time of LDR to change its resistance under change in illumination ranges from 2-50ms, therefore the maximum frequency of blinking LED that can be sensed using LDR is limited to 20 Hz. To ensure the effectiveness of using LDR in proposed methodology, the minimum and maximum frequency range under minimum and maximum active power load is calculated below.

Considering refrigerator as base load, since it is always turned on, the minimum active power load of 0.05 kW has been chosen. Further, in most cases, the maximum sectioned load to a household is limited to 5.0 kW, therefore maximum active power load of 5.0 kW has been chosen. Using (1) and (2), the maximum and minimum frequency of blinking of LED, f_{max} and f_{min} is computed as in (3) and (4) respectively.

$$f_{max} = (5 \times 3200) / 3600 = 4.444 \text{ Hz} \quad (3)$$

$$f_{min} = (0.05 \times 3200) / 3600 = 0.044 \text{ Hz} \quad (4)$$

To ensure a resolution of 0.01 kW in computation of active power, code for frequency measurement f, on micro-controller must have execution time less than 0.5 msec when 5.0 kW of active power has been registered by AMR enabled energy meter. This has been achieved by using polling technique for detection of LED blinking and further computation of frequency f. The expression of active power consumption is obtained by re arranging (1) and (2)

$$P= (3600 \text{ x } f)/3200 \text{ kW} \quad (5)$$

Then power consumption can be calculated from the frequency at which pulse LED blinks, using (5). With power consumption less than 0.01 kW, the system has been designed to record zero as active power.

B. Data Storage and Remote Access of Power Consumption data

In this proposed work, the computed power consumption data is communicated to cloud and uploaded in a database server by utilizing softwares viz PHP, HTML and MySQL. After computation of active power consumption data using LDR, the proposed system sends the HTTP GET request to a web URL, requesting for a PHP page. Thereafter, the requested PHP page on web server decodes the argument received in GET request and upload the decoded data into a cloud database server.

For remote access of power consumption data, any digital device at user end capable of browsing internet sends an HTTP GET request to a designated PHP page specifically designed for providing interactive display of information on user's device. Thereafter, the requested page on web server fetches the required data from MySQL database and populates the user screen with relevant information.

IV. EXPERIMENTAL SETUP

In this section, the complete experimental setup and lab level infrastructure for emulating the field environment has been explained in details. The overall block diagram of experimental setup is shown in Fig. 1.

Fig. 1. Block diagram of experimental setup

It consists of AMR enabled energy meter wherein LDR based sensor was mounted on it for frequency measurement of blinking of LED. The LDR was interfaced to ESP8266-12E module to compute and transmit the power consumption data to webserver using wireless medium. A user agent, here PC and smartphone, can be used to access the data available on online database server. The crucial element in the experimental setup was designing and developing the hardware for frequency measurement to enable reliable sensing of LED blink under different ambient conditions of lighting.

As an alternative to LDR in the circuit shown in Fig. 3, there exists colour sensor, LED or phototransistor which can be used as light detector. Due to less cost and all favorable factors as detailed in section III, like response time and spectral sensitivity of LDR, it has been chosen as a light sensor in proposed system. Spectral sensitivity of the LDR is also suitable for detecting frequencies of red, green color LED. The design of proposed system is explained below -

A. Hardware Circuit and Assembly of LDR Sensor

The LDR was tested under different ambient light condition and it was found that resistance of LDR varies from 870 k ohms to 60 k ohms under variation of illuminance from 15 Lux to 184 Lux. Therefore, in the proposed system, the LDR needs to be shielded from ambient light. This is achieved by placing the LDR sensor inside a bulb holder as shown in Fig. 2.

Fig. 2. Assembly of LDR for shielding ambient light

As detailed in section III, frequency counter was designed to measure frequency ranging from 0.044 Hz to 4.444 Hz with a resolution of 0.01 Hz. Fig. 3 shows the schematic which uses an op-amp as a buffer to interface output of LDR to micro controller.

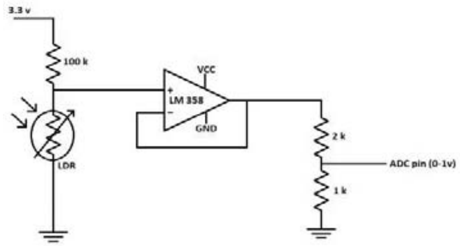

Fig. 3. Schematic for interfacing LDR with ESP8266-12E

The LDR sensor was placed over LED of AMR enabled energy meter and the sensor output was connected to ADC pin of ESP8266-12e module through buffer.

A frequency counting program is uploaded on ESP8266-12E module to compute the frequency of the blinking LED using the signal provided by LDR. After the calculation of this frequency, active power has been be calculated using (5). Fig. 4 shows the complete assembly of the proposed device.

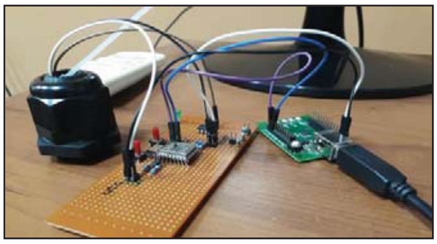

Fig. 4. Complete assembly of the proposed device

B. IoT Framework: Transmitting data to cloud

This proposed device computes the active power data registered by an energy meter. After the computation this data is uploaded to the data base server using internet, via an HTTP GET request. Subsequently this data can be retrieved by the users from the developed UI at any time by requesting the server. Software tools viz PHP, HTML and Arduino IDE with ESP8266 library have been used for development of proposed system. For storing the data MySQL database has been used.

Debug is an important feature for any system as using the debug console facilitates to understand the problems when the system doesn't work as designed. For debug purpose the proposed system had the facility to be connected to local PC via USB while the system continued its normal operation to upload data on cloud using internet. Debug console for the proposed system shows the output for measured active power and also the HTTP GET request status and HTTP response received from server. For this the proposed system continuously monitors for server response once request has been send by it.

An UI has been designed using HTML, PHP, AJAX and JavaScript for making the consumption data stored in database to be easily accessible by the users. It has representation in form of graphs which are more easily interpretable by humans as compared to raw numbers. By accessing a URL user can view data about their energy usage from the web application. This web application shows the various meter stats and the time when the data was recorded. Fig. 5 shows the glimpse of UI page.

Fig. 5. Dashboard view of the web application

V. Results

Fig. 6. Proposed system in lab level testing emulating the field environment

For testing the accuracy of the developed system an AMR enabled energy meter was connected across an AC and proposed device was placed over it. As the AMR enabled energy meter's display was of one decimal place, the readings collected from it were not accurate, so to validate the data of proposed device, GENUS Achook-1080 was used. Fig. 6 shows the complete setup. The GENUS Achook-1080 was powered from same source as AC and its non-invasive current transformer was placed around the output phase wire of AMR enabled energy meter, so with the help of GENUS, accuracy of the system can be continuously monitored. The calculated active power data from our proposed device was visually compared with GENUS Achook-1080.

The test setup was put under observation for three hours (3:15 pm to 6:15 pm). Table I tabulates the observations.

TABLE I. Observation Table

Time	Readings from GENUS Achook	Database readings
3:15 pm	22.21 kWh	0.150574 kWh
6:15 pm	23.91 kWh	1.923474 kWh

Energy consumed during testing as recorded by Genus Achook = 23.91-22.21=1.7 kWh
Energy consumed during testing as recorded by proposed device = 1.923474 - 0.150574=1.7729 kWh
Error percentage = (1.7729-1.7)/1.7 = 4.29 %.

Thus the error of the proposed system was found to be 4.29%.

VI. Conclusion

This paper describes development of an economical device to monitor AMR enabled energy meter which will lead to control residential electricity consumption by providing real time feedback of energy consumption data to residents. The cost incurred in development of proposed system is approximately Rs. 2000, which is significantly less than the cost of the other energy monitoring devices like Sense, Neurio etc. Moreover, Neurio doesn't have service support in India and Sense technical specifications are not suitable for usage in India. Though the error of proposed system was reported to be 4.29% but still this will be useful for providing users with intuition of their energy consumption pattern. Moreover, the proposed device is not for billing purpose, it's only for making consumers energy aware, so an error of 4.29% is acceptable in this case. These consumption data will help the users of the proposed device to analyze and manage their power consumption. In this way the work described in this paper will contribute to increase energy efficiency by making people think rationally.

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