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RESEARCH ARTICLE

Smart Energy Meter

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Abstract

Objectives: To present a Smart Energy Meter (SEM) that reduces errors effectively while generating the electricity bill. **Methods:** This SEM confluence of modern technology and existing electrical architecture, yet it is a low-cost device suitable for the Indian environment. The proposed SEM is only incorporated with a current sensor and other associated circuitry. **Findings:** A quantitative comparison between our SEM and other existing SEMs revealed that the proposed SEM is superior in the economy, circuit complexity, and accuracy. With mere Indian Rupees (INR) around 3k to 3.5k, it can be designed to be used. There is no complex circuitry associated with this proposed SEM. The accuracy of the proposed SEM is also comparable with the existing meters that it could attain up to 0.7-0.9 % accuracy. **Novelty:** The proposed system deals with the digitalization of the billing process with the help of sensors that are used to calculate the usage time of each household device. Subsequently, it alerts the user about the consumed units using a GSM (Global System for Mobile Communication) module. An Advanced Reduced Instruction Set Computer Machine (ARM7) microcontroller continuously monitors the system, and the results can be viewed through a built-in Android App. A Wi-Fi module allows for continual data updates and control of home appliances. **Achievements:** The real-time solution for the overloading problem is provided in this research.

Keywords: Smart Energy Meter; GSM module; Relay module; ARM7; WiFi module

1 Introduction

It is roughly estimated that around three billion units of power have been wasted every year in India, according to a study by the Energy Information Administration (EIA). This wastage is mainly caused due to improper monitoring of the power supply. An automatic electricity bill generating system and proper monitoring of each appliance is the need of the hour. Though various technologies/approaches have been developed to measure the power consumption more smartly compared to conventional meters (Electro-Mechanical Induction Type), which include, Electronic Energy Meters[1] and Internet of Things (IoT)-based Smart Energy Meters[2], the proposed smart energy meters have been suffered in several aspects in one or other way.

For example, an SEM designed by[3] has an automated metering system, billing system, LCD, household station, two sensors (both current and voltage), and a GSM communication module. The proposed system sends an alert via mobile to the user to pay or recharge for an uninterrupted supply. The main disadvantage of this SEM is that power leakage may occur due to the usage of both current and voltage sensors for continuous monitoring of the electric devices.

An IoT-based SEM using GSM fabricated by[4] has implemented a system that used an Arduino Uno as a controller and a GSM module for sending information. This system collects information from the Arduino regarding the power consumption and the GSM module sends this information to the mobile device as a notification message. However, alerts regarding slab rates were not provided by these researchers. Slab rate alerts are important that could save a good amount of consumers' money.

An SEM using GSM architecture has been proposed by Sultan[5] and this GSM-based system enables the electricity department to get the meter readings regularly while avoiding manual meter readings. The proposed smart meter also enables prepaid billing, electricity management, energy-saving and implements a mechanism for electricity theft detection. Nevertheless, as current and voltage sensors, as well as tampering and theft alarms, have been incorporated, power leakages are an issue that needs to be considered.

Arduino-based SEM proposed by[6], uses a GSM shield module on a microcontroller together with an LDR sensor and relay. The system allows users to get energy consumption updates via SMS, as well as final bill creation and load re-configuration by SMS. But, the proposed SEM looks too complex, as it also has current, voltage sensors and other different periphery electronic components.

An SEM developed for Bangladesh[7], which consists of an Arduino and GSM module for sending the billing details to the customer through a mobile notification message. The billing data has been stored on an SD card for further analysis. However, to determine the consumed energy, different electrical parameters such as AC voltage, the current, and phase angle are measured in real-time, which could create huge amounts of power leakage problems. This proposed SEM, hence, seemed too complex.

While designing an intelligent SEM with home automation[8], it has been reported that the proposed system overcomes the drawbacks of a conventional meter and that it could afford extra offerings together with energy cut and tampering alert. The proposed system, however, is too complex in terms of its size and its various subsystems, albeit it could be a feasible system to be used in home automation.

An IoT-based energy meter using a simple low-cost NodeMCU microcontroller, an esp8266 Wi-Fi chip module, and Blynk application were initiated by[9] that enable users to control their energy consumption since it has been programmed in such a way that it could send a notification through the App. Since it is a two-way (bi-directional) approach that it receives data from the Blynk server and re-directs the same to customers, and, often, these important users' data may be tampered with by fraudsters, which may create further security issues[10].

This research aims to propose a smart energy meter that must be simple yet highly accurate and, most importantly, economically feasible. By keeping these points in mind, we proposed this smart energy meter in this research and an accuracy test against the existing SEMs is done to evaluate its prowess. It is, therefore, found that it is superior in many aspects compared to the prevailing SEMs.

2 Proposed methodology

As discussed in the introduction, the existing SEMs were suffered in the several aspects, and we tried to minimize the discussed gaps. The system is helpful to calculate continuous units consumed based on the current readings taken from each appliance and this can, later, be observed on the LCD display as well as in the developed App. To the best of our knowledge, each and individual electric appliance assessment has not been done by any research team, including[2–9].

For a better understanding of the slab pricing, the consumer gets an alert message when there would be a change in slab based on the consumed units, which is also an interesting feature that has not been incorporated by any researcher[2–9]. The overloading of a device can be observed from the readings of a current sensor and the device can be protected by automatic power supply interrupt system. Last, not least, the user will establish a limit for variety of units consumed for on a daily basis and the consumer gets alerted about the consumption of this unit at regular intervals of our time.

3 System architecture

The brief explanation of architectural design for developing the Smart Energy Meter and Controller is provided mentioned below.

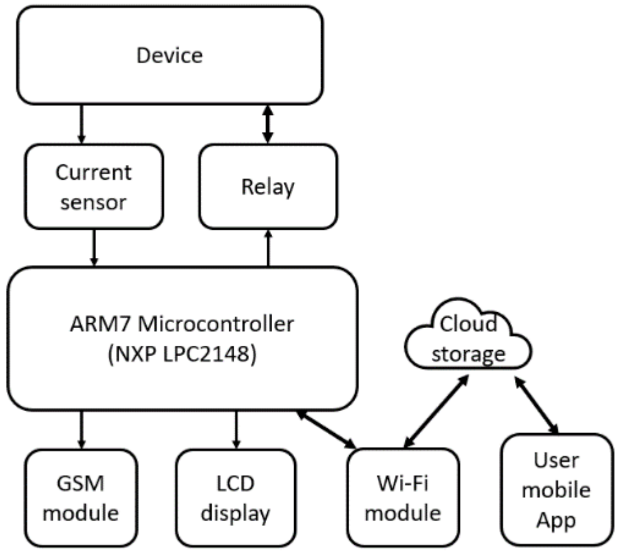

Fig 1. Block diagram of Smart energy meter controller

Figure 1 shows the connection flow between the sensor, microcontroller, and other hardware components. The detailed specification of each block represented in above Figure 1 is explained in detail.

A device's functional requirements determine the amount of current required. Some devices are so sensitive that they are damaged by an excessive amount of current [11]. To prevent such a situation and monitor the amount of current being used in an application, the ACS712 current sensor is used to measure the amount of current.

ARM stands for advanced reduced instruction set computer (RISC) and is a 32-bit processor built by ARM Holdings. Microcontrollers, as well as processors, can be built using ARM processors. ARM processors are among the best choices available for embedded system designing. There are several applications of ARM processors, including mobile phones, automobile braking systems, etc.

ESP8266 Wi-Fi module is a self-contained system on chip (SOC) that has an integrated TCP/IP protocol stack, so any microcontroller can connect to our Wi-Fi network. It is either capable of hosting an application or offloading all Wi-Fi networking functions to another application. The ESP8266 modules come with pre-programmed ATtention (AT) command sets which can be used to implement wireless devices.

The SIM900A GSM Module is a cheap and tiny module used for GPRS/GSM communication. It is often used with a microcontroller and Arduino for embedded applications. The module provides GPRS/GSM communication through the use of a mobile SIM. Frequency bands of 900 and 1800 MHz are used. The power relay module is an electromagnet-controlled electrical switch. A separate low-power signal from the microcontroller activates the electromagnet. The electromagnet, therefore, pulls to open or close an electrical circuit when it is energized.

3.1 Implementation and working

Figure 2 represents the workflow of the designed model which is useful to observe current readings of devices and also for the generation of bills. This system works by providing 230 volts common household power supply. The current sensor detects the flow of current in an application and provides an equivalent analog signal. Here, the usage of 30 Ampere ACS712 sensor helps to increase the accuracy of the current readings.

The generated analog signal has further proceeded to the ARM7 microcontroller. The 32-bit analog-to-digital converter (ADC) of the microcontroller converts the analog signal into digital readings. The calculated readings are in milli Amperes (mA). The generation of consumed units of the overall system is calculated using the below formula.

$$Number\ of\ units\ consumed\ =\ \frac{Sum\ of\ each\ load\ reading}{230Volts*1000}$$

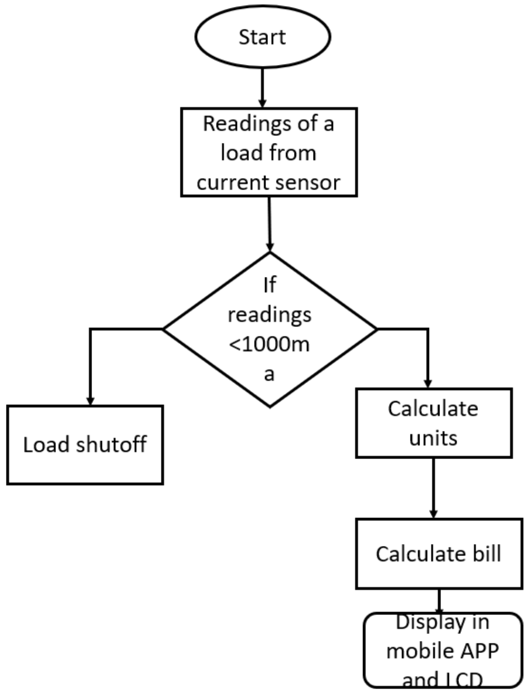

Fig 2. Flow chart used for bill generation

The bill will be generated by the slab ratings of each unit. The current readings of each appliance, the consumed units, and the bill generated are displayed on LCD Display and developed into a simple android App. The Wi-Fi module ESP8266 is used as a communication channel between the App and the system. The implemented App is also helpful for on and off electrical devices.

This system also alerts the user about power consumption similar to a prepaid meter by sending messages to the consumer's mobile number. This is possible by using the SIM800L GSM module. The user also gets notifications about the change in slab pricing prior.

One of the main causes of the damage to a home appliance is electric overload. The overloading occurs when there is a heavy flow of current in an electrical device which causes melting or damage to the device. To overcome this situation, we have programmed the microcontroller to shut the power supply of the device when the current readings of the device exceed the defined range and the working of other devices proceeds as usual.

4 Results and Discussion

Table 1. Comparisons of several technical aspects between earlier and the proposed SEM

Type of Incorporated Sensor(s), Accuracy, Easy to Handle and Install, and Individual Appliance Assessment	Research Team of fabricated SEM	Reference number of this research	Remarks
i) Current and voltage ii) Good iii) Yes iv) No	Kumar et al. 2020	[3]	Complex, economically not feasible
i) Current and voltage ii) Good iii) Yes iv) No	Sultan et al. 2019	[5]	Complex, economically not feasible
i) Current and voltage ii) Good iii) Yes iv) No	Patel et al., 2019	[6]	Complex, economically not feasible

Continued on next page

Table 1 continued

i) Current and voltage ii) Good iii) No iv) No	Nigar et al. 2020	[7]	Extremely Complex, economically not feasible
i) Current and voltage ii) Good iii) Yes iii) Yes	Kannan et al. 2021	[8]	Complex
i) Current, voltage, and power ii) Good iii) No iii) No	Gadekar et al. 2022	[12]	Extremely complex and economically not feasible
i) Current, voltage, active and reactive power ii) Good iii) No iii) No	Salunkhe et al. 2022	[13]	Too complex and economically not feasible
i) Current ii) Good iii) Yes iv) Yes	Present SEM	[This research]	Simple, easy to implement and economically cheap

The results obtained by the developed system are as follows:

The implementation of prototype smart energy meter as shown in Figure 3 is done by considering the two filament bulbs as loads.

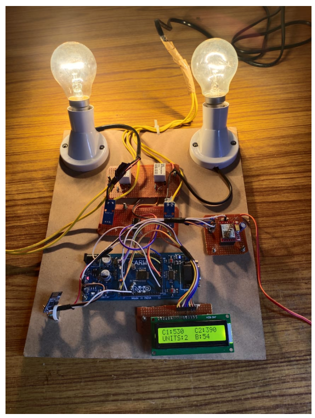

Fig 3. Display of hardware implementation

Figure 3 represents the hardware implementation model of the proposed SEM. The connection between the sensor ACS712 and loads is made through the single-channel relay module, which is further connected to the ARM7 microcontroller as an input. The LCD, GSM module, and Wi-Fi are connected to the microcontroller as output devices.

Figure 4 shows the LCD results. The C1 and C2 represent the corresponding loads (filament bulbs), as represented in Figure 3. The C1 and C2 bulbs have different wattages of 100 watts, and 60 watts respectively, and the current readings of loads are in milli Amperes. UNITS represent the consumed units and B represents the bill generated.

Fig 4. LCD display results

Figure 5 is the prototype representation of overloading. To demonstrate overloading effect, an extra load to C1 is added.

Fig 5. Shows how overloading problem will be sorted out

Fig 6. Shutting off of loadC1 is shown on an LCD, wherein the left display shows that load has received and the right display shows shutting down of load

Figure 6 represents the sudden current readings change in load C1 which results in power cut off to load C1. So that in next step, the current readings of C1 is zero.

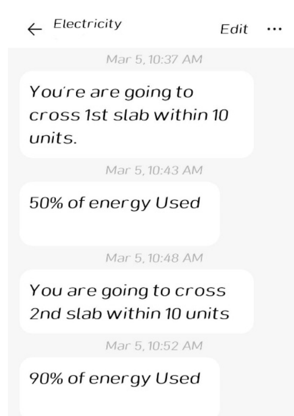

Fig 7. Alert messages

Figure 7 represents the alert messages sent to the user's mobile number when there is a change in slab pricing and consumption of energy in percentages.

5 Conclusion

Though the modus operandi of this present SEM is not new compared to the existing models, it has got many attention-grabbing features that keep this SEM different and unique; yet, it is an economically feasible model. When making a comparison with the existing SEMs, one can understand its essential features, including

a) It is a simple device to be installed and handled

b) It is economically feasible, which may need Indian Rupees ~ 3000- 3500 to make this model so that it is best suitable for Indian households

c) Due to the current consumption assessment capability of every electrical appliance, consumers would be able to assess the individual electrical appliances' consumption

d) Once the individual consumption of electrical appliances is known, the wastage of the electricity will be reduced by controlling the over usage of those electrical appliances.

e) The slab rate alert to the customers is an important aspect that could bring awareness among them so that appropriate electricity utilization may be possible.

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