Design and Implementation of IoT-Based Smart Energy Meter to Augment Residential Energy Consumption

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2023 3rd International Conference on Robotics, Electrical and Signal Processing Techniques (ICREST) | 979-8-3503-4643-5/23/$31.00 ©2023 IEEE | DOI: 10.1109/ICREST57604.2023.10070068

***Abstract*—There is a constant push for automation, portability, and remote control in the management systems of all organizations. A new IoT-based multifunctional smart energy meter is presented in this paper for automated metering and billing system. Arduino Nano with GSM Short Message Service (SMS) connection provides a meter reading system with predefined automatic functions followed by ESP-8266 WiFi Module to monitor energy parameters. Proteus 8.0 was used to model the project before the hardware implementation was built. With the GSM module and embedded controller, the proposed system can transmit data such as kWh consumption and generated bills over the GSM network, which can then be fed into existing energy management systems at power companies or organizations to provide services to customers without the need for human intervention. As a result, consumer energy analysis is made considerably simpler and more manageable. This device aids in the detection of power theft as well. As a result, this smart meter facilitates wireless connection and home automation utilizing IoT, which is a significant step towards a Digital Bangladesh. Moreover, a prepaid mode is incorporated as part of billing system.**

Keywords— Smart Energy Meter (SEM), Arduino (Microcontroller), Global System for Mobile (GSM), Short Message Service (SMS), Internet of Things (IoT), Prepaid Energy Meter, WiFi Module, Overload & Electricity Theft.

I. INTRODUCTION

Automated systems are increasingly being connected to a network via wireless applications. Research into wireless applications and remote control has grown in importance and popularity as technology has advanced. The amount of electricity used by a home, company, or electrically powered device is measured by electricity meters, electric meters, or energy meters. A smart energy meter (SEM) is a type of electric appliance that combines an energy meter chip with other peripheral devices for security, data display, meter control, and wireless data transfer (such as GSM Modem).

Embedded controllers such as GSM modems can be used to transfer data via the mobile network in energy meter devices [1-2]. These data can be included into and fed into the current energy management systems at power companies and other organizations.

The existing system is time-consuming and a lot of effort is required. In our proposed system, the data is received on its energy consumption at regular intervals. Monthly billing information could also be made available to customers. If the consumer's energy usage reaches a threshold level, an alarm system is activated [7]. The older, electromechanical meter is used to waste more electricity. Since a postpaid billing method is used by electromechanical meters, customers cannot keep track of their energy usage. The Arduino, the Android app, and the prepaid system are all employed in our case. This meter aids in the calculation of the utility bill by allowing the user to monitor energy consumption [3]. Mobile applications save and transmit this data to the end-user. Moreover, the current energy billing system has more problems, such as additional charges or utility notifications even if the electricity payment has been paid, than in previous systems [4]. Users can recharge through SMS using a pre-paid energy monitoring system. In the next section, the overall operation of the proposed system is discussed.

II. ENERGY METERING SYSTEMS

A. Conventional System

To calculate the amount of energy consumed, electricity meters use continuous monitoring of instantaneous voltage (volts) and current (amperes) (in joules, kilowatt-hours etc.). Electromechanical meters and electronic meters are the two basic types of meters. Watt-hour meters that use electromechanical induction are the most prevalent.

Conventional billing has numerous problems and inaccuracies. In manual billing, some human errors may also

occur [4]. When analyzing conventional billing, the following common errors and faults were found:

• This process takes a while.
• When taking a manual meter reading, human error is always possible.
• There is no system in place to check, balance, and verify this meter reading.
• Theft and corruption are always a possibility.
• Consumer's use is not updated.
• Additional human labor is necessary [5].

III. PROPOSED WORK

The proposed system is both cost effective and compact, making installation much easier. It consists of Arduino Nano V3.0, SIM 800L GSM Module, ESP-8266 WiFi Module, Current Transformer (CT) and potential transformer (PT), relay and LCD.

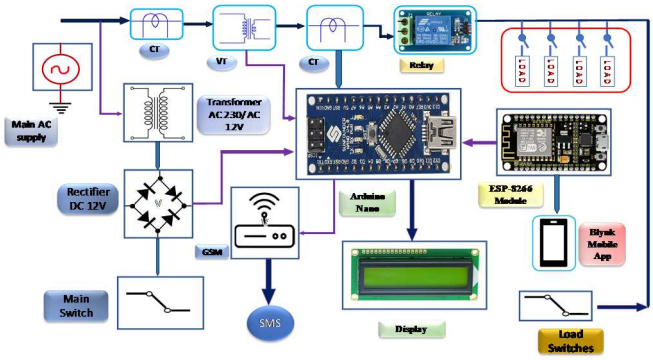

Fig. 1. Block Diagram of IoT Based Smart Energy Meter

A. Sensing Element

The CT and PT sensors are this system's primary sensor components. These are utilized to link the load to the microcontroller system. Both invasive and non-invasive current sensing devices are available. In this system, a split-core current sensor is used [6].

B. Arduino Nano V3.0 Microcontroller

Arduino Nano V3.0 is a single-chip microcontroller that acts as the brain of the system and it is designed by Arduino.cc. It calculates the amount of energy used as well as the cost. When energy usage exceeds the set unit, a microcontroller is utilized to regulate it. The information is displayed on an LCD attached to the Microcontroller.

C. ESP-8266 WiFi-Module

Wi-Fi Module is referred to as Wireless Fidelity. Wi-Fi is the IoT's power source. It has a microcontroller connected to it. Through the Wi-Fi module, the threshold value is modified. By connecting to the internet, the Wi-Fi Module is used to send and receive data to and from the user. By tracking the data and displaying the information online, accurate readings of unit and cost are displayed on the Blynk Application.

D. IoT

IoT is an abbreviation for the Internet of Things. The internet of things (IoT) is a technology that connects various physical objects to the internet. After connecting the program, it will automatically modify the device or sensor without requiring the consumer to do so.

The Internet of Things system is made up of four parts:

1) Sensors/Devices

First, sensors or gadgets are used to collect environmental data. CT and PT are the sensors utilized to collect current and voltage in this case.

2) Information Processing

After receiving data from the cloud, the software does several types of processing on it. For example, it checks to see if the energy use is within a certain limit.

3) User Interface

The information is then made available to the user in some fashion, such as by notification or SMS text. For example, when the energy usage is extremely high, or if someone tampers with the energy meter, an alarm SMS is sent to the user.

E. GSM Module SIM 800L

SIM800L GSM/GPRS module is a tiny GSM modem that may be used in a wide range of IoT projects. This module allows us to perform almost whatever a conventional mobile phone can do: send SMS text messages, make or receive phone calls, connect to the internet through GPRS, TCP/IP, and more. [5].

F. Power Supply Unit

A power supply is a type of electronic device that supplies electricity to a load. As we all know, no modern technological invention can function without a power supply. All electronic components, from diodes to Intel integrated circuits, require a direct current (DC) source, which normally runs from 5 to 12 volts. As the cheapest and most generally available energy source, we chose 220V-50Hz, stepping down, rectifying, filtering, and controlling the voltage to convert it to an acceptable DC voltage. We require +5V and +6V to power the load, Microcontroller, and display unit in our project. [6].

G. Prepaid Mode

In this strategy, the consumer pays the energy bill amount before consuming energy. The prepaid method can alleviate the burden on the traditional billing system while also reducing the need for meter reading personnel.

a) Advantages of Prepaid Meter

- For Utility:
  1. No bill generation.
  2. No distribution of bills.
  3. Reduce the workforce.
  4. Lower overhead.
  5. No additional action for disconnection.

- For Consumer:

1. Pay the bill for the required energy consumption.
2. There is no error in billing.
3. Cut down on energy waste.
4. It displays the usage unit and the remaining unit.

IV. SIMULATED RESULTS

The simulation model designed in the Proteus design suite is shown in Fig 2. The simulation contains all the electronic parts including voltage and current sensor, GSM, and Vibration Sensor to detect theft. However, the IoT integration was done separately in our hardware implementation. In order to incorporate the IoT and establish the communication with the mobile app, we have used a few different sensors and components for which coding was done separately while resembling our simulated model; and the code was directly transferred to the microcontroller.

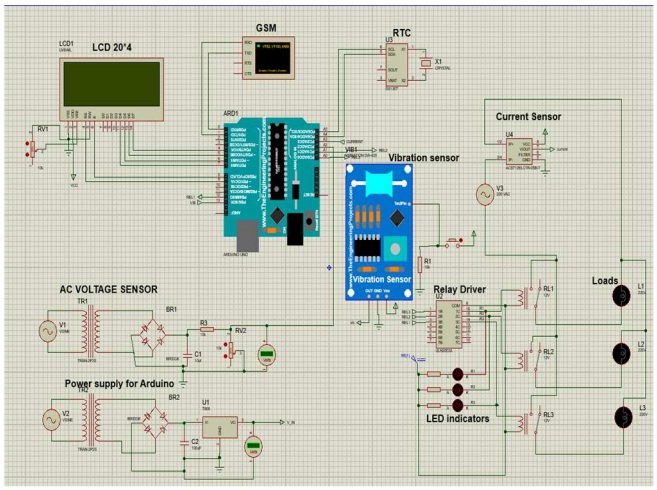

Fig. 2. Simulated model designed on Proteus

A. When Load is Turned ON

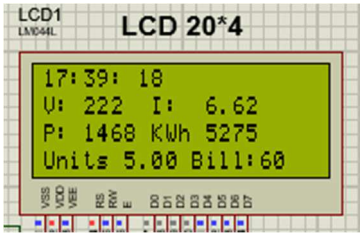

Fig. 3. Readings from smart energy meter when Load is ON

When the load is turned on, the LCD displays all of the parameters, including voltage, current, power, and energy, as illustrated in Fig. 3.

B. When User Sends SMS

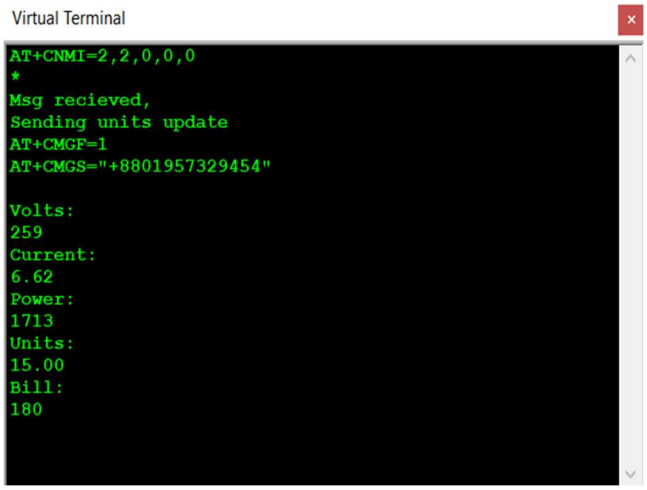

Fig.4 SMS from smart energy meter

When a user sends a message, GSM sends information about the user's energy and billing usage. For instance, when the user sends a message, the mobile phone receives an SMS with information about the consumed units.

C. When the meter is Tampered

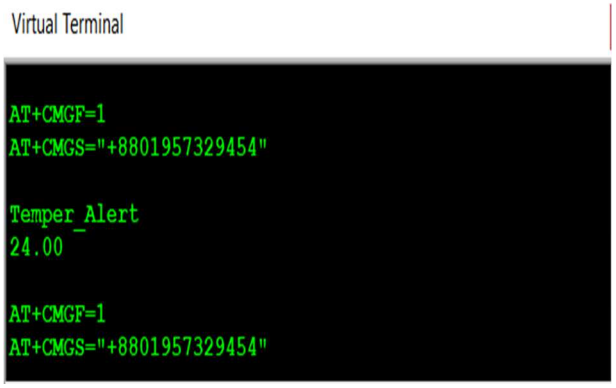

Fig. 5. When meter is Tampered

D. When the load exceeds the maximum demand limit

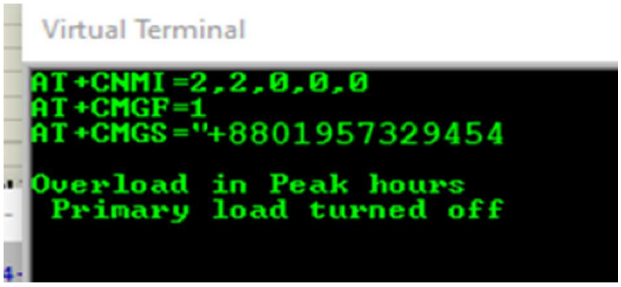

Fig. 6. When load is cut off

V. HARDWARE RESULTS

The proposed energy monitoring system is practically implemented to be analyzed. The following are the specific practical implementations:
As illustrated in Fig. 7, we have linked all of the project's circuit parameters and components to a project board, and almost resembled that with simulation connection. We assembled all of the components on a board and linked the microcontroller, Wi Fi- Module, CT, and PT to a project board. In addition, we linked the GSM Module directly to the Microcontroller, and data from the microcontroller is sent to the ESP-Module and LCD.

Fig. 7. The prototype of implemented IoT based smart energy meter.

For the demo operation, two mobile phone sets with GSM SIM are employed, one as the consumer end and the other as the service provider end. Because the Arduino has been programmed with specified operations, such as energy meter reading code, SMS reading, checking, and sending code, AT commands for SMS and security services, it will operate in the manner described below.

Fig. 8. Initiation of the Smart Energy meter

When the main switch is turned on, the Arduino returns to its original state and displays the message "System Ready..." as shown in Fig. 8. After a short time, the Arduino will read the EEPROM, calculate the data, and display it on the LCD. After that, the relay turns on, and the load is connected via the microcontroller's relay. Furthermore, the Arduino will check for fresh SMS indications from the GSM modem on a constant basis. If there is a new SMS, Arduino will send the appropriate AT instruction to read the SMS. Arduino will send related AT command to read the SMS.

A. Billing System

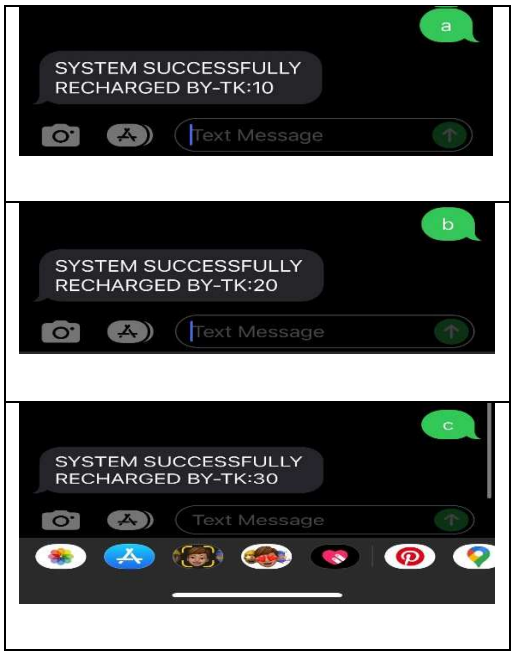

Fig. 9. Recharging Tk 10, 20, 30 for Prepaid Mode through SMS

In our proposed work, we have added the prepaid method for billing. The meter can be recharged through special SMS codes denoted by: *a=10Tk, b=20Tk, c=30Tk, d=50Tk, e=100Tk* for demonstration in our prototype. When user sends the SMS, our energy meter gets recharged respectively as shown in Fig. 9.

Fig. 10. LCD showing the previous running balance of energy meter

Fig. 10. Shows the running balance as the reading gets subtracted gradually after unit consumption. However, the system will shut down automatically when the balance is low and will send a message to the user through SMS to recharge as shown in Fig. 11.

Fig. 11. SMS sent to the user when meter balance is low

B. *Overload and Tampering*

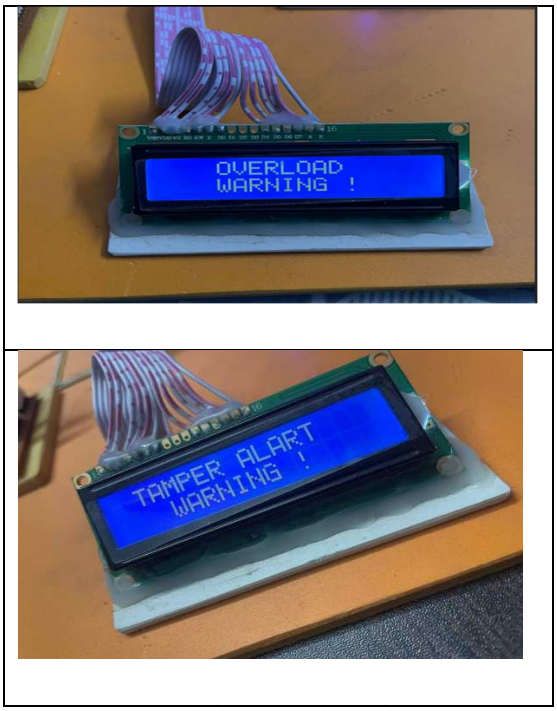

Fig. 12. LCD displaying Overload and Tampering

In our system, for demonstration, we have considered 230W for maximum power consumption. Whenever multiple loads are turned on and eventually exceed 230W, then an "Overload Warning" message is shown on the LCD on Fig. 12 and will also send a SMS to the user through GSM. Similarly, we have used an additional load to determine and justify the meter tampering (electricity theft) when that particular load is turned on.

C. *Monitoring Energy Parameters with IoT*

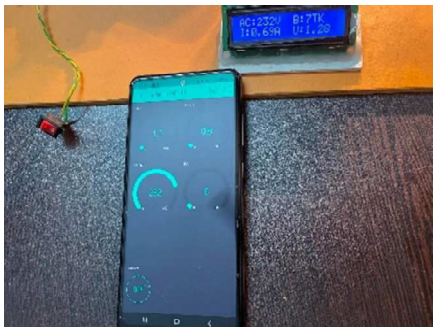

Fig. 13. Blynk app used to monitor the parameters of energy meter

The information received from the hardware will be displayed on the Blynk app which will help the consumers to monitor and making them aware of daily energy usage as shown in Fig. 13.

VI. CONCLUSION AND FUTURE WORK

In our project, an IoT Based Smart Energy Meter with multifunctional features incorporated is used to monitor energy parameters and let consumers know their energy usage through SMS. To make this project more accurate, dependable, and satisfying, more changes are still needed. One of the crucial details for the GSM module is the SIM's utilized network coverage. In order for the GSM module to function properly, the network strength needs to be strong enough. Additionally, comprehensive metering and invoicing systems, multipurpose capabilities, and both prepaid and postpaid modes can be implemented simultaneously. To sum up, this endeavor is essential for the present day. We will benefit from this project in many different ways if it is marketed. Bangladesh will advance one step if we can apply this project in our country. We used a single GSM modem for this meter, but in future work on this topic, a single GSM modem might be used for several meters, thus saving money.

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