Smart Energy Management and Load Monitoring of Individual Loads

Mohamed Aashik S, Jayarama Pradeep, Abishlal N S, Abinayaa Sri T, Jenin Benedict A

Department of EEE, St. Joseph’s college of engineering, Chennai, India
aashik25@ieee.org, hodeestedaffaffairs@stjosephs.ac.in, abishlalns03@ieee.org, abinayaa19@ieee.org, benedictjenin@gmail.com

Abstract. As India continues to urbanise with its manufacturing sector growing, its energy demands have increased rapidly. In this period, the need for energy monitoring and conservation must be evident. So the consumers can monitor their load consumption by a digital wattmeter. But the digital wattmeter measures and shows the total power consumed by consumer appliances. The consumer has no idea about which appliance consumes more power. Also, the consumer will not be able to know whether any appliance is getting damaged. To resolve these issues, we have come up with this project which is an IOT-based energy monitoring and controlling system, used to measure the power consumed by each appliance (Load). The power consumed by each appliance can be monitored individually by the consumer and it also informs us if there is an issue through a web application. Also the web application stores the historical data of the power consumed by each load. An Internet of Things (IoT) technique was employed to make the system smart. A microcontroller with built-in Wi-Fi - ESP32 - was used to monitor and control each load using a web application.

Keywords— ESP 32, Energy meter, IoT, Current sensor, Voltage sensor, Relay, Blynk app

1 Introduction

The first section – The introduction discusses the preface of the project titled “Smart Energy Management and Load Forecasting of Individual Loads”, statement of problem prevailing in the society, literature survey conducted to the specific problem, and the main objective of the project.

1.1 Preface

In India, the power consumption of the load is calculated by the energy meter. Energy meter used for the live calculation of electric load. The energy is the total power consumed and utilized by the load at a particular interval of time. The individual monitoring of appliances is not viable for consumers with the use of conventional energy meters.
A Smart Energy Meter is an intelligent digital device that is designed to replace the traditional electricity meter. It will let you know how lovely the consumption of energy usage is. Installing a smart energy meter helps you to know the estimated bills according to the tariff rate by allowing you to control and reduce energy consumption. Smart Energy meters help people understand how the energy is being utilized.

In this paper, we designed a prototype for implementing a smart energy monitoring system so that consumers can know the electricity expenditure for a single equipment and multiple loads. Also, with this data the consumers are able to find the over power consumption load and can be able to replace it with new energy efficient counterparts.

1.2 Objective

To solve the problem statement discussed in this section, the literature survey has given ample knowledge to pursue the following objectives.

- To measure and compute the energy consumed by individual load using voltage and current sensors along with the Arduino Mega.
- To send and process the data to the consumer’s mobile in order to monitor any abnormal behaviour in each load through a Web application using ESP 32 MCU.
- To control each load independently through the Web app.
- To calculate the cost of individual loads on the basis of state government consumption criteria.
- To display the statistical data about each load’s power consumption for every second, minute, hour, and up to years.
- To compare and keep track of the power usage of each load at the necessary time.
- To predict the lifespan of each load by knowing the power limit and the date of purchase of the load.

2 Literature Survey

From the resources available in the web, the information and details that are relevant with energy management and monitoring are analysed and discussed below as follows.

The paper proposed by Saikat Saha [1] in 2018 uses a PT and CT for power data. The data is sent to ThingSpeak – Cloud and the data is used for Analytics. The project proposed by Potuganti prudhvi [3] in 2012 uses a Conversion topology to convert the energy meter data to processable data by the microcontroller and displays the parameters using an LCD display.

The paper proposed by Champ prapasawad [4] in 2012 takes the power values which are obtained from the conventional Energy The project proposed by Sneha Chaudhari [6] in 2017 simply uses an Energy meter to measure the power consumed and using an Arduino and GSM module, the user will be intimated about the power usage. In the project proposed by Himashu K Patel [7] during the year 2019, the energy meter wires are tapped for power readings and the readings are processed by Arduino UNO. The power consumed is measured using an Energy meter and the user is intimated using the GSM module through SMS.

The paper proposed by Luis I. Minchala-Avila [8] presents the design of a smart meter (SM) with demand response (DR) capabilities. The SM design is put through its paces in a simulation that uses an advanced measurement infrastructure (AMI) to enable bidirectional
communication between household smart metres and the distribution management system (DMS).

In the project proposed by Zahid Iqba [9] during the year 2014 uses PIC 30F series MCU to get the values of current and voltage using respective sensors and the data are shown to the user via LCD display and through SMS using GSM module. The project proposed by Preethi V [10] in 2016 uses an ARM 7 Processor, GSM module, and Zigbee communication protocol. It measures the load using voltage and current sensor. Intimates the user through SMS. In the project proposed by Fadhela K handhal [11] during 2017, the voltage and current sensors are used. The data received is sent to Arduino Mega and displayed to the user using an LCD display.

This paper proposed by Birendakumar Sahani [12] presents the system which monitors the energy consumption and displays the data Inna website (HTML) and send messages to users to inform them when it exceeds the threshold amount, through Global System for Mobile (GSM) module which cuts down the energy waste and lowers the electricity bills.

This paper proposed by Prathik.M [13] presents the system which gives energy consumption on daily basis and displays them in the Liquid Crystal Display (LCD) also it calculates the electricity bill through the web server using IOT and informs the user through GSM module. An alarm is set so that alerts the message when over consumption occurs or when it reaches near the threshold value. Also the system is much useful when user is out of station they can disconnect the malfunctioning device by sending a message to the system with the help of GSM module.

![Figure 1. Energy consumption in India. X-axis: year, Y-axis: Energy consumption in kWh](image)

The energy consumption kWh in India rises yearly as shown in the Figure (1.1). This provides a caution that we should conserve the energy in a proper manner.
From Figure 1.2 & 1.3 we are able to observe the energy consumption of a Residential building in India. In the graph it is clearly depicted that the lighting and the fans consume more than 60% percent of energy in the households. Our ultimate aim of our research project is to target these two parameters and try to conserve the energy in an efficient manner. Fig 3 also shows the energy consumption of commercial buildings, where it is visible that 60% percent of energy consumed by the lighting.

3 Existing System

This section deals with the model of the existing system block diagram, working, advantages, and disadvantages of the existing system.

3.1 Model of Existing System

The projects and proposals follow a common architecture to measure the power consumed by the loads. The total power consumed by the loads is measured either by using the
conventional energy meter directly or by using a current sensor in series with the energy meter. The collected data from the energy meter / current sensor is processed using the MCU

3.2 working of the existing system

The total power consumed by all the loads is calculated with the help of the conventional energy meter where the current measurement is tapped or a current sensor is used to measure the current drawn by the loads to calculate the total power consumed by the load. In some projects [1] [2] [3] different topologies are used to measure the power consumed but most commonly [5] [6] [7] the energy meter and the current sensor are used.

After the analog data is taken, it is then given to the microcontroller such as PIC series MCU, ARM series MCU, Arduino UNO/Mega, ESP8266, etc., to process the information as digital readable data that can be used to display the measured value to the user by various means.

The digital data is then presented/intimated to the user via different means. A 16x2 LCD is commonly used to display the data to the user. In addition to that provision to send SMS to the user using the GSM module is also integrated [9]. To take this further, Wi-Fi modules such as ESP8266 are used to connect with the web application (ThingSpeak) [14] through the internet.

3.2.1 Advantages of Existing System

By implementing the idea of the Existing system in accordance with the conventional Energy meter, the advantages are as follows.

- The power consumption is taken as digitally readable data that can be used to process and visualize it in a desired way.
- The data can be monitored not only near the system but also away from the system by SMS or web application.
- The measured value can be displayed to the user as desired as the power values are taken as raw data.

3.2.2 Limitations of Existing System

Although the existing system has some noticeable advantages, it also has some limitations concerning some useful technology available in the world that are discussed as follows.

- The system only measures and calculates the total power consumed, not the individual power consumed by each load.
- No provision to display data as cost per consumption
- No provision for mobile-friendly interface
- No provision to turn ON/OFF the loads as desired by the user.
- The system does not give any alert/prediction when the load is misbehaving.

4. Proposed System

The proposed system section deals with the model and block diagram of the proposed system.
4.1 Model of Proposed System

The ultimate goal of the proposed system is to calculate the individual loads consumed by each appliance and to detect the lifespan of individual loads. To attain this, a voltage sensor - ZMPT101B should be connected in parallel with the supply, and a current sensor - SCT013 should be connected in series with the load. As the voltage remains constant around 220 Volts AC to 240 Volts AC, the current drawn by the individual load is measured and the power consumed by each load will be calculated and conveyed to the user. The power consumed by each load will be measured by the voltage and current sensors and will be given to the microcontroller – Arduino Mega and it will make the data to be displayed and it will make it transferable. An algorithm should be used to interface the LCD 128 x 64, Website with the ESP32, raise an alert when the load consumes more power than usual, and figure out the load's lifespan, etc. Separate Relay modules will be used in series with the current sensor for turning ON/OFF the loads whenever wanted. Finally, we can have a web application- The Website that will lively do the things we have mentioned above. To demonstrate the proposed system, 3 individual loads will be plugged into a 230Volts AC junction box. One phase wire of each load is taken wired with the Current sensor and Relay module in series to measure the current drawn and to turn ON/OFF each load desirably. The output of the voltage sensor, the current sensor, and the input of the relay module will be coupled with the ESP32. For display purposes, a 128x64 LCD will be used to display the current drawn, power consumed by each load, voltage across the loads, the total power consumed by all the loads, and the cost of consumption in real time. All the above-mentioned parameters will be present in the Website interface with a provision to turn ON/OFF each load as desired.

4.2 Block Diagram of the Proposed System

The above-proposed system is realized as a block diagram fashion for better understanding.

The block diagram shown in Figure 4. The first section where three loads are connected parallel to the single-phase 230 volts AC power line and in series with the Current sensor & Relay. The current sensor gives an output signal that indicates the current drawn and a relay requires an input signal to turn the load ON/OFF. In our case, the single-phase 230 volts AC power line is a 5 amps junction box where the loads are plugged in.
Fig. 4. Block Diagram of the Proposed System.

Fig. 5. Block Diagram of the Proposed System
The figure 5 shows the microcontroller involved where the data from the sensor is connected to the Arduino and the data is transferred to the web application through esp 32.

5. Data Employed

The below list is the TNEB unit rate or TNEB tariff table for home 2020 -2021. From the table you can see that if units consumed are less than 100 units, the consumer doesn't need to pay for it. By taking the second row, if the consumer takes less than 200 units, the first 100 units the consumer doesn’t need to pay for it. But, from 101 to 200 the consumer needs to pay an amount of Rs 1.50 for each unit. The table (5.1) shows the tariff table for the unit of power consumed.

<table>
<thead>
<tr>
<th>Units</th>
<th>Tariff Charges</th>
<th>From</th>
<th>To</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed</td>
<td>Subsidy</td>
<td></td>
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</tr>
<tr>
<td>≤ 100</td>
<td>₹0</td>
<td>₹150</td>
<td>1</td>
<td>100</td>
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<tr>
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<td>₹150</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>201</td>
<td>500</td>
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<tr>
<td>≥ 500</td>
<td>₹50</td>
<td>₹150</td>
<td>1</td>
<td>100</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≥ 500</td>
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</tr>
</tbody>
</table>

6. Working Principle

This section deals with the working principle of the proposed system that has been discussed in section IV and the algorithm used to program the microcontroller to extract desired output. This section explains in detail how all these things work using the algorithm used in the proposed system.

6.1 Working of the Proposed System

Initially, the single-phase AC source is turned on. Then the readings are noted using the voltage and current sensors. The program is uploaded to the ESP32 from Arduino IDE using a micro-USB cable. The Wi-Fi is turned ON in order to connect ESP32 to the website. Then the Website is opened on mobile phones/Systems for monitoring the readings. Now all the sensors, microcontrollers, relays, loads, etc are turned on. Initially, the current sensors measure the current through 3 loads. Then the voltage sensors measure the voltage. Now the output of 3 current sensors and 1 voltage sensor is given to the 4 analog input pins of Arduino. Then by using an algorithm, the output of current and voltage sensors are converted to RMS current and true RMS voltage values. Now the power consumed by each load is calculated by using the RMS current and RMS voltage values. By using the power consumed, the cost per power consumption is calculated by referring to the TNEB tariff data. For digital display,
LCD is operated at serial interface mode for which three communication pins are required. The LCDs the RMS current through the loads, RMS voltage value across the loads, power consumed by the loads, cost per consumption by each load. The output fetched by the ESP32 and is been sent to the server and the user can study each load entirely via the website. The website displays the power consumption and the expected power consumption by a load and so the difference between them can also be calculated. This power consumption analysis determines the life span of the load and thus the user can interpret when the load has to be changed. Also, the website displays the statistical power consumption of each load for every second, minute, hour, day, week, month, and year. The website also displays the current TNEB tariff amount for user reference. It also displays the power comparison of load with other loads and at different timings.

7. Hardware Implementation

This section shows the hardware implementation of the proposed system discussed in section IV. All the sensors, modules, power supply, LCD, web application are interfaced together to produce the desired output discussed in the proposed system.

![Fig.6. A Single-phase Junction Box with Current Sensors, Voltage Sensor, Relay and +5V DC Adapter](image)

Figure 6 represents the Junction box along with the current sensors and relays connected in series with the phase wire, voltage sensor, and adapter connected to it. The junction box is plugged into a single-phase AC source which makes it the same for the four sockets. The male plugs of all the loads are connected to the sockets. Now, the loads are connected to the female plug sockets. The fourth socket is used for a voltage sensor and a +5V DC 2A Adapter to power up the entire circuit using a multi-socket plugged into it.
Figure 7 shows the three loads with color-coded wires. The LED lamp and the Axial Fan are color-coded with yellow and blue colours representing phase and neutral wires. The heater coil - a hairdryer with a male plug is taken which can be connected to the female socket from the power line.

8. Results and Observations

This section discusses in detail the output that is obtained from the proposed system implemented using the hardware parts, software, and data employed. The output of the proposed system is observed in two ways, one from the LCD and the other from the web application which is explained in detail. Also, to verify the output values, the Meco Clamp meter is used which is also explained in detail.
8.1 LCD Output

The measured values from the current and voltage sensor are processed by the ESP32 and the processed data such as true RMS values of current for all the loads, true RMS value of voltage across all the loads, individual power consumption of all the loads, total power consumption of all the loads and the cost per consumption for individual loads are sent to the LCD from ESP32 for displaying these values to the user.

![LCD Output](image)

**Fig. 10.** Output of LCD when all the Loads are turned ON & OFF

8.2 Web Application Output

The figure 8.3 shows the login page of the web application of the proposed system. The figure 8.4, 8.5, 8.6 shows the digital meter which shows the current and voltage of the load consumed, statics show the power consumption of each load at different time interval and lifespan of the each load respectively.

![Login Page](image)

**Fig. 11.** Login page of web application

![Digital Meter](image)

**Fig. 12.** Digital meter showing the current and voltage of the load consumed
Fig. 13. Statics show the power consumption of each load at different time interval

Fig. 14. shows the lifespan of the each load

8.3 Discussion

From the output of the proposed system, the observation of the measured values of true RMS current and voltage, and verification of the measured values - it is evident that the proposed system is working as expected. The implemented hardware model of the proposed system produces the desired output. All the sensors are calibrated in a way that measures the absolute value of the parameter. The proposed system measures the current drawn by each load, measures the voltage across all the load, calculates the true RMS values of current and voltage, calculates the power consumed by each load, calculates the cost per consumption of each load, and displays all these parameters in the LCD and Web application.

9. Conclusion

In this paper, we have proposed a smart IoT based energy meter which can be installed in houses and industries to measure the power consumption of a single load without the modification of the entire wiring system. This smart energy meter is a cost-effective prototype which uses ESP-32 and with other assisting sensor modules. During the working of the prototype, it was found to be capable of extracting voltage and current of a single load perfectly in an accurate manner, which is then relayed to the Web Application. The consumers can view, monitor, log the consumption data of a single load and are able to manage the electrical appliances with ON and OFF features. This can help them in ensuring if their appliances are working well within their expected power ratings. Using the data, the proposed system also finds the faults and abnormal activity occurring in a load. As the consumers are equipped with their consumption behavioural data, they can consciously reduce their energy consumption and hence, minimize energy expenditure.
9.1 Future Scope

- To provide these data to the Electricity Board people so that they can manage electricity demand in a specific area accordingly.
- Power theft database will also be implemented if all the houses are connected with this prototype.
- Card based recharge systems will be employed with smart energy meters so that consumers can pay the bill in their mobile application like recharging television.
- In-depth data analysis for the consumers in order to predict the electricity bill for a month and also for the upcoming year.
- These will be further implemented at Industry level in order to do economical usage of electricity and will also help in reducing cost.

10. References
