Energy consumption monitoring in smart home system

R S Harihanar¹, Reema Agarwal², Madhurya Kandamuru³ and H Abdul Gaffar⁴

¹,²,³,⁴School of Computer Science and Engineering, VIT University, Vellore, Tamil Nadu, India

Email: haran8861@gmail.com, reemasmu1398@gmail.com

Abstract: Energy Consumption, especially electricity consumption, is one of the serious problems that we are facing in today’s world. There is a need for an efficient system to monitor this energy consumption. Internet of Things opens a way to solve these problems by interconnecting hardware, software and cloud. Therefore, we propose an energy consumption monitoring system for home appliances which can be used to calculate the energy consumption of the household and to keep the user informed about the electricity consumption through an android app where he can view the units of electricity used and a prediction of the bill at the end of the month. The system can also be incorporated with the features of controlling the energy consumed by the appliances as desired by the user and the app will notify if the electricity consumption exceeds a threshold value set by the user.

1. Introduction

Electric meters installed in houses take a reading at the end of every month to determine the monthly bill based on the units of electricity consumed by each household. The energy consumption meter calculates the amount of energy consumed by various electrical devices and appliances. The meter counts the number of kilowatt-hours delivered and the annual electricity consumption is measured directly on the meter. The billing unit is typically kWh- kilowatt hour, which is used to take readings at the end of each billing period from the electric meters installed in a household or workplace premises.

But what if we can monitor electricity usage and be notified by a mobile app when the electricity bill for a given month is above a certain threshold? The electricity bill for a household is measured by calculating the electricity consumed in a month. Households belonging to the middle or low-class face difficulties to minimize and keep track of the electricity consumption and end up paying a higher bill amounts due to very few extra units consumed by that household that could have been conserved easily. As a result, an effort was made to propose a solution by taking readings of all devices in the house and predicting the bill of that month by calculating the amount of the bill of consumption of electricity each day until the current date to help people realize how much electricity they consume each day and how to reduce it to keep consumption below a certain threshold. Implementation of IoT in an energy monitoring system can transform the way industries, companies and individuals consume and control electric devices and household appliances and IoT can offer a solution to optimize power consumption.
Once a system such as a house or an office building or a facility is equipped with this IoT technology, it incorporates the particular space with the features of energy monitoring and control overconsumption. Among them are Periodical statistics on power consumption in each day, month and year with the additional functionality of monitoring each appliance in the house/workspace through a mobile app. Prediction of electricity bill by the end of the month on an analysis of data i.e., units consumed in that particular month till the current date and giving an estimate of the bill for the amount of consumption.

2. Literature review

Chupong et al. proposed a home energy monitoring system that uses an application which can forecast the user’s electricity bill. The proposed system uses an Application Programming Interface (API) which allows the application to fetch stored data from the hardware unit, predict the user’s electricity bill and send a report to the user via email every day. This system uses only the last 7 days energy consumption to predict the electricity consumption and the effect of energy saving with larger sampling size is unknown [1]. Maheepala D C et al. addressed the issues of energy auditing and proposed a system which monitors energy consumption in real time, analyses the measured data, finds out the problems and provides technical solutions to it. The system also generates reports and warns its users in case of any emergency [2].

Another method proposed by Mohammed Abo Zahhad et al. consists of a sensor nodes network in which the nodes are deployed in different locations which will measure the power consumption and send the readings through a multi-hop network to the EMU that has a graphical user interface to send control signals to nodes during peak loads and show runtime data. It is integrated with WSN and the energy management unit records the energy consumption, manages it and predicts ensuing energy consumption [3]. Chooruang and Meekul proposed a system which comprises energy monitoring nodes that make use of Peacefair PZEM-004T, a low-cost energy meter, SD3004 chip and microcontroller for measuring voltage, current, power and transferring that data as JSON via MQTT protocol. This data is interpreted and the user gets an energy consumption pattern [4].

Energy Monitoring System design based on IoT was designed by Luan and Leng for energy conservation by improving energy management levels. The EMS along with IoT can collect, transmit and save a huge amount of data in energy running processes by making use of a database, communication networks, etc. The execution of the system has 3 layers namely perception, transport and application layer. This proposed IoT system has some advantages over traditional methods like strong reliability and practicability [5]. Jinsoo Han et al. designed a smart HEMS architecture using ZigBee and PLC-based renewable energy gateway which considers both energy consumption and generation. The home server collects data on energy consumption and performs analysis for energy estimation and controls the home energy usage schedule [6]. Al-Ali A R et al. proposed a system in which all of the devices in a house are interfaced with an IoT object with a unique IP address in a data acquisition module which results in a large mesh wireless network of devices. A prototype with a smart approach to monitor, control and cut the energy cost has been developed and tested [7].

Woong Hee Kim et al. proposed an energy management system based on a wireless sensor network i.e., ZigBee and an intelligent home gateway where it senses, records and updates electricity data to provide real-time electricity consumption monitoring. The method makes use of three technical components such as information acquisition, information processing and information presenting. The system allows users to detect and control electrical appliances using web and mobile interfaces [8]. Smart energy monitoring using IoT and GSM-based Cloud computing was proposed by Govindarajan
R et al. which makes use of a two-way communication protocol between metering infrastructure and the consumer end. To alert about power utilities, the multiple energy conservation live report is sent to the user [9]. Devadhanishini A Y et al. proposed the idea of a Smart Power monitoring system by integrating Arduino, WiFi and GSM Short Message Service (SMS). The system includes the design of a smart power meter that reduces power consumption and ensures energy saving with a motion sensor which automatically sends signals to cut the power supply when there is no sign of humans in the place [10].

Rishabh Jain et al. proposed an IoT-based energy meter reading system that consists of fault detection and SMS alert to the user. The method makes use of EEPROM as a flash storage memory and consists of Arduino board, buzzer, 16*2 LCD, ESP 8266 Wi-Fi module and power supply. The user can deal with their vitality utilization by knowing the vitality from time to time using this system [11]. Ganesh Shirsat K et al. designed a cost-effective IoT-based energy monitoring system with a low-fee PZEM-004T, the use of non-invasive CT sensors, SD3004 electric powered electricity dimension chip and ESP8266. This system is used as a power billing device and strength monitoring appliance [12]. Collins K et al. addresses the challenges faced by industries in maintaining energy cost and comes up with an energy monitoring and management system which identifies the individual machine’s energy consumption, processes the collected data to a fuzzy inference system that helps to reduce energy costs by providing feedback to a graphical user interface [13]. Sarmad Sohaib et al. proposed a low-cost design using ADE7753 energy meter IC, ATmega8 microcontroller, current sensor, etc. for real-time energy-consumption monitoring and control to reduce energy wastage. Compared to the commercially deployed energy meters, their system has high accuracy with a low average error rate of 0.66% in power measurement and led to reduction in average power utilization of about 12% [14].

3. Proposed Methodology

Recently in many places, the government has come up with strict electricity bill calculation procedures to avoid people from overusing and wasting electricity. According to these procedures, the cost per unit of electricity increases with increasing total energy consumption in a month. Due to this, the public needs a product that could help them to monitor and keep the number of kilowatts consumed in a month under control. This product must be able to predict and tell them the details of the expected bill based on their usage from the beginning of the month so that they can control their energy usage and get benefited from it.

The main focus is to develop a system that monitors the energy consumed by all appliances to predict the electricity consumed in a month by a household. Internet of Things (IoT) makes it easy for us to connect hardware and software components of the system using Cloud and Database. A system has been proposed in which the hardware component such as current sensor sends the electricity consumed by all appliances in the household to the cloud database. An android app is made which gets the stored energy consumption data for the household from day one of the month till the current date from the database. It runs a test using the consumption data for predicting the electricity bill of a month using a machine learning regression model algorithm and calculates the expected bill amount to be paid at the end. The application also provides the user with many other features like visualizations to compare the energy consumption in the house day-wise using a bar graph and controlling the appliances to turn them on/off within room distance.

3.1 System Architecture and Block Diagram

The ACS712 current sensor measures the units of electricity flowing through an AC appliance. This data sensed by ACS712 is collected in the Things peak channel through either HTTP or web socket protocol
via Node MCU. The Android application sends a GET/POST request to retrieve the data from the database for further processing. The received data is then visualized using a bar plot corresponding to the dates and it is given as input to the regression model that predicts the electricity units with high accuracy and precision. Then, the app calculates the monthly bill of the household based on energy consumption from the beginning of the month to the current date. It takes the energy consumed by appliances into account, which helps to monitor and reduce the daily usage to conserve electricity.

![Flowchart for the energy consumption monitoring system.](image)

**Figure 1.** Flowchart for the energy consumption monitoring system.

Figure 1 explains the working flow of the entire energy monitoring system. ACS712 sends measured current to Node MCU, which sends the data to the cloud and then, the app retrieves this data to give corresponding output as requested by the user. The user has three choices: to view the bill prediction, to control appliances and to check the energy consumption. According to the requirement of the user, the data is fetched from the cloud and displayed to the user.

![System Architecture of the Energy monitoring system for Smart Home Appliances.](image)

**Figure 2.** System Architecture of the Energy monitoring system for Smart Home Appliances.
Figure 2 shows the System Architecture of the Energy monitoring system. Current sensors measure the amount of current flow in every appliance such as LED bulb, fan, tube-light, etc., and sends the data to the cloud (Thingspeak) via IOT gateway i.e., Node MCU. Thingspeak maintains the record of electricity consumed by all household appliances each day in the database. The data is retrieved when the user uses the app and enter his/her choice to either get the bill prediction or control energy consumption. The system makes use of a machine learning regression model to predict the expected monthly bill accurately.

![Figure 2: System Architecture of the Energy monitoring system.](image)

**Figure 2.** System Architecture of the Energy monitoring system.

Figure 3 shows the block diagram for the energy monitoring system. Hardware Components in the circuit include a buzzer, motor and LED which act as the electrical appliances in the prototype implementation. Node MCU connects Arduino to the internet and endures connection between cloud and hardware circuit. The voltage regulator is used to convert 12DC to 5DC voltage and the relay module is used to convert DC to AC current to make the load work. Load is any device which needs electricity to run. The current sensor measures the current flow in each appliance. From Arduino, current flows through the buzzer, motor, LED and the ACS712 current sensors find the current passing through these devices respectively and send the value to the Arduino board. Node MCU receives this value from Arduino and sends it to Thingspeak Cloud.

3.2 Hardware Components

![Figure 3: Block Diagram for Energy monitoring system for Smart Home Appliances.](image)

**Figure 3.** Block Diagram for Energy monitoring system for Smart Home Appliances.

Figure 4 shows the block diagram for the energy monitoring system. Hardware Components in the circuit include a buzzer, motor and LED which act as the electrical appliances in the prototype implementation. Node MCU connects Arduino to the internet and endures connection between cloud and hardware circuit. The voltage regulator is used to convert 12DC to 5DC voltage and the relay module is used to convert DC to AC current to make the load work. Load is any device which needs electricity to run. The current sensor measures the current flow in each appliance. From Arduino, current flows through the buzzer, motor, LED and the ACS712 current sensors find the current passing through these devices respectively and send the value to the Arduino board. Node MCU receives this value from Arduino and sends it to Thingspeak Cloud.

![Figure 4: Hardware Circuit Connection for the Energy monitoring system.](image)

**Figure 4.** Hardware Circuit Connection for the Energy monitoring system.

Figure 4 shows the model hardware circuit of a simple energy monitoring system that functions the same as the proposed system for Smart Home. Hardware Components include buzzer, motor and LED in the circuit which acts as the electrical appliances in the prototype implementation. Node MCU connects
Arduino to the internet and endures connection between cloud and hardware circuit. The voltage regulator is used to convert 12DC to 5DC voltage and the relay module is used to convert DC to AC current to make the motor work. The current sensor measures the amount of current flow in each appliance. Jump wires are used to connect all the components to make a complete circuit.

Components used in the circuit:

- Arduino Uno
- ESP12/NodeMCU
- ACS712-30Amp Current sensor
- AC Appliances
- Jumping Wires
- Voltage regulator
- Relay module
- Battery and Breadboard

The Arduino UNO which is an open-source microcontroller board with input/output pins plays an important part in making the circuit by interfacing with all other components like NodeMCU, Buzzer, Current Sensor, etc. It needs to be powered from the computer through a USB cable for functioning. Sometimes, a voltage regulator is required for regulating the current entering the Arduino board. Arduino has the input/output pins which establish a connection with other components of the circuit through Jumping Wires. Arduino code needs to be run in the computer to start processing the data from sensors in the circuit. A reset button present on the board will restart the Arduino code running on the computer. Thus, this component plays a vital role in the development of this prototype. Node MCU is connected directly to Arduino in the circuit. From Arduino, current goes to the buzzer, motor, LED and the ACS712 current sensors read the current passing through these devices respectively and sends the value to the Arduino board. Node MCU receives this value from Arduino and sends it to Thingspeak Cloud. The ACS712 current sensor can be used to detect both AC and DC using the Indirect sensing method based on the Hall effect which explains the potential difference across a conductor when the magnetic field is applied perpendicular to the direction of current flow.

3.3 Software Components

![Splash Screen and Main Page Screen of the Android App.](image)
Figure 6. Daily, Weekly, and Monthly Energy Consumption Page of the Android App.

Figure 7. Bill Prediction and Smart Home Control Page of the Android App.

Figure 5, Figure 6, and Figure 7 show the user interface of an android application developed for the prototype. Figure 5 shows the splash screen and the main page of the application. From the main page, the user can choose the services of the app and experience it. Figure 6 shows the energy consumption service in the application and has an example bar graph to illustrate the interface of the application and depicts how the end users can monitor energy consumption on each day and total energy consumption in a particular week and month. Likewise, Figure 7 shows the bill prediction and the features of controlling the appliances in the app. The graph in Figure 7 (right) illustrates an example line graph and
expected predicted amount of bill on each day of the month which depends on the usage of electricity till the current date. When the user opens the application, the splash screen appears for few seconds and directs him to the main page where he can choose to check energy consumption, make bill prediction or control the electrical appliances in his home. The Energy consumption page shows the visualization of energy consumed by his household from the beginning of the month till the current day plotted against days in a bar graph. This helps the user to understand his energy consumption properly and to keep track of the expense. The Bill prediction page gets the energy consumption data and previous month dataset to run the machine learning regression model to predict the expected monthly bill more accurately and precisely. The control page gives the user a Smart Home experience and he can turn on/off the appliances in his house connected to the system.

3.4 Cloud database and Regression model

The Thingspeak cloud database gets the energy consumption data from NodeMCU and maintains the record of electricity used by all household appliances each day. It also maintains a database with records of the previous month-end bill, total energy consumed in kilowatt, and number of days in that month. A Multiple linear regression model is trained with the energy consumption for n days with the number of days(n) as input and equivalent bill amount for the month as output. This type of regression model uses two or more independent variables to predict the output dependent variable. This technique helps to determine the variation of the model and the relative contribution of each independent variable in determining the output feature. The formula used by this regression algorithm is

\[ y = b_0 + b_1 x_1 + b_2 x_2 + b_3 x_3 + \ldots + b_n x_n \]  

where \( y \) is the dependent variable, \( x_1, x_2, x_3, \ldots, x_n \) are independent variables and \( b_1, b_2, b_3 \ldots, b_n \) are constants.

Then the trained model is used to predict the total bill amount since day one of the month and the current day of the month. The dataset instances are split into \((X_{\text{train}}, y_{\text{train}})\) and \((X_{\text{test}}, y_{\text{test}})\) which are used for training and testing the machine learning model respectively. On running the testing phase, the model can be evaluated by using Root mean squared error, Mean Squared Error, Coefficient of Determination\((R^2)\), Adjusted \(R^2\), or Mean Absolute Error. The Thingspeak cloud database also maintains the record of all required user details during the login of an application corresponding to their energy consumption details. Hence using the Internet of Things (IoT), the hardware circuit, software application, and cloud database are integrated and linked together for the functioning of the entire prototype.

The data from the sensors are stored in the cloud database on daily basis. The multiple linear regression model will be trained based on the previous month’s reports and predict the equivalent bill amount for the month daily by considering the energy consumption data from the beginning of the month until the current day consumption. In this way, sufficient data is formulated to train the machine learning model.

A User Registration channel in Thingspeak holds all the value of user details when they sign up in the mobile application. Here phone number is verified and is used as a unique primary key to recognize the user. A Bill prediction channel in Thingspeak that holds dataset with columns of date, kilowatts, expected bill, and actual bill. This column is the input in the machine learning model training phase. In the backend, Thingspeak uses MATLAB to plot this bar graph and update it every day from the starting of the month.
4. Novelty of the system

The system helps the user to predict the monthly bill amount to keep consumption of energy under control and save money. The visualization of the electricity usage and expected monthly bill against the days helps the user to understand and to keep track of the rate of energy consumption properly and find out if they are exceeding their threshold or not. Through the android application, the user can control all the electrical appliances connected to the system wherever he is inside the house. All these features are the main advantages of the proposed Energy Monitoring System for Smart Home.

The proposed method is cost-effective since it makes use of an application installed in a mobile device to generate the bill and predict the amount of energy consumed. The unique feature of this system is that it provides three different services in one android application i.e., showing the amount of energy consumed in the app, generating the bill and also providing the feature to control the energy consumption through the app. This system aims to build up sustainable energy IOT based system operating at low cost, maximum efficiency and accuracy in the context of smart homes. It uses a multiple linear regression algorithm to predict the amount of energy consumed with higher accuracy and precision. Thus, the proposed system incorporates the advantageous features of the existing systems mentioned in Section 2 along with their limitations and stands unique from them.

5. Conclusion

After understanding the growth and increased demand for electricity, if energy consumption is not controlled and is wasted it will bring a great impact on our lives soon. To sustain it for the future and to effectively control it and make people aware, an attempt has been made to develop a viable system of ‘Energy Consumption Monitoring in Smart Home System’ that solves the consumption problem faced in Households. The proposed system is used to calculate the energy consumption of the household and even make the energy monitoring to be handy. The mobile application provides an interface to the end-user to check daily electricity consumption retrieving data from Thingspeak cloud database and the regression model predicts the bill amount by the end of the month based on the consumption of electricity on each day till the current day and gives an estimated amount so that the users can be aware of how much they are spending on electricity. Hence it reduces the wastage of energy and brings awareness among its users. Thereby, it can be concluded that the proposed system is an efficient energy consumption proposition made with the hardware components Arduino, ACS12 current sensor, electrical appliances and Thingspeak as the cloud database from which an approach for larger systems can be drawn i.e., collecting sensor data and monitoring usage with a mobile application and prediction of the monthly bill using a regression model to conserve energy and to minimize electricity consumption.

6. Future work

There is a need for an app that is self-optimized i.e., without the actual need of the user, the app can itself control the energy consumption which can be done based on a threshold value set by the user. According to daily consumption of electricity/energy in the house, the user can set a limit/threshold value, and based on the same limit set by the user, the app can reduce the energy consumption by controlling the current flow and reducing the intensity of bulb or tube-light, speed of a fan, etc. This will thus eliminate the need of the user to control/monitor the consumption manually when the user is not using the application. This is one of the additional features that can be brought in the future research.
7. References

[1] Chupong C and Plangklang B 2017 Electricity bill forecasting application by home energy monitoring system *Int. Electrical Engineering Congress* (Pattaya: IEEE) pp 1-4

[2] Maheepala D C, Nayanajith R M N, Somarathna M W R P, Bandara R A A M and Hemapala K T M U 2018 Designing an Energy Monitoring, Analysing and Solution Providing System for Energy Auditing *4th Int. Conf. on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics* (Chennai: IEEE) pp 1-5

[3] Mohammed A Z, Sabah M A, Mohammed F, Mohammed F A Ahmed and Abdelhay Ali 2015 Design and implementation of building energy monitoring and management system based on wireless sensor networks *10th Int. Conf. on Computer Engineering & Systems* (Cairo: IEEE) pp 230-233

[4] Chooruang K and Meekul K 2018 Design of an IoT Energy Monitoring System *16th Int. Conf. on ICT and Knowledge Engineering* (Bangkok: IEEE) pp 1-4

[5] Luan H and Leng J 2016 Design of energy monitoring system based on IOT *Chinese Control and Decision Conf.* (CCDC) (Yinchuan: IEEE) pp 6785-88

[6] Jinsoo H, Chang-Sic C, Wan-Ki P, Ilwoo L and Sang-Ha K 2014 Smart home management system including renewable energy based on Zigbee and PLC *IEEE Transactions on Consumer Electronics* 60 198-202

[7] Al-Ali A R, Mohammed R, Imran, Ali Karar M and Gupta R 2017 A Smart Home Energy Management System Using IoT and Big Data Analytics Approach *IEEE Transactions on Consumer Electronics* 63 426-434

[8] Woong Hee K, Sunyoung L and Jongwoon H 2011 Real-time Energy Monitoring and Controlling System based on ZigBee Sensor Networks *2011 Int. Symp. on Intelligent Systems Techniques for Ad hoc and Wireless Sensor Networks (IST-AWSN)*, *Procedia Computer Science* 5 794-97

[9] Govindarajan R, Meikandasivam S and Vijayakumar D 2019 Cloud Computing Based Smart Energy Monitoring System *Int. Journal of Scientific & Technology Research* 8 886-90

[10] Devadhanishini A Y, Malasri R K, Nandinipriya N, Subashini V and Padma G 2019 Smart Power Monitoring System Using IoT *5th Int. Conf. on Advanced Computing & Communication Systems (ICACCS)* (Coimbatore: IEEE) pp 813-16

[11] Jain R, Gupta S, Mahajan Cand Chauhan A 2019 IOT based Smart Energy Meter Monitoring and Controlling System *Int. Journal Of Research In Electronics And Computer Engineering* IJRECE 7 1600-04

[12] Ganesh K S, Nilesh U B, Urvesh Y G and Suraj A J 2020 IOT Based Energy Monitoring System for Energy Conservation *Int. Research Journal of Engineering and Technology (IRJET)* 7 758-63

[13] Collins K, Mallick M, Volpe and Morsi W G 2012 Smart energy monitoring and management system for industrial applications *IEEE Electrical Power and Energy Conf.* (London: IEEE) pp 92-97

[14] Sohaib S, Sarwar I, Muhammad Haseed I, and Mahmood A 2016 A low cost smart energy monitoring and control system for smart building *5th IET Int. Conf. on Renewable Power Generation (RPG)* (London: IET) pp 1-5