Prudence: A Budgeting Solution Using Energy Management System in Smart Homes

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Abstract— In the last decades, energy and energy management has grown as an important research area worldwide. Electricity is one of the most used energy sources in homes. Each household spends a considerable amount of money on electricity consumption every year. Effective energy usage at the residential side is a huge potential for energy saving and power load balancing. Monitoring and controlling applications and innovative metering methodologies through smart wireless devices are becoming increasingly important. It is necessary for someone who follows a budget to know how much electricity is consumed by each appliance and make sure the monthly charges does not exceed the spending limit. Demand Response (DR) is an important measure to manage energy from the residents' side. In such an approach, energy consumption can be significantly reduced by making people aware of their behaviour as energy consumers. The consumer should also know when an appliance consumes more power than it should, due to possible faults. The proposed project is a Home Energy Monitoring and Managing System which uses smart sockets to obtain the energy consumption and appliance information on an Android application where the user can manage and set limits to energy usage.

Keywords—Smart Home, Smart Socket, Home Energy Management, Budgeting, Wi-Fi, Energy Monitoring, Android Application

I. INTRODUCTION

Taking in account of the current scenario, energy management and conservation is a necessity. Approximately 80 percent of the energy used globally are derived from fossil fuels. We have been relying on fossil fuel for centuries as they are energy-rich and cheap to process. However the main concern with fossil fuels is that they are available in a limited amount in nature and are non-renewable resources. Fossil fuels also releases carbon dioxide into the atmosphere when burnt which cause global warming. Due to the growing environmental concerns, several researches are being conducted to harness the renewable energy sources such as wind and solar energy. Both of these sources are available in unlimited supply and provide clean energy.

Buildings contribute to one third of the worldwide energy consumption [1]. As of 2016, the Government of India(GoI) statistics claim that 32% of the country's total energy is consumed by residential and commercial buildings. This includes lighting, electrical appliances, Heating Ventilation and Air Conditioning Systems (HVAC) [2]. A considerable amount of money is spent on electricity bills each year. Environmentally and financially, energy efficiency at home is desirable. It allows homeowners to not only help the environment but also protect them from spending an unnecessary amount on energy bills year after year. For someone who wants financial security, it is important to follow a budget. Budgeting allows a person to focus on the needs other than wants. As energy bills contribute to the overall expenses, it can be considered as a major factor in budgeting. For consumers who set a budget in their day to day lives, it is necessary to know how much electricity is consumed by each appliance within the household and make sure the monthly charges does not exceed the spending limit. In homes, people carelessly keep lights and fans on which leads to unnecessary wastage of energy. Faulty appliances also contribute to energy wastage by consuming more than it's rated value. It is necessary for the consumers to know when an appliance is malfunctioning and contributing to energy wastage. An important role is played by consumers in energy conservation and management at homes. Reduction of energy consumption can be achieved in households by providing the consumption profile of appliance s to consumers [3]. This encourages them to change their behaviour and modify their pattern of electricity usage. Such an approach is called Demand Side Management(DSM) and it typically includes monetary incentives. A practical method to reduce energy consumption at homes and thereby reduce the money spent on bills is by shifting the operation of appliances such as grinders, vacuum cleaner, water heater, etc from peak hours to off-peak hours. Other approaches are based on Time of Usage pricing(TOU) where different tariff rates are set for different time of usage. The tariff rates are lower during off peak hours and higher for peak hours. This encourages users to switch the usage time of appliances to off peak hours when the energy demand and usage is less. The main objective of energy management is to track and optimise energy consumption to conserve usage in a building. Smart homes are one of the most important components of energy management and budgeting [4]. A smart home is a convenient home setup equipped with sensors and smart appliances that can be controlled from anywhere using mobiles, laptops or any other wireless connections. Devices in a smart home are connected to the internet, allowing users to control and manage various functions. Sensors and devices also provide security access to homes, alerts during hazards, smart lighting and ventilation. Smart energy meters are employed in smart homes to track and control energy consumption. They measure the amount of energy consumed by each appliance , voltage levels, current and power factor and communicate these information to the consumers for the greater clarity of consumption behaviour. Smart sockets can be implemented in smart homes, which has an in built smart meter to record the consumption profile of an appliance connected to it. Case studies showed a satisfying performance on the real time electricity price prediction [5]. It can monitor a devices' energy usage in real time and can be controlled by an application, a smart home hub or a virtual assistant. Protocols used for communication with smart sockets include Wi-Fi, Bluetooth and ZigBee.

In this project Intrusive Load Monitoring(ILM) is employed which measures the appliances' energy usage by installing smart sockets to facilitate budget billing, which consists of predicting the utility bill for each month by analysing previous utility bills.

The proposed approach involves a smart budgeting solution which involves communication among smart sockets and an Android application. Smart energy metering is implemented using PZEM-004T V3 which is an electronic module that measures the voltage, current, frequency and power factor of the appliances plugged into the smart sockets. Wi-Fi is used to establish connection between the smart module and the mobile application. Users can monitor energy consumption profile of each appliance and set budgets for each month. The proposed system also alerts the consumer about faulty appliances.

II. RELATED WORKS

Several smart meters and smart meter integrated sockets implemented on smart homes to conserve and reduce energy consumption has been proposed over the years. Most of them focus on the Home Energy Management Scheme(HEMS) implementation. Mon-Chau Shie et al. [6] proposed an intelligent energy monitoring system using smart sockets equipped with ZigBee that provides users with several functions for monitoring and remote control of home appliances enables by a home based remote server. Data so obtained are provided to power company as well as to the users for energy saving and safe usage. Ching-Hu Lu [7] modified traditional smart sockets by incorporating machine-to-machine(M2M) advancement to implement m2mSocket. The sockets are reconfigurable and can dynamically change its configuration by flexibly connecting to remote smart machines. These sockets have several enhancements over traditional smart socket such as IoT enabled context aware services while achieving energy savings without compromising user comfort. The Residence Energy Control System (RECoS) was proposed by Kun-Lin Tsai et al. [8] which is based on wireless smart socket Internet of Things(IoT) technology to minimise the energy consumption within homes and other residential buildings without deploying sensors. RECoS provides several control modes such as peak-time control, energy-limit control, automatic control and user control. It not only monitor and control the standby power consumption of individual appliances but also manages the energy consumed by all the controllable appliances. A network algorithm is used by the system to analyse user patterns and behaviours. MorSocket (“more sockets”), proposed by Yi-Bing Lin et al. [9] allows users to control multiple separated sockets within a control page unlike traditional smart sockets that allows the user to control single-sockets. The sockets can be controlled automatically by arbitrary sensors for humidity, UV, temperature and so on. A reconfigurable sensor system called MorSensor is used to automatically control MorSocket. Eslam Al-Hassan et al. [10] developed a smart power socket and central control system that utilizes the Zigbee communication protocol to control usage of energy. Smart sockets obtain the data and provide it to the central controller wirelessly. The system then processes this data to generate control commands to turn the devices on or off.

Chunjiao Yu et al. [11] applied non-intrusive load monitoring method to the smart socket to solve a series of existing problems. The proposed system uses relative Euclidean distance algorithm and vector distance algorithm to learn about the electricity parameters of various appliances and provide users with information such as voltage, current, active power, power factor and so on and propose a single load identification algorithm and multi load identification algorithm. Jiawei Zhang and Jing Qiu [12] created a smart socket for real-time measurement of instantaneous power, based on IoT. The proposed system effectively measure output power from each test device and a smart user interface records this information for the user to visualise the power consumed by each appliance. Jiawei Zhang et al. [13] designed a low-cost smart socket to implement Home Energy Management Scheme(HEMS). Experimental results showed that the designed smart socket can be fully utilized for monitoring and controlling electrical appliances within the household. S. P. Makhanya et al. [14] proposed a smart switch control system to remotely control devices in residential environments and automatically minimize energy consumption. The device consists of a unit comprising of a programmable Arduino board, ESP8266 Wi-Fi module, wall socket, an SD card, and an Android application where the user can control the switches and appliances. Muliadi et al. [15] developed a smart home energy consumption monitoring. It is a web based real-time system for monitoring energy consumption inside a household. An ESP8266 controller chipset programmed using Arduino IDE, is used to control a relay and a sensor PZEM-004T V3 which measures real time value of current, voltage and power. Users can view the collected data on a web-based application.

III. PROPOSED SYSTEM : PRUDENCE

A. System Hardware

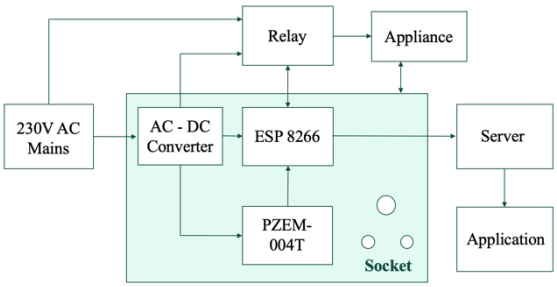

Fig. 1 Block Diagram of the Proposed System

Fig. 1 shows the block diagram of the proposed system “Prudence”. The system mainly consists of a smart socket which is designed with an Arduino built into it along with the sensor module PZEM-004T. A relay along with AC-DC converters are also added to the module. PZEM-004T V3 is an electronic module that functions to measure the voltage, current, power, frequency, energy and power factors. It can be interfaced with several microcontrollers and uses TTL serial communication. PZEM-004T is also equipped with a CT coil which senses current by electromagnetic induction. The sensor module has passive seral communication to connect to Arduino. Its RX and TX pins need external power supply and can work as hardware serial as well as software serial. NodeMCU ESP8266 or WeMos D1 Mini which is a miniature wireless 802.11 microcontroller development board, can be used to interface the sensor module. Both of them are equipped with a microUSB which allows the module to be programmed

directly from the Arduino IDE with no additional hardware. The electricity consumed by each appliance is measured by the sensor PZEM-004T and the data is the read by the ESP8266, which also facilitates the communication between mobile application and the smart socket The relay is equipped to control the AC socket and the appliance connected to it. When relay is switched ON, the appliance is also turned ON. The switching ON and OFF of the relay is controlled by the Android Application.

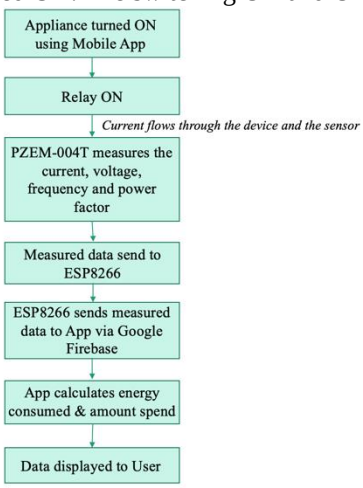

Fig 2. Algorithm of the Proposed System

When the user turns on the appliance using the application, instructions are send to the ESP8266 from the application which in turn switches on the relay. The appliance is turned on and current starts flowing through the sensor PZEM-004T. The voltage is stepped down using HLK-PM01 which is an AC to DC converter. The sensor measures the current drawn by the appliance, its voltage, power factor, frequency, power and energy consumed. These measured values are then send to the ESP8266 which uploads these measured values to Google Firebase. The values are then fetched by the android application which carries out necessary computations and display the data to the consumer.

B. System Software

The interfacing of PZEM-004T with the NodeMCU is done using the Arduino Integrated Development Environment or Arduino IDE. The convenient and user-friendly mobile application was set up using Android Studio. ESP8266 uploads the values received from the sensor to a platform such as Google Firebase. The values are then fetched by the application which carries out necessary evaluations and computations to obtain the overall units consumed by each appliance and the corresponding amount spend. The Graphical User Interface of the developed Android application is shown below. It is simple and convenient to use, and consist of a login page, control of sockets page where the user can view the current status of each smart socket and the appliance connected to it, and add switches.

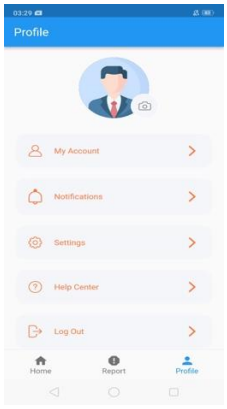

Fig. 3 Developed Android Application Login and User Profile Set-up Page

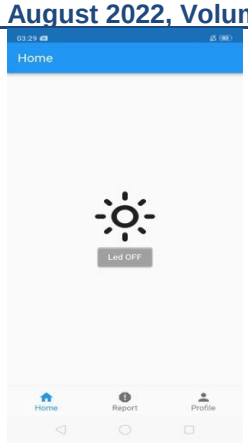

Fig. 4 Developed Android Application Control Page

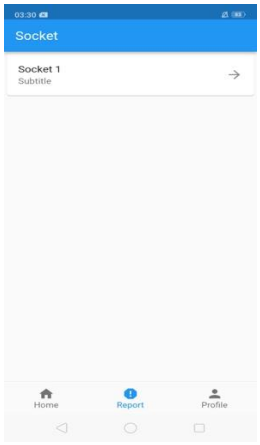

Fig. 5 Status of Sockets Page

Users can set limits and allocate a limited amount for electricity bills for each month and the application shows how much of that amount has been spend and how much is left. In other words, the user can track his/her monthly spending using the application.

IV. RESULTS AND DISCUSSIONS

The system was set us as follows: the NodeMCU ESP8266 was interfaced to the sensor module PZEM-004T using the Arduino IDE. The programs for interfacing were written using the library of PZEM-004T available on Arduino IDE.

```
pzem.voltage();
pzem.current();
pzem.power();
pzem.energy();
pzem.frequency();
pzem.pf();
```

The Arduino code was run on the Arduino IDE and the application is run on a compatible smartphone. The switch is turned on using the application. The proposed system starts calculating the required parameters immediately which can be viewed either on the application or on an IP-Address that was inserted in the interfacing code as shown in Fig. 6 and Fig. 8. The values are uploaded to a real-time database like Google Firebase from where the application fetches the information.

Parameters	Value	Units
Voltage	232.20	Volts
Current	0.13	Amperes
Power Factor	0.57	XXXX
Power	17.30	Watts
Frequency	50.0	Hz

Fig. 6 Values Measured by PZEM-004T

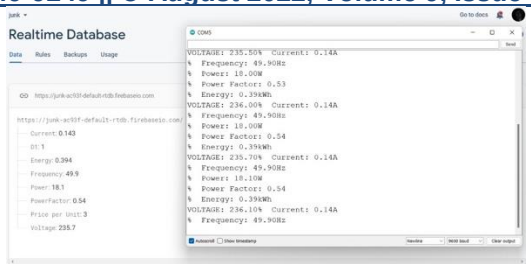

Fig. 7 Measured Values Uploaded to the Realtime Database

The values give the user information about the amount of units consumed and the corresponding amount spend, taking into account the current tariff rates for peak and off-peak hours. Power rating of each appliance connected to the socket is also set on the app so that the user gets notified whenever an appliance is faulty. This will also enable the users to keep track of their device health and make repairs if necessary. Detecting faulty equipment also allows the user to eliminate possible hazards such as fires. The proposed system has many use case scenarios mainly being the fact that it can effectively reduce the power consumption in a household by properly analysing the data collected.

Fig. 8 Measured Values Displayed on Application

V. CONCLUSION

The main objective of this work was to research, design, develop and implement a smart socket that facilitates budgeting and energy conservation within residential buildings. The system mainly consists of a socket and a software application. Socket is designed with an Arduino ESP8266 built into it along with a sensor module, PZEM-004T. The measurements obtained by the sensor PZEM-004T is read by the NodeMCU. The Android application is used to remotely control switches and appliances.

The proposed system helps the end user to interact with the home devices and get their respective power consumption profiles in real time. The data collected from the appliances are displayed in the Android application. It also helps the user to detect the faulty equipment, if it draws extra current. Thus improves, the energy efficiency and manage the electricity bill which in turn helps in smart budgeting. Thus, the proposed system prevents unwanted wastage of energy and resources.

In future, the hardware can be made into a small module by integrating the NodeMCU, sensor, relay and power supply into a single circuit board. The Android application can be updated to include all the user expenses including day to day expenditure for proper management of budget.

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