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Development of IoT-Based System for Monitoring Electrical Energy Consumption of the Smart and Rental Houses in Tanzania

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ABSTRACT

Electricity has a significant impact on human productivity when using a variety of electrical appliances in households. Appliances hooked into the electric network are now causing an increase in electric energy usage in rental homes hence the increases in the user's electricity expenses. Some tenants consume high electrical energy compared to others due to the electrical meters cannot determine the amount of usage by each tenant in the house, all tenants contribute the same universal payment which is not realistic. To offset these costs, a monitoring system for electric energy consumption based on each appliance in a household is formulated, allowing customers to see how much money and energy they are wasting. Different studies have thus far proposed monitoring electric energy consumption in households. However, most of the solutions did not consider the electric energy consumption of individual appliances which is a main problem for the end-users. The primary focus of this paper is to present an Internet of Things-based system to provide information to the users through an application on their daily consumption usage updates whether they are online with the presence of a Wi-Fi module. Researchers design the system which has a backup battery to allow giving information in case the power supply is off. Moreover, our system is designed to monitor the real-time energy consumption of individual appliances. Results show that 90% of end-users that observed the implemented system are capable of monitoring daily electrical consumption hence tenants can put a good budget on their purchase of electrical units.

Key Words: *Energy consumption, Electricity, Appliance, Internet of Things.*

1. INTRODUCTION

Electricity is the essential source of energy in our daily life with a tremendous contribution to the performance of human beings during the application of electrical appliances. According to statistics, the number of people who use energy grows every year for example In 2016, Indonesia's electrification rate was 91.16 percent, and the country's power plants consumed 132.41 million barrels of oil [1]. Each used appliance has its purpose as well as electrical consumption rate. The usage of energy has aided in the growth of human civilization by allowing for environmental adaptation. Africa's main source of energy is water, and the world significantly relies on oil as a primary supply of energy. The consequences of the high energy consumption rate in the world lead to weather change, environmental pollution, and personal health. Electricity as another kind of energy is generated by different sources like water, coal, wind, and solar for utilization at home, industries, schools, colleges, etc. However, the improvement in the efficiency and rationalization of consumption remains one of the most important factors affecting the energy future in African countries and the world.

A house comprising a large number of appliances such as a refrigerator, Television set, Heater, electric iron, Subwoofer, etc. has a huge energy consumption rate than one with a small number of appliances since the electric usage of each appliance differs from one another. An Inhabitant may be in a predicament when it happens the electrical units bought easily depleted due to the absence of a direct technique to monitor, control, and reduce the operating conditions of this equipment depending on the weather conditions.

In Tanzania, until now a single rented house may be inhabited by more than one family. Each family is independent of their livelihood according to their income hence a variety of electrical appliances with different power consumption may be possessed. Tenants lack an understanding of the electrical power rating and consumption of the appliances used within the house. Consequently, there have been many cases in which tenants who are living in the same rental house complain to each other about excessive electrical power consumption in their houses. Additionally,` These complaints occur in a short time after the purchase and insertion of the electrical units in the energy meter which are addressed to their neighbors who are sharing the same electrical energy meter in a residential apartment. Whenever the number of power units is bought, consumers get difficult to understand the consumption mechanism of their devices. Often in these rental houses, some conflicts result from the payment of electricity bills where some tenants feel that they continue to pay electricity bills that are outside their level of consumption.

2. RELATED WORKS

Some systems have been developing to encounter this concept. The developed systems allow the user to monitor the power consumption using Smartphones and tablets that run the Android operating system or any web browser. The Raspberry Pi serves as a microcontroller, and data is sent to the smart device using the WebSocket protocol, which is highly recommended for real-time connection[2]. But the system has no backup battery and can’t work in offline mode.

The monitoring system shown in this article allows the client to remotely monitor the consumption of several appliances in his home. Logging in, selecting data intervals, and generating reports and visualizations are all considered HMI functions. The monitoring system is based on a combination of technologies that are already in use and deployed in homes and buildings[3]. But the system has no backup battery and can’t work in offline mode and doesn’t provide stabilization of appliances.

The web-based system is designed and implemented and aims to manage the energy by monitoring different house appliances that are linked to the monitoring system. The systems have been ave designed such that, they can perform the monitoring automatically by turning ON/OFF the devices like lights and alike by considering the condition such as darkness or the presence or absence of people in the house. ability to check the daily or monthly consumption as a graph displayed on a smartphone and can remotely turn ON/OFF any device by using a mobile app[4]. The paper has the following limitation as indicated by the author, the system works only on Windows-based computers and can’t operate in IOS, and also Can’t measure the consumption of the individual device.

In another system, each household equipment/device is interfaced with a data acquisition module that is an IoT object with a specific IP address to form a wireless network of devices. The System modules collect power consumption data from each particular device of each smart house and send the data to a centralized server for more processing and analysis. The data from residential units are collected using wireless sensors associated with that the house and analyzed using Big Data technology. The system provides the information to both house owners and energy service providers. The service provider can monitor the consumption from each customer as an accumulated power of individual devices for a particular house. On the other hand, the house owner can monitor and control the power consumption associated with each device through h mobile application[5]. The limitation of this system it requires a high-speed Storage Server which is currently a problem in our country.

The system is designed to intimate the user about his /her consumption rate. It shows the number of units of power consumed and how many units remain to remain in a minimum slab rate for some time. Hence the system makes the consumer aware of daily usage of the power since he/she currently continued being updated through the mobile app. When the maximum threshold value is reached the system will cut off the power with prior notification[6]. The limitation of this system is that the system does not provide the individual device power consumption and is cut off automatically when the maximum set level is reached.

The developed automation system is used to control different appliances and monitor the rate of daily usage of each device. It employs raspberry pi interfaced with other kinds of sensors to meet the contribution to energy savings, and

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ensure minimum incurred expenses[7]. The EE-HMA has used colorful LEDs to alert residents of various factors, to turn devices on and off based on the price of power use, and allow them to monitor portions of their household appliance usage through a phone app.

Through modern technologies such as optical fiber hybrid wire home, a smart home is an organic mixture of various subsystems connected to life at home [8]. Home automation service, as a major element of smart grid electricity consumption, is a critical tool for achieving real-time interactive responses in the center of the grid and users, enhancing wide-ranging grid service capability, meeting the need for consumer engagement, and enhancing levels of service, and reinforcing relevant data between users and the grid, achieving smart collaboration, integrate sharing, and real-time interaction, and strengthening information between users and the grid.

3. MATERIALS AND METHODS

3.1. System design

An architecture diagram, as well as a module description, were used to define the proposed system. The electronic circuits of the sensors are soldered in PCB boards after designing and coding, followed by microcontroller programming, characterization, and blynk app customization, as well as tests with various appliances. To begin, determine a sampling time for each appliance before continuing with the experiments as shown in Figure 1 conceptual operation of the system. It is also required to know the voltage to calculate the watts. As a result, it was necessary to determine an average voltage for the testing by measuring the tension of all the electrical points throughout the system sockets. The following are hardware components used to build up the prototype of the project

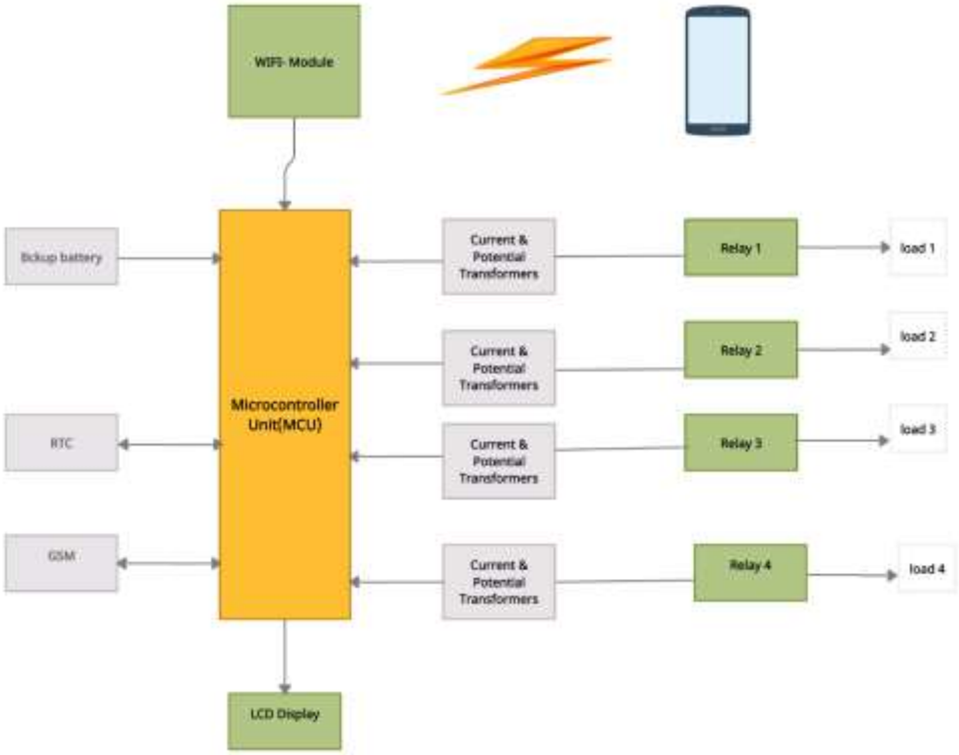

Figure 1:Block diagram of Proposed System

3.1.1. ESP32

The ESP32 is a sophisticated system-on-chip microcontroller with Wi-Fi 802.11, dual-mode Bluetooth 4.2, and a variety of peripherals. The ESP32 boards are widely utilized in smart home applications. [9]The Arduino core for the ESP32 Wi-Fi chip can be utilized in the Arduino IDE environment. It's safe, reliable, and adaptable to a wide range of uses. The device shown in Figure 2 provides an internet connection link to the rental house with each tenant's smartphone.

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Figure 2: ESP32

3.1.2. Current transformer

For measuring the alternating current of each power line, a current transformer (CT) can be used. If indeed the current flowing is too large to apply to measurement equipment, the transformer's energy may provide a decreasing current that is proportional to the current in the loop and may be coupled to the measured and recorded instruments[10]. The transformer current protects the instruments being measured from any excessively high voltages in the monitoring circuit. Figure 3 shows Current transformers are commonly used in the electrical power sectors for metering and guarding relays.

Figure 3: Current Transformer

3.1.3. GSM Sim800

GSM stands for Global System for Mobile Communications, and it is currently the most extensively utilized cellular technology on the planet. This shield connects directly to the ESP32, allowing it to send and receive SMS, as well as Perform voice communication even when connected to the internet. A global quad-band network is the GSM module shown in Figure 4.

Figure 4: GSM Sim800

3.1.4. Relay

Figure 5 is an electronic circuit, a relay is a switch with an electromagnetic field and an iron shaft. Because the magnetic field around the coil tends to shift the switch position, everything starts when there is a current flowing around the coil[11]. A 5V relay that can work with the Arduino is required. The relay's main benefit is that it controls the current and provides the required electrical voltage.

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Figure 5: Relay

3.1.5. Arduino IDE

The ARDUINO IDE is a cross-platform development environment built on the Java programming language. This facilitates the upload of code to the ARDUINO UNO board.

3.2. System Architecture

The ESP 32 microprocessor served as the system's brain, processing energy consumption. It is simple to collect energy utilization in real-time through the internet thanks to the Wi-Fi module that is built into the ESP32 microcontroller. The system calculates the current power consumption and sends it to the app. SCT-013-030 obtains all essential current values in real-time and sends them wirelessly using the ESP32 microcontroller Wi-Fi module as shown in Figure 6. The system is capable of sending the message offline via GSM. In case of power shortage, the system has a Backup battery. If overvoltage happens the system is equipped with an Automatic volage stabilizer to tackle the problem. Figure 7 shows the PCB layout and its Surface mount pinout configuration before the fabrication process and Figure 8 shows the simulation of the electronic components before soldering.

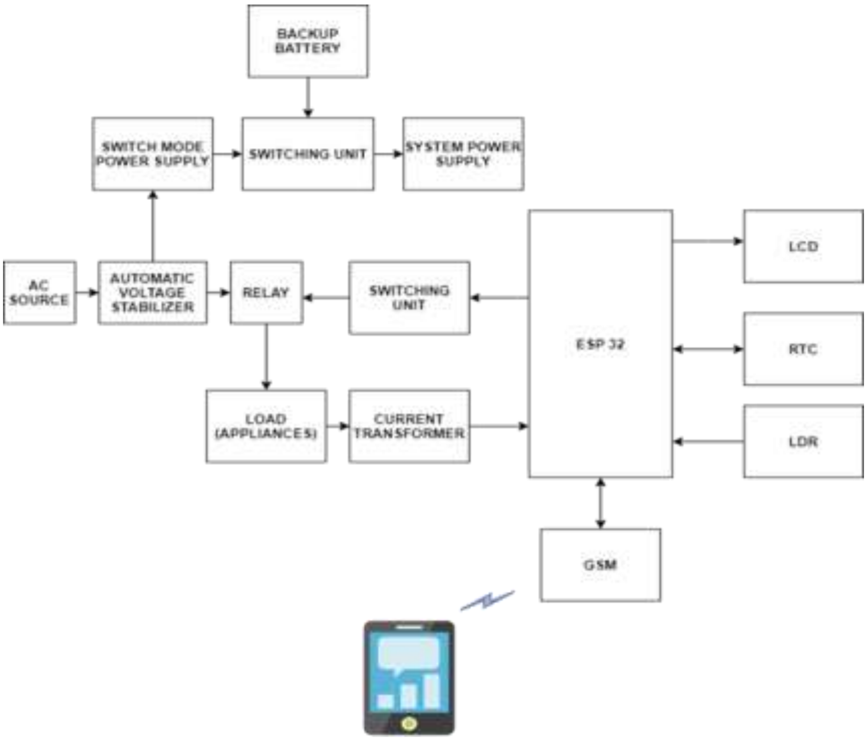

Figure 6: Architecture diagram

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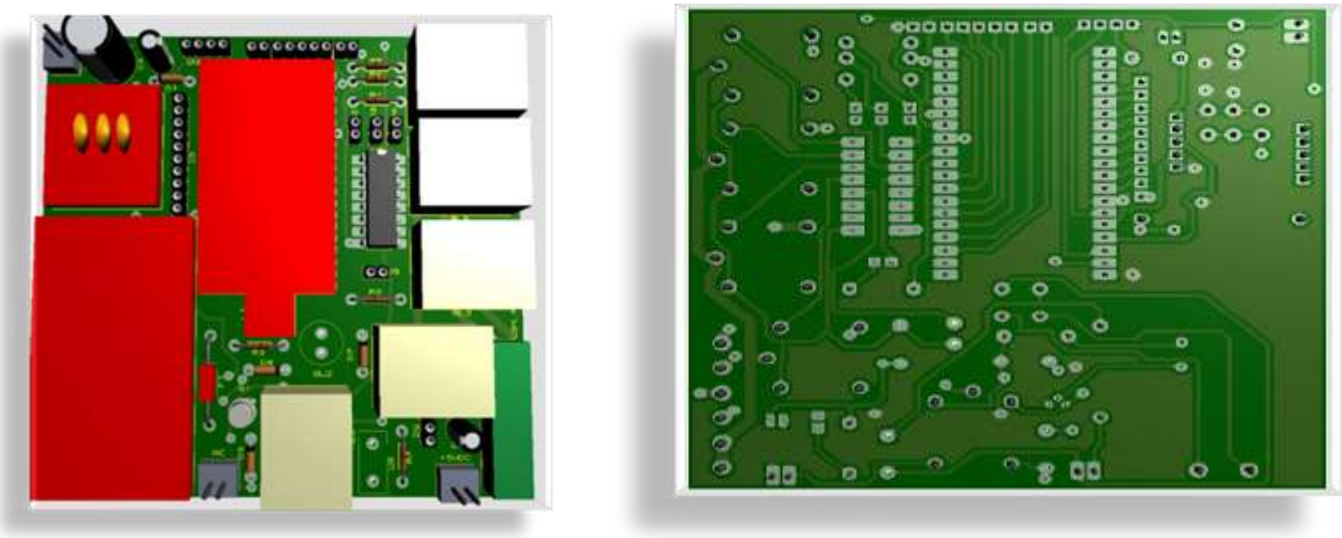

Figure 7: The 3D view of PCB layout and its Surface mount pinout configuration

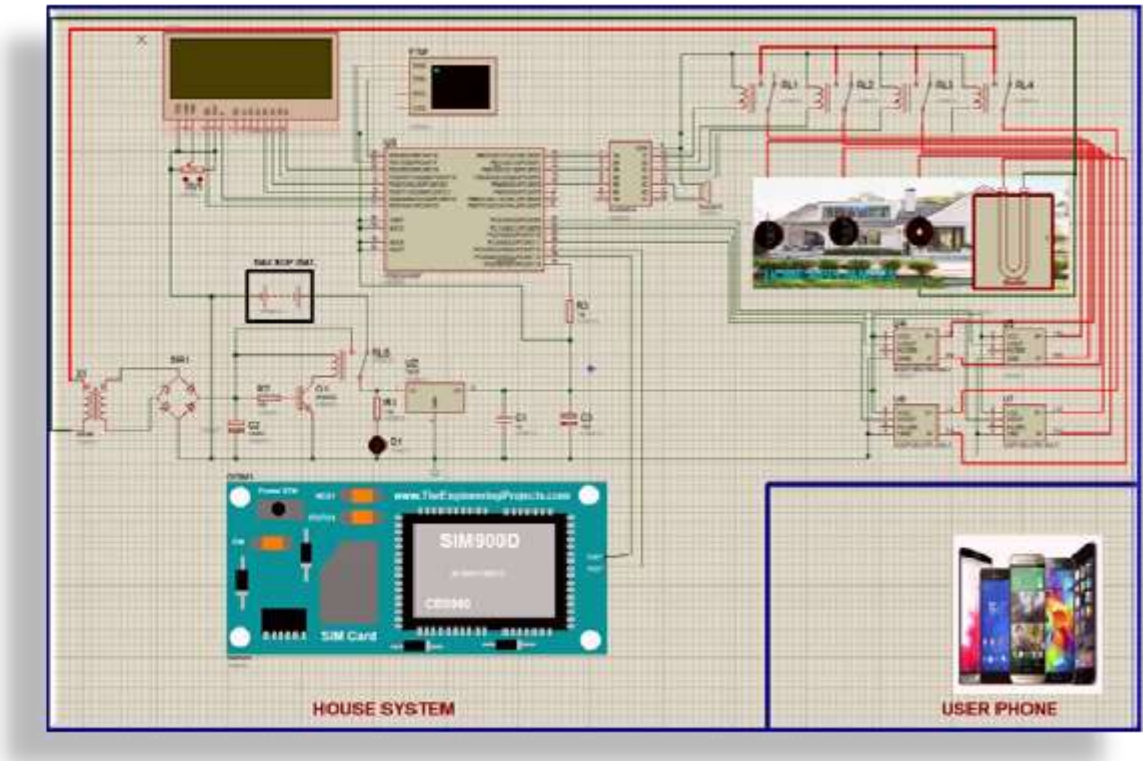

Figure 8:The Design and performance of the simulation circuit diagram of the System

4. RESULTS AND DISCUSSION

4.1. Results

4.1.1. Sensoring and monitoring unit

The ESP 32 microprocessor served as the system's brain, processing energy consumption. To transmit real-time energy use, the ESP32 microcontroller also handles internet access via its inbuilt WIFI module. The system calculates the current power consumption and sends it to the app. The current values are sensed in real-time by the SCT-013-030 and wirelessly communicated to the server using the ESP 32 microcontroller's in-built Wi-Fi module. The system is capable of sending the message offline via GSM. In case of power shortage, the system has a Backup battery. Hardware parts of the prototype are shown in Figure 9 and Figure 10.

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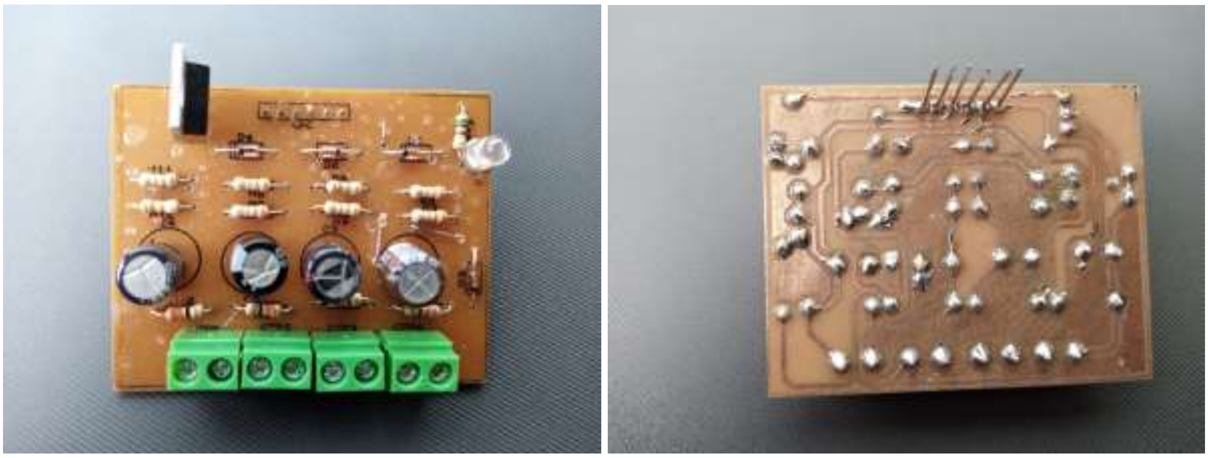

Figure 9: Front and back views of the sensor interfaces

Figure 10: Front and Side views of the designed prototype

4.1.2. Mobile App visulization

The app connects the tenant's appliances, allowing the remote capability to see and protect what matters most. Each tenant may use the app to monitor the appliance, view electrical usage, and see a clear view of the appliance because it supports several systems. Since the I/O pins of the microcontroller are well connected to the server, each appliance in the house may be controlled and monitored using the mobile application. Figure 11 shows four appliances that can be connected, controlled, and monitored remotely. The same technology may be used to switch on/off each power line of each tenant in the same rental house. Since A single main switch distributes electrical power to various rooms in the rental house.

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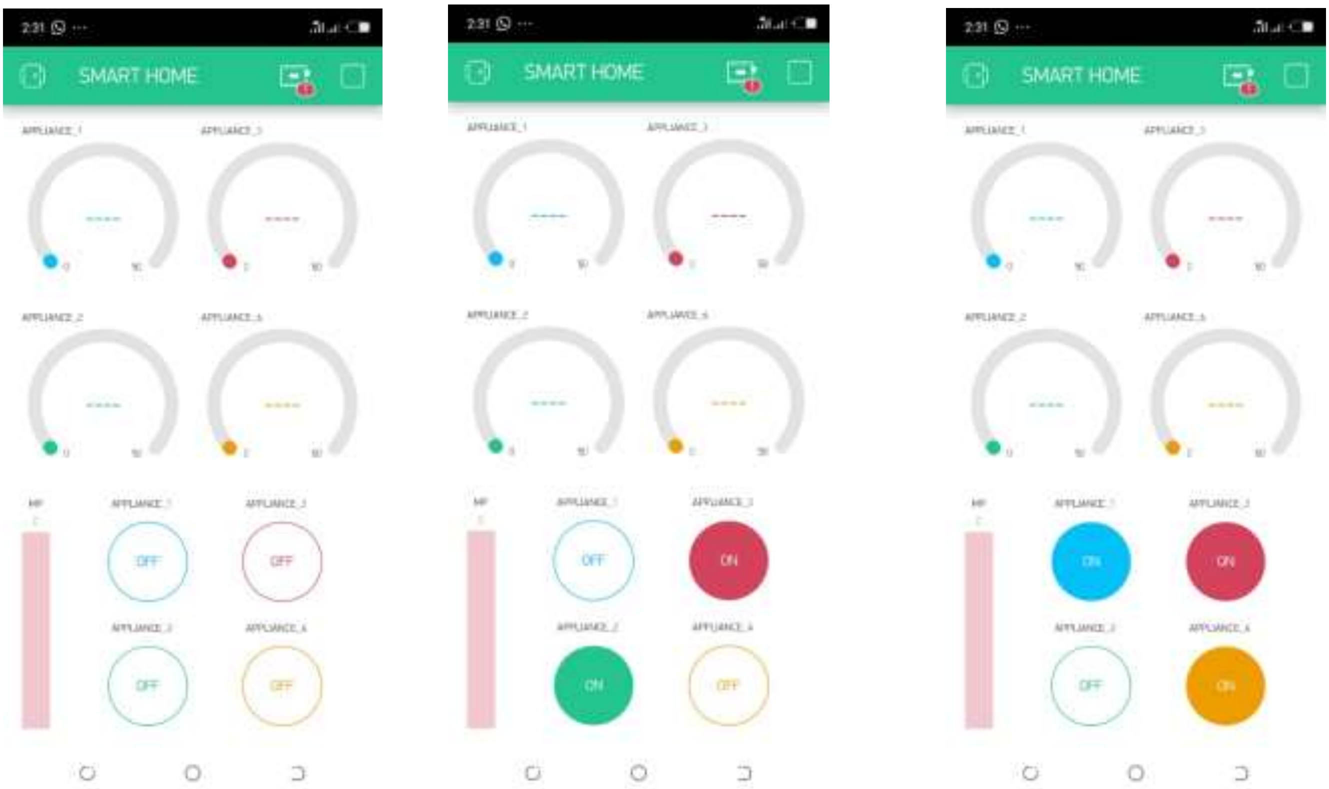

Figure 11: Screenshot of the control of appliances (ON or OFF) and consumption information (red bars)

4.1.3. Load control via GSM in offline mode

The ESP32 microcontroller is coupled to the GSM module SIM 800. Then, using the C programming language, the ESP32 is programmed to control the loading. The user can turn on or off the appliances by sending SMS to the GSM module, which the microcontroller will receive and execute. This is everything done in offline mode.

4.1.4. Load control via a mobile application

Using the Blink mobile app, which is a free and open-source web application. The user can control the appliances by turning them on and off. All of this is accomplished through the use of the internet.

4.1.5. Power consumption visualization

If the network is available, the system is structured in such a way that the user may see the power consumption of the appliances in real-time. The application allows for the easy charting of appliance data and monitoring of power use. All of this is accomplished through the Blink mobile app, which is synchronized with Wi-Fi and extracts data from current and voltage sensors.

4.1.6. Back up battery

The system is capable of operating in the absence of a power supply. Once the incident occurs, the user will receive an alarm, and it will be simple to turn off the switches to avoid overvoltage and appliance burnout.

4.1.7. Automatic lighting at the night

The majority of people forget to turn on or off their lights at night. As a result, it has been implanted with LDR in the system to regulate the light switching mechanism. The presence of lights is required for the LDR to function.

4.1.8. Voltage stabilization

Because we're working with appliances, it's critical to activate stabilization in the event of an overvoltage. The system includes an Automatic Voltage Stabilizer (AVS) to ensure that the output voltage is stabilized for the safety of the device appliances. As a result, the voltage received will be safe for the devices to receive.

4.2. Testing and validation

Evaluation of the system was done from different rental houses involving 100 tenants who are living in the Arusha region of Tanzania. A simple questionnaire was prepared and provided to them after showing them the basic

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functionality and operation of the system. The result shown in Figure 12 shows that 90% of the tenants were satisfied with the overall performance of the project. Nonfunctional requirements including performance, security, speed, availability, and usability were taken into consideration. Figure 12 shows the evaluation result after analysis.

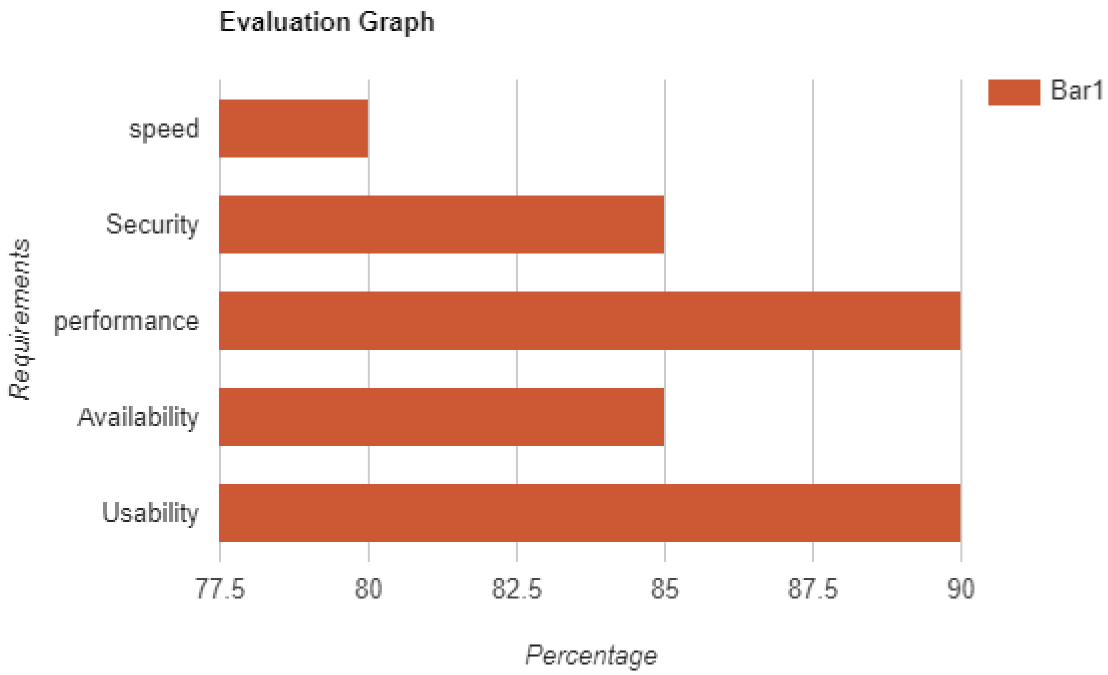

Figure 12:Evaluation of results

5. CONCLUSION AND RECOMMENDATION

This proposed project seeks to add value to rental house users equipped with smart technology by providing them with a system that will give them full detailed information about each appliance or power line about the power consumption of each room in their houses. These will help the users to be able to understand the full house power consumption and also remove unnecessary or unused devices in the consumption line. The design of the smart meter will help to reduce the estimated type of bills from the consumers but also give awareness of the total energy consumption. Some of the features that the system incorporates include:

(i) Voltage stabilization and load protection

(ii) Remote appliance control

(iii) Back up battery

(iv) Online load consumption data plotting and storage

(v) Real-time monitoring

This project could be done differently by the addition of the predictive model that can allow the transition of appliances usage based on the time and need. This can be well done by using machine learning.

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