AN IOT BASED SMART ENERGY MANAGEMENT SYSTEM FOR RESIDENTIAL BUILDING CONSIDERING SOLAR PV GENERATION

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A Thesis Presented to the University of Energy and Natural Resources in Partial Fulfillment of the Requirements for the Degree of Bachelor of Science

In

Electrical and Electronics Engineering

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September 2023

AUTHOR'S DECLARATION

We understand that copyright in our thesis is transferred to University of Energy and Natural Resources.

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ABSTRACT

This thesis presents the design and implementation of an IoT-based Smart Home Energy Management System (SHEMS) with a primary focus on integrating solar photovoltaic (PV) generation. Leveraging the ESP8266 microcontroller and the Blynk app, the SHEMS aims to automate and remotely control electrical appliances, facilitate seamless power source switching between the grid and solar PV, and incorporate a smart meter for precise energy consumption monitoring.

The project addresses the increasing demand for energy-efficient and environmentally conscious solutions in residential settings. It harnesses the capabilities of IoT technology to optimize energy usage, thus contributing to energy conservation and cost savings for homeowners. Real-time energy data is collected, stored, and visualized through a user-friendly web application, enabling users to make informed decisions about their energy consumption patterns. Economic analysis tools are integrated into the system to calculate and display energy costs, further enhancing its utility.

The deliverables of this project encompass a fully functional IoT-based SHEMS, comprehensive documentation, and thorough testing and validation. This research endeavors to advance the field of home energy management by providing an integrated and adaptable solution that empowers users to actively participate in energy conservation and economic efficiency, ultimately fostering sustainable energy practices in residential environments.

DEDICATION

This research project is dedicated to our family and loved ones, whose infallible love and support have been our guiding light throughout our academic journey. Your sacrifices and belief in us have made this achievement possible.

ACKNOWLEDGEMENT

We humbly acknowledge the almighty God for how far he has brought us with this project. We extend our heartfelt gratitude to our supervisor, Mr. Amoako Kyeremeh for his invaluable guidance and support during this research work. We are also grateful to our family, friends, and the participants who contributed their time and expertise to this project, especially Mr. Quarshie Trinity. Lastly, we acknowledge the university, faculty, and authors whose work laid the foundation for our research. Your support has been a pivot to our success.

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CHAPTER I

INTRODUCTION

1.1. Overview

Energy is the pivot for which the entire universe revolves or exist and everything in the universe (matter) possess energy. According to the first law of thermodynamics; energy can neither be created nor destroyed; it can only be converted from one form to another; thus, the energy of the universe is constant as Albert Einstein in 1907 stated. Since the discovery of electrical energy which can be transmitted from one point to another through conductors and its clean nature, it has revolutionized the demand of the world's energy, more and more research has been made to convert different forms of energy like solar, wind, chemical, thermal, hydro, and nuclear energy to electrical energy, more alternatives sources are being sought after in many researches.

In recent decades, there has been great research into finding alternatives sources of energy around the globe and efficient use of the limited fossil fuels to reduce its exploitation and negative impacts on our planet, which is carbon emission and global warming. Many renewable energy systems have been adopted to achieve this goal, one of the 14 sustainable goals of the UN, example is wind energy, hydroelectric and solar energy has been widely used. With the increasing population of humans and demand for electrical energy [1], there lies the challenge to meet the increasing demand without compromising the sanctity of our dear planet. Whiles scientist tap into new sources of energy, there has been significant research in optimizing the use of the existing electrical power system for both domestic and industrial usage using diverse techniques whiles reducing electricity tariffs of consumers [2-4]. The exponential increase of energy consumption globally has resulted to problems caused by green-house gases (GHG) and leads global warming. The worlds energy consumption rose by 2.3% in 2018, almost twice the average growth rate since 2010[1]. The high consumption of fossil fuel energy and its carbon gas emissions can be attributed to the building sector. This increasing energy consumption and gas emissions from the building sector is as a result of elevated cooling and heating demands in the building sector globally. Emissions resulted from fossil fuel energy amount to about 80% of the European union's total GHG emissions, also 40% of the European union's overall energy consumption is accounted to the building sector [2]. It is expected that the world's total energy consumption would rise from about 20% in 2018 to 22% by 2050 according to the U.S. Energy Information Administration (EIA) [3]. The building sector being the major contributor to the globe's total energy dissipation, the most efficient energy savings can be achieved in that sector [4]. Across the world, 45%-50% of total energy consumption in countries is attributed to buildings [6]. As demand of energy is on the rise, energy management and efficiency has become very critical in residential buildings [6]. This calls for real estate developers to implement emerging technologies to mitigate energy consumption and environmental pollution [7-10].

There are various techniques proposed for energy management in residential building. From the many research reviews or articles read concerning energy management systems, many techniques has been adopted, using Demand side management(DSM)[2], Fuzzy logic(FL) controller[2], Deep neuro-fuzzy optimization by combining FL and neural network[6], Integrated automation of Demand response(DR), photovoltaic(PV) and ice storage[7], as well as other artificial intelligent algorithm like genetic algorithm[8], bat algorithm and a hybrid bacterial foraging algorithm[9] has been utilized. Other several schemes have been adopted, all to provide energy and cost savings for the demand of electricity.

The project seeks to design and build IoT based smart energy management system for residential building considering solar PV generation to improve energy saving efficiency and carry out economic analysis of energy consumption to the user over the internet.

1.2. Problem Statement

The idea of IOT based smart energy management systems for residential building considering solar PV generation originated from the failure of the existing research to target the loads which consumes the power with flexibility in switching. Thus, by creating the IOT based smart energy management system considering solar PV generation, we can target the electrical appliances to operate autonomously only when there is/are users to prevent wastage of power when the appliances are not in use.

1.3. Aims And Objectives of Study

1.3.1 Aim

The aim of this project is to design and build IoT based smart energy management systems for residential building considering solar PV generation.

1.3.2 Objectives

The objectives of this projects are summarized as follows;

I. To automatically and remotely regulate the operation of multiple electrical appliances to save energy using microcontroller.

II. To switch between power sources from the grid and solar PV.

III. To incorporate a smart meter and build a web application to monitor energy consumption and to carry out economic analysis of electrical energy consumption.

1.4. Scope of Work

This thesis project focuses on the development of an IoT-based Smart Home Energy Management System (SHEMS) with the incorporation of solar photovoltaic (PV) generation. The central objectives of this project include the automation and remote control of electrical appliances using the ESP8266 microcontroller, seamless power source switching between the grid and solar PV, and the integration of a smart meter. The project aims to provide a holistic solution for optimizing energy consumption and conducting economic analyses of electrical energy usage.

The project will employ the ESP8266 microcontroller and the Blynk app as key components for appliance control and monitoring. It will ensure the efficient utilization of solar energy by seamlessly switching between power sources based on real-time conditions. Additionally, the project will integrate a smart meter into the system to accurately measure energy consumption and provide valuable data for economic analysis. The web-based application will facilitate real-time monitoring of energy consumption and empower users to make informed decisions regarding energy usage.

Upon completion, the project will deliver a fully functional IoT-based SHEMS with comprehensive documentation, including system design, circuit diagrams, codebase, user manuals, and installation guidelines. The project timeline will be carefully managed to ensure successful execution, with a budget plan covering hardware, software, and other necessary expenses. Ultimately, this project endeavors to create an efficient and cost-effective energy management system suitable for residential use, offering remote control, power source flexibility, and economic analysis capabilities.

For all the works reviewed, a real-world model was not built that targets the loads (HVAC) which consumes the power to switch off automatically when there are no users for some time to save power. Also, we will switch power sources between solar PV and the grid. This work will incorporate a smart meter and build a web application to monitor energy consumption and to carry out economic analysis of electrical energy consumption over IoT to the user.

1.5. Thesis Outline

This thesis is made up of five chapters and each of the chapter clearly describes the process taken to provide full details for our project work.

Chapter I presents the introduction of the project which include the background of study, aim and objectives, problem statement, scope of work and thesis outline.

Chapter II gives a literature review of the existing work on this project.

Chapter III involves the proposed principle to design the energy management system and the algorithm to work for achieving the required outcome along with the technique to measure and monitor. It also gives detail idea about designs and working of each component associated with the energy management system and the final hardware implementation.

Chapter IV shows the result obtained by the measuring and monitoring the loads under different conditions and load patterns. It also involves economic analysis.

Chapter V provides conclusion and recommendation for future enhancement of the project work.

CHAPTER II

LITERATURE REVIEW

2.1 Introduction

This chapter entails existing work which is categorized into simulation applications, algorithms, switching circuits, microcontrollers used and network architecture of the energy management systems as well as the mode of communication to the user or operator. The role of the simulation application is to produce an intangible working system which will give the designer ideas or overview of how the actual work would behave. Algorithm is the step-by-step process in executing a specific task. The switching circuits have been incorporated with human detection sensors to switch of appliance at the absence of users for a given time. Switching circuits for switching between the Solar PV and the power grid would be considered. Microcontrollers execute important role in smart energy management system. In smart energy management systems (SEMS), the microcontroller controls the SEMS and relay instructions to the switching devices. It also provides instructions to the user interface to display information to the user. Internet of Things (IoT) offers the network architecture which interconnects multiple devices, users, processes, and data, which ensure all devices and hosts communicate with each other continuously. That is, IoT provides an efficient way to collect more data for diverse processing which is measurable.

2.1.1 Microcontrollers

[2] In this article, an overview of Energy Management System (EMS) strategies to increase energy efficiency was presented. Then a case study was carried out in a residential model in Matlab/Simulink environment. The electrical devices were controlled with a Fuzzy Logic Controller (FLC), considering comfort, cost, and Demand Response (DR). In addition, Renewable

Energy Resources (RES) to demonstrate their contribution were modelled and integrated into the system. Finally, case studies were conducted, and a comparative analysis of obtained results was carried out. Energy consumption and energy cost results are investigated of four SB conditions for summer and winter days. The four SB conditions are uncontrolled SB, FLC controlled SB, uncontrolled SB with RES, FLC controlled SB with RES. The building with FLC and RES has been saved 3.88% energy and 10.46% cost in winter, 4.05% energy, and 5.03% cost in summer, compared to an uncontrolled building with RES. The best result in the case study is obtained by feeding system from RES if there is generation, limiting power consumption of some loads during peak hours if there is no renewable energy generation and shifting these loads to the RES generation time or off-peak period. So, SB with FLC and RES makes the best use of RES and consumes the least energy from grid compared to other situations.

Authors [6] presents reviews of existing articles in the literature, mostly since 2000, to explore technological advancement in building energy and environmental systems that can be applied to smart homes and buildings. This review study focuses on an overview of the design and implementation of energy-related smart building technologies, including energy management systems, renewable energy applications, and current advanced smart technologies for optimal function and energy-efficient performance. Smart home/building technologies are becoming mature, and research is now focused on integrating systems to enhance daily activities and sustainability in a cost-effective manner. Understanding the energy flow between buildings and connected systems (such as distributed renewable energy, energy storage, and EVs) is crucial for energy-efficient and sustainable smart homes/buildings. Advanced energy control and management systems are required for energy-efficient and cost-effective operation of energy subsystems and their integration into a communication network for real-time information exchange within the community and regional levels.

2.1.2 Energy Monitoring Devices

A new smart residential building energy management system using an IoT-based multifunction compatible relaying system was proposed. The system monitors loads, provides uninterruptible power supply with minimal energy conversion losses, and achieves load prioritization and demand-side management. The proposed system was implemented in a DC residential building in India, showing a reduction of losses by 18%, with an additional 5% through demand-side management. However, the lack of universal standards, safety concerns, and security issues may limit large-scale implementation. The research did not address excess solar energy generation. [11]

A practical solution using dynamic programming (DP) and IoT for load-sharing in households, reducing grid energy consumption by 17.59%. The system determines which loads receive power from rooftop solar PV by using 0-1 knapsack and includes a mobile app for remote control. A prototype system was designed and verified experimentally, but the study's limitation is the time and space complexity, which could increase significantly with a high number of loads. [12]

Authors [13] presented a load monitoring system for residential households that included a model for classifying household appliances. The model uses Long Short-Term Memory (LSTM) and was trained on data from the Plug-Load Appliance Identification Database (PLAID) dataset to classify 16 different appliances. The system could manage energy usage and detect faulty behaviors. The results demonstrate the system's end-to-end capabilities and its usefulness for demand side flexibility and demand response programs for both consumers and utility providers.

2.1.3 Mode of Communication

[14] Power consumption monitoring system was designed to help customers manage energy usage and keep electricity costs within reasonable limits. It utilized an ARDUINO circuit and GSM module to enable intelligent energy consumption. The proposed system aimed to create a circuit that allows users to take control of power usage, improve energy-saving techniques, and ultimately reduce costs. The system provided users with daily energy consumption reports via messages and web pages, and big data analytics provided valuable insights using machine learning and predictive analytics. All data collected from customers was stored on a Big Data server, and a Smart Energy Management System (SEMS) minimized costs while still meeting energy demands.

[17] proposed to minimize energy consumption, reduce operating costs, and increase comfort for residents of these buildings. It interconnects standardized KNX system (konnex or connectivity) of smart home and the cloud-based IoT platform which serves as an integrational layer. Natural language interface; using cloud services it allows interacting with the smart home in a way that is very close to the behavior of human beings. KNX technology is a decentralized bus system, which is used for smart building automation of various operational and technical function like lights, sockets, push buttons, environmental sensors, HVAC, alarms etc. It provides a communication channel for actuators and sensors inside a building within which up to 65,536 devices/nodes can interact using 16 bits addressing.

[16] proposes an internet of things (IoT) based architecture for HRES, consisting of a wind turbine, a photovoltaic system, a battery storage system, and a diesel generator. The proposed architecture is divided into four layers: namely power, data acquisition, communication network, and application layers. Due to various communication technologies and the missing of a standard communication model for HRES, this work, also, defines communication models for HRES based

on the IEC 61850 standard. The monitoring parameters are classified into different categories, including electrical, status, and environmental information. The network modeling and simulation of a university campus is considered as a case study, and critical parameters, such as network topology, link capacity, and latency, are investigated and discussed. The communication models for the hybrid energy system consisting of a small-scale wind turbine, PV system, diesel generator, and battery storage system based on IEC 61850 standard, which is suitable for the isolated and small power system have been designed and implemented in different scenarios. The performance has been evaluated with respect to end-to-end delay using Ethernet-based and Wi-Fi-based communication architectures. The simulation results showed that the performance is sufficient for the operation using Fast Ethernet and Gigabit Ethernet, which ensures the latency requirements.

2.1.4 Renewable Energy Sources

[15] focus on how off grid systems/stand-alone systems can help to reduce the dependency of grid and allow us to live in self-sufficient manners without reliance on one or more public utilities. Further, a PV system was designed for a bus shelter at EIU to demonstrate the concept. The paper presents the methodology for designing an off-grid PV system to provide electricity to remote areas where grid-tied systems are not feasible due to high costs. The design was implemented on a bus shelter at EIU to provide necessary equipment such as WIFI, charging points, lights, and sensors for students. The design methodology can be used for other off-grid systems as well. The economic aspect of the system is not covered, and equipment selection depends on financial preferences. [4] contributes to the development of smart microgrid systems in Saudi Arabia and the integration of hybrid renewable energy systems.

[18] proposed an IoT Appliance Scheduling Controller (ASC) for Smart Residential Building (SRB) thereby reducing the electricity tariff of the SRB consumer and minimizing the peak load. It is more economical to schedule home appliances effectively rather than adding more capacity to ensure the balance during peak and off-peak loads. Also, SRB users choose to install rooftop renewable energy sources that generate energy that can be utilized for their own loads which reduces load on the grid. They considered only renewable energy source integration and power consumption but failed to discuss the peak demand reduction electricity cost minimization and complexity of machine learning. This study presents a new IoT based ASC for SRB with rooftop RES.

[19] proposed an IoT task management mechanism based on predictive optimization for energy consumption minimization in smart residential buildings. Energy data is obtained from different appliances to evaluate the proposed predictive optimization approach. The approached result was compared with prediction and optimization modules. The performance is evaluated in terms of regression performance metrics. The case study results show that the predictive optimization mechanism based on task management performs better than standalone prediction and optimization-based energy consumption mechanisms in residential buildings.

For all the works reviewed, a real-world model was not built that targets the loads (HVAC) which consumes the power to switch off automatically when there are no users for some time to save power. Also, we will switch power sources between solar PV and the grid. This work will incorporate a smart meter and build a web application to monitor energy consumption and to carry out economic analysis of electrical energy consumption over IoT to the user.

CHAPTER III

SYSTEM DESIGN AND CONSTRUCTION

This chapter provides details of the proposed system design. It shows the algorithm of the proposed system, the block diagram of the system, the circuit diagram, simulations, and the construction of the system prototype as well as how the system was connected to the website. It also shows how the system was designed.

3.1 Block Diagram of Proposed System.

The figure 3.1 shows the block diagram of the proposed system. The block diagram shows how the various components would be connected and are presented in blocks.

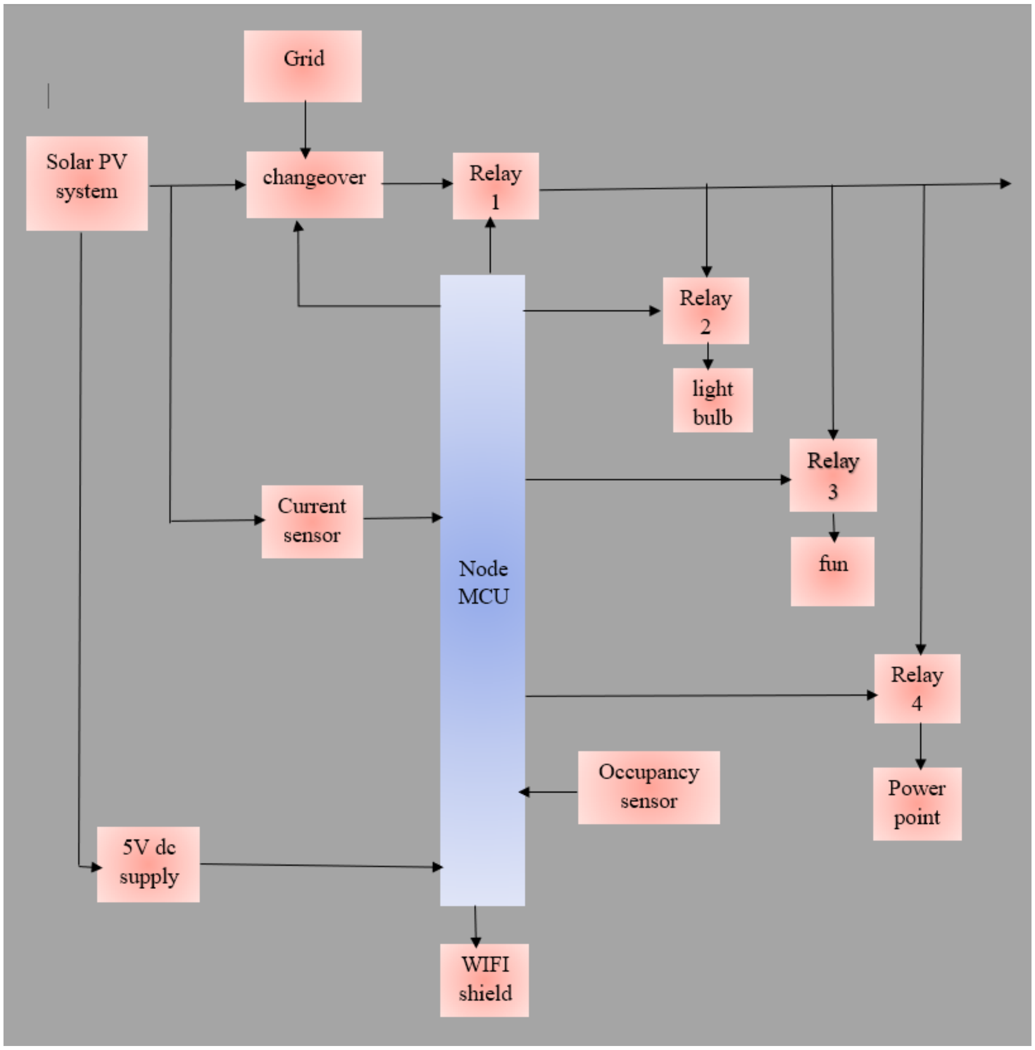

Fig. 3.1: Block Diagram of Proposed System.

From Fig. 3.1, the DC voltage from the Solar PV (9V – 19V) is stepped down to 5V by voltage regulator (L7805CV) with a filter to supply a constant voltage to the NodeMCU (ESP8266). The power grid was also modelled with a constant 12V dc source and together with the Solar PV supplied to the changeover inputs. The occupancy sensor and relays are powered by tapping the power source from the NodeMCU.

The current sensor sends current signal to the NodeMCU for measurement; current that is being drawn by the loads multiplied by the constant voltage to calculate the power consumption. The displayed of the calculated power is sent through the cloud to the user's mobile device. In this project, Blynk IOT application was used to receive the data and to control the appliances over the internet.

With an output value of high (1) from the occupancy sensor, the nodemcu reads human presence in the room and keep appliances operating. Upon the absence of human, the output of the occupancy sensor is low (0), and the nodemcu reads it and after a specific time delay (say 5 minutes), switch of the appliances by de-energizing the coils of the respective relays.

Once the sensor reads high upon human presence, the process is repeated. The energy consumption, and economic analysis are carried by the nodemcu and uploaded to the API of the Blynk App through the internet which can be viewed remotely. There is functionality of switching the appliances on/off over the internet using the Blynk application.

3.2 Flow Chart of Proposed System

The fig. 3.2 below shows flowchart of the proposed system. It provides the steps by which the system executes its functionality.

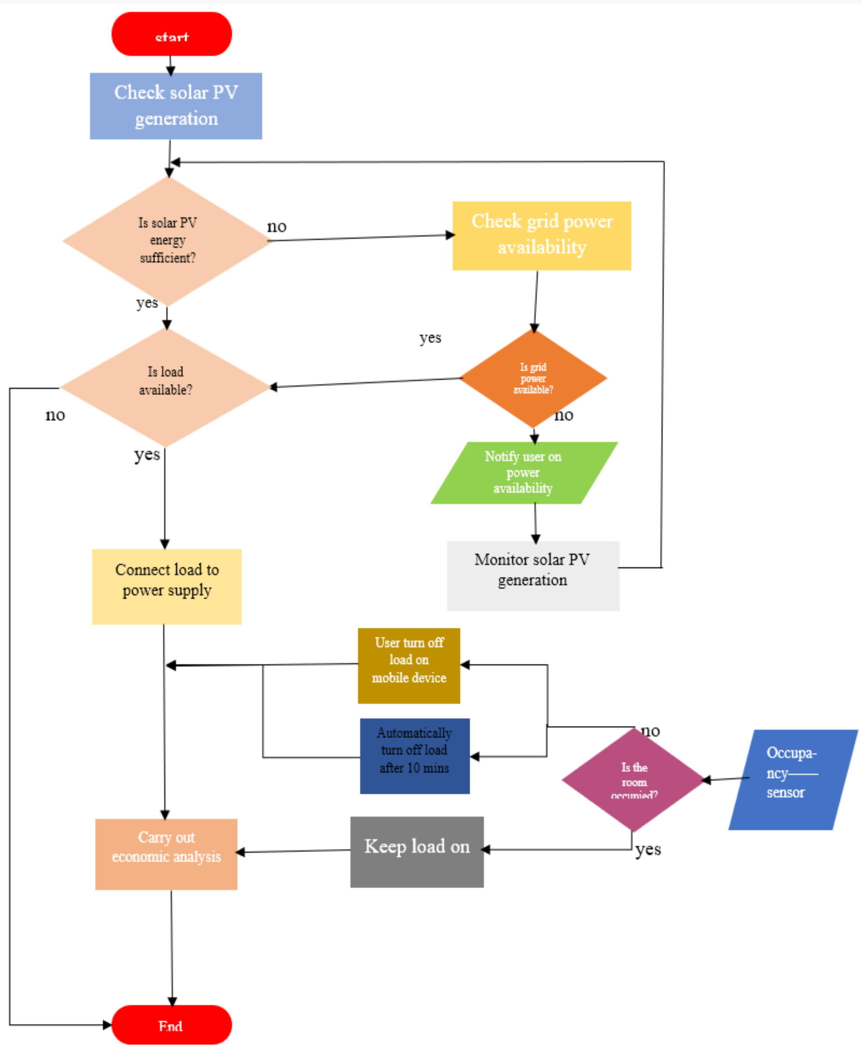

Fig. 3.2: The flow chart of the proposed system

The changeover is sensitive to allow only 12V to pass from the solar PV terminals, and with insufficient output power generation from the solar PV which reduces its output voltage, the changeover automatically switched to the grid to keep the appliances on; so that user's comfortability is not compromised. With power outage from the grid, and the solar PV power not sufficient, there is no other choice than to keep some of the appliances off to meet the available solar PV power or off all the appliances. Once there is sufficient power from the solar PV, all appliances would be powered by the solar PV.

The occupancy sensor (infrared based) has a transmitter and a receiver, the transmitter radiates infrared waves in the room and human reflects the waves back to the receiver. The output pin of the sensor writes high (1) to the assigned pin of the Nodemcu to inform the processor to keep appliance on. With absence of human, the output pin of the sensor writes low (0) to the assigned pin of the Nodemcu, and with a given time delay (say 10 mins) the appliances are switched off. The user can switch on/off appliances at any time over the internet using the Blynk web application.

To display the power consumption, the energy cost and economic analysis on the user's mobile device, the analog pin of the Nodemcu (A0) receive the input current signal from the current sensor (ACS712) and the programming code fetch the corresponding current in mA drawn by the loads using the analog Read(current) command. The current read is multiplied by the constant voltage of 12V from the Solar PV to get the power consumption measured Watts. The calculated power is then multiplied by the time interval of usage to get the energy consumed measured in Watt-hours (Wh). The energy consumed is multiplied by the energy price per Watt (10Gp) to get the total energy cost at the given time. The economic analysis is carried out by expressing the energy cost for using solar power as a percentage of the total average energy cost using only the power from the grid. All the calculated parameters and the economic analysis are sent through the internet to the Blynk web application for the user to see or per usual.

3.3 Circuit Diagram of Proposed System

The fig. 3.3 shows the circuit diagram of the proposed system in proteus software.

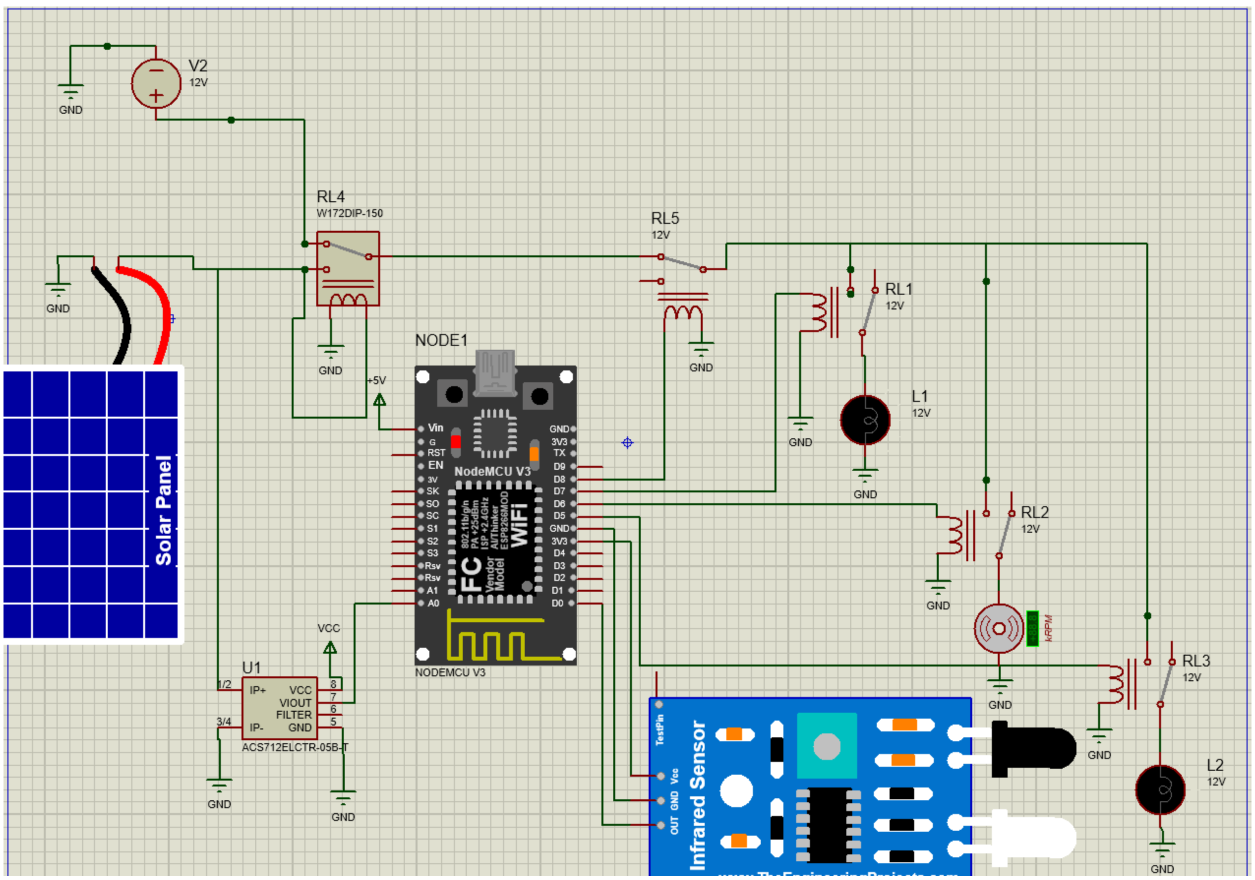

Fig. 1.3 Circuit Diagram of Proposed System

The DC voltage from the Solar PV (9V – 19V) is stepped down to 5V by voltage regulator (L7805CV) with a filter to supply a constant DC voltage to the Vin of the NodeMCU (ESP8266) and the ground connected to common to power it. The power grid was also modelled with a constant 12V dc source and together with the Solar PV supplied to the changeover inputs. The occupancy sensor and relays are powered by tapping the 3V source and the GND from the NodeMCU.

The current sensor (ACS712) sends analog current signal to the analog pin (A0) of NodeMCU for measurement and calculation; current that is being drawn by the loads multiplied by the constant voltage (12V) to calculate the power consumption. The displayed of the calculated power (W), energy (Wh), and energy cost (GHC) is sent through the cloud to the user's mobile device. The occupancy sensor and current sensor are powered by connecting their VCC to 3V pin and its GND to the GND pin of the NodeMCU respectively. In this project, Blynk IOT application was used to receive the data and to control the appliances over the internet.

With an output value of high (1) from the occupancy sensor connected to the D3 pin of the nodemcu, the nodemcu reads human presence in the room and keep appliances operating. Upon the absence of human, the output of the occupancy sensor is low (0), and the nodemcu reads it and after a specific time delay (say 5 minutes), switch of the appliances by de-energizing the coils of the respective relays. Zener diodes are connected in parallel to the relays to prevent the reverse flow of current which may cause damage to the circuit.

Once the sensor reads high upon human presence, the process is repeated. The energy consumption, energy cost accumulated and economic analysis are carried by the nodemcu and uploaded to the API of the Blynk App through the internet which can be viewed remotely. There is functionality of switching the appliances on/off over the internet using the Blynk application.

3.4 Prototype of The Entire System

The Fig. 3.4 below shows the prototype of the entire system. It consists of the modelled house built with thick cardboard, the circuitry on top of it and the sensors and loads inside the building.

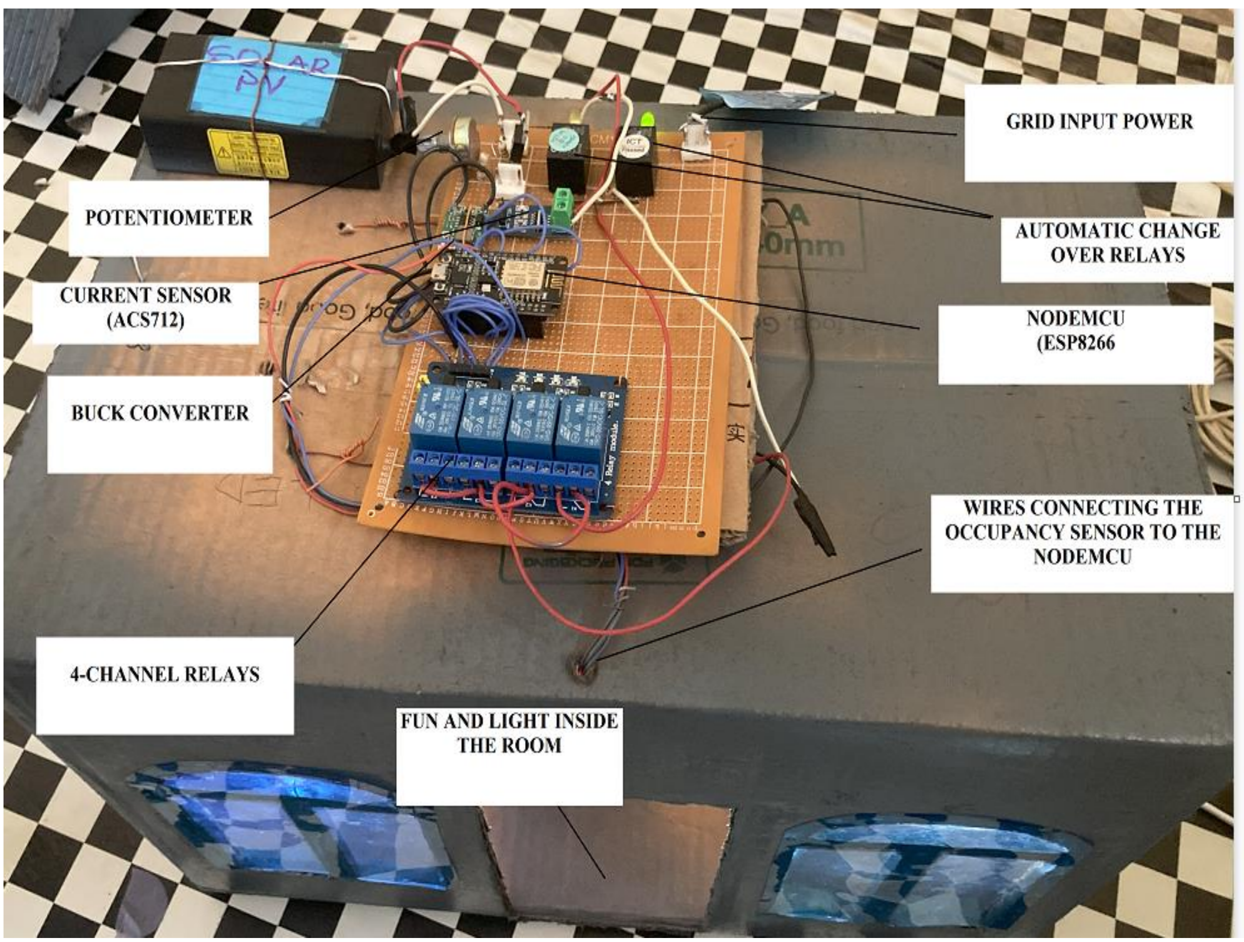

Fig. 3.2: Prototype of Entire System

3.5 Power Consumption Calculation and Economic Analysis

The step-by-step calculations of the energy consumption, energy cost and economic analysis are presented by the formulas below. Power consumption of the system is obtained by multiplying the system voltage (12V) by the current drawn by the loads when connected to the solar PV (Eqn. 3.2). The power consumption is multiplied by the time interval when the system is connected to the solar PV to obtain the energy consumed.

Power = voltage × current ……………………………………………. Eqn. 3.1

Power = $\frac{\text{energy}}{\text{time}}$ ……………………………………………………Eqn. 3.2

Energy = power × time ……………………………………………….Eqn. 3.3

Energy = (power) × (time interval / 3600) measured in "Wh" ………Eqn. 3.4

3.5.1 Economic Analysis

Economic analysis is carried out to know the amount of money saved in using the solar PV as compared to using the grid. Energy cost by using the solar PV is obtained by multiplying the corresponding energy consumption bracket shown in Table 3.1 by the power and the time the solar PV was used. Energy cost saved is calculated by dividing the energy cost by using solar PV by the total average energy cost of the house multiplied by 100%. The energy cost saved is expressed in percentage.

Energy Cost = (energy Price / 100) × (power) × (interval / 3600), expressed in GHc.

Note: energy price of 10 Gp is to 1W was used in this project and is variable.

$$\text{Energy Cost saved} = \frac{\text{Energy cost by using solar PV}}{\text{Total average energy cost of the house}} \times 100\%$$

Table 3.1: This is a table of energy consumption bracket.

Demand in consumption bracket (Wh)	Cost (GHc / Wh) from using the grid
10 – 50	0.08
50 – 100	0.10
100 – 200	0.12

Profit gained (GHc) = (energy Price in Solar PV / 100) × (power) × (interval / 3600).

Table 3.1 shows the assumed energy consumption brackets with their corresponding unit cost by the utility service.

3.5. Webpage And Mobile Application Design

Blynk is an IoT platform that enables the creation of mobile applications for controlling and monitoring hardware devices, like Arduino or ESP8266-based boards. To begin, we installed the Blynk app and created an account. Then, established a new project, specifying our hardware board and connection type (WIFI). Blynk generates an Auth Token, essential for linking your hardware to the app. With our project, we added widgets (buttons, sliders, displays) to control and display data from our hardware.

We configured these widgets by assigning them Virtual Pins, which act as communication channels between the app and our hardware (e.g., V1 for LED button). We wrote Arduino code using the Blynk library, establishing a connection with Blynk's server using our Auth Token, and exchanging data via Virtual Pins. We uploaded this code to our hardware, ensuring it's connected to the specified WIFI network.

Finally, we open the Blynk app to interact with our hardware, offering real-time monitoring, control of sensors and relays, and data visualization. Blynk simplifies IoT app development, making it accessible for diverse projects, but it requires an internet connection to communicate with the server. The Fig. 3.5 below shows the interface of the Blynk webpage.

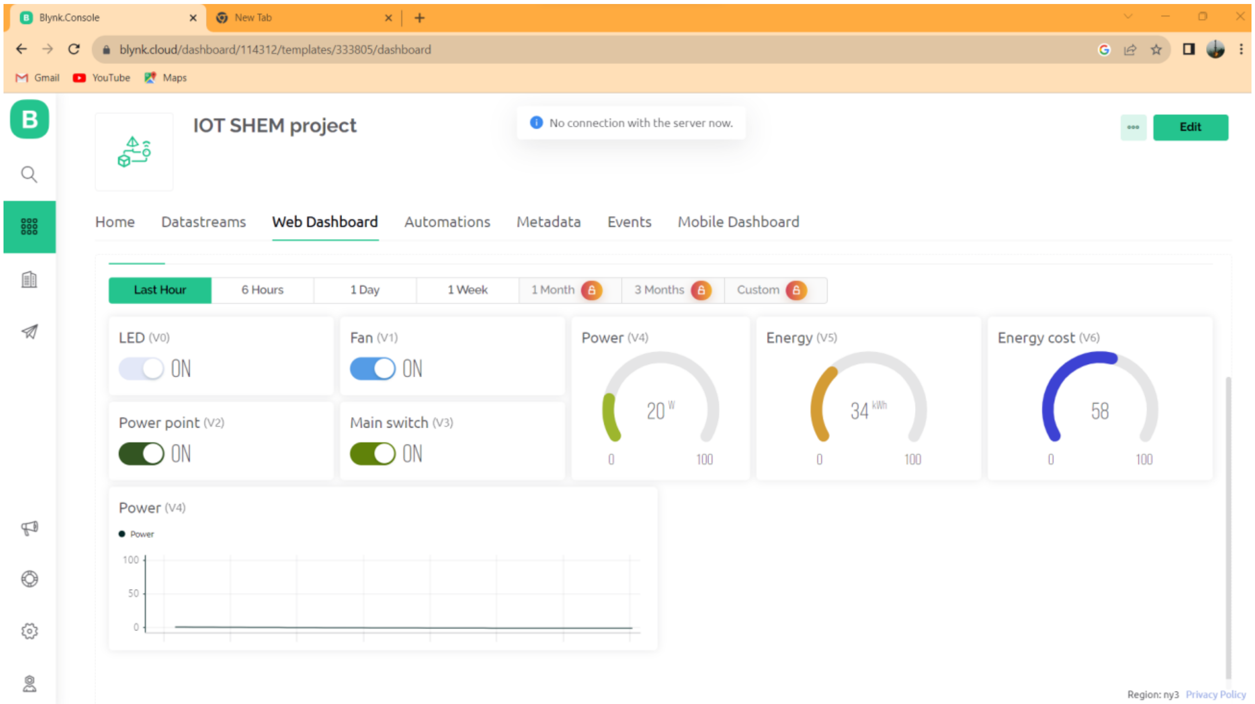

Fig. 3.3 The image shows the Interface of the Blynk Webpage

CHAPTER IV

CONSTRUCTION AND TESTING

4.1 Introduction

This chapter contains the construction of the system, and the components used. It comprises of the specification of the electronics components.

4.2 Specification of Load Used

In testing the system, a 12V 1.2W fan and 12V LEDs were used. The Fig. 4.1 shows the fan and LED lamp that was used for the test. A 12V power point was also provided.

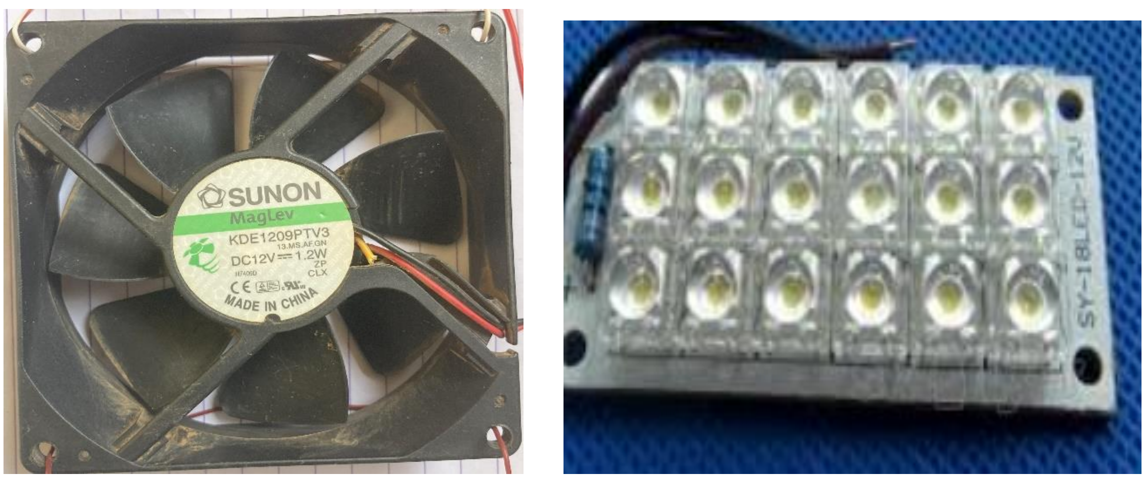

Fig. 4.1 The image of Fan and LED Used

4.3 Construction

In the construction, relays serve as a switch to control the loads. It uses small electrical signals to energize the coil to control it operation. It taps it power from the Node MCU. That's the 3V pin and the Ground pin. The source voltage for the loads is 12V for this project and the current drawn depends on the loads working. With the fun drawing 0.1A, the power consumed is expected to be

1.2W from the power calculation. The DC voltage from the Solar PV (9V – 19V) is stepped down to 5V by voltage regulator (L7805CV) with a filter to supply a constant DC voltage to the Vin of the NodeMCU (ESP8266) and the ground connected to common to power it. The power grid was also modelled with a constant 12V dc source and together with the Solar PV supplied to the changeover inputs. The occupancy sensor and relays are powered by tapping the 3V source and the GND from the NodeMCU.

4.3 Testing

After connecting the various components, we were able to on and off the loads on the Blynk app interface or turns off the loads when the pre-determined time has elapsed after the occupancy sensor sensed that there is no occupant in the building(room). Once there is sufficient power from the solar PV, all appliances would be powered by the solar PV. With insufficient power from the solar it automatically switches to the grid. Also, it was possible to perform the economic analysis which tells the energy saved or energy used by loads depending on the solar PV generation system.

4.3.1 Results Shown on The Blynk App Interface

Fig. 4.2 shows the cost of energy used in GHC by the loads, accumulating(updating) after every 15ms when the loads are connected to the solar PV.

Fig. 4.2: Representation of Energy Cost

Fig. 4.3 shows the energy consumed by loads by accumulating(updating) after every 15ms by loads when depending on the solar PV.

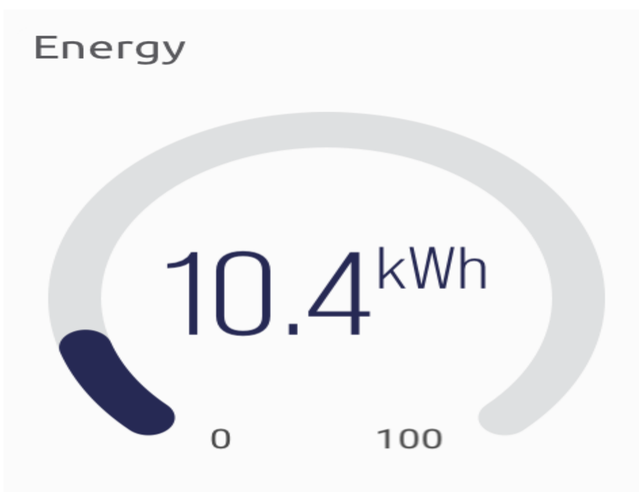

Fig. 4.3: Representation of The Energy

Fig. 4.4 shows the power consumed by the loads at a constant voltage of 12V when relying on the solar PV.

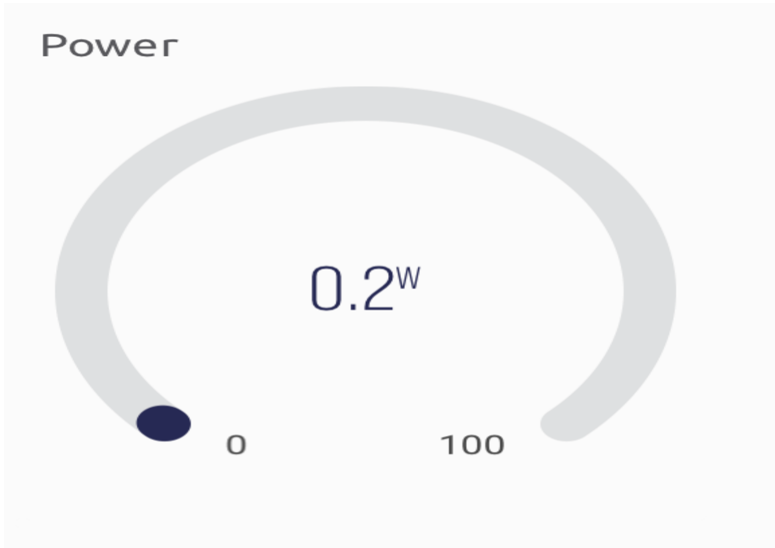

Fig. 4.4: Representation of the Power Consumed

Fig. 4.5 represent the power consumed against time. The time interval can be changed according to the user's preference. The graph can show the energy dynamics within a given period (i.e. Hourly, daily, weekly, monthly and annually).

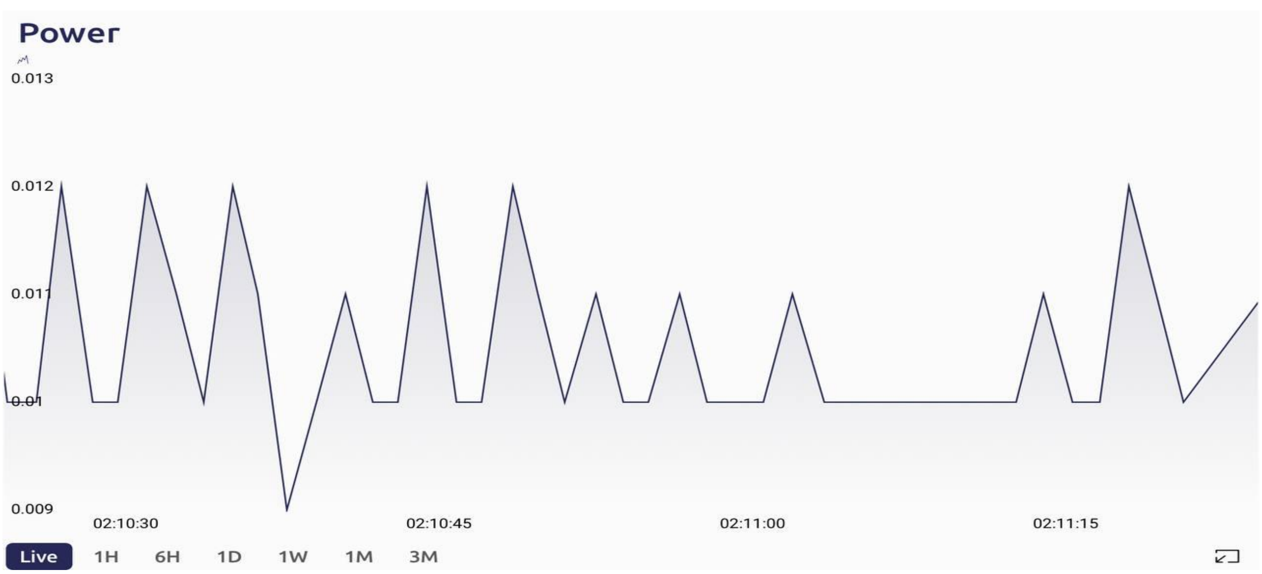

Fig. 4.5: Graphical Representation of Power

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Solar PV generation decreases the amount of energy dissipated by the loads from the power grid and in effect reduces customer's electricity cost from using the grid. All electrical loads on the grid results to more current drawn and more energy usage and cost. With low dependency on the grid, the least cost per Wh from the lowest consumption bracket is consistently maintained over the billing month; this also significantly contribute to reduction in electricity bills. Moreover, the IoT and Smart functionality allows for flexible energy optimization as the loads goes off automatically without a user after an elapsed time and can be remotely switched on / off over the internet.

IoT based smart home energy management system for residential area considering solar PV generation decreases payable energy consumption reducing electricity bills within the margins of 10% to 80% depending on the installed capacity of the Solar PV and settings of the smart functionality.

5.2 Recommendation

The observation and results using this system for energy management has proven to achieve the expected results and beyond depending on the installed capacity of the solar PV and settings of the sensors. However, damping was seen in switching between the power sources of the grid and solar PV due to the potentiometer (100k ohms) and relays used which required two coils in a single relay. The availability of such relay was a challenge and the switching was not very fast or hard real time operation; the user would experience a dip during changing of power sources.

The occupancy sensor, infrared sensor which works in unidirectional was used instead of omnidirectional which would not recognize human presence in the room from its rectilinear propagation. [20] AMG8833 IR Thermal camera sensor is recommended but not available in Ghana. It is omnidirectional and can detect human presence from distance of up to 7 meters. With a minimum frame rate of 10Hz and its perfect for human detection.

All these challenges and inconveniences can be improved to make the system very accurate and responsive as well as improve access to information and commands remotely by building a customized web app with higher network security.

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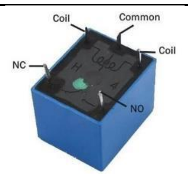
APPENDIX A

A.1 Hardware Components

FIGURE (NAME)	IMAGE	USES	SPECIFICATION
Relay		It used in an automatic control circuit and to control a high-current using a low-current signal	Input Voltage: 0-5V
Current sensor (ACS712)		It is used to calculate and monitor the amount of voltage in an object.	Operating Voltage: DC 5V-30V Measure within 250V AC
Nodemcu (ESP8266)		It contains processor for execution of codes and Wi-Fi	Operating voltage: DC 5V 2.4GHz Wi-Fi

		for communication.	
Infrared sensor module		It is use for detecting human presence.	Operating voltage: 3.3V
Potentiometer		It is use to vary the output voltage.	100kohm 2W
MOSFET IRF3205		It is used for voltage regulation .	12V
12V automatic relay		It automatically switch between power source	12V 20/10 A

APPENDIX B

B.1 Arduino Codes

```
#define BLYNK_TEMPLATE_ID  “TMPL2GapRjpsV”

#define BLYNK_TEMPLATE_NAME  “Relay”

#define BLYNK_AUTH_TOKEN  “jfQWXdF408RcRJ-7_rTSoqHDFL6cI90a”



#define BLYNK_PRINT  Serial



#include <ESP8266WiFi.h>

#include <BlynkSimpleEsp8266.h>



char auth[] = BLYNK_AUTH_TOKEN;



char ssid[] = “xzibit”;

char pass[] = “solo1222”;



//infrared

//…................................................................
```

```
// digital pin 2 has a pushbutton attached to it. Give it a name:

int IR = D3;

int relay = D7;



//energy calculations

//…......................................................................

unsigned long previousMillis = 0;

unsigned long interval = 5000;

float power;

int voltage = 12;

float current=A0;

float currentread;

float energy = 0.00;

float energyCost= 0.00;

float energyPrice = 10;//pesewas

float energycostsaved;// %

int totalenergycost = 50; //cedis
```

```
BLYNK_WRITE(V0)

{

  int value = param.asInt();

  Serial.println(value);

  if(value == 1)

  {

    digitalWrite(D5, LOW);

    Serial.println("LED ON");

  }

  if(value == 0)

  {

     digitalWrite(D5, HIGH);

     Serial.println("LED OFF");

  }

}


BLYNK_WRITE(V1)
```

```
{
  int value = param.asInt();
  Serial.println(value);
  if(value == 1)
  {
    digitalWrite(D6, LOW);
    Serial.println("LED ON");
  }
  if(value == 0)
  {
     digitalWrite(D6, HIGH);
     Serial.println("LED OFF");
  }
}

BLYNK_WRITE(V2)
{
  int value = param.asInt();
```

```
  Serial.println(value);
  if(value == 1)
  {
    digitalWrite(D7, LOW);
    Serial.println("LED ON");
  }
  if(value == 0)
  {
     digitalWrite(D7, HIGH);
     Serial.println("LED OFF");
  }
}

BLYNK_WRITE(V3)
{
  int value = param.asInt();
  Serial.println(value);
  if(value == 1)
```

```
  {
    digitalWrite(D8, LOW);
    Serial.println("LED ON");
  }
  if(value == 0)
  {
     digitalWrite(D8, HIGH);
     Serial.println("LED OFF");
  }
}


void setup()
{
  Serial.begin(115200);
  Blynk.begin(auth, ssid, pass);
  pinMode(D5,OUTPUT);
  pinMode(D6,OUTPUT);
```

```
  pinMode(D7,OUTPUT);

  pinMode(D8,OUTPUT);


  //infrared pins

  //…..........................................................


  pinMode(IR, INPUT);

  pinMode(relay, OUTPUT);

  digitalWrite(relay, HIGH);


  //current reading

  //…..........................................................

   pinMode (current, INPUT);

}


void loop()

{

  Blynk.run();
```

```
// infrared loop

//…................................

int IRState = digitalRead(IR);

Serial.println(IRState);

if (IRState==0){

  Serial.println("There is someone in the room !");

  digitalWrite(relay, LOW);

  delay(60000);

} else {

  digitalWrite(relay, HIGH);



}

// send data to blynk app

//…...................................................

float currentread = analogRead(current);



float power= (current/1000) * 12;
```

```
 energy += (power) * (interval / 3600); // Wh

 energyCost += (energyPrice / 100) * (power) * (interval / 3600); // GHc.

 Energycostsaved = (energyCost/totalenergycost)*100; //%


if (current <0.16) {

  current = 0;



}

 // Send data to Blynk

Blynk.virtualWrite(V7, energy);

Blynk.virtualWrite(V6, power); // Power in watts

Blynk.virtualWrite(V5, String(“Ghc.”) + String(energyPrice));


Serial.print(“Current: “);

Serial.print(current);

Serial.println(“mA”);

delay (3000);
```

```
  Serial.print("Power: ");

  Serial.print(power);

  Serial.println("W");

  delay (3000);

  Serial.print("Energy: ");

  Serial.print(energy);

  Serial.println("Wh");

  delay (3000);

  Serial.print("Energy Cost: ");

  Serial.print("GhC");

  Serial.println(energyCost);

  delay (3000);

  Serial.print ("Energy Cost Saved:");

  Serial.print(energycostsaved);

  Serial.println ("%");

}
```

B.2 Interface Of Serial Monitor