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NEW TECHNIQUE FOR RELIABLE POWER MANAGEMENT OF MICROGRID BASED ON IOT

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بِسْمِ اللهِ الرَّحْمٰنِ الرَّحِيمِ

اِقْرَأْ بِاسْمِ رَبِّكَ الَّذِي خَلَقَ

* خَلَقَ الْإِنْسَانَ مِنْ عَلَقٍ * اقْرَأْ وَرَبُّكَ
الْأَكْرَمُ * الَّذِي عَلَّمَ بِالْقَلَمِ * عَلَّمَ
الْإِنْسَانَ مَا لَمْ يَعْلَمْ *

صَدَقَ اللهُ العَلِيُّ العَظِيم

سورة العلق الآية (1-5)

Dedication

To the greatest person that Allah has ever created,

Prophet Mohammad peace be on him.

To the best person that Allah has ever created after His Prophet,

Imam Ali peace be upon him.

To those who have all the credit on me, to those who were the cause of my existence, to my beloved **parent**.

To my **husband** who supported me, my **supervisor** who taught me and directed me.

To all my friends who supported and encouraged me to achieve my success.

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I would also like to express my thanks to **Dr. Ghufran Mahdi** for providing advice throughout the research period.

Finally, I would like to express my thanks to my family for their patience and for supporting me during the study period.

Supervisor Certification

We certify that this thesis titled **“New Technique for Reliable Power Management of Microgrid Based on IoT"** which is being submitted by **Noor Saleh Mohammed** was prepared under our supervision at the Communication Techniques Engineering Department, Engineering Technical College-Najaf, AL-Furat Al-Awsat Technical University, as a partial fulfillment of the requirements for the degree of Master in Communication Techniques Engineering.

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Abstract

In this thesis, a prototype DC electric system was practically designed. The idea of the proposed system was derived from the Microgrid concept that begun to spread in many countries of the world. The system consists of two virtual homes each contains a DC source (PV panels or batteries) and load that consists of four $12V_{DC}$ lamps each has a power of 10 watts. Each home is controlled Automatically by Arduino UNO microcontroller to work in island mode or connected it with the second home or main electric grid (to import or export power). The operating mode of each home depends on the magnitude of the power generated by the home and the availability of the main grid. Under all operating conditions, the minimum cost of the consumption energy must satisfy as possible.

The energy management is done by the Arduino UNO microcontroller with the help of the current sensor (CS) and voltage sensor (VS). The CS senses the amount of total current that drawn by the load of the home while the VS used to detect the presence of the main grid. Information between the two homes about the operating mode and the main grid state was exchanging wirelessly with the help of the radio frequency (RF) module that linked with the Arduino UNO board. This information uploaded to the Ubidots platform by the Wi-Fi module included in the Node MCU microcontroller. This platform has several advantages such as capture, visualization, analysis, and management of data.

The designed system was tested under different conditions to confirm its operation by changing the load in each home. The practical test for each home explained that the home moves from one operating mode to another automatically with high reliability and at the lowest possible cost energy. Also, with the help of the Ubidots platform, the data of the grid condition and the home sources were monitored remotely and stored in good and secure patterns.

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Nomenclatures

Symbol	Definition	Unit
k	Voltage transformation ratio	-----
V_1	r.m.s value of the primary	Volt
V_2	r.m.s value of the secondary	Volt
V_o	Output voltage	Volt
V_p	Peek voltage value	Volt
R	Resistance	Ohm

Abbreviations

Abbreviation	Meaning
AC	Alternating Current
ADC	Analog-to-Digital Converter
API	Application Programing Interface
C	Capacitance
CB	Circuit Breaker
CHP	Combined heat of power
CoAP	Constrained Application Protocol
Com	Common
CS	Current Sensor
D	Diode
DC	Direct Current
DG	Distributed Generation
DS	Distributed Storage
FBP	Flow-Based Programming
G	Grid
Gen	Generation
GUI	Graphical User Interface
H	Home
HTTP	Hypertext transfer protocol
HTTPS	Hypertext transfer protocol secure
I2C	Inter-Integrated Circuit
ITC	Information Technology and Communication
IDE	Integrated Development Environment
IoT	Internet of Thing
L	Load
LCD	Liquid Crystal Display

LDR	Light Dependent Resister
M2M	Machine to Machine
MQTT	Message Queuing Telemetry Transport
NC	Normally Closed
NO	Normally Open
PCC	Point of common coupling
PIR	Passive Infrared
P-to-P	Peer to Peer
PV	Photovoltaic
RF	Radio Frequency
RFID	Radio Frequency Identification
SCL	Serial Clock
SDA	Serial Data
SG	Smart grid
SSID	Service Set Identifier
SSL	Secure Socket Layer
T	Transformer
TCP/IP	Transport Control Protocol/ Internet Protocol
USB	Universal Serial Bus
V Grid	Voltage of Grid
VS	Voltage Sensor
Wi Fi	Wireless Fidelity

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List of Publications

The following papers have been published:

1- Noor Saleh Mohammed and Nasir Hussein Selman, "**Home energy management and monitoring Using Ubidots platform**", Al-Furat Journal of Innovation in Electronic and Computer Engineering (FJIECE), Vol.1, No.3, 2020.

2- Noor Saleh Mohammed and Nasir Hussein Selman**, " Real-Time Monitoring of the Prototype Design of Electric System by the Ubidots Platform",** This paper has been submitted for publication in the international Journal of Electrical and Computer Engineering (IJECE).

Chapter One

Introduction

1.1 Background

The smart Microgrids have begun to spread in many countries of the world in order to increase reliability and improve the efficiency of electrical power systems. These grids require communication systems and smart devices that are connected to the Internet in order to achieve optimal management and remote monitoring. The following sections offer an introduction to the Microgrid systems.

1.1.1 Traditional Electrical Grid to the Smart Grid

The traditional electrical power system is divided into four parts with different voltage levels: generation, transmission, distribution and consumption as shown in Fig. 1.1. The power grid provides the energy from generation plants to the millions of consumers through long distances of transmission lines. During the energy transfer process, there will be losses in the transmission lines, which reduces the efficiency of the electrical system [1]. The conventional electric grid infrastructure with its uni-directional power and data flows requires to be developed for accommodating increasing in energy demands. The future electric grid will be integrated, intelligent, hence a more robust and flexible called smart grid (SG). The conventional electric grid with one-directional power flow cannot deal effectively with increases in energy demands, therefore, the smart grid system became required to make the electric network more powerful and flexible [2].

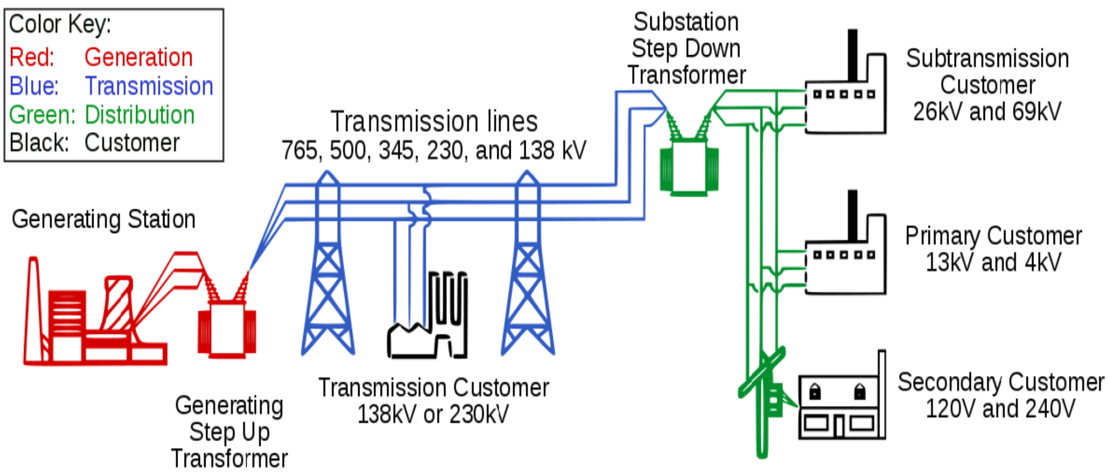


Fig. 1.1 Traditional electric power system [1]

1.1.2 Microgrid

The Microgrid is considered an initiative to smart grid and is expected to be a prototype for the smart grid because of its experimentation scalability and flexibility. The concepts of the Microgrid are varied and there is still no common concept for it. However, it can be defined generally as a relatively small scale localized power grid, that comprises a controllable load, a group of distributed generation sources (DG), and distributed storage devices (DS)[2,3]. Microgrid usually includes a communication system that links all parts of the Microgrid. It transfers and monitors the data gathered from all Microgrid components to ensure optimal management and control. Microgrids can be applied to single consumers, such as sports stadiums; neighborhood Microgrids with multiple customers, such as campuses [2].

Figure 1.2 illustrates a local Microgrid configuration. All Microgrid DG's deliver energy to local consumers like residential and commercial buildings, factories, and offices. The main grid is tied with Microgrid at the PCC to purchase energy if there is no sufficient energy produced from local DGs of the Microgrid and to vend energy back to the main grid when there is extra power generated. When a disturbance occurs in the utility grid, it disconnects and the Microgrid operates in the 'islanded' mode. In this case, only the necessary loads remain at work when insufficient generation is in the Microgrid.

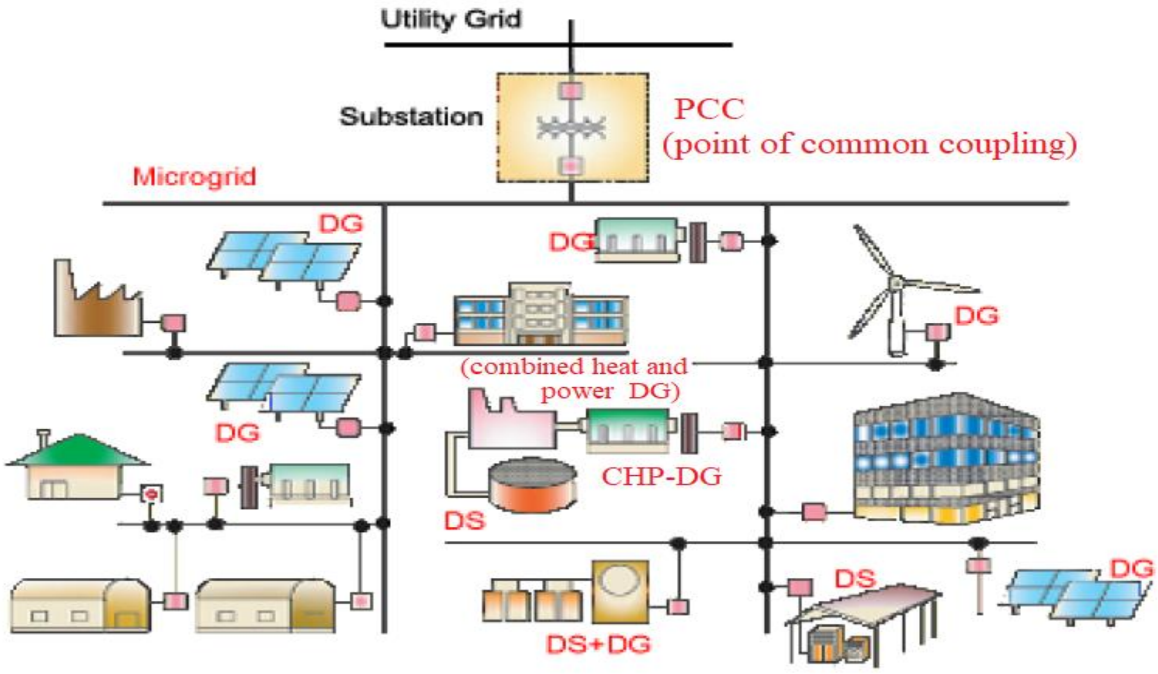


Fig. 1.2 Microgrid configuration [3]

The developments that occurred with the Microgrid are attributed to many reasons, including [2]:

1- They can offer enhanced power quality and reliability in the event of outage or other external network problems.

2- They enhance voltage profile.

3- They may have economic and environmental advantages when emission balance is considered because they can utilize renewable energy.

4- They are localized which means that some transmission infrastructures and related costs can be avoided.

5- Microgrids support the main grid from DG during peak load consumption periods which mitigate or delay current main grid upgrades and also reduces the main generation reserve use.

6- The Microgrid is one solution for generated power in remote regions that do not have electricity services.

7- Finally, Microgrid also has the advantages of being linked by a local network, thereby the participants help each other thus increasing equipment utilization and offering more benefits.

1.1.3 Smart Energy Home

Smart energy home is an essential part of smart cities. It plays an important role in the move towards SG. It can be described as a ”nano grid” as it can contain generation, distribution, and loads. The ability of homes is developed to supply surplus power back to the grid. This interaction between homes and the grid is important for improving the performance of sustainable residential neighborhoods because the smart residential infrastructure is expected to need less energy use which increases the efficiency and reliability of the system [4].

1.2 Proposed system Description

Smart Microgrid helps the consumers to reduce dependence on the main grid in supplying electricity by managing automatic energy-saving and better managing the use of renewable energy sources within buildings. The problem presented in this thesis is the control of the consumption of energy in any home in a Microgrid. To make the system able to perform its operation, the following specifications have been assumed in the design:

1- The system consists of two smart buildings (two homes) and the main grid as in Fig. 1.3.

2- Every home has its own demand which varies during time according to home conditions.

3- It is assumed that each home has its own source (such as PV panels with storage devices) to supply power locally.

4- The two homes in the system are connected to the main grid to provide power to the homes during peak load time or if there is no enough power produced from local home sources. Also, if there is surplus power generated from the local home source, it is injected into the grid.

5- Each home has a Local controller to manage the energy of the system.

6- Each home supposed to have a communication system that links the two homes with server and internet platforms to monitor the status of the home source and the main grid.

7- The price of electricity in the grid is assumed higher than the price electricity of the homes. Consequently, any home needs electricity will purchase it from the other home when it has more available energy to minimize the energy cost. Otherwise, it will have to purchase it from the electrical grid.

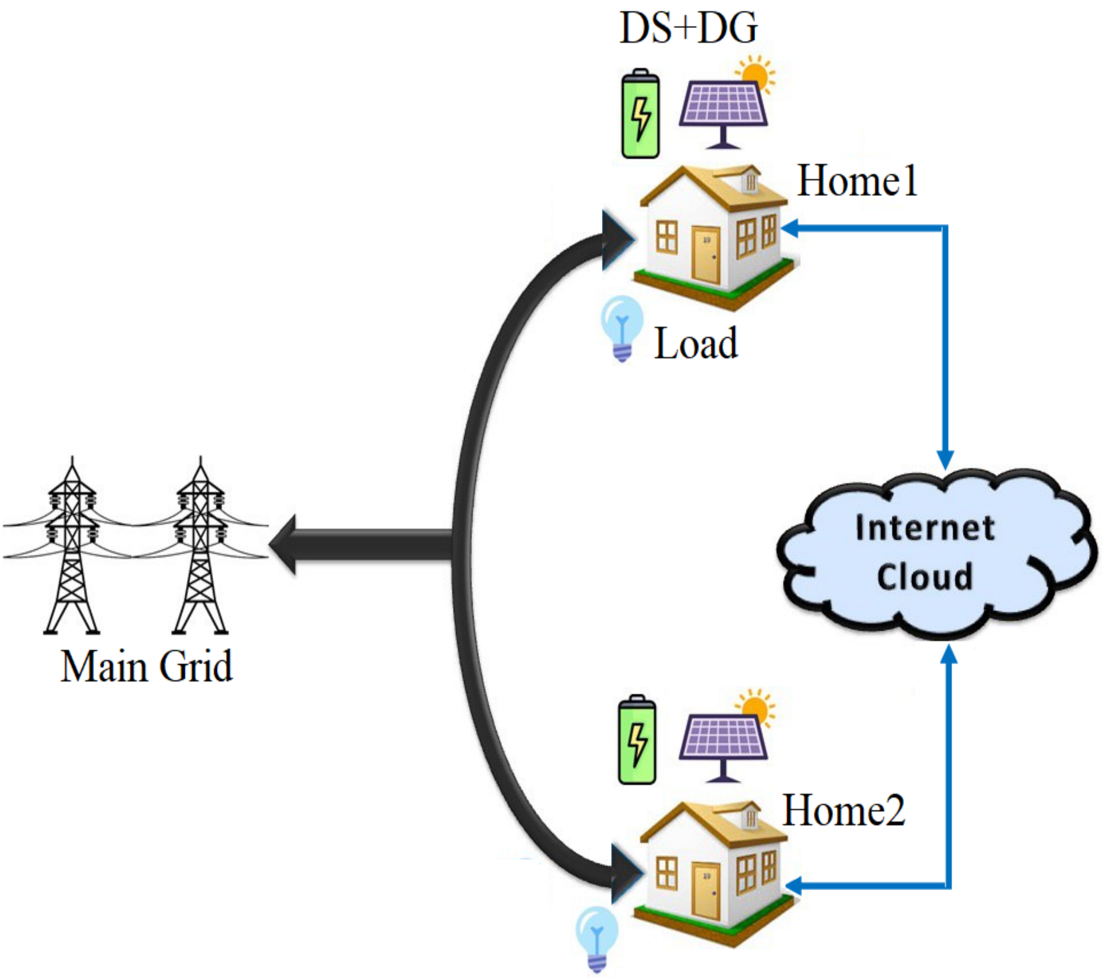


Fig. 1.3: Proposed prototype Microgrid system

1.3 Motivation

The demand for electrical energy in all countries of the world is constantly rising. The power grids should respond quickly to the growth in this demand and continuously produce electricity to meet it. But the power generation is highly dependent on fossil fuels, which causes carbon dioxide emissions, and increasing electricity production means an increase in environmental pollution. Thus, we need an energy generation system that can deal with these challenges in a reliable, economical, and environmentally friendly manner. The smart Microgrid system can overcome these challenges, as it integrates information and communication technology and reduces pollution by using renewable energy sources. These modern electricity grids are complex systems because they consist of a huge number of consumers, each has an active role in these systems and so it is not easy to understand their management and operation [5]. Therefore, this study focuses on the implementation of a simple electric system that clears the concept of the Microgrid operating and management according to the environmental conditions of generation and load demand.

1.4 Thesis Objectives

In this thesis, the following objectives have been established:

1. Design and implementation of a prototype smart micro-electric system. The proposed system controlled fully by the microcontroller and works in island mode with the possibility of connecting it with another or more electrical system.
2- Design program to implement an Internet platform for monitoring system data remotely for the proposed system.

1.5 Thesis contributions

The proposed system have to cover the following contributions:

1- Apply the Ubidots platform to monitor the data of the proposed system in real-time.

2- Perform the lowest energy consumption cost among the participants in the designed system according to their energy demand. Each consumer vies with other neighbors for the lowest energy bill according to acceptable cost limits.

1.6 Thesis Outlines

The remaining chapters of this thesis are:

Chapter 2 includes a literature survey. It was divided into parts according to the topics dealt with in the literature, which included the Internet of things, the management of smart grid, control of smart homes, as well as the references that dealt with the Ubidots platform and MQTT protocol.

Chapter 3 focuses on the hardware and software used in the designed proposed system. It offers detailed description and functions of the most essential hardware components used in the system. Also, the software programs required to implement the proposed system.

Chapter 4 covers the complete practical circuit design of the proposed system. The practical results of many cases of the proposed system have been presented and discussed.

Chapter 5 discusses the results and conclusions. Also, some suggestions to improve the work in the future have been offered.

Chapter Two
Literatures Review

Before explaining the previous work related to the proposed system given in this study, a brief description of the main components of the Microgrid must be illustrated.

2.1 Microgrid Main Components

Microgrids commonly consist of DG sources, power conversion devices, communication system, and control system to obtain flexible energy management [6]. The consumers are another component for the Microgrid to be implemented [7]. Figure 2.1 explains the main components of the Microgrid. The red line represents the communication system data transfer.

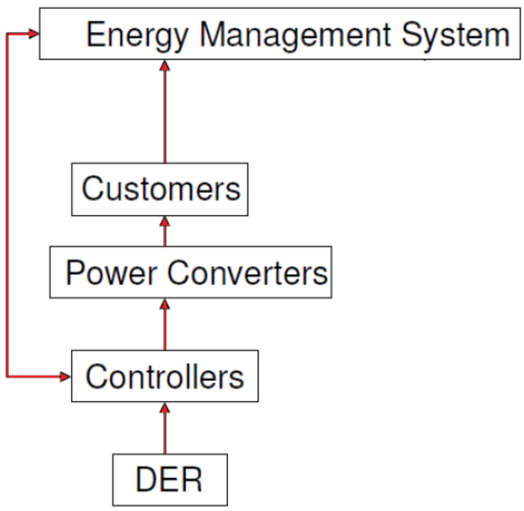


Fig. 2.1 Main components of Microgrid [2]

2.1.1 Distributed Energy Resources (DER)

A Microgrid consists of a set of DER that includes distributed generators and storage devices that provide energy to meet energy demand. The capacity of the DER considered in Microgrid is a relatively small scale (from less than 3kW up to 500 kW)[2].

2.1.2 Control System

Controll system is necessary for the Microgrid to apply demands to DERs and control their parameters, such as frequency, voltage and power quality [8].

2.1.3 Power Converter

Power conversion devices, such as voltage and current transformer, are employed to detect the Microgrid running state. Also, the DERs produce DC or AC voltage with different amplitudes and frequencies than the grid [9].

2.1.4 Communication System

The communication system is a medium to transfer, monitoring, and control data in Microgrids. It is applied to interconnect different elements within the system and ensures management and control [10].

2.1.5 Energy Management System

The energy management system is utilized for information gathering and equipment control and reliability estimation of the Microgrid [11]. It also functions in power generation prediction from renewable energy sources, load forecasting, and power planning [12].

2.1.6 Customers

Customers (also may be suppliers) have a strong effect on load control and management of Microgrid. The participation of customers is the main factor for the smart grid and strongly encourage the engagement desired from the developers [2].

2.2 Related Works

This section is a survey of some existing literature related to the work introduced in this thesis. Since smart Microgrid represents numerous smart homes consisting of many smart-devices, therefore; some studies concerned with smart home appliances control, management, and monitoring are summarized. First, energy management studies on smart homes and control of its appliances remotely using IoT applications are presented. Then, some papers related to smart Microgrid are discussed. Finally, researches that dealt with the Ubidots platform and MQTT Protocol are introduced.

2.2.1 Related Works of Smart Home Energy Management

Each consumer can reduce the cost of energy consumed when he knows the amount of energy needed and available as well as its price. Microcontrollers have provided great opportunities for researchers to optimize energy management in smart homes. The following studies covered part of this concept:

Q. Hu and F. Li [13] designed a control system to manage the power of a smart home that helps the users to minimize the consumption power by the house automatically with the help of sensors that sense human activities. The energy consumption will automatically reduce because appliances operate only when the human at home. The prototype model reduced the consumption by a considerable value (about 10%) during peak hours.

Ninad K. et al [14] introduced a technique for a non-intrusive appliance to monitor a number of loads using the Zigbee protocol. The consuming energy of the system is kept at the optimal value and below a critical level by shutting down unnecessary loads during peak periods.

I. Abubakar et al [15] used Arduino microcontroller for designing and implementing an automatic system that calculates the instantaneous overall power, current, voltage, and power factor for the smart home. The consumption of the loads should not exceed 2000W. The system displays a certain alarm if the load is greater than its maximum value.

2.2.2 Related Works of IoT for Control of Smart Home

The Internet of Things (IoT) means a network of a huge number of devices having sensors and can connect with the internet to facilitate the exchange of products and services around the world[4]. IoT is divided into three main layers [16]. The first layer is the perception in which the data sensor is collected. These data are sent to the network layer which responsible for exchanging data from one host to another. Then, the data is sent to the application layer. IoT permits control and monitors on devices remotely across the internet network by the smartphone, creating an improvement in the efficiency, accuracy, and economic benefits as well as reducing human effort [5]. The following works deal with IoT applications for smart homes.

Jetendra Joshi et al [17] dealt with the development of a simple home automation system for controlling various devices and monitoring from anywhere in the world. The technique includes Raspberry Pi and the webserver. The Raspberry Pi and Arduino incorporated with Nrf modules for monitoring home status appliances, and the readings are transferred to the webserver. when any threat is detected, a message or alarm is sent to the mobile. Performance analysis of various protocols (MQTT,HTTP and CoAP) is estimated employing visualization.

Amar Pawar et al [18] proposed a smart home using the Arduino UNO board, HC-05 Bluetooth, and ESP8266 Wi-Fi modules. The home is linked with the internet via the Wi-Fi technique to control the home devices with help IoT technology.

Lalit Mohan Satapathy et al [19] introduced an economic and reliable smart home using the Arduino board. The home is connected to the internet through the esp8266 WiFi module in order to apply remote control with the help of smart mobile. The proposed home is server independent and uses IoT to control any device in the home. To ensure the activity of the design, the system was tested in different cases.

2.2.3 Related Works of Microgrid Management

The designing, managing, and running of the Microgrid are based on the cooperative benefits for all sharers. The optimal management of energy is very important to maximize the efficiency of any electric grid. Therefore, the following studies have looked at designing the capability of a Microgrid framework to minimize the cost of electricity.

Seyed Ali et al [20] present a novel method for the optimal design of communications and control systems in a distributed system based on the idea of the Microgrid. The proposed design was simplified and optimized the distribution system into a group of virtual Microgrids with optimal communication requirements and power quality aspects. The whole cost concerning the structure of communication and control was reduced while maintaining acceptable network reliability. The PG&E 69-bus and IEEE 123-bus distribution test systems were chosen to inspect the robustness of the proposed algorithm. The proposed technique is considered a great move toward introducing a more intelligent and cost-efficient smart grid.

Yoon-Sik Yoo et al [21] designed energy optimal management for smart-grid. The priority of supplying energy is from the neighboring energy supplier to the energy requesting user. When there is extra energy from the provider, the smart-grid as being the closest to the requesting user allocates the optimal energy to that user so that it increases his satisfaction.

Amit Adhikaree et al [22] suggested IoT application for a multi-agent system for residential DC-Microgrid. The system consists of five smart homes that help each other to mitigate the peak load of the Microgrid and to reduce the energy cost of the consumed by homes. Furthermore, an efficient communication technique was suggested by applying message queuing telemetry transport (MQTT) protocol via MQTT brokers. The proposed method was implemented and validate using five Raspberry pi controller.

Leo Raju et al [5] suggested Internet of Things (IoT) to manage the demand side of three Microgrids each with two solar panels, wind unit, batteries, and loads. For optimal management and economic operation for the three Microgrids, Arduino microcontroller with IoT Ubidots cloud was applied.

C.Nayanatara et al [23] proposed a Microgrid management model that focused on using renewable energy sources (Photovoltaic panel and wind turbine) to reduce power consumption from the electric network. The system can operate in stand-alone using the storing energy in a battery with good efficiency. This system was implemented with LDR and PIR sensors for control scheduling loads through the IoT platform according to the consumer's needs. The energy consumption was compared in two modes traditional and automatic Modes. The results show increasing efficiency and reducing the total energy bills.

Chenghua Zhang et al [24] designed a hierarchical model construction to define the key parts and techniques involved in Peer to Peer (P-to-P) electricity commerce. A P-to-P direct energy trading platform was simulated between peers using game theory. The system was tested in low voltage grid-tied Microgrid and the results show that energy commerce between P-to-P is fit to enhancement the local balance between generating and consuming power. Moreover, the ability to decrease the drawn energy from the main grid and increase the benefit of P-to-P from energy trading between them.

2.2.4 Related Works with Ubidots Platform

IoT platform that will be employed in this thesis is Ubidots. Thus, some information about the Ubidots platform are given in this section before summarizing the studies that use this platform for monitoring data of the systems.

2.2.4.1 Introduction to Ubidots Platform

Ubidots is the cloud platform of the IoT Applications. It provides a simple and secure method for sending and receiving various sensor data to and from IoT devices using the global cloud network in real-time. Ubidots optimize computation, visualization, and recovery of the IoT data storage [5]. Ubidots provides a firm platform for hobbyists, innovators, and professionals which enables them to prototype and scale IoT projects for production. For information on Ubidots, please visit https://ubidots.com/.

2.2.4.2 History about Ubidots Platform

Ubidots company began in 2012 by "Agustin Palaez", who is considered the co-founder and CEO of Ubidots. When he worked for Airbus Germany, he experienced a series of challenges that hardware engineers everywhere face when attempting to create internet-enabled projects. The lessons he learned on that venture eventually led to the birth of Ubidots.

At first, the company was specialized in connected hardware and software solutions to remotely monitor, control, and automate processes. Its clients were healthcare businesses at well-funded startups and Fortune 1,000 companies in the American Southeast and across Latin America. Between 2012 and 2014, the organization expanded its support to other industries and worked on projects in utilities, manufacturing, transportation, and retail. Agustin and his co-founder, Gustavo, have led their company to become a leading creator of comprehensive IoT application cloud platforms for system integrators and businesses implementing or retrofitting monitoring and control solutions.

2.2.4.3 Benefits and Features of the Ubidots

i- Useful for capture, visualization, analysis and management of data.

ii- The Ubidots GUI is simple and easy to use.

iii- Ubidots offers users and operators access to Apps anywhere there is an Internet connection.

iv- It is free.

v- Data stored in it are secured and protected and only users with permission can reach this data.

The following studies use the Ubidots platform to monitor the data of the sustem:

G Kesavan et al [25] used the Ubidots platform to monitor smart home conditions with the help of four sensors (Gas, Flame, Sound, and Temperature sensors). The data sensors are sent to the Ubidots Platform using the Arduino UNO board with help RFID. The work is designed and implemented to take prompt action by alerting the smartphone of any unusual situation with no effort from a human.

Srinidhi Siddagangaiah [26] implemented a plant safety surveillance program by monitoring certain environmental parameters such as temperature, humidity .. etc. that affect plants. All environmental data are sent to the Ubidots IoT platform via the Arduino Uno board with the aid of an Ethernet shield. If there is any deviation in the Ubidots stored data, a warning message will be sent to the user's smartphone.

Zainal Hisham Che Soh et al [27] used Ubidots Dashboard to monitor the data of water consumption by the home as a graphic on the cell phone or laptop in real-time. When water begins to flow, a water sensor reads water quantity. This water signal is linked to an Intel Edison board to start calculating water volume and send data to the IoT network. Using Ubidots, the data collected on water use are analyzed and a warning is sent to owner smartphones for any improper use of water.

Pamarthi Kanakaraja et al [28] proposed a technique for tracking patient health at home by the doctor or relatives. Raspberry Pi, Arduino Mega board, and MCP3008 ADC converter were used in the design. The camera was used to monitor the safety of the patient by using the Raspberry Pi to transmit data to the cloud Ubidots. If any variation in patient health occurs, an alarm with dates and times are sent to doctors about patient with live video in their mobiles.

2.2.5 Related Works with MQTT Protocol

Before studying the related works that use MQTT Protocol to exchange data between Machine to Machine (M2M), some details about communications protocols related to the proposed system should be illustrated.

M2M Communications is the independent interaction of a huge number of sensing, processing, and action without human intervention [29]. M2M communications considered an important part of the IoT [30]. Also, it is considered a building block for the smart electric grid as a way of implementing a wide-ranging monitoring and control network. This will establish great information and communication opportunities for Industrial Information Technology and Communication (ICT). With real-time information available on the energy flow in the grid, different tariff levels can be calculated and made available to the user. The user could make a more intelligent and responsible option [31].

To exchange data between machine to machine, there is a need for communication protocols. The communication system designed in this thesis uses the following communications protocols:

2.2.5.1 Message Queuing Telemetry Transport (MQTT) Protocol

MQTT is one of the most common protocols used in IoT applications [32]. The protocol operates over Transport Control Protocol(TCP)/ Internet Protocol (IP). It provides lossless, ordered, and bi-directional connections and has the following features:

i- small messaging size and require little bandwidth

ii- Easy to implement in software.

iii- Fast transmit data in real-time.

iv- Using publish/subscribe processes for data exchange between clients and server.

All these features make it perfect for M2M and IoT applications [33]. MQTT protocol handles data of mutual control packets according to the specified method.

MQTT is based on several basic concepts, all aimed to ensure delivery of messages while keeping the messages as light as possible (see Fig. 2.2). These concepts are[34]:

- **Publish**: is the process by which a device (client) sends data packets to the MQTT broker.

- **Subscribe**: is the process by which a client receives data packets from the MQTT broker.

- **Topics**: messages (data packets) in MQTT that a client receives when the subscribing process or transmit when publishing process information.

- **Broker**: the server that handles the distribution of information and mainly responsible for receiving all messages from the publisher, filtering them, decide who is interested in it, and then sending the messages to all subscribed clients.

- **QoS**: refers to Quality of Service for message delivery, where the server ensures that the message delivered to the client.

- **Database**: refers to the web server that receives updates on the client data from the MQTT broker and writes these data, to enable the web users to get them.

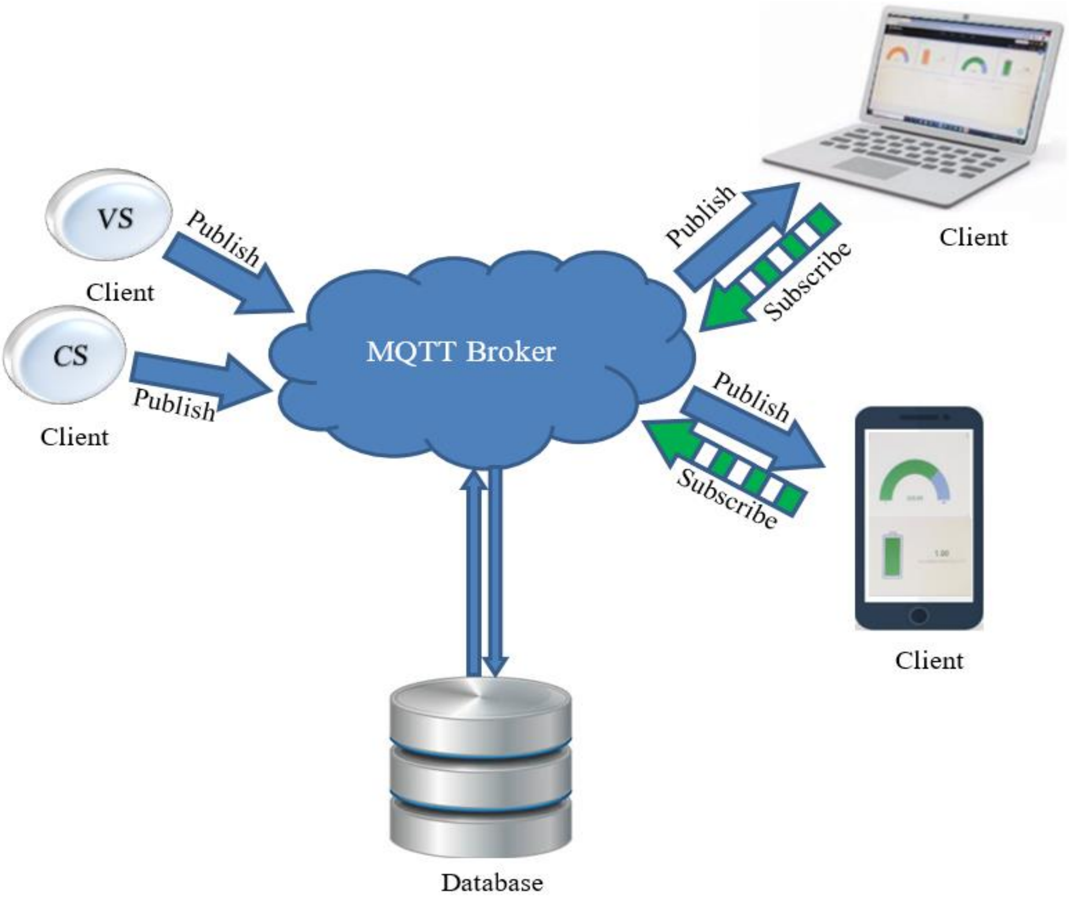


Fig. 2.2 Principle of MQTT works

2.2.5.2 Hypertext Transfer Protocol Secure (HTTPS) Protocol

It is a IoT protocol and represents a secure version of HTTP, which transmits data between the user and the website that is connected to it. It is commonly used and in almost all software applications with a TCP/IP. This protocol is designed to support different devices in application layer Laptops, phones, etc...[35]. HTTP provides reliable communication and employed to transfer large quantities of tiny packets.

The concept work of HTTP protocol includes the idea that files program that is designed to wait for and manage HTTP requests when they arrive. An HTTP client, sending requests to the webserver. The Client / Server process known as the request/response process.

2.2.5.3 Serial Communication Protocol

In this communication protocol, the exchanging data between devices in the form of series data over the communication channel. The protocol feature is that it minimizes the code size of embedded applications and the most important thing is no data loss or collision [36]. The types of transmission modes and data transfer in serial communication protocol classified as Simplex, Half Duplex, and Full Duplex.

2.2.5.4 Inter-Integrated Circuit (I2C) Serial Communication Protocol

I2C is the synchronous type of serial communication protocols. This protocol represented by two-line communication between various integrated circuits these lines are SDA (Serial Data) line and SCL (Serial Clock) line[37].

Various papers dealing with the MQTT communication protocol implementations discussed below.

Aimaschana Nirunt et al [38] presented the design and implementation of MQTT IoT. The design is based on an open authorization standard for web applications (OAuth 1.0a). Some modifications were made on the base structure to fit it with the MQTT features. Many requirements are considered, including limited node resources, lack of node's user interface, and key distribution and management. The design was implemented based on a real MQTT platform and proved its work successfully.

F. J. Bellido et al [39] developed an energy management system for a residential home (or nano-grid). This nano-grid is able to control and schedule the main loads such as heating, air conditioning lighting...etc. UNO microcontroller equipped with a WiFi module is used to test and validate the MQTT protocol for connecting devices in a home environment.

David Nettikadan and Subodh Raj M.S.[40] presented a monitoring scheme for a smart group consists of three smart homes having various functionalities based on environmental conditions. The information is transfer to the main server via the MQTT protocol. The data received at the server is stored in a database and is displayed on a webpage of the server to be monitored remotely. The monitoring system was implemented worked successfully.

Zhonghua Li et al [41] suggested a smart home management system based on MQTT protocol and flow-based programming (FBP)which allows users to connect some visual components according to their own preferences. The system provides a user-friendly and simple graphical user interface, which can be easily understood by children and elderly people.

Table 2-1 provides a comparison between previous publications and current work in terms of the microcontrollers used, the internet platform, the protocol used, the sensors and the problem addressed.

Table-2.1 Comparison Summary between previous publications and current work

Reference No.	Microcontroller used	Internet Platform	Protocol or comm. technology	sensors	Main problem addressed
13	Not mentioned	---	---	human activities sensors	Focuses only on minimize the consumption power by the home.
14	Pic-Microcontroller	---	Zigbee protocol	potential transformer & current transformer	Control home devices. There is no Internet platform used in the design for remote monitor or control.
15	Arduino Mega 2560	---	---	ZMPT101B VS & CS ACS716	Smart home operate and controlled in Island mode only.
17	Raspberry P& Arduino	Not mentioned	MQTT,HTTP and CoAP	temperature, humidity, and CO2 sensors	Dealt only with the smart home to control various devices and monitor them from anywhere.
18	Arduino UNO	not mentioned	Bluetooth & Wi-Fi	---	Include only smart home system to control various home appliances remotely via smartphone.
19	Arduino UNO	Android application	Wi-Fi	Gas & Temperature Sensors	Only controlling on home loads remotely
22	Raspberry pi	----	MQTT	---	Manage energy of DC Microgrid without monitoring data system.
24	Arduino Uno	Ubidots	RFID	Gas, Flame, Sound, and Temperature sensors	Monitor the sensor data with Ubidots and sent alert message and mail to Smartphone on any abnormal condition.
26	Arduino Uno	Ubidots	Wi-Fi	temperature, humidity & light intensity sensors	Work focuses on implementation of a plant health monitoring system.
27	Intel Edison with Arduino Board	Ubidots	MQTT	water flow & Hall-effect sensors	Framework proposed to monitor the water consumption at home.
28	Raspberry Pi and Arduino Mega	Ubidots	Bluetooth & Wi-Fi	Body, Temp. , ECG, and heart rate sensors	Focuses on Patient Health Monitoring
39	Arduino Uno	---	Wi-Fi & MQTT	temperature, gas, humidity sensors	Proposed only control strategy for the home load management
40	NodeMCU & Arduino Mega2560 Raspberry Pi	Not mentioned	WiFi & MQTT Bluetooth	Temp. , LDR Flame, Gas,.. Etc sensors	Manage smart home only according to sensor of the system
Current Study	NodeMCU & Arduino	Ubidots	WiFi, RF & MQTT, HTTPS,	CS and VS	- Monitor system data remotely. - Manage operating modes of virtual home in prototype Microgrid system.

Chapter Three
Prototype Design Requirements and Architecture Circuit of the Proposed System

3.1 Introduction

It is very important to shed light on the information about both hardware and software specifications that are required in the proposed system in this work. Therefore; this chapter offers an idea about the most essential hardware components of the designed system. The software programs required to implement the final prototype system is also illustrated.

3.2 Block Diagram of Proposed Prototype Microgrid Model

The complete diagram of the proposed prototype Microgrid system is given in Fig.3.1. The system is composed of two homes. Each home has its energy source (often renewable sources such as solar arrays) and connected to the main electric grid. Also, each home has its own microcontroller that manages and controls its loads. Generally, both homes in proposed design can receive the power from any generator in the system. The power exchange between the homes is controlled by local control of each home. Homes are tied to the main grid to supply the energy to them during times the generation of the home is insufficient or unavailable. The two homes communicate wirelessly to each other and with the Node MCU-ESP8266 through the local network by radio frequency (RF) attached to every microcontroller board. All data conditions of the homes and the statuses of the main electric grid are transferred to the main Node MCU, and then uploaded to the IoT platform. The data of the system can be opened and monitored from anywhere by using a laptop or smartphone.

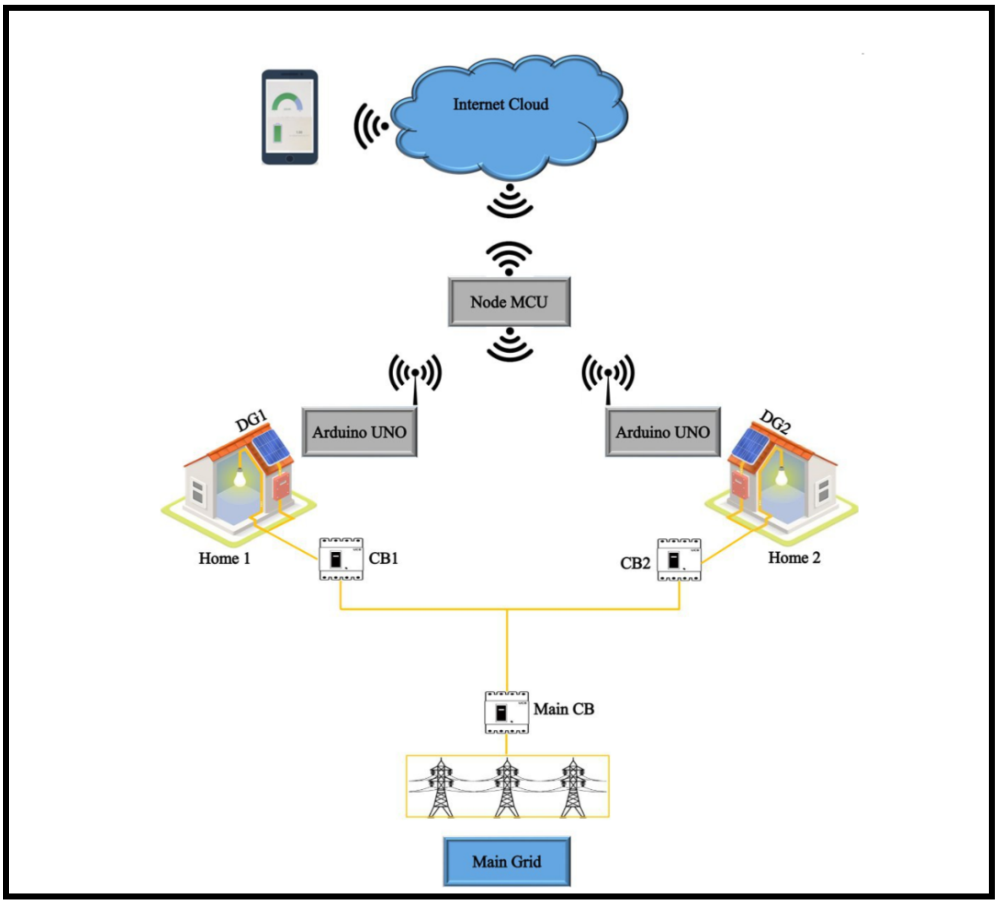


Fig. 3.1: Block diagram of proposed model

3.3 Hardware Components

3.3.1 Microcontrollers

The core of this design will be microcontrollers. All sensors and actuators are connected with them directly or by the amplification and isolating circuits. Also, they are linked together and with internet cloud via different wireless communication technologies to transfer and upload the required data. Therefore, the hardware and software of these boards will be studied in detail.

The Arduino microcontrollers used in this work because they are of low cost, operated with many platforms, and have their own Integrated Development Environment (IDE) which provides facilities for software development. Arduino board comes in many forms such as UNO, MEGA 2560, nano, etc.

3.3.1.1 Arduino UNO

The Arduino UNO is a microcontroller board based on the ATmega328P (Fig. 3.2). It is powered via a USB cable connected to a computer or by battery or with an AC-to-DC adapter. It has the main features listed in Table-3.1[42].

According to the prototype design introduced in this work, Arduino UNO is a suitable board for our work to execute the following main functions:

1. It performs wireless communication with the Node MCU and the other home remotely using RF.
2. It displays the real-time reading in the liquid-crystal display (LCD) display.
3. It ensures smart control and manages loads of the home.

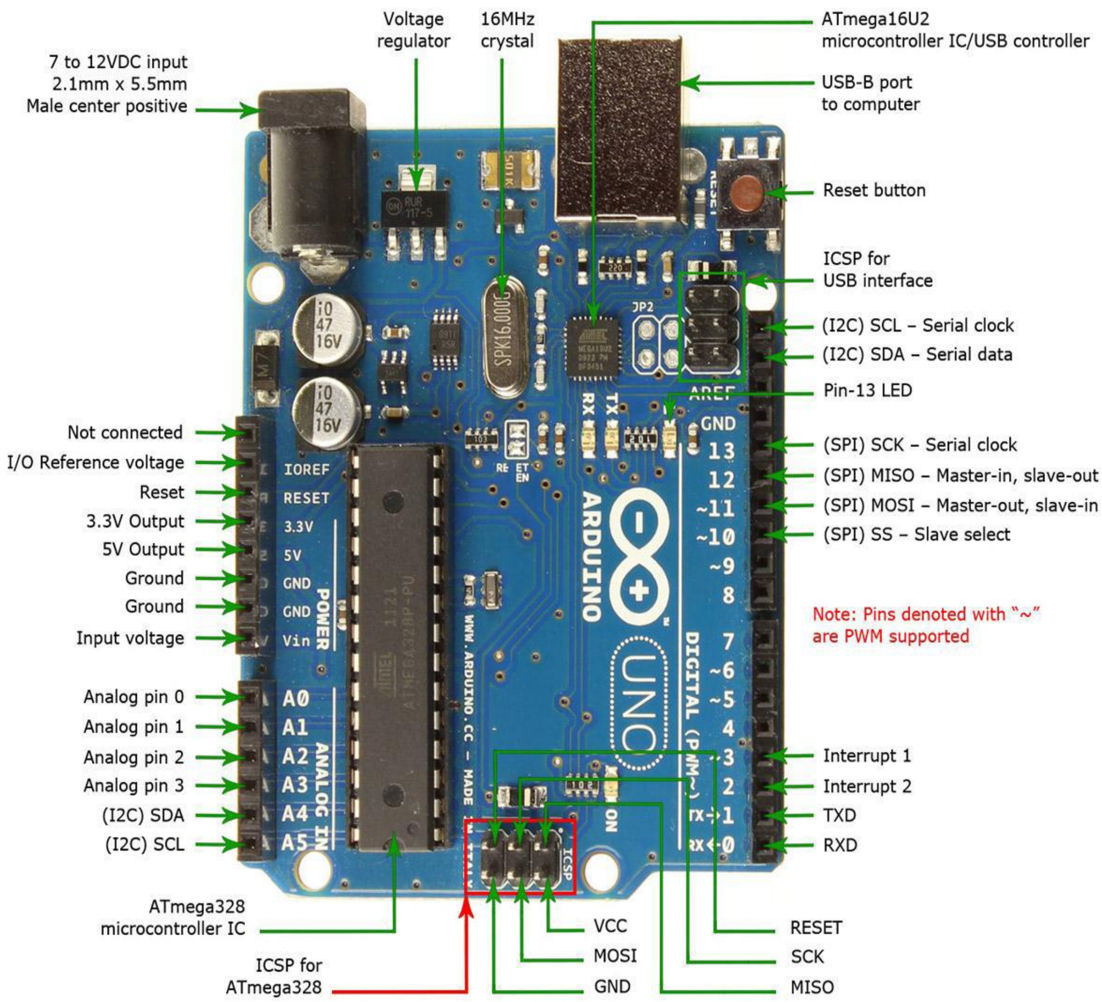


Fig. 3.2 Arduino UNO layout [42]

Table-3.1 Main technical specifications of Arduino UNO [42]

Microcontroller	ATmega328P
digital input/output pins	14 (6 of which can be used as)
analog input pins	6
PWM outputs	6 can be used as
Clock Speed	16 MHz
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB
EEPROM	1 KB
SRAM	2 KB

3.3.1.2 Node MCU- ESP8266

Node MCU is an open-source firmware and expansion board that helps to implement prototype projects or IoT products. It has the capability to transfer or receive the information to or from the cloud. It includes ESP8266Wi-Fi integrated with the ESP-12 unit. The name "Node MCU" combines node and MCU (microcontroller unit). It supports the Arduino C programming language. It has the main features listed in Table-3.2[43]. These specifications make Node MCU used in many devices such as automated vehicle engine controller, implantable medical devices, remote control, dolls, etc. The ESP8266 Node MCU has a total of 30 pins (Fig.3.3).

Table-3.2 Main technical specifications of Node MCU- ESP8266 [43]

ESP-12E Chip features	80 to 160 MHz Clock Freq.
	128kB internal RAM
	4MB external flash
	802.11b/g/n Wi-Fi transceiver
Power Requirement	Operating Voltage: 2.5V to 3.6V
	On-board 3.3V 600mA regulator
	80mA Operating Current
	20 µA during Sleep Mode
Peripherals and I/O	17 GPIO pins
Serial Communication	CP2102 USB-to-UART converter
	4.5 Mbps communication speed

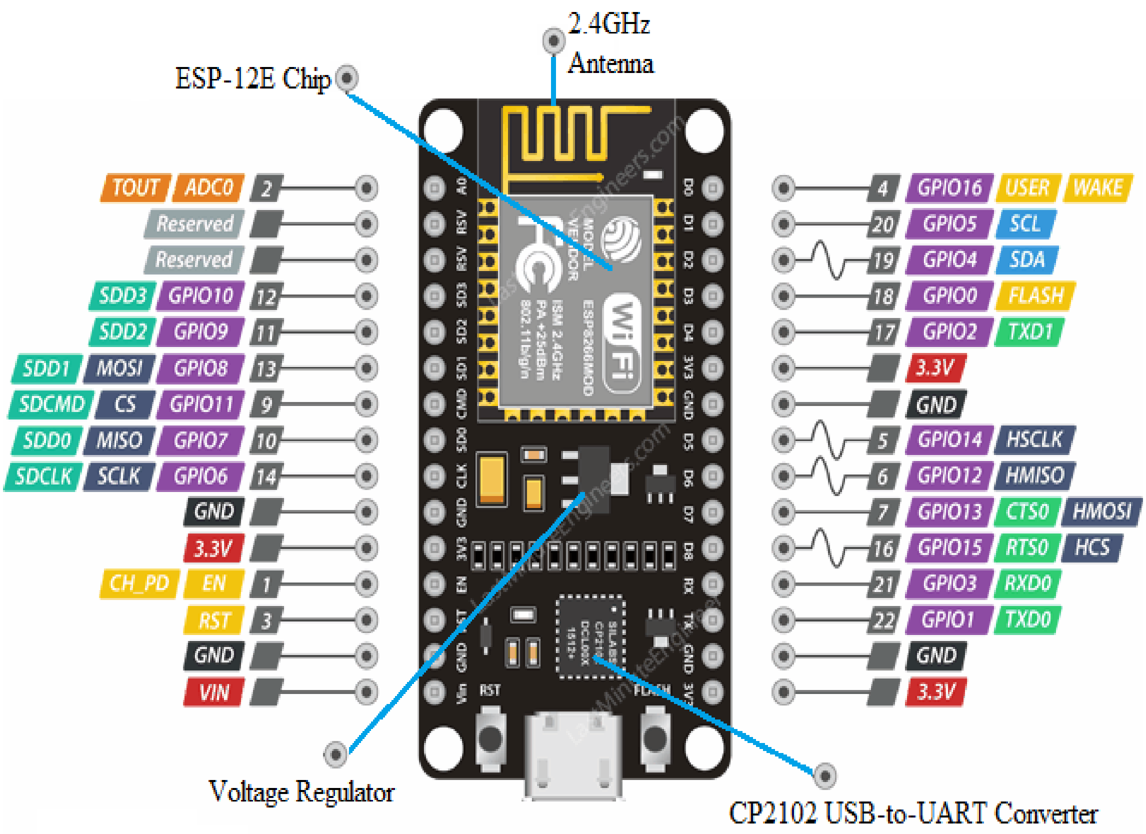


Fig. 3.3 Node MCU- ESP8266 layout [43]

3.3.2 Sensors

Sensors are devices that convert any physical variables such as temperature, pressure, moisture, etc., to an electric signal. Each sensor has a sensitivity that specifies the response of how much the output of the sensor changes with the changes in the input quantity to be measured. All sensors are analog which yields continuous signals. To process this signal by a digital device, such as a microcontroller, an analog to digital converter is required.

To calculate the power consumption of any system, the current and voltage should be measured. In a microcontroller, power is measured with the help of voltage and current sensors. The following subsections illustrate these sensors.

3.3.2.1 Voltage Sensor (VS)

To sense the 220V_{rms} AC voltage of the main grid, a circuit of Fig.3.4 is used. First, the voltage is step-down according to the following equation [44]:

$$V_2 = kV_1 \quad .... (3.1)$$

Where; V_1 and V_2 are the r.m.s value of the primary and secondary voltage of the transformer respectively, k is the voltage transformation ratio.

The transformer is selected with a transformation ratio of (1:44), so the r.m.s. value of secondary side is 5V. This r.m.s voltage has a peak value (V_p) which is given by:

$$V_p = \sqrt{2} \times V_2 \approx 7\ V \quad ……………….. (3.2)$$

Then, the above value of voltage is rectified using a full-wave rectifier to get a DC value of 7V. After that, this voltage is divided into halves using voltage divider as follow:

$$V_o = V_p \times \frac{R_2}{R_1+R_2} = 3.5\ V \quad ……………….. (3.3)$$

Hence, this voltage can be handled by the input pins of the Arduino microcontroller (less than 5V).

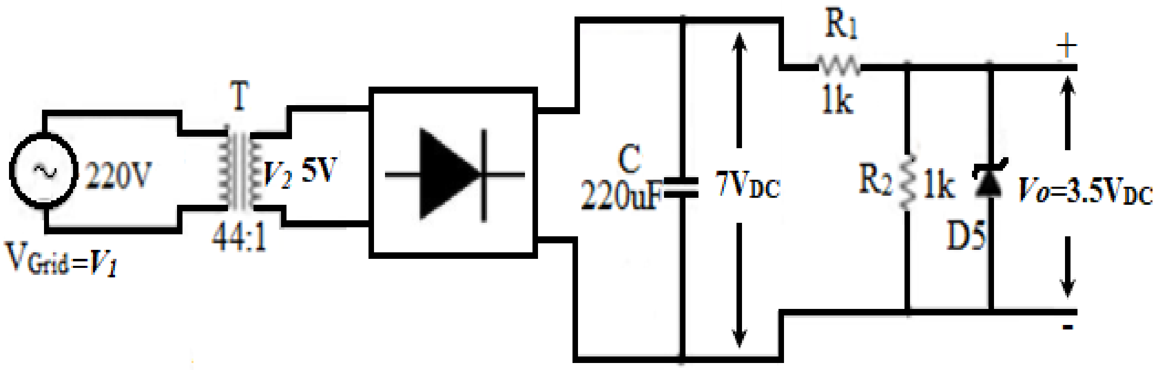


Fig. 3.4 Grid voltage sensing circuit

3.3.2.2 Current Sensor (CS)

There are different categories of CS existing with different ranges and the choice depends on the magnitude of the current to be measured. ACS712-20A current sensor is appropriate for current measurement in our prototype design because it is of low cost, negligible power dissipation, and compatible with Arduino. Figure 3.5 shows the ACS712-20A current sensor.

ACS712-20A CS transforms the current value to an equivalent voltage. The term that relates to the input and output quantities is called the sensitivity of CS. From the datasheet of an ACS712-20A type [45], the following significant features are given:

i- It can measure ± 20A current (AC or DC) with 0.1V/A sensitivity.

ii- The operating voltage is 5V.

iii- If the current =0A, the sensing voltage is 2.5V (Table-3.3). To cancel this voltage, 2.5V digital equivalent voltage must be subtracted in programming.

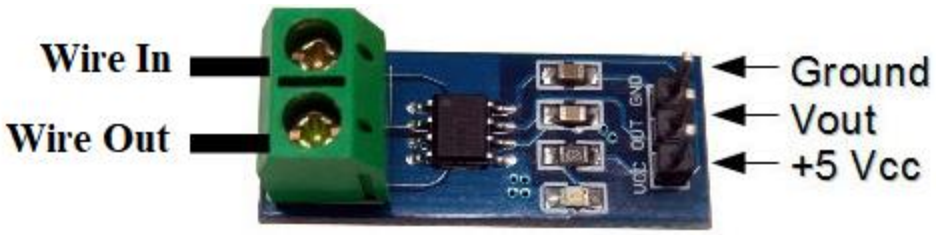


Fig. 3.5 ACS712-20A current sensor [45]

Table-3.3 Sensitive of ACS712-20A current sensor

Range of input current to the CS	equivalent output voltage of CS	Arduino equivalent digital
20 A	(2.5V +0.1 * 20) = 4.5V	1023
0	2.5V	512
-20A	(2.5V-0.1 * 20) = 0.5V	0

According to the above table, the following equation is used in the program to convert the equivalent digital sensing current to equivalent analog voltage:

$$equivalent\ \ analog\ voltage = \frac{4.5}{1023} \times equivalent\ digital \quad \text{………... (3.4)}$$

To calibrate the current to actual value by the program, it's required to subtract voltage offset value (2.5V) from the above equivalent analog voltage, then divided the result by the sensitivity value of the ACS712 CS as illustrated in the following equation:

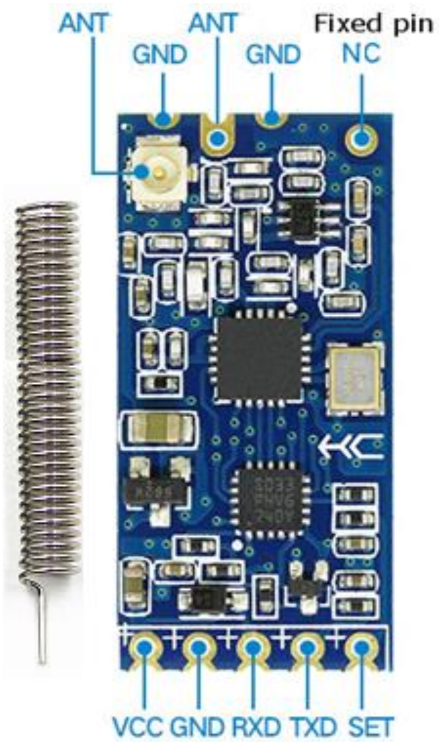
$$actual\ current = \frac{quivalent\ \ analog\ voltage - 2.5}{0.1\ V/A} \quad \text{…………….. (3.5)}$$

3.3.3 Radio Frequency (RF) Module

RF HC-12 module is a multi-channel wire-less transceiver module that is capable of creating a wireless link between many Arduino microcontrollers through distance more than 1 km. It is suitable to provide coverage around homes. It is combined with an external antenna. Figure 3.6 shows the pins of RF-HC-12. The specifications of HC-12 module are [46]:

- Operating voltage is from 3.2 V to 5.5 V.
- Working frequency is between 433 and 473 MHz.
- It has a 100 channels (400kHz between each channel

- Transmitting power from 0.79 mW to 100 mW.
- Receiving sensitivity from 0.019 pW to 10 pW.
- Maximum operating current is 100mA.



PIN	Description
VCC	Power input, DC3.3 ~ 5V
RXD	UART input port, TTL level
TXD	UART output port, TTL level
SET	AT command setting pin, active low
ANT	433MHz spring antenna welding feet
GND	Public ground
NC	No connection for module fixing

Fig. 3.6 Pins of HC-12 [46]

3.3.4 (20×4) LCD Display

A 20×4 -LCD display (Fig.3.7) is used in the design to display the conditions of the grid and home source. LCD display shows the following data at each home:

- Grid status: If it is present (AC VOLT: ON) and if it's not present (ACVOLT: OFF).
- The magnitude of the drawn current by home.
- Supply source (GRID or CELL).
- Status the power of the home (import or export power)

Table-3.4 presents the configuration of the pins of the LCD display[47].

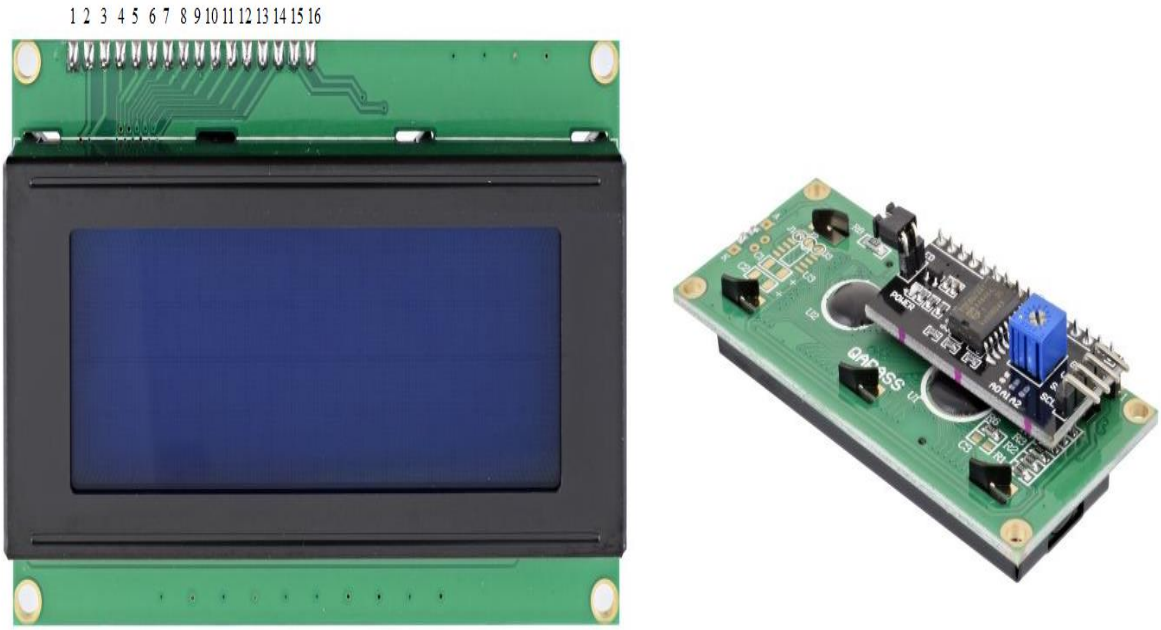


Fig. 3.7 (20×4) LCD Display [47]

Table-3.4 The configuration of the pins of the LCD display [47]

Pin No.	Symbol	Description
1	VSS	Ground
2	VDD	Power supply for logic
3	VO	Contrast Adjustment
4	RS	Data/ Instruction select signal
5	R/W	Read/Write select signal
6	E	Enable signal
7~14	DB0~DB7	Data bus line
15	A	+ Power supply
16	K	- Power supply

3.3.5 Relays

A relay is an electromagnetic switch that operates by a small electric current to control the operation of the high current loads. When the current passes through the relay coil, it magnetizes the coil that pulls a moving rod and thus turns on the power switch to deliver the current to the load.

Since the control coil and power switches are electrically isolated, the relay is used to control a high current load without damage to a microcontroller that activates the relay coil.

There are different sizes of relays and they are used according to their connected load. Here, 8-Channel relay, Fig. 3.8, is connected to the Arduino Uno to control the home loads. These modules have the following specifications according to relay user guide [48]:

- Operating with both 3.3V and 5V DC.
- Relay output maximum is AC 250V, 10A, and DC 30V, 10A.
- Each relay needs 15-20mA Driver Current.
- It has optical and magnetic isolation that offer more protection to the input from faults on the outputs.

The circuit of the relay module that is used to switch the load is given in Fig.3.9. The coil of this relay is triggered with 5V that is given from the digital signal of the output pins of Arduino UNO. The function of the transistor is a switch to control the flow of the current of the relay coil. A resistor R2 and R3 are connected to limit the current. A resistor R1 is used to prevent false switching. A Zener diode has two functions, the first is regulation the voltage across the coil and second serving the purpose of the freewheeling diode. The power pins of the relay are called Normally Closed (NC), Normally Open (NO), and common (COM) pins. If the relay coil is not triggered, the NC pin is connected to the COM pin and the NO terminal is disconnected. If the relay coil is triggered, the COM pin is linked to the NO pin and the NC pin is disconnected.

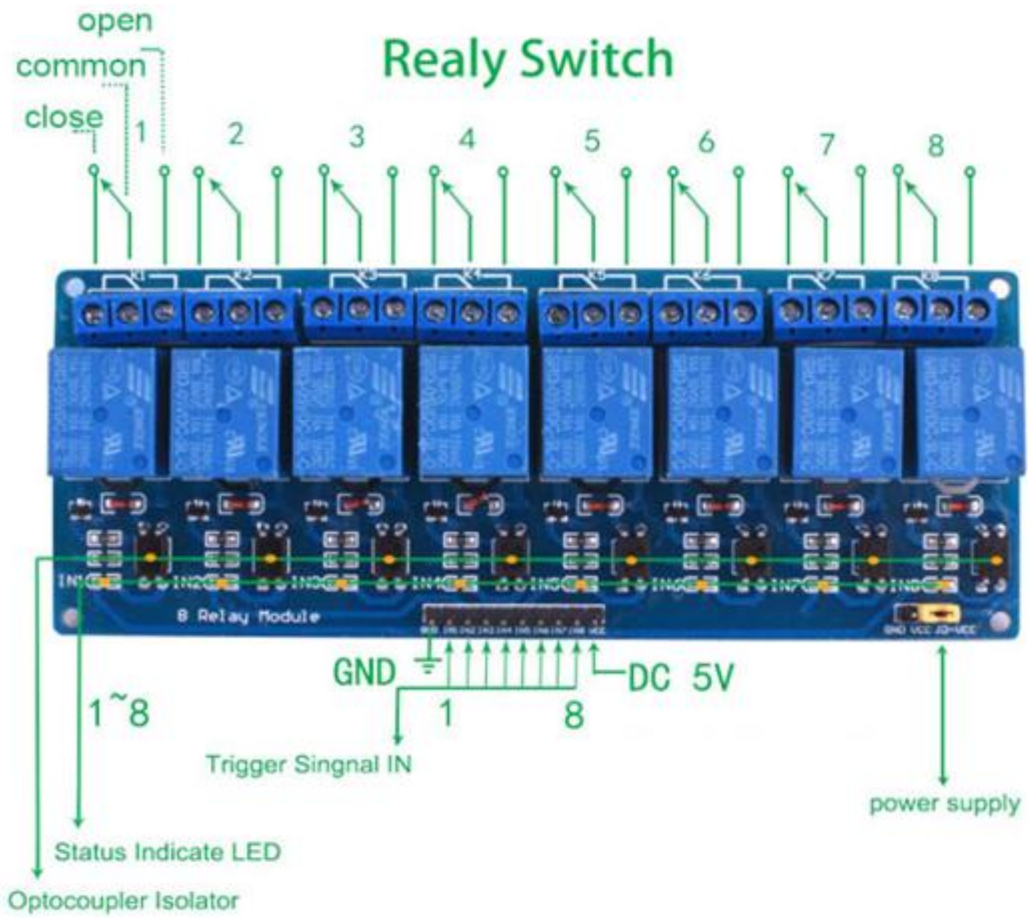


Fig. 3.8 (8-Channels) relay module [48]

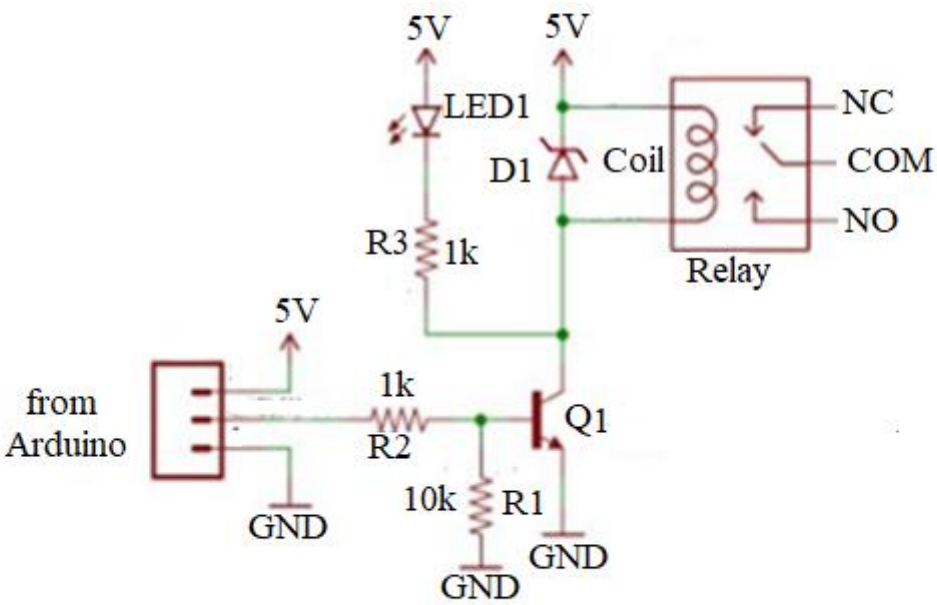


Fig. 3.9: Relay module circuit

3.4 Software Implementation

The software is divided into two main parts. The first part is related to the control side. In which, the Arduino board is programmed to collect information about the sensors that programmed to manage the loads and switch the home with the main grid. The second is related to the communication side. In which, the exchange of information through the system's local network is managed and the system is connected with the internet cloud to monitor the data remotely.

Figure 3.10 shows the flowchart of the software program where data processing is involved. The steps of the algorithm are:

i- Before executing the program, initialize all required libraries, such as ESP8266WiFi, Ubidots, ESP8266, and LiquidCrystal_I2C libraries must be set up first. All serials and ports are initialized and the Arduino pins modes are set. Also, Ubidots token, WiFi SSID, and password have been defined.

ii- The data sensors are defined and processed by Arduino UNO of each home,

iii- These data are transferred and received via RF to the Node MCU,

iv-The data is uploaded to the Ubidots platform to monitor and store.

The program continually reads the data for managing and store it for use in the future study of load and generation forecasting for the system.

The software used here is the Arduino IDE. It is open-source software that writes the code on the computer and upload it to the Arduino board easily. The following sections illustrated the software requirements to complete the system operation.

3.4.1 Analog to Digital Converter

After Arduino takes analog data, it converts them to a digital value. The command "analogRead" specifies the value of the analog pin. The Arduino UNO comprises 6 analog pins (A0-A5). These pins map input voltage range (0-5)V into integer values between (0-1023). This gives a sensitivity that is given by:

$$Sensitivity = \frac{maximum\ inupt\ voltage}{\text{maximum equivalent digital}} = \frac{5}{1023} = 0.00488 \quad \ldots\ldots\ (3.6)$$

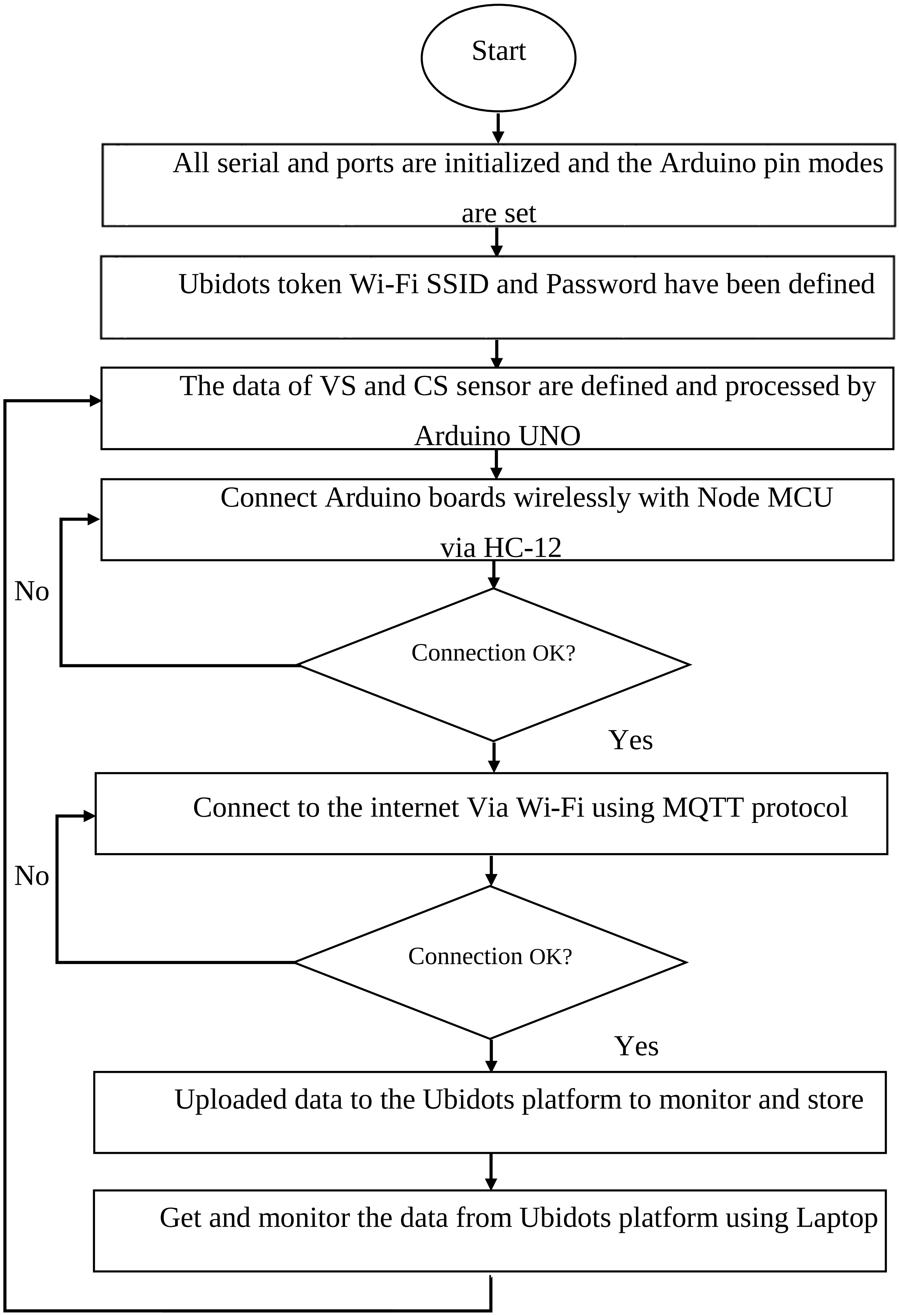


Fig 3.10: Flowchart of the software program

3.4.1.1 Current Measurement Code

As mentioned previously, ACS712-20A has a sensitivity of 100mV/A. It senses of 2.5V output when the input current is 0A. This voltage is converted to the equivalent integer of 512 by ADC of Arduino. So, 1023 will equivalent to (20A) and 0 will equivalent to (-20A) as offered in Table 3.3 previously. According to these features of CS, the programming part for current measurement is as follows:

```
// Current measurement code for ACS712-20A CS
float VperAmp = 0.1; // sensitivity for ACS712-20A CS
float ACSoffset = 2.5; // offset voltage=2.5v
float Amps=0;
float Current1=0;
int current= 0;
void setup() {
}
void loop()
{
Current = analogRead(A1);  // read the analog current value at pin A1
Current1=(5/1023) * Current; // convert to equivalent analog
Amps = (Current1 - ACSoffset) / VperAmp; //current calibration
delay(500); // delay 0.5s
}
```

3.4.1.2 Voltage Measurement Code

Here, only the presence or absence of grid is sensed at the analog pin (A0), so the programming code will be easy because it contains only two states. Since the unavailability of the grid is equivalent to zero, therefore any integer more than zero is equivalent to the availability of the grid.

3.4.2 Connecting ESP8266WiFi with WiFi Network

Linking ESP8266WiFi to any WiFi network needs the name of the WiFi network, identified as Service Set Identifier (SSID). Some WiFi networks have passwords, while others do not, which are called open networks. The password must be known to connect ESP8266WiFi with a protected network. The Arduino code setup order can be seen below:

```
#include<ESP8266WiFi.h>
#define WIFISSID "Redmi" // Put her the name of  Wi-Fi network
#define PASSWORD "12345678" // Put here the Wi-Fi password
void setup(){
// connects WiFi shield to a Wi-Fi Protected network.
client.wifiConnection (WIFISSID, PASSWORD);
}
void loop(){
// code program condition that linked to the network
}
```

3.4.3 Connection the Node MCU to the Ubidots

This section discusses how to connect the Node MCU ESP8266 to the Ubidots platform with the help of its WiFi. This aspect is important since data can be stored and then analyzed in the Ubidots. Once the data are uploaded to the Ubidots, it can be accessed via smartphones or laptops from anywhere at any time. This work is composed of three parts (see Fig. 3.11).

1- The first part explains how to collect data from sensors (current and voltage sensors) connected to the Arduino board and send this information to a Node MCU board.

2. The second part explains how to send and receive data of the sensors between the controller of each home and the Node MCU via their RF (HC-12).

3- The Third part describes how to collect data from the Node MCU and send this information to a Ubidots platform that stores it.

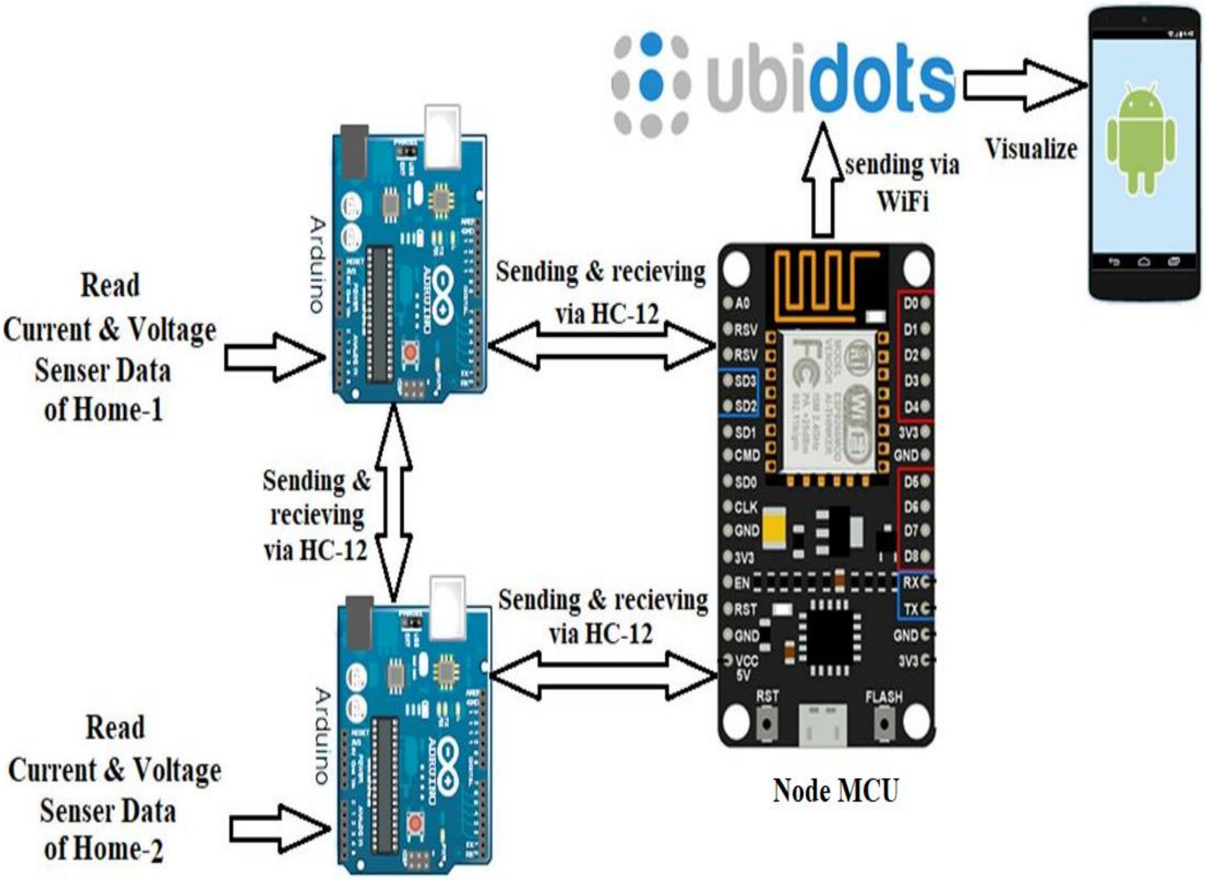


Fig. 3.11 Architecture Steps of upload data to the Ubidots

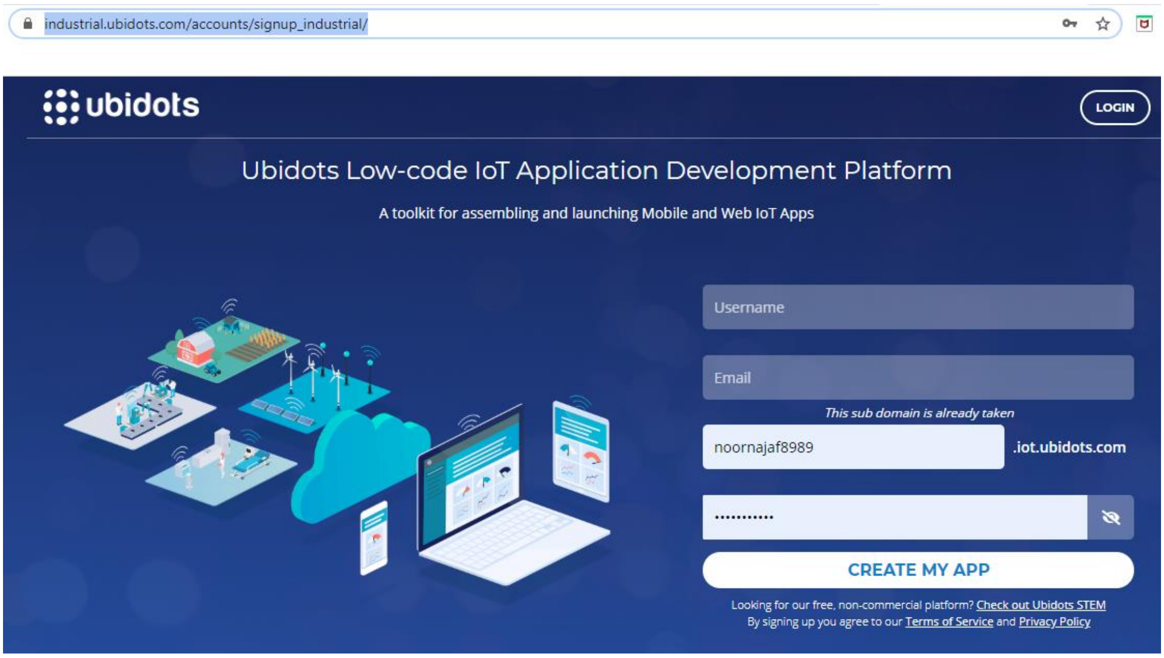
3.4.4 Node MCU Communication Steps with Ubidots

Step 1: Setting Up an Account in Ubidots

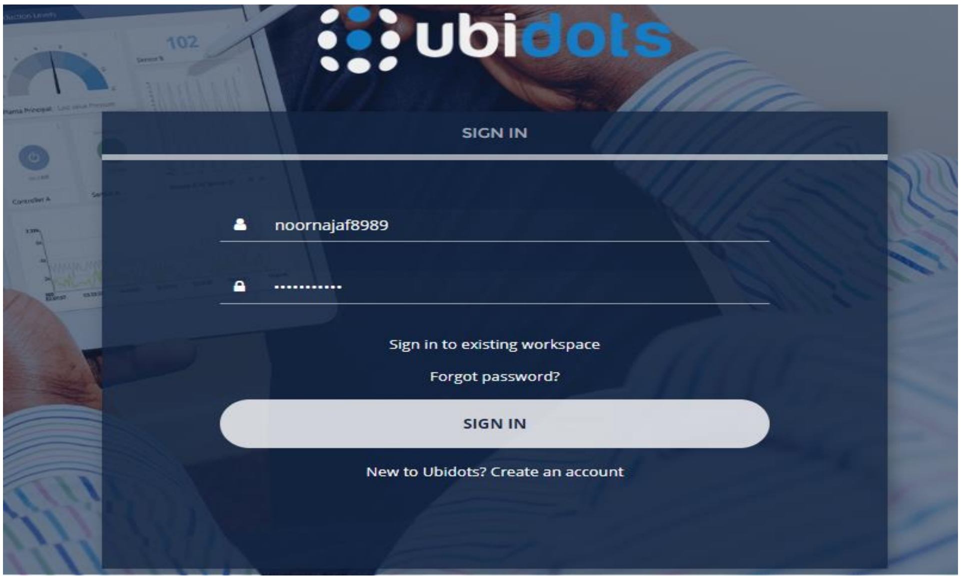
To create an Ubidots account, go to the following link (see Fig. 3.12-a):

https://industrial.ubidots.com/accounts/signup_industrial/

After completing entering the required information and creating the account, you can log in to the account at any time by entering your username and password as given in Fig. 3.12-b.



a- Create Ubidots account link

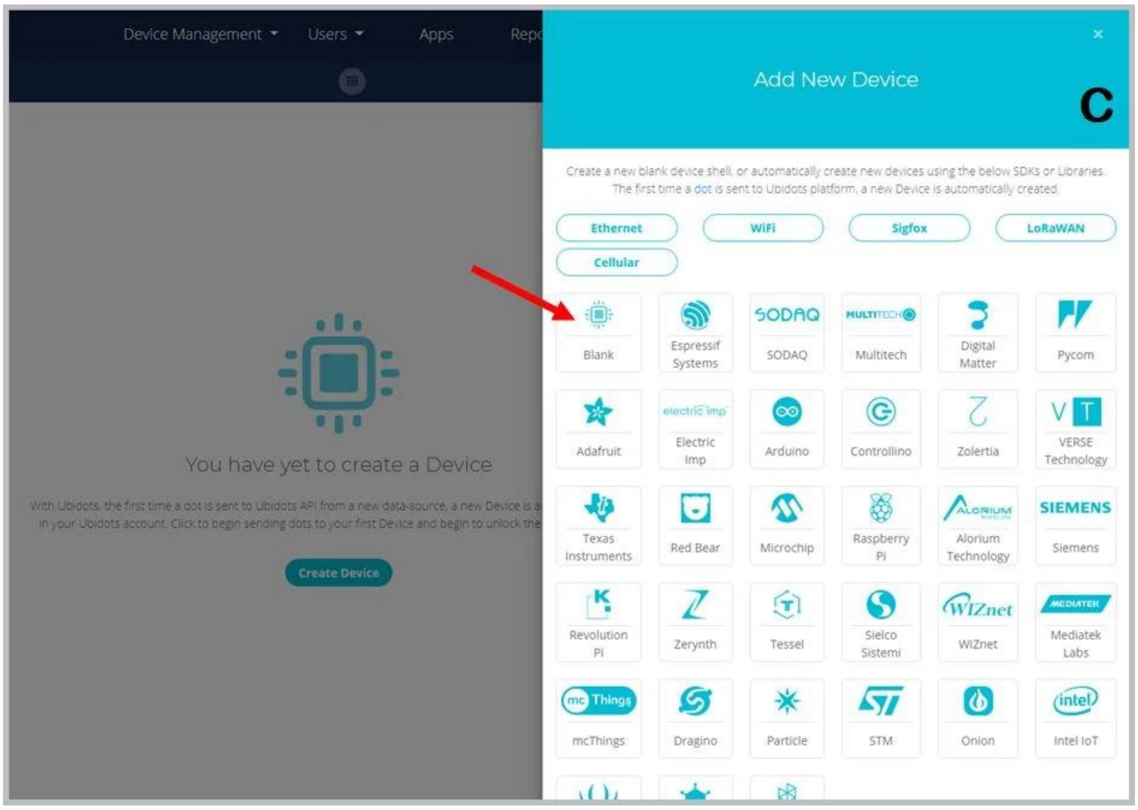


b- SIGN IN to the Ubidots account

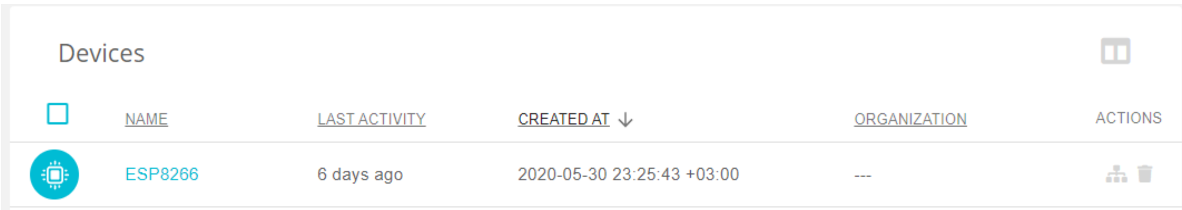
Fig. 3.12 Setting Up an Account in Ubidots

Step 2: Create a Device

To create a device, click on "Add New Device" and select "Blank" as shown in Fig. 3.13-a. Because this work use the Message Queuing Telemetry Transport (MQTT) protocol between Node MCU- ESP8266 and Ubidots, the device has been named as "ESP8266" (Fig.3.13-b).



a) Blank device



b) Device named ESP8266

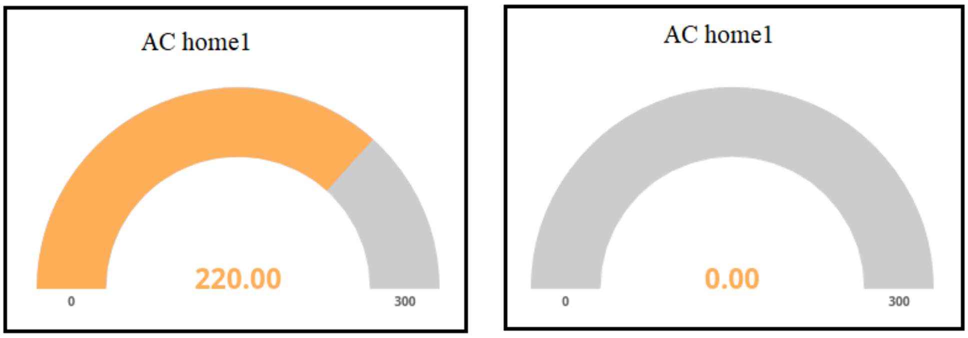
Fig. 3.13 Create a device step in Ubidots account

Step 3: Setting the Variables in Ubidots

In this step, the required variables in the system are created. Take a note of the variables written in the Ubidots are the same ones used with the code written in the microcontroller.

In this work, four data values will be uploaded to the Ubidots platform via the Node MCU-ESP8266, namely:

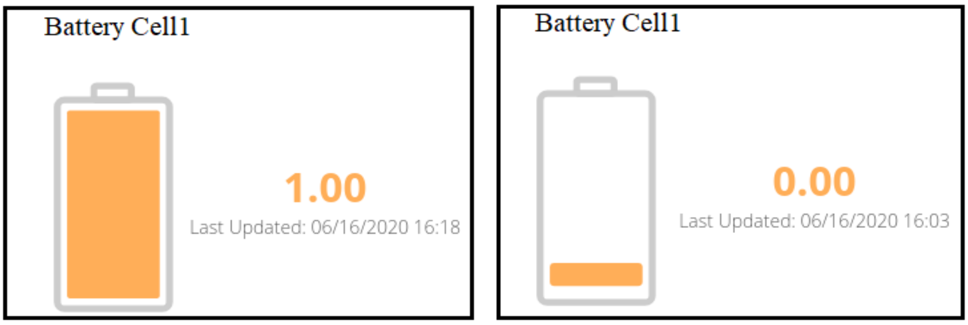
1 - The state of the main grid of home-1, which was expressed as (AC home1). When it is available, it will appear in the Ubidots control panel in the form of half-circle filled with an orange color and below it, the number (220) is written, see Fig. 3.14-a. If the grid is not available, it will be gray and below it (0) will be written, see Fig.3.14-b.



a) Grid available. b) Grid unavailable.

Fig. 3.14 Ubidots style of state of the main grid at Home-1

2 - The state of generated power of the home-1, is expressed as (Battery Cell1). When the power generated is available in the home, it will be represented by a battery filled with an orange color and beside it is written the number (1), see Fig. 3.15-a. If the power generated in the home is not available, the battery will be without color and beside it (0) will be written, see Fig. 3.15-b.

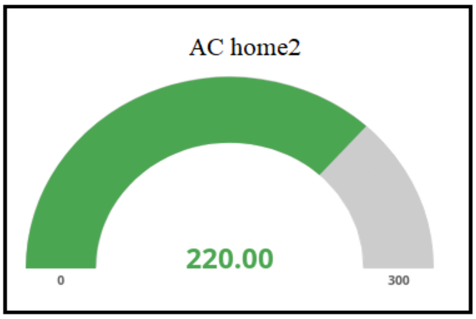


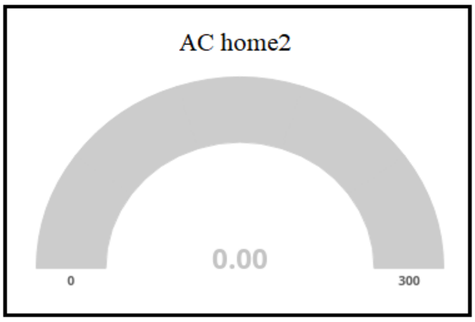
a) Generator power available. b) Generator power unavailable.

Fig. 3.15 Ubidots display of state of the generator of Home-1

3 - The state of the national grid of home - 2, is expressed as (AC home2). When it is available, it will be represented in the form of half-circle filled with an

green color and below it, the number (220) is written, see Fig. 3.16-a. If the grid is not available, it will be gray and below it (0) will be written, see Fig.3.16-b.

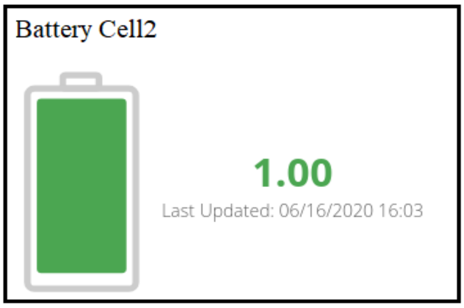


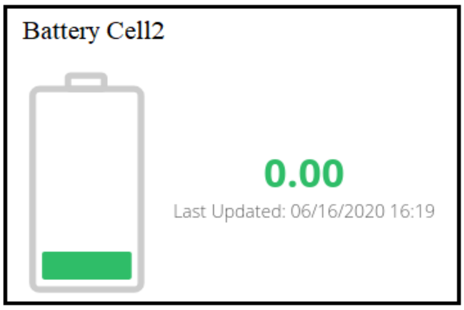


a) Grid available. b) Grid unavailable.

Fig. 3.16 Ubidots style of state of the main grid at Home-2

4- The state of generated power of the home-2, is expressed as (Battery Cell2). When the power generated is available in the home, it will be represented by a battery filled with an green color and beside it is written the number (1), see Fig. 3.17-a. If the power generated in the home is not available, the battery will be without color and beside it (0) will be written, see Fig. 3.17-b.





a) Generator power available. b) Generator power unavailable.

Fig. 3.17 Ubidots display of state of the generator of Home-1

Step4: Authentication

Every packet requires a TOKEN. It can be accessed by clicking on “API Credentials” under the profile tab as given in Fig. 3.18. There are two types of keys in the Ubidots account:

i- Tokens: Temporary and revocable key that is to be embedded in all your API requests.

ii- API Key: This is a “Master Key”; a unique and unchangeable key.

Notice that the Token written in the microcontroller code is the same as the Ubidots account. For the security mechanism Tokens generated from the account profile, indeed, will never be expired. They are useful for prototyping IoT solutions because to get a token, you didn't need an extra request in your code.

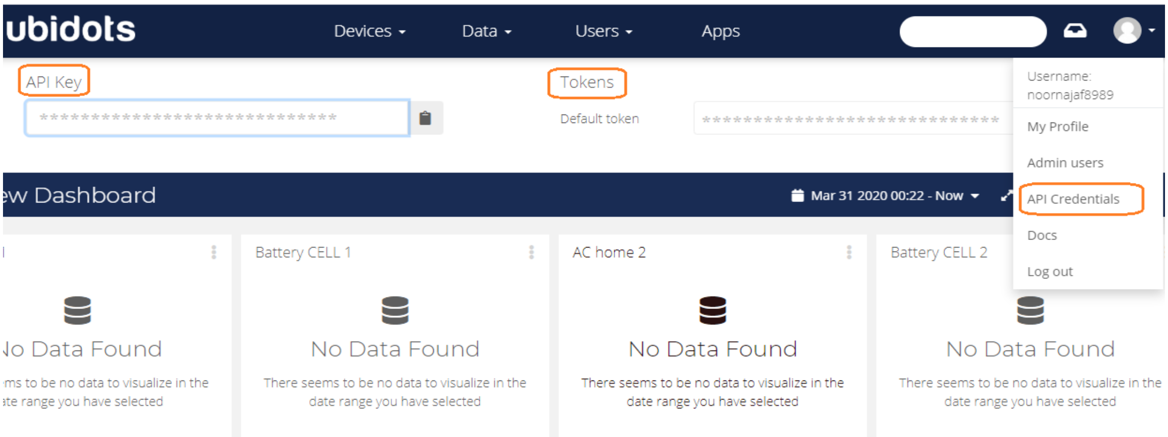


Fig. 3.18 Types of keys in the Ubidots account

Step 5: Testing of the Project

After checking the connection of all components of the circuit and verifying the Arduino sketch, open the Ubidots browser and click on the "dashboard" from the Data menu, as illustrated in Fig. 3.19. You will see that the Ubidots server receives and displays the information of the system and any change in the operation of the system will appear in Ubidots Dashboard as will explained in detail when studying the cases of the practical circuit.

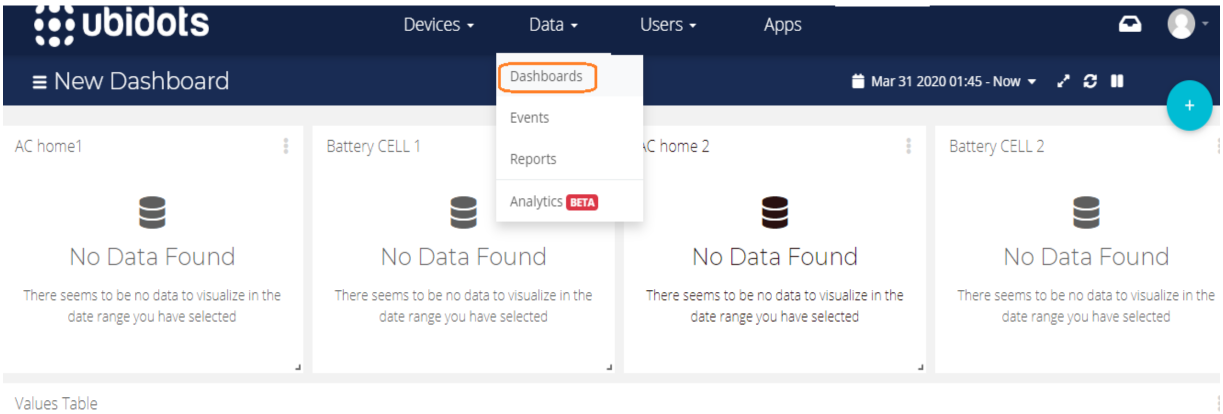


Fig. 3.19 Ubidots receives and displays the information of the system

3.5 System Communication Architecture

The communication system designed in this work offers two communications protocols. The first used device-to-device (wireless communication represented in RF and WiFi network) and the second humane-to-device (represented by Ubidots IoT platform). Hence, the protocols implemented are:

i- Two IoT protocols, MQTT and HTTPS,

ii- Serial communication protocols.

All the above protocols used to store sensor data in the cloud and analyzed it. Fig. 3.20 represented the whole communication architecture system. The sensor data are collected to read by the UNO controller, which sends these data wirelessly to the Nod MCU by RF. The data are sent to the MQTT Broker (server) where all data about the two homes and the main grid are collected and stored. The Web server receives updates from the MQTT server and writes them to a database. HTTPS communication protocol presented at the Ubidots platform. The network users get all data from the Web server.

Serial communication protocol is used to exchange of data between Nod-MCU and the HC-12 in the form of series data over the communication channel. The mode type used in the this work is Half Duplex. It means the sender and receiver might be active but not at the same time. When HC-12 sends the sensor data to the Node MCU, the Nod accepts the data and uploaded it to the internet network but could not send any data toward HC-12 at once.

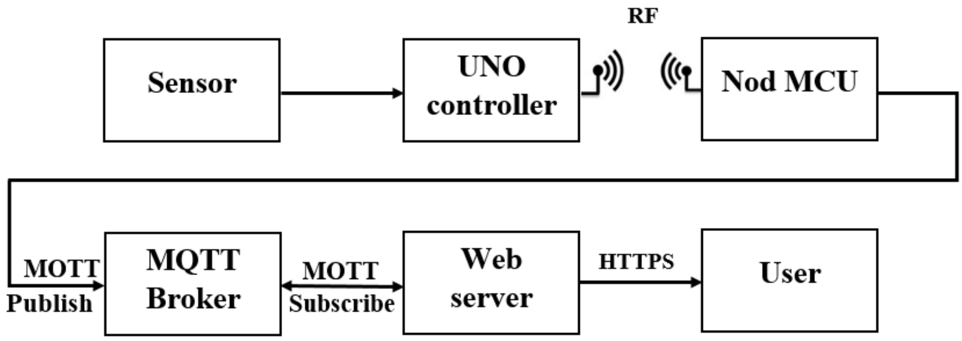


Fig.3.20 proposed system communication architecture

Chapter Four
Operation of the Practical Circuit and Results

4.1 Introduction

In this chapter, the final practical circuit implementation is introduced. The operation of the circuit is illustrated. Many cases are discussed for different types of load conditions. The discussion of all practical results is given.

4.2 Complete Circuit Connection of the System

The complete circuit of the system designed in this work is depicted in Fig. 4.1. The circuit connection description for the single home can be summarized as follows:

The main electric grid signal is linked to the analog input pin (A0) of microcontroller after step downing by transformer and voltage divider. This voltage signal is used to detect the availability of the grid or not. The current sensor (ACS712) senses the current drawing from the total load of the home and this signal is sent to the analog pin (A1). According to this current value, it will be determined whether or not the home has excess energy.

The (LCD 20×4) is used to display the output of the microcontroller, which refers to all statuses for the homes and grid. It connects with pins (A4 & A5) of Arduino by I2C communication serial protocol, where SDA (Serial Data) pin connected to A4 pin and SCL (serial clock) pin connected to A5 pin. The SDA line and the SCL line are bidirectional, providing easy and efficient transmission of data [49]. Arduino digital output pins (2, 3, 4, 5,6,7,8, and 9) are connected with an 8-channel relay module, where it used to ON/OFF power of the loads.

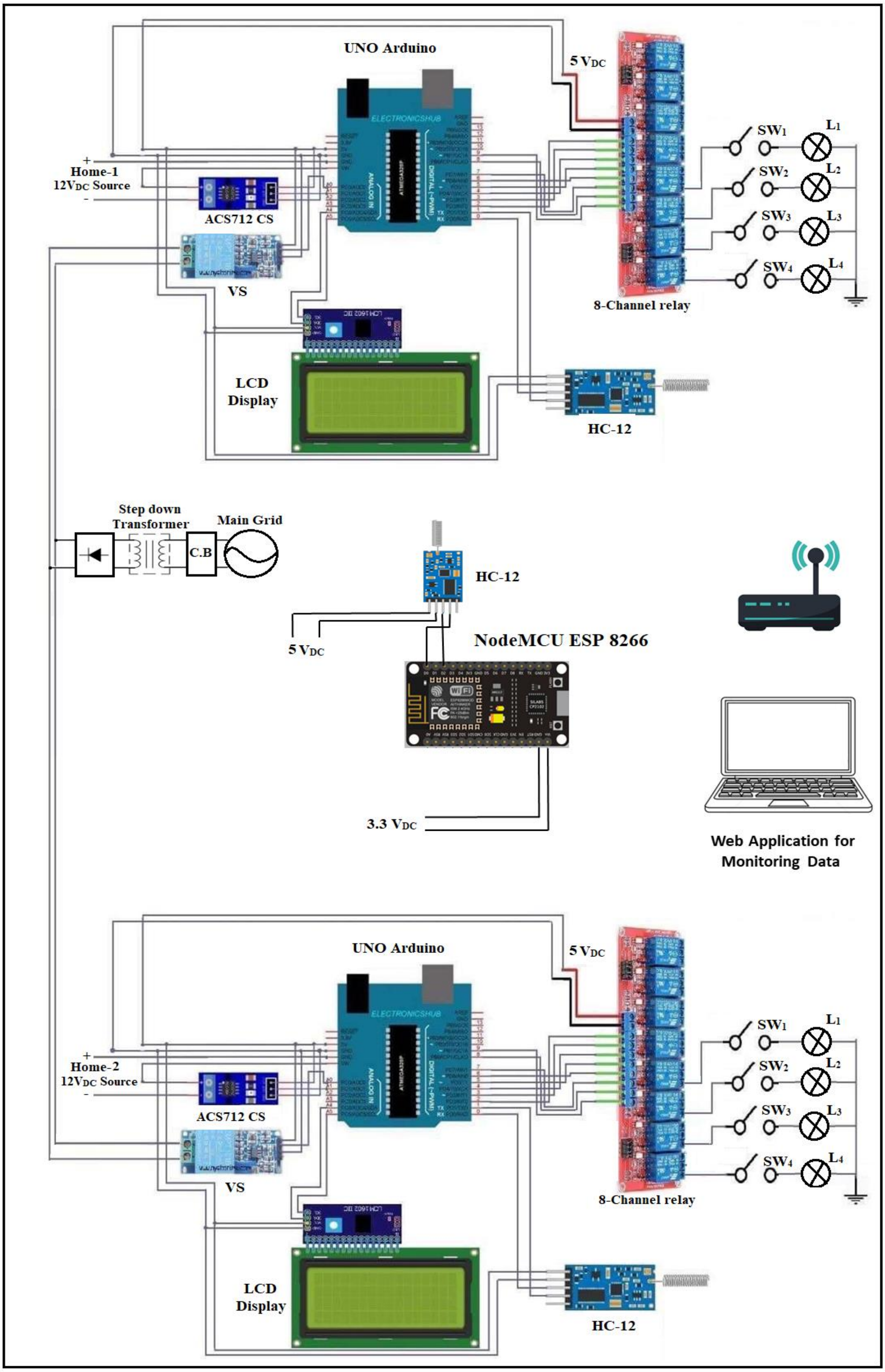


Fig. 4.1 Complete circuit diagram connection of the system

RF-HC-12 module, that exchanges data between homes and Node MCU about their load's condition and operating mode wirelessly, is connected to (TX, RX) pins of the Arduino. All parts of the circuit (C.S, RF, LCD, and relay coil) are powered by an Arduino Uno board power supply. Figure 4.2 shows the pictorial image of the practical components and connection of the circuit.

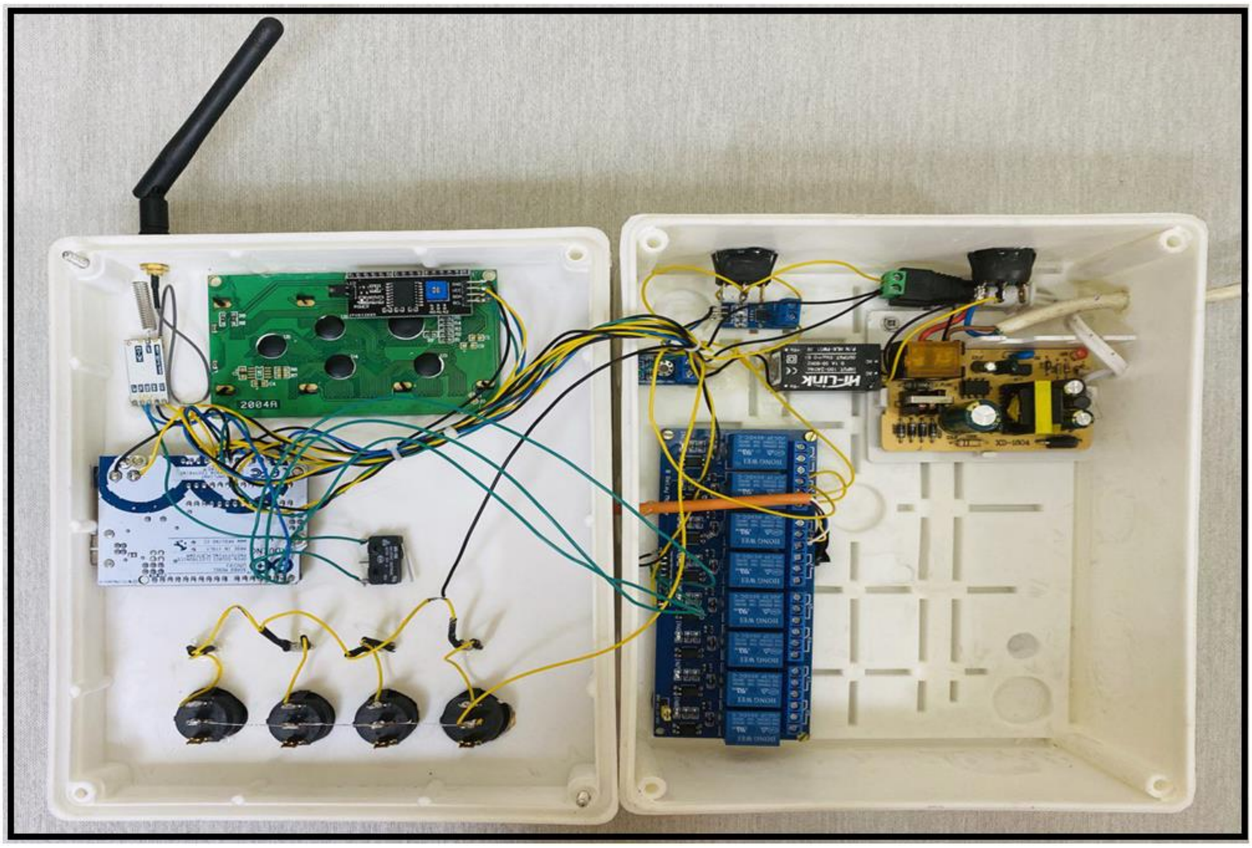


Fig. 4.2 Pictorial image of the single home practical circuit.

The controller Node MCU ESP8266-01is used to connect the system with the Ubidots platform by its WiFi for establishing remote monitoring continuously with a laptop or smartphone. Node MCU board is connected with the RF-HC-12 with serial ports (TX, RX) as given in Fig. 4.3. This connection is made by using a logic level convertor, which contains 3.3V & 5V where ESP8266 operated with 3.3V and HC-12 operated with 5V. The pictorial image of the Node MCU circuit connection is given in Fig. 4.4.

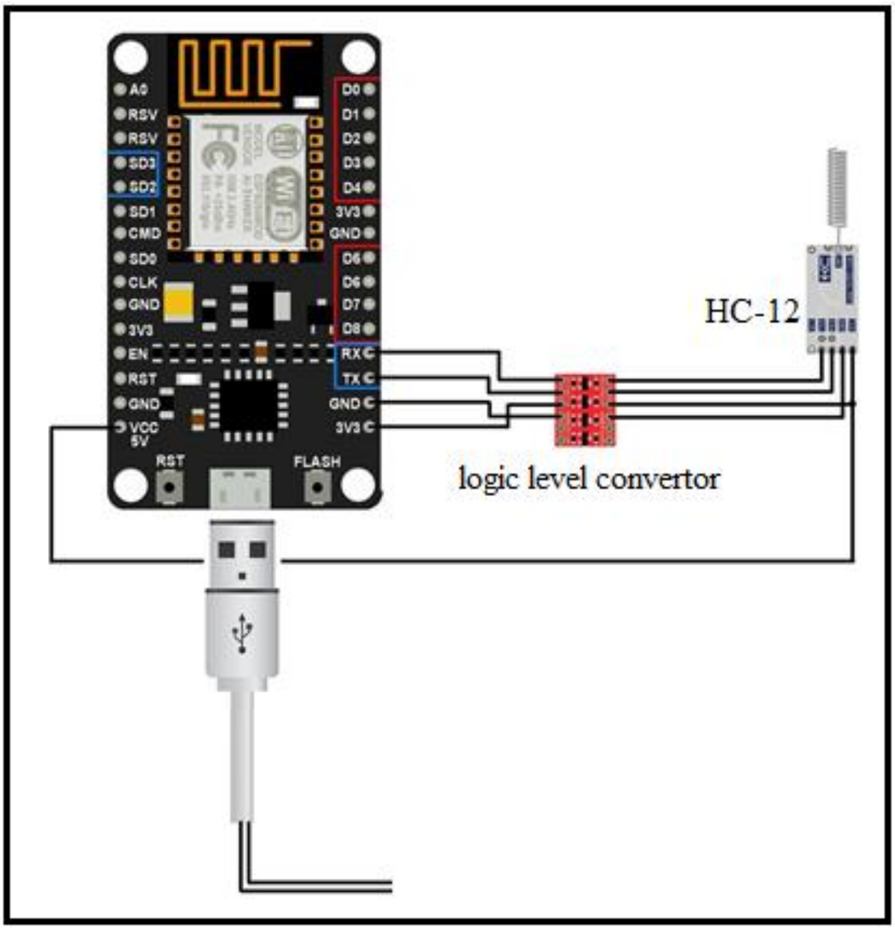


Fig. 4.3 Circuit diagram connection of the Node MCU

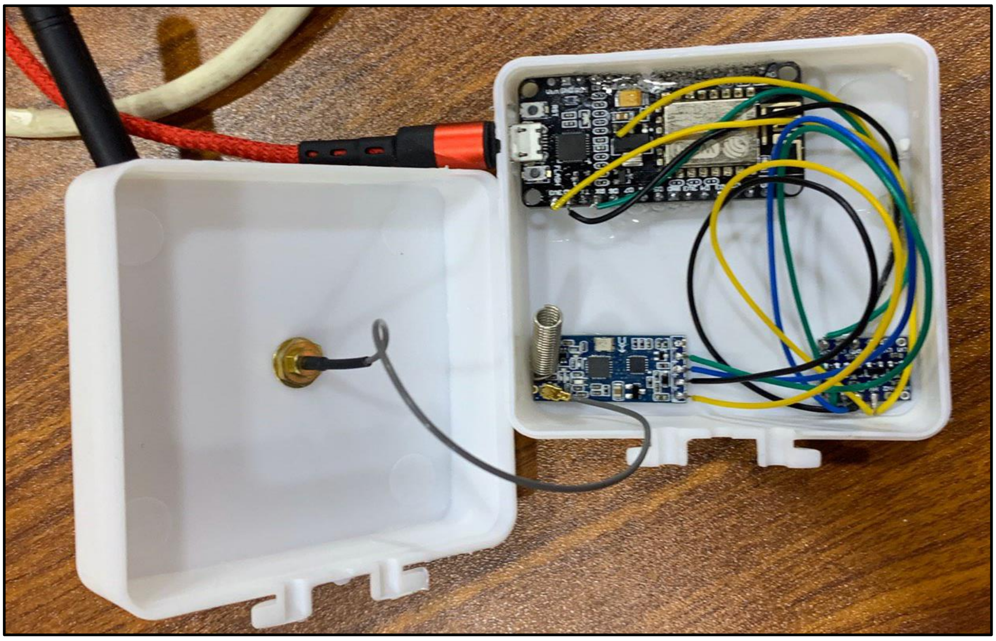


Fig. 4.4 Pictorial image of the Node MCU circuit

4.3 Proposed System Work Description

For simplicity and to achieve the main objectives of the thesis, which include transferring data to the Internet cloud and monitor it in the best way and achieving control over the system, a 12 V DC system was proposed. Four lamps each have 10 watts power were used in each home to represent the load. The lamps are controlled manually to interpret the change in the load during the day in the system. The transition from the Island mode to the grid-connected mode or to the connection with the second home is fully automatic and as follow:

1- When the generated power of the homes is greater than its load, the homes supply the extra power to the grid or any part in the system needs power.

2- When there is a power deficit in one home, and excess energy is available in the other home, the priority of receiving energy is from the home that has excess energy (because the assumption in the proposed system that the price of energy supplied from neighboring home is less than from the grid).

3- When the generated power in both homes is less than their load, the required energy is provided from the main grid.

4- When the main grid is not available and the generated power of each home is insufficient to operate all the loads in it, it becomes obligatory for each house to operate only the necessary loads and work in the Island mode.

The supplied DC power for each home is obtained from an external DC source. The supplied power is controlled and determined by microcontroller programming according to all cases mentioned above. It is changed programmatically to satisfy the operation of the proposed system under all conditions and to simulate the PV solar power that varies changed according to weather conditions.

4.4 Results Analysis of the Cases Studied

Two states for the prototype system designed in this thesis are studied to check the operation of the proposed system. The following sections offer a detailed illustration.

4.4.1 Single Home with Grid

In this section, we will study the system with only a single home (which represents a Nano- Microgrid system). This home has its own power supply and it can be tied with the national grid, according to its load and the grid status. The practical circuit of the system is shown in Fig. 4.5.

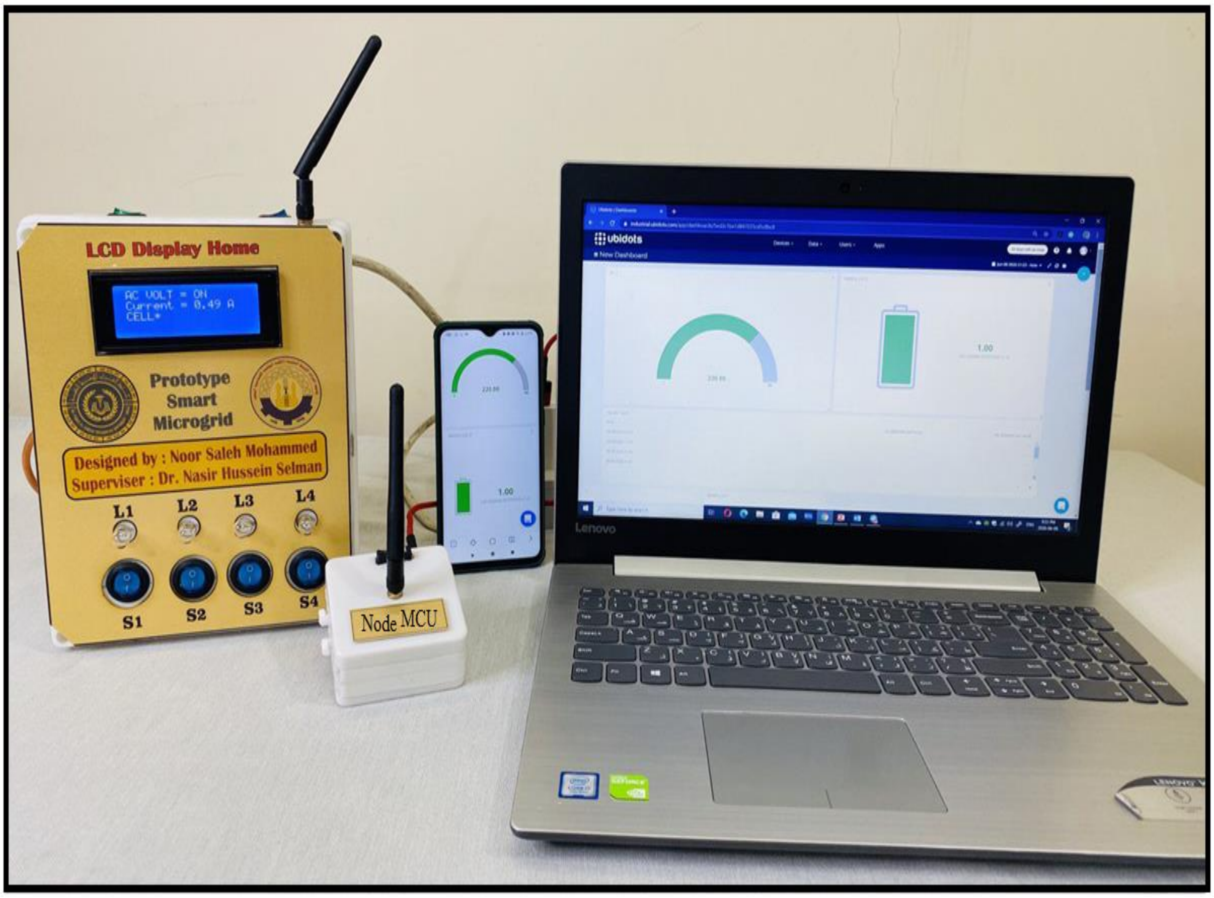


Fig. 4.5: Image of the final design

The system flowchart is shown in Fig. 4.6. According to the flowchart, the following three cases will be studied.

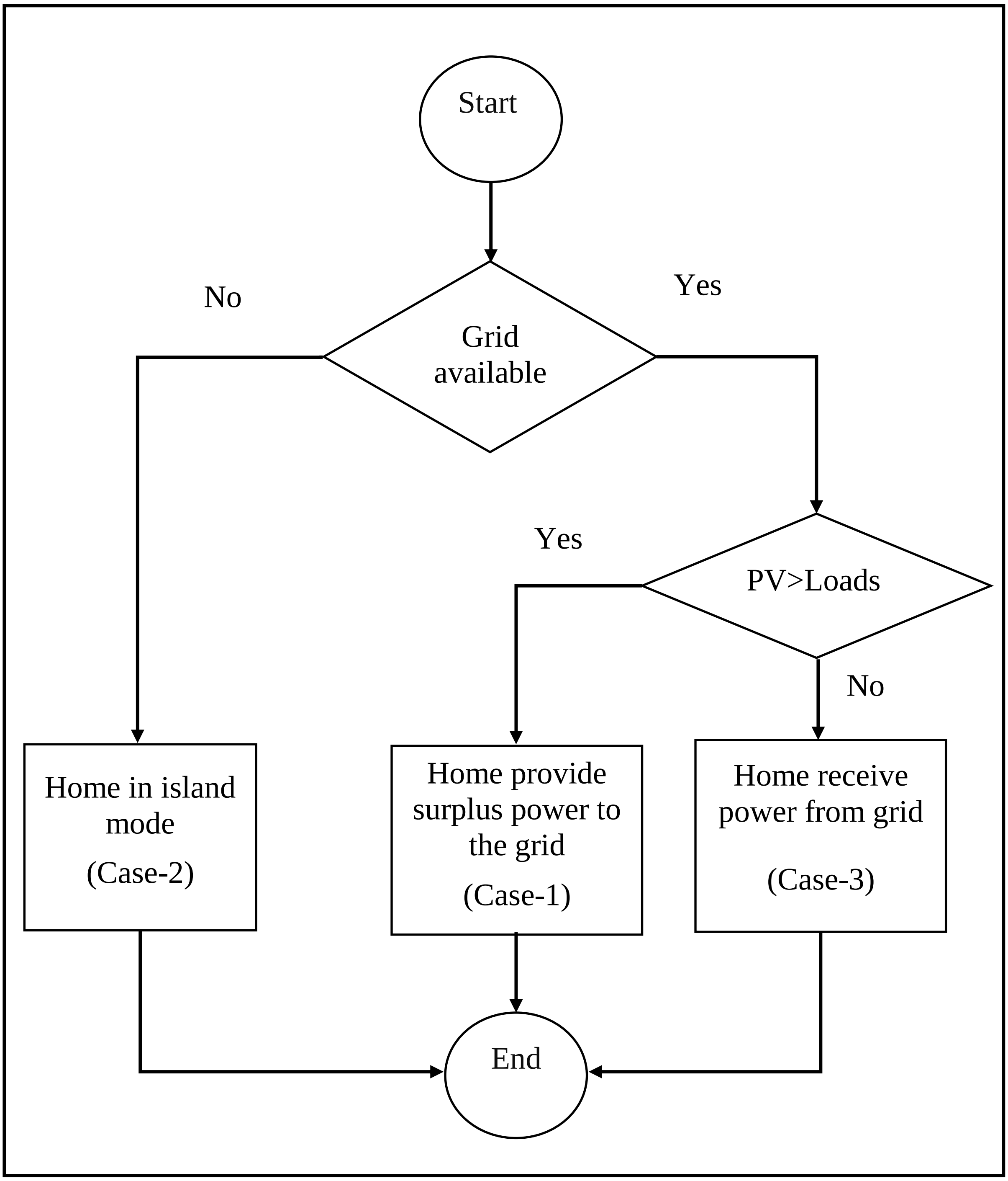


Fig. 4.6 Flowchart of the management single home with grid

Case1: Grid available and home generated power > load

In this case, the grid is present and the home generates power greater than the total home load (load current less than 2.5A). This case is indicated by the symbol (cell*) in Fig. 4.7, which means the home loads are fed from the home's source and there is surplus power in the home. The wireless RF of the home sends a signal to the Node MCU to let him know that there is extra power available, as defined by the symbol (A) in Fig. 4.7. Here, The surplus power is being assumed sold and added to the main grid. Table 4.1 illustrate the meaning of the symbols that appear on the LCDs of each home.

Fig. 4.7 Print screen of the state of the grid and home for case-1

Table 4-1 Summary results LCD displays of single homes with grid for case -1

Case1: Grid available and home generated power > load		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	ON	Grid available
Signal sending from home	A	Home export power to the main grid
Feeding of home loads	CELL *	Home loads are fed from the home's source and there is surplus power in the home.

Figure 4.8 shows the results uploaded to the Ubidots platform which represents home power and grid status. The battery represents the state of DC generated power of the home where they appeared fully charged in this case to indicate the availability of additional energy. Also, the main electric grid is present on the Ubidots platform.

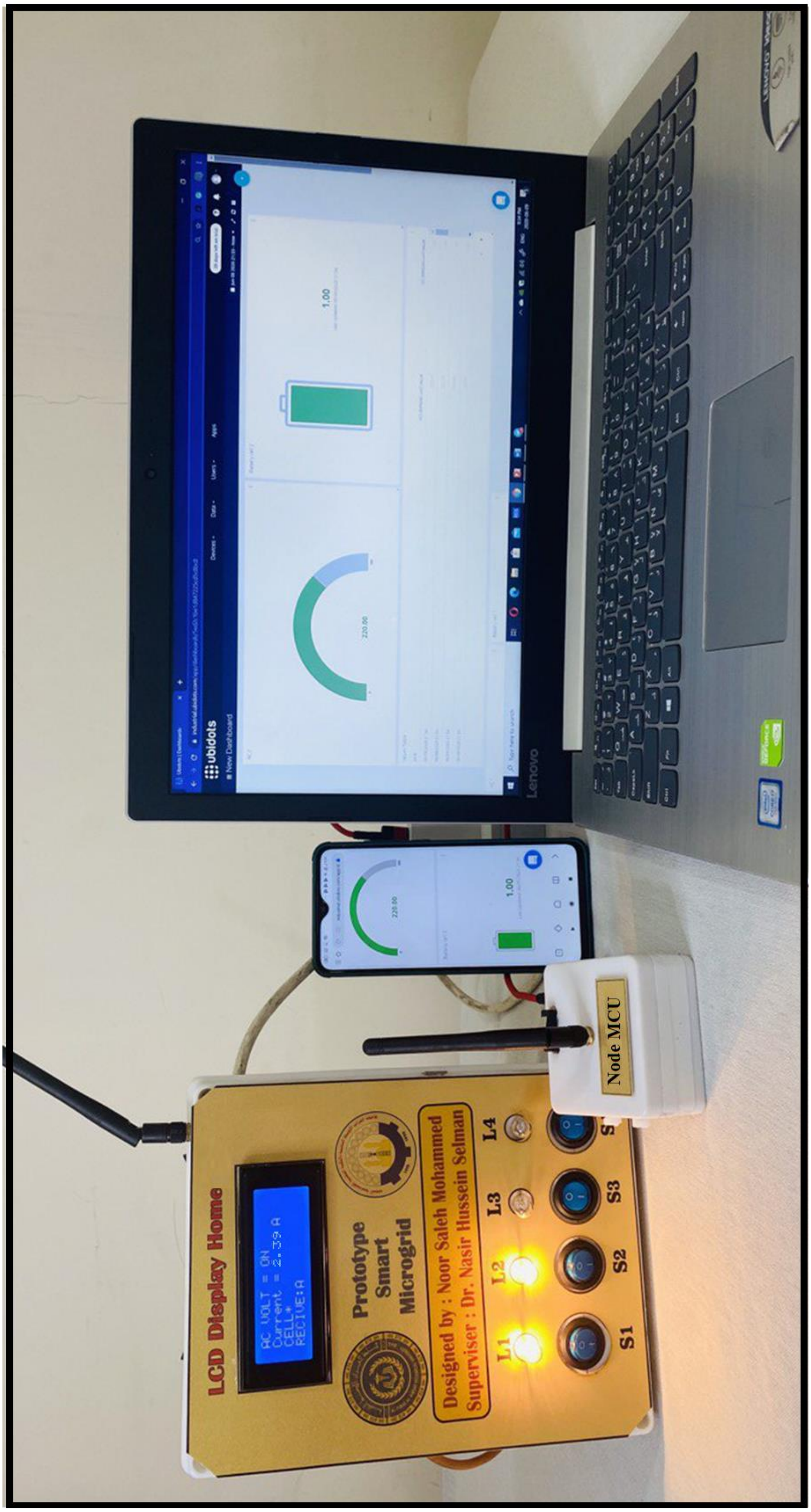


Fig. 4.8: Ubidots data of the home and grid of case-1

Case 2: Grid is not available

This case discusses the absence of the main grid and the home operate in Island mode. Figure 4.9 shows print screen of LCD of this case. It displays (cell) that means this house is in island mode, i.e. the house is fully provided by its own generation only. The state of grid is expressed by (AC VOLT:OFF) to refer that the grid unavailable. This case represented by a letter (C) in the LCD. Table 4.2 illustrate the meaning of the symbols that appear on the LCDs of each home

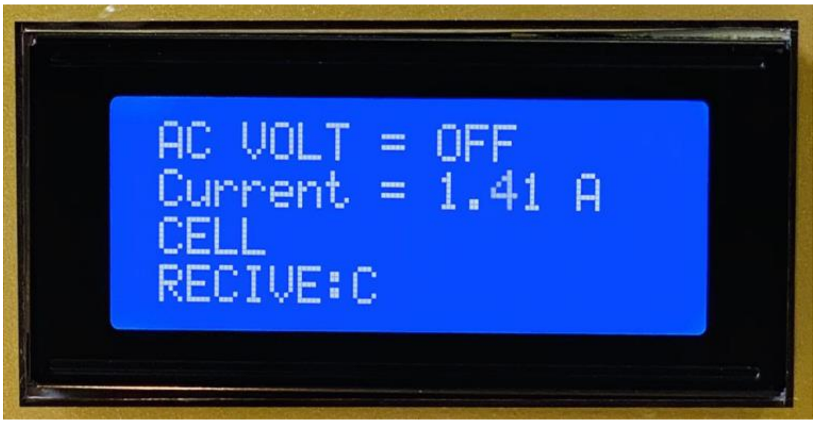


Fig. 4.9 Print screen of the state of the grid and home for case-2

Table 4-2 Summary results LCD displays of single homes with grid for case -2

Case 2: Grid is not available (Island mode)		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	OFF	Grid unavailable
Signal sending from home	C	Home operate in Island mode
Feeding of home loads	CELL	Home loads are fed from its sources only.

Figure 4.10 shows the results uploaded to the Ubidots platform for home power and grid status. From the figure, we note that the home power is available and represented by a full battery and the grid is not available.

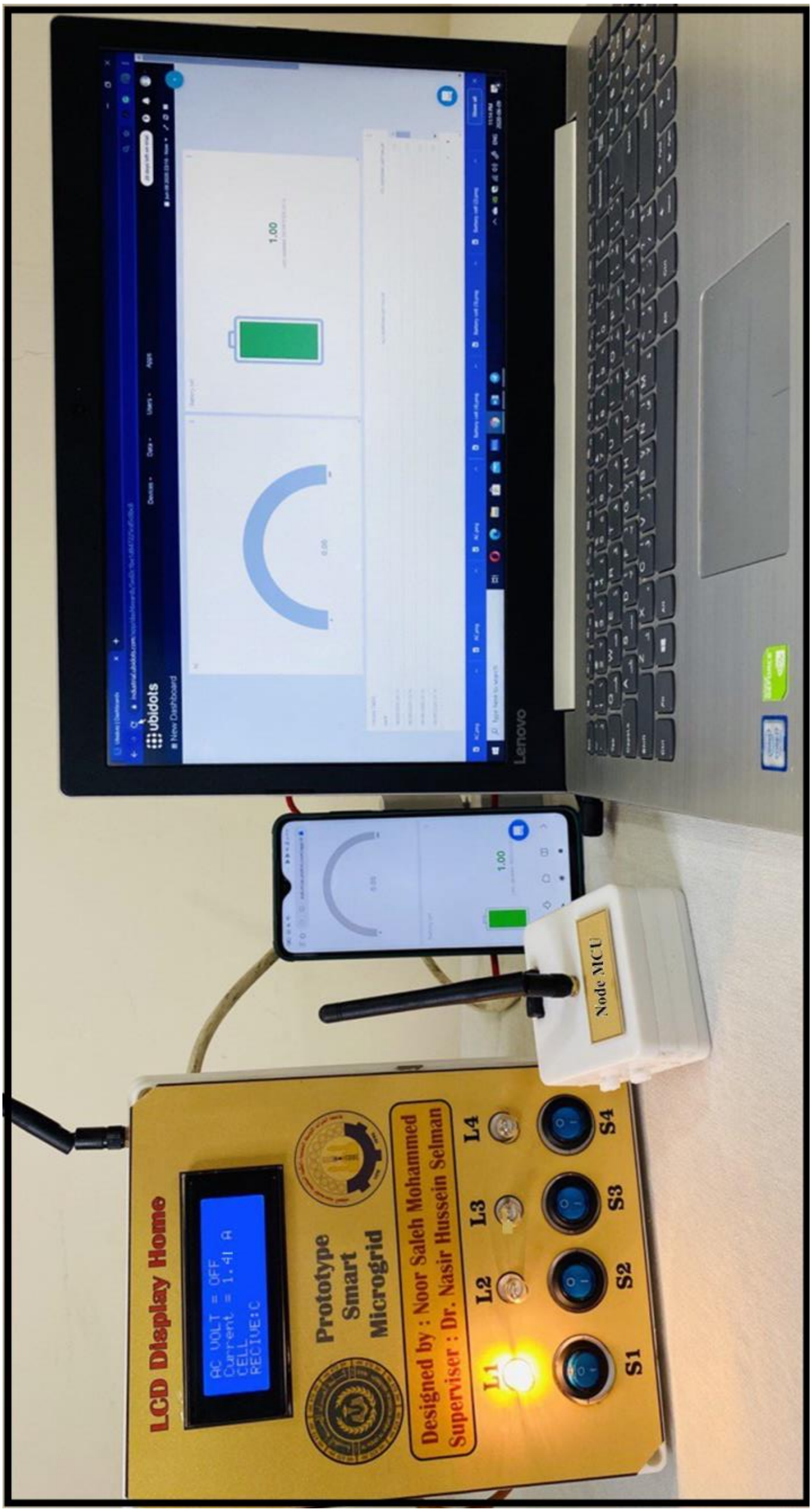


Fig. 4.10: Ubidots data of the home and grid of case-2

Case3: Grid available and home generated power < load

In this case, the home power consumption is greater than the home generation, so the home sends a signal to the Node MCU that its generator power not enough to cover the total loads (current 4.27A). Therefore, the home imports power from the main grid, and the LCD display shows the status (GRID) to refer that the home depends on the main grid. This case represented by a letter "D" in the LCD. Table 4.3 illustrate the meaning of the symbols that appear on the LCDs of each home

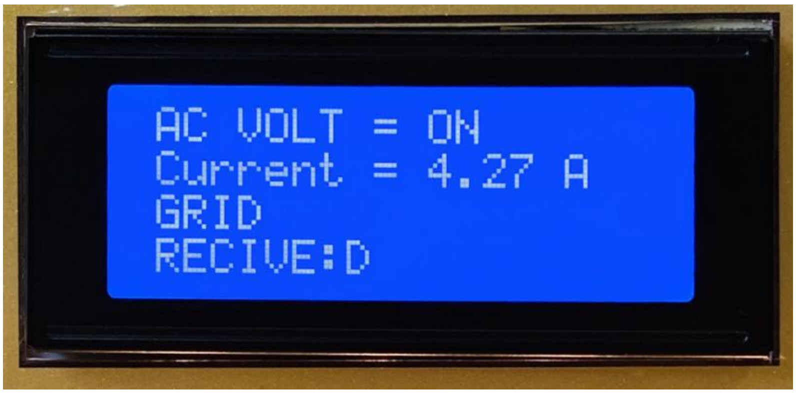


Fig. 4.11 Print screen of the state of the grid and home for case-3

Table 4-3 Summary results LCD displays of single homes with grid for case -3

Case3: Grid available and home generated power < load		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	ON	Grid available
Signal sending from home	D	Home import power from the grid
Feeding of home loads	GRID	Home loads are fed from the grid

Figure 4.12 shows the results uploaded to the Ubidots platform for home power and grid status. From the figure, we note that the grid is available while the power generated from the home is low and represented by a battery with low charge.

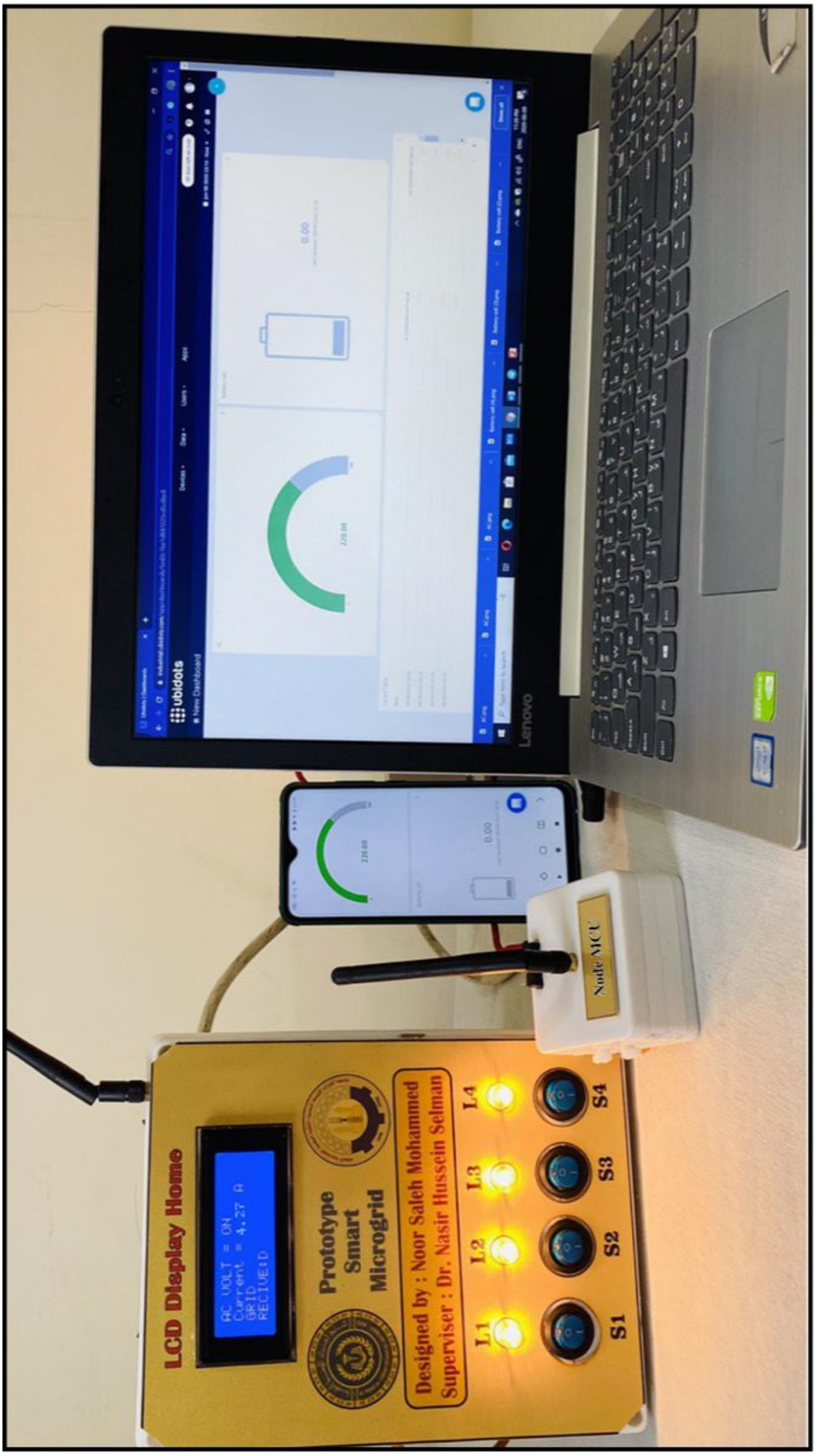


Fig. 4.12: Ubidots data of the home and grid of case-3

4.4.2 Two Homes with Grid

Figure 4.13 explains the flowchart of the proposed model which consists of two homes and represents the idea of the prototype smart Microgrid.

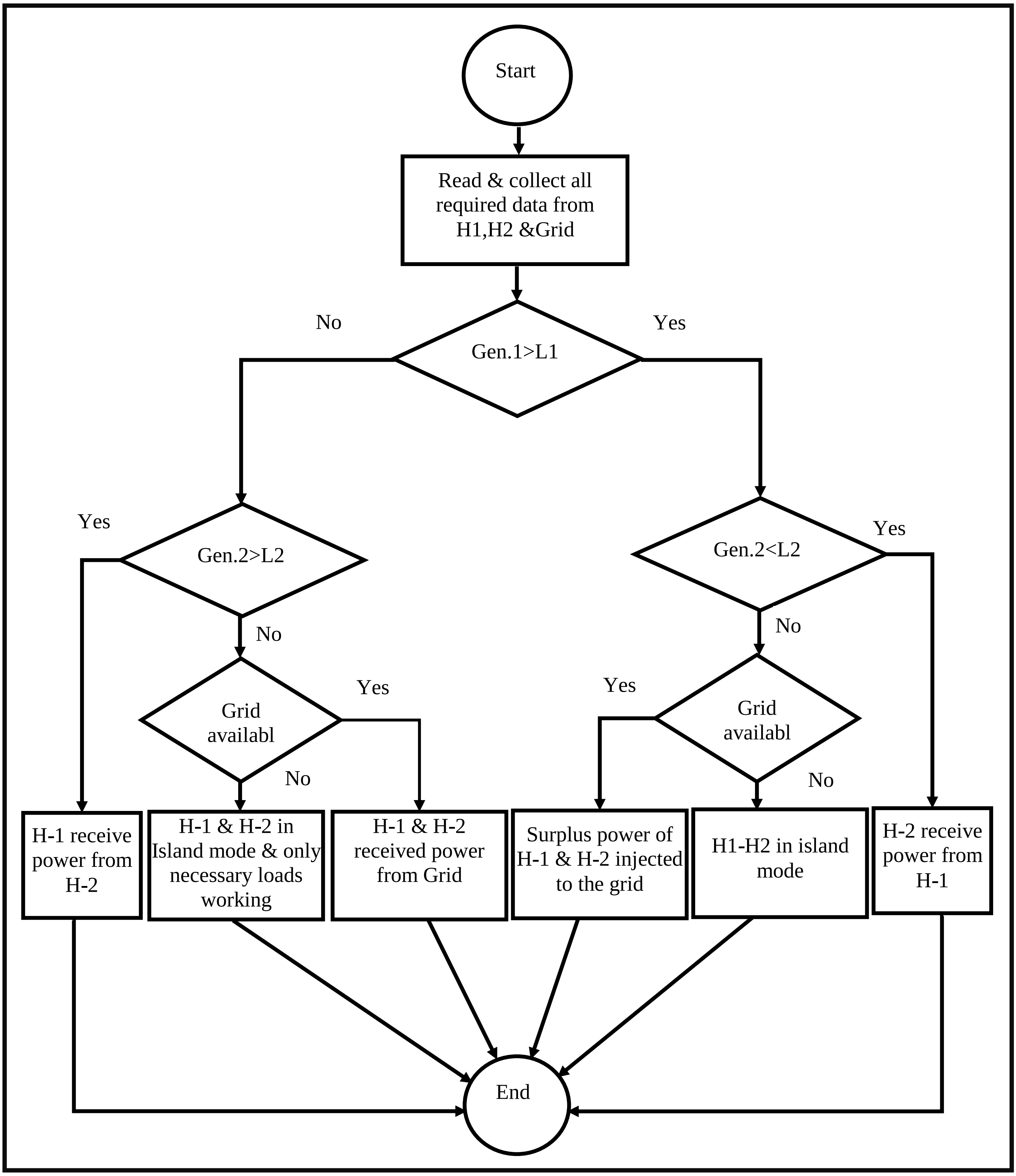
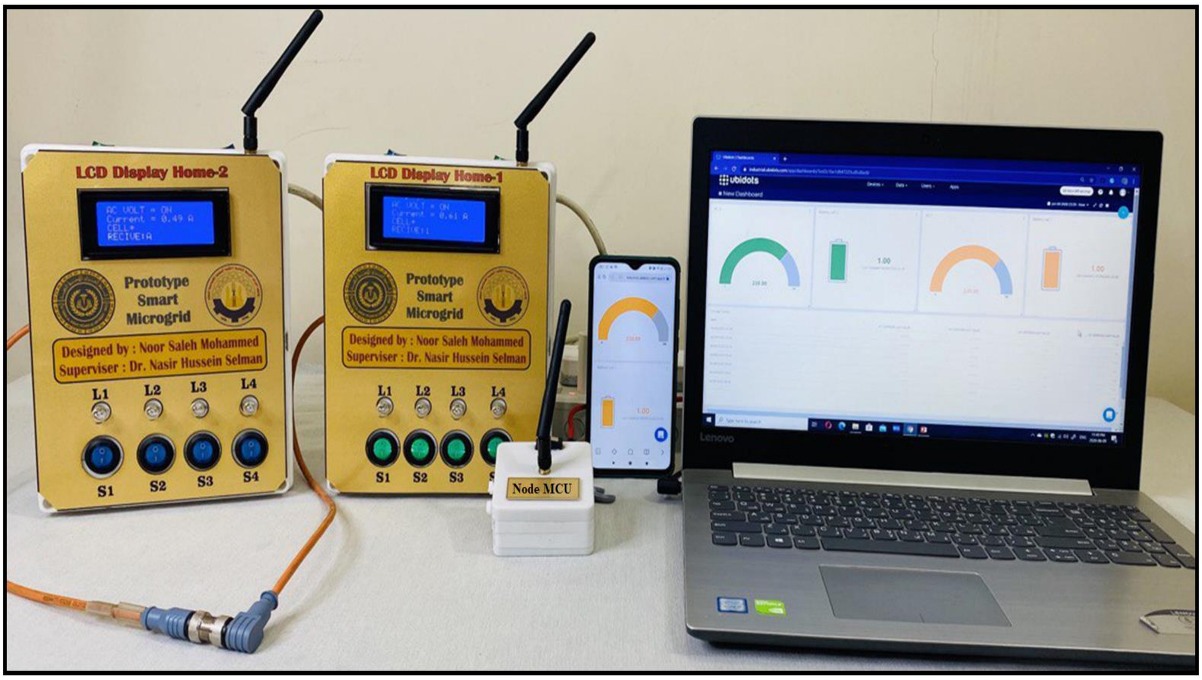
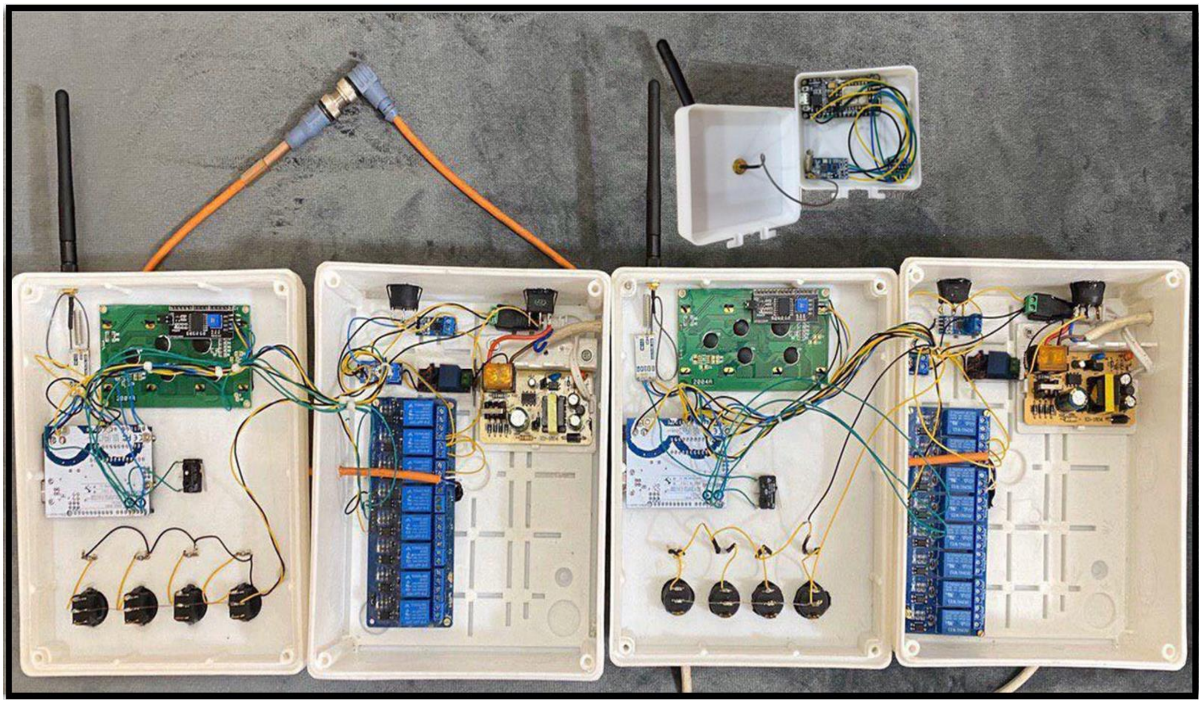


Fig. 4.13 Flowchart of the management the smart Microgrid

An image of the final design of the system is depicted in Fig. 4.14. The following cases are studied for the prototype system.



a) Exterior design



b) Internal connection

Fig. 4.14 Final image of the complete prototype system

Case 1: Grid available and generated power > load for each home

In this case, both homes generate power greater than their loads. Home-1 transfer a signal (RECEIVE: A) and Home-2 transfer a signal (RECEIVE: 1) to the Node MCU to inform each subscriber of the state of its available power. The word (CELL *) in the screen picture of Fig. 4.15 means that the home covers its load and injects the excess power into the electrical network. Table 4.4 illustrate the meaning of the symbols that appear on the LCDs of each home

Fig. 4.15 Print screen of the state of the two homes for case-1

Table 4-4 Summary results LCD displays of two homes with grid for case -1

Case 1: Grid available and generated power > load for each home		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	ON	Grid available
Signal sending from Home-2	1	Home-2 export power to the main grid
Signal sending from Home-1	A	Home-1 export power to the main grid
Feeding of homes loads	CELL *	Homes loads are fed from the home's sources and there is surplus power in the home.

Figure 4.16 shows the results that appear on the Ubidots platform which represents home conditions and grid. The generated power of each home where they appeared by fully charged batteries, i.e. there is extra power available in each house. Also, the electric grid is presented clearly.

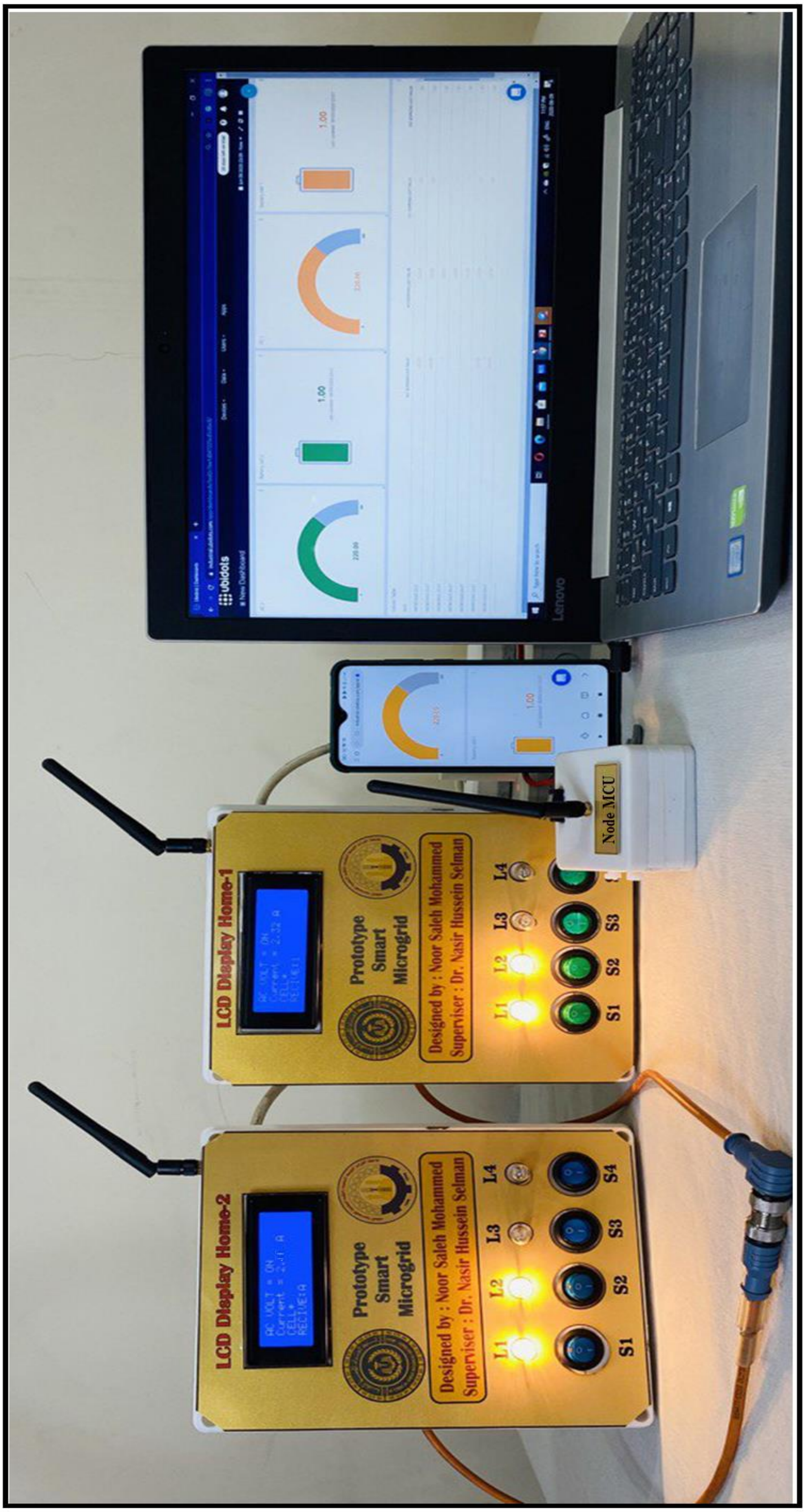


Fig. 4.16: Ubidots data of the two homes and grid of case-1

Case 2: Grid available and (Generated1 > load1 & Generated2< load2)

In this case, Home-1 generates power greater than it's loads, and Home-2 needs power. Here, Home-2 sends a signal (RECEIVE:2) that it needs additional power and at the same time Home-1 sends a signal (RECEIVE:A) that it has additional energy. By assuming that the cost of energy is less in selling when trading between homes, therefore, the priority is to import and export energy from homes among themselves rather than importing them, when needed, from the grid. Thus, Home-2 is equipped with the necessary power from the Home-1. This case is illustrated in the private LCD of Home-2 with (CELL+HOM1, which means Home-2 is fed from its source and from the Home-1) and in the private LCD for the Home-1 with (CELL*, which means the Home-1 feeds itself and has surplus power). This situation is illustrated in the screen image of the LCD of Fig. 4.17. Grid availability status is shown in the figure with the symbol "AC VOLT: ON". Table 4.5 illustrate the meaning of the symbols that appear on the LCDs of each home

It is worth noting that even if the Node MCU does not work and the internet is interrupted, the data between the two homes can be transferred between them through RF and thus the reliability of data transmission is excellent.

Fig. 4.17 Print screen of the state of the two homes for case-2

Table 4-5 Summary results LCD displays of two homes with grid for case-2

Case 2: Grid available and (Generated1 > load1 & Generated2< load2)		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	ON	Grid available
Signal sending from Home-2	2	Home-2 received power from Home-1
Signal sending from Home-1	A	Home-1 export power to Home-2
Feeding of Home-1 loads	CELL*	Home-1 supply its load and surplus power is sent to the Home-2
Feeding of the Home-2 loads	CELL+HOM1	Home-2 loads are fed from its internal source and from the Home-1 source.

Figure 4.18 shows the results that appear on the Ubidots platform which represents both homes and grid conditions. The battery of HOME-1 is full which represents the extra energy found in this home while the battery of HOME-2 is not full which represents the home needs power.

Fig. 4.18: Ubidots data of the homes and grid of case-2

Case 3: Grid unavailable (Island mode)

In this case, the electrical network is not present because a disturbance and the power generated in each house is present. By assuming that each house can only supply its own load and does not have surplus power. Therefore; each home will operate separately (Island mode) and only necessary loads will work from each house according to its generative power. The Node MCU will send a signal to all homes that there is a fail in the grid as specified in Fig. 4.19 with the symbol "AC VOLT: OFF". Also, each house will know the state of the other houses through the symbol "CELL". Also, each home will know the status of the other home through the symbol “RECEIVE:3” and the symbol “RECEIVE:C” sent from Home-1 and Home-2, respectively. Table 4.6 illustrate the meaning of the symbols that appear on the LCDs of each home

Fig. 4.19 Print screen of the state of the two homes for case-3

Table 4-6 Summary results LCD displays of two homes with grid for case -3

Case 3: Grid unavailable (Island mode)		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	OFF	Grid unavailable
Signal sending from Home-2	3	Home-2 operate in Island mode
Signal sending from Home-1	C	Home-1 operate in Island mode
Feeding of Homes loads	CELL	Homes loads are fed from their sources only and there is no surplus power.

Figure 4.20 shows the results that appear on the Ubidots platform which represents the status of the homes and grid. As illustrated in the figure, the power generated in each home is available but the grid signal is unavailable.

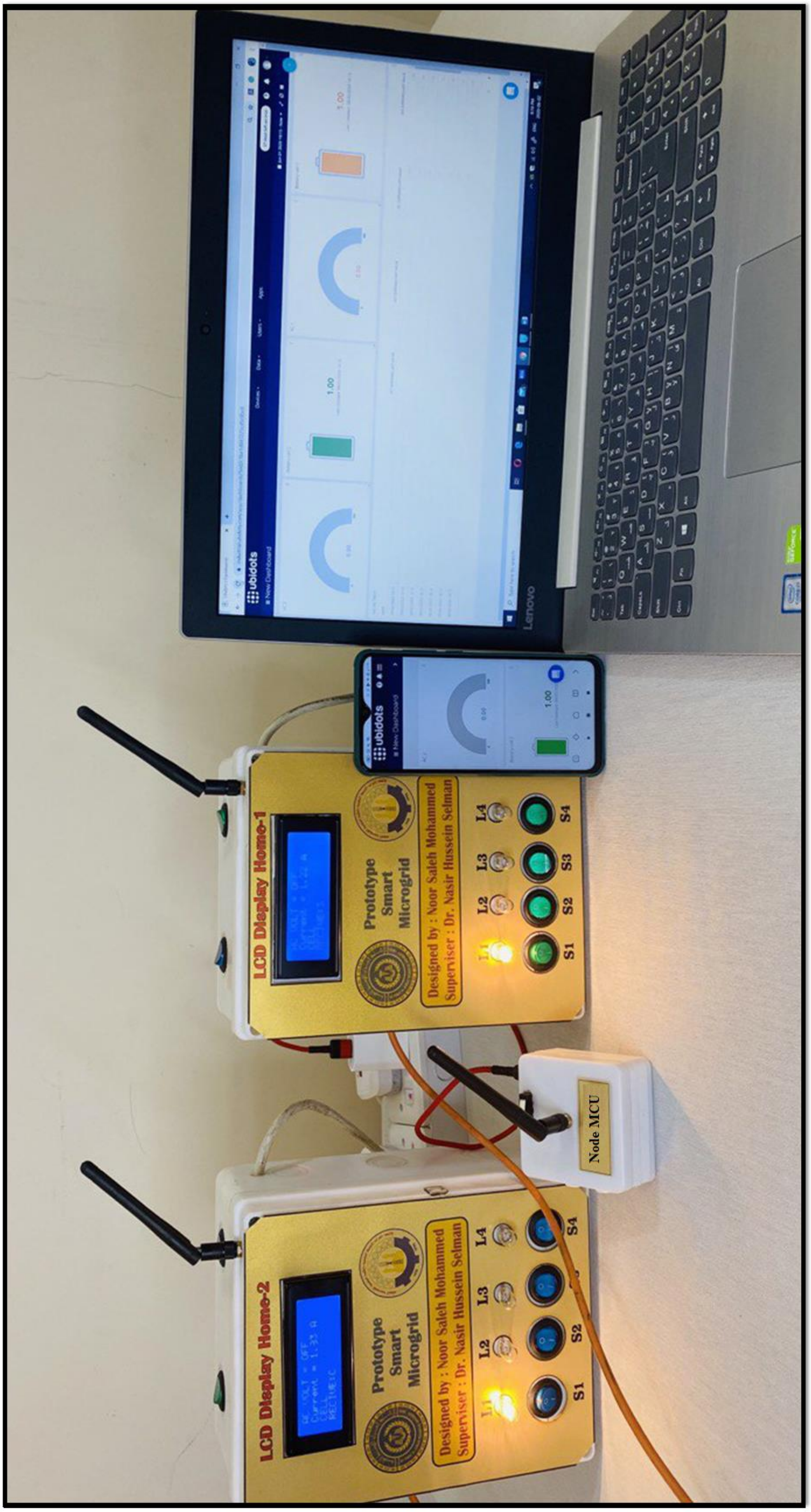


Fig. 4.20 Ubidots data of the homes and grid of case-3

Case 4: Grid available and homes power generated unavailable (or homes generated power < load)

In this case, power generation in both homes is less than the load and they depend entirely (or partially) on the electrical network for supplying electrical power. Figure 4.21 shows the detail of the state, where the grid is shown with the symbol "ACVOLT: ON", which indicates the presence of the grid. The two homes receive power from the grid, as shown by the "GRID" symbol in the same figure. Also, each home aware of the state of the other house that it receives its power from the grid through the symbols "RECEIVE:4" and "RECEIVE:D" sent from Home-1 and Home-2, respectively. Table 4.7 illustrate the meaning of the symbols that appear on the LCDs of each home

Fig. 4.21 Print screen of the state of the two homes for case-4

Table 4-7 Summary results LCD displays of two homes with grid for case-4

Case 4: Grid available and homes generated unavailable (or homes generated power < load)		
Item state	**Symbol signal**	**Meaning**
State of Grid (AC VOLT)	ON	Grid available
Signal sending from Home-2	4	Home-2 import power from grid
Signal sending from Home-1	D	Home-1 import power from grid
Feeding of Home-1 loads	GRID	Home-1 loads are fed from Grid
Feeding of the Home-2 loads	GRID	Home-2 loads are fed from Grid

Figure 4.22 shows the results that appear on the Ubidots platform which represents the status of the homes and grid. As illustrated from the figure, the battery of each home has no power but the grid power is available

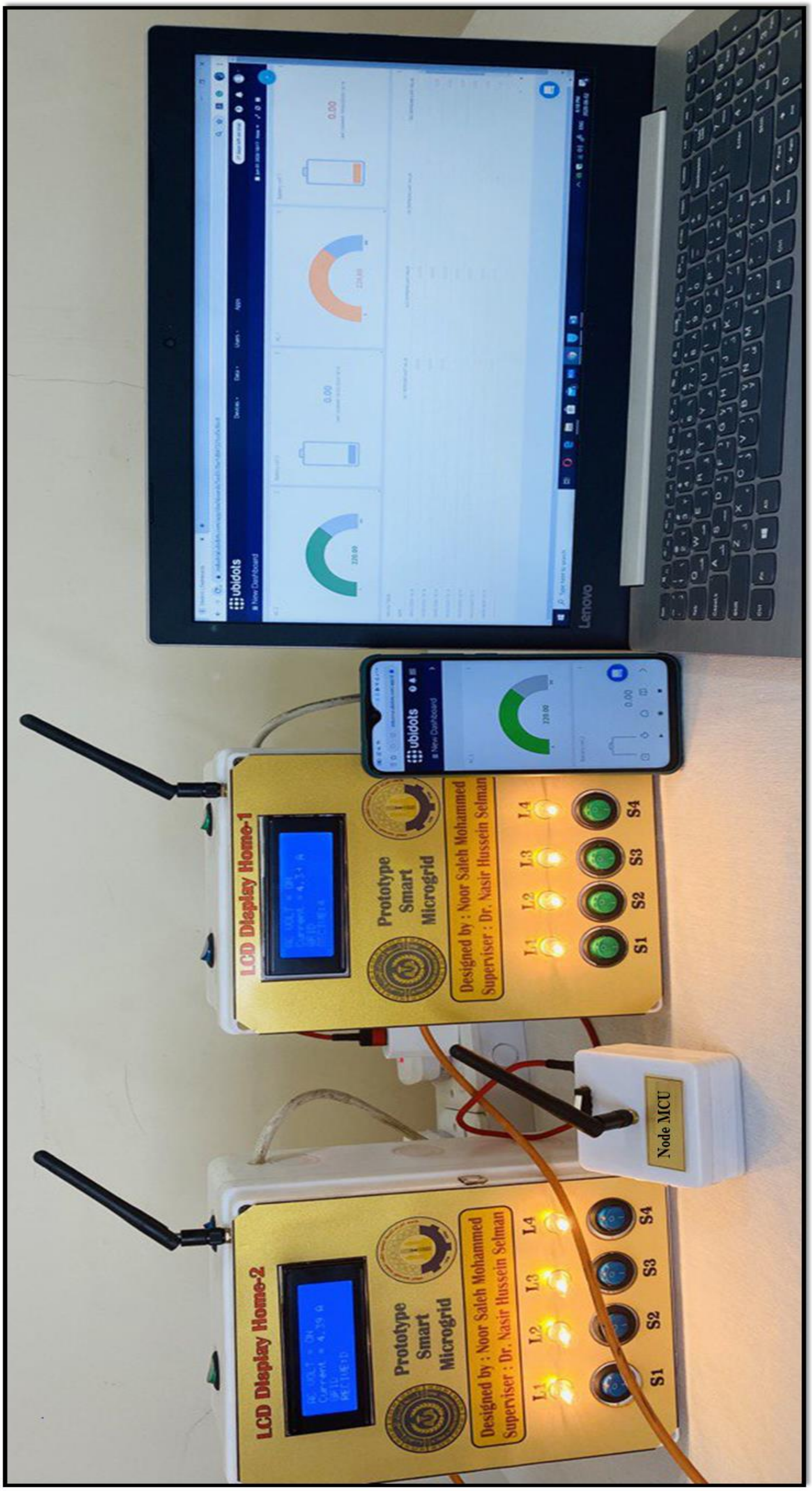


Fig. 4.22: Ubidots data of the homes and grid of case-4

Chapter Five
Conclusions and Suggestions for Future Work

5.1 Conclusions

In this thesis, a prototype DC Microgrid model is practically designed. The work focusses on the power management of power and the remote monitoring of the system data by using the Ubidots platform. All hardware and software parts of the system selected to satisfy the efficient operation of the proposed model. The designed model comprises two virtual homes each have 12 VDC source. Four lamps of 10 W were assumed to represent the load for each home. The energy exchange between the two homes and the main grid is controlled by Arduino UNO. The data were uploaded to the Ubidots platform by Node MCU using WiFi technology. This platform has many benefits such as capture, visualization, analysis, and management of data. The uploaded data were according to the existing sensors in the system which was the voltage sensor to check the grid availability status or not and a current sensor to know energy availability at home.

To confirm that the implementation of energy management for the system is efficient, different cases were performed by varying the number of lamps that operate in each home to interpret the change in the load during the day. Practical tests for all cases have been implemented and the results show that the system could operate efficiently under all conditions automatically. The management of the energy of the system was performed to reduce the cost of electricity as possible. The data of the grid condition and the home sources are monitored remotely and stored in a secure manner with the help of the Ubidots platform. The designed system in this study is the first step towards designing a practical system that is closer to the real Microgrid system.

5.2 Suggestions for Future works

The following are future suggestions for future research of some of the ideas in this thesis that have not been handled:

1- Developing the system and making it larger in terms of the number of houses and using one of the classical optimization methods to find the optimal management of the system such as Linear Programming or Dynamic Programming. As well as artificial intelligence methods, such as Neural Networks or Genetic Algorithm, can be used to manage the system practically.

2- Designing a practical system that is closer to reality, so that every house is equipped with solar panels and according to the loads in the house and it works on a system of 220 volts.

3- Uploading more data to the Ubaidot platform, which includes curves for drawing current and consuming, exporting, or importing power.

4- Using the smartphone to control smart home loads remotely in order to make the system more integrated.

5- Developing and expanding the system's communications network to include more advanced wireless technologies such as Zigbee or LoRaWAN techniques.

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الخلاصة

في هذه الرسالة ، تم تصميم نموذج أولي لنظام كهربائي يعمل بالتيار المستمر. استمدت فكرة النظام المقترح من مفهوم (Microgrid) الذي بدأ ينتشر في العديد من دول العالم. يتكون النظام من منزلين افتراضيين يحتوي كل منهما على مصدر للتيار المستمر (ألواح كهروضوئية أو بطاريات) وحمولة تتكون من أربعة مصابيح تعمل بفولتية مقدارها ($12V_{DC}$) وقدرة كل منها لكل (10 W). يتم التحكم في كل منزل تلقائيًا بواسطة متحكم (Arduino UNO) للعمل في وضع المنفصل أو توصيله بالمنزل الثاني أو الشبكة الكهربائية الرئيسية (لاستيراد أو تصدير الطاقة). يعتمد وضع التشغيل لكل منزل على حجم الطاقة المولدة من المنزل وتوافر الشبكة الرئيسية. في جميع ظروف التشغيل ، يجب تلبية الحد الأدنى من تكلفة استهلاك الطاقة قدر الإمكان. تتم إدارة الطاقة بواسطة متحكم (Arduino UNO) بمساعدة متحسس التيار (CS) ومتحسس الجهد (VS). يتحسس (CS) مقدار التيار الكلي الذي يسحبه حمل المنزل بينما يستخدم (VS) للكشف عن وجود الشبكة الرئيسية. تم تبادل المعلومات بين المنزلين حول وضع التشغيل وحالة الشبكة الرئيسية لاسلكيًا بمساعدة وحدة التردد اللاسلكي (RF) المرتبطة بلوحة (Arduino UNO). تم تحميل هذه المعلومات إلى منصة (Ubidots) بواسطة وحدة (Wi-Fi) المضمنة في المتحكم الدقيق (Node MCU).

تم اختبار النظام المصمم تحت ظروف مختلفة للتأكد من عمله عن طريق تغيير الحمل في كل منزل. وأوضح الاختبار العملي، أن كل منزل ينتقل من وضع تشغيل إلى آخر تلقائيًا مع موثوقية عالية وبأقل تكلفة ممكنة للطاقة. أيضا ، بمساعدة منصة(Ubidots) ، تم رصد بيانات حالة الشبكة ومصادر الطاقة للمنازل عن بعد وتخزينها في أنماط جيدة وآمنة.

جمهورية العراق

وزارة التعليم العالي والبحث العلمي

جامعة الفرات الاوسط التقنية

الكلية التقنية الهندسية– نجف

تقنية جديدة لإدارة موثوقة للطاقة
في الشبكات الدقيقة تعتمد على إنترنت الأشياء

رسالة مقدمة الى
قسم هندسة تقنيات الاتصالات
كجزء من متطلبات نيل درجة ماجستير تقني في هندسة تقنيات الاتصالات

تقدمت بها
نـــــور صــالح محمد
بكالوريوس في هندسة تقنيات الاتصالات

إشراف

د. ناصر حسين سلمان

آ ب - 2020