DESIGN AND IMPLEMENTATION OF ONLINE REPORT STATION FOR SOLAR ENERGY PLANT

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CERTIFICATION

This is to certify that IKHILLE AHUOSE OSEHAUMEN in the Department of Computer Engineering, Faculty of Engineering, University of Benin, carried out this study. For the award of Bachelor of Engineering (B.Eng.). This project “DESIGN AND IMPLEMENTATION OF ONLINE REPORT STATION FOR SOLAR ENERGY PLANT” has been under the supervision of Engr. I. OMOSIGHO and has been duly approved.

Engr. I. Omosigho **Project Supervisor**	**Engr. Dr. U. Iruansi** **Head of Department**
Date	Date

DEDICATION

I want to dedicate this project to Almighty God, my parents and my project supervisor ENGR I.OMOSIGHO

ACKNOWLEDGEMENT

I thank God Almighty for seeing this endeavor through to its final conclusion. My sincere appreciation is extended to my supervisor, Engr. I. Omosigho, for making time despite his busy schedule to oversee and carefully review the work.

I also want to thank everyone who helped make this endeavor a success, including my family, friends, professors, and colleagues. I sincerely pray that the labor of your hands will be blessed by the all-powerful God

ABSTRACT

Renewable energy sources are a practical solution for addressing the ongoing supply gap in the power industry. Because of the availability of solar energy throughout the world, unlike other geographically restricted resources, solar energy is most beneficial of all renewable energy resources. The Internet of Things can be seen as a network of physical objects, which have access to the internet and communicate with each other sharing and collecting data (Madadi, 2021) . The application of this technology in solar panels can greatly enhance the monitoring, performance and maintenance of the panel. Since the greater part of them are set in areas that are inaccessible and therefore monitoring them is not possible from a specific location. Sophisticated frameworks for remote monitoring of the plant using web-based interface is required for this massive scale of solar system deployment systems.

In this project, an online report station for solar energy plant was developed. The system was designed using three major layers of IOT architecture, which are perception layer, network layer, and application layer. The perception layer contains the sensor devices. This layer reads the value of the monitored parameters and converts it from analog to a digital signal. Three parameters, voltage, temperature and humidity are measured using Resistive voltage sensor, DHT11.The network layer acts as a gateway using a wireless network architecture like Wi-Fi. It receives the data from the perception layer and routes the data to the cloud using ESP8266. The application layer delivers the processed data to the user in an interface the user can interact with.

This project entails the design and implementation of an online report station that is capable of monitoring the status, condition and generated output of a solar energy plant. Three parameter, voltage, temperature and humidity are measured using the designed system. The result is displayed on the developed webpage and can be access by the user.

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CHAPTER ONE

INTRODUCTION

1.1 Background Study

The Internet of Things (IoT) is one of the most important technologies of everyday life, which helps people live and smarter. An IoT is a device, which is used to enable the connection between machine and the cloud. This technology helps to exchange the data between the connected devices on the available network. Through the internet, the user can acquire the data and control the devices from any place all over the world (B. Vikas Reddy, 2016) . It is an ecosystem which consists of web enabled gadgets that use processors, sensors and other communication hardware devices to fetch and send the data. By using IoT we can set up machine to machine connection or device to device connection without human interference. It also utilizes computing facilities and software systems for information processing. The need for using IoT technology in this solar power monitoring system is as the range of sun's radiation is not fixed and may vary according to the location, time and climatic conditions, the solar panels which are exposed to the sun always need to be monitored. The solar panels can be monitored from any location by using IoT technology.

Solar energy is the most potential natural-renewable energy source for a green future since it has a lower environmental impact than other common energy sources. Oil, coal, and natural gas are traditional but nonrenewable energy sources that will run out very quickly if they are utilized on a large scale. Furthermore, burning these fossil fuels raises greenhouse gas concentrations, resulting in global warming. Solar energy does not affect the greenhouse effect. Solar energy can be harnessed in three ways: photovoltaics, solar heating & cooling, and concentrating solar power. Photovoltaics generate electricity directly from sunlight via an electronic process. A single PV device is known as a cell. An individual PV cell is usually small, typically producing about 1 or 2 watts of power. These cells are made of different semiconductor materials and are often less than the thickness of four human hairs. To withstand the outdoors for many years, cells are sandwiched between protective materials in a combination of glass and/or plastics. To boost the power output of PV cells, they are connected in chains to form larger units known as panels. Panels can be used individually, or several can be connected to form arrays. One or more arrays is then connected to the electrical grid as part of a complete PV system (Solar Photovoltaic Technology Basics, n.d.).

The IoT is a network of physical objects. It involves the connection of objects with one another and to the internet using sensors and wireless network connection all collecting and sharing data. This provides the connection of each and every object in the world by means of wireless sensor network. Some devices, buildings, vehicles and other objects embedded with software, network connectivity and sensors can enable these objects to collect and exchange data.

IoT cloud computing acts as part of collaboration and is used to store IoT data. The cloud is a centralized server with computing resources that you can access when you need it. Cloud computing is an easy way to move large amounts of data generated by the IoT over the Internet. Devices connect to the cloud using different methods**,** depending on the device's connectivity capabilities. These methods include connecting directly to the Internet via cellular, satellite, WiFi, low power wide area networks (LPWAN), and Ethernet. Gateways allow devices that are not directly connected to the Internet to access cloud services. The IOT gateway acts as a network router, transferring data between IOT devices and the cloud.

Communication protocols are needed to govern, control and secure the collecting and sharing of data between devices. There are two forms IOT communication protocols (Sapna, 2020):

1. IOT Network protocol – which are designed to connect medium to high power devices over the network. This protocol allows data communication within the scope of the network.
2. IOT data protocol - which are designed to connect low power IOT devices. Without any internet connection, they are capable of providing end-to-end communication with the hardware. Though the connectivity in IOT data protocols can be done via a wired or cellular network.

The IoT devices are able to get access to the internet and share data through the IoT Network protocol. This protocol uses the TCP/IP protocol. The TCP/IP protocol is used for communicating and addressing data packets over a network (Types of Network Protocol and Their Uses, n.d.). The establishment of a connection between the IoT devices and the cloud relies on the Wi-Fi protocol. Wi-Fi is a wireless local area network (WLAN) that uses the IEEE 802.11 standard at 2.4 GHz UHF and 5 GHz ISM frequencies. Wi-Fi provides internet access to devices within range (iotdesignpro website, 2019).

Internet of things (IoT) is playing a crucial role in the daily life of humans by enabling the connectivity of many physical devices through internet where the devices are intelligently linked together enabling new kinds of communication between objects and people, and between objects themselves to exchange the data for monitoring and controlling the devices from anywhere around the globe using the internet connection. Additionally, the communication between machines or different devices is possible without human intervention using the IoT applications.

The purpose of solar energy plant monitoring systems is to offer continuously a clear information about various parameters, namely the energy potential, extracted energy, fault detection, historical analysis of the plant, and associated energy loss. Furthermore, the monitored data can be used for preventive maintenance, early detection of warning and evaluating the weather variations …etc.

In this work we present the design and implementation of an online report station for monitoring the solar plant using IoT technology. Our system will make use of a NodeMCU ESP8266 microcontroller which will be interfaced with temperature & humidity sensor, voltage sensor.

1.2 Problem Statement

Most solar plants are situated at inaccessible locations thereby making it difficult to consistently monitor them. To ensure proper functioning and output of the plant, it must be monitored regularly. In this research we will design and implement an online report station for solar plant to monitor the status, performance and environmental condition of the panels using IoT technology.

1.3 Aim and Objectives

1.3.1 Aim

The aim of this project is to design and develop an online report station that is capable of monitoring the status, condition and generated output of a solar energy plant.

1.3.2 Objectives

The proposed objectives of this project is to:

1. Design a monitoring system that can keep track of the output from the solar plant.
2. Program a microcontroller to acquire data from the various sensors.
3. Create a back-end script to interface the harnessed data from the solar plant to a web server

4. Design a front-end interface to allow site engineers\users check the status of the plant from anywhere on earth.

1.4 Scope of study

This project "Design and Implementation of an Online Report Station for Solar Energy Plant" is aimed at designing an online report station that is capable of monitoring the status, condition and generated output of a solar energy plant. This monitoring will be done by using temperature/humidity sensors, current and voltage sensor. The sensors are placed on the solar PV module for measurement which affect the efficiency of the solar panel. The microcontroller is critical in processing the measured data and forwarding it to the cloud platform via the Wi-Fi module. When the data get to the cloud, the backend script analyses, organizes and processes the data to be viewed on the website.

CHAPTER TWO

LITERATURE REVIEW

This chapter explains terminologies and principles with regards to an online monitoring station for solar plants as well as insight and concise review of previous studies conducted by outstanding researchers into closely related problems

2.1 THEORETICAL REVIEW

Internet of things can be seen as a play on words. The first word is "Internet" and the second word is "Things". The Internet is a global system of interconnected computer networks that use the standard Internet Protocol (TCP / IP) suite to serve billions of users around the world. It is a network of millions of private, public, academic, business, and government networks that reach from local to global, connected by a variety of electronic, wireless, and optical network technologies. While Things can be any object or person that can be distinguished from the real world. Everyday things include not only the electronic devices we encounter and use on a daily basis, but also technologically advanced products such as electrical appliances and gadgets.

The Internet of Things (IoT) describes the network or connection of physical objects that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet. These devices range from ordinary household objects to sophisticated industrial tools (What is the Internet of things (IOT), n.d.).

Physical objects are now connected to each other and the cloud and can now be controlled remotely through Internet services. The cloud refers to servers that are accessed over the internet, and the software and databases that run on those servers (What is the cloud? | Cloud definition, n.d.). Cloud computing allows data to be stored on a secure database without having to house the equipment and infrastructure for that.

To ensure that the system of constituent elements, network structure and cloud technologies work in compliance with established IOT protocols, the IOT architecture is needed. It consists of layers that could address security and Quality of Service (QoS). There are different forms of IOT architecture with three major layers which are perception layer, network layer and application layer. A six-layer architecture that is based on network hierarchical structure is generally divided into six layers which are described as follows (M.U. Farooq, 2015):

2.1.1. Coding layer

The coding layer is the foundation of IoT that enables identification to the objects of interest. In this layer, for each object a unique ID that makes it easy to distinguish is assigned.

2.1.2 Perception layer

This is the IoT device layer that gives each object a physical meaning. It consists of various types of data sensors such as RFID tags, IR sensors, and other sensor networks that can detect the temperature, humidity, velocity, position, etc. of objects. This layer collects useful information about an object from the sensor devices attached to it and converts that information into a digital signal. The digital signal is transferred to the network layer for further action.

2.1.3. Network layer

The purpose of this layer is to receive useful information in the form of digital signals from the perception layer and transfer it to the processing system of the middleware layer via transmission media such as WiFi, Bluetooth, WiMaX, Zigbee, GSM, 3G. Use protocols that are transmitted, such as IPv4, IPv6, MQTT, DDS, etc.

2.1.4 Middleware layer

This layer processes the information received from the sensor device. It includes technologies such as cloud computing and ubiquitous computing that allow you to access the database directly and store all the information you need in the database. Some intelligent processing devices are used to process information and perform fully automated actions based on the results of processing the information.

2.1.5 Application layer

This layer enables IOT applications for all kinds of industries based on the processed data. This layer is very useful for large-scale development of IOT networks as applications drive the development of IOT.

2.1.6 Business layer

This layer manages IOT applications and services and is responsible for all IoT related research. Generate different business models for effective business strategies. It describes everything that has to do with the stakeholders.

2.2 Components of IOT

A complete IOT system integrates four different components: sensors / devices, connectivity, data processing and user interface.

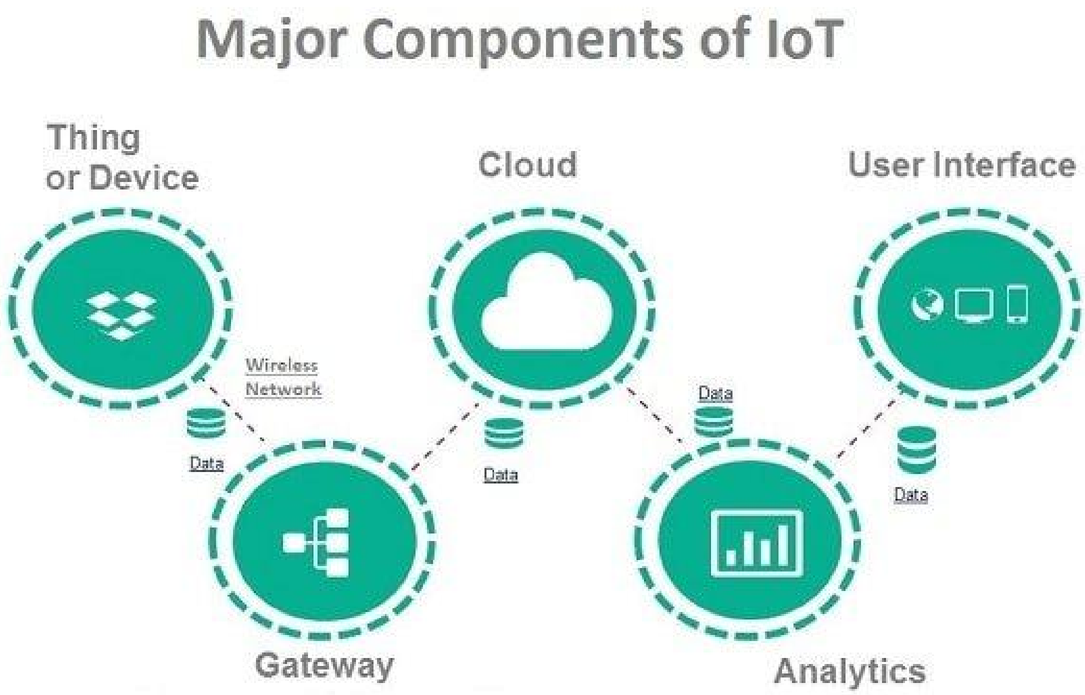


Figure 2.1: Components of IOT

The foremost component to consider in Internet of Things technology is sensors / devices. The sensor gets all the details from the environment.

Next this data is then sent to the cloud. Sensors / devices can connect to the cloud using a variety of methods such as cellular, satellite, WiFi, Bluetooth, low power wide area networks (LPWAN), or connect directly to the Internet via Ethernet which serves as a gateway. Each option has a trade-off between power consumption, range**,** and bandwidth. Choosing the best connection option depends on your particular IoT application, but they all perform the same task. That is, getting the data into the cloud.

On getting to the cloud infrastructure, the data needs to be analyzed so that the appropriate action can be carried out**.**

The final step is to notify the user of the action using a notification or alert sent to the user's device. In this way, the user knows that his command has passed the system**.**

2.3 Communication protocols

In the world of technology, devices communicate and transmit data between each other on a network. There are standards that govern this communication process. These standards are referred to as protocols. A protocol is a set of rules that help in governing the way devices communicate over a network. Some of this protocols are TCP and HTTP. TCP stands for Transmission Control Protocol. It is a communication protocol which is used for communicating over a network. TCP organizes data so that it can be transmitted between a server and a client. It guarantees the integrity of the data being communicated over a network. Before it transmits data, TCP establishes a connection between a source and its destination, which it ensures remains live until communication begins. It then breaks large amounts of data into smaller packets, while ensuring data integrity is in place throughout the process. TCP is a transport protocol. TCP works together with IP to ensure communication between the devices over the internet. IP stands for Internet Protocol; it is an addressing protocol. It obtains and defines the address of the device the data must be sent to. Each device that connects to the internet is assigned a unique number. This number is the IP address. The IP address is used to route the data packets. The TCP transports the packets with the IP address attached to it. The IP address specifies the destination of the packet. The TCP/IP protocol ensures that the data packets moves from the source to the destination over the network. The TCP/IP model has four layers which are (What is Transmission Control Protocol TCP/IP?, n.d.):

2.3.1 Datalink layer

This layer defines how data would be sent, handles the physical act of sending and receiving data. It defines how data would be signaled by hardware and other transmission devices on a network, such as a computer's device driver, an Ethernet cable, a network interface card (NIC), or a wireless network.

2.3.2 Internet layer

This layer is responsible for sending packets from a network and controlling their movement across a network to ensure they reach their destination. It provides the functions and procedures for transferring data sequences between applications and devices across networks.

2.3.4 Transport layer

This layer is responsible for transmitting data across the network. It provides a solid and reliable data connection between the source device and its destination. This is the level where data is divided into packets and numbered to create a sequence. The transport layer then determines how much data must be sent, where it should be sent to, and at what rate. It ensures that data packets are sent without errors and in sequence and obtains the acknowledgment that the destination device has received the data packets.

2.3.5 Application layer

This layer refers to programs that need TCP/IP to help them communicate with each other. This is the level that users typically interact with, such as email systems and messaging platforms.

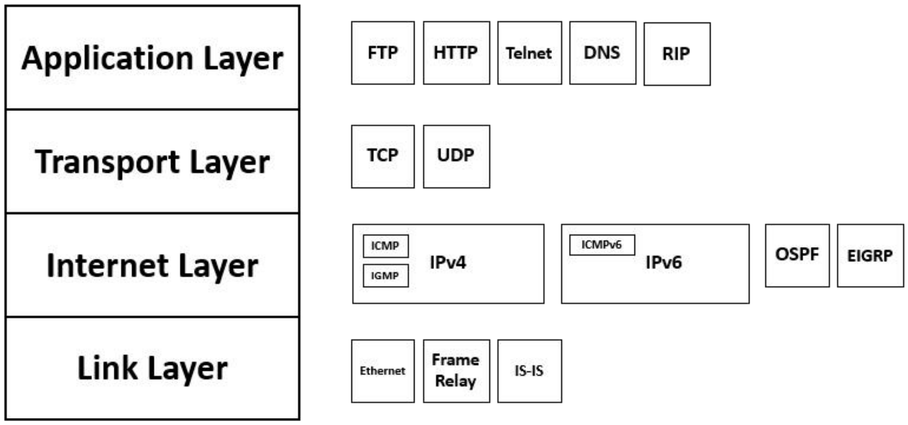


Figure 2.2: Illustration of TCP/IP model

HTTP stands for Hypertext Transfer Protocol. It is an application layer protocol that is used to transfer data over the internet. It is part of the internet protocol suite and defines commands and services used for transmitting webpage data (Garzon, 2022) . It uses a client-server model, a client being a user and the server being the host device running the web server software. HTTP basically involves a client making a request to the server and getting a response to that request. HTTP has commands which it uses in carrying out its basic operations. This commands are called HTTP methods. These methods are used to query the database in the server. Two most common methods are 'GET' and 'POST'. The GET method is used to make a request for data (which could be a website or webpage) from the web server. GET method retrieves a representation of the specified resource and include all required data in the URL. POST method is used to send data to the web server. It uploads or updates information on a website. It sends data to the database. POST is for writing data, submits data to be processed to the identified resource (Ibanez, 2018).

2.4 Wireless communication

Communication systems can be wired or wireless. A wired communication system uses a physical medium to transmit information. A wireless communication system does not use a physical medium but propagates the signal through space. Wireless communication system uses antennas to transmit and receive signals. The antennas transform the electrical signal to radio waves in the form of Electromagnetic waves for propagation. There are several types of wireless network technologies. Some of them are (Sapna, 2020):

2.4.1 Wi-Fi

Stands for Wireless Fidelity. This is a type of wireless network that gives devices such as mobile phones, computers and so on access to the internet. It uses radio waves to transmit data from the wireless router to the Wi-Fi enabled device. Wi-Fi is one of the most popular IOT communication protocol. It is based on the IEE 802.11n standard with a frequency of 2.4GHz-5GHz and a range of 50-100m. It is often used in homes and various businesses. It has a relatively high power usage and a maximum data rate of 600mbps. IEEE 802.11 is a set of standards for wireless local area network (WLAN) for computer communication and it is developed by the IEEE LAN/MAN Standards Committee (IEEE 802) in the 5 GHz and 2.4 GHz public spectrum bands, these two public spectrum bands are most popular and widely used for internet connection. The 802.11 family supports or uses wireless modulation technology for communication using several basic protocols. The protocol defines a set of rules. The most common protocols are defined by the IEEE802.11b and IEEE802.11g protocols which are improvements to the original standard. IEEE 802.11a was the first wireless network standard, but IEEE 802.11b was the first widely accepted standard, followed by IEEE 802.11g and IEEE 802.11n (IEEE 802.11a WiFi Standard, n.d.):

IEEE Standard	802.11a	802.11b	802.11g	802.11n	802.11ac	802.11ax
Year Released	1999	1999	2003	2009	2014	2019
Frequency	5Ghz	2.4GHz	2.4GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz	2.4Ghz & 5GHz
Maximum Data Rate	54Mbps	11Mbps	54Mbps	600Mbps	1.3Gbps	10-12Gbps

Table 2.1: Family of 1EEE standards

IEEE 820.11 (Legacy mode): It specified two raw data rates. The first 1 Mbit / s (Mbps) and the second 2 Mbit / s (Mbps) are transmitted Industrial Scientific Medical frequency band at 2.4GHz. Traditional IEEE 802.11 was quickly complemented (and popularized) by IEEE 802.11b.

IEEE 802.11a: The IEEE 802.11a standard uses the same core protocol as the original standard. It's completely different from 11b and 11g. It operated in the 5GHz band with a maximum raw data rate of 54Mbps and demonstrated excellent performance in the mid-20Mbps. IEEE 802.11a is more flexible because it allows you to combine multiple channels for faster throughput and allows more access points to be co-located. It uses the 5 GHz range, which reduces interference from other devices. This is because the 2.4 GHz band is frequently used until it becomes overcrowded. However, this high carrier frequency also has minor drawbacks. The valid overall range of IEEE802.11a is slightly lower than the valid range of IEEE802.11b / IEEE802.11g.

IEEE 802.11b: The maximum raw data rate for IEEE 802.11b is 11 Mbps, which uses the same media access scheme as defined in the original IEEE 802.11 standard. IEEE802.11b is the longest-lived, well-supported, stable and inexpensive technology, but security is a major drawback of this standard. The number of access points is limited. It uses Direct-Sequence spread spectrum technology. For some time, IEEE 802.11b devices will be affected by interference from other products operating in the 2.4GHz band. Devices operating in the 2.4 GHz range include microwave ovens, Bluetooth devices, baby monitors and cordless phones.

IEEE 802.11g: IEEE 802.11g uses the 2.4 GHz band (similar to IEEE 802.11b), but operates at a maximum data rate of 54 Mbps, or about 19 Mbps. IEEE 802.11g uses frequency division multiplexing technology. It has a shorter range than 802.11b. IEEE 802.11g is flexible in that it allows you to combine multiple channels for faster throughput, but it is limited to one access point, which is the main problem with IEEE 802.11g. Some time, IEEE 802.11g devices are affected by interference from other products operating in the 2.4 GHz band which is similar to IEEE 802.11b.

IEEE 802.11n: IEEE 802.11n is a modification designed to improve the previous IEEE 802.11 standard by adding multi-input multi-output (MIMO) with many other new features.

Wi-Fi network architecture consists of a set of APs (access points) or one or more Aps and one or more clients. The client is directly connected to one AP. The AP communicates with the client by broadcasting the service set identifier (SSID) or network name through a packet called a beacon. The AP sends a beacon every 100ms at a data rate of 1 Mbps. The connection between the client and AP basically depends on the SSID setting, but if the setting is not complete, you may not be able to connect. If there are multiple APs with the same SSID, the client firmware will use the signal strength as a measure of the APs to connect to (Kaushik, 2011).

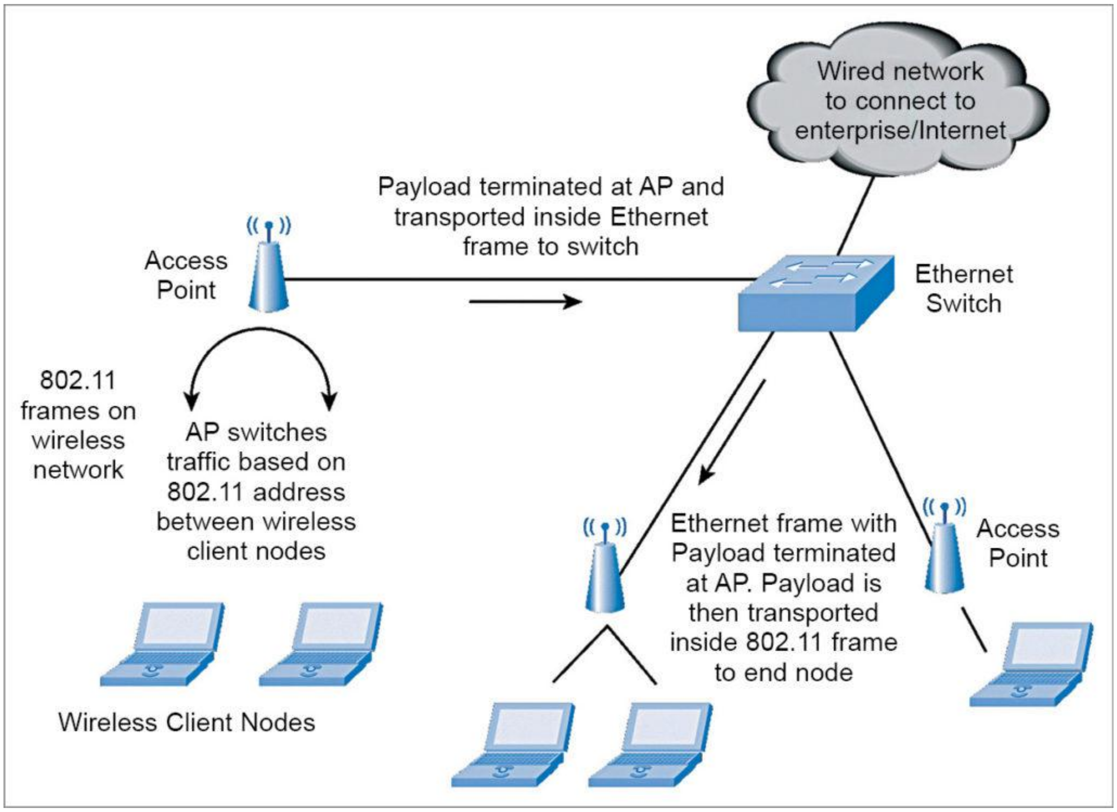


Figure 2.3: Wi-Fi Architecture

Wi-Fi networks use radio signals to provide a connection to the Internet or your mobile operator's network or used for internet services. The end-to-end connectivity relies on a wired IP infrastructure as it only provides services up to the link layer level

2.4.2 Bluetooth

Highly suitable for mobile devices, it is one of the most important short-range communication technology. It is suitable for sending small chunks of data. It uses short wavelength UHF radio waves and has a frequency of 2.4GHz (ISM). Its range is similar to Wi-Fi. It has a reduced power usage. Bluetooth uses a master/slave model called Piconet to control when and where devices can send data. In this model, a single master device can be connected to up to seven different slave devices. Any slave device in the network can only be connected to a single master. The master coordinates communication throughout the network. It can send data to any of its slaves and request data from them as well. Slaves are only allowed to transmit to and receive from their master. They can't communicate to other slaves in the network. The master can communicate with a maximum of seven devices on the network (Bluetooth Basics, n.d.).

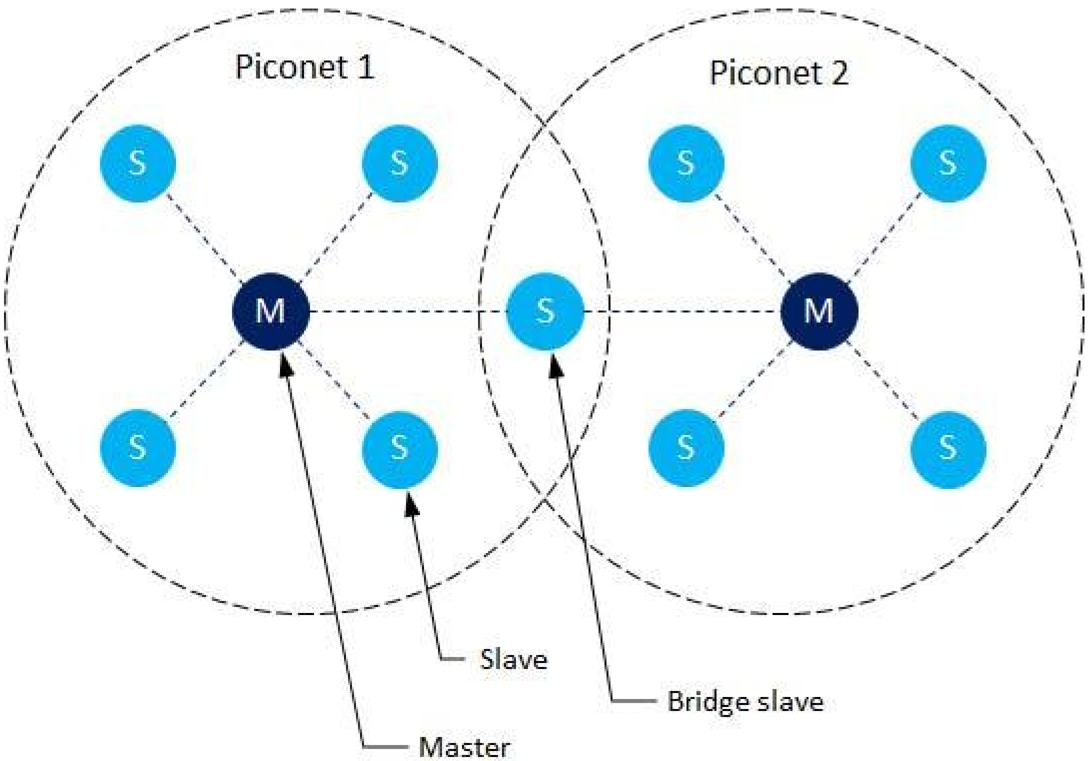


Figure 2.4: Piconet architecture

There are different versions of Bluetooth which has developed over the years with different speed and data rates. These versions as described as follows:

2.4.2.1 Bluetooth 1.0-1.2

Bluetooth was developed to replace the RS232 serial port on a computer. It was commonly used to connect PC peripherals such as modems and printers. Over the next few years, Bluetooth 1.2 was eventually integrated into a variety of devices. Some of these are wireless headsets, cell phones, laptops, cars, and digital cameras. Bluetooth 1.0a and 1.0b provided peak data transfer rates of approximately 732.2 kb/s over a 10m or 33ft connection range. Version 1.2 has improved this by increasing the data transfer rate to 1 Mbps. It also implemented improved adaptive frequency hopping (AFH) to reduce signal interference and enhanced synchronous connectivity (eSCO) for improved voice quality.

2.4.2.2 Bluetooth 2.0-2.1

Branded as Bluetooth 2.0 + EDR (Enhanced Data Rate), 3-bit encoding increased the data rate from 1 to 3 Mbps. Interference processing has been improved and power consumption has been reduced. Secure Simple Pairing (SSP) was added to make pairing faster and more secure. Encryption was made mandatory, security was improved, and less power was used.

2.4.2.3 Bluetooth 3 + HS

Branded as Bluetooth 3.0 + HS (High Speed), it started the connection via Bluetooth but transmitted data over Wi-Fi. L2CAP Enhanced modes and alternative MAC and PHYs for transferring large digital files. Enhanced Power Control of wireless devices to adjust power levels as needed. This helps maintain a good Bluetooth connection Unicast Connectionless Data facilitated the quick transfer of smaller amounts of data

2.4.2.4. Bluetooth 4.0-4.2

Bluetooth 4 brought forth Bluetooth Low Energy (BLE) or Bluetooth Smart. Bluetooth Smart allows smaller devices like fitness trackers, hearing aids, and headphones to stay paired longer using less power. Bluetooth Smart Ready allows primary devices like laptops, tablets, and smartphones to act as connection hubs that could send and receive data from Smart devices. It brought about increased connection range to 60m or 200ft, less interference between Bluetooth and 4G/LTE signals, improved pairing and re-pairing of devices, increased packet capacity and data range for IOT devices and improved data transmission with Adaptive Frequency Hopping (AFH)

2.4.2.5. Bluetooth 5.0-5.2

This version, Bluetooth 5, was released in July 2016 and focused on providing a better operation framework for IOT devices. It provides an increased bandwidth capacity of 2 Mbps. It also extended the connection range to up to 240m. Plus, it comes with Low Complexity Communication Codec (LC3). This is a new audio protocol that transfers audio data at lower bitrates without sacrificing audio quality. It also has backward compatibility with Bluetooth 4 versions and Addition of Slot Availability Mask (SAM) which further lessens interference with LTE.

2.4.3. ZigBee

Is designed mainly for industrial sites where low power is required and less of the consumer's network. It is another important protocol that offers high security, low power operation and high scalability. It uses the IEE802.15.4 standard with a frequency of 2.4GHz and a range of 10-100m. The structure of ZigBee protocol consists of three main elements which are: ZigBee coordinator, ZigBee router and ZigBee end device. The ZigBee coordinator is used for connecting the devices. It acts as a hub for receiving and storing important information during transmission of data. The ZigBee router is used for moving data between the devices. It acts as an intermediary establishing a connection between the end devices and the coordinator. The end devices are the devices that are to be controlled or devices that are used to collect data. These elements are connected with each other in a mesh network pattern. The ZigBee protocol architecture consists of several layers which are (Imran Amin, 2018):

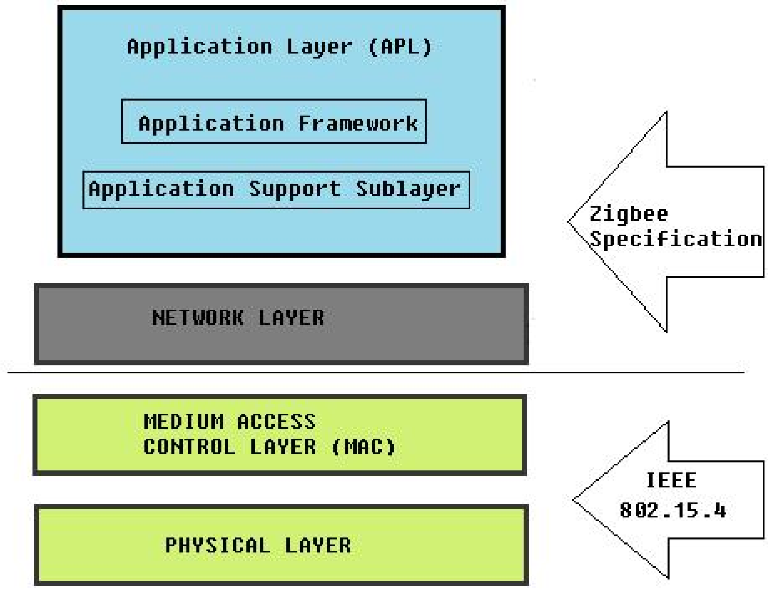


Figure 2.5: ZigBee protocol architecture

2.4.3.1 Physical layer: This layer performs the task of modulating and demodulating various transmit and receive signals. This layer uses different frequencies, data rates, and channels depending on the location.

2.4.3.2 MAC layer: The function of this layer is to enable reliable data transmission by accessing various networks using Carrier Sense Multiple Access collision avoidance (CSMA).

2.4.3.3 Network layer: This layer involves all network-related operations such as connecting routers to different end devices, disconnecting from the network, routing, and different device configurations.

2.4.3.4 Application support layer: This layer is responsible for interfacing ZigBee devices with various object application devices and communicating over the network layer.

2.4.4 Cellular

Also known as satellite are capable of facilitating massive flows of data. It uses GSM/GPRS/EDGE (2G), UTMS/HSPA (3G), LTE (4G) depending on the speed. It has a frequency of 900/1800/1900/2100MHz and a range of about 10 to 15 miles. Continual costs are a major obstacle to cellular communications, as the SIM card must be recharged and kept with good balance for data to be available. The power consumption of the cellular module is also very high, which limits long-term battery operation.

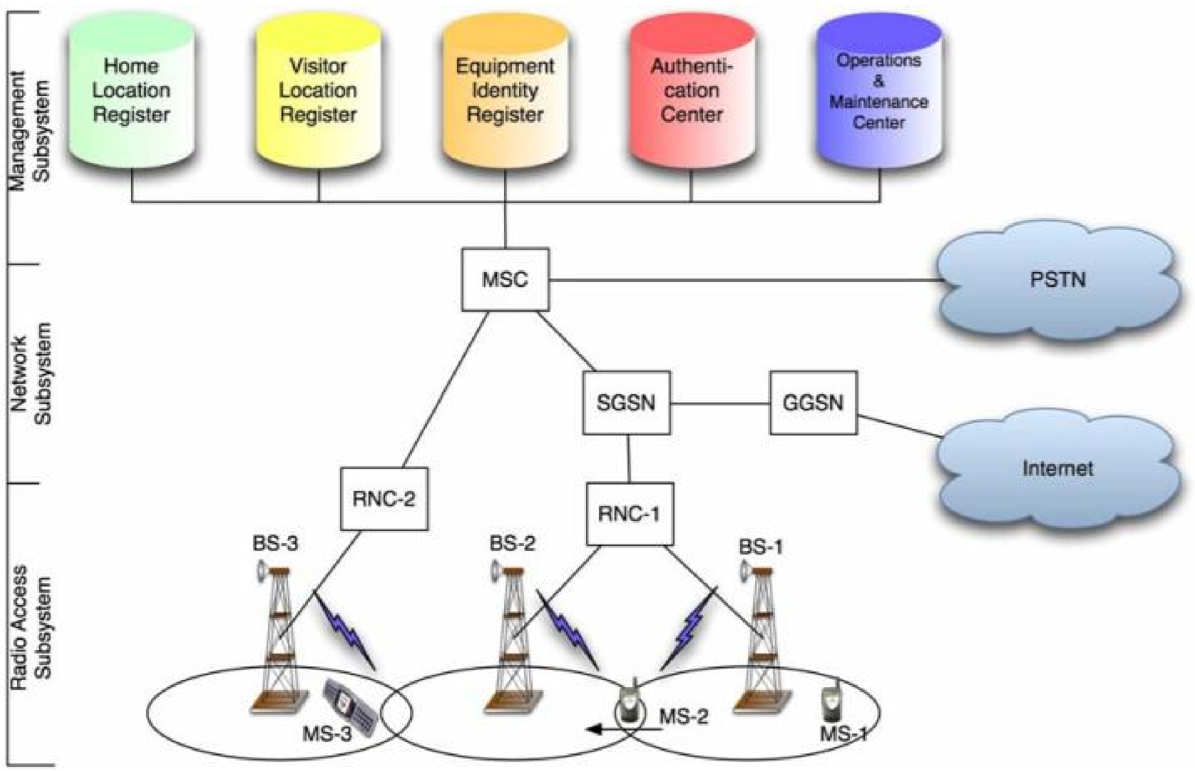


Figure 2.6: Cellular network architecture

In the radio access subsystem, the mobile station (MS), sometimes called user equipment is the device whose position is to be determined. Base stations (BSs – also called Node Bs) are fixed transmitters that are points of access to the rest of the network. A MS communicates with a BS during idle periods (signaling), cellular phone calls (voice) or other data transmission. Base stations are controlled by radio network controllers (RNCs) that also manage the radio resources of each BS and MS (frequency channels, time slots, spread spectrum codes, transmit powers, and so on). The network subsystem carries voice and data traffic and also handles routing of calls and data packets. The mobile switching center (MSC) and the serving and gateway GPRS1 support nodes (SGSN and GGSNs) are responsible for handling voice and data respectively. These network entities perform the task of mobility management, where they keep track of the cell or group of cells where a MS is located and handle routing of calls or packets when a MS performs a handoff, i.e., it moves from one cell to another 1 GPRS stands for General Packet Radio Service. They connect to the public switched telephone network (PSTN) or the Internet. Several databases in the management subsystem are used for keeping track of the entities in the network that are currently serving the MS, security issues, accounting and other operations (David Tipper).

2.4.5 LoRaWAN

This is a long-range radio wide area network that provides low cost mobile security to IOT and industrial applications. It is optimized for low power consumption and supports large network of devices. It has a wide range of frequencies and a range of about 2.5 to 15km. LoRaWan is designed as cloud-based medium access control (MAC) layer protocol The main principle behind LoRaWAN is spread spectrum modulation technology derived from chirp spread spectrum. The frequencies used for LoRaWAN vary by region, with the most common bands being 433MHz, 868MHz, 915MHz, and 923MHz. The main drawback of LoRaWAN is that in the most energy efficient mode, data can only be received from the cloud when the devices (nodes) are transmitting data. The data rate is also very low because each payload is limited to just a few hundred bytes (Staff, 2020) . Its network architecture is typically deployed in Star topology, where gateways send messages between end devices and central network servers. The gateway connects to the network server over a standard IP connection and acts as a bridge, translating RF packets into IP packets and vice versa. LoRaWan is at the data link and network layer on the OSI model.

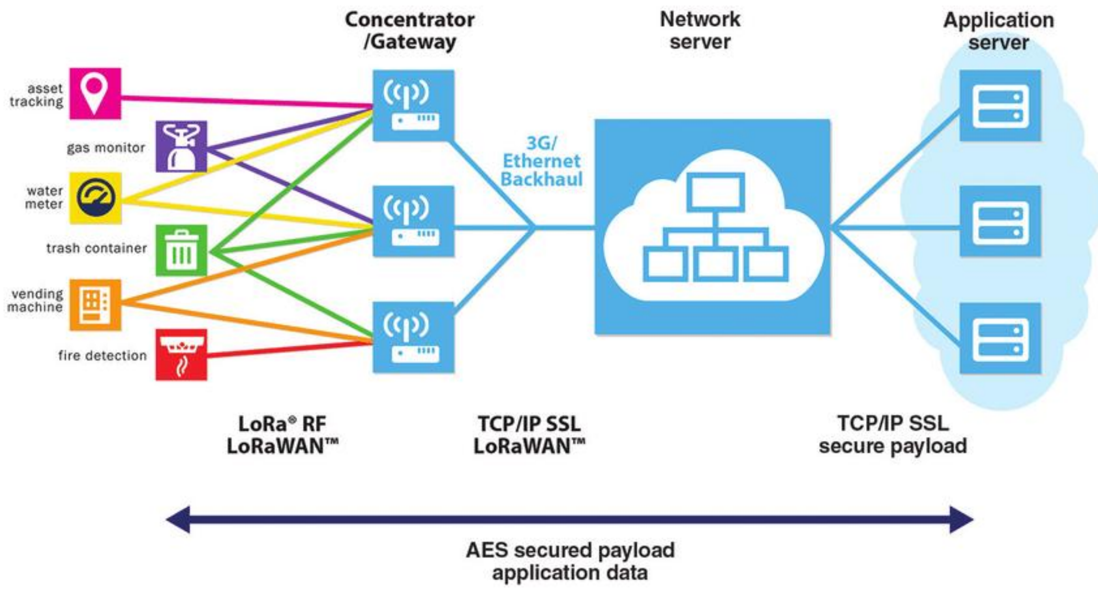


Figure 2.7: LoRaWan protocol architecture

End devices communicate with nearby gateways and each gateway is connected to the network server. LoRaWAN networks use an ALOHA based protocol, so end devices don't need to peer with specific gateways. Messages sent from end devices travel through all gateways within range. These messages are received by the Network Server. If the Network Server has received multiple copies of the same message, it keeps a single copy of the message and discards others. This is known as message deduplication (LoRaWan Communication Protocols: A Comprehensive Survey under an Energy Efficiency Perspective, 2022).

2.5 Basics of Solar energy conversion

Solar energy is one of the most common non-conventional energy sources today. Solar power plants utilize thermal energy from the sun, which is abundant, available, intermittent and cheap. When the sun hits the solar panel, the energy from the sun is absorbed by the Photovoltaic (PV) cells inside the panel. This cells converts sunlight to electrical energy by absorbing light energy from the sun and knocking electrons loose. These loose electrons cause current flow. This current flow is direct current (DC) which needs to be converted to alternating current (AC) using a component before it can be supplied to our homes. This component is called inverter. Basically, the inverter performs the DC to AC conversion by switching the direction of the DC input back and forth very quickly**.** This changes the DC input to an AC output. In addition, filters and other electronic devices can be used to generate a changing voltage as a clean repeating sine wave that can be injected into the mains**.** A sine wave is a shape or pattern in which the voltage changes over time and is a pattern of current that can be used by the mains without damaging electrical equipment designed to operate at a particular frequency and voltage**.**

2.6 Web servers

Web servers are nothing more than software and hardware that use the Hypertext Transfer Protocol, commonly known as HTTP, and several other protocols that respond to requests from clients on the internet. The main task of a web server is to display the content of a website by storing the web pages, processing them, and finally delivering them to the user who requested them**.** Web servers also support Simple Mail Transfer Protocol SMTP and file transfer protocols FTP and HTTP. These are used to transfer files for email and storage. The web server working process is an example of a client/server model. This model describes how web servers work. It involves a program or device sending a request for resources from another program or device on a network. The device or program making the request is called the client while the program or device sending the answer to the request is called the server. The web server software is accessed through the domain name of the website to ensure that the content of the website is delivered to the requesting user. The software side controls how users access hosted files and also consists of several components, at least with an HTTP server. The HTTP server can understand HTTP and URLs. A web server as hardware is a computer that stores web server software and other files related to websites, such as HTML documents, images, and JavaScript files. A web server can be used to serve either static or dynamic content. A static web server consists of a computer and HTTP software. The server sends the hosted file unchanged to the browser and is therefore considered static. A dynamic web browser consists of a web server and other software such as application servers and databases**.** It is considered dynamic because you can use the application server to update all hosted files before sending them to the browser. The web server can generate content in response to requests from the database files (S., 2020). There are two forms of server communication in the client/server model web servers. They are synchronous and asynchronous web servers.

2.6.1 Synchronous web servers

In traditional web applications, when a user sends a request and that request is answered, no further communication between the server and the client until the user sends another request. This type of communication in a web server is referred to as synchronous. The nature of legacy web applications is that they are synchronous. The user interacts with the web interface in the browser, the browser sends requests to the server depending on that interaction, and the server answers with a new response for the user - this is a fundamentally synchronous operation. This means that the user's presentation is a snapshot of a dynamic system at a specific point in time.

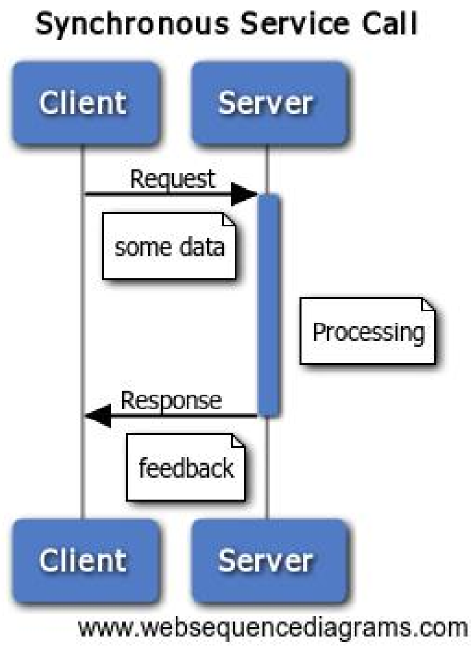


Figure 2.8: Illustration of a synchronous web server operation

2.6.2 Asynchronous web servers

Asynchronous web server changes how web applications behave. In asynchronous web server, it is possible to deliver spontaneous request answers to the user without the user having to continuously make requests (Understanding Synchronous and Asynchronous Communication, n.d.). Unlike synchronous servers, asynchronous servers don't wait after the user makes a request without any communication between the server and the client occurring. The web applications on an asynchronous web server continuously deliver data to the users even if there is no interaction between the user and the web application. To achieve an asynchronous web server, there should be a mechanism that sends back responses to the client spontaneously since a response cannot be sent to a non-existent request in HTTP. One of the best way to achieve that is with HTTP long polling where the request is made in anticipation of a future response, but that response is blocked until some event occurs that triggers its fulfillment (Stephen, 2009).

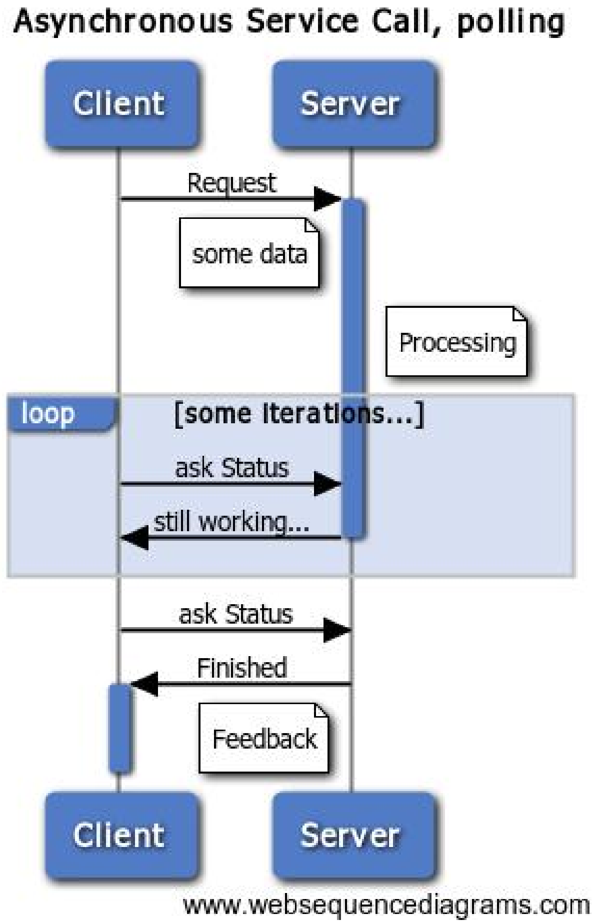


Figure 2.9: Illustration of asynchronous web server operation using polling

2.7 Web development

For a complete communication on the internet, a client/server model is used. The client being the user interacts with the websites on the internet. For a website to work, there are two important parts to it. The front-end which focuses on the client side and the back-end which focuses on the server side. The front-end has to do with the website and its layout. The user interacts with the front-end to send requests to the server. The front-end is set up and designed using HTML, CSS and JavaScript which are the most popular tools used in developing the front-end of a website.

2.7.1 Hypertext Markup Language (HTML)

This is the standard markup language for documents designed to be designed in a web browser (Wikipedia, n.d). A hypertext is a text that is used to reference other pieces of text, while a markup language is a series of markings that tells web servers the style and structure of a document (T., n.d.) . HTML describes the structure of a webpage semantically and originally included cues for the appearance of the document. Several essential elements make up HTML markup, including those referred to as tags. HTML tags function similarly to keywords in that they specify how a web browser will format, and present text. A web browser can tell the difference between plain content and HTML content with the aid of tags. The opening tag, content, and closing tag are the three essential components of an HTML tag. However, some HTML tags are not closed. The HTML document type declaration, which starts standards mode rendering, is another crucial element.

2.7.2 Cascading Style Sheet (CSS)

It is used to add styles (which include colors, fonts etc) to a webpage. It is used together with HTML to develop a good looking webpage. It is a stylesheet language used to describe the presentation of a document written in HTML and XML. Its describes how elements should be rendered on a website (CSS: Cascading Style Sheets, n.d.).

2.7.3 JavaScript

This is a scripting language that is used to add functionality and behavior to a webpage. It is used together with HTML and CSS to develop an interactive and functional website. It has dynamic typing, prototype-based object orientation, and first-class functions. It has an Application Programming Interface (APIs) for working with text, dates, regular expressions, standard data structure, and the Document Object Model (DOM). JavaScript is a high-level, often just-in-time compiled language that conforms to the ECMAScript standard. It has dynamic typing, prototype-based object-orientation, and first-class functions. It is a multi-paradigm, supporting event-driven, functional, and imperative programming styles. It has application programming interfaces (APIs) for working with text, dates, regular expressions, standard data structures, and the Document Object Model (DOM). (.R, n.d.).

2.7.4 Hypertext Preprocessor (PHP)

One of the most popular languages used for back-end development is PHP which stands for Hypertext Preprocessor. It is an open-source server scripting language used for the development of web applications (PHP: Server-side Scripting Designed for Web Development [Revie], n.d.). This denotes that a server carries out a script's commands. The server then responds to requests for data, routes them, and compiles them into databases. It is used to program and develop the interaction between the website and the web server. For example, when a user downloads data, PHP is used to program that functionality in which the user makes a request and gets a response. When a web server gets a script request, it processes the request and sends HTML-formatted output to a web browser. So that other user cannot access the data and source code, the information is stored in a web server database. Users can customize websites, make dynamic changes to website content, and access databases by using scripts. A scripting language is frequently used by users to create web apps.

2.7.5 Web frameworks

A web framework is a software framework that provides web developers with the tools and resources necessary to build websites. It was developed to make the web development process easier and simple. It includes templating capabilities that allow the developer to present information within the browser and also contains many Application Programming Interfaces (APIs) for gaining access to underlying data resources. The internet can be accessed using several devices such as a computer, tablet, smartphone, etc. These devices have different views and screen sizes. For web developers to build websites that work well on all devices, the concept of responsive web design was developed. This concept involves developing websites that are flexible and adjust properly to all screen sizes without losing information. The websites render well on all devices. This has become an important practice today when developing websites

2.8 Database

Server-side scripting language access the database on the server. A database is an organized collection of structured information or data, usually stored electronically on a computer system. The database is usually controlled by a database management system (DBMS). Collectively**,** data and DBMSs and related applications are called database systems and are often simply abbreviated as databases. The most common types of database data in operation today are typically modeled with a set of table rows and columns for efficient processing and data retrieval. You can then easily access, manage, modify, update, control, and organize your data. Most databases use a structured query language (SQL) to write and query data. SQL is a programming language that is used by all relational database. It is used to query, update and manipulate the database. There are different types of database, some of them are:

2.8.1 Relational database

This type of database uses a tabular scheme. It is organized as a set of tables with columns and rows. In a relational database it is quite easy to search through the tables for data hence it is often used. The columns in a table are called fields while the rows are called records. The field is designed to maintain specific information about every record in a table while a record is each individual entry in a table (Introduction to SQL, n.d). MySQL is an example of a relational database management system. It runs on the web and is used mainly as a web server database. It is used to store and retrieve data in a wide range of web applications. MySQL works with an operating system to implement a relational database in a computer's storage system, manages users, allows for network access, and facilitates testing database integrity and creation of backups.

2.8.2 Non-relational database

This type of database does not store data in tables. It stores data in a way that is optimized for the specific data type. It is also called NoSQL database. It uses other types of query language aside from SQL to query, update and manipulate the database. A good example is MongoDB. There are four different types of NoSQL databases (Relational vs Non-relational databases, n.d.):

1. Document-oriented databases – Also known as a document store, this database is designed for storing, retrieving, and managing document-oriented information. Document databases usually pair each key with a complex data structure (called a document).
2. Key-Value Stores – This is a database that uses different keys where each key is associated with only one value in a collection.
3. Wide-Column Stores – this database uses tables, rows, and columns, but unlike a relational database, the names and format of the columns can vary from row to row in the same table.
4. Graph Stores – A graph database uses graph structures for semantic queries with nodes, edges, and properties to represent and store data.

2.8.3 Cloud database

A cloud database is a collection of data, either structured or unstructured, that resides on a private, public, or hybrid cloud computing platform (What is a Cloud Server?, 2022). The cloud computing platform is usually provided by another company offering it as a service. The company using this service does not have to worry about the infrastructure of running the cloud.

2.9 Data types

In programming, data type is an attribute associated with a piece of data that tells a computer system how to interpret its value (Arpit, 2022). The various values that an expression, such as a variable or a function, might take are limited by the data type. This data type describes how to store values of that kind as well as the operations that may be performed on the data and its meaning. There are several data types, but for this research we will be focusing on the following integer data type such as short, long and float and sequence data type such as strings.

2.9.1 Short data type

Numerical values with no fractional portion are known as integer data types. Integer data type stores whole numbers with a precision of 9 or 10 digits, ranging from -2,147,483,647 to 2,147,483,647 and is generally used to store counts, amounts, and other data since it is stored as a signed binary integer and requires 4 bytes of storage per value (Documentation Integer data type: IBM, 2021).

The short type can convey a range of values equal to 2^{16} because its size is 2 bytes (16 bits): 216 = 65 536. The numbers range from -32 768 to 32 767 because the short type is a signed one and contains both positive and negative values.

2.9.2 Long data type

Long is another type of integer data type. It is 8 bytes in size (64 bits). The value ranges from -9 223 372 036 854 775 808 to 9 223 372 036 854 775 807.

2.9.3 Float data type

Because it contains a fraction that is expressed in decimal format, a float is a data type that is made up of a number that is not an integer. It is also called a real. A float is stored in 4 or 8 bytes.

2.9.4 String data type

String is a sequence data type that is used to represent text not numbers. It consists of digits and symbols but they are always treated as plain text. String is a sequence of characters, either as a literal constant or as some kind of variable. Strings are usually enclosed in quotation marks (‘,”) single or double depending on the programming language.

2.11 Embedded systems

An embedded system is a microprocessor-based computer hardware system with software that is designed to perform a dedicated function, either as an independent system or as a part of a large system, at the core is an integrated circuit designed to carry out computation for real-time operations (Embedded Systems, n.d.) . Complexities range from a single microcontroller to a suite of processors with connected peripherals and networks; from no user interface to complex graphical user interfaces. The complexity of an embedded system varies significantly depending on the task for which it is designed. They are managed by microcontrollers or digital signal processors (DSP), application-specific integrated circuits (ASIC), field-programmable gate arrays (FPGA), and gate arrays. These processing systems are integrated with components dedicated to handling electric and/or mechanical interfacing. The basic structure of an embedded system includes the following components:

1. Sensor: The sensor measures and converts the physical quantity to an electrical signal, which can then be read by an embedded systems engineer or any electronic instrument. A sensor stores the measured quantity to the memory.

2. A-D Converter: The analog-digital-converter converts analog signals received by the sensors into digital signal.

3. Processor & ASICs: Processors assess the data to measure the output and store it to the memory.

4. D-A Converter: A digital-to-analog converter changes the digital data fed by the processor to analog data.

5. Actuator: An actuator compares the output given by the D-A Converter to the actual output stored and stores the approved output.

2.12 Microcontrollers

A microcontroller can be described as a single-on-chip computer that contains a number of peripherals such as RAM, EEPROM, timers, and so on needed to perform some predefined tasks. Microcontrollers come in a variety of shapes and sizes, each with its own architecture.

2.12.1. AVR Microcontrollers

AVR stands for Advanced Virtual RISC. It was developed in 1996 by Atmel Corporation. The architecture of AVR was developed by Alf-Egil Bogen and Vegard Wollan It is an 8bit RISC single-chip microcontroller with Harvard architecture that comes with some standard features such as on-chip program (code) ROM, data RAM, data EEPROM, timers and I/O ports and additional features like ADC, PWM, and different kinds of serial interface such as USART, SPI, I2C, USB and so on (Muhammad Ali Mazidi, 2013) . They are generally classified into four groups: Tiny AVR, Mega AVR and XMega AVR. The Tiny AVR has less memory (about 0.5-8kb) and is suitable for easy applications. The Mega AVR is quite popular and is used for many applications. It has a memory of up to 256kb and quite a number of inbuilt peripherals and is suitable for moderate to complex application. The XMega AVR is larger in size and has more memory than the others (about 16-384kb). It is suitable for high speed and complex applications.

It consists of 32 x 8-bit general purpose working registers. Within a single clock cycle, the AVR can take inputs from two general purpose registers, pass them to the ALU, perform the requested operation, and return the result to any register. ALU can perform both arithmetic and logical operations through input from a register or between a register and a constant. Single register operations such as complement of a number can also be performed on the ALU. The AVR does not have an accumulator register. Operations can be performed between any register and stored in any register. Some types of AVR microcontroller are (EmbeddedSchool Elysium, 2019):

1. ATMega8 AVR Microcontroller - It consists of 28 pins, 1 Kbytes of internal SRAM, and 8 Kbytes of flash memory, and supports two external interrupts. It has a two-wire interface and external pins for connecting two voltages to the two inputs of the comparator. It is used mainly in electrical projects
2. ATMega16 AVR Microcontroller - It consists of 40 pins. It has a flash memory type, 16 MIPS speed, 1 KB RAM and 6 power saving modes. It has an internal oscillator for its clocking. By default, it operates at a frequency of 1MHz with a maximum of 8MHz. It can also use an external crystal oscillator with a maximum frequency of 16MHz. It has an 8 channel Analog to Digital Converter with two 8-bit and one 16-bit timer. It consists of 21 interrupts four of which are external interrupts, the remaining are internal interrupts

which support peripherals such as ADC, USART etc. The ATMega16 supports USART (Universal Synchronous and Asynchronous Receiver and Transmitter) for interfacing with external devices and serial communication. It is used mainly for mobile embedded systems.

3. ATMega32 AVR Microcontroller – It consists of 32KB ISP flash memory and read / write function, 1KB EEPROM, 2KB SRAM, 54/69 general purpose I / O line, 32 general purpose work registers, JTAG interface for boundary scan and on-chip debugging / programming, 3 flexible timers / counters Combination mode, internal and external interrupts, serial programmable USART, universal serial interface (USI) with start condition detector, 8-channel 10-bit Analog to Digital converter, programmable watchdog timer with internal oscillator, serial SPI interface and 5 Two software-selectable power saving modes. The ATMega32 operates between 1.85.5 volts. It is mostly used in systems with less human intervention for automation.
4. ATMega328 AVR Microcontroller – It consists of 32KB ISP flash memory and read / write function, 1KB EEPROM, 2KB SRAM, 23 general purpose I / O lines, 32 general purpose working registers, 3 flexible timers / counters with comparison mode, internal and external interrupts, serial programmable USART, byte-directional 2-wire serial interface, SPI serial interface, 6-channel 10-bit Analog to Digital converter, programmable watchdog timer with internal oscillator, and 5 software-selectable power-saving modes. The device operates between 1.8 to 5.5 volts. This device delivers a throughput of approximately 1 MIPS / MHz It is mostly used in robotics, Arduino, Power monitoring and management systems (Wikipedia, n.d).

2.12.2. ARM Microcontroller

Developed by Acron Computers in 1987. ARM stands for Advanced RISC Machine based on the RISC architecture which is commonly used in computer configuration. It is a 32-bit microcontroller that uses SPI, CAN, Ethernet, I2S, DSP, SAI, UART, USART communication protocol. It uses Flash, SDRAM, EEPROM memory and provides high speed operation. It has less power consumption along with reduced complexity in the circuits. This ARM is a family of microcontrollers developed by companies such as ST Microelectronics and Motorola. The ARM architecture is divided into several versions, such as ARMv1 and ARMv2, each with its own advantages and limitations. There are several generations of ARM design. The original ARM1 used a 32-bit internal structure, but had a 26-bit address space and was limited to 64MB of main memory. This limitation was removed in the ARMv3 series, which has a 32-bit address space, and some additional generations up to ARMv7 remained 32-bit. The ARMv8A architecture, released in 2011, added support for 64-bit address space and 64-bit operations using the new 32-bit fixed-length instruction set. To carry out the user task, the ARM employs seven processing modes:

1. USER Mode – This mode is the simplest with the fewest registers. There is no SPSR and access to the CPSR is restricted.
2. FIQ and IRQ Mode - The two interrupt-causing modes for the CPU are FIQ and IRQ. FIQ stands for Processing Interrupt and IRQ stands for Standard Interrupt. When handling critical interrupts, FIQ mode has five additional bank registers for flexibility and excellent performance.
3. SVC Mode - Supervisor mode is the processor's software interrupt mode for booting or resetting.

4. UNDEFINED Mode - When invalid statements are executed, they are caught by undefined mode. The 32-bit data bus and faster data transfer are part of the ARM core.
5. THUMB Mode - In this mode, 32-bit data is divided into 16 bits to improve processing speed.

2.13 Electrical components

In an electronic circuit design, electrical components are used to build the circuit. These components are classified as either active or passive components. Active components are those components that are capable of delivering and controlling energy in the circuit. It supplies energy to the circuit. Some examples are

2.13.1. Voltage and Current Sources

When current leaves from the positive terminal of a voltage source like a battery, energy is sent to the circuit and from the explanation that is what an active device does. The internal resistance of an ideal voltage source is zero; it is able to supply or absorb any amount of current. The current through an ideal voltage source is completely determined by the external circuit. When connected to an open circuit, there is zero current and thus zero power. When connected to a load resistance, the current through the source approaches infinity as the load resistance approaches zero (a short circuit). Thus, an ideal voltage source can supply unlimited power. A current source controls the flow of current in the circuit and supplies current to the circuit also. Some examples are secondary current in a current transformer. An ideal current source generates a current that is independent of the voltage changes across it. An ideal current source is a mathematical model which real devices can approach very closely. If the current through an ideal current source can be specified independently of any other variable in a circuit, it is called an independent current source. Conversely, if the current through an ideal current source is determined by some other voltage or current in a circuit, it is called a dependent or controlled current source. The internal resistance of an ideal current source is infinite. The simplest non-ideal current source consists of a voltage source in series with a resistor. The amount of current available from such a source is given by the ratio of the voltage across the voltage source to the resistance of the resistor (Ohm's law; $I = V/R$). (Wikipedia, n.d).

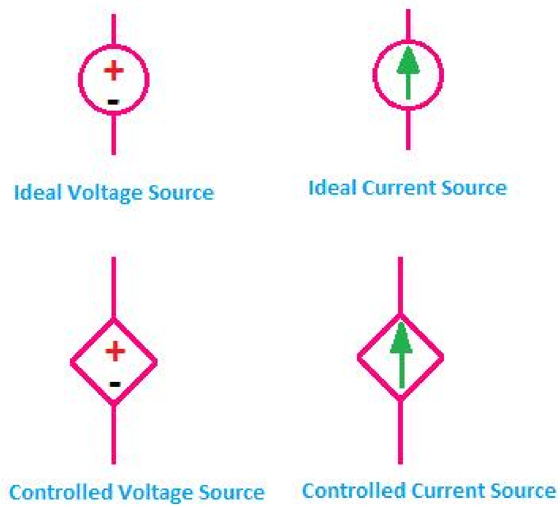


Figure 2.9: Symbol of Voltage and Current Sources

2.13.3. Diode

This is a two terminal component that conducts in one direction i.e it allows current to flow in one direction only. It is used to control the flow of current in the circuit thus it is an active component. A diode is effectively like a valve for an electrical circuit. Semiconductor diodes are the most common type of diode. A PN junction is the simplest form of the semiconductor diode. We can form a PN junction by joining a p-type semiconductor and n-type semiconductor together with a special fabrication technique. The terminal connected to the p-type is the anode. The terminal connected to the n-type side is the cathode. The operating principle of a diode depends on the interaction between an n-type semiconductor and a p-type semiconductor. N-type semiconductors have many free electrons and very few holes. In other words, it can be said that the concentration of free electrons in n-type semiconductors is high and the concentration of holes is very low. Free electrons in n-semiconductors are called majority charge carriers, and holes in n-semiconductors are called minority charge carriers. The p-type semiconductor has a high concentration of holes and a low concentration of free electrons. Holes in p-semiconductors have a large number of carriers, and free electrons in p-semiconductors have a small number of carriers.

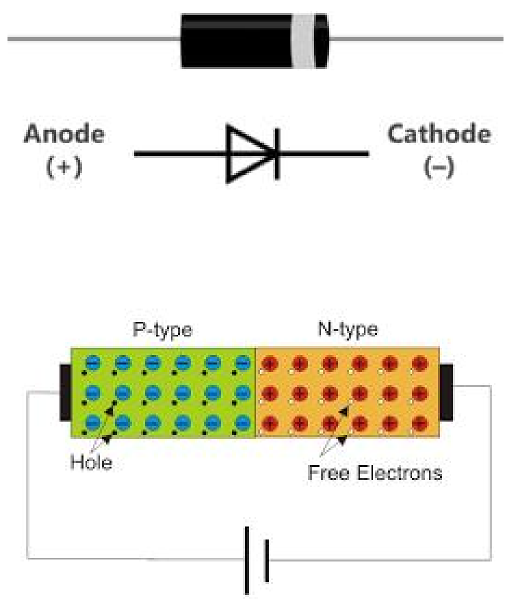


Figure 2.10: Schematic of a PN junction Diode

In ideal conditions, this PN junction behaves as a short circuit when it is forward biased, and as an open circuit when it is in the reverse biased.

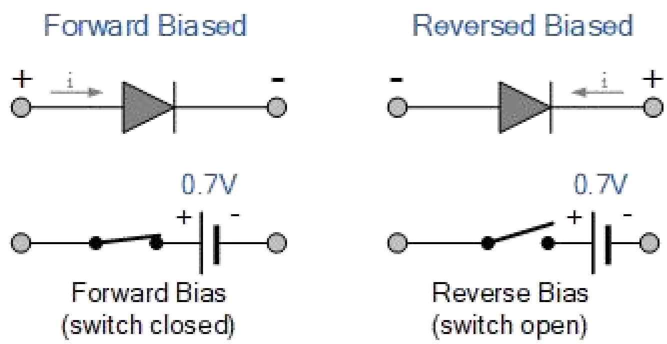


Figure 2.11: Forward and Reversed Biased PN Junction Semiconductor Diode

When the diode is connected in the reverse bias state, a positive voltage is applied to the N-type material and a negative voltage is applied to the P-type material. The positive voltage applied to the N-type material attracts electrons towards the positive electrode and keeps them away from the junction. On the other hand, the holes at the P-type end are also attracted from the junction toward the negative electrode. The end result is that the depletion layer expands due to the lack of electrons and holes, a high impedance path exists, an insulator and a high potential barrier are almost created at the junction, and current flows through the semiconductor material.

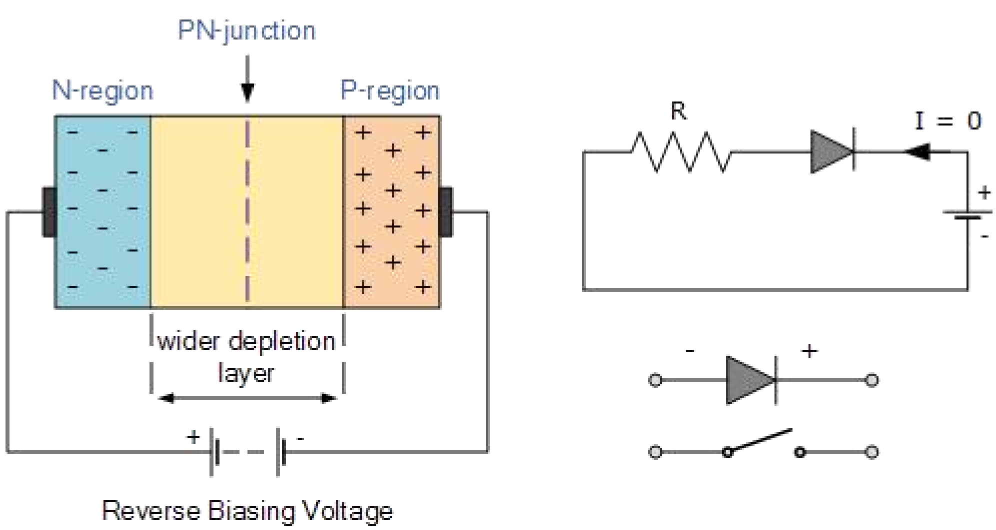


Figure 2.12: Reversed biased PN Junction Diode

When the diode is connected in the forward bias state, a negative voltage is applied to the N-type material and a positive voltage is applied to the P-type material. If this external voltage is greater than the value of the potential barrier, about 0.7 volts for silicon and 0.3 volts for germanium the potential barrier is overcome and current begins to flow. This is because the negative voltage pushes and repels the electrons towards the junction, giving them the energy to cross and connect to the holes being pushed in the opposite direction towards the junction by the positive voltage. The application of a forward biasing voltage on the junction diode results in the depletion layer becoming very thin and narrow which represents a low impedance path through the junction thereby allowing high currents to flow.

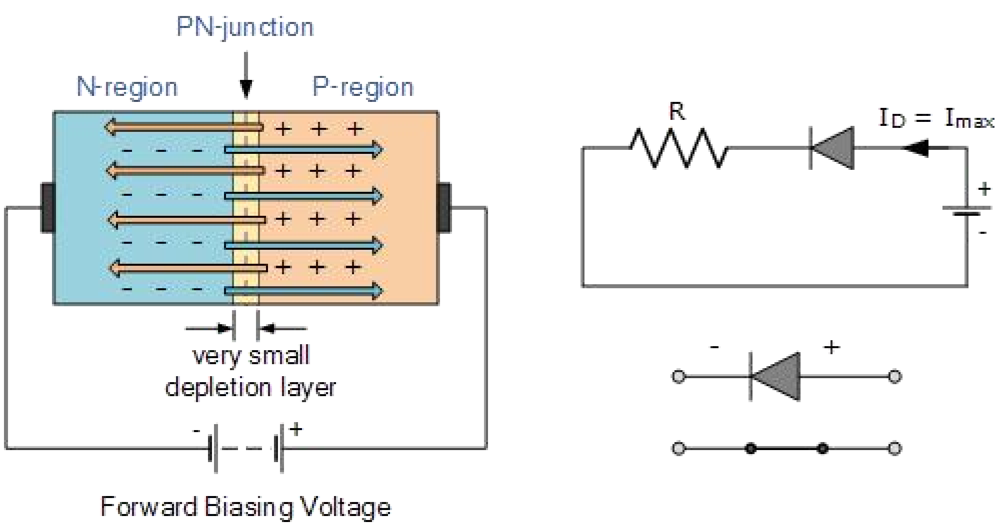


Figure 2.13: Forward biased PN Junction Diode

Passive components are those components that responds to the flow of electrical energy. It can either store, absorb or dissipate energy. They cannot generate an electrical signal. Some examples are

2.13.3. Resistors

This is a device that reduces or limits the flow of current in the circuit. When an electric current flows through a resistor, the resistor absorbs electrical energy and dissipates it in the form of heat. Resistors can be variable or fixed resistors as seen

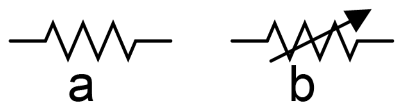


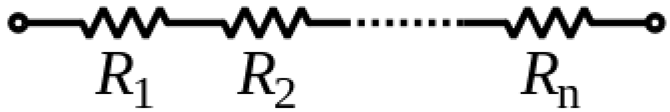
Figure 2.14: (a) Resistor Symbol (b) Variable Resistor symbol

Figure 2.15: A Resistor

The behavior of an ideal resistor is described by Ohm's law:

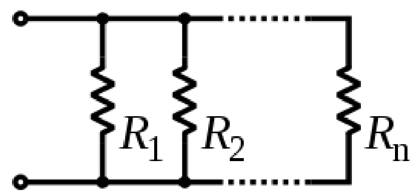
$$V = I.R \quad \text{…equ (2.1)}$$

Ohm's law states that the voltage (V) across a resistor is directly proportional to the current (I) passing through it where the constant of proportionality is resistance (R). In practice, resistors deviate from the behavior stated by Ohm's law. For example, they have inductance and capacitance, which affect the relationship between voltage and current in alternating current circuits. The ohm (symbol: Ω) is the SI unit of electrical resistance. An ohm is equivalent to a volt per ampere. In an electrical circuit, resistors are connected in Series and in parallel. In series connection, the total resistance of resistors is the sum of their individual resistance values.



$$Req = R1 + R2 + \cdots + Rn \ldots equ(2.2)$$

In a parallel connection, the total resistance of the resistors is the sum of the reciprocal of the individual resistance of the resistors.



$$\frac{1}{Req} = \frac{1}{R1} + \frac{1}{R2} + \cdots + \frac{1}{Rn} \ldots equ(2.3)$$

2.13.4. Capacitor

A capacitor is a two-terminal linear passive component consisting of two conductive plates with an insulator in between separated by a non-conductive region. The non-conductive region can either be a vacuum or an electrical insulator material known as a dielectric. Examples of dielectric media are glass, air, paper, plastic, ceramic, and even a semiconductor depletion region chemically identical to the conductors.

(a) (b)

Figure 2.16: (a) A Capacitor (b) Capacitor Symbol

From Coulomb's law a charge on one conductor will exert a force on the charge carriers within the other conductor, attracting opposite polarity charge and repelling like polarity charges, thus an opposite polarity charge will be induced on the surface of the other conductor. The conductors thus hold equal and opposite charges on their facing surfaces, and the dielectric develops an electric field (Capacitance and Charge on a Capacitors Plates, n.d).

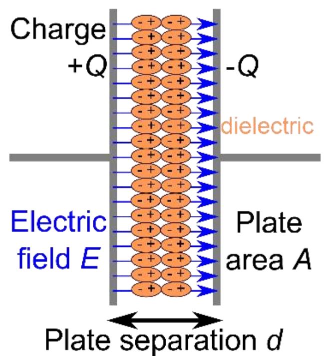


Figure 2.17: Schematic diagram of a Capacitor

An ideal capacitor is characterized by a constant capacitance *C*, in farads in the SI system of units, defined as the ratio of the positive or negative charge *Q* on each conductor to the voltage *V* between them:

$$C = \frac{Q}{V} \ldots equ(2.4)$$

The main function of a capacitor is to store electrical energy when the power supply forces a charge on the terminal. It keeps charging even after the power is turned off. Capacitors with resistors are used in timing circuits and can also be used as filters to allow AC signals and block DC signals. Parallel plate capacitors are the simplest form of capacitors. It can be constructed from two metal or metallized foil plates placed parallel to each other, and the capacitance value in Farad is determined by the surface area of the conductive plate and the distance between them. Changing any two of these values will change the value of that capacitance, which forms the basis for the operation of variable capacitors. Capacitors store electron energy in the plate in the form of electric charges, so the larger the plate and / or their spacing, the greater the charge the capacitor holds on the plate at a given voltage. In other words, larger plates, smaller distance, more capacitance.

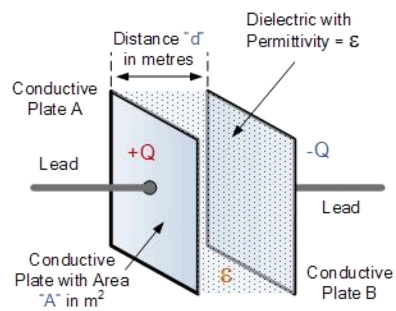


Figure 2.18: Parallel plate Capacitor

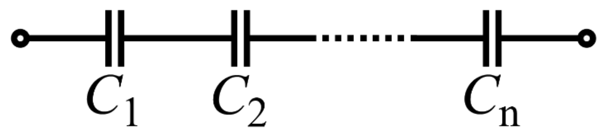
The characteristic of a capacitor that stores charge on its plate in the form of an electrostatic field is called the capacitance of the capacitor. The capacitance of a parallel plate capacitor is directly proportional to the area A in meters^2 of the two plates, and inversely proportional to the distance between the two plates d in meters. The general equation for the capacitance of a parallel plate capacitor is:

$$C = \frac{\varepsilon A}{d} \ldots equ(2.5)$$

Where ε represents absolute permittivity of the dielectric material used. A parallel capacitor can only store a limited amount of energy before the dielectric material becomes a conductor and current flows through it. The equation to represent this maximum energy is:

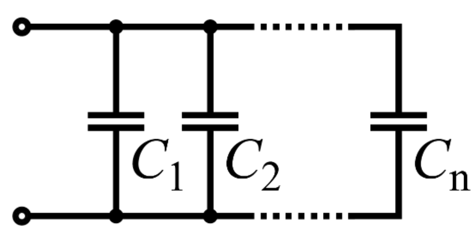
$$E = \frac{1}{2} CV^2 \ldots equ(2.6)$$

In an electrical circuit, a capacitor can be connected in serial connection and parallel connection. Capacitors connected in series have different voltage applied across each of them. The total capacitance in a series connection is equivalent to the sum of the reciprocal of each of the capacitors in the series connection. The equation for such connection is



$$\frac{1}{C_{eq}} = \sum_i \frac{1}{C_i} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n} \dots equ(2.7)$$

For capacitors connected in parallel, the total capacitance is equivalent to the sum of the individual capacitance of the capacitors in the connection. Each capacitor has the same voltage applied across them. The equation for the total capacitance in this connection is:



$$C_{eq} = \sum_i C_i = C_1 + C_2 + \dots + C_n \dots equ(2.8)$$

2.13.5. Inductor

This is a two-terminal passive electrical component. The main function of inductors is to store electrical energy in the form of magnetic energy. Inductors are typically made up of conductors, usually wound around a coil that operates according to Faraday's law of inductance. When current flows through the coil from left to right, the coil creates a clockwise magnetic field and induces and electromotive force (emf) or voltage. According to Lenz's law, an induced voltage has a polarity (direction) that opposes the change in the current that generated it. As a result, inductors counteract changes in the current flowing through them. Inductors are characterized by inductance, which is the ratio of voltage to the rate of change of current. The SI unit for inductance is the Henry (H). In the measurement of magnetic circuits, it is equivalent to weber/ampere. An electric current flowing through a conductor generates a magnetic field surrounding it. The magnetic flux linkage Φ_B generated by a given current I depends on the geometric shape of the circuit. Their ratio defines the inductance L:

$$L = \frac{\Phi_B}{I} \ldots equ(2.9)$$

(a)

(b)

Figure 2.19: (a) A Ferrite Inductor (b) Inductor symbol

An inductor is usually constructed as a coil of conducting material, typically copper wire, wrapped around a core either of air or of ferromagnetic material. Core materials with a higher permeability than air increase the magnetic field and confine it closely to the inductor, thereby increasing the inductance. Low frequency inductors are constructed like transformers, with cores of electrical steel laminated to prevent eddy currents. "Soft" ferrites are widely used for cores above audio frequencies, since they don't cause the large energy losses at high frequencies that ordinary iron alloys do. This is because of their narrow hysteresis curves, and their high resistivity prevents eddy currents. Inductors come in many shapes. Most are constructed as enamel coated wire wrapped around a ferrite bobbin with wire exposed on the outside, while some enclose the wire completely in ferrite and are called "shielded." Some inductors have an adjustable core, which enables changing of the inductance. Inductors used to block very high frequencies are sometimes made by stringing a ferrite cylinder or bead on a wire (Inductor, n.d).

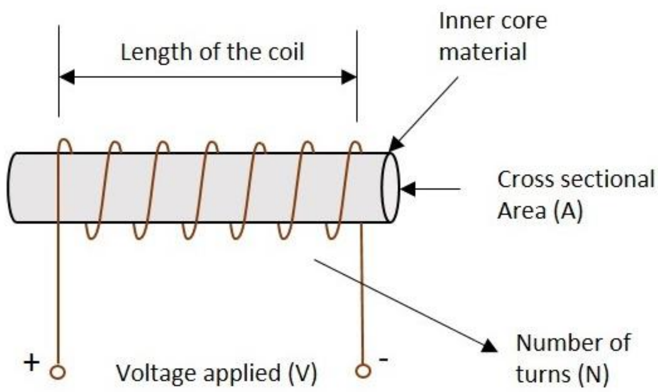


Figure 2.20: Schematic of an Inductor

There is different type of inductors. Depending on the type of material used, they are classified as:

1. Iron core inductor - As the name implies, the core of this type of inductor is made of iron. These inductors are small footprint inductors with high power and high inductance values. However, there is a limit to the high frequency capacity. These inductors are used in audio equipment.

2. Air core inductor - These inductors are used when the required inductance is small. There is no core loss because there is no core. However, this type of inductor has more

turns than cored inductors. This will increase the quality factor. Traditionally, ceramic inductors are often referred to as air-core inductors.

3. Iron powder inductor - In this type of inductor, the core is Iron Oxide. They are formed by very fine and insulating particles of pure iron powder. High magnetic flux can be stored in it due to the air gap. The permeability of the core of this type of inductor is very less. These are mainly used for switching power supplies.

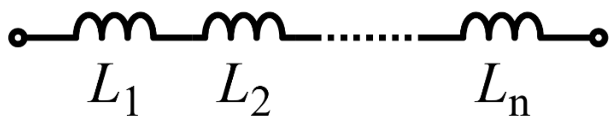
4. Ferrite core inductor - This type of inductor uses a ferrite material as the core. The common composition of ferrite is XFe2O4. Where X represents the transition material. Ferrites can be divided into two types. Soft ferrite and hard ferrite. Soft ferrite: A material that can invert its polarity without external energy. Hard Ferrites: These are permanent magnets. In other words, the polarity does not change even if the magnetic field is removed.

5. Choke - A choke is a type of inductor primarily used to cut off radio frequency alternating current (AC) in a circuit. On the other hand, it can pass DC or low frequency signals. The function of this inductor is to limit changes in current, so it is called a choke. This inductor consists of a coil of insulated wire wound around a magnetic core. The main difference between chokes and other inductors is that they do not require a high Q factor design technique aimed at reducing the resistance of the tuned circuit inductor.

Ideal inductors do not provide resistance to constant direct current. However, only superconducting inductors have truly zero electrical resistance. The relationship between the time-varying voltage v(t) at the inductance of the inductance L and the time-varying current i(t) flowing through it is expressed by a differential equation:

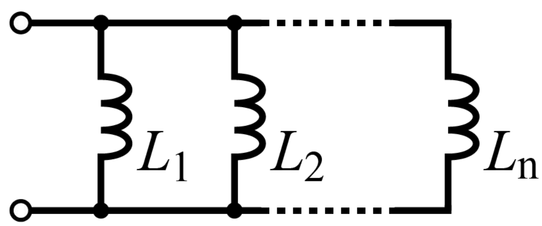
$$v(t) = L\frac{di(t)}{dt} \dots equ(2.10)$$

In an electrical circuit, inductors can be connected in both serial and parallel connections. For inductors in series, the inductors are connected end to end to each other. Different voltage is applied across each inductor. Inductors in series are similar to capacitors in parallel. The total effective inductance is equivalent to the sum of individual inductance in the inductors



$$L_{eq} = L_1 + L_2 + \dots + L_n \dots equ(2.11)$$

For inductors in parallel, the same voltage is applied across each inductor. Inductors in parallel behave like capacitors in series. The total effective inductance in this connection is equivalent to the sum of the reciprocal of each inductance of the individual inductors in the circuit



$$\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2} + \dots + \frac{1}{L_n} \dots equ(2.12)$$

2.13.6. Transformer

A transformer is an electrical device that consists of two wire coils connected by an iron core. It provides the very necessary functionality to easily change current and voltage levels. The main function of the transformer is to increase (step up) or decrease (step down) the AC voltage.

Transformers operate according to Faraday's law of electromagnetic induction which states that The electromotive force around a closed path is equal to the negative of the time rate of change of the magnetic flux enclosed by the path (Wikipedia n.d), that is, mutual inductance between two circuits connected by a common magnetic flux.

$$V_p = - N_p \frac{d\Phi}{dt} \ldots equ(2.13)$$

$$V_s = - N_s \frac{d\Phi}{dt} \ldots equ(2.14)$$

Where V_p and V_s are the instantaneous voltage in the primary and secondary winding respectively, N is the number of turns in a winding, $d\Phi/dt$ is the derivative of the magnetic flux Φ through one winding over time.

Transformers convert electrical energy from one circuit to another with the help of mutual induction between two windings without electrical connections. It also converts electricity from one circuit to another at different voltage levels without changing the frequency.

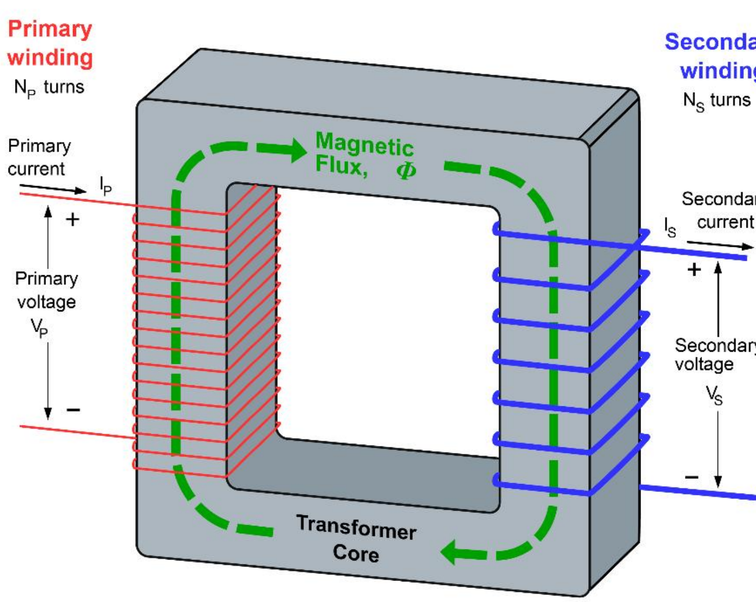


Figure 2.21: Ideal transformer and law of induction

There are four basic parts of a transformer, they are: input connection, ouput connection, windings, and core

1. Input connection - The input side of the transformer is called the primary side because it is where the main power to be changed is connected.

2. Output connection - On the output or secondary side of the transformer, power is sent to the load. The input power increases or decreases depending on the load needs.

3. Windings - The windings are a set of copper wires wound around the core of the transformer. The transformer has two windings, a primary winding and a secondary winding. The primary winding is a coil that draws current from the source. The secondary winding is a coil that energizes the load with a converted or modified voltage. Normally, these two coils are split into multiple coils to reduce the formation of magnetic flux.

4. Core - The transformer core is used to provide a controlled path for the magnetic flux generated by the transformer. The core is generally not a solid steel bar, but a structure of many thin laminated steel sheets or layers. This structure is used to eliminate and reduce heating. Transformers usually have one of two types of cores: core type and shell type. These two types differ in the way the primary and secondary coils are placed around the steel core. For core type, the windings surround the laminated core while in shell type, the windings are surrounded by the laminated core.

When an input voltage is applied to the primary winding, alternating current begins to flow in the primary winding. When an electric current flows, an alternating magnetic field is generated in the core of the transformer. When this magnetic field intersects the secondary winding, an AC voltage is generated in the secondary winding. The actual wire turns ratio for each coil is key to determining the transformer type and output voltage. The ratio of output voltage to input voltage is equal to the ratio of turns between the two windings.

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \ldots equ(2.15)$$

If the secondary winding has more wires than the primary winding, the output voltage of the transformer will be higher than the input voltage. The output voltage is boosted and is considered a "step-up transformer". If the number of turns of the secondary winding is less than that of the primary winding, the output voltage will be low. This is a "step-down transformer".

There are different configurations of a transformer, they are:

1. Single phase transformer - A single-phase transformer is a type of power transformer that uses single-phase AC power. That is, the transformer relies on a voltage cycle that operates in a uniform time phase. They are commonly used to down convert long-distance and localized transmission streams to power levels that are more suitable for residential and light commercial applications. The ratio of the primary winding (input winding) to the secondary winding (output winding) determines the change in current.

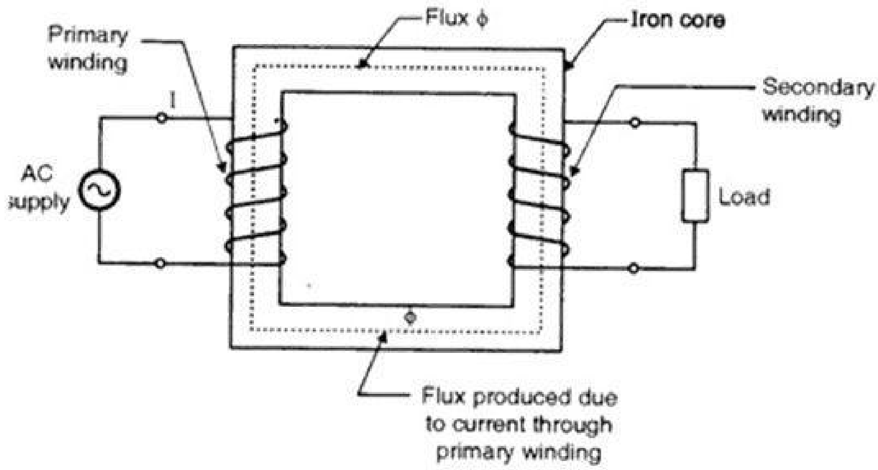


Figure 2.22: Schematic of a Single phase transformer

2. Three phase transformer - A three phase transformer can be constructed either by connecting together three single-phase transformers, thereby forming a so-called three phase transformer bank, or by using one pre-assembled and balanced three phase transformer which consists of three pairs of single phase windings mounted onto one single laminated core (Three phase transformers, n.d). Three-phase transformers have six windings; three primary and three secondary. The six windings are connected by the manufacturer as either delta or wye. The three available voltages that shift 120 electrical degrees from each other not only determine the type of electrical connection used on the primary and secondary sides, but also the flow of transformer current. With three interconnected single-phase transformers, the magnetic flux phases of the three transformers differ by 120 time-degrees.

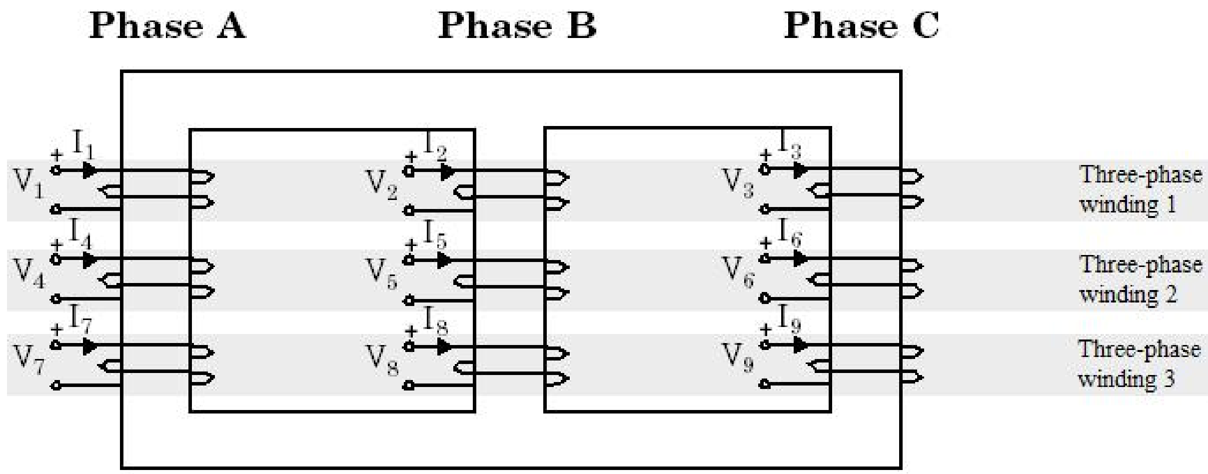


Figure 2.23: Schematic of a three phase transformer

The standard method for marking three phase transformer windings is to label the three primary windings with capital (upper case) letters A, B and C, used to represent the three individual phases of RED, YELLOW and BLUE. The secondary windings are labelled with small (lower case) letters a, b and c (Three phase transformers).

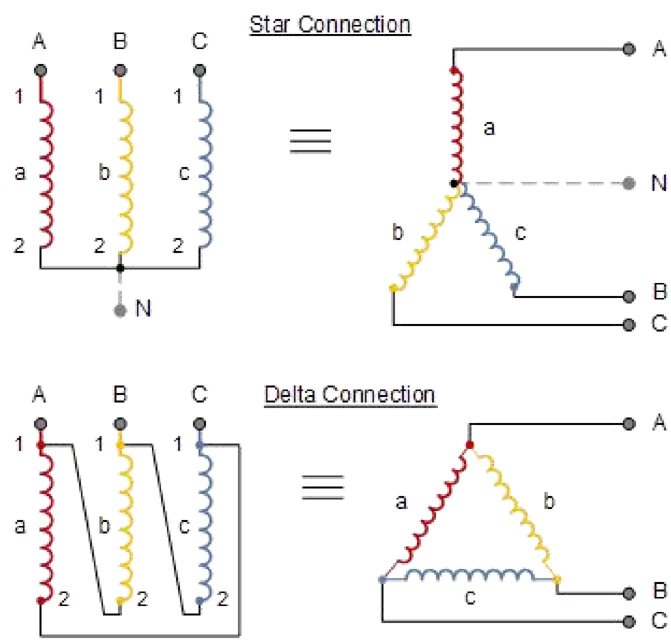


Figure 2.24: Star and Delta connections for a three phase transformer

2.14 RELATED WORKS

In this section, we present the details of various recent systems for monitoring the solar plants, and data analytics methods for identifying faults.

1. Solar Power Monitoring System Using IOT by Nehali Datar (Nehali Datar, 2021)

The main objective of this research is to design and implement a Smart Remote monitoring system using IOT that is capable of monitoring the Solar power conditioning unit which consists of a solar charge controller and provides the facility to charge the battery bank either through solar or grid and stores data in the cloud database through an easily manageable web interface (firebase). The limitation is that the system fails if there is no internet access.

2. Solar Power Monitoring System Using IOT by Neelanshi S Palkar, Ashish Janwe, Ashlesh Chopde, Ankit Yadav, Vinit Borkar, Poonam Bhad (Neelanshi S Palkar, 2021)

The development of monitoring online and the control of the system is based on the android platform by Bluetooth interface of mobile phone as a communication link it creates data exchange with the hardware of power conditioning unit, with the help sensing circuits the value of Current and the voltage measurement of the renewable source is processed by the microcontroller of the microchip. The limitation is that the system fails if there is no internet access.

3. IOT Enabled Solar Power Monitoring System by R.L.R. Lokesh Babu (R.L.R. Lokesh Babu, 2018)

The main objective of this project is to get an optimum power output from the solar panels while dust is accumulated on it. Also, if there is any malfunctioning of the solar panels will be displayed to get information about whether the solar or battery-connected for the loads. The limitation is that the system fails if there is no internet access or access to mobile phones.

4. Intelligent Monitoring and Maintenance of Solar Plants using Real-time Data Analysis by Mayuri Ejgar, Dr. Bashirahamad Momin (Mayuri Ejgar, 2017)

In this paper, we present a system to identify various malfunctioning and possible breakdowns of such devices based on real-time monitoring and various real-time anomaly detection techniques. This system is limited by the dependency on numerous devices and access to the internet.

5. Solar Energy Monitoring System by IOT by K.G. Srinivasan (K.G. Srinivasan, 2017)

The main objective of this proposed work is to monitor the system using the current and voltage value sensed by the Arduino. The monitor of the solar energy system shows the power and energy usage. This system helps to implement a smart grid for efficient usage. The limitation is that the system fails if there is no internet access.

6. An IOT based Smart Solar Photovoltaic Remote Monitoring System by Monika P. Tellawar (Monika P. Tellawar, 2019)

The main objective of this proposed work is to monitor the output of a PV system using the current and voltage value sensed by the Arduino. To implement a smart grid, this system helps for efficient usage**.** This system is heavily dependent on internet access and as such is limited in areas of no coverage.

7. A Study of IOT based Solar Panel Tracking System by Subhasri.G (Subhasri.G, 2018)

The main objective of this proposed work is to determine the solar radiation that reaches the ground. It may vary according to location, time and climatic conditions. For that, the solar panel can be completely exposed to the sun's radiation. And hence the solar panel can be monitored by using Internet of Things. This system is limited by the dependency on numerous devices and access to the internet.

8. Real Time Monitoring of Solar PV Parameter Using IOT by Shailesh Sarswat (Shailesh Sarswat, 2019)

In this project, the vehicle will be equipped/embedded with sensors all around it which would sense the impact in the accident, and then will send the readings to the MCU which will process the readings and send a text message containing the current whereabouts of the vehicle along with its registration number and the owner's name to the nearest medical service. The drawback of this system is that it needs internet access to operate and it relies heavily on an Android app.

9. Low Cost Data Logger And Monitoring System for a Small Solar PV Energy System by Debobrata Gupta (Debobrata Gupta, 2018)

In this project, a system for Load estimation and system sizing, the design of low power and low-cost data logger for pico-solar energy system and the design of a cell phone app for data monitoring and analysis was developed. This system is limited by the dependency on a phone app and access to the internet.

10. Exploring IOT-based Applications in Power Systems Monitoring, Demand Side Management And Protection by Long Zhao (Long Zhao, 2020)

IoT-based monitoring systems are developed for power substations at petrochemical facilities, power substations for large power grids, and holistic wind turbine monitoring, respectively. IoT platform provides real-time and remote capabilities for a monitoring system which are extremely critical in power system monitoring. These monitoring systems are developed on Hybrid FPGA CPU controllers. This system is limited by the dependency on numerous devices and access to the internet.

11. IOT Based Weather Monitoring and Reporting System Project (Anita M. Bhagat, Ashwini G. Thakare, Kajal A. Molke, Neha S. Muneshwar, Prof .V. Choudhary, 2019)

The IOT based Weather Monitoring and Reporting System project is used to get Live reporting of weather conditions. It will Monitor temperature, humidity, moisture and rain level. Suppose Scientists/nature analysts want to monitor changes in a particular environment like volcano or a rain-forest. And these people are from different places in the world. In this case, SMS based weather monitoring system has some limitations. Since it sends SMS to few numbers. And time for sending SMS increases as the number of mobile numbers increases. In order to know the information about weather of a particular place then they have to visit that particular sites. Where everyone can see it.

12. Development of IOT Based Weather Reporting Station (A F Pauzi and M Z Hasan, 2020)

This project focuses on the development of the Thingspeak, an IOT platform that shows the data of the sensor. The method is divided into two parts which are hardware and software development part. The hardware involves the circuit construction and developing the prototype. Meanwhile the software part involves the IOT coding and data acquisition. By using three types of sensor to monitor the weather parameter that are temperature, humidity, rain and air quality the system will be able to display the weather condition by an analysis about the current weather with the sensor value data. All the data will be controlled by a microcontroller ESP32 and Wemos as the client that will receive the sensor data from ESP32 and display it on OLED. Also this system will also be seen on ThingSpeak channel that has been created to simplify user to check online and also an android application that is Blynk to display the sensor data. The data collected will be analysed to ensure precise weather condition on the current location.

13. Web Based Monitoring of Solar Power Plant using Open Source IOT Platform Thingspeak and Arduino (Jayaharsha Kandimalla and Dr.D.Ravi Kishore, 2017)

The aim of this project is to measure the solar panel parameters through multiple sensor data acquisition. This helps to facilitate small scale installations with cost effective and reliable monitoring system, with access from anywhere in the world. The different parameters of the solar panel like the light intensity, voltage, current, power and temperature are monitored. The system is designed using Arduino UNO controller. The light intensity is monitored using an LDR sensor, voltage by voltage divider principle, load current is measured using ACS712 current sensor and temperature by temperature sensor LM35. When the system is switched on, Arduino and other components gets power from the solar panel. Battery connected to solar panel is also charged as charging circuit will control the voltage. The data form the panel can be monitored using Thingspeak web interface from anywhere in the world.

14. Design and Construction of an Arduino-based solar power measuring parameter measuring system with data logger (Oladimeji I, Adediji Y.B., Akintola J.B, M.A. Afonlayan, O. Ogunbuyi, Ibrahim S.M., Olayinka S.Z., 2020)

This study was aimed at the development of a cost-effective parameter-measuring system for a solar photovoltaic panel using Arduino microcontroller. The system measures five parameters including voltage, current, light intensity, temperature and pressure. The hardware circuit was designed to link different sensors with the Arduino board and measured data were in turn documented into a computer for further analysis. The accuracy of the constructed device was ascertained by comparing the measured parameters with that of a conventional standard measuring instrument which shows good agreement. The measured parameters show that the output energy generation from solar photovoltaic panel largely depends on the solar irradiance and temperature.

15. Design and Implementation of an intelligent low-cost IOT solution for Energy Monitoring of Photovoltaic stations (Youssef Cheddadi, Hafsa Cheddadi, Fatima Cheddadi, Fatima Errahimi, Naija Es-sbai, 2020)

This research aimed at presenting a cost-effective and open source internet of things solution that could collect in intelligent manner and monitor in real-time the produced power and environmental conditions of solar stations. In the proposed monitoring system, the ESP32 DEVKIT V1 board acts as the microcontroller that acquires and processes the incoming data from the various sensors, then it transmits the processed data to the cloud via built-in Wi-Fi. The data collected by the various sensors is stored in the cloud. Five parameters namely power, current, voltage, temperature and irradiance level are measured using the system. This is connected wirelessly to the InfluxDB database and visualized via Grafana platform.

16. Solar Based IOT Plant Monitoring and Controlling System in Bio-Agri Environments (Dr. M. Braveen, Dr. Shafali Jain, Dr. Rambabu Vatti, Mr. Chilukuri Bala Venkata Subbarayudu, Mr. Ravi Naragani, 2020)

17. A Review on Solar Monitoring System (Dinesh Kumar Sahu and Anil Brahim, 2021)

This paper contained a concise review on similar works related to solar monitoring plant. It carefully analysed the system proposed by outstanding researchers. Most work using IOT technology.

18. Solar Monitoring System in Malawi (Mayamiko Nkoloma, Macro Zennaro, Antonie Bagula, n.d)

This paper describes recent work on the development of a wireless based remote monitoring system for renewable energy plants in Malawi. The main goal was to develop a cost effective data acquisition system that continuously presents remote energy yields and performance measures. The project output gives direct access to generated electric power at the rural site through the use of wireless sensor boards and text message (SMS) transmission over cellular network. The SMS recipient at the central site houses an intelligent management system based on FrontlineSMS for hosting SMSs and publishing remote measurement trends over the Internet. Preliminary experimental results reveal that the performance of renewable energy systems in remote rural sites can be evaluated efficiently at low cost.

19. A Smart Solar PV Monitoring System Using IOT (V. Kavitha and V. Malathi, 2019)

The aim of PV monitoring system is to offer a cost-effective solution, which incessantly displays remote energy yields and its performance either on the computer or through smart phones. The proposed system is tested with a solar module of 125-watts to monitor string voltage, string current, temperature, and irradiance. This PV monitoring system is developed by a smart Wi-Fi enabled CC3200 microcontroller with latest embedded ARM processor that communicates and uploads the data in cloud platform with the Blynk application. Also the Wireless monitoring system maximizes the operational reliability of a PV system with minimum system cost. The result shows the maximum power generation of solar panel which is nearly close to standard rating of PV.

20. New Monitoring System for Photovoltaic Power Plants Management (Vaclav Beranek, Tomas Olsan, Martin Libra, Vladislav Poulek, Jan Sedlacek, Minh-Quan Dang and Igor I. Tyukhov)

An innovative solar monitoring system is developed. The system is aimed at measuring the main parameters and characteristics of solar plants; collecting, diagnosing and processing data. The system communicates with the inverters, electrometers, metrological equipment and additional components of the photovoltaic arrays. The developed and constructed long working system is built on special data collecting technologies. At the generating plants, a special data logger BBbox is installed. Data downloaded to BBox from inverters, substations and other devices are generally processed, stored and properly labeled. Data are sent over a secure SSL channel to the database server Solarmon-2.0. The monitoring system helped to identify and eliminate installation errors and contributed to the continuous operation of the photovoltaic arrays.

TABLE 2.2: META-ANALYSIS TABLE

S/N	AUTHOR	YEAR	TITLE	METHOD	RESULT	DRAWBACK
1	Jayaharsha Kandimalla and Dr.D.Ravi Kishore	2017	Web Based Monitoring of Solar Power Plant using Open Source IOT Platform Thingspeak and Arduino	It made use of Arduino UNO, LDR sensor, voltage divider principle, ACS712 current sensor and temperature sensor LM35.	The system was able to monitor the data from the panel using Thingspeak web interface from anywhere in the world.	Dependency on numerous devices and access to the internet.
2	K.G. Srinivasan	2017	Solar Energy Monitoring System by IOT	It made use of ACS712 and voltage divider to monitor the system using the current and voltage value sensed by the Arduino.	The system was able to monitor the data from solar panel using IOT	System fails if there is no internet access
3	Mayuri Ejgar, Dr. Bashirahamad Momin	2017	Intelligent Monitoring and Maintenance of Solar Plants using Real-time Data Analysis	It uses the method of real-time monitoring and various real-time anomaly detection techniques.	The system was able to identify various malfunctioning and possible breakdowns of solar plant.	Dependency on numerous devices and access to the internet.
4	R.L.R. Lokesh Babu	2018	IOT Enabled Solar Power Monitoring System	All the panels are attached and the sensors are precisely connected to the central controller which supervise the panels and	The system was able to monitor current, voltage and sunlight from solar panel using IOT	System fails if there is no internet access or access to mobile phones.

				loads.		
5	Debobrata Gupta	2018	Low Cost Data Logger And Monitoring System for a Small Solar PV Energy System	This data logger based on the ESP 32 microcontroller saves all monitoring parameters to a micro SD card and display them on a webpage. Only three sensor temperature, current, voltage are used.	An android app is created to display all parameter in real time for effective monitoring and sends a text message to maintenance personnel if the battery voltage goes beyond a threshold value.	Dependency on a phone app and access to the internet.
6	Subhasri.G	2018	A Study of IOT based Solar Panel Tracking System	All the panels are attached and the sensors are precisely connected to the central controller which supervise the panels and loads.	The system was able to monitor current, voltage and sunlight from solar panel using IOT	Dependency on numerous devices and access to the internet.
7	Monika P. Tellawar	2019	An IOT based Smart Solar Photovoltaic Remote Monitoring System	All the panels are attached and the sensors are precisely connected to the central controller which supervise the panels and loads.	The system was able to monitor the data from solar panel using IOT	The system was heavily dependent on internet access and as such is limited in areas of no coverage.
8	Shailesh Sarswat	2019	Real Time Monitoring of Solar PV	Voltage, current, temperature is being sensed using sensors the	The system was able to monitor the data from solar	It needs internet access to operate and

			Parameter Using IOT	parameter are transferred over the cloud using node MCU Esp8266.	panel using IOT	it relies heavily on an Android app.
9	Anita M. Bhagat, Ashwini G. Thakare, Kajal A. Molke, Neha S. Muneshwar, Prof .V. Choudhary.	2019	IOT Based Weather Monitoring and Reporting System Project	All parameter sensor are controlled by ESP32 microcontroller as the server will send all data collected by sensors to the database by ThingSpeak	The system was able to monitor the data and made it visible anywhere in the world using IOT and also display on OLED.	System fails if there is no internet access or access to mobile phones.
10	V. Kavitha and V. Malathi	2019	A Smart Solar PV Monitoring System Using IOT	This PV monitoring system is developed by a smart Wi-Fi enabled CC3200 microcontroller with latest embedded ARM processor that communicates and uploads the data in cloud platform with the Blynk application.	The system was able to monitor the data from solar panel using IOT	The system was heavily dependent on internet access and as such is limited in areas of no coverage.
11	Long Zhao	2020	Exploring IOT-based Applications in Power Systems Monitoring, Demand Side Management And Protection	These monitoring systems are developed on Hybrid FPGA CPU controllers.	The system was able to monitor the data from solar panel using IOT	Dependency on numerous devices and access to the internet.

12	A F Pauzi and M Z Hasan	2020	Development of IOT Based Weather Reporting Station	All the data will be controlled by a microcontroller ESP32 and Wemos as the client that will receive the sensor data from ESP32 and display it on OLED.	The system was able to monitor the data and made it visible anywhere in the world using IOT and display on OLED.	The system was heavily dependent on internet access and as such is limited in areas of no coverage
13	Oladimeji I, Adediji Y.B., Akintola J.B, M.A. Afonlayan, O. Ogunbuyi, Ibrahim S.M., Olayinka S.Z	2020	Design and Construction of an Arduino-based solar power measuring parameter measuring system with data logger	The hardware circuit was designed to link different sensors with the Arduino board and measured data were in turn documented into a computer for further analysis.	The system was able to monitor the data from solar panel using IOT	Dependency on numerous devices and access to the internet.
14	Youssef Cheddadi, Hafsa Cheddadi, Fatima Cheddadi, Fatima Errahimi, Naija Es-sbai,	2020	Design and Implementation of an intelligent low-cost IOT solution for Energy Monitoring of Photovoltaic stations	It uses the method of ESP32 DEVKIT V1 board acts as the microcontroller that acquires and processes the incoming data from the various sensors, then it transmits the processed data to the cloud via built-in Wi-Fi.	The system is connected wirelessly to the Influx DB database and visualized via Grafana platform.	Dependency on numerous devices and access to the internet.
15	Dr. M. Braveen, Dr. Shafali Jain, Dr. Rambabu Vatti, Mr. Chilukuri Bala Venkata Subbarayudu, Mr. Ravi	2020	Solar Based IOT Plant Monitoring and Controlling System in Bio-Agri Environments	It uses the method of arduino uno, water level sensor, soil moisture sensor, nodejs app on pi and AWIS iot.S	The system was able to track the plant growth and also help to irrigate plant remotely.	The system was heavily dependent on internet access and as such is limited in areas of no coverage

	Naragani					
16	Mayamiko Nkoloma, Macro Zennaro, Antonie Bagula,	2020	Solar Monitoring System in Malawi	The hardware circuit was designed to link different sensors with the Arduino board and measured data were in turn documented into a computer for further analysis	Direct access to generated electric power at the rural site through the use of wireless sensor boards and text message (SMS) transmission over cellular network	The system was heavily dependent on internet access and as such is limited in areas of no coverage
17	Nehali Datar	2021	Solar Power Monitoring System Using IOT	All parameter sensor are controlled by ESP32 microcontroller as the server will send all data collected by sensors to the database by ThingSpeak.	The system was able to monitor the data from solar panel using IOT	System fails if there is no internet access.
18	Dinesh Kumar Sahu and Anil Brahim	2021	A Review on Solar Monitoring System	This paper contained a concise review on similar works related to solar monitoring plant.	The system was able to monitor the data from solar panel using IOT.	Dependency on numerous devices and access to the internet.
19	Neelanshi S Palkar, Ashish Janwe, Ashlesh Chopde, Ankit Yadav, Vinit Borkar, Poonam Bhad	2021	Solar Power Monitoring System Using IOT	This system is based on the android platform by Bluetooth interface of mobile phone as a communication link it creates data exchange	The system was able to monitor the data from solar panel using IOT.	System fails if there is no internet access

				with the hardware of power conditioning unit, with the help sensing circuits the value of Current and the voltage measurement of the renewable source is processed by the microcontroller of the microchip.		
20	Vaclav Beranek, Tomas Olsan, Martin Libra, Vladislav Poulek, Jan Sedlacek, Minh-Quan Dang and Igor I. Tyukhov)	2021	New Monitoring System for Photovoltaic Power Plants Management	A special data logger BBbox is installed. Data downloaded to BBox from inverters, substations and other devices are generally processed, stored and properly labeled. Data are sent over a secure SSL channel to the database server Solarmon-2.0	The system was able to collect diagnose and processing data.	Dependency on numerous devices and access to the internet.

CHAPTER THREE

METHODOLOGY

The photovoltaic conversion of sunlight into electricity is the most popular technique used to harvest solar energy. To address the aforementioned problem of inaccessibility of solar energy plants, we are going to design and implement a low-cost online system for monitoring a solar energy plant using IOT.

3.1 Project design Implementation

The research design and implementation was a low-cost online system for monitoring a solar plant and the following process was used. The proposed online monitoring system is based on the major three layers of IOT architecture which are perception layer, network layer, and application layer. The perception layer contains the sensor devices. This layer reads the value of the monitored parameters and converts it from analog to a digital signal. The network layer acts as a gateway using a wireless network architecture like Wi-Fi. It receives the data from the perception layer and routes the data to the cloud using TCP/IP protocols. The application layer delivers the processed data to the user in an interface the user can interact with.

3.1.2 Materials used

This section of the project would concentrate on the various materials that will be used during the project's construction phase. The construction materials are listed below.

3.1.2.1 Solar panels

Solar panel is a device which is used to absorb the sun's rays and convert them into electricity. solar panel is actually a collection of photovoltaic cells, which can be used to generate electricity through photovoltaic effect. These cells are arranged in a grid-like pattern on the surface of solar panels. Solar cells are usually made from silicon. To generate electric current, silicon is doped or treated so that electrons are liberated when light strikes it. Solar panel is basically a structure that allows photons, or light particles, to knock electrons away from atoms, resulting in a flow of electricity. For this project we used a panel with the rating of 180W maximum power, output tolerance ± 5%, current at maximum power of 9.95A and voltage at maximum power of 18.1V because it can be used for generating AC.

Figure 3.2: Solar panel

3.1.2.2 NodeMCU ESP Module

The ESP8266 is a low-cost Wi-Fi microchip, with built-in TCP/IP networking software, and microcontroller capability, produced by Espressif Systems in Shanghai, China (Espressif Systems, nd.). It provides internet connectivity to the project design as a station connecting to the Wi-Fi router. ESP8266 has 17 general Input/Output (GPIO) pins which can be assigned to various functions by programming the appropriate registers. Each GPIO can be configured with internal pull-up or pull-down, or set to high impedance, and when configured as an input, the data are stored in software registers; the input can also be set to edge-trigger or level trigger CPU interrupts. In short, the IO pads are bidirectional, non-inverting and tristate, which includes input and output buffer with tristate control inputs. These pins can be multiplexed with other functions such as I2C, I2S, UART, PWM, IR Remote Control (Espressif, 2020).

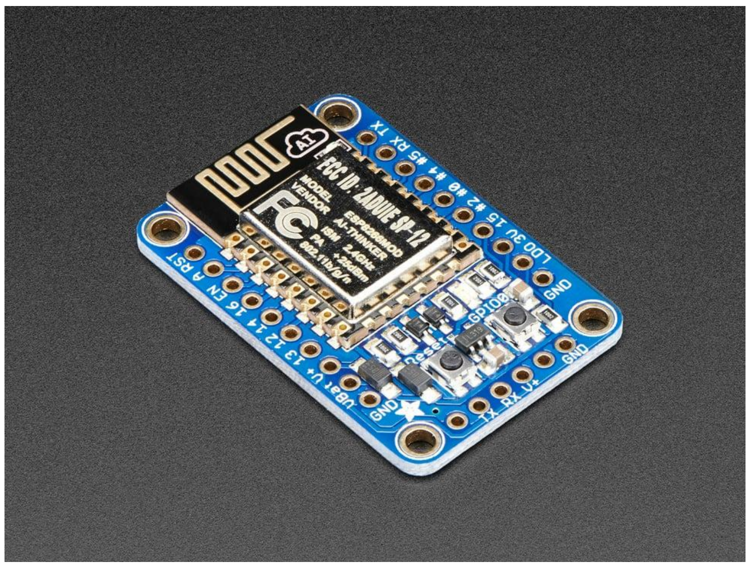


Figure 3.3: ESP8266 module chip

For this project we made use of the NodeMCU ESP8266 module because it has an inbuilt wifi module so we didn’t have to use a separate component to connect to the wifi. This microprocessor has an adjustable clock frequency range of 80 MHz to 160 MHz and supports RTOS. To store data and programs, NodeMCU contains 4MB of Flash memory and 128 KB of RAM.

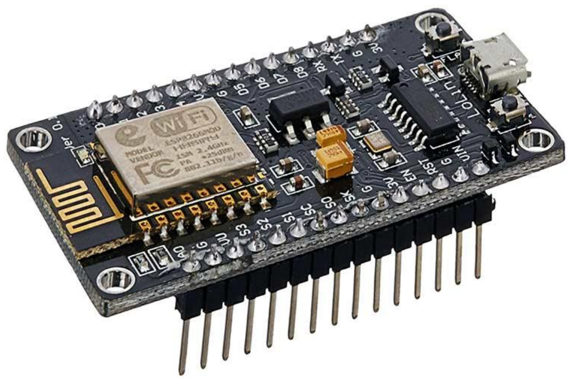


Figure 3.4: NodeMCU ESP8266 module

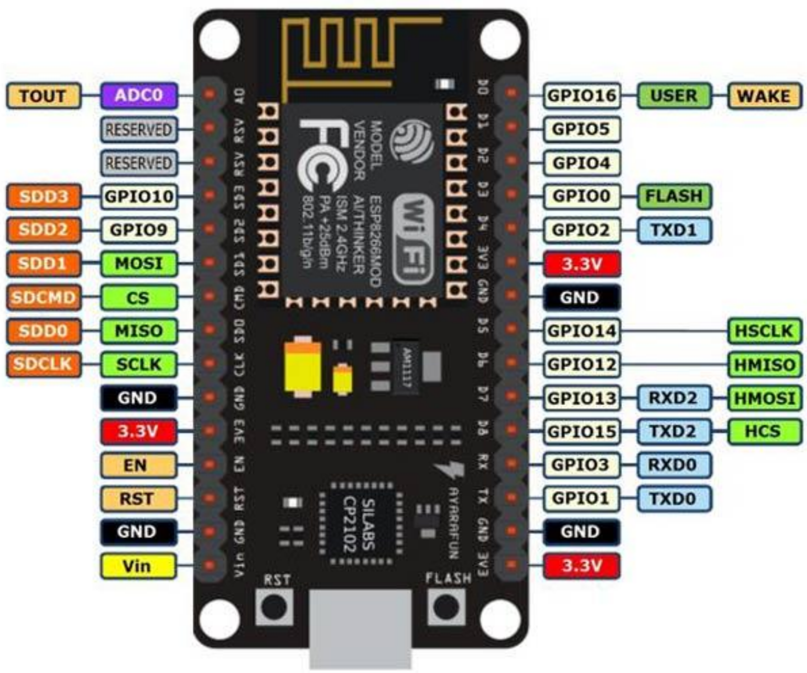


Figure 3.5: Pinout diagram for NodeMCU ESP8266 module

3.1.2.3 Liquid Crystal Display

Liquid crystal display (LCD) is an electronic display that works by changing the electric voltage applied to a layer of liquid crystal to affect changes in its optical characteristics. Portable electronic games, viewfinders for digital cameras and camcorders, video projection systems, electronic billboards, computer displays, and flat-panel televisions are all common applications for LCDs (Walton, H. G. and Dunmur David, 2022). The liquid crystal, which is composed of intricate molecules, is the fundamental component of LCD technology.

For this project we are using a 16x2 I2C LCD module so we can view the data on site. This module is a daughter board with an I2C interface that has a 2 line by 16-character display. It will have a total of (16 + 2) 32 characters, each made up of 5 x 8 pixels. Figure 3.6 shows the pinout diagram of the LCD.

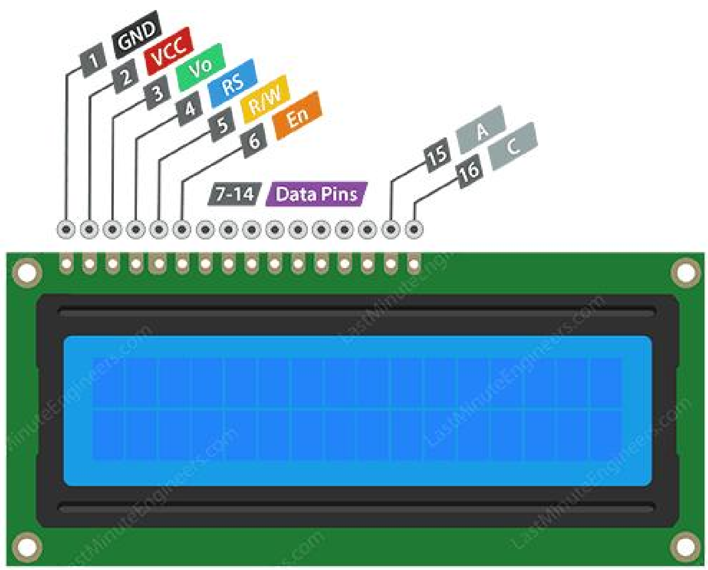


Figure 0.2

Figure 3.6: Pinout diagram of LCD screen

The I2C module is mounted on the backside of the LCD in order to get instructions and data from the microcontroller to process them and display information on the LCD screen. Figure 2.12 shows the diagram. Using the I2C we only require 4 pins for the LCD display: Gnd, Vcc, SDA, and SCL.

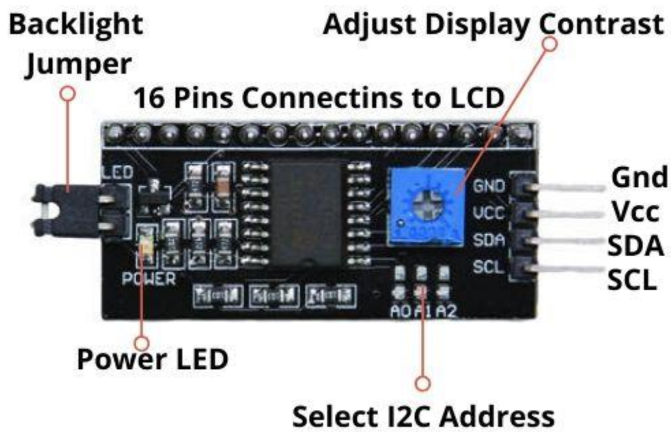


Figure 3.7: I2C module

3.1.2.4 Voltage sensor

The voltage sensor is utilized to monitor, calculate and determine the voltage supply. This sensor can determine the AC or DC voltage level. The input of this sensor can be the voltage whereas the output is analog voltage signal, an audible signal, a frequency etc. That is, certain voltage sensors can provide sine waves or pulse trains as output, and others can create amplitude modulation, pulse width modulation, or frequency modulation outputs. In voltage sensors, the measurement is based on a voltage divider. A voltage divider is a passive circuit that lowers the output voltage in relation to the input voltage. In other words, it produces a constant fraction of the provided voltage after every voltage drop. This decrease is achieved by connecting numerous resistors or capacitors in a series. It is this serial design that permits the voltage to be divided. How much the voltage is decreased is depending upon the ratio of the resistors or capacitors.

Two primary types of voltage sensors are available: capacitive type voltage sensor and resistive type voltage sensor. For this project we used a resistive type voltage sensor which uses a network of resistors only. We used this type because it works best with DC and low-frequency AC and that is what we were dealing with in the project.

3.1.2.5 DHT11 Temperature/Humidity sensor

The DHT11 is a basic, ultra-low-cost digital temperature and humidity sensor. It uses a capacitive humidity sensor and a thermistor connected to an 8-bit microcontroller to measure the surrounding air, and spits out a digital signal on the data pin (no analog input pins needed). Its temperature range is from 0 to 50°C and humidity range from 20% to 90% with ± 2 °C accuracy for temperature and ± 5% accuracy for humidity. We used this type of sensor because it is low cost and gets the readings in digital values so no need to convert from analog.

Figure 3.8: DHT11 sensor

The block diagram below was used to implement the design of the online monitoring station for a solar plant.

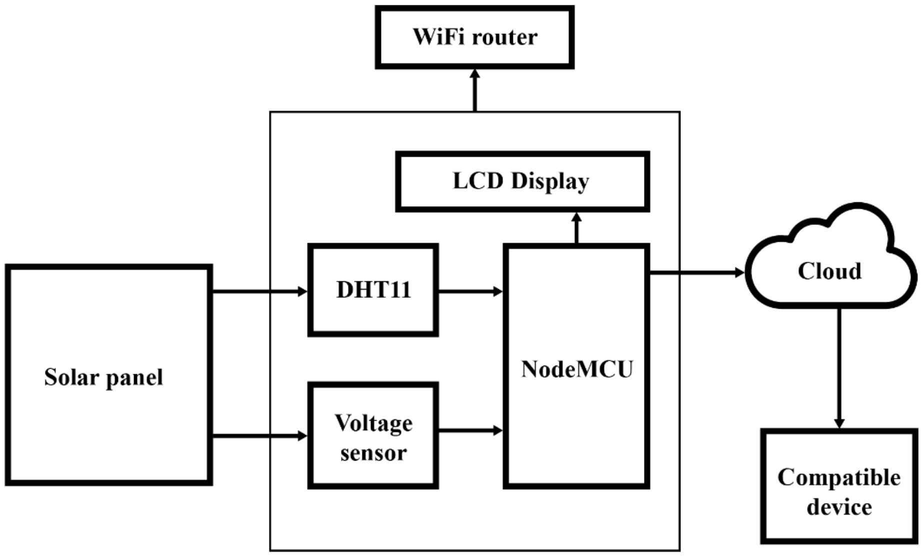


Figure 3.1: Block diagram of system

3.1.3 Solar Panel

The panel converts energy from the sunlight to electrical energy which can be used by consumers. For this project we used a solar panel of 180W power rating.

3.1.4 Wi-Fi Router

In order to send the readings to the website the device needs to have internet connectivity. The router provides internet connectivity for the system. We used Airtel VIDA M4 LTE router because of its affordability, portability, durability and usability. It has an upload speed of 0.5 Mbps and a download speed of 1.5 Mbps.

3.1.5 LCD Display

To see the readings from the system on-site we used the LCD display. We used a 16x2 LCD display with I2C protocol because it is low cost and consumes less power and can display 32 characters.

3.1.6 DHT11

This sensor is used to read temperature and humidity. It is one of the major components of the system. We used this sensor because it is low cost and gives the output in digital form which makes it easier to transmit the data to the website.

3.1.7 Voltage sensor

We used this sensor to read the output voltage from the solar panel. For the project we used a resistive type voltage sensor which uses a series of resistor. We chose this type because it works best with DC and the system runs with DC.

3.1.8 NodeMCU

This is the microcontroller for the system. It computes the readings from the sensors and sends the values to the web system. It also serves as a web server. We used NodeMCU ESP8266 Module for the project. We chose this type because it is low cost, has an inbuilt Wi-Fi module so we didn't have to use a separate component and it supports UART and I2C communication protocols.

3.1.9 Cloud

This is the web server that stores the value of the readings from the system on the internet so anyone can access the readings from anywhere in the globe. We used an asynchronous web server so that the readings will be updated regularly without waiting for the user to make a request.

3.1.10 Compactible device

It is the last part of the system flow. This is any device that has access to the internet. The users can interact with the web system by using any compactible device.

3.2 Hardware setup

This setup involves mounting and coupling of the physical components of the system which is made up of the circuit units and interface between the voltage sensor, DHT11 sensor, LCD and NodeMCU ESP8266 module.

NodeMCU ESP8266 has an operating voltage of 3.3V and a maximum input voltage of 7-12V. The voltage from the solar panel exceeds that of the microcontroller. To enable the microcontroller to be able to handle this voltage level, we use the 7805 voltage regulator IC to provide a constant voltage that the microcontroller can handle without getting damaged. We used two capacitors of values 10 µF input capacitor and 16 µF output capacitor to get the IC working. We used these capacitors because it gave us the value of the voltage which we wanted to regulate the input voltage to. The input capacitor addresses the issue of input inductance and the output capacitor increases the stability of the circuit. The output from the IC is 1 therefore there is heavy heat loss. In order not to damage the IC from the heat dissipated we used a heat sink for the IC.

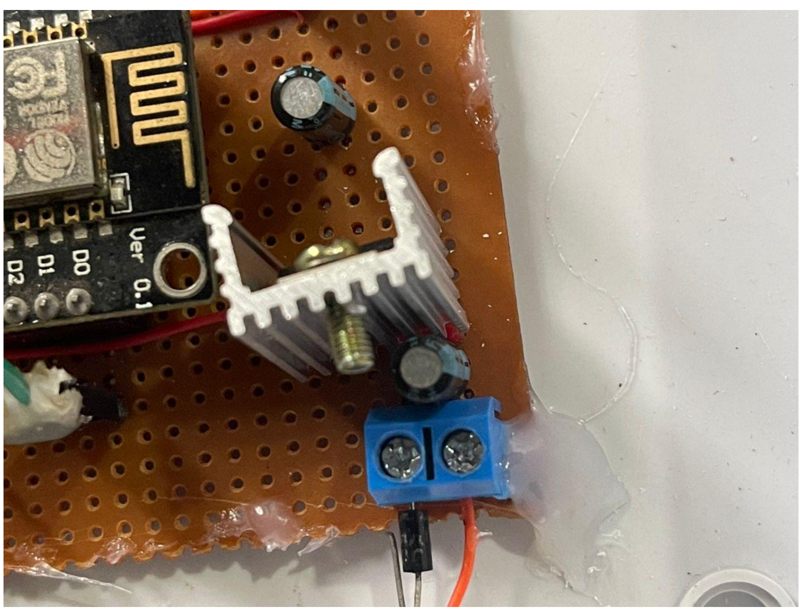


Figure 3.2: 7805 IC with heat sink and capacitors

The voltage sensor measures the voltage generated by the solar panel and sends the analog value to the microcontroller. To measure the voltage of the solar panel a resistive type voltage sensor is used. This sensor works on voltage divider principle. It produces an output voltage (Vout) that is a fraction of its input voltage (Vin). Two resistors form a potential divider that helps to lower the voltage being measured to a level that the microcontroller can read. The formula is (Administrator, 2018)

$$V_{out} = \left(\frac{R_2}{R_1 + R_2}\right) V_{in} \ldots equ(3.1)$$

We used resistors of value 2.2 kΩ and 47 kΩ for R_1 and R_2 respectively because this values gave us an accurate reading for the voltage. The value obtained is converted back to the original value of the solar panel using the resistance factor (R_f). The value is given by the equation

$$Measured\ Voltage = \frac{Voltage\ divider\ analogue\ value\ \times Reference\ voltage}{Resistance\ factor\ (R_f)} \ldots equ(3.2)$$

Where $R_f = \frac{1023}{R_1/(R_1+R_2)}$

The voltage sensor is connected to GPIO15 (D8) pin of the ESP8266 module. This pin is the analog pin A0 of the microcontroller. The DHT11 sensor measures the temperature and humidity of the solar panel but provides the digital values. DHT11 data pin is connected to GPIO12 (D6) pin of ESP8266 module.

The LCD I2C module SDA and SCL pins are connected to GPIO4 (D2) and GPIO5 (D1) pins of the ESP8266 module respectively. The LCD displays the values measured by the sensors.

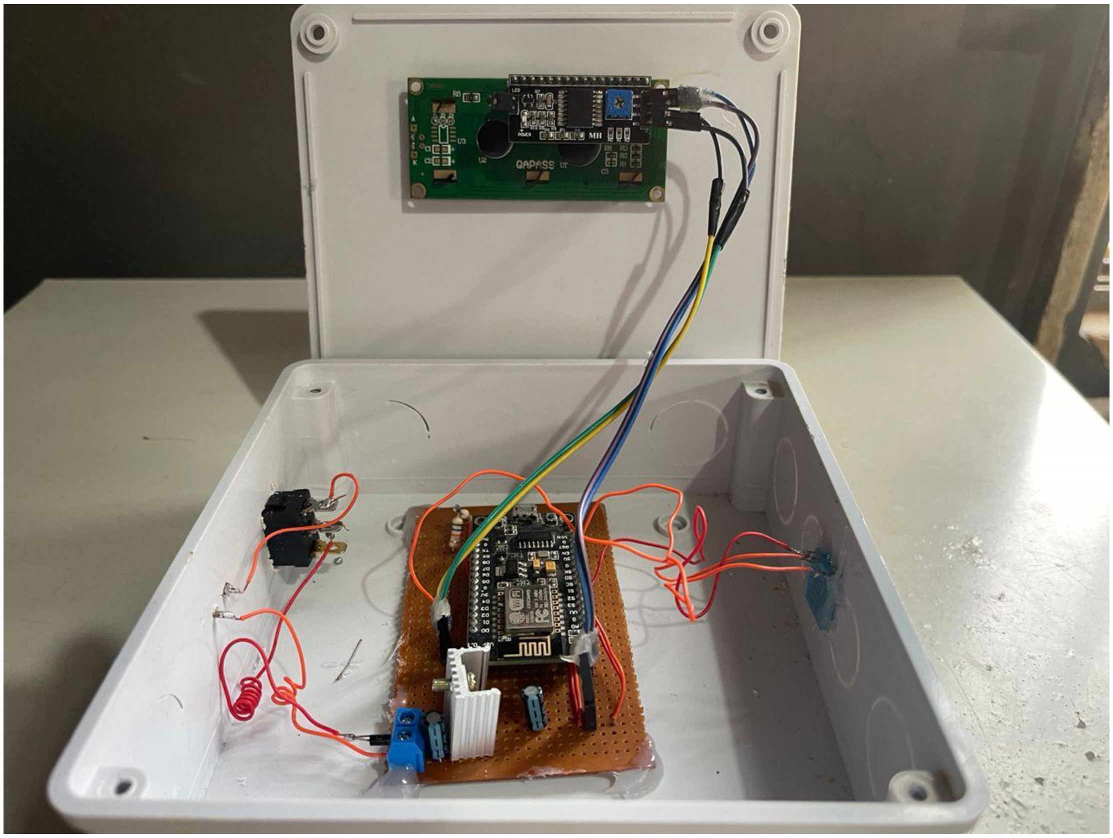


Figure 3.3: Complete connection of the circuit

3.3 Software setup

This stage involves writing the instructions for the sensor devices and ESP8266 module, writing the back-end script to interface and harness data from the plant to the web server and designing the user interface of the website. The sensor devices and ESP8266 module was programmed using Arduino IDE (Integrated Development Environment) which is an open-source customized software for Arduino development which provides central control for the system and supports C.

3.3.1 Programming ESP8266

For this project we created an asynchronous web server with ESP8266. We chose an asynchronous web server in order for the data being measured to be updated automatically without the need to refresh the web page. For the website to be accessible we used Bluehost as the hosting service with “UNIBENCPEIOT” as the domain name. We chose Bluehost because it supports PHP and MySQL.

We installed the ESP8266 board in the Arduino IDE so we could write the code for it. To build the asynchronous web server we used the ESPAsyncWebServer library as it provides an easy way to build an asynchronous web server using Arduino IDE for ESP boards. The library requires the ESPAsyncTCP library to work as they both work together. We assigned our network credentials to protect the server from unauthorized access and defined the pins for interfacing with the voltage sensor and DHT11 while also declaring the data types used by the sensors and a set variable that determines the time interval for the readings to be updated. We used float for the voltage, temperature and humidity in order to accommodate decimals thus giving a more accurate reading.

3.3.2 Designing and implementation of the web system

The web-based system was designed using HTML, CSS and JavaScript to display data coming from the ESP8266. The ESP module was already programmed to automatically send data to the webserver. We designed the layout and structure of the webpage with HTML giving us access to the function to send and receive data over the internet and make the webpage responsive so it can be assessed on any compatible device with internet access.

We used CSS to style the contents of the webpage from color and text to the meter icons for the temperature, humidity and voltage readings. The webpage displays text with Arial font family with the contents aligned to the center.

We added functionality to the webpage using JavaScript. The functionality in this case is to have the webpage automatically update the values of the readings. We wrote a script that makes a request to the web server, get a response and display the data automatically at a set time interval of. We used PHP for the back-end script with MySQL for the database to store the readings.

The use case diagram for the web system of the project is illustrated below. The user has access to view the reading and the chart. The user can copy the values and use it for analysis. Basic information about the website can also be viewed by user to get idea of the operation of the project.

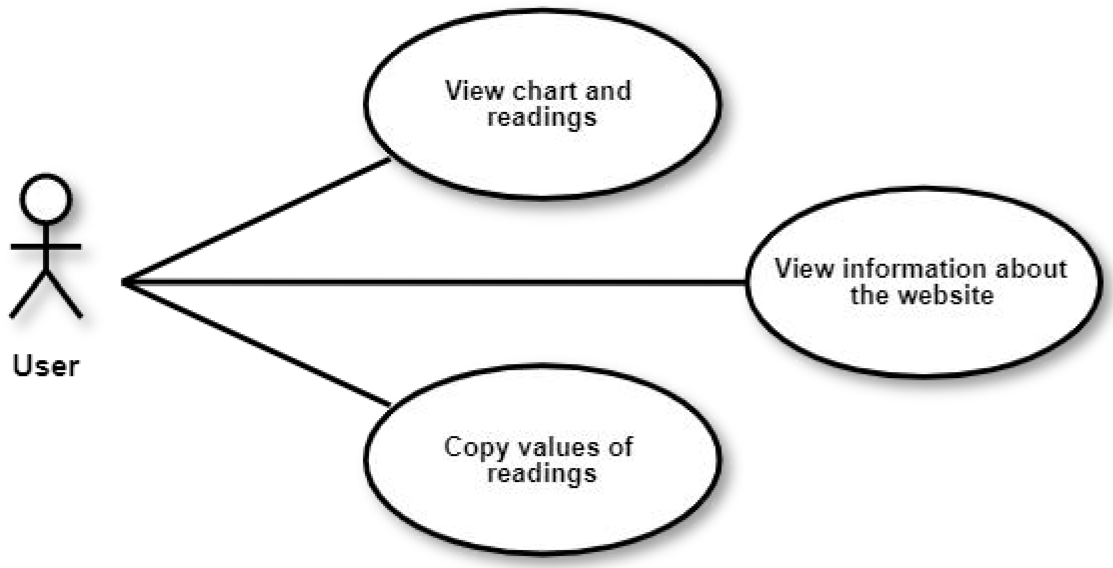


Figure 3.4: UML of the web system

CHAPTER FOUR

RESULTS AND DISCUSSION

This chapter presents the test and result that were obtained in the project, the choice and forms of packaging was discussed.

4.1 Hardware Configuration setup

The hardware system has a single unit for input voltage from the solar panel and power supply for the microcontroller, so as long as the hardware system is connected to the panel the system continues running. We tested the terminals of the solar panel to determine the positive and ground before connecting to the hardware system. After powering the device, it connects to the Wi-Fi and starts recording the values from the sensors and sends them to the website.

Figure 4.1 Complete monitoring hardware assembly

The website displays the readings from the hardware unit in a table and a chart with an average value of the reading over a time period. The website updates the values automatically. By opening the website, we can monitor the solar panel. The monitored parameters are visualized using half pie chart. The website is responsive so the website can be opened on any screen size.

The hardware system was mounted at civil engineering car park UNIBEN and was monitored at computer engineering 500l class.

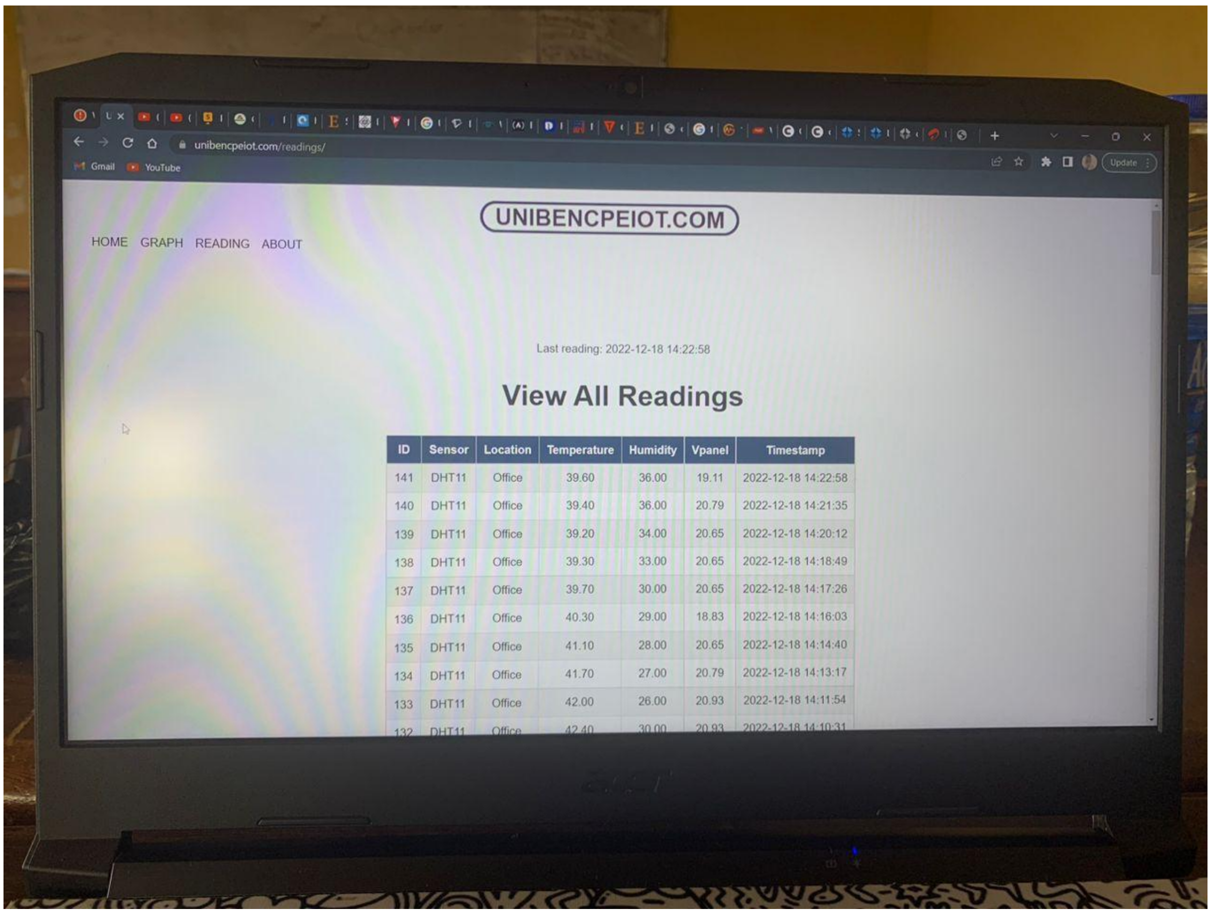


Figure 4.2: Readings from the hardware system

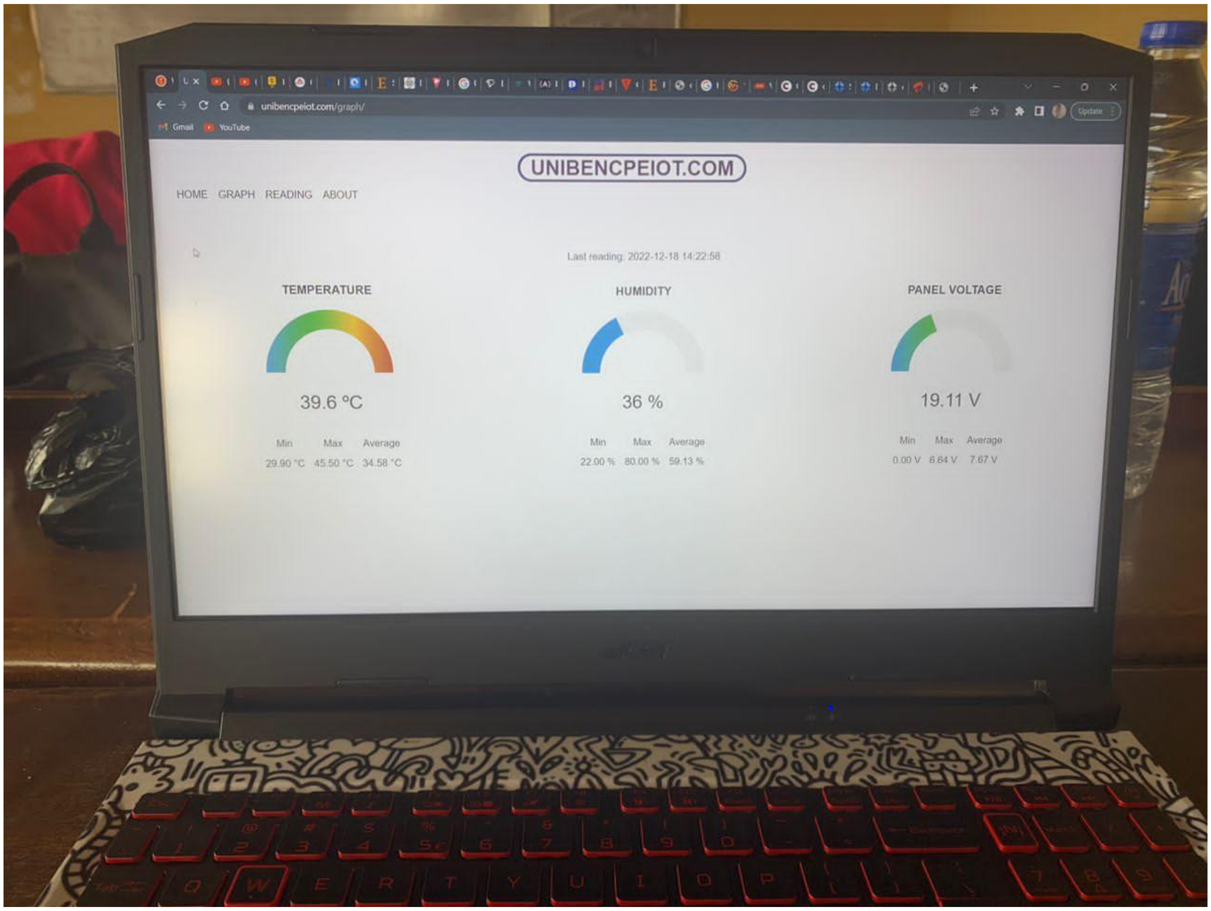


Figure 4.3: Chart of the monitored parameters

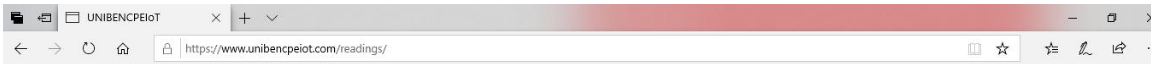
4.2 Result Presentation

We tested the system over a period of two days and analyzed the results. The readings fall within the Nominal Operating Conditions (NOC) for outdoor measurement of the solar panel used. The result from the operation of the online monitoring system is shown in the table below

Day 1				
S/N	**Timestamp**	**Temperature**	**Humidity**	**Panel Voltage**
1	14:22	39.6	36	19.11
2	14:21	39.4	36	20.79
3	14:20	39.2	34	20.65
4	14:18	39.3	33	20.65
5	14:17	39.7	30	20.65
6	14:16	40.3	29	18.83
7	14:14	41.1	28	20.65
8	14:13	41.7	27	20.79
9	14:11	42	26	20.93
10	14:10	42.4	30	20.93
11	14:09	42.5	27	20.79
12	14:07	42.7	29	20.79
13	14:04	42.2	30	20.65
14	14:02	42.5	25	21.07
15	14:00	43.7	23	20.37
16	13:59	44.6	22	20.65
17	13:57	45.5	26	20.23
18	13:56	45.4	24	20.79
19	13:55	44.8	27	20.93

Table 4.1: Readings table for day 1 from the website

The web system was designed to be responsive so we opened the website on a laptop and a smartphone. Figure 4.4 and 4.5 shows the data readings table on a separate webpage for laptop and mobile respectively in real time which is updated at a set time interval. The value of the panel voltage increases as the temperature rises. This rise in temperature signifies there is a high radiation from the sun, the more sunlight that hits the panel, the more electrical energy is produced.



View All Readings

ID	Sensor	Location	Temperature	Humidity	Vpanel	Timestamp
187	DHT11	Office	43.80	5.00	21.07	2022-12-19 15:43:37
186	DHT11	Office	43.80	6.00	19.81	2022-12-19 15:42:14
185	DHT11	Office	43.10	3.00	19.95	2022-12-19 15:39:24
184	DHT11	Office	43.40	3.00	21.07	2022-12-19 15:37:58
183	DHT11	Office	43.50	2.00	21.07	2022-12-19 15:36:35
182	DHT11	Office	44.30	2.00	21.07	2022-12-19 15:35:12
181	DHT11	Office	44.50	2.00	19.67	2022-12-19 15:33:48
180	DHT11	Office	44.50	3.00	21.07	2022-12-19 15:32:25
179	DHT11	Office	44.70	2.00	21.07	2022-12-19 15:31:01
178	DHT11	Office	44.60	4.00	21.07	2022-12-19 15:29:38
177	DHT11	Office	44.40	2.00	19.81	2022-12-19 15:28:14
176	DHT11	Office	44.70	1.00	21.07	2022-12-19 15:26:52
175	DHT11	Office	44.90	3.00	21.07	2022-12-19 15:25:29

Figure 4.4 Output result of the system on laptop

Last reading: 2022-12-19 15:32:25

View All Readings

ID	Sensor	Location	Temperature	Humidity	Vpanel	Timestamp
180	DHT11	Office	44.50	3.00	21.07	2022-12-19 15:32:25
179	DHT11	Office	44.70	2.00	21.07	2022-12-19 15:31:01
178	DHT11	Office	44.60	4.00	21.07	2022-12-19 15:29:38
177	DHT11	Office	44.40	2.00	19.81	2022-12-19 15:28:14
176	DHT11	Office	44.70	1.00	21.07	2022-12-19 15:26:52
175	DHT11	Office	44.90	3.00	21.07	2022-12-19 15:25:29
174	DHT11	Office	44.80	4.00	21.07	2022-12-19 15:24:06
173	DHT11	Office	45.10	2.00	21.07	2022-12-19 15:21:21
172	DHT11	Office	45.50	2.00	21.07	2022-12-19 15:19:58
171	DHT11	Office	45.80	3.00	20.93	2022-12-19 15:18:33
170	DHT11	Office	45.90	3.00	20.93	2022-12-19 15:17:10

Figure 4.5 Output result of the system on mobile phone

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

Renewable energy integration into the power distribution network has become a requirement, necessitating the search for new and effective remote monitoring and control solutions. An IOT-based solar panel remote monitoring system has been presented in this project to collect data on essential solar panel parameters. The IOT based remote solar energy monitoring system is developed using a low-cost smart microcontroller. The monitored parameters show the optimized result that matches approximately with electrical ratings of solar panels tested under Nominal Operating Conditions (NOC). IOT-based monitoring will improve the energy efficiency of the system, reduce time for intervention and supervision, and network management is simplified.

Following the research of online solar panel remote monitoring architecture, the next stage will be to implement, test, and achieve this IOT-based system in order to create a reliable and secure system that will allow real-time data collecting. This can be extended to a large-scale solar plant in order to take preventative measures by monitoring the solar plant's performance on a frequent basis. It will be extremely beneficial in both industrial and commercial settings. Aside from that, other Machine Learning methods and models can be used to make the system smart enough to make data and performance decisions.

RECOMMENDATION

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APPENDICES

```
/***/


// Import required libraries


#include <ESP8266HTTPClient.h>
#include <WiFiClient.h>
#include <Arduino.h>
#include <ESP8266WiFi.h>
#include <Hash.h>
#include <ESPAsyncTCP.h>
#include <ESPAsyncWebServer.h>
#include <Adafruit_Sensor.h>
#include <DHT.h>
#include <LiquidCrystal_I2C.h>
LiquidCrystal_I2C lcd(0x27,16,2);


// Replace with your network credentials
const char* ssid = "hot";
const char* password = "2020hott";
const char* serverName =  "http://www.unibencpeiot.com/esp-post-data.php";
String apiKeyValue = "tPmAT5Ab3j7F9";
String sensorName = "DHT11";
String sensorLocation = "Office";
```

```
#define SOLARPIN A0 // PIN D8=GPIO15 monitor battery voltage
#define DHTPIN 12    // PIN D6=GPIO12 Digital pin connected to the DHT sensor


#define DHTTYPE    DHT11     // DHT 11


DHT dht(DHTPIN, DHTTYPE);

// current temperature & humidity, updated in loop()
float t = 0.0;
float h = 0.0;

int count = 0;

// Create AsyncWebServer object on port 80
AsyncWebServer server(80);

// we use "unsigned long" for variables that hold time
// The value will quickly become too large for an int to store
unsigned long previousMillis = 0;    // will store last time DHT was updated

// Updates DHT readings every 10 seconds
```

```
const long interval = 10000;


const char index_html[] PROGMEM = R"rawliteral(

<!DOCTYPE HTML><html>

<head>

  <meta name="viewport" content="width=device-width, initial-scale=1">

  <link rel="stylesheet" href="https://use.fontawesome.com/releases/v5.7.2/css/all.css"
integrity="sha384-
fnmOCqbTlWIlj8LyTjo7mOUStjsKC4pOpQbqyi7RrhN7udi9RwhKkMHpvLbHG9Sr"
crossorigin="anonymous">

  <style>

    html {

     font-family: Arial;

     display: inline-block;

     margin: 0px auto;

     text-align: center;

    }

    h2 { font-size: 3.0rem; }

    p { font-size: 3.0rem; }

    .units { font-size: 1.2rem; }

    .dht-labels{

      font-size: 1.5rem;

      vertical-align:middle;

      padding-bottom: 15px;

    }
```

```
  </style>
</head>
<body>
  <h2>ESP8266 DHT Server</h2>
  <p>
    <i class="fas fa-thermometer-half" style="color:#059e8a;"></i>
    <span class="dht-labels">Temperature</span>
    <span id="temperature">%TEMPERATURE%</span>
    <sup class="units">&deg;C</sup>
  </p>
  <p>
    <i class="fas fa-tint" style="color:#00add6;"></i>
    <span class="dht-labels">Humidity</span>
    <span id="humidity">%HUMIDITY%</span>
    <sup class="units">%</sup>
  </p>
</body>
<script>
setInterval(function ( ) {
  var xhttp = new XMLHttpRequest();
  xhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
      document.getElementById("temperature").innerHTML = this.responseText;
    }
```

```
  };
  xhttp.open("GET", "/temperature", true);
  xhttp.send();
}, 10000 ) ;

setInterval(function ( ) {
  var xhttp = new XMLHttpRequest();
  xhttp.onreadystatechange = function() {
    if (this.readyState == 4 && this.status == 200) {
      document.getElementById("humidity").innerHTML = this.responseText;
    }
  };
  xhttp.open("GET", "/humidity", true);
  xhttp.send();
}, 10000 ) ;
</script>
</html>)rawliteral";

// Replaces placeholder with DHT values
String processor(const String& var){
  //Serial.println(var);
  if(var == "TEMPERATURE"){
    return String(t);
  }
```

```
  else if(var == "HUMIDITY"){
    return String(h);
  }
  return String();
}

void setup(){
  Serial.begin(115200);
  Serial.println(F("DHTxx test!"));
     lcd.init(); lcd.backlight();   lcd.clear();
  dht.begin();
  lcd.setCursor(0, 0);
  lcd.print("OnlineReport Sys");
  lcd.setCursor(0, 1);
  lcd.print("For Solar Energy");
  delay(4000);
  // Connect to Wi-Fi
  WiFi.begin(ssid, password);
  Serial.println("Connecting to WiFi");
  while (WiFi.status() != WL_CONNECTED) {
    delay(1000);
     Serial.print(".");
  }
  Serial.print("\n\n");
```

```
  // Route for root / web page
  server.on("/", HTTP_GET, [](AsyncWebServerRequest *request){
    request->send_P(200, "text/html", index_html, processor);
  });
  server.on("/temperature", HTTP_GET, [](AsyncWebServerRequest *request){
    request->send_P(200, "text/plain", String(t).c_str());
  });
  server.on("/humidity", HTTP_GET, [](AsyncWebServerRequest *request){
    request->send_P(200, "text/plain", String(h).c_str());
  });

  // Start server
  server.begin();
  lcd.clear();
}

void loop(){
  unsigned long currentMillis = millis();
  if (currentMillis - previousMillis >= interval) {
    // save the last time you updated the DHT values
    previousMillis = currentMillis;
    // Read temperature as Celsius (the default)
    float newT = dht.readTemperature();
    // Read temperature as Fahrenheit (isFahrenheit = true)
```

```
    //float newT = dht.readTemperature(true);
    // if temperature read failed, don't change t value
    if (isnan(newT)) {
      Serial.println("Failed to read from DHT sensor!");
    }
    else {
      t = newT;
    }
    // Read Humidity
    float newH = dht.readHumidity();
    // if humidity read failed, don't change h value
    if (isnan(newH)) {
      Serial.println("Failed to read from DHT sensor!");
    }
    else {
      h = newH;
    }
  }

  delay(2000); // Reading temperature or humidity takes about 250 milliseconds! // Sensor readings may also be up to 2 seconds 'old' (its a very slow sensor)
  float h = dht.readHumidity();// Read temperature as Celsius (the default)
  float t = dht.readTemperature(); // Read temperature as Fahrenheit (isFahrenheit = true)
  float f = dht.readTemperature(true);// Check if any reads failed and exit early (to try again).
  if (isnan(h) || isnan(t) || isnan(f)) {
```

```
    Serial.println(F("Failed to read from DHT sensor!"));
    return;  }
  float hif = dht.computeHeatIndex(f, h);// Compute heat index in Fahrenheit (the default)
  float hic = dht.computeHeatIndex(t, h, false); // Compute heat index in Celsius (isFahreheit = false)



  int sensorValue = analogRead(SOLARPIN);
  // Convert the analog reading on 5v scale(which goes from 0 - 1023) to a voltage (0 - 5V):
  float voltage1 = (sensorValue * (4.95 / 1023.0));
  float voltage2 = (voltage1 *47.6) + 0.00; //30V max  30/5=6
  float voltage =("%.0f", (voltage2 * 0.61)); //VOLTAGE
 float SOALRpercent=(voltage - 11)*50;
      Serial.println(voltage);



  lcd.setCursor(0,1);lcd.print("T:");lcd.setCursor(2,1); lcd.print(t); lcd.setCursor(4,1); lcd.print("C ");
  lcd.setCursor(6,1);lcd.print("H:");lcd.setCursor(8,1); lcd.print(h); lcd.setCursor(11,1); lcd.print("%           ");
  lcd.setCursor(0,0); lcd.print("Vpanel:"); lcd.setCursor(7,0); lcd.print(voltage); lcd.setCursor(11,0); lcd.print("V         ");
  Serial.print(F("Humidity: ")); Serial.print(h); Serial.print(F("%  Temperature: ")); Serial.print(t);Serial.print(F("C "));
  Serial.print(f); Serial.print(F("F  Heat index: "));  Serial.print(hic); Serial.print(F("C ")); Serial.print(hif); Serial.println(F("F"));
```

```
if(WiFi.status()== WL_CONNECTED && count > 15){
  Serial.print("Connected to WiFi:"); Serial.print( ssid ); Serial.print("\n");
  Serial.print("ESP82666 IP is :");Serial.print(WiFi.localIP( ));  Serial.print("\n");
  WiFiClient client;
  HTTPClient http;

  // Domain name with URL path
  http.begin(client, serverName);

  // content-type header
  http.addHeader("Content-Type", "application/x-www-form-urlencoded");

  // Prepare your HTTP POST request data
  String httpRequestData = "api_key=" + apiKeyValue + "&sensor=" + sensorName +
"&location=" + sensorLocation + "&value1=" + String(t)
                        + "&value2=" + String(h) + "&value3=" + String(voltage) + "";
  Serial.print("httpRequestData: ");
  Serial.println(httpRequestData);
  Serial.print("\n\n");



  // Send HTTP POST request
  int httpResponseCode = http.POST(httpRequestData);
```

```
      if (httpResponseCode>0) {
        Serial.print("HTTP Response code: ");
        Serial.println(httpResponseCode);
      }
      else {
        Serial.print("Error code: ");
        Serial.println(httpResponseCode);
      }
      // Free resources
      http.end();
      count = 0;
    }
++count;
Serial.println(count);
delay(3000);
}
```