INSTITUTO POLITÉCNICO DE BRAGANÇA
Escola Superior de Tecnologia e Gestão

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# MPPT BATTERY CHARGE CONTROLLER WITH LORAWAN COMMUNICATION INTERFACE

Mortadha BEN TALEB – a44196

Dissertation submitted to the School of Technology and Management of Bragança to obtain the Master Degree in Industrial Engineering in the context of the dual degree program with the Tunisia Private University (ULT Tunisie)

IPB supervisor : Prof. Dr. **João Paulo Coelho**
ULT supervisor : Prof.Dr. **Oussama TOUATI**

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# Dedication

This dissertation effort is devoted to my family and to all my friends. This thesis is dedicated to Allah, my Creator and my Master.

My great teacher and messenger, Mohammed (May Allah bless and give him), who taught us the meaning of life.

An extra measure of appreciation goes out to my doting parents, Naoufel and Thouraya Ben Taleb, whose words of support and encouragement and prodding toward persistence continue to ring in my ears.

To my future wife Oumayma Chouihed, that has never left my side. She is a wonderful person. Firas and Fourat, both of my brothers.

In addition, I would like to dedicate my dissertation to all of my wonderful friends who have been there for me during this whole process. I will never be able to thank them enough for everything they have done for me, especially Ahmed Alaya Khouadja for assisting me in the development of my technological skills and for the many hours of proofreading, and Oussema Touati for assisting me in the mastery of the leader dots. I will always be grateful to both of them.

# Acknowledgment

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Last, but not the least, to my parents, I would like to thank you for being beside me as a source of care, love, encouragement and motivation, which has filled me with patience and commitment.

# Abstract

Renewable sources, such as Photovoltaic Systems (PV), have been employed for decades to focus on cleaner types of electricity generation. Today, it is a subject of worry as to how to cut costs and enhance efficiency in order to harness and utilise these natural resources in the best way possible. As a result, the concept of Maximum Power Point Tracking Technique (MPPT) evolved, which is essentially a system used by charge controllers for wind turbines and Photovoltaic Systems to use and also give a maximised power output. This thesis is primarily focused with the application of such a system in order to achieve controlled photovoltaic power using the MPPT mechanism. The main goal is to add LoRaWAN capability such as to be able to transmit information regarding the solar charge battery controller internal state A micro-controller, which is part of a larger circuit, such as a solar charge controller, is required for MPPT hardware implementation. The heart of the hardware circuit is the solar charge controller. Furthermore, the system was integrated with a dashboard to provide easier access to data for analysis from anywhere, eliminating the physical work of data collecting.

# Resumo

Fontes de energia renovável, como é o caso dos sistemas fotovoltaicos, têm sido vindo a ser cada vez mais utilizadas como alternativas menos impactantes do ponto de vista ambiental. Atualmente, é motivo de preocupação o recurso a métodos e tecnologias que permitam aproveitar os recursos naturais sustentáveis e, ao mesmo tempo, reduzir os custos e aumentar a sua eficiência. Neste contexto, é importante o recurso a técnicas de seguimento de ponto de potência máximo (MPPT), usado por controladores de carga para turbinas eólicas e sistemas fotovoltaicos, de modo a extrair a máxima potência do sistema elétrico de produção de energia. Esta tese assenta no desenvolvimento de um sistema fotovoltaico capaz de regular o processo de carga para baterias de gel, dotada de mecanismo MPPT integrado e com a capacidade de transmitir toda a telemetria associada à operação do regulador usando o protocolo LoRaWAN. Este sistema de controlo de carga é baseado num microcontrolador que implementa o algoritmo MQTT e os dados enviados, via LoRaWAN, são apresentados numa interface gráfica

# Contents

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# List of Abbreviations

| | |
|---|---|
| **PV** | *Photovoltaic* |
| **MPPT** | *Maximum Power Point Tracking* |
| **PWM** | *Pulse Width Modulation* |
| **SEIA** | *Solar Energy Industries Association* |
| **Si** | *Silicium* |
| **DC** | *Direct current* |
| **AC** | *Alternating current* |
| **Li** | *Lithium* |
| **DOD** | *Depth of Discharge* |
| **SOC** | *State Of Charge* |
| **IoT** | *Internet of Things* |
| **AI** | *Artificial intelligence* |
| **UID** | *A unique identifier* |

| | |
|---|---|
| **IIoT** | *Industrial Internet of Things* |
| **LPWAN** | *Low-power wide-area networks* |
| **ADC** | *Analog to Digital Converters* |
| **SPI** | *Serial Peripheral Interface* |
| **I2C** | *Inter Integrated Circuit* |
| **UART** | *Universal Asynchronous Receiver Transmitter* |
| **LCD** | *Liquid crystal display* |
| **TFT** | *Thin-film transistor* |
| **SDA** | *Serial Data Line* |
| **SCL** | *Serial Clock Line* |
| **VRLA** | *Valve Regulated Lead Acid* |
| **IDE** | *Integrated Development Environment* |
| **API** | *Application Programming Interface* |
| **MQTT** | *Message Queuing Telemetry Transport* |
| **LoRa** | *Long Range Modulation* |
| **ISM band** | *Industrial, scientific, and medical radio band* |
| **MOSFET** | *Metal Oxide Semiconductor Field Effect Transistor* |

**PCB** *Printed circuit board*

**Na-S** *Sodium Sulfur*

# Chapter 1

# Problem statement

## Introduction

Adoption of new forms of energy generation can sometimes be combined with the use of batteries to overcome daily fluctuations in the energy supply and demand of individuals, small businesses, and communities meeting their own needs as alternatives or supplements to traditional centralized grid-connected systems. Batteries, when combined properly with renewable energy production, can increase the flexibility of an energy system by providing energy storage that enables the system to meet the highly fluctuating electrical load of a single residence, consequently altering usage patterns on the national grid. Charging batteries require a system that manages critical parameters like charge/discharge voltage, temperature, and maximum current to extend battery life while maintaining a high level of safety. This first chapter introduces the problem overview of the thesis. The objectives of our project are presented.

## 1.1 Problem overview

Solar energy is the most popular renewable energy system that is being used today. The reason for this is that solar energy may be applied at the individual house or industry level to meet small energy requirements, as well as at a big scale to meet commercial requirements in megawatts.

In most cases, solar energy is used to store energy in battery backup while also supplying energy to the load. The energy storage requires a variable current flow and a constant voltage between the two terminals.

However, the solar panel generates a current flow as well as a potential difference solely based on sunshine. If the current flowing into the batteries exceeds what the circuit can handle, the system may overload causing overheating.

## 1.2 Objectives of this work

There are numerous major factors that contribute to the widespread adoption of charge controllers. First, multistage charging of batteries protects the battery from harm. Second, the ability to modify the power settings for the batteries while they are charging.

This is important for keeping the battery healthy. Third, the reverse current prevention feature stops the solar panel from draining the charge from the battery banks throughout the night when the panel is not powered.

Furthermore, when the battery is low, it disconnects the load and reconnects when it charges again. Finally, it shows the battery bank voltage as well as the amount of charge from the panel.

As a result, the goals of this project are to construct a solar charge controller with battery protection and to create a dashboard to monitor voltage, current, and battery charge level.

We begin **Chapter 1** by describing the problem and defining our goals. We will discuss the theoretical foundation, including batteries, MPPT, and LoRa, in **Chapter 2**. The state of the art will then be presented in **Chapter 3** by demonstrating commercial solutions and discussing MPPT research data. **Chapter 4** will next show examples of our hardware and firmware needs. Also, we will examine our apps and the outcomes of the deployment in **Chapter 5**. Lastly, we will wrap up our project and make some suggestions for future work in **Chapter 6**.

# Chapter 2

# Theoretical background

## Introduction

This chapter presents the various axes of the thesis. The composition, technologies, and specifications of the battery also the battery charge controller are detailed. The operation of Maximum Power Point Tracking and the significance of photovoltaic panels are examined. The chapter finishes with a discussion of the applications of the Internet of Things and the connectivity with Lo Ra.

## 2.1 Battery charge control

this section theoretically introduces battery operation and specifications and battery charge controlling.

### 2.1.1 Battery

A battery is a storage device used to store chemical energy and convert it into electrical energy. Groups of two or more electric cells connected in series and in parallel make up batteries. The battery's components are presented in Figure 2.1.

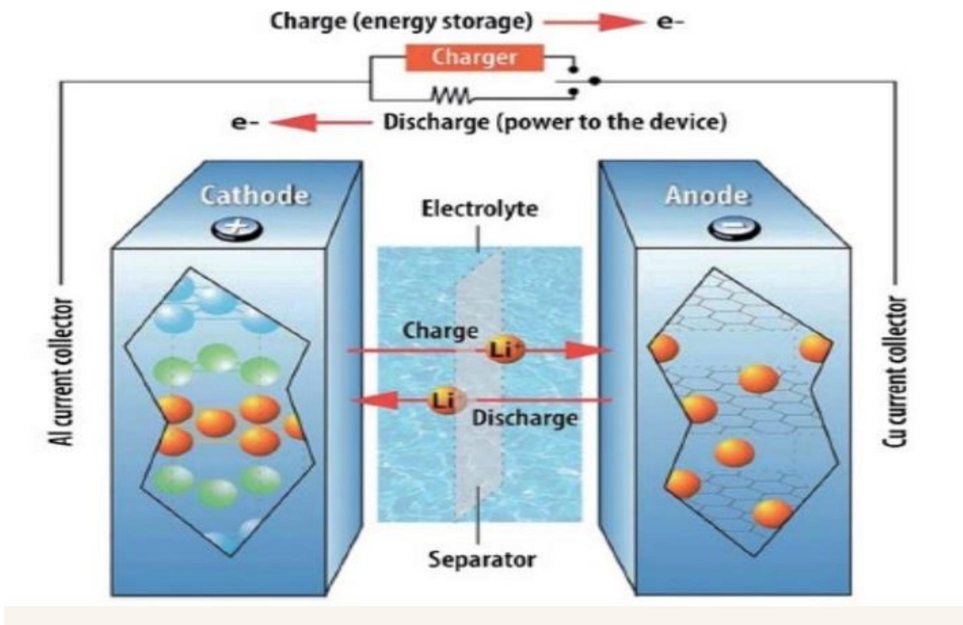


Figure 2.1: Components of a typical battery[1]

Each voltaic cell consists of four half-cells connected in series by an electrolyte containing anions and cations.

Electrolyte and the electrode to which anions (negatively charged ions) move to make up one half-cell. The anode or negative electrode; the other half-cell consists of the electrolyte and the electrode to which cations (ions with a positive charge) flow.

In the red-ox reaction that powers the battery, cations at the cathode undergo reduction (addition of electrons). At the anode, oxidation (removal of electrons) occurs to anions. The electrolyte, which can be solid or liquid, electrically connects the electrodes without their physical contact.

Numerous cells utilize two half-cells with distinct electrolytes. In such a circumstance, each half-cell is encased in a container, and a separator that is permeable to ions but not to the majority of electrolytes prevents mixing.

### 2.1.2 Battery technologies

On the basis of energy density, charge and discharge (round trip) efficiency, device lifetime, and environmental friendliness, battery technologies for energy storage devices can be differentiated. Energy density is the amount of energy that may be stored per unit volume or per unit mass in a single system. Lithium secondary batteries can store 150–250 watt-hours per kilogram (kg), 1.5–2 times more energy than Na–S batteries, two to three times more than red-ox flow batteries, and approximately five times more than lead storage batteries.

Charge and discharge efficiency is a performance metric that may be used to evaluate the efficiency of a battery. Lithium secondary batteries have the highest charge and discharge efficiency at 95%, followed by lead storage batteries and redox flow batteries at 60%–70% and 70%–75%, respectively.

Lifespan is an essential aspect of the performance of energy storage devices, and it has the greatest impact on evaluating economic efficiency. Another important factor is environmental friendliness or the extent to which the devices are safe to the environment and recyclable.

| | Energy density (kW/kg) | Round Trip Efficiency (%) | Life Span (years) | Eco-friendliness |
|---|---|---|---|---|
| Li-ion | 1st<br>150–250 | 1st<br>95 | 1st<br>10–15 | 1st<br>Yes |
| NaS | 2nd<br>125–150 | 2nd<br>75–85 | 2nd<br>10–15 | 2nd<br>No |
| Flow | 3rd<br>60–80 | 3rd<br>70–75 | 4th<br>5–10 | 4th<br>No |
| Ni-Cd | 4th<br>40–60 | 4th<br>60–80 | 3rd<br>10–15 | 3rd<br>No |
| Lead Acid | 5th<br>30–50 | 5th<br>60–70 | 5th<br>3–6 | 5th<br>No |

Li-ion = lithium-ion, Na-S = sodium-sulfur, Ni-Cd = nickel-cadmium.

Figure 2.2: Differentiating characteristics of different battery technologie[2]

### 2.1.3 The battery specification

Before employing any form of battery, certain aspects must be addressed. In this section, the primary quantities influencing the battery are described. Each battery has a unique **charge/discharge curve**, which may be retrieved from an experimental discharge test by applying a constant current approach and constant power.

As the voltage gradually decreases, the current supplied by the battery will also decrease. It is therefore essential to control the current supplied by the battery, this can be accomplished by regulating the power consumed by the load, and maintaining constant the impedance or voltage at the load [3].

It is crucial to know the **theoretical capacity** of a battery, which is measured in ampere-hours (Ah) or coulombs (C) and indicates the entire amount of charge involved in the reaction [4] and the amount the battery is able to store. This metric varies from battery to battery and degrades when batteries are overheated or get old.

When calculating the greatest amount of energy that may be delivered by a battery cell, the **theoretical energy** value [4] considers the cell's theoretical capacity and voltage. Similar to the prior quantity, it is measured in watt-hours(Wh) and can shift as a result of changes in environmental conditions, electrical current, and cell age. In practice, the theoretical energy of the battery cannot be obtained due to voltage drops (energy loss) in the various battery components.

**Internal impedance** is the parameter that describes how a battery behaves when a current passes through it, it is useful for estimating output voltage (power). This parameter is directly related to the battery's temperature, state of charge, and health (aging) and is utilized as a representational variable in the electrical model.

The closer the **faradaic efficiency**, that is the efficiency of electron (charge) transfer in a system that supports an electrochemical process, is to one, the greater the battery's efficiency. Consequently, represents an essential indicator of the effectiveness of any battery. **Energy efficiency** is identical to faradaic efficiency, except that it indicates the ratio of energy discharged to energy charged in a battery and correlates to energy loss in the cells.

**Capacity Retention and Self Discharge**, the battery gradually loses its capacity and this becomes more apparent when the battery remains unused for an extended period of time. This phenomenon is due to an internal reaction and depends heavily on the SOC and the temperature. For instance, after 28 days at a constant temperature of 25°C, a fully charged LIR18650 2600 mAh battery loses 20% of its total charge, leaving the battery with a charge of 2080 mAh [5] [6].

**Lifespan and aging effects** are dependent on temperature, external environment, charging and discharging conditions, battery consumption, and deep discharge. There are numerous causes of aging that alter the behavior and characteristics of batteries, and there are two main aging modes: calendar aging and cyclic aging. After 299 cycles at 100% Depth of Discharge (DOD) with a charge and discharge current of 1.3 A, the LIR16850 Battery's residual discharge capacity reaches 80% (2050mAh) of its initial capacity (2600mAh)[5].

### 2.1.4 Battery charge controlling

Charge controllers are employed in PV systems that utilize batteries, which are typically stand-alone systems. A battery must be charged with a small over-potential. However, batteries have precise voltage restrictions that are required for proper operation. Furthermore, for the battery to perform properly, the amount of current provided to the battery by the PV array and the current flowing through the battery while being discharged must be within well-defined limitations. As a result, a device is required to control the currents flowing between the battery, the PV array, and the load, as well as to ensure that the electrical parameters existing in the batteries remain within the battery manufacturer's standards.

**Types of Charge controller:**

Solar charge controllers are essential in isolated solar systems. Their purpose is to guarantee that the batteries are operating at peak performance, primarily by preventing overcharging (by disconnecting solar panels when the batteries are full) and too deep discharging (by disconnecting the load when necessary).

- **Series charge controllers**

  In a series controller, overcharging is avoided by first disconnecting the PV array and then reconnecting it to the battery after a specific voltage drop is noticed. Figure 2.3 shows the wiring of the series controller.

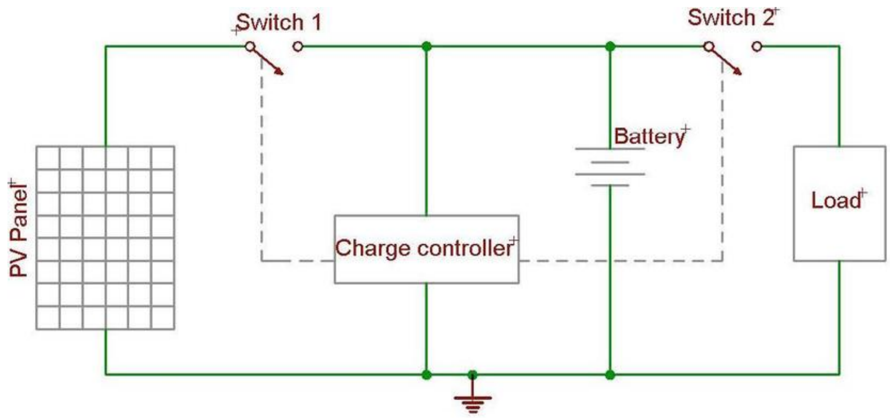


Figure 2.3: Series charge controller[7]

- **Shunt charge controllers**

  Overcharging is prevented in a parallel or shunt controller by short-circuiting the PV array. This signifies that the PV modules are operating in short circuit mode, and no electricity is flowing into the battery.The Figure 2.4 shows the wiring of the shunt charge controller.

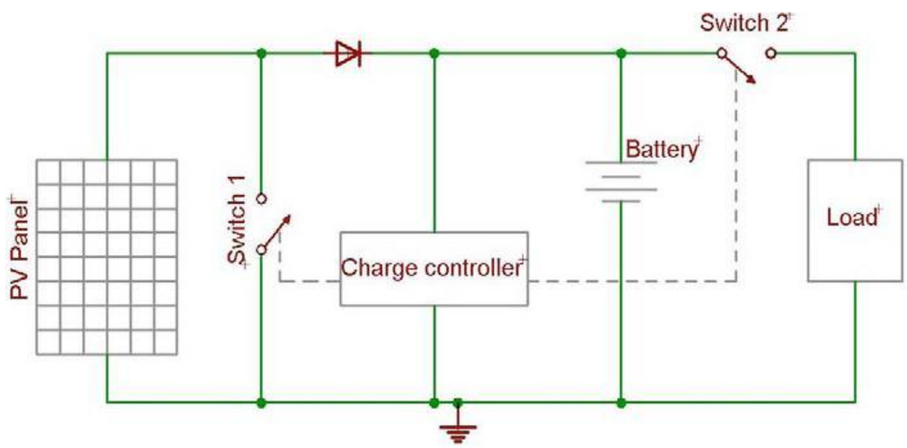


Figure 2.4: Shunt charge controller

## 2.2 Solar panel MPPT regulator

### 2.2.1 Solar panel

Solar energy is an energy source derived from the sun's electromagnetic radiation. It creates electricity and heat in a more sustainable compared to many other energy generation solutions as it is presented in Figure 2.5. The actual rapid development of solar energy, now promises to play a key part in the unfolding energy transition. According to Solar Energy Market Data (SEIA), the global PV industry has grown at an average compound annual rate of over 35% over the past decade. Solar photovoltaic (PV) deployment will continue to increase as the global energy portfolio shifts toward renewable sources.

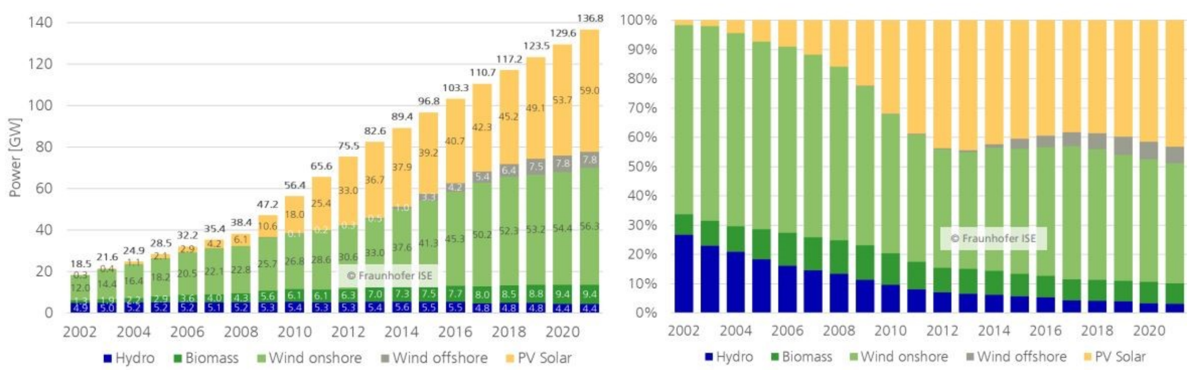


Figure 2.5: Electrical capacity of renewable energy sources[8]

### 2.2.2 Photovoltaic categories

Photovoltaic cells can be made in a variety of ways and from various substances. Despite this distinction, they all perform the same function of collecting solar energy and transforming it into usable electricity. Silicon, which possesses semiconducting qualities are the most prevalent material for solar panel fabrication. Multiple solar cells are required to create a solar panel, and the interconnecting solar panels comprise a photovoltaic array.

There PV cell technologies can be:

- Monocrystalline Solar Panels (Mono-Si)
- Polycrystalline Solar Panels (Poly-Si)
- Amorphous Silicon Solar Cell (A-Si)
- Thin-Film Solar Cells (TFSC)

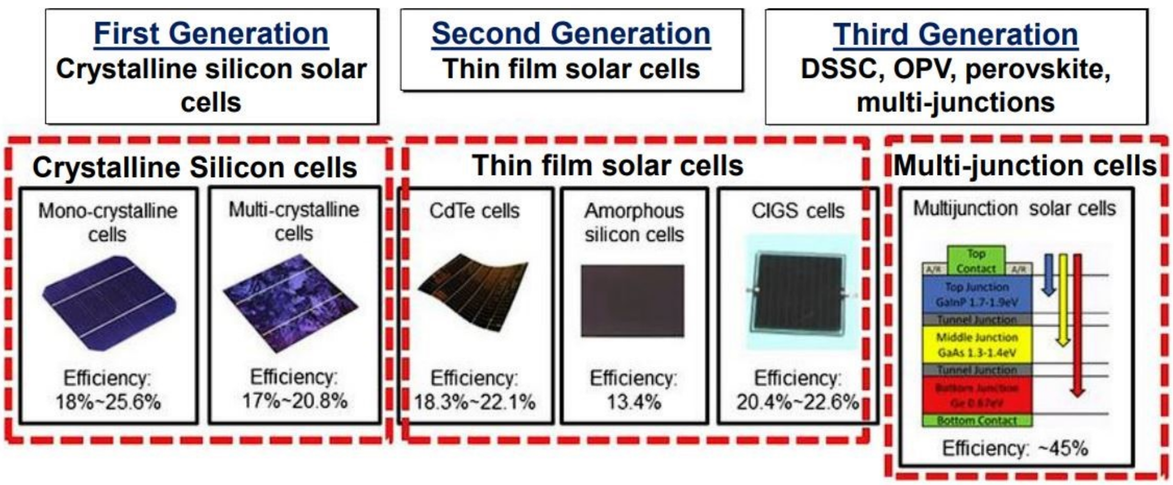


Figure 2.6: Solar panel generations[9]

### 2.2.3 Solar energy production

Solar power may be transformed into electricity by photovoltaic panels or concentrated solar power systems as it is presented in Figure 2.7.

**Photovoltaic effect**

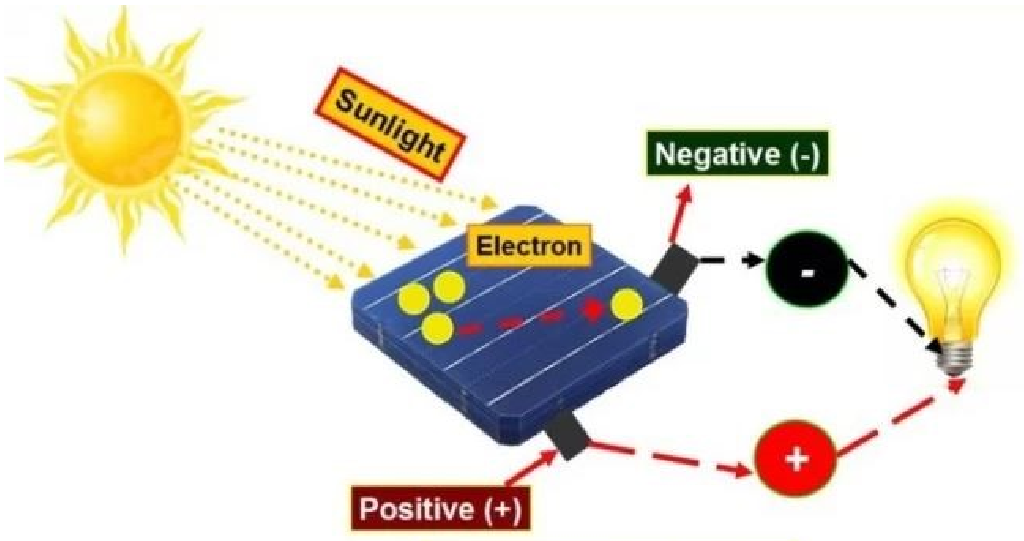


Figure 2.7: Photovoltaic effect[10]

The photovoltaic effect transform solar energy directly into electricity. When exposed to light, certain materials absorb photons and emit free electrons. The photoelectric effect is the name given to this occurrence. The photovoltaic effect is a method of producing direct current power that is based on the photoelectric effect.

Based on the photovoltaic effect, solar cells or photovoltaic cells are constructed. They generate direct current (DC) power from sunlight. However, usually, a single solar cell cannot generate sufficient amounts of power. Consequently, a number of photovoltaic cells are put on a frame and electrically coupled to form a photovoltaic module or solar panel. Solar panels commonly range from a few hundred watts (say 100 Watts) to a few kilowatts. They are available in a variety of sizes and pricing points. Solar panels or modules are intended to produce electricity at a specific voltage (for example, 12 Volts), but the current they generate is directly proportional to the amount of incoming light. Multiple solar modules are electrically linked to make a PV array in order to generate additional electricity, as needed. Depending on how they are set up, solar photovoltaic systems can be classified into several distinct categories [11]:

- **Off-grid systems:**

  This type of system is frequently employed in areas where grid electricity is unavailable or unreliable. A solar power system that is not connected to any electric grid is considered off-grid. It is composed of solar panel arrays and batteries.

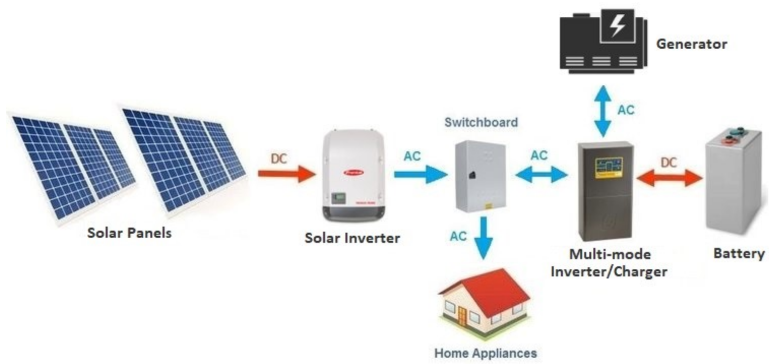


Figure 2.8: Off-grid system[12]

- **Grid connected systems:**

  These solar energy installations are linked to networks so that any unused energy can be drawn from the grid during peak demand. It is uncertain if they run on batteries or not.

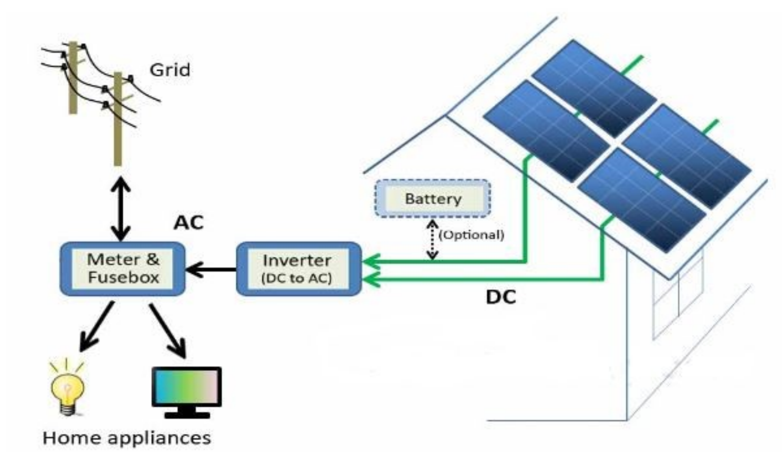


Figure 2.9: Typical grid-connected PV solar system [13]

- **Hybrid solar systems:**

  Hybrid solar systems generate power in the same manner as traditional grid-tied solar systems do, but they use hybrid inverters and batteries to store energy for later use. Because of their ability to store energy, most hybrid systems can also function as a backup power supply during a blackout. Originally, the term hybrid referred to two generating sources such as wind and solar; however, in the solar sector, the term "hybrid" refers to a system that employs a combination of solar and batteries that may interact with the energy grid.


Figure 2.10: Hybrid solar system[14]

### 2.2.4 Maximum Power Point Tracking (MPPT)

The theory and operation of "Maximum Power Point Tracking" as used in solar electric charge controllers are covered in this section.

An MPPT, or maximum power point tracker, is a DC-to-DC converter that optimizes the connection between the solar arrays (PV panels) and the battery bank or utility grid. Simply put, they transform the higher voltage DC output of solar panels to the lower voltage required to charge batteries. These are sometimes referred to as "power point trackers" for short, as opposed to panel trackers, which are solar panel mounts that follow, or monitor, the solar radiation.

Panel tracking is when the panels are mounted on a track that moves with the sun. These optimize output by following the sun's movement across the sky to collect as much sunlight as possible. These generally provide a 15% increase in the winter and up to a 35% increment in the summer.

This is the inverse of seasonal variation for MPPT control systems. Because panel temperatures are lower in the winter, they generate more power. Winter, with its shorter days, is typically when you necessitate the most power from your solar panels.

Maximum Power Point Tracking is a type of electronic tracking that is usually digital. The charge controller compares the production of the panels to the battery voltage. It then calculates the best power output from the panel to charge the battery. It takes this and transforms it to the best voltage possible in order to get the most powerful form of the panel. The conversion efficiency of most modern MPPTs is around 93-97%. In the winter, it's possible to expect a 20 to 45% increase in power and a 10- 15% increment in summer. Actual gain can very greatly depending on weather, temperature, battery charge level, and other factors.

### 2.2.5 The Operation of a Maximum Power Point Tracker

The primary premise of MPPT is to obtain the most available power from PV modules by operating them at the most efficient voltage (maximum power point). In other words, the MPPT examines the output of the PV module, compares it to the battery voltage, and determines the optimal amount of power that the PV module can provide to charge the battery before converting it to the optimal voltage for maximum current to flow into the battery. Additionally, it can provide power to a DC load that is directly linked to the battery.

MPPT is most efficient in the following conditions:

- Cloudy or foggy days, cold weather: Typically, PV modules perform better at colder temperatures, and MPPT is used to harvest the maximum quantity of electricity from them.
- If the battery's state of charge is low, the MPPT can extract more current and charge it.

MPPT, a power electronic device, is used to increase the efficiency of solar panels. The system will start operation-using MPPT. Running at Maximum Power Point (MPP) and producing maximum power by monitoring maximum solar energy entering the PV module. As a result, it produces overall system costs.

The maximum power point (MPP) of a photovoltaic (PV) cell or module is the point on the current-voltage (I-V) curve at which the product of the current and voltage is maximum. The MPP varies depending on the temperature, irradiance level, and load resistance.

Temperature: The MPP of a PV module decreases with increasing temperature. This is because the open-circuit voltage (Voc) decreases with temperature, while the short-circuit current (Isc) increases slightly. As a result, the MPP shifts towards lower voltages and currents as the temperature increases.

Irradiance: The MPP of a PV module increases with increasing irradiance level. This is because both the Voc and Isc increase with irradiance, but the increase in Isc is typically larger. As a result, the MPP shifts towards higher currents and voltages as the irradiance level increases.

Load resistance: The MPP of a PV module depends on the load resistance connected to it. A load resistance that is too low will cause the module to operate at a lower voltage than the MPP, while a load resistance that is too high will cause the module to operate at a lower current than the MPP. The ideal load resistance that maximizes power output is known as the maximum power point load resistance (MPL).

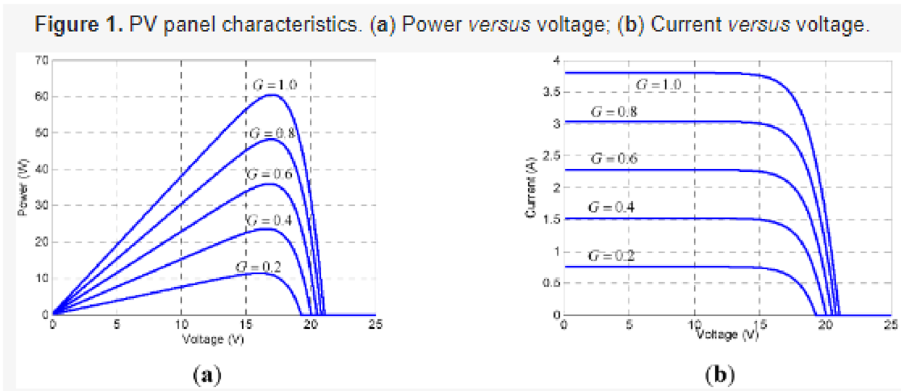


Figure 2.11: Maximum power point variation[15]

Typically, the solar panel is able to convert 20% of the total solar irradiation received be converted to electrical energy[16] , hence the effectiveness of a certain solar panel can be enhanced by MPPT approaches. The MPPT algorithm integrated in the controllers for maximizing resource extraction optimum power from the solar panel while sending from the photovoltaic module to the load. Maximum Power Point Tracking is an electronic system that modifies a module's electrical working point in order for the modules to function.

Offer the maximum power available. It shall enhance the efficiency and power output of a solar panel. Numerous MPPT approaches are researched [17].

The MPPT algorithm typically works by measuring the output voltage and current of the solar panel and using that information to calculate the power output. The algorithm then adjusts the operating voltage and current to find the MPP. This process is typically repeated many times per second to track changes in weather conditions, shading, and other factors that can affect the MPP .

There are several different MPPT algorithms that can be used, including perturb and observe, incremental conductance, and the hill climbing method. Each algorithm has its own advantages and disadvantages, and the choice of algorithm will depend on the specific requirements of the PV system.

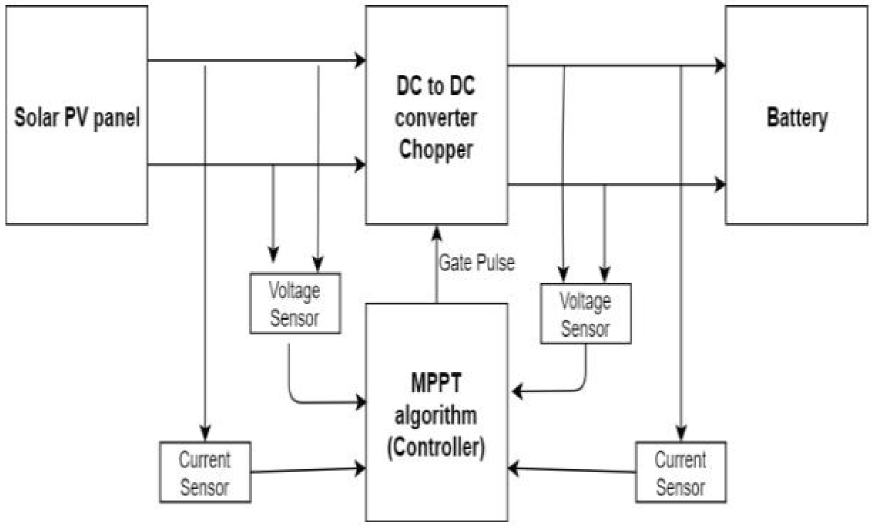


Figure 2.12: MPPT diagram[17]

## 2.3 Telemetry and LoRa communication

### 2.3.1 The Internet of Things

The Internet of Things (IoT) refers to the network of physical items implanted with sensors, software, and other technologies in order to connect and exchange data with other devices and systems over the internet [18].

IoT is an umbrella word for the billions of Internet-connected physical objects or "things" that collect and exchange data with other devices and systems over the Internet. While IoT has existed since the 1990s, recent advancements in a variety of technologies have made it more applicable, including:

- Access to cost-effective and dependable sensors
- Increase in cloud computing platform availability
- Technological advances in machine learning and AI

There is a wide spectrum of possible IoT devices, from simple kitchen gadgets to complex machinery. Each piece of equipment connected to the internet of things has its own unique identifier (UID) and may send and receive data without any human intervention.

Specific IoT applications have different requirements for networking, communication, and connectivity protocols. There are as many distinct kinds of IoT applications as there are kinds of IoT devices. Some of the most typical examples are as follows:

- Consumer IoT is intended mostly for everyday use. Home appliances, voice assistance, and light fixtures are examples.
- Commercial IoT is mostly employed in the healthcare and transportation industries. Smart pacemakers and monitoring systems, for example.
- Industrial Internet of Things (IIoT) - Used mostly in industrial applications such as manufacturing and energy. For example, consider digital control systems, smart agriculture, and industrial big data.
- IoT infrastructure is mostly used to connect smart cities. For instance, infrastructure sensors and management systems.

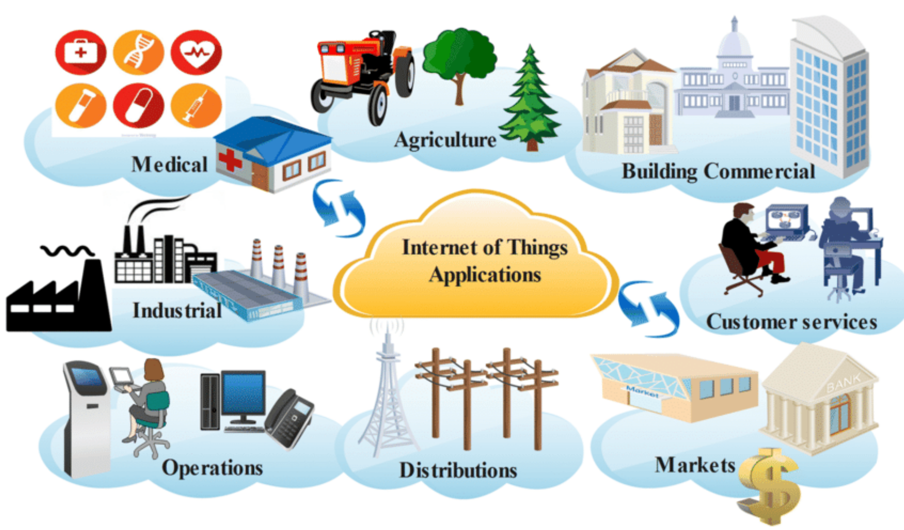


Figure 2.13: Internet of Things applications[19]

### 2.3.2 Working of IoT devices

In 1999, Kevin Ashton invented the term "Internet of Things." After being included on Gartner's list of emerging technologies in 2011, IoT quickly gained popularity around the world, 11.7 billion (54%) of the 21.7 billion active connected devices in 2021 will be IoT devices. Today, there are far more Internet of Things devices than non-IoT ones. The Figure 2.14 shows the IoT devices working, and how the IoT gadgets detect physical objects, also the firmware, network card, and central processing unit are all built in, and they communicate with a server running Dynamic Host Configuration Protocol. The Figure also shows the ability to manage devices from mobile.

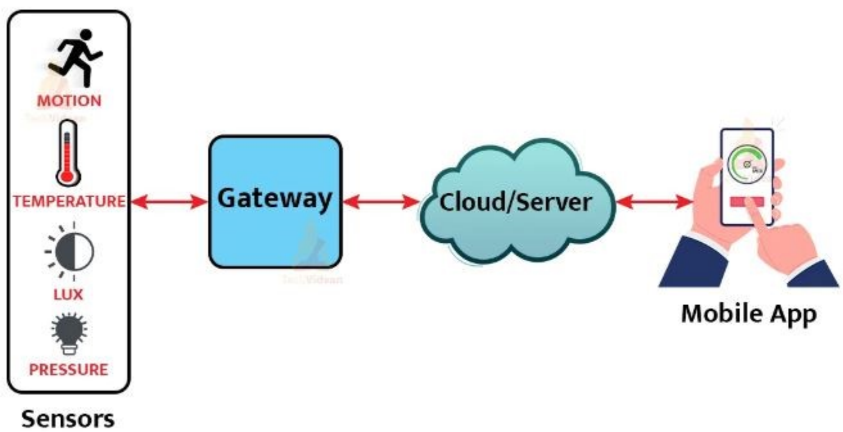


Figure 2.14: IoT devices process[20]

### 2.3.3 IoT's importance

IoT has become one of the most essential technologies of the 21st century in recent years. Now that it's possible to connect common objects (kitchen appliances, automobiles, thermostats, baby monitors) to the internet via embedded devices, communication between people, processes, and things is seamless.

Physical objects can share and collect data with minimum human intervention using low-cost computers, the cloud, big data, analytics, and mobile technologies. Digital systems can record, monitor, and alter every interaction between connected objects in this hyper-connected world. IoT has made it feasible for the physical and digital worlds to interact and collaborate. It provides several benefits to enterprises by automating and simplifying routine activities.

As IoT increases significantly each year, businesses are capitalizing on the immense business benefits it offers. Here are many of the most significant advantages of IoT:

- To develop new business models and income channels
- To enhance business decisions using IoT data-driven insights
- To enhance the efficiency and productivity of corporate operations
- To increase customer experience

### 2.3.4 Connectivity with Lora

The data is delivered to the cloud, but it must have a means of transport.
The sensors/devices can connect to the cloud via cellular, satellite, WiFi, Bluetooth, low-power wide-area networks (LPWAN), connecting via a gateway/router, or connecting directly to the internet via Ethernet. There are compromises between each alternative's power consumption, range, and bandwidth. The optimal connectivity method depends on the IoT application in question, but they all accomplish the same goal: sending data to the cloud.

LoRa is an abbreviation for long range. It is one of Semtech's efficient long-range and low-power wireless communication technologies. LoRa's long range connectivity and low power consumption make it perfect for IoT applications in the industrial sector.

**LoRa technology basics**

In 2012, Semtech purchased the LoRa technology developed by the French startup Cycleo. Semtech was a founding member of the LoRa Alliance, which governs LoRa Technology today. The LoRa Alliance is one of the technology alliances with the quickest growth rate. Through the development and promotion of the LoRaWAN open standard, this non-profit group is committed to allowing large-scale deployment of Low Power Wide Area Networks (LPWAN) Internet of Things.

There are numerous essential components of LoRa technology. Among its important characteristics are the following:

- Long range: 15 - 20 kilometers
- Numerous nodes
- There are several components of LoRa technology that offer the system's overall operation and connectivity
- Interface PHY / RF LoRa: The LoRa physical layer, or PHY, is essential to the system's functionality. It regulates the RF signal transmission between nodes or end-points, i.e. sensors and the LoRa gateway where signals are received. The physical layer or radio interface determines signal characteristics like frequencies, modulation format, power levels, signaling between transmitting and receiving devices, and other relevant topics.
- LoRa protocol stack: The LoRa Alliance has specified both the LoRa physical layer and an open protocol stack. Since the construction of the open source stack, the LoRa concept has been able to expand, as all the many types of companies interested in LoRa research, use, and deployment have been able to collaborate on a low-cost, easy-to-use connection solution for all IoT devices.

- LoRa network architecture (LoRaWAN): In addition to the RF components of the LoRa wireless system, the network architecture also includes the overall system architecture, backhaul, server, and application computers. Typically, this architecture is referred to as LoRaWAN.

LoRa Technologies operates across several frequency bands throughout the world . It operates in the United States on the 915 MHz band, in Europe on the 868 MHz band, and in Asia on the 865 to 867 MHz and 920 to 923 MHz bands.

LoRaWAN is a Low Power, Wide Area (LPWA) networking protocol developed by the LoRa Alliance. It wirelessly connects battery-powered 'things' to the internet in regional, national, or global networks, addressing key Internet of Things (IoT) requirements such as bi-directional communication, end-to-end security, mobility, and localization services.

LoRaWAN leverages unlicensed spectrum in the ISM bands to design the network's communication protocol and system architecture, while the LoRa physical layer creates long-range communication links between network-connected distant sensors and gateways. This protocol facilitates the rapid installation of public or private IoT networks utilizing hardware and software.

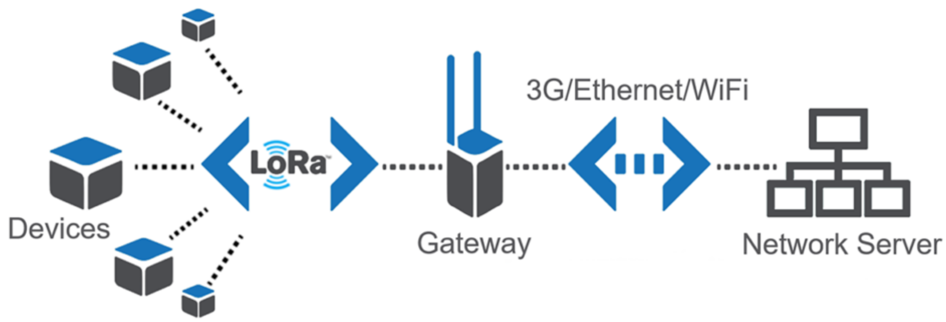


Figure 2.15: LoRa technology[21]

# Chapter 3

# State of the Art

The purpose of this chapter is to first discuss the commercial solutions, such as charge methods and charge controller methods, before going on to describe the various MPPT approaches used in research projects.

## 3.1 Overview of commercial solutions

### 3.1.1 Charging methods

**- Constant voltage charging[22]**

This is the typical method for charging a lead-acid battery since it saves overall charging time and boosts capacity by up to 20%. However, this strategy reduces efficiency by about 10%. The charging voltage is kept constant in this approach throughout the charging procedure. When the battery is in a discharged state, the charging current is significant at first. As the battery charges, the current value steadily decreases, resulting in an increase in back emf.

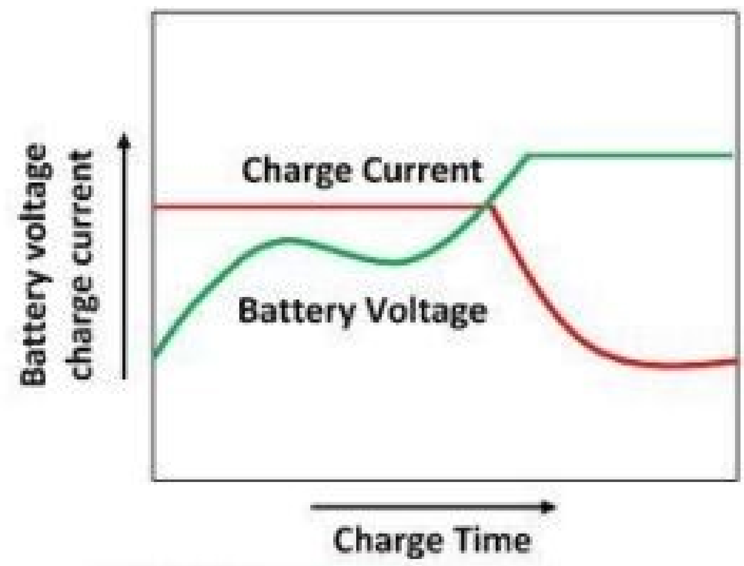


Figure 3.1: Constant voltage charging[23]

**- Constant current charging**

The batteries are connected in series to form tiny groups in this mode of charging, and each group charges from the DC supply mains. Each group's charging is determined by the charging circuit voltage, which should not be less than 2.7 V per cell.
The charging current is kept constant during the charging period by lowering the resistance of the circuit as the battery voltage rises. To avoid excessive gassing or overheating, charging can be done in two steps: an initial charging at a higher current and a finishing rate at a lower current.

The charge current in this method is approximately one-eighth of the ampere ratings. The supply circuit's excess voltage is absorbed by the series resistance. The charging groups of the battery should be connected in such a way that the series resistance consumes as little energy as possible.

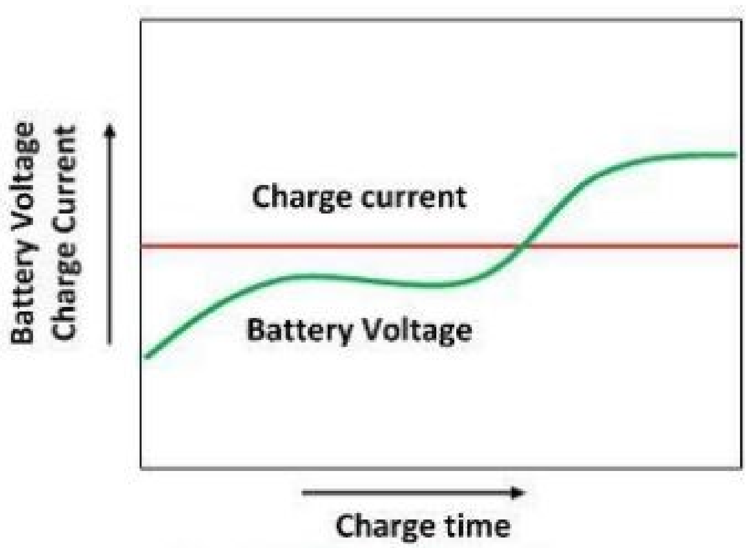


Figure 3.2: Constant current charging[23]

The series resistance's current carrying capacity should be larger than or equal to the charging current. else, the opposition will overheat and burn out.
The collection of batteries to be chosen should all have the same capacity. If the battery has a varied capacity, it must be adjusted to use the least amount of power.

**- Mixed constant current/constant voltage charging method**

As previously stated, the constant voltage and constant current charging methods each have advantages and downsides. A constant current/constant voltage charging approach is presented to address the drawbacks of the two methods.

This charging method can greatly shorten charging time while also self-regulating current with a constant voltage charging method and does not cause the battery to overload.

The constant current mode is utilized at the start of charging, as indicated in the image below. Because the battery allows a higher current when it is low, the majority of the energy released can be swiftly restored. This mode is maintained until the battery voltage reaches. When the voltage is set, the charger will enter constant voltage mode and continue charging. It is currently known as the equalization mode. When the battery has been fully charged, the charger will automatically switch to floating mode to keep it fully charged.

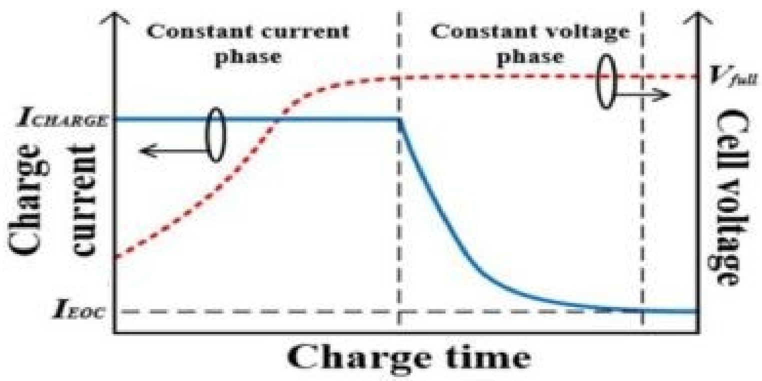


Figure 3.3: Mixed constant current/constant voltage charging[24]

## 3.2 Charge controller methods

### 3.2.1 Simple On/Off charge controller

Depending on the battery's level of charge, a basic on/off charge controller employs a switch to turn the charging current on and off. In order to replenish the battery when it is low on charge, the controller turns on the charging current. To avoid overcharging, the charging current is then turned off when the battery is fully charged.

In order to regulate the switch that links the solar panel or other charging source to the battery, the basic working concept of a simple on/off charge controller is monitoring the battery's voltage. The switch is activated when the battery voltage drops below a predetermined threshold, enabling the charging current to flow into the battery. The voltage of the battery grows as it charges, and the switch is switched off to halt the charging current when the voltage reaches a certain level.

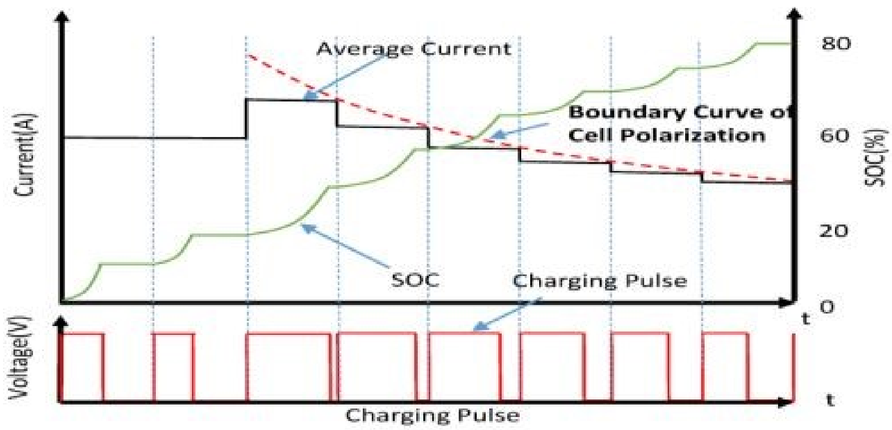


Figure 3.4: Simple On/Off charge controller[?]

### 3.2.2 PWM charge controller

PWM controllers are similar to series regulators in that they open the array with a transistor rather than a relay. A constant voltage can be maintained by switching the transistor at a high frequency with different modulation widths. The PWM regulator self-adjusts by adjusting the widths (lengths) and speeds of the pulses transmitted to the battery. Unlike on/off charge controllers, which cut off power flow instantly to prevent battery overcharging, PWM regulators serve as a continual on/off controller.

When the width reaches 100%, the transistor is fully ON, allowing the solar array to charge the battery in bulk. When the width is 0%, the transistor is turned off and open, short-circuiting the array and preventing any current from passing to the battery when it is fully charged. The transistor, like the series regulator, can be placed in either the positive or negative line, allowing the regulator to be utilized in both positive and negative ground systems. The PWM of the transistor distinguishes the series regulator from the PWM regulator. The regulator is essentially a series regulator when the modulation width is set to 100% or 0%. The modulation width variation enables the PWM regulator to generate a steady voltage to the battery as opposed to the series regulators on/off operation.

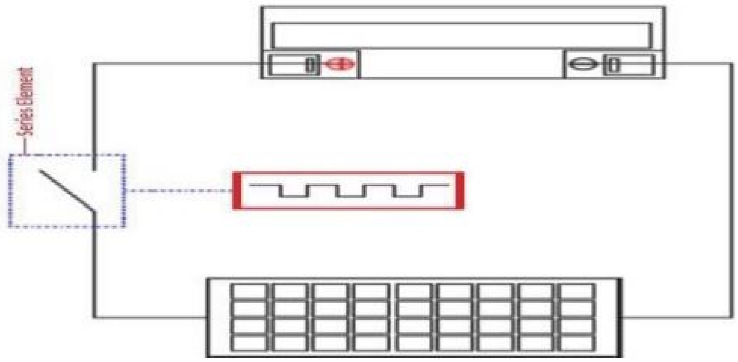


Figure 3.5: PWM charge controller[?]

## 3.3 MPPT Techniques

A typical solar panel converts only 20% of incident solar energy into electrical energy. To increase the efficiency of a solar panel, the maximum power point tracking technique is applied. According to the Maximum Power Transfer theorem, the power output of a circuit is maximum when the circuit's Thevenin impedance (source impedance) matches the load impedance. As a result, tracking the maximum power point reduces to an impedance matching problem. On the supply side, we utilize a buck converter connected to a solar panel to boost the output voltage so that it may be used for various applications such as motor load. We can match the source impedance to the load impedance by adjusting the duty cycle of the buck converter.

**Different MPPT techniques**

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

1. Perturb and observe (hill climbing method)
2. Incremental Conductance method
3. Neural networks
4. Fuzzy logic

### Perturb and Observe

The most basic strategy is Perturb and Observe. Because it only needs two sensors, the voltage and current sensors, to sense the PV array voltage, the cost of implementation is low and thus easy to implement. This algorithm has a low time complexity, but when it gets close to the MPP, it does not stop and continues to perturb in both directions. When this happens, the algorithm has gotten very near to the MPP, and we can either establish an appropriate error limit or utilize a wait function, which increases the method's time complexity.

However, the approach ignores the quick change in irradiation level (due to which MPPT changes) and interprets it as a change in MPP owing to perturbation, resulting in the calculation of the incorrect MPP. Because of its simplicity, perturb and observe (PO) is a well-known approach for maximum power point tracking. This algorithm is used to track MPP and is based on voltage and current sensing. To track MPP, this controller requires power and voltage calculations. In this technique, voltage is perturbed in one direction, and if power continues to increase, the algorithm continues to perturb in the same direction. If the new power is less than the previous power, the perturbation is reversed. When the module reaches MPP, there is oscillation around the MPP point [25].

### Incremental Conductance

The incremental conductance method detects the output voltage and current of the PV array using two voltage and current sensors. When this instantaneous conductance equals solar conductance, MPP is reached. In this case, we are monitoring both voltage and current at the same time. As a result, the inaccuracy caused by changes in irradiance is eliminated.

However, the complexity and cost of implementation grow. As we move down the list of algorithms, the complexity, and expense of implementation increase, which may be appropriate for a very complex system. This is why the Perturb and Observe Incremental Conductance algorithms are the most extensively employed. The controller measures incremental changes in module voltage and current to observe the effect of a power adjustment in this technique [26].

This method is more computationally intensive, but it can track faster than the perturb and observe strategy (PO). As maximum power point changes abruptly as the irradiation level fluctuates continually, PO receives it as a change in MPP owing to perturbation rather than isolation and occasionally ends up calculating inaccurate MPP. However, incremental conductance solves this problem (INC). To optimize power from a solar module, this approach algorithm uses two samples of voltage and current. However, the effectiveness and complexity of the incremental conductance approach are significantly higher when compared to perturb and observe.

#### Fuzzy Logic Control

Over the last decade, microcontrollers have made fuzzy logic control common for MPPT. Fuzzy logic controllers have the advantage of being able to cope with imprecise inputs, without requiring an accurate mathematical model, and dealing with nonlinearity.

#### Neural Network

Neural networks are another method for implementing MPPT that is ideally suited for microcontrollers. In most cases, neural networks include three layers: input, hidden, and output. The number of nodes in each tier varies depending on the user. PV array parameters such as VOC and ISC, atmospheric data such as irradiance and temperature, or any combination of these can be used as input variables.

The output is often one or more reference signals, such as a duty cycle signal, that are utilized to drive the power converter to run at or near the MPPT.

## 3.4 Conclusion

In our project, we will use the perturb and observe algorithm, this algorithm continuously perturbs the operating point of the solar panel and measures the corresponding output power to determine the maximum power point (MPP) of the panel. Once the MPP is found, the MPPT controller adjusts the duty cycle of the DC-DC converter to maintain the panel operating point at the MPP.

Overall, the perturb and observe algorithm is an effective strategy for tracking the MPP of a solar panel and managing the charging of a battery system, including bulk absorption and float charge stages.

# Chapter 4

# Material and Methods

## Introduction

This chapter presents all the hardware and firmware used with the specifications of each one. Also, the details of each part are needed to create the dashboard.

## 4.1 Hardware Developed

### 4.1.1 TTGO LoRa32 SX1276 OLED

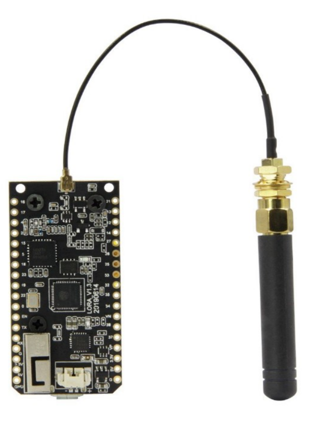

Figure 4.1: TTGO LoRa32 SX1276 OLED[27]

The TTGO LoRa32 SX1276 OLED is an ESP32 development board with an integrated LoRa chip and a 0.96-inch OLED display (SSD1306).

The TTGO LoRa32 SX1276 OLED transmits or receives tiny data packets using a long-range radio frequency spectrum. This reduces interference and protects against signal loss. Specific LoRa bands are allotted to distinct regions. LoRa offers a wider frequency range than cellular networks and is applicable to the public, business, and non-profit sectors. This technology has had a significant impact on artificial intelligence and the Internet of Things.

The module is composed of an Espressif ESP32 chip, a Semtech SX1276 chip, and an OLED display. It integrates WiFi and Bluetooth and includes an antenna. The SX1276 OLED module features high-resolution ADCs, SPI, I2C, and UART communication protocols. It is equipped with a 32-bit LX6 processor and 540 KB of SRAM. The module is equipped with an internal battery connector for power and a USB connector for direct connection to a personal computer for programming.

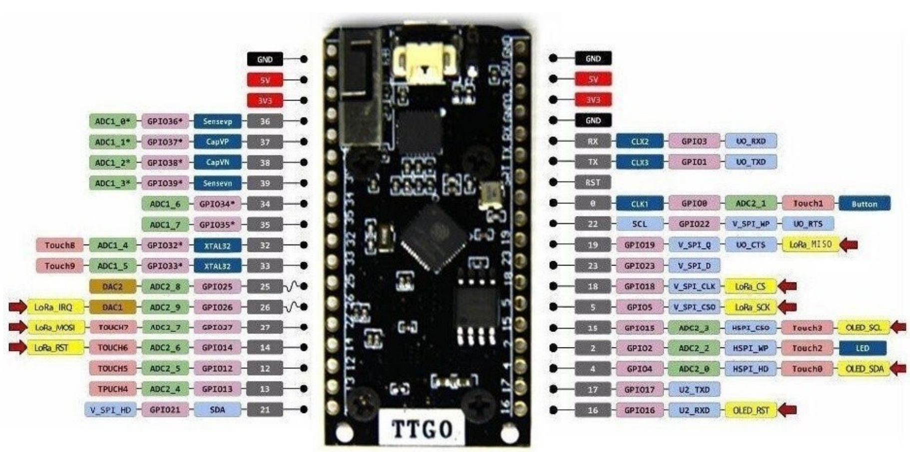


Figure 4.2: TTGO LoRa32 SX1276 OLED PINOUT[28]

### 4.1.2 Liquid crystal display

Pixels make up a display. A 4K monitor consists of 3840x2160 or 4096x4096 pixels. Red, blue, and green sub-pixels make up a pixel (RGB). When subpixels of a pixel change color, a new hue is created. The pixels of a display may create millions of colors. A picture is created by rapidly activating and deactivating pixels.

CRT, LED, LCD, and subsequent display technologies manage pixels differently. LCDs employ a backlight and electrical on/off pixel switching to spin-polarized light. In front of and behind each pixel is a polarizing glass filter with a 90-degree angle. Between the two filters are liquid crystals made of electricity.

LCDs contain either a passive or an active matrix grid. Thin-film transistor (TFT) screens are active matrix liquid crystal displays (LCDs). LCDs with a passive matrix feature pixels at grid intersections. A current delivered between two grid conductors regulates the illumination of each pixel. A transistor at each pixel intersection enables an active matrix to manage pixel luminance with less current due to its placement at each pixel junction. Thus, an active matrix display current can be cycled on and off more often, improving the screen refresh rate.

**LCD 16×2** refers to an electronic device used to show data and the message. As its name suggests, it consists of 16 Columns and 2 Rows, allowing it to display 32 characters ($16\times2 = 32$) in total, with each character consisting of $5\times8$ (40) Pixel Dots. Therefore, the total number of pixels in this LCD can be computed as 32 x 40, or 1280 pixels. The majority of 16 X2 displays utilize multi- segment LEDs.

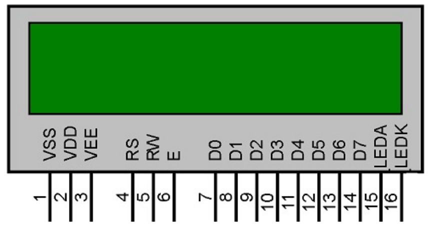


Figure 4.3: Liquid crystal display[29]

**The characteristics of LCD 16X2**

- This display's working voltage varies from 4.7V to 5.3V.
- The display bezel measures 72 x 25 millimeters.
- Operating current without a backlight is 1mA.
- The module's PCB dimensions are 80L x 36W x 10H mm.
- HD47780 controller.
- LED backlight colors are green or blue.
- Number of columns: sixteen.
- Count of rows – 2.
- Count of LCD pins: 16.
- 32 characters.
- It operates in both 4-bit and 8-bit modes.
- Each character's pixel box measures 5 by 8 pixels.


Figure 4.4: LCD Display with I2C/IIC interface[30]

This display eliminates the problem of the LCD 1602 Parallel LCD Display, which necessitates the use of about 8 Arduino Pins. Fortunately, an I2C adapter is immediately attached to the display's pins in this device. Therefore, you only need to connect the I2C pins, indicating a good library and minimal coding.

Philips invented the I2C serial bus, which consists of two bidirectional lines designated SDA (Serial Data Line) and SCL (Serial Control Line) (Serial Clock Line). Both must be linked using pull-up resistors. The standard operating voltages are 5V and 3V.

### 4.1.3 GNB Sonnenschein 985006 Dry Fit Solar Battery S12/17 G5


Figure 4.5: Solar Battery S12/17 G5[31]

**Facts:**

- Maintenance-free gel electrolyte constant-charge voltage 2.35 V / cell
- Low energy consumption and cost-saving lengthy storage times without charge; minimal capacity loss during extended periods of shadow in solar operation.
- Durability and dependability Even in the partially discharged condition of the 50-90% state of charge, the battery's low self-discharge overcharge hard deep discharge controls the charging current.
- Sturdy construction loads under extreme situations
- Two-year shelf life at 20 °C without recharging by very low self-consumption Completely recyclable
- Transport of operational blocks by train, road, sea, or air without incident (IATA, DGR, set A67)
- Designed with IEC 61427 and IEC 60896-21 / 22 UL (Underwriters Laboratories) certification in mind.

The space-saving substitute for smaller solar applications Sonnenschein SOLAR batteries are primarily developed for leisure and consumer applications with modest to moderate performance needs. The strong worldwide reputation and technical image of dry fit technology enhances the benefits of maintenance-free VRLA batteries.
Certified by UL (Underwriters Laboratories)

- Cycling performance - 1200 cycles at 60% Depth of Discharge C10 (at 20 degrees Celsius).
- Dryfit Gel - VRLA technology.
- The lowest energy use - cost savings.
- Robust construction - resistant to extreme situations

- Proof against deep discharge - greater long-term energy delivery proof against deep discharge - greater long-term energy delivery

- Completely recyclable - low $CO_2$ footprint

**Exide Sonnenschein Solar S12/17 G5 12V 17Ah**

Exide's Sonnenschein Solar series are stationary, user-friendly lead-gel batteries developed to meet the needs of small and medium-sized solar-powered applications. This battery is compact and durable enough to survive extreme environmental conditions.

**Applications:**

- Solar panels or vacation homes

- Photovoltaic systems

- Mobile houses and boats

- Construction site illumination

- Informational markers

- Parking machine

**Properties:**

- Maintenance-free sealed battery (VRLA) with gel technology (no water refill)

- Low energy consumption extended energy supply defense against overcharging

- Constant charging voltage with 2.35 volts and extended storage without charge

- Almost no capacity loss occurs during long periods of shade in solar operation. Technical data

Figure 4.6: bp solar SX5M [32]

### 4.1.4 Photovoltaic bp solar SX5M

The BP SX5M comes with a twelve-year power warranty.

The BP SX5 solar module, the smallest in BP Solar's SX module family, operates DC loads with small to moderate energy requirements.

With an optional charge controller, the SX 5 charges 12V batteries in nearly any climate by connecting 36 multi-crystalline cells in series. This module, which generates 4.5 watts of nominal maximum power, is commonly used for remote telemetry, instrumentation systems, security sensors, and signals. The SX5versatile M's Multimount frame allows for mounting versatility.

Dual channels parallel to the edge and back of the module accept the heads of 8mm or 5/16" hex bolts, allowing the module to be mounted from the side or the back. Bolts can be placed anywhere along the channels, which prevents nuts from moving during tightening and allows for installation with a single spanner.

Electrical Characteristics

| | SX 5 |
|---|---|
| Maximum Power ($P_{max}$)[2] | 4.5W |
| Voltage at $P_{max}$ ($V_{mp}$) | 16.5V |
| Current at $P_{max}$ ($I_{mp}$) | 0.27A |
| Warranted minimum $P_{max}$ | 4W |
| Short-circuit current ($I_{sc}$) | 0.3A |
| Open-circuit voltage ($V_{oc}$) | 20.5V |
| Temperature coefficient of $I_{sc}$ | (0.065±0.015)%/°C |
| Temperature coefficient of $V_{oc}$ | -(80±10)mV/°C |
| Temperature coefficient of power | -(0.5±0.05)%/°C |
| NOCT[3] | 47±2°C |

Figure 4.7: Electrical characteristics of SX5[33]

## 4.2 System behaviour

### 4.2.1 Polarity

Connecting a diode in series is the simplest technique to add reverse polarity protection to a circuit. A reverse biased diode does not allow current to pass through it, therefore if a reverse voltage is provided, the associated circuit is unpowered and will not be harmed.

### 4.2.2 Input/Output measure

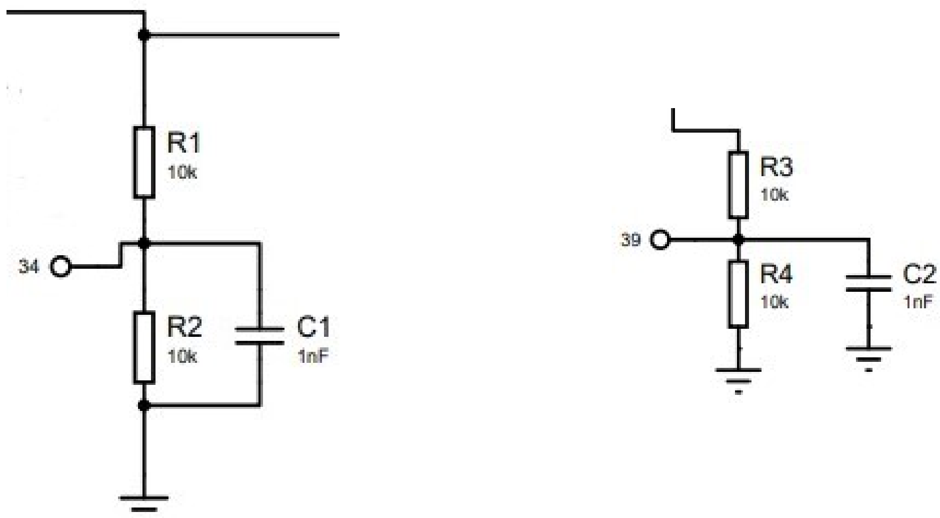


Figure 4.8: Input/Output measuring

The analog inputs of the TTGO may be used to measure DC voltage between 0 and 5V (when using the usual 5V analog reference voltage), and this range can be expanded by constructing a voltage divider with two resistors. The voltage divider reduces the voltage being measured within the TTGO analog input range. This may be used to calculate the size of the solar panel and battery voltages.

### 4.2.3 Buck converter

A buck converter is a DC-DC converter with an output voltage that is always less than or equal to the input voltage. The above image depicts the schematic of a buck converter.

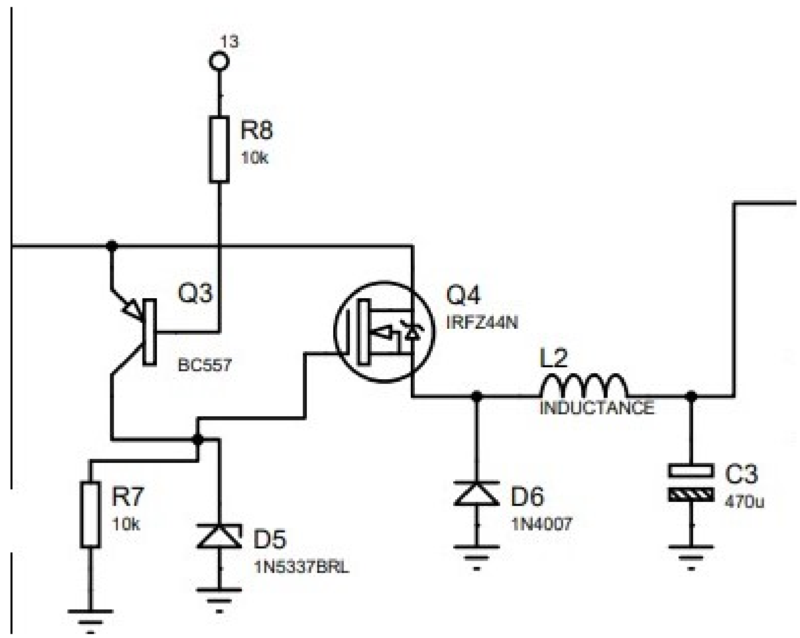


Figure 4.9: Buck converter circuit

A variable buck converter with the ability to regulate and maintain a steady output voltage is required. This circuit will be created by us, and the TTGO's PWM signal will control it. To read the current and establish restrictions on it, we need current sensors. A switching regulator is a buck converter. With the aid of a PWM signal, some transistors, a capacitor, an inductor, and a feedback, it regulates voltage and current.

### Working principle of buck converter

The principle of operation of a buck converter changes depending on whether the MOSFET is on or off.

When the MOSFET is on, it allows the input voltage to flow through the inductor and charge up the capacitor. During this time, the inductor stores energy in its magnetic field. The MOSFET is typically turned on for a short period of time, known as the on-time or duty cycle, which is controlled by the controller or oscillator of the converter.

When the MOSFET is turned off, the energy stored in the inductor's magnetic field is transferred to the output capacitor and load. The inductor acts as a current source, and the energy is transferred to the capacitor and load until the current in the inductor reaches zero. During this time, the diode in the circuit conducts and allows current to flow from the output capacitor to the load.

The process then repeats as the MOSFET is turned on again, and the inductor is charged up once more. The frequency at which the MOSFET switches on and off, known as the switching frequency, determines how quickly the inductor charges and discharges and therefore affects the output voltage.

In summary, the MOSFET is used to switch the input voltage on and off, allowing the inductor to store energy and transfer it to the output capacitor and load. The diode ensures that current flows in only one direction and prevents reverse current flow.

We conclude that a buck converter is a type of power converter that steps down the input voltage to a lower output voltage. It can be used in a battery charging circuit to regulate the charging current and voltage, and to implement the bulk, absorption, and float charge stages.

### 4.2.4 Output load control

This job is to configure the output load control: If it's nighttime and the battery voltage is greater than the "Low Voltage Disconnect" threshold of 11.9V, the output is activated and the battery powers the load. If the battery voltage level the "Low Voltage Disconnect" threshold of 11.9V during the day, the output is also enabled, but the load is supplied by the battery and the extra energy provided by the PV Panel.

If the battery voltage falls below the 11.9V "Low Voltage Disconnect" threshold, the output is deactivated and the load is unplugged.

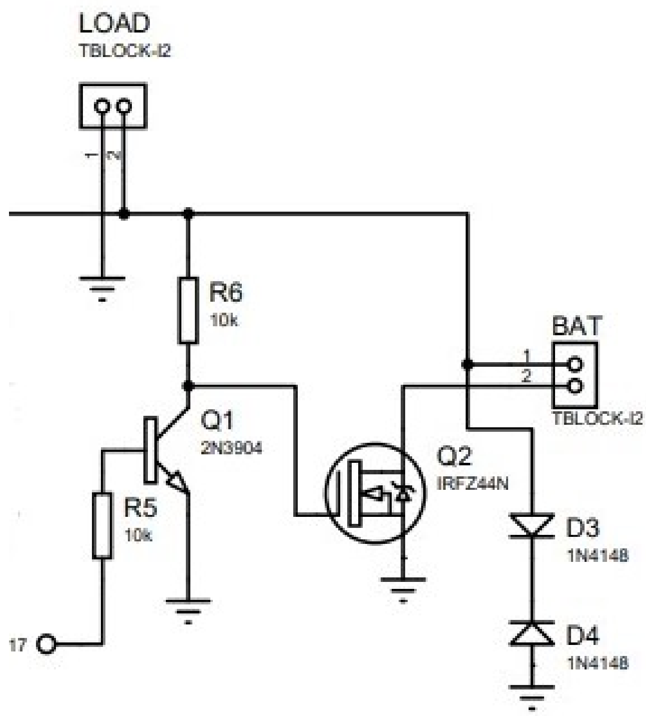


Figure 4.10: Output load control

### 4.2.5 Full schematic

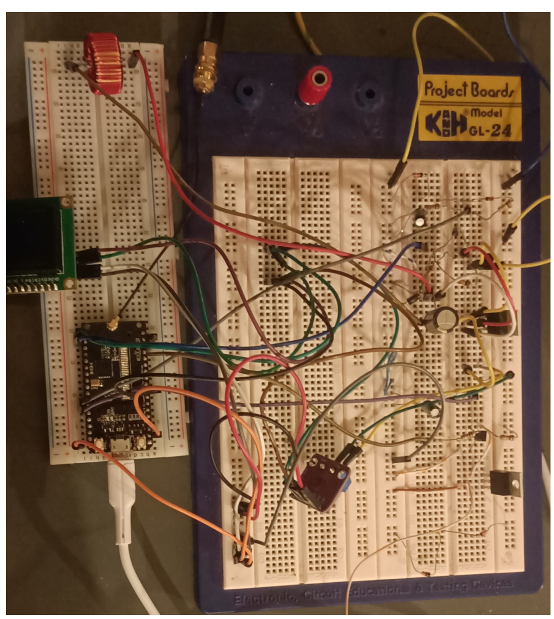


Figure 4.11: Full schematic

Figure 4.11 illustrates the whole schematic from the solar panel to the battery. The figure represents the TTGO's input and output, as well as the real wiring of the buck converter. It is feasible to test the charging process's proper operation using this circuit.

### 4.2.6 Working process description

- Stages of charging:

Bulk, absorption, and float charge are the three charging stages for lead-acid batteries. These steps are intended to guarantee that the battery is charged efficiently and without damage caused by overcharging or undercharging. The first stage, bulk charge, involves delivering a high current to the battery in order to quickly charge it up to around 80-90% of its capacity. This stage is typically used when the battery is deeply discharged or when fast charging is required. During the bulk charge stage, the battery voltage rises rapidly, and the charger maintains a constant current until the battery voltage reaches a preset level.

The second stage, absorption charge, involves delivering a constant voltage to the battery while gradually reducing the charging current. This stage is used to fully charge the battery and ensure that it is ready for use. During the absorption charge stage, the battery voltage continues to rise, but at a slower rate than during the bulk charge stage. Once the battery voltage reaches a preset level, the charger switches to the third stage, float charge.

The third stage, float charge, involves maintaining a constant voltage across the battery terminals while delivering a very small charging current. This stage is designed to maintain the battery at its fully charged state, without overcharging it.

- Process of charging:

We will need to connect it to the battery and apply power to the charger. The charger will then begin the charging process, starting with the bulk charge stage, during which it will deliver a high current to the battery to quickly charge it up. Once the battery voltage reaches a preset level, the charger will switch to the absorption charge stage, where it will deliver a constant voltage to the battery while gradually reducing the charging current. Finally, when the battery is fully charged, the charger will switch to the float charge stage, where it will maintain a constant voltage across the battery terminals while delivering a very small charging current.

- Charging algorithm:

We need to write code that controls the charging current and voltage applied to the battery. we will also need to monitor the battery voltage and adjust the charging current and voltage as necessary to ensure that the battery is charged properly.

We used TTGO LORA to programmed with an algorithm that controls the charging current and voltage and to monitors the battery voltage to determine when to switch between the different charging stages.

The algorithm start by applying a constant current to the battery during the bulk charge stage, until the battery voltage reaches a preset level. Then, it switch to the absorption charge stage, where it applies a constant voltage while gradually reducing the charging current. Finally, when the battery is fully charged, it switch to the float charge stage, where it applies a constant voltage while delivering a very small charging current to maintain the battery at its fully charged state.

- Control of buck converter :

We write code that controls the output voltage of the buck converter based on the battery voltage and charging stage. during the bulk charge stage, the algorithm increase the output voltage to deliver a high charging current to the battery. During the absorption charge stage, the algorithm reduce the output voltage to deliver a constant voltage to the battery while gradually reducing the charging current. Finally, during the float charge stage, the algorithm maintain a constant output voltage to deliver a very small charging current to maintain the battery at its fully charged state.

## 4.3 Firmware description

### 4.3.1 Arduino

Arduino IDE (Integrated Development Environment) is used to write and upload computer code. Arduino's popularity may be due in part to its simple IDE. Compatibility with the Arduino IDE is now a must for new microcontroller boards. Many valuable features have been introduced to the Arduino IDE over the years. It's possible to manage third-party libraries and boards from the IDE while maintaining the board's simplicity.

Arduino software (IDE) is compatible with different operating systems (Windows, Linux, Mac OS X), and supports the programming languages (C/C++).

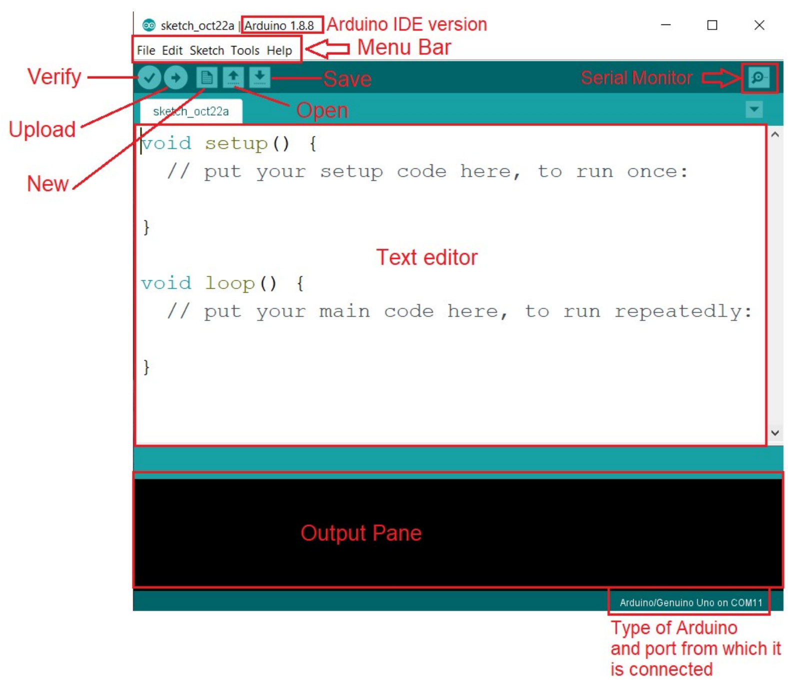


Figure 4.12: Arduino IDE interface[34]

# 4.4 Dashboard and data collection

## 4.4.1 Node-RED

Node-RED is a programming tool for wiring together hardware devices, APIs, and online services in new and interesting ways. It provides a browser-based editor that makes it easy to wire together flows using the wide range of nodes in the palette that can be deployed to its runtime in a single click.

Node-RED uses graphical flows and nodes, which have individual components in a flow to essentially create a program. What I really like about Node-RED is that it is both graphical, so it gives you the visual capability of creating a program, also, it allows you a lot of functional control through JavaScript. JavaScript is the programming language that is underlying Node-RED.

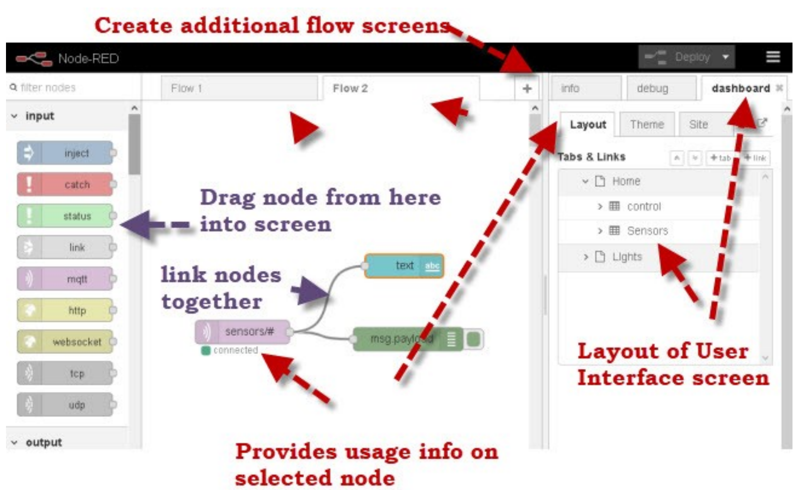


Figure 4.13: Node-RED editor[35]

## 4.4.2 Mosquitto MQTT

In the twenty years that followed its inception, MQTT became the messaging protocol of choice for IoT devices. In 2014, Oasis recognized MQTT as an ISO standard, signaling the protocol's global ascent as an IoT messaging standard. Today, MQTT in IoT facilitates the connection of millions of devices in a variety of businesses.

The MQTT protocol provides a lightweight approach for publishing and subscribing to messages. This makes it appropriate for Internet of Things messaging with low-power sensors or mobile devices such as phones, embedded computers, or microcontrollers. There are a few fundamental ideas in MQTT that you must comprehend:

- Publish/Subscribe - In a publish and subscribe system, a device may either publish a message on a subject or subscribe to a topic to receive messages.
- Messages - Messages are the data you wish to send between your devices. This may be a command or it may be data.
- Topics - Topics allow you to indicate your interest in incoming messages or to select where you wish to post them.
- Broker - The broker is largely responsible for receiving all communications, sifting them to determine who is interested in them, and then distributing them to all clients who have subscribed.

MQTT protocol is simply a lightweight IoT protocol that offers various benefits:

- The MQTT protocol takes very little code and costs very little energy. Thus, the MQTT protocol is energy-efficient and simple to implement for millions of devices.
- MQTT in IoT uses QoS levels to assure the delivery of messages to receivers, even over unstable networks, while connecting devices.
- MQTT protocol for IoT allows rapid communication between cloud servers and IoT devices located in remote locations.
- Last will feature: If an IoT device suddenly disconnects, the MQTT protocol uses the last will feature to broadcast a relevant message to the remaining IoT devices.

- MQTT offers wide support for programming languages such as Python, making it easy for developers to implement.

**IoT uses MQTT:**

**Automobile:** MQTT IoT projects in the automotive industry enable the prevention of vehicle theft, vehicle monitoring, and remote vehicle maintenance.

**Logistics:** One of the best MQTT protocols in IoT is found in the logistics industry. Airtel IoT, for example, uses MQTT IoT hubs to track freight vehicles and deliver real-time notifications for freight safety and movement.

**Energy:** IoT MQTT panels in the energy industry aid in the development of a smarter energy grid and the optimization of consumer power use.

**Home automation:** IoT dashboards use MQTT to remotely manage home equipment via mobile phones.

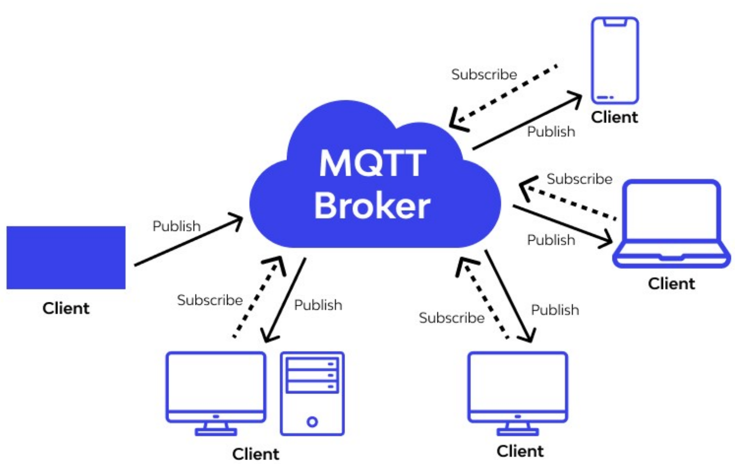


Figure 4.14: MQTT protocol[36]

### 4.4.3 The Things Network

LoRaWAN is utilized in the construction of networks, devices, apps, and integrations as part of The Things Network, which is a global collaborative ecosystem for the Internet of Things.

The Things Network is an open, decentralized, and crowdsourced LoRaWAN network that is powered by The Things Stack Community Edition.

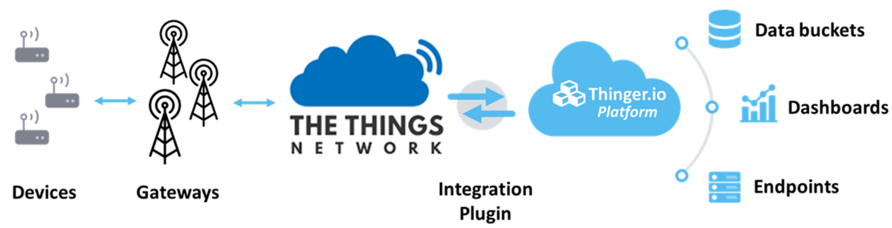


Figure 4.15: Principle of the things network[37]

# Chapter 5

# Obtained Results

A wider customizable range of PWM frequencies was also added, along with improved PWM precision, to facilitate switching. The many components of our project are described in depth in this chapter, along with images of the PCB design. The chapter outlines the procedures for adding data to the dashboard.

## 5.1 Implementation

### 5.1.1 Firmware

- Constant current and voltage :

The voltage is incremented or decremented in this code depending on whether the panel voltage has increased or decreased since the last measurement. The power is then compared to the panel power to decide if the voltage should be increased or decreased further. The maximum permitted current is set, and the loop waits a little period before measuring again. This process is performed indefinitely to track the maximum power point of the PV panel and optimize the system's power output.

```
float get_solar_voltage(int n_samples)
{

   float voltage = 0;
  for(int i=0; i < n_samples; i++)
  {
    voltage +=0.0094907223* analogRead(solar_voltage_in);
    delay(1);
  }
  voltage = voltage/n_samples;
  if(voltage < 0){voltage = 0;}
  return(voltage);
}

float get_battery_voltage(int n_samples)
{
  float voltage = 0;
  for(int i=0; i < n_samples; i++)
  {
    voltage += analogRead(battery_voltage_in) * 0.0046003417968 ;
    delay(1);
  }
  voltage = voltage/n_samples-0.2;
  if(voltage < 0){voltage = 0;}
  return(voltage);
}


float get_solar_current(int n_samples)
{
  float current = 0;
  current = ina219.getCurrent_mA();
  return(current);
}
```

Figure 5.1: Constant current and voltage

- Bulk stage :

```
///////////////////////////BULK//////////////////////////
/////////////////////////////////////////////////////////
if(mode == BULK){
  if(solar_current > charging_current)
  {
    pwm_value--;
    pwm_value = constrain(pwm_value,0,254);
  }

  else {
    pwm_value++;
    pwm_value = constrain(pwm_value,0,254);
  }
  ledcWrite(PWM_out,pwm_value);
}//End of mode == BULK
```

Figure 5.2: Bulk stage

The charging current is normally adjusted to its maximum value during the bulk stage of charging a lead-acid battery to charge the battery as rapidly as possible, but the voltage is still crucial to ensure that the battery is not overcharged. The charging voltage is often set to a constant number, such as 12 volts, which is high enough to completely charge the battery while remaining low enough to avoid overcharging. To prevent overheating or damage from excessive current flow, the charging current is regulated to a maximum amount. As a result, during the bulk stage of charging a lead-acid battery, both voltage and current are critical factors.

- Absorption stage:

```
/////////////////////////ABSORPTION/////////////////////////
////////////////////////////////////////////////////////////
if(mode == ABSORPTION){
  if(solar_current > absorption_max_current)
  {    //If we exceed max current value, we reduce duty cycle
    pwm_value--;
    pwm_value = constrain(pwm_value,0,254);
  }//End if > absorption_max_current

  else{
    if(bat_voltage > absorption_voltage)
    {
      pwm_value++;
      pwm_value = constrain(pwm_value,0,254);
    }

    else {
      pwm_value--;
      pwm_value = constrain(pwm_value,0,254);
    }

    if(solar_current < absorption_min_current)
    {
      mode = FLOAT;

    }
  }//End else > absorption_max_current
```

Figure 5.3: Absorption stage

The charging voltage is kept constant during the absorption stage of charging a lead-acid battery, but the charging current steadily decreases as the battery becomes more fully charged. To guarantee that the battery is properly charged, the charging voltage is often kept at a little higher level than the bulk charging voltage, such as 14.9 volts. During the absorption stage, the battery voltage steadily rises as it becomes more fully charged, while the charging current gradually decreases as the battery becomes less charging resistive. The absorption stage is deemed complete and the battery is fully charged when the charging current reduces to a low level, generally about 1-2% of the battery's rated capacity. Therefore, during the absorption stage, the charging voltage is held constant while the charging current gradually decreases until the battery is fully charged.

- Float stage:

```
///////////////////////////FLOAT///////////////////////////
////////////////////////////////////////////////////////////
if(mode == FLOAT){
  if(bat_voltage < float_voltage_min)
  {
    mode = BULK;

  }

  else{
    if(solar_current > float_max_current)
    {    //If we exceed max current value, we change mode
      mode = BULK;

    }//End if >

    else{
      if(bat_voltage > float_voltage)
      {
        pwm_value--;
        pwm_value = constrain(pwm_value,0,254);
      }

      else {
        pwm_value++;
        pwm_value = constrain(pwm_value,0,254);
      }
    }//End else > float_max_current
```

Figure 5.4: Float stage

In the float stage of charging a lead-acid battery, the charging voltage is maintained at a constant, lower level than the absorption voltage, typically around 13.4 volts. This voltage level is sufficient to maintain the battery at a fully charged state without overcharging it.

The charging current during the float stage is typically very low, usually less than 0.1% of the battery's rated capacity, which is just enough to compensate for any self-discharge of the battery. This low charging current helps to prevent excessive gassing and water loss in the battery, which can occur if the battery is overcharged. Therefore, during the float stage, the charging voltage is held constant at a lower level than the absorption voltage, and the charging current is very low to prevent overcharging and minimize water loss.
-Full code :
https://github.com/MortadhaBenTaleb/thesis-

### 5.1.2 PCB Design

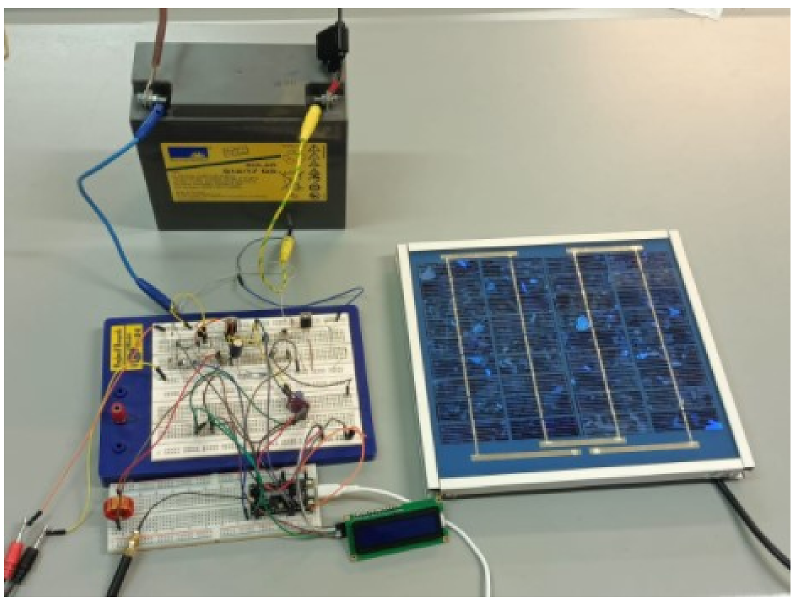

Figure 5.5: Charging battery circuit

To combine all the components, we must use the PCB. The circuits on a PCB might occupy significantly less space than the individual components, resulting in a substantially smaller final product. This also makes it easy to assemble the various components of circuit and route the traces where they need to go. They are also extremely durable and long-lasting. They are resistant to extreme conditions such as heat, dampness, and even physical force. The ability of the boards to endure these factors is essential for ensuring that they continue to function effectively, especially when it comes to vital systems such as the braking system. Finally, they are incredibly secure. PCB circuits are enclosed so that it is nearly hard to touch two connections simultaneously with naked skin. This eliminates the possibility of receiving a shock from your equipment.

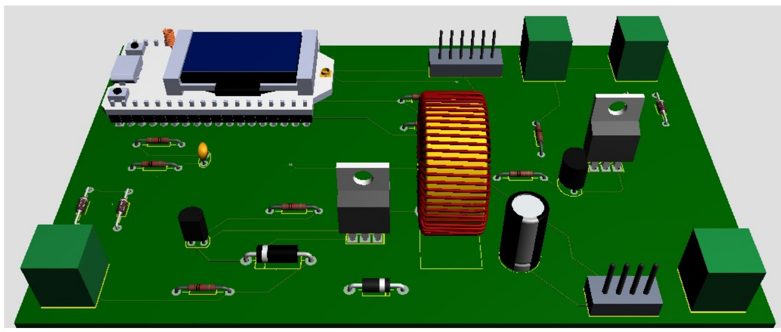

Figure 5.6: PCB design

### 5.1.3 Tests

| charge % | 12V battery |
|---|---|
| 0% | 11.80V |
| 25% | 12.00V |
| 50% | 12.20V |
| 75% | 12.40V |
| 100% | 12.70V |

Table 5.1: Battery charging level

### 5.1.4 Data transfer

Here, the Things Network is used for the transport of data. Initially, we develop an application.

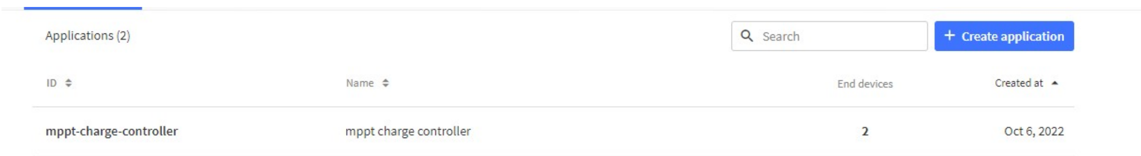


Figure 5.7: Create application

Implementing Integrations to keep receiving and sending uplink and downlink traffic using the built-in MQTT Server. End devices are also created within apps.

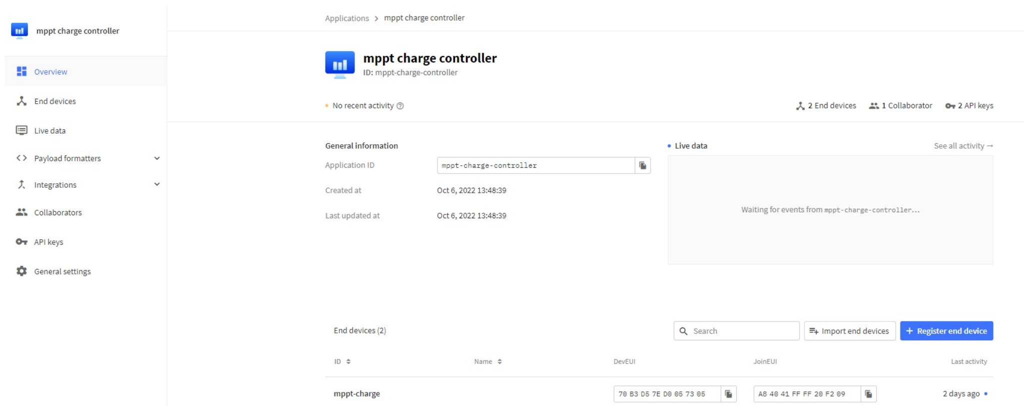


Figure 5.8: End devices

Once the application has been created, its settings can be modified to exclude uplink payload decryption and downlink payload encryption. This will result in the Application Server forwarding messages to integrations without any processing, for instance, it will disregard payload formatters, so integrations will be responsible for decrypting uplink messages in order to comprehend them. Additionally, scheduling downlinks from The Things Stack will be prohibited, as it is assumed that downlinks will be planned via integrations in this scenario.

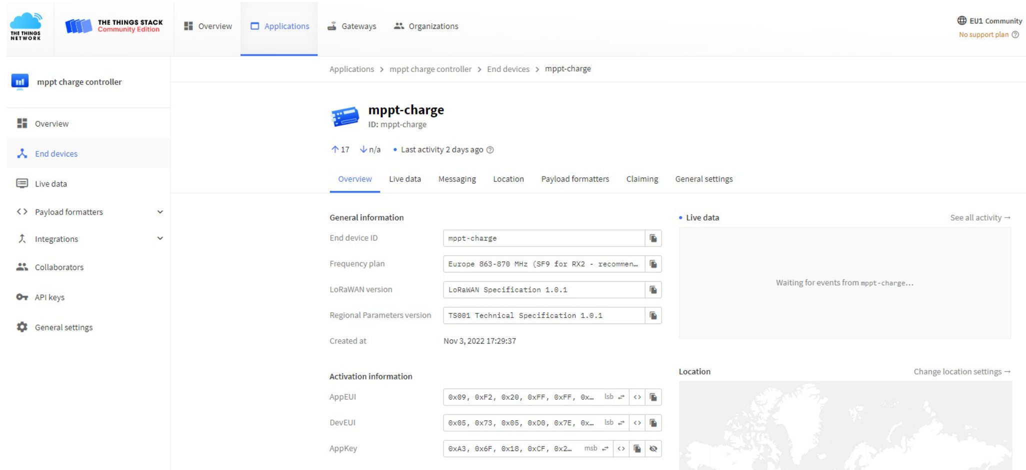


Figure 5.9: Activation information

We need to decode this payload by making use of the uplink payload formatter method in such a manner that the access point records are included inside the decoded payload object that is a component of the uplink message.

```
function Decoder(bytes,port)
{

  var decoded = {};
  decoded.inp = bytes[0] ;
  decoded.out = bytes[1] ;
  decoded.Curr = bytes[2] ;

return decoded ;
}
```

Figure 5.10: Payload formatters

```
"received_at": "2022-11-09T15:46:51.527425377Z",
"uplink_message": {
  "session_key_id": "AYRdCOoD5pKH3SGioRLPHA==",
  "f_port": 1,
  "f_cnt": 29,
  "frm_payload": "EwYD",
  "decoded_payload": {
    "CRR": null,
    "Curr": 3,
    "inp": 19,
    "out": 6
  },
```


Figure 5.11: Live data

### 5.1.5 Node-RED application

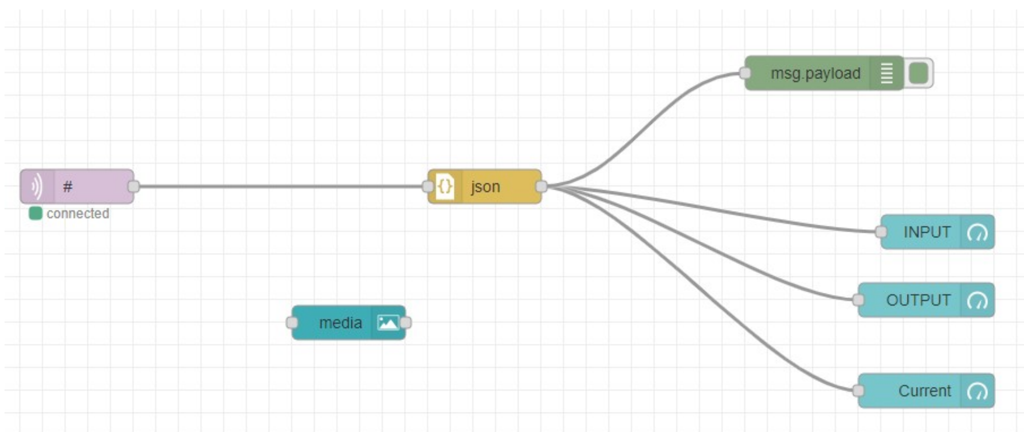


Figure 5.12: Test implementation of the flow editor

To construct a flow a drag and drop interface. We used with this interface, it is easy to assemble nodes in configurations that result in a program that does something useful. Each node is pre-programmed to do something specific (similar to a function in a text language line Python or Ruby)


Figure 5.13: Debug message

Below the MQTT in the node is where the connected status will be provided. To see the published event messages together with their payloads in JSON format, we click on the debug button located in the top right corner of the screen. This module provides a set of nodes in Node-RED to quickly create a live data dashboard.

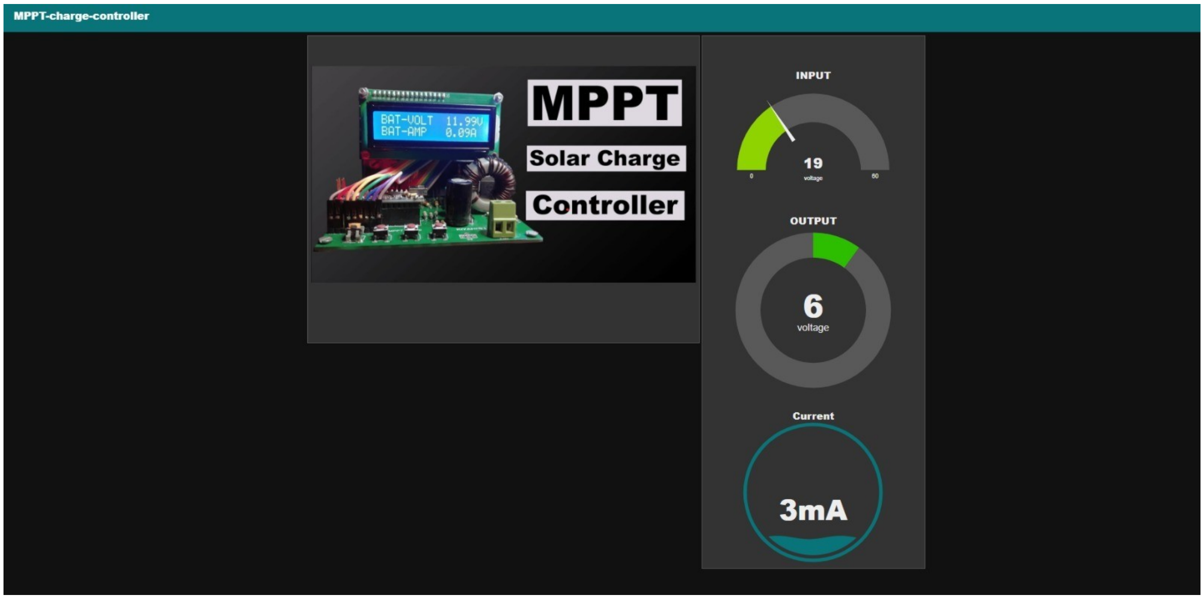


Figure 5.14: Live dashboard

## 5.2 Comparision with commercial solutions

PWM aids in charging the batteries, improves their lifespan, and stores more of the energy provided by the solar panels. Since batteries absorb more energy on average, a smaller battery (or fewer batteries in a battery bank) can be employed, hence reducing the overall system cost.

MPPT solar charge controllers enable the use of PV modules with a higher output voltage than the battery system's operational voltage. Since MPPT devices are often larger, they are more expensive than PWM controllers.

| PWM | MPPT |
|---|---|
| • PWM controllers are based on tried-and-true technology.<br>• These controllers are reasonably priced.<br>• Up to 60 amps are offered for PWM controllers.<br>• Controls high voltage and current. | • MPPT solar charge controllers provide a 30% efficiency gain.<br>• These controllers may also support an array with a higher input voltage than the battery bank.<br>• Used to adjust for identifying differences in solar cell I-V characteristics.<br>• Reduces system complexity while increasing system output efficiency. |

Table 5.2: Advantages of PWM over MPPT

| PWM | MPPT |
|---|---|
| • If we want to employ PWM, the nominal input voltage of the solar array must equal that of the battery bank.<br>• There is currently no controller with a DC current rating of over 60 amps.<br>• PWM controllers have limited system expansion capacity.<br>• Not effective for usage with 60A panels. | • MPPT controllers are more expensive.<br>• MPPT devices are often larger.<br>• Without MPPT controller manufacturer guidelines, sizing an adequate solar array can be difficult.<br>• Using an MPPT controller compels the solar array to consist of identical photovoltaic modules arranged in identical strings. |

Table 5.3: Disadvantages of PWM over MPPT

In order to match the panel voltage to the battery voltage, the PWM charge controller reduces the panel output voltage. MPPT is the most recent technique designed to maximize solar panel output. They function according to the panel voltage and convert excess panel voltage into current, increasing the solar system's output. MPPT controllers are 30% more efficient than PWM controllers at a minimum [38].

# Chapter 6

# Conclusions

This chapter presents in first time the final remarks and shows the futre work to conclude our project.

## 6.1 Final remarks

Given the world's population and electricity consumption, it is vital to utilise solar power and extract more power from it; MPPT is one approach for doing so efficiently. As previously established, the parasitic capacitance methodology outperforms both the P AND O and the Increment conduction methods in terms of power output.

As the population grows, there is a greater need to employ renewable energy sources. As a result, solar energy is increasing popularity. To extract maximum power, it is preferable to utilise the MPPT algorithm; thus, several types of MPPT algorithms must be developed so that maximum power may be collected from solar energy with high efficiency. A comparative analysis is performed based on the advantages and disadvantages, voltage ripple, average power obtained, and time response.

## 6.2 Suggestions for future work

It is generally known that many techniques of generating energy are employed, such as thermal power plants (nuclear, coal, petroleum, etc.), hydro (water) power plants, however these are non-renewable resources that are also hazardous to humanity and the environment.

Other charge controllers, such as PWM, are also available, but due to their low efficiency, users cannot fully utilise them. As a result, more affordable and effective MPPT algorithms are required to reach nearly 100% efficiency.

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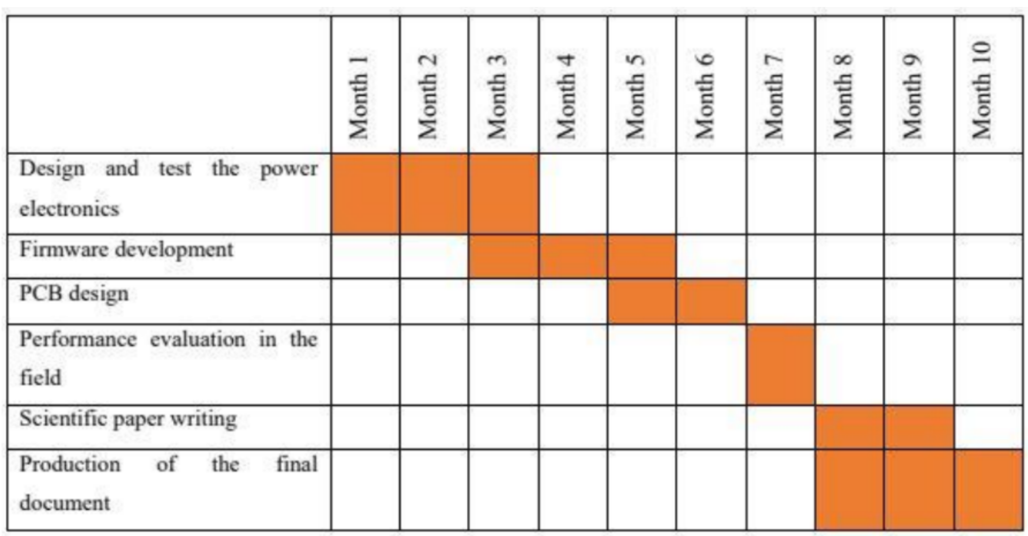
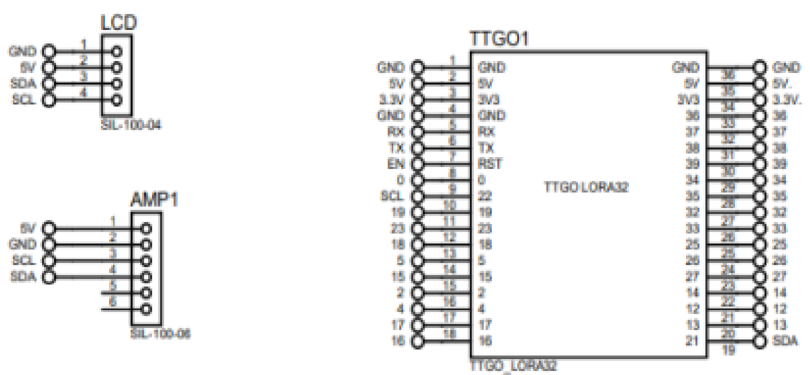
# Appendix A

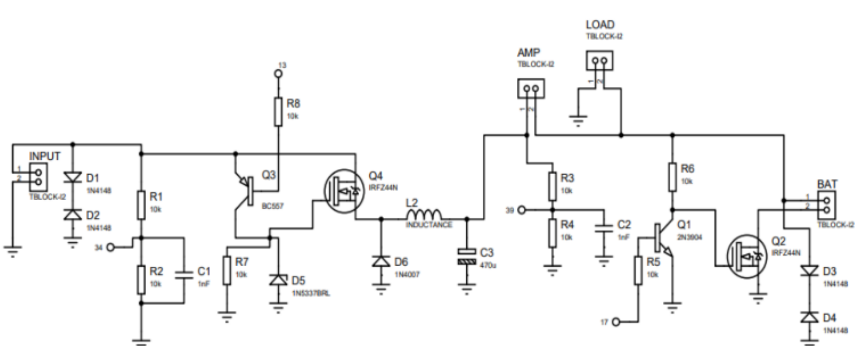
# Timing of work phases

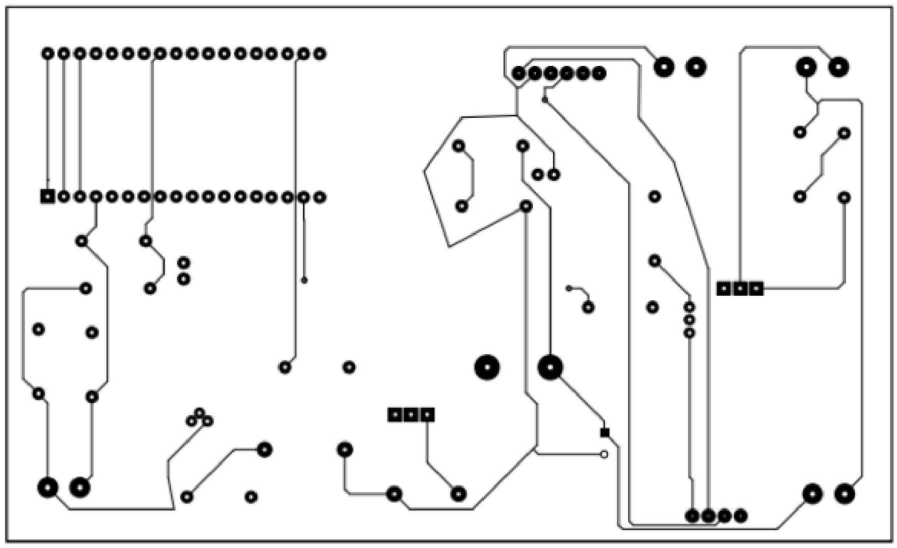


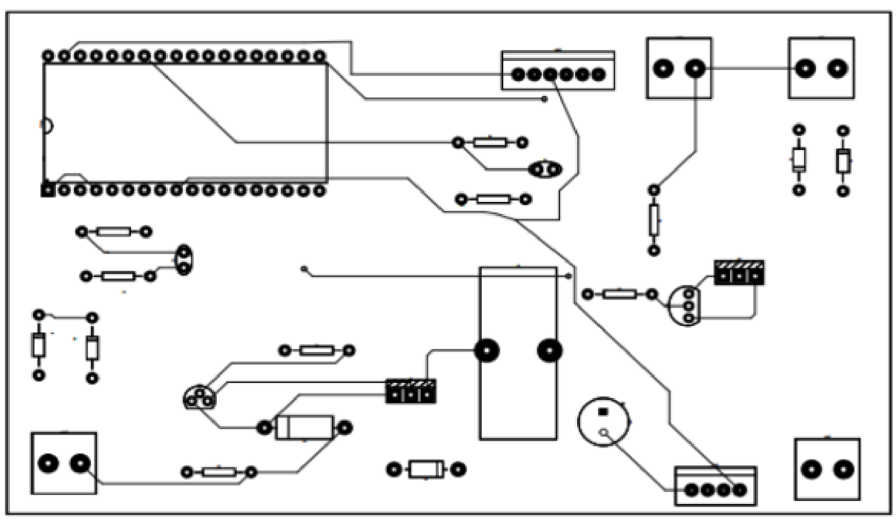
# Appendix B

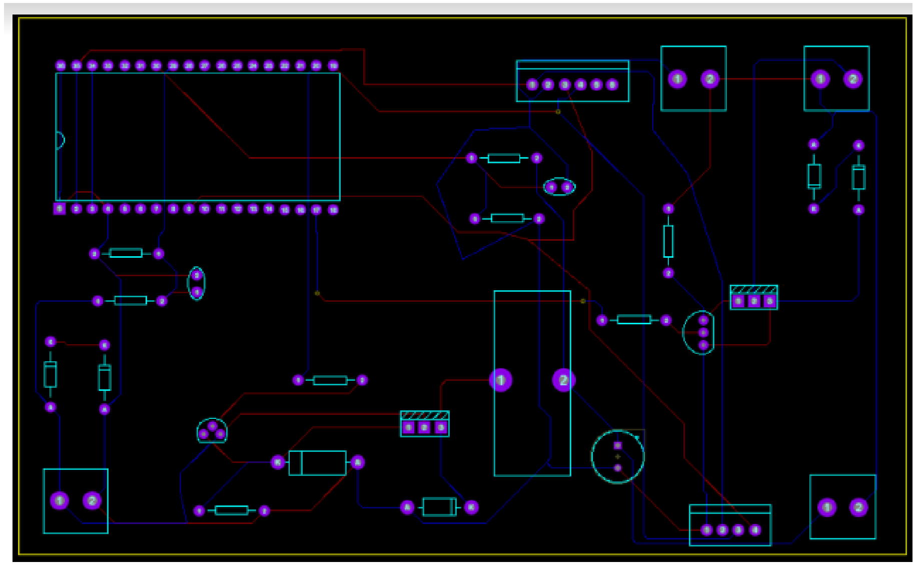
# Wiring Scheme

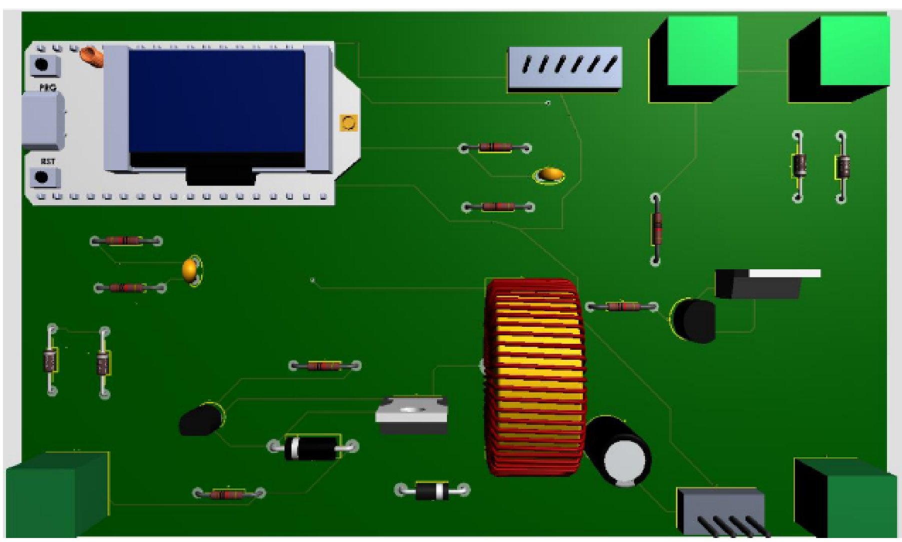










# Appendix C

# Firmware

```
#include <lmic.h>
#include  <hal/hal.h>
#include <SPI.h>
#include <Wire.h>
#include  <LiquidCrystal_I2C.h>//LiquidCrystal_I2C  lcd(0x27,20,4);   //LCD
i2c adress sometimes 0x3f or 0x27
#include  <Adafruit_INA219.h>
LiquidCrystal_I2C lcd(0x27,16,2);
//Icons
uint8_t Battery[8]  = {0x0E, 0x1B, 0x11, 0x11, 0x1F, 0x1F, 0x1F, 0x1F};
uint8_t Panel[8]  = {0x1F, 0x15, 0x1F, 0x15, 0x1F, 0x15, 0x1F, 0x00};


//Constants
#define bulk_voltage_max 12.5
#define bulk_voltage_min 11
#define absorption_voltage 14.7
#define float_voltage_max 13
#define battery_min_voltage 10
#define solar_min_voltage 19
#define charging_current 2.0
#define absorption_max_current 2.0
#define absorption_min_current 0.1
#define float_voltage_min 13.2
#define float_voltage 13.4
#define float_max_current 0.12

Adafruit_INA219 ina219;

byte BULK = 0;         //Give values to each mode
byte ABSORPTION = 1;
byte FLOAT = 2;
byte mode = 0;         //We start with mode 0 BULK

//Inputs
#define solar_voltage_in 34

#define battery_voltage_in 39

//Outputs
#define PWM_out 13
#define load_enable 17

//Variables
float bat_voltage = 0;
int pwm_value = 0;
```

```
float solar_current = 0;
float current_factor = 0.185;        //Value defined by manufacturer ACS712
5A
float solar_voltage = 0;
float solar_power = 0;
String load_status = "OFF";
int pwm_percentage = 0;
int16_t Vin;
int16_t Vout;
int16_t Curr;

void affichage();

static const u1_t PROGMEM APPEUI[8]={ 0x09, 0xF2, 0x20, 0xFF, 0xFF, 0x41,
0x40, 0xA8 };
void os_getArtEui (u1_t* buf) { memcpy_P(buf, APPEUI, 8);}


static const u1_t PROGMEM DEVEUI[8]={ 0x05, 0x73, 0x05, 0xD0, 0x7E, 0xD5,
0xB3, 0x70 };
void os_getDevEui (u1_t* buf) { memcpy_P(buf, DEVEUI, 8);}

static const u1_t PROGMEM APPKEY[16] = { 0xA3, 0x6F, 0x18, 0xCF, 0x22,
0x0C, 0xA8, 0x6B, 0x35, 0x47, 0x94, 0xEA, 0x61, 0x19, 0x61, 0x00 };
void os_getDevKey (u1_t* buf) {  memcpy_P(buf, APPKEY, 16);}

//static uint8_t mydata[] = "Hello, world!";
static osjob_t sendjob;


const unsigned TX_INTERVAL =  15;

// Pin mapping
const lmic_pinmap lmic_pins = {
    .nss = 18,
    .rxtx = LMIC_UNUSED_PIN,
    .rst = 14,
    .dio = {26, 33, 32}
};



//////////////void  declaration////////////////
void sensor_reading();
/////////////////////////////////
```

```
void onEvent (ev_t ev) {
    Serial.print(os_getTime());
    Serial.print(": ");
    switch(ev) {
        case EV_SCAN_TIMEOUT:
            Serial.println(F("EV_SCAN_TIMEOUT"));
            break;
        case EV_BEACON_FOUND:
            Serial.println(F("EV_BEACON_FOUND"));
            break;
        case EV_BEACON_MISSED:
            Serial.println(F("EV_BEACON_MISSED"));
            break;
        case EV_BEACON_TRACKED:
            Serial.println(F("EV_BEACON_TRACKED"));
            break;
        case EV_JOINING:
            Serial.println(F("EV_JOINING"));
            break;
        case EV_JOINED:
            Serial.println(F("EV_JOINED"));

            // Disable link check validation (automatically enabled
            // during join, but not supported by TTN at this time).
            LMIC_setLinkCheckMode(0);
            break;
        case EV_RFU1:
            Serial.println(F("EV_RFU1"));
            break;
        case EV_JOIN_FAILED:
            Serial.println(F("EV_JOIN_FAILED"));
            break;
        case EV_REJOIN_FAILED:
            Serial.println(F("EV_REJOIN_FAILED"));
            break;
            break;
        case EV_TXCOMPLETE:
            Serial.println(F("EV_TXCOMPLETE (includes waiting for RX
windows)"));
            if (LMIC.txrxFlags & TXRX_ACK)
              Serial.println(F("Received ack"));
            if (LMIC.dataLen) {
              Serial.println(F("Received "));
```

```
                Serial.println(LMIC.dataLen);
                Serial.println(F(" bytes of payload"));
              }
              // Schedule next transmission
              os_setTimedCallback(&sendjob,
os_getTime()+sec2osticks(TX_INTERVAL), do_send);
              break;
          case EV_LOST_TSYNC:
              Serial.println(F("EV_LOST_TSYNC"));
              break;
          case EV_RESET:
              Serial.println(F("EV_RESET"));
              break;
          case EV_RXCOMPLETE:
              // data received in ping slot
              Serial.println(F("EV_RXCOMPLETE"));
              break;
          case EV_LINK_DEAD:
              Serial.println(F("EV_LINK_DEAD"));
              break;
          case EV_LINK_ALIVE:
              Serial.println(F("EV_LINK_ALIVE"));
              break;
          default:
              Serial.println(F("Unknown event"));
              break;
    }
}

void do_send(osjob_t* j){
/////
   sensor_reading();
    byte mydata[3];
    mydata[0] = Vin ;
    mydata[1] = Vout ;
    mydata[2] = Curr;
    if (LMIC.opmode & OP_TXRXPEND)
    {
         Serial.println(F("OP_TXRXPEND, not sending"));
    }
    else
    {

         LMIC_setTxData2(1, mydata, sizeof(mydata)-1, 0);
         Serial.println(F("Packet queued"));
    }
```

```
}

void setup() {
     Serial.begin(9600);
     Serial.println(F("Starting"));
  pinMode(solar_voltage_in,INPUT);     //Set pins as inputs
   pinMode(battery_voltage_in,INPUT);

  pinMode(PWM_out,OUTPUT);              //Set pins as OUTPUTS
  digitalWrite(PWM_out,LOW);            //Set PWM to LOW so MSOFET is off
   pinMode(load_enable,OUTPUT);
  digitalWrite(load_enable,LOW);        //Start with the relay turned off
//  TCCR1B = TCCR1B & B11111000 | B00000001; //timer 1 PWM frequency of
31372.55 Hz
   Serial.begin(9600);

  lcd.init();
  lcd.backlight();
  lcd.createChar(0, Battery);
  lcd.createChar(1, Panel);

  if (! ina219.begin())
   {
    Serial.println("Failed to find INA219 chip");

    while (1)
    {
      delay(10);
    }
   }

    #ifdef VCC_ENABLE
    pinMode(VCC_ENABLE, OUTPUT);
    digitalWrite(VCC_ENABLE, HIGH);
    delay(1000);
    #endif

    // LMIC init
    os_init();
    // Reset the MAC state. Session and pending data transfers will be
discarded.
    LMIC_reset();

    // Start job (sending automatically starts OTAA too)
    do_send(&sendjob);
```

```
}

void loop()
{
  //   os_runloop_once();
 solar_voltage = get_solar_voltage(15);
  bat_voltage =    get_battery_voltage(15);
//    Serial.println(solar_voltage);
//delay(1000);
Serial.println(bat_voltage);
delay(1000);
 affichage();
}



void sensor_reading()
{
//   solar_voltage = get_solar_voltage(100);
//   bat_voltage =    get_battery_voltage(100);
   solar_current = get_solar_current(100);
   solar_power = bat_voltage * solar_current;
   pwm_percentage = map(pwm_value,0,255,0,100);




   if(bat_voltage < battery_min_voltage)
   {
     digitalWrite(load_enable,LOW);          //We DISABLE the load if battery
is undervoltage

   }
   else{
     digitalWrite(load_enable,HIGH);         //We ENABLE the load if battery
charged

   }

    ///////////////////////////FLOAT///////////////////////////
    ///////////////////////////////////////////////////////////
   if(mode == FLOAT){
     if(bat_voltage < float_voltage_min)
     {
       mode = BULK;
```

```
  }

  else{
    if(solar_current > float_max_current)
    {     //If we exceed max current value, we change mode
      mode = BULK;

    }//End if >

    else{
      if(bat_voltage > float_voltage)
      {
        pwm_value--;
        pwm_value = constrain(pwm_value,0,254);
      }

      else {
        pwm_value++;
        pwm_value = constrain(pwm_value,0,254);
      }
    }//End else > float_max_current

    ledcWrite(PWM_out,pwm_value);
  }
}//END of mode == FLOAT



//Bulk/Absorption
else{
  if(bat_voltage < bulk_voltage_min)
  {
    mode = BULK;

  }
  else if(bat_voltage > bulk_voltage_max)
  {
    mode = ABSORPTION;
  }

   ////////////////////////////BULK///////////////////////////
   /////////////////////////////////////////////////////////////
  if(mode == BULK){
    if(solar_current > charging_current)
    {
```

```
      pwm_value--;
       pwm_value = constrain(pwm_value,0,254);
    }

    else {
      pwm_value++;
       pwm_value = constrain(pwm_value,0,254);
    }
     ledcWrite(PWM_out,pwm_value);
  }//End of mode == BULK



    //////////////////////////ABSORPTION////////////////////////
    ////////////////////////////////////////////////////////////
  if(mode == ABSORPTION){
     if(solar_current > absorption_max_current)
    {    //If we exceed max current value, we reduce duty cycle
      pwm_value--;
       pwm_value = constrain(pwm_value,0,254);
     }//End if > absorption_max_current

    else{
       if(bat_voltage > absorption_voltage)
      {
        pwm_value++;
         pwm_value = constrain(pwm_value,0,254);
      }

      else {
        pwm_value--;
         pwm_value = constrain(pwm_value,0,254);
      }

       if(solar_current < absorption_min_current)
      {
        mode = FLOAT;

      }
     }//End else > absorption_max_current

     ledcWrite( PWM_out,pwm_value);
  }// End of mode == absorption_max_current

}//END of else mode == FLOAT
Vin= solar_voltage;
```

```
  Vout= bat_voltage;
  Curr= solar_current;
}


float get_solar_voltage(int n_samples)
{

   float voltage = 0;
  for(int i=0; i < n_samples; i++)
  {
     voltage +=0.0094907223* analogRead(solar_voltage_in);
    delay(1);
  }
  voltage = voltage/n_samples;
  if(voltage < 0){voltage = 0;}
  return(voltage);
}

float get_battery_voltage(int n_samples)
{
  float voltage = 0;
  for(int i=0; i < n_samples; i++)
  {
     voltage += analogRead(battery_voltage_in) * 0.0046003417968 ;
    delay(1);
  }
  voltage = voltage/n_samples-0.2;
  if(voltage < 0){voltage = 0;}
  return(voltage);
}


float get_solar_current(int n_samples)
{
  float current = 0;
  current = ina219.getCurrent_mA();
  return(current);
}

void affichage(){

    lcd.backlight();
    lcd.clear();
    lcd.setCursor(0,0);                //Column 0 row 0
    lcd.write(1);                      //Panel icon
```

```
lcd.print("");                         //Empty space
lcd.print(solar_voltage);                         //Soalr voltage
lcd.print("V");                         //Volts
lcd.print(" ");                      //Empty spaces
lcd.write(0);                           //Battery icon
lcd.print("");                         //Empty space
lcd.print(bat_voltage);                       //Battery voltsge
lcd.print("V");                         //Volts

lcd.setCursor(0,1); //Column 0 row 1

lcd.print("I ");                        //Empty spaces
lcd.print(solar_current);                          //Solar current
lcd.print("mA");
```