Fast response MPPT switched charger for the Técnico Solar Boat

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Introduction to the Research in

Electrical and Computer Engineering

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Abstract

Resumo do trabalho
Keywords: MPPT, MPPT topology, DC-DC Converter

Contents

Acronyms

IST	Instituto Superior Técnico
TSB	Técnico Solar Boat
MPPT	Maximum Power Point Tracker
MPP	Maximum Power Point
PCB	Printed Circuit Board
CAN	Controller Area Network
USB	Universal Serial Bus
GUI	Graphical User Interface
PV	Photovoltaic

1 Introduction

1.1 Motivation

As the world is reaching a point where pollution is taking over the news, solar panels are one of the main solutions available. In 2024, 7% of the energy produced in the world comes from solar panels, and in Portugal this number rises to 14.5% [1]. Solar energy still plays a miniscule role that it is listed behind the other sources of energy in terms of the contribution for meeting the world's energy demand. But as the years go by, solar energy is becoming more and more relevant, with the cost of solar panels dropping significantly in the last decade.

In comparison to other forms of alternate energy, Photovoltaic energy is relevant due to its availability, simplicity, lower maintenance, environmental friendliness, reliability and many other benefits. More recently, is becoming more and more relevant in the automotive industry, with solar powered cars, boats and robots. The CO_2 emissions of automotive sector is one of the main contributors to global warming. More than 30% of total CO_2 emissions in the EU in 2018 came from transport, with 3% of global pollution coming from the maritime sector alone [2] [3]. And that is where the Técnico Solar Boat (TSB) project fits in.

In 2015, TSB was created with the goal of designing and building a solar powered boat to compete in international competitions. Since then, the project has growth and built several vessels. It begined with the construction of the first prototype, São Rafael 01 wich had a lot of room to improvement and so São Rafael 02 and 03 were built.

All of these prototypes used solar energy to maximize their range and efficiency. In the first years the energy produced was not much and the all system were commercial available. But as a team of students that want to push the limits of solar power boats and the overall technology, the "built your self" philosophy was presented all over the years. And that is why we started building our own solar panels in 2020 for São Rafael 03. As the years went by, a lot of other systems were designed and built in house but there is still one system that is yet to be developed, the Maximum Power Point Tracker (MPPT).

The MPPT is a fundamental part of any solar energy system. Its main goal is to maximize the energy extracted from the solar panels by operating them at their Maximum Power Point (MPP). This is done by adjusting the electrical operating point of the modules or array.

1.2 Objectives

This project aims to design and implement a MPPT system for solar panels used in the TSB project. The MPPT will convert the energy produced by the solar panel as efficiently as possible with the use of a quality DC-DC converter and the implementation of MPP tracking algorithms.

So the main objectives of this project are:

- Study and understand the operation of solar panels and MPPT techniques;
- Chose the most suitable DC-DC topology for the system;
- Design and simulation of the hardware and software.
- Implement a fast response and efficient control algorithm;
- Implement the system in hardware and develop a Printed Circuit Board (PCB).
- Test and validate the performance of the PCB.
- Ensure the safety and reliability of the MPPT for its integration in the TSB project.
- Provide data to the user about the performance of the solar panel and of MPPT through a Controller Area Network (CAN) communication interface.

By achieving these objectives, the project will contribute for a better control of the system, maximizing the data received from the solar panels to later improve the energy efficiency of the MPPT or even take conclusions about the manufacture quality of the solar panels build by TSB project.

1.3 Outline

Explain how the work is organized by chapters.

2 Background

Before entering into the specific details about the project, in this chapter i will explain some general concepts about solar panels and and how to convert there energy to useful energy. This concepts will help a better understanding of the following chapters.

2.1 Solar Panels

Solar panels, also know as Photovoltaic (PV) panels are devices that convert sunlight into electrical energy. Each solar panel is made of multiple solar cells connected in series and/or parallel. As in electrical circuits, the connection type will affect the voltage and current output of the panel. More specifically, series increases voltage and parallel increases current.

Each cell is made of semiconductor materials, usually silicon. This semiconductor is doped with phosphorus, a group V element, to create a negative type layer. On the other side, a layer is doped with boron, a group III element, to create a positive type layer. This creates a p-n junction, which is essential for the photovoltaic effect.

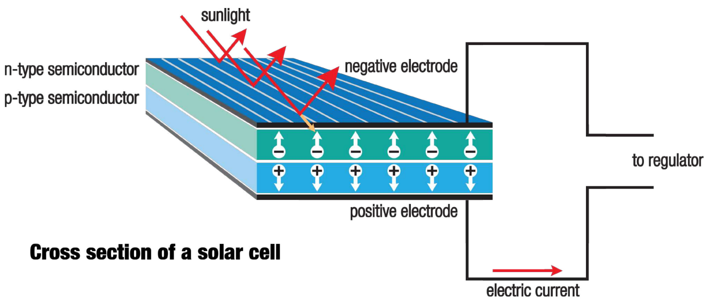


Figure 2.1: Principle of operation of a solar panel

When sunlight hits the solar cell, photons from the light energy are absorbed by the semiconductor material. This energy excites electrons, allowing them to break free from their atoms and create electron hole pairs. The electric field at the p-n junction drives these free electrons towards the n-type layer and holes towards the p-type layer, generating a flow of electric current when the cell is connected to an external circuit, [4].

This energy produces a direct current (DC) voltage and current output, which are not constant. Both voltage and current are codependent, so if one suffers variation the other will too. This variation is not linear and can be represented in an I-V curve, as in Figure 2.2. Also, the power output suffers variations, which can be represented in a P-V curve.

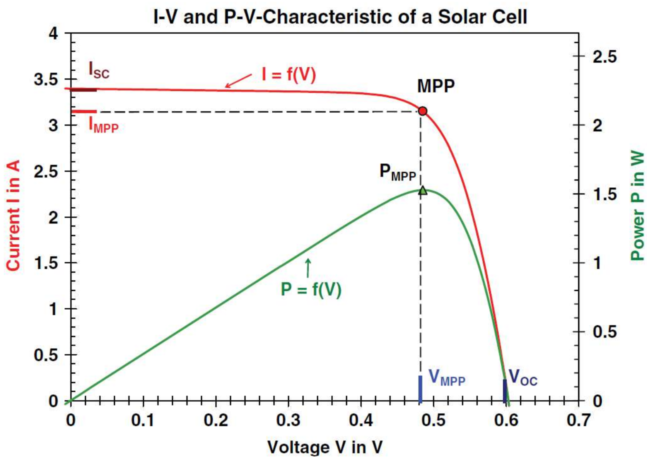
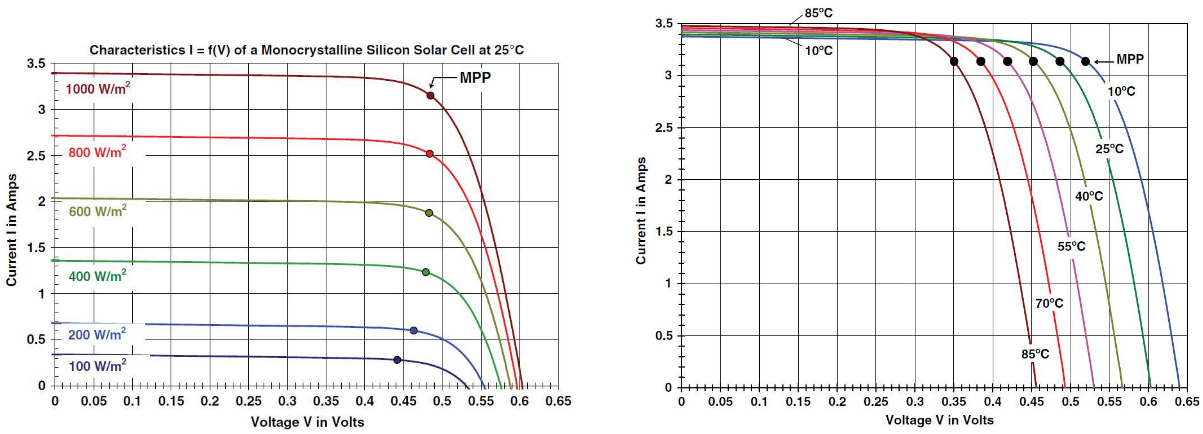


Figure 2.2: I-V and P-V curves of a solar panel [4]

The efficiency of a solar panel depends on various factors, including the quality of the materials used, the design of the cells, and environmental conditions such as temperature and irradiance.

As you can see in Figure 2.3a, the variation of the irradiance change the I-V and P-V curve of the solar panel. The increase of irradiance produces more more power by mainly increasing the current output of the panel. On the other hand, the temperature has an opposite effect, Figure 2.3b. The increase of temperature produces a decrease in power output, mainly by decreasing the voltage output of the panel.



(a) I-V curves of a solar panel with cell temperature of 25 ºC and variable Irradiance

(b) I-V curves of a solar panel with $1KW/m^2$ of irradiance and variable temperature

Figure 2.3: I-V curves under different conditions. Left: irradiance variation. Right: temperature variation [4].

substituir pelas i-v, p-v do survey

Both environmental conditions have a meaningful impact on the Maximum Power Point (MPP) of the solar panel and there for on the power output of the system. So, if we want to maximize the power extracted by the solar panels, we can not use a classic power converter like a buck converter since neither the current nor the voltage are constant. Instead, we need to use a Maximum Power Point Tracker (MPPT).

2.2 Solar energy production

As discussed in the previous section, solar panels produce a variable DC voltage and current output which depends on environmental conditions. To extract as much energy as possible, commonly an MPPT are used.

An Maximum Power Point Tracker (MPPT) is a device that is used to optimize the power output from solar panels by continuously tracking and adjusting the operation point of the panels to ensure they operate at their MPP.

To achieve it's goal, an MPPT is usually composed by an DC-DC converter, an microcontroller and some sensors (Figure 2.4). The sensors are used to measure the input variables of the control system (typically voltage and current). The information acquired by this sensors are processed by the microcontroller, which runs an algorithm to determine if the MPP was reached or what needs to be done to reach it. In the second case, the microcontroller sends control signals to the DC-DC converter to adjust its operation accordingly.

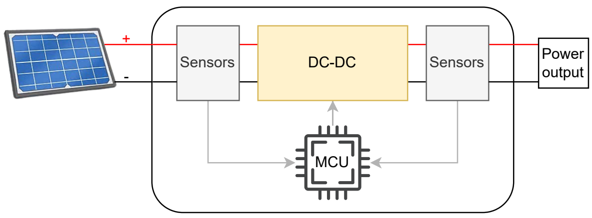


Figure 2.4: Top view of a basic MPPT system

Than, the output can be connected to different types of loads, like batteries, DC loads or inverters to convert the energy to alternative current and inject it in the grid (usually in this cases the MPPT is built in with the inverter).

2.3 MPPT Algotithms

There are plenty of MPPT algorithms, each one with its own advantages and disadvantages. The choice of the algorithm will depend on the specific application, the desired performance, and the available resources.

In this work the aim is to achieve the max efficiency possible of a solar panel installed in a moving boat, which will produce an i-v curve variation due to the quick changes in irradiance caused by changes of inclination and clouds, and also temperature changes due to waves and wind. So the tracking speed and accuracy are the most important factors to consider to be able to follow the MPP in these conditions.

With that in mind, some of the most relevant algorithms will be briefly explained, so we can choose the most suitable one for this project.

2.3.1 Constant Voltage

This is the simplest and the most inefficient. This method uses a fixed reference voltage to operate the solar panel. This voltage enters in a PID controller that will adjust the duty cycle of the DC-DC converter to maintain the solar panel voltage at this reference value.

There are some well know variations of this method that improve the performance by adjusting the reference voltage to a fraction of the open circuit voltage of the solar panel (usually between 71% and 78%) [5], Equation 2.1. This open circuit voltage can be measured periodically by disconnecting the solar panel from the load for a short period of time. This way, the reference voltage will be more accurate and the efficiency will increase.

$$V_{ref} = k \cdot V_{oc} \tag{2.1}$$

Other variation is based on the short circuit current of the solar panel, setting the reference voltage to a fraction of this value [6].

Both methods are simple and low cost, but they are inefficient, since they have to stop producing energy to do measurements. But there is also some variations that solve this problem by using a dummy cell to do the measurements or even an diode since its there physical properties are similar to a solar cell [5] [7].

2.3.2 Perturb and Observe (P&O)

The perturb and observe method is widely used in commercial products and is the basics of many advanced algorithms. Its popularity lies on its simplicity, low cost and ease of implementation.

Its name says exactly what it does, it perturbs the voltage of an PV array and observes the resulting effect on the power output. This means that if the voltage was increased and the power output also increased, the algorithm is working in the direction to the MPP, so it will continue increasing the voltage. In the opposite case, if the power output decreased, the algorithm is working away from the MPP, so it will reverse the direction of the perturbation [8]. Figure 2.5 shows an flow chart of the algorithm.

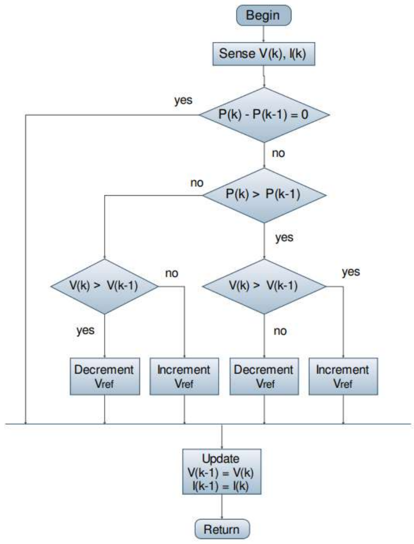


Figure 2.5: Flow chart of the classic version of Perturb and Observe algorithm [9]

The biggest drawback of this algorithm is that it oscillates around the MPP, which produces power losses. This oscillation can be reduced by decreasing the step size of the perturbation, but this will also reduce the tracking speed of the algorithm. So there is a trade off between tracking speed and accuracy [6].

To mitigate this issue an adaptive step size can be used, where the step size is larger when the MPP is far away and smaller when it is close. This way, the tracking speed is maximized while minimizing the oscillations around the MPP. This can be achieved by measuring the power and voltage and calculating the p-v curve solve ($\frac{\Delta P}{\Delta V}$). In the MPP this values must be zero, so the step size can be reduced. This variation of the algorithm is called ”differential power-perturb and Observe (dP-P&O)”.

Another weal know issue of this algorithm is that it can get confused in rapidly changing environmental conditions, like fast irradiance changes caused by clouds. In this case, the algorithm can misinterpret the power change caused by the environmental variation as a result of its own perturbation, leading it to move away from the MPP instead of towards it. For example, if the perturbation was in the wrong direction but the irradiance increased, the power output would increase and the algorithm would continue perturbing in the wrong direction.

To solve this issue, a new conditions must be added to the algorithm to take into account two consecutive musers of ΔP and ΔV. This way, if the sign of both ΔP are different, it means that the power change was caused by an environmental variation and not by the perturbation, so the algorithm must not change the voltage. This variation is called ”two point algorithm” or ”improved P&O” [10]. Table 2.1 shows the 16 possible cases of the truth table of this algorithm with an extra column showing the changes caused by the perturbation or by the environment. Por acabar e rever (não sei se gosto muito desta tabela e explicação)

Table 2.1: Truth table for the Improved P&O algorithm (extended with one extra column) [10].

$\Delta V(k-1)$	$\Delta P(k-1)$	$\Delta V(k)$	$\Delta P(k)$	$\Delta V(k+1)$	Changes caused by:
$-$	$-$	$-$	$-$	$-$	
$-$	$-$	$-$	$+$	$+$	
$-$	$-$	$+$	$-$	$-$	
$-$	$-$	$+$	$+$	$+$	
$-$	$+$	$-$	$-$	$-$	
$-$	$+$	$-$	$+$	$+$	
$-$	$+$	$+$	$-$	$-$	
$-$	$+$	$+$	$+$	$+$	
$+$	$-$	$-$	$-$	$-$	
$+$	$-$	$-$	$+$	$+$	
$+$	$-$	$+$	$-$	$-$	
$+$	$-$	$+$	$+$	$+$	
$+$	$+$	$-$	$-$	$-$	
$+$	$+$	$-$	$+$	$+$	
$+$	$+$	$+$	$-$	$-$	
$+$	$+$	$+$	$+$	$+$	

There are some more relevant variations of this algorithm that will not be explained here, like the Variable Step Size P&O (VSS-P&O), the three point P&O, a-factor P&O and others.

Posso explicar o three point algorithm e o a-factor aqui no futuro se achar relevante.

Note for the future: The pilot could have an automatic mode and a manual mode where it could say the type of weather and the step size could be adjusted accordingly.

2.3.3 Incremental Conductance (IncCond)

The Incremental Conductance algorithm is another widely used MPPT method due to its accuracy and ability to track the MPP under rapidly changing environmental conditions.

This algorithm lies on the fact that at the MPP the derivative of power with respect to voltage is zero. By knowing the output voltage and current of the solar panel, the algorithm can calculate the cundactance and the incremental conductance.

The following formulas (Equation 2.3) show the equation which this algorithm is based on.

$$\frac{dP}{dV} = \frac{d(V \cdot I)}{dV} = I + V\frac{dI}{dV} \rightarrow \frac{1}{V} \times \frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV} \tag{2.2}$$

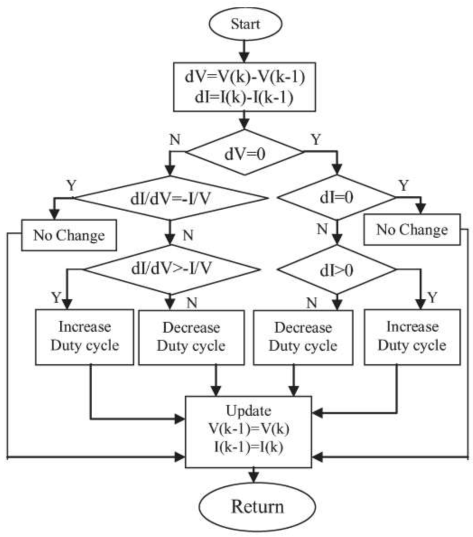
So at the MPP point, the slope of the p-v curve is zero (Figure 2.6b), which means that the negative of the conductance is equal to the incremental conductance. So the algorithm compares these two values to determine if the operating point is at, to the left or to the right of the MPP [6]:

$$
\left.
\begin{array}{lcl}
\frac{dP}{dV} = 0 & \iff & \frac{dI}{dV} = -\frac{I}{V} \\
\frac{dP}{dV} > 0 & \iff & \frac{dI}{dV} > -\frac{I}{V} \\
\frac{dP}{dV} < 0 & \iff & \frac{dI}{dV} < -\frac{I}{V}
\end{array}
\right]
\begin{array}{l}
\text{at MPP} \\
\text{(left of MPP)} \\
\text{(right of MPP)}
\end{array}
\tag{2.3}
$$

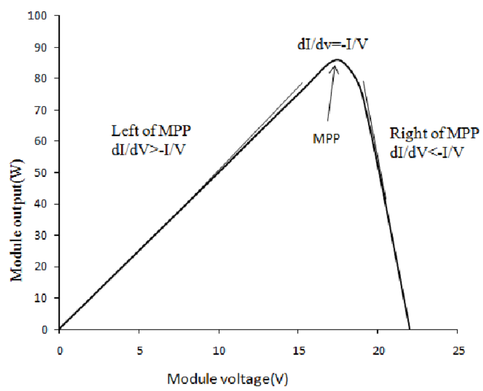
Base on this conditions the algorithm adjust it's operating point (increasing or decreasing the voltage) using a fix step size to track the MPP, as shown in the flow chart of Figure 2.6a.

As in the P&O method, there is a trade off between tracking speed and accuracy when choosing the step size. A larger step size will increase the tracking speed but will also increase the oscillations around the MPP, while a smaller step size will reduce the oscillations but will also reduce the tracking speed. To solve this issue, an variable step size can be used, where the step size is larger when the MPP is far away and smaller when it is close by sizing the step accordingly with the slope derivative [11] [12].

Comparative analysis demonstrates that the IncCond algorithm exhibits superior efficiency relative to the Perturb and Observe method. This outcome is expected, as the Incremental Conductance technique was developed specifically to address the limitations inherent in the P&O approach. Experimental studies conducted in 2006 further corroborate these findings, demonstrating that efficiencies of up to 95% can be achieved when employing a buck converter [13].



(a) Flowchart of the IncCond method with direct control [14].



(b) IncCond method principle.

Figure 2.6

2.3.4 Look Up Table (LUT)

The Look Up Table method is a simple and fast MPPT algorithm that relies on pre-calculated/measured data to determine the optimal operating point of a solar panel.

The LUT table contains several entries organized by voltage and current. Each of this entries contains the optimal duty cycle of the DC-DC converter, that are pre calculated or measured for a specific voltage and current. This way, the algorithm can reach the mpp in one clock cycle by measuring the voltage and current of the solar panel, looking for the closest entry in the LUT table and applying the corresponding duty cycle to the converter.

The main advantage of this method is its speed since it can reach the MPP in one clock cycle. This makes it suitable for applications where fast tracking is required, like in this project. But the main drawback is that it is not very acquired.

To improve the accuracy the LUT table needs be larger, which increases the required memory resources. Also, by adding the temperature and/or irradiance to the table would increase the accuracy, making it almost 100% accurate, but this would increase the size of the table exponentially, making it unfeasible for most applications.

2.3.5 Fuzzy logic

tenho de ler melhor sobre este algoritmo antes de escrever algo. Não sei se é assim tão relvante e tabém não sei como funciona. Li num survey que foram obetidos bons resultados com ele.

https://ieeexplore.ieee.org/document/349703

2.4 DC-DC types

2.4.1 Non-isolated versus isolated DC-DC converters

DC-DC converters can be classified into two main categories: isolated and non-isolated converters. The main difference between these two types of converters is the presence or absence of galvanic isolation between the input and output circuits.

This galvanic isolation is usually achieved by using a transformer which provides electrical separation between the input and output sides of the converter. This isolation is important in applications where safety is a concern, such as in medical devices or industrial equipment, as it helps to prevent electrical shock and damage to sensitive components. In the context of solar energy systems and E-mobility, isolated converters are often used when the solar panel is connected to the grid [15], as they help to protect against voltage spikes and other electrical disturbances or when the solar panels MPP voltage is very different from the battery or load voltage typically medium voltages .

On the other hand non-isolated converters do not provide isolation between the input and the output circuits but they are generally more efficient and at lower costs.

Table 2.2: Comparison between Switching Converters and Galvanic Isolated Converters.

Type	Switching Converters	Galvanic Isolated Converters
Price	Cheaper	Expensive
Isolation	No	Yes
Circuit Complexity	Low	High
Efficiency	High	Medium
Size	Compact	Large
Electromagnetic Interference (EMI)	High	Medium/High
Switching Frequency	Low/Medium	Medium
Thermal Management	Easier	Moderate
Control Complexity	Simple	Complex

In summary, the choice between isolated and non-isolated DC-DC converters depends on the specific requirements of the application, including safety, efficiency, cost, and complexity. In many solar energy applications where the solar panel voltage is not too different from the battery or load voltage, non-isolated converters are preferred due to their higher efficiency and lower cost. So in this project, non-isolated converters will be considered. Nenhum paper que eu li fala diretamente dum caso como este. Em que os paineis são usados para alimentar uma bat de baixa tenção e que fale da opção de ser isolado ou não. Encontrei sim para veiculos de baterias de media tensão e ai já faz sentido ser isolado.

2.4.2 Non-isolated DC-DC converters

Modern conversion circuits generally use one of three basic topologies: buck, boost or buck-boost converters. They are 'basic' in the sense that only one switch is used and there is no isolation from the output circuits. A given topology is used to obtain a specific result, such as voltage step-down, voltage step-up, or hybrid mode [16].

2.4.2.A Boost converter

The boost converter is a step-up DC-DC converter that is widely used in MPPT because solar panels usually have a lower voltage than the battery or load they are powering. There are multiple papers that use this topology buscar alguns.

Also this DC-DC topologies are simple to implement, low cost and have high efficiency, reaching efficiencies of up 98% [17].

One down side of this topology is that can not emulate smaller impedances than the load impedance, and therefore, it does not reach values near the short circuit current of the PV module, so it can not be used for all algorithms [18].

2.4.2.B Buck converter

The buck converter is a step-down DC-DC converter also widely use for applications where the solar panel voltage is higher than the battery or load voltage. But in most automotive applications the area of the solar panel is limited, so the voltage is usually lower than the battery voltage, making the boost converter a more suitable choice.

similar with the boost converter, the buck converter can emulate smaller impedances than the load impedance, and therefore, it can reach values near the open circuit voltage of the PV module [18].

2.4.2.C Buck-Boost converter

Buck-Boost converters are step-up and step-down DC-DC converters that can operate in both modes. This makes them more versatile than the previous two topologies, but also more complex and less efficient [17].

They are used in applications where the solar panel voltage can be both higher or lower than the battery or load voltage, also certain MPPT use it to have a wider range of operation or versatility of the used batteries.

This type of converter has some variations. The most common are the Zeta, Cuk and SEPIC converters.

The classic buck-boost and Zeta topologies have an input current always working in discontinuous conduction mode, which produces high ripple current and harmonic distortion. To solve this issue, the Cuk and SEPIC topologies are used, which have an input current working in continuous conduction mode (CCM), reducing the ripple current and harmonic distortion [18]. Also, the classic buck-boost and Zeta have an inverted output voltage referred to the input voltage.

2.4.3 Comparison between Non-isolated DC-DC converters

All of the non-isolated DC-DC topologies explained before have their own advantages and disadvantages. The choice of the topology will depend on the specific application, the desired performance, and the available resources. To help with this choice, Table 2.3 shows a comparison between the most relevant characteristics of each topology. In green the best vantages of each topology are highlighted.

2.5 Voltage and current sensing

Operation Amplifier, Diferential Amplifier, Instromentation Amplifier, Hall effect sensors, etc.

High side vs low side

Table 2.3: Comparison of non-isolated DC-DC topologies.

Topology	Boost	Buck	Buck-Boost	Zeta	Cuk	SEPIC
Price	Low	Low	Low	Medium	Medium	Medium
Isolation	No	No	No	No	No	No
Circuit complexity	Low	Low	Low	Medium	High	Medium
Efficiency	High	High	Medium	Medium	High	Medium
Size	Low	Low	Low	Medium	Medium	Medium
Type	Step-Up	Step-Down	Step-Down/Up	Step-Down/Up	Step-Down/Up	Step-Down/Up
Versatility	Low	Low	Medium	High	High	High
Inverted output	No	No	Yes	Yes	No	No
Input current ripple	High	Low	High	Low	Very low	Low
Output current ripple	Low	High	High	Very low	Low	Low
Energy-storage elements	1 inductor	1 inductor	1 inductor	2 inductors, 2 caps	2 inductors, 2 caps	2 inductors, 2 caps
Switch stress	No	Yes	No	Yes	Yes	Yes
Continuous input current	No	Yes	No	Yes	Yes	Yes
EMI	Low	Low	High	Medium	Medium	Medium

2.6 Protection circuits

Overvoltage, overcurrent, reverse polarity, temperature, mosfet protections, etc

explain why they are important and how they can be implemented

2.7 Battery charging techniques

As the demand of electronic devices and E-vehicles increased, emerge the need for efficient, compact and light weight batteries. Among the exiting technologies lithium-ion batteries have one of the best energy-to-weight/volume ratios and, at this moment, it is the technology use in Técnico Solar Boat (TSB) batteries. But, as every other battery technology, they need to be charged properly to ensure their safety and longevity [19].

To charge this batteries properly, the MPPT algorithm can stand alone if an additionally converter is used in series. But in most cases, the MPPT and the battery charging unit are integrated in the same converter. This way, the MPPT can adjust the operating point of the solar panel to extract the maximum power while the battery charging unit ensures that the battery is charged properly.

There several Algorithms to charge lithium-ion batteries being the most relevant for this use case the Constant Current-Constant Voltage (CC-CV) method [20]. This method consists in two main phases, Figure 2.7. In the first phase, the battery is charged with a constant current until it reaches a predefined voltage limit (usually 4.2V per cell). In the second phase, the voltage is held constant at this limit while the current gradually decreases as the battery approaches full charge. Once the current drops below a certain threshold, the charging process is terminated to prevent overcharging.

Some variations of this method are relevant for other types of charges. For example, DL-CC/CV eliminates the need for a current sensor with a positive and negative feedback loop, the BC-CC/CV adds efficiency by charging faster at the first 30% of the battery capacity and then switching to CC-CV.

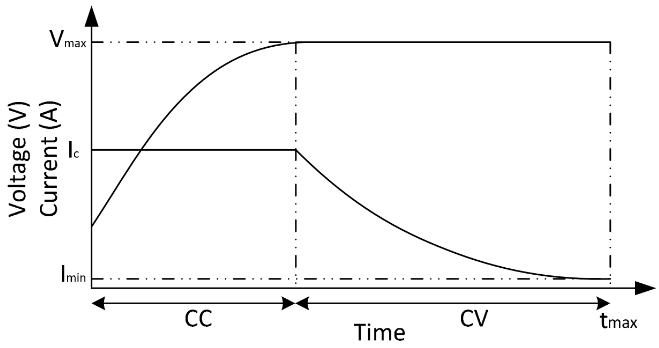


Figure 2.7: Charging profile of CC/CV [19]

There are two more complex methods that use advanced control techniques to implement CC-CV, mainly the fuzzy logic and grey predict (FL-CC/CV and GP-CC/CV). These methods can adapt the charging process based on the battery's state of charge, temperature, and other factors, potentially improving charging efficiency and battery lifespan. As downside they required computational power.

In cases that the digital resources are limited, analog methods such as PLL-CC/CV and IPLL-CC/CV can be used. These methods use phase-locked loop (PLL) circuits to regulate the charging current and voltage, providing a simpler and more cost-effective solution compared to digital control methods.

There is also Multistage current charging (MSCC) method that divides the charging process into multiple stages with different current levels.

Finally, the pulse charging method uses short bursts of high current to charge the battery, which can help reduce heat generation and improve charging efficiency.

2.8 Processing unit

Microcontroller vs FPGA vs DSP este paper implementa um MPPT numa FPGA [**?**]

Arduino, STM32, Raspberry Pi, others

tentar justificar o uso do STM32

3 State-of-the-Art

Intro if needed

3.1 Commercial MPPTs

Table with comercial MPPTs and some of their carateristics.

explain their advantages and disadvantages

Provide some specs about their control methods, dcdc topolgys, protection circuit, processing unit, frequecy of operation, etc.

4 Solucion Proposal

4.1 System architecture

Visão geral da arquitetura do sistema proposto (paineis usados, bateria usada, diagrama de blocos do controlador).

4.2 Requirements

tendo em conta a secção anterior e os requesitos impostos pela equipa, quais são os requesitos para este projeto???!!!

4.3 Power electronics

Escolha da topologia do conversor dc-dc. Justificar a escolha. APENAS SE JÁ TIVER SIDO FEITA A ESCOLHA!!!

4.4 Microcontroller

Escolha do microcontrolador. Justificar a escolha. APENAS SE JÁ TIVER SIDO FEITA A ESCOLHA!!!

4.5 Communication and sensors

Quais os sensores e meios de comunicação que serão usados no projeto. Justificar as escolhas. APENAS SE JÁ TIVER SIDO FEITA A ESCOLHA!!!

5 Preliminary Work

5.1 Mostrar simulações já feitas

6 Planning and Scheduling

Fazer um planeamento com um gantt chart e explicar as decisoes

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A Appendix Name