



**UNIVERSIDAD PONTIFICIA COMILLAS**  
ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)  
INDUSTRIAL ENGINEER

**INDUSTRIAL ENGINEER MII**

# System Identification and control of MPPT DC-DC converters.

Author: Nuria Santiso Serrano      Director: Dr Fazil Najafi

Coordinator: Tomás Gómez San Román

Madrid July 2019



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Madrid, a 1 de mayo de 2017

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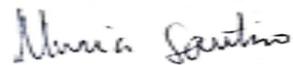
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System Identification and control of MPPT DC-DC Converters  
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Fdo.: Nuria Santiso Serrano

Fecha: 02/07/2019



Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Dr Fazil Najafi

Fecha: 02/07/2019





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## SYSTEM IDENTIFICATION AND CONTROL OF MPPT DC-DC CONVERTERS.

**Autor: Santiso Serrano, Nuria.**

Director: Najafi, Fazil.

Entidad Colaboradora: ICAI – Universidad Pontificia Comillas.

### RESUMEN DEL PROYECTO

En los últimos años, los progresos tecnológicos han proliferado con un crecimiento exponencial; y no va a ser menos el mercado automovilístico.

En las últimas décadas se ha hecho cada vez más palpable el impacto de las emisiones de gases de vehículos convencionales que funcionan con motores de gasolina o diésel. Día a día se buscan soluciones innovadoras que sean respetuosas con el medioambiente y sigan cubriendo las necesidades de transporte por tierra.

Solar Gators es una organización de estudiantes que se ha propuesto desarrollar un vehículo que funciona con un motor eléctrico y que se energiza con la luz del sol recogida por paneles solares situados en la superficie de éste. El equipo presentará el vehículo a la competición universitaria Formula Grand Prix, donde competirá contra otros vehículos solares.

### METODOLOGÍA

Este proyecto pretende desarrollar la parte eléctrica del automóvil, centrándose en el MPPT (Maximum Power Point Tracker), dispositivo que tratará de optimizar el flujo de energía desde los paneles solares hacia las baterías, que alimentarán, entre otros dispositivos, los motores. Los motores serán el punto central del sistema, que será dimensionado en torno a éste.

A partir de las características de motor se podrá dimensionar los demás elementos del sistema, es decir, disposición de paneles solares y baterías, así como de la programación del MPPT.



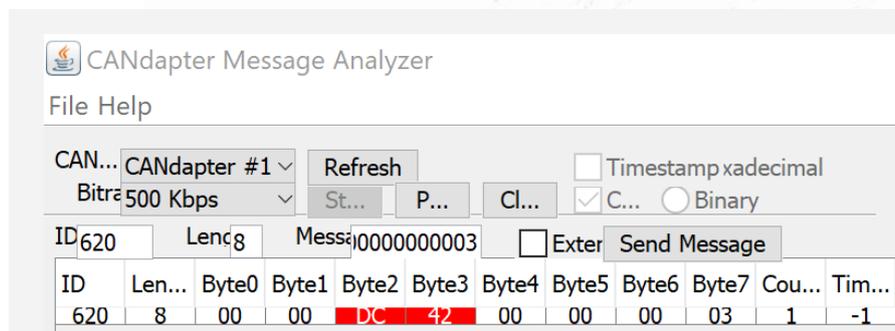
Se estima que, si las baterías se conectaran directamente a los paneles solares, las baterías usarían únicamente un 31% de su capacidad. Se estima que con un MPPT esta eficiencia podría rondar fácilmente el 90%.

## RESULTADOS

Los MPPT utilizados finalmente son los Photon 1, dos de ellos irán instalados sobre la estructura del coche, mientras que un tercero se empleará para cargar otro módulo de baterías adicionales, con unos paneles solares que van fuera del coche y dotarán de una mayor autonomía al vehículo durante la competición.

La configuración del MPPT se realiza con una interfaz GUI, donde se usará un programador PICKit3 y el micro dsPIC33FJ4GS606. El sistema eléctrico del vehículo se comunica por telemetría utilizando un bus CAN a 500Kbps. Por esta razón, el firmware se configura conforme estos parámetros mediante la instalación del MPLAB y siguiendo los pasos indicados en la sección 2.5.1.

Mediante la interfaz del MPPT Photon 1 CANdapter Message Analyzer, se ajustaron los parámetros necesarios. La comunicación con los MPPTs se realizó utilizando el protocolo de mensajes CAN en little indian.



Captura de pantalla del CANdapter Message Analyzer.

La comunicación con el MPPT es bidireccional, es decir, se permite tanto la lectura como la escritura de mensajes.



Mediante la lectura de los mensajes en CAN se comprobó que la configuración por defecto fuera correcta.

Se modificaron parámetros de tensión máxima en el MPPT mediante tareas de escritura en CAN.

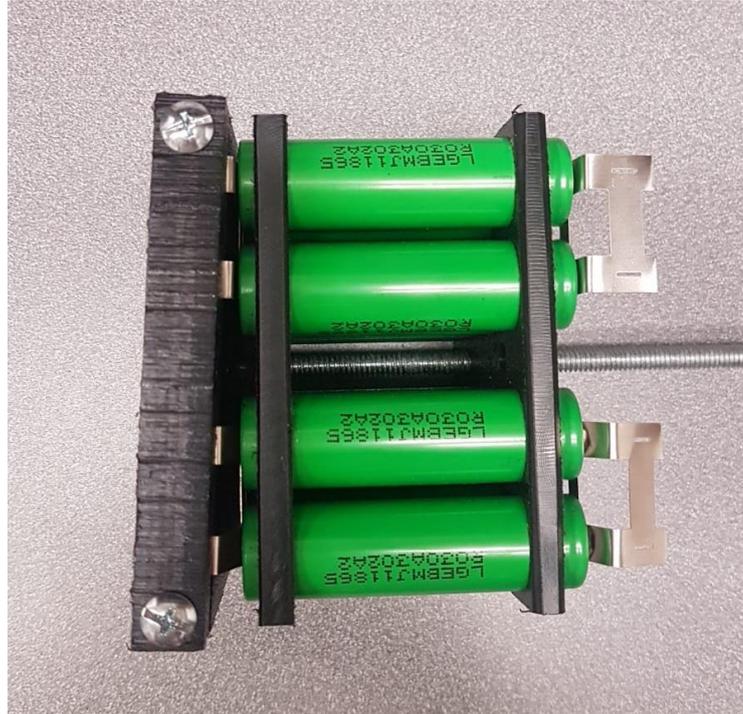
La configuración inicial establece el valor de tensión máxima por defecto en 99V, sin embargo teóricamente la tensión máxima debe ajustarse a 110V, dado que la configuración inicial de baterías es de 26 en serie con 4,2 V de tensión máxima en carga. Concretamente, este parámetro se denomina “constOutputVoltage”.

Finalmente, el MPPT ha terminado siendo configurado a 105V por seguridad y restricciones del Battery Management Department, quienes han variado la configuración de las baterías a 24 celdas en serie y 16 en paralelo. El parámetro “maxOutputVoltage” también se ha modificado de 100V a 106 V.

La configuración de las baterías se ha calculado teóricamente usando los parámetros de la hoja de características, que definieron la tensión nominal de 3,7 V y la máxima tensión en 4,2V. Dado que los motores son de 96V, dividiendo  $96 \text{ V} / 3,7 \text{ V}$  se define el número de celdas en serie teóricas, 25,9 o 26 redondeando.

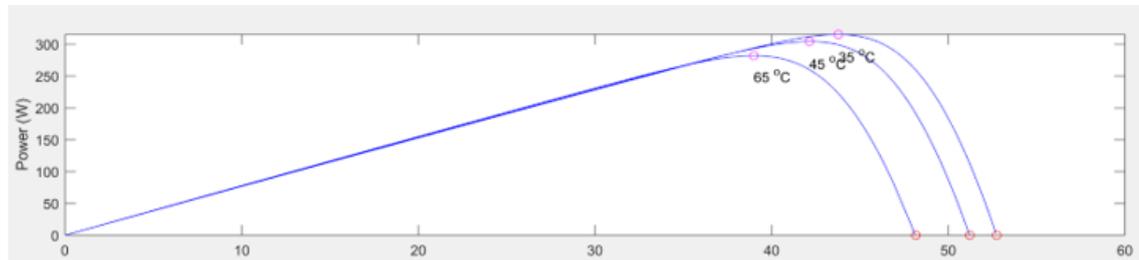
Por otro lado, el reglamento de la competición limita el peso máximo de las baterías, limitando a 430 unidades el número de baterías dentro el vehículo. Una simple división del total de baterías entre 26, determina las 16 baterías en paralelo. Esta configuración cumple con los parámetros de corriente máxima del motor.

Las baterías han sido soldadas en el laboratorio con láminas y ejes metálicos que ayudaron a obtener módulos rígidos y manejables.



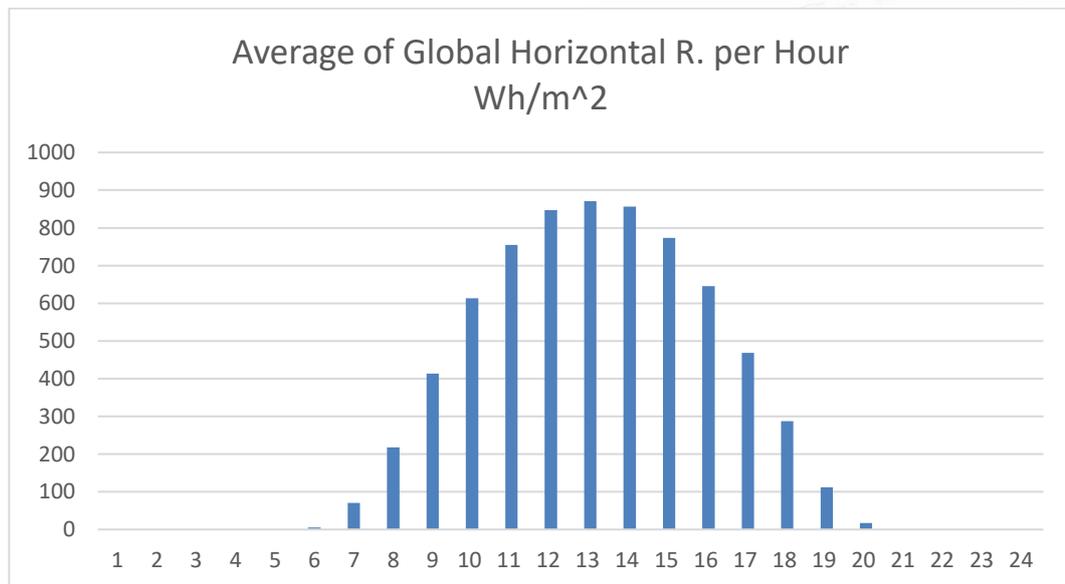
*Vista lateral de un módulo de 16 baterías en paralelo.*

Por otro lado, la configuración de los paneles solares se definió como 81 celdas en serie, debido a la limitación de superficie habilitable para instalar paneles solares de 162 paneles. El ajuste de tensión con el MPPT hizo la configuración de paneles solares compatible con los 96 V de los motores. El módulo externo al vehículo ha sido diseñado igual que los otros dos módulos localizados en el coche. Éste servirá para ayudar a cargar el coche en los periodos de descanso de la carrera. En el apartado del estudio de eficiencia, se plantea una posible mejora de eficiencia energética controlando la temperatura de las celdas solares. Se observa que a menor temperatura de los paneles solares, se aumenta la potencia útil. La mejora es muy notable, dado que un incremento de temperatura de 30 grados (De 35 a 65°C ) supone una pérdida de unos 35 W.



Curvas de potencia a diferentes temperaturas de las celdas solares.

Por otro lado, el estudio de irradiación solar en Austin determinó una insolación media de radiación horizontal en el mes de julio de 6,56 KWh/m<sup>2</sup>/día. El estudio realizado con cinco años de datos, estableció el rango de horas con mayor radiación global horizontal en julio, entre las 11 de la mañana y las 3 de la tarde, tal y como se esperaba, en las horas centrales del día. Se alcanzaron máximos de hasta 880 Wh/m<sup>2</sup> de radiación global horizontal. El estudio se centro en julio, dado que la carrera se desarrolla en ese mes. La alta variabilidad de los datos dada su naturaleza estocástica dificulta en gran medida la planificación.



Media horaria de la radiación global horizontal por metro cuadrado en Julio, en Austin.



El test realizado en el laboratorio con 40 celdas solares en serie, 4 baterías de 12 Voltios cada una y el MPPT Photon 1 determinó la importancia de limitar la corriente con resistencias pequeñas (de unos 8 ohmios) , en el transitorio inicial, para evitar quemar los fusibles de las baterías.

El test determinó una eficiencia del MPPT del 90,2% y un procedimiento seguro para controlar el encendido y apagado del MPPT en el sistema.



## SYSTEM IDENTIFICATION AND CONTROL OF MPPT DC-DC CONVERTERS.

**Author: Santiso Serrano, Nuria.**

Director: Najafi, Fazil.

Colaborating Entity: ICAI – Universidad Pontificia Comillas.

### **ABSTRACT OF THE PROJECT**

In recent years, technological progress has proliferated with exponential growth; and it has worked the same way within the car market.

In recent decades, the impact of gas emissions from conventional gasoline or diesel-powered vehicles has become increasingly palpable. There is an every-day-search for innovative and environmental-friendly solutions that meet the needs of ground transportation.

Solar Gators is a student organization that develops an electric vehicle energized with the sunlight collected by solar panels located on its surface. The team will present the vehicle to the University Competition “Formula Grand Prix”, where it will compete against other solar vehicles.

#### **METHODOLOGY**

This project aims to develop the electrical subsystem of the car, focusing on the MPPT (Maximum Power Point Tracker), a device that will try to optimize the flow of energy from the solar panels to the batteries. The batteries will power, among other devices, the engines. The engines will be the central point of the system, which will be sized around it.

The engine defines the voltage and current limits for the solar panels and batteries sizing and the MPPT programming.

It is estimated that if the batteries were connected directly to the solar panels, the batteries would use only 31% of their capacity. It is estimated that with an MPPT the energy efficiency could reach around a 90% efficiency.

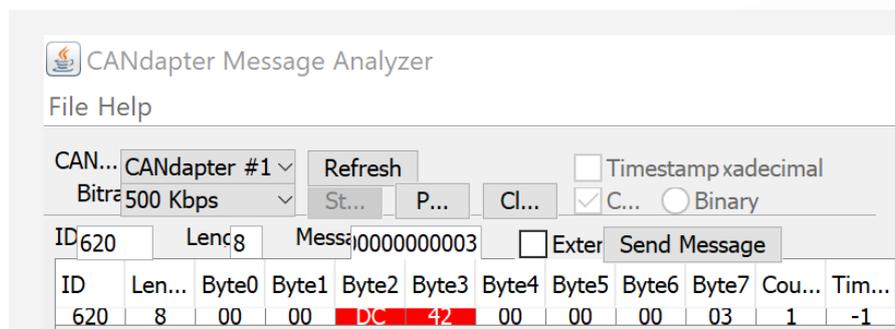


## RESULTS

The MPPT finally used are the Photon 1. Two of them will be placed in the car, and a third one will be used to charge another module of additional batteries, with solar panels that will be laid out of the car and will increase the vehicle's autonomy during the competition.

The MPPT configuration is done through a GUI interface. A PICKit3 programmer and the dsPIC33FJ4GS606 micro have been used to enable the configuration. The vehicle's electrical system communicates by telemetry using a 500Kbps CAN bus. For this reason, the firmware is configured according to these parameters using the MPLAB software and following the steps in section 2.5.1. of this report.

The Photon 1 CANdapter Message Analyzer interface was used to adjust all the required parameters. All the communications with the MPPT were done through CAN messaging, in little Indian.



*Screenshot of the CANdapter Message Analyzer.*

The MPPT works with a two-way communication, reading and writing.

Using the CANdapter interface, the default configuration was checked (reading CAN messages).

Some parameters regarding the maximum voltage were changed (writing CAN messages).

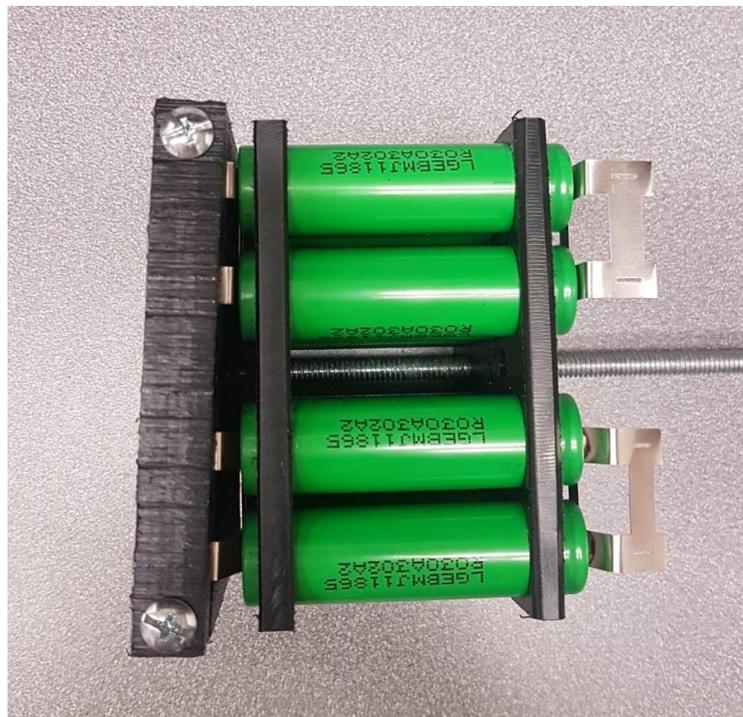
The initial default configuration set the constant maximum value to 99V. this value was theoretically required to be adapted to 110 V, since the initial battery



configuration is 26 in series of 4.2 V of maximum voltage at load. The name of this parameter is "constOutputVoltage", and has finally been set to 105V for safety reasons and restrictions of the Battery Management Department, who have varied the configuration of the batteries to 24 cells in series and 16 in parallel. The "maxOutputVoltage" parameter has also been changed from 100V to 106 V for the same reasons.

The battery configuration was theoretically calculated using the data sheet parameters, which defined the nominal voltage as 3.7 V and the maximum voltage as 4.2V. As the motors are 96V of nominal voltage, an easy division of  $96 \text{ V} / 3.7 \text{ V}$  gives the number of theoretical serial cells for the system, which is 25.9 or, rounded up to 26. On the other hand, the regulations of the competition limit the maximum weight for all the batteries, limiting to 430 units the number of batteries inside the vehicle. A simple division of the total number of batteries by 26 determines the 16 batteries in parallel.

Batteries have been welded in the lab with metal sheets and shafts that make the modules rigid and easy to manipulate.

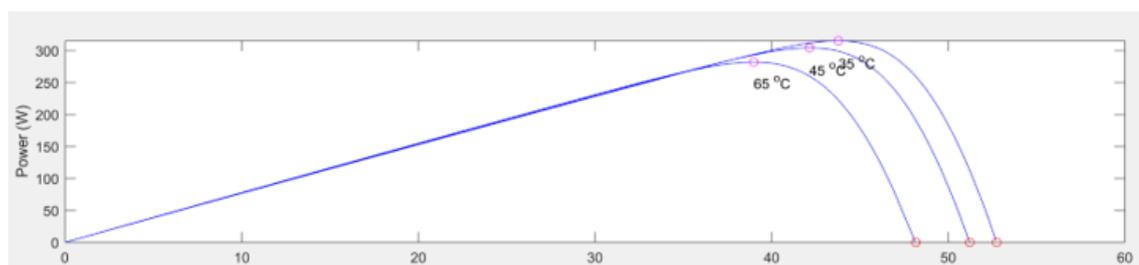


*Side view of a module of 16 batteries in parallel.*



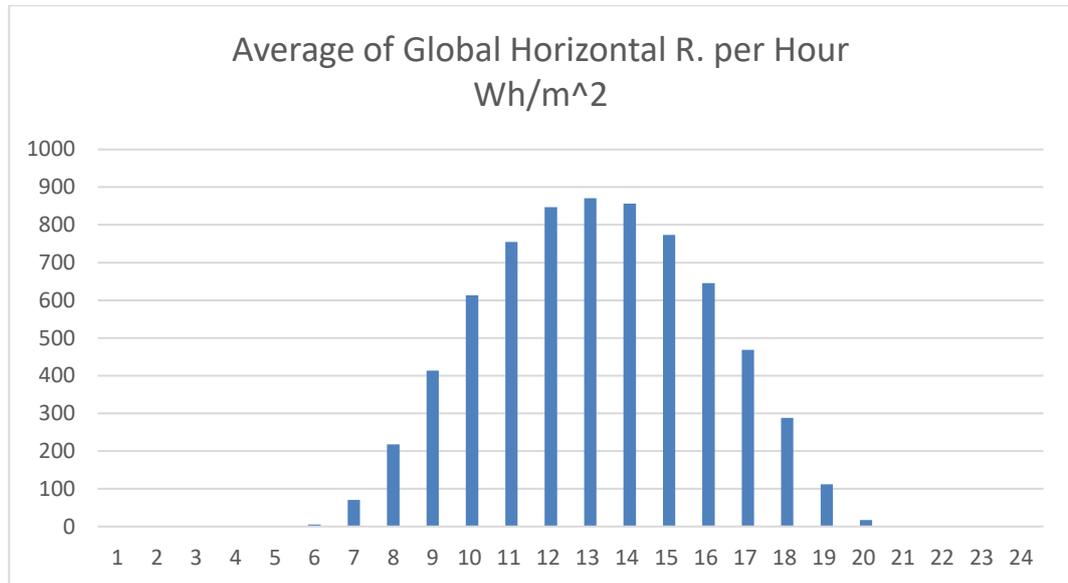
On the other hand, the configuration of the solar panels was defined as 81 cells in series, due to the surface area limitation of 162 cells. The MPPT voltage adjustment will make the voltage of the solar cells compatible with the 96 of the motors. The module external to the vehicle has been designed just like the other two modules located in the car. It will help provide extra energy to the car during the breaks of the race.

Regarding the efficiency study section, there is a possible energy efficiency improvement by controlling the temperature of the solar cells. It has been observed that the lower the temperature of the solar panels, the more useful power is obtained. The improvement is slightly noticeable, since a temperature increase of 30 degrees (from 35 to 65°C) represents a loss of about 35 W.



*Power curves at different temperatures of solar panels.*

Moreover, the solar irradiation study in Austin determined an average of 6.56 KWh/m<sup>2</sup>/day of horizontal irradiance for the month of July. The five-year data study defines the range of hours with the highest global horizontal radiation in July, between 11 a.m. and 3 p.m. These results confirm that the central hours of the day account for the most important irradiation. The maximum horizontal radiation peak was reached at 880 Wh/m<sup>2</sup>. The study is focused in July, as the race takes place in that month. It can be concluded from the irradiation study that there is a high data variability due to its stochastic nature.



*Hourly average of the Global Horizontal Irradiance per square meter 1 July, in Austin.*

In addition, in the laboratory test 40 solar cells in series, the Photon 1 MPPT and four 12-volt batteries, determined the importance of limiting the current with small resistors, of 8 ohms, (specially at the initial transient response) to avoid burning the fuses of the batteries.

The test determined a 90.2% MPPT efficiency and defined a safe procedure to turn on and off the MPPT.



This Project discusses about the identification and control of the MPPT DC-DC controller in a solar car.

It contains the following documents:

A. General index of the documents in the project:

1. Report
2. Schematics
3. Budget

B. Document index

**REPORT**

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- 1.2 Objectives
- 1.3 Research and Approach Methodology
- 1.4 Problem Statement

1.4.1 Electric Cars

Chapter 2 Project development

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- 2.2 State of the art
- 2.3 Electrical system overview
- 2.4 MPPT Overview
  - 2.4.1 MPPT Definition
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- 1.4 Competition and travel expenses



## INDUSTRIAL ENGINEER MII

# System Identification and control of MPPT DC-DC converters.

### REPORT

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Madrid July 2019



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***PART 1. REPORT***



## **1. CHAPTER 1 INTRODUCTION**

This report is structured in introduction, development, results and conclusions. Then, it is followed by all the datasheets, schematics and other internal documents used in the development of the project. The last section of the thesis includes the financial report with the costs for the vehicle's production.

On the other hand, this chapter of the report gives an overview of the purpose of the project, methodologies and motivation to its development. The execution of this project is not only a learning experience, but also a compelling experience where team work will also be involved in order to yield the best results in the race.



## ***1.1 MOTIVATION***

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As a graduate industrial engineering student, I have been interested in solar energies since I took a subject related to electricity production back in my junior year of major, called Electrical machinery. I enjoyed the lab practices so much and felt motivated to continue my path towards electrical engineering, which is one of the three main areas of my degree.

In order to fulfil my thirst for learning within the electricity area, I joined a group in the university, where sustainable engineering projects in Africa are conducted. I was assigned to a project where we had to provide electricity for a school in Meki, Ethiopia. I designed the entire stand-alone PV system that will be implemented when we find the required funding.

I enjoyed the project not only for the expertise it provided me within the electricity area but for the sake of helping people with lacking resources.

In fact, solar energies blend in two of my main passions.

I really enjoy working in the electrical sector and I really love the way renewables are respectful with the environment. After all, the world is our home and we are the ones responsible to take care of it.



## ***1.2 OBJECTIVES***

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The research and development of electric cars seems like the path for progress for the next few years. However, car batteries still require power from the electricity grid to obtain energy.

The power grid is fed with the energy produced in different power plants. Some of them use conventional sources of energy and some others renewable sources of energy.

Renewable energies are clean and environmentally friendly ways to produce energy. They come from renewable resources, which are naturally replenished on a human timescale, such as sunlight, wind, rain, tides, waves, and geothermal heat. In 2015, according to REN21's 2017 report, renewables contributed 19.3% to humans' global energy consumption and 24.5% to their generation of electricity.

First world countries are very focused on developing renewable sources of energies. One of the primary goals currently being targeted is the development of a battery fully charged by renewable energies. A battery that with future advancements would reach full autonomy, working as a standalone system.

Indeed, there is a growing interest over the implementation of solar cells on the car's surface in order to power the car with the biggest autonomy possible.

This dissertation aims to explain the development process of the electrical area of the solar vehicle designed by the Solar Gators team, precisely the module that connects solar panels and batteries and considering the engine's characteristics for the design.



In fact, this seems to be a hot topic for the near future, as renewable energies and, in particular, solar energies, have a growing interest for the industry of electric cars, especially in areas with high irradiance. The development of new solar cells materials that yield higher efficiencies as well as the research for cheaper and more efficient batteries to store energy, are key points for the years to come, especially in the development of electric cars.

### ***1.3 RESEARCH APPROACH AND METHODOLOGY***

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The main goal of this project is the development of the MPPT subsystem of a solar car that will be competing in the Formula Grand Prix competition, in July 2019, in Austin, Texas. The purpose of the race is to achieve the highest autonomy for the vehicle, for this reason, it is very important optimize the energy flowing from the solar cells to the battery, fulfilling all the race requirements and rules.

The research approach will follow the next steps:

1. Research over the MPPT method. Understand how it works, its main basis and the parameters considered in its development.
2. Research the irradiation characteristics at the race location, analyzing direct and diffuse radiations, implications of which for the car's efficiency and ways to optimize the vehicle's performance.
3. Define the motors used in the race and design the electrical system around them, sizing the different components.
4. Decide the batteries and solar cells layout, the number of MPPTs, decide the MPPT desired configuration and other general parameters for the electrical department.
5. Program the required changes in the MPPT and do lab tests to try the devices.



The final implementation in the car will be done later but will not be included in these paper due to time constraints. However, that will be the easiest step in the whole development process.

Steps	Description	Time frame
1	Research	January
2	Irradiation characteristics and possible optimization methods	February
3	Components' sizing and selection	March
4	Batteries and solar cells layout	April 1st to 15th
5	Programming and testing	April 16th to May 10th

*Table 1. Steps of the thesis research.*

## ***1.4 PROBLEM STATEMENT***

---

Technological progress is a key factor in the new era. It has eradicated diseases, helped increase life expectancy, reduced starvation and extreme poverty, enabled



globalization through communications technologies development and made this generation the wealthiest one in human history.

However, an irresponsible misuse of technologies has led to the destruction of natural resources on a mass scale. Technologies can be used to either create positive value or destroy the environment.

As the world evolves, there is a clear trend towards an increase of energy consumption. This leads to a sustainability problem that is increasingly concerning. Unfortunately, some ways of energy production and distribution produce a high impact on the environment. These practices either release harmful chemicals that contribute to the Greenhouse effect or use limited sources of energy that will eventually be eradicated in the future.

The following image shows the increasing trend of energy demand with empiric data.

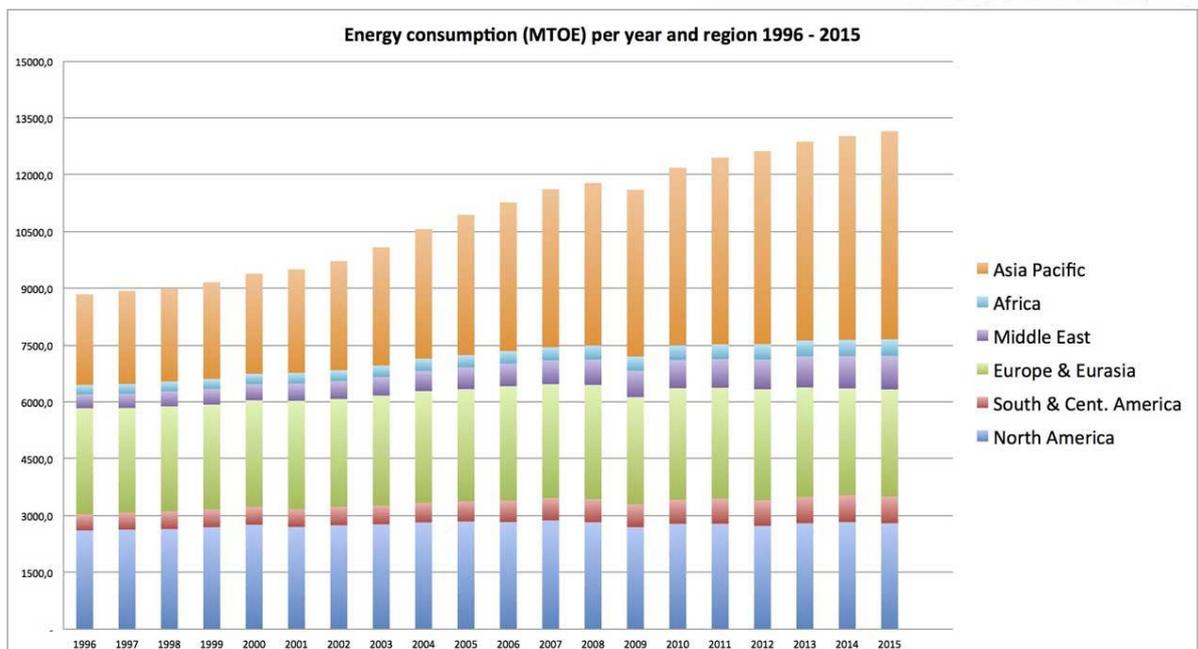


Figure 1. Increased energy demand. Source: [https://energyfaculty.com/wp-content/uploads/2016/10/Energy\\_consumption\\_year\\_region.jpg](https://energyfaculty.com/wp-content/uploads/2016/10/Energy_consumption_year_region.jpg)



The ozone shield is a region of Earth's stratosphere that absorbs most of the ultraviolet radiation (97-99%).

The ozone layer thinning is mainly caused by the chemical reactions triggered by the combination of the CO<sub>2</sub> and other gases with ozone O<sub>3</sub>, that transform the ozone into oxygen and other components. The CO<sub>2</sub> released in the atmosphere also creates a layer that blocks the IR radiation from escaping into the outer space.

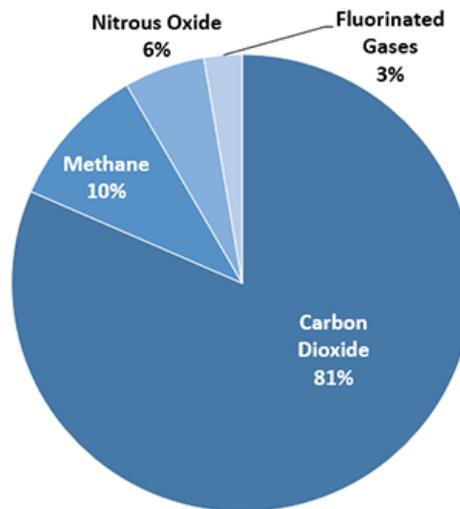
The net impact of these two effects, is the gradual heating of the earth's atmosphere and surface, process commonly known as global warming.

The greenhouse effect is expected to cause climate change, a rise in sea levels, increase of ocean acidification, extreme weather events, in addition to other severe natural and societal effects.

The Greenhouse effect is mainly caused by CO<sub>2</sub> emissions, although there are other gasses that, despite being released in smaller quantities, also make a negative impact in the environment. This is the case for methane, nitrous oxide or fluorinated gases.



### Overview of Greenhouse Gas Emissions in 2016



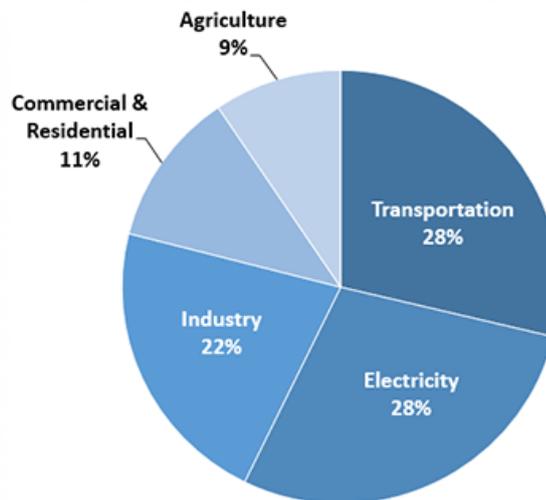
U.S. Environmental Protection Agency (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016

Figure 2. Overview of the greenhouse gas emissions in the USA.

Basing the focus of the study on the United States of America, electricity, industry and transportation are the three main sources of greenhouse gas emissions. As it is shown in the next graph, 28% of greenhouse gas in the United States is produced by the transportation sector.



### Sources of Greenhouse Gas Emissions in 2016



U.S. Environmental Protection Agency (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2016

Figure 3. Percentages of gas emissions in each economic sector in the USA. Source: <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

In fact, transportation is a main issue in terms of energy consumption, as most of the vehicles burn fossil fuels to run their engines. Therefore, it is important to find a sustainable way to power the automotive sector, using renewable sources of energy.

It is commonly believed that electric cars are the future of the vehicle industry. For this reason, the next section will explain some of its characteristics, advantages and disadvantages.

#### ***1.4.1 ELECTRIC CARS***

An electric car is a vehicle driven by one or more electric motors that use the electrical energy stored in rechargeable batteries and transforms it into kinetics. This energy is stored in rechargeable systems, known as batteries, which will



provide the energy stored to the engines, when required. The most advanced technology nowadays in electric vehicles is that of lithium-ion batteries

Electric cars are not a modern invention. In fact, they existed before diesel and petrol vehicles. In the 19<sup>th</sup> century, between 1832 and 1839, Robert Anderson, a Scottish inventor, created the first pure electric vehicle. Parallely, around 1835, Professor Sibrandus Stratingh of Groningen patented and built small-scale electric vehicles.

France and the United Kingdom were the pioneer countries in promoting the widespread development of electric vehicles. Unfortunately, they were not very successful at the time, due to its maximum speed limitation of km/h. These vehicles were mainly owned by the upper classes and women.

Electric cars have a long set of advantages, some of them will be described in the next paragraph.

Advantages of standard electric cars over conventional cars:

Electric engines are more compact, lighter and simpler than conventional internal combustion engines. They do not burn any fuel; therefore, a refrigerating system nor oil are required.

They power the system from 0 rpm, instantly providing momentum.

Reuse of the power from the braking to recharge the batteries (in these cases the electric engine works as an electric generator, recovering some of the kinetic energy).

Electric motors are very low maintenance due to their mechanical simplicity. An average electric vehicle. Electrical vehicles have between 6 and 12 moving pieces, whereas conventional engines have around 100 pieces, having a higher breakage chance. An average electric car can save up to 35% of maintenance costs over conventional vehicles.

Independency on crude oil imports.



As daily journeys are usually (in 90% of the cases) less than 60Km, the maximum autonomy of 150 Km is enough for an average driver.

Speed is not a constraint for electric vehicles, as standard electric vehicles such as iOn model from Peugeot company, can reach a maximum speed of 130 Km/h or 81mph and a maximum power of 47 KW, and therefore can be driven even at highways.

Electric engines are more efficient than gasoline engines, as they convert from 59% to 62% of electric energy into useful energy, whereas conventional gasoline motors yield a 21% of useful energy.

These engines are environmentally friendlier than conventional motors, producing much less emissions than conventional motors. In addition, electrical motors are silent.

The car battery can be charged within 30 minutes and 8 hours depending on the fast, semi-fast or slow recharging mode.

Batteries do not require to be fully charged, nor be fully discharged, as they do not have a memory effect.

It is commonly believed that the future of cars (in countries with high solar irradiation rates) leans towards electric cars that are charged with renewable sources of energy, such as solar photovoltaic cells. In addition, the future of charging methods points at induction recharge, which is a charge method currently under development, where cables are not required.

Induction charging is based on electromagnetic induction; it is an easy and user-convenient way of charging the vehicle without the driver leaving the car. A step ahead towards progress is recharge process in motion, which would involve creating concrete streets in which electric car could receive energy along them.

There are two main types of electrical motors, direct and alternate current motors.



DC or direct current engines are the most common and traditionally used engines. Despite reaching high maximum speed rates and being more economical than DC motors, their acceleration performance is poorer.

Many electric cars in the current electrical vehicle market, such as Tesla and Nissan use DC engines. Despite being more expensive than AC engine cars, they yield faster accelerations and are compatible with regenerative braking systems, where the vehicle's impulse is used to recharge the batteries.

In order to reduce the carbon footprint, electric cars are currently being developed and launched to the vehicle market. Although they have less autonomy than conventional vehicles, they are environmentally friendly and contribute to reduce the pollution in the atmosphere.

Crude oil and petroleum products account for one third of gross inland energy consumption in the European Union (EU). Most of this demand comes from the transport sector, particularly from road transport.

By 2014, 88% of crude oil supply in Europe was imported. Therefore, substituting conventional cars with electrical cars will reduce drastically the oil imports, making a great and positive impact on the EU economy.

The European trend can also be paralleled to the US. The next graph shows the growing tendency of worldwide car stocks.



Figure 1 • Evolution of the global electric car stock, 2010-16

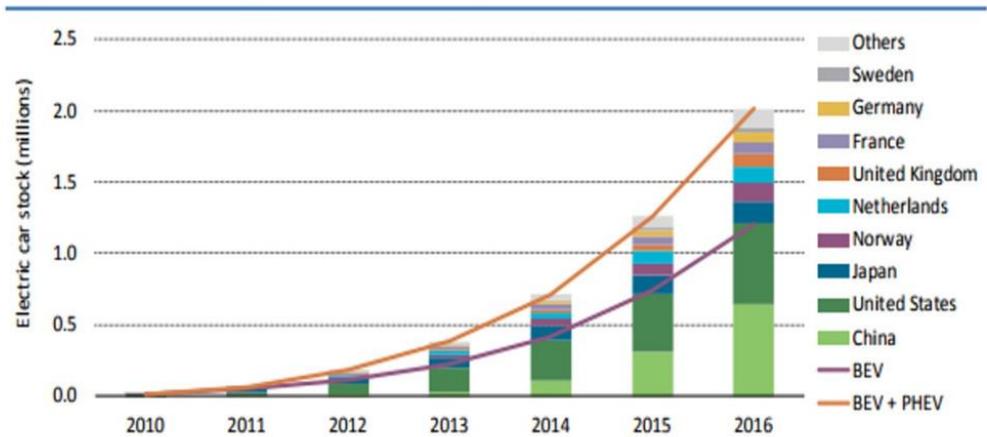


Figure 4. Electric car stock evolution. <https://evautocars.files.wordpress.com/2017/09/graph-1.jpg?w=1108>

The growing interest over the development of electrical cars is a fact. Not only from an economical perspective, but also from an environmental perspective.



## **2. CHAPTER 2 PROJECT DEVELOPMENT**



## ***2.1 INTRODUCTION***

---

---

This chapter is an overview of the state of art of the project, the electrical system and the MPPT. It starts with the description of other university student races where solar cars compete. Then it tilts towards a more technical field and describes the whole electrical system, showing schematics and diagrams. Once the global system is explained, there is a general description of the MPPT general functioning, its algorithms, configuration and programming to adjust the required parameters.

## ***2.2 STATE OF THE ART***

---

There are already prototypes of vehicles that combine an aerodynamic design and high-end, lightweight materials such as carbon and aluminum, that reach a very energy efficient design.

For instance, the Eindhoven student team, a group of students from the Eindhoven University of Technology (TU/e) developed a solar-powered car to compete at the Bridgestone World Solar Challenge in Australia on 18 October 2015. This competition consists of a 3,000km race for solar-powered cars. The trajectory goes right through the heart of the outback from Darwin to Adelaide.

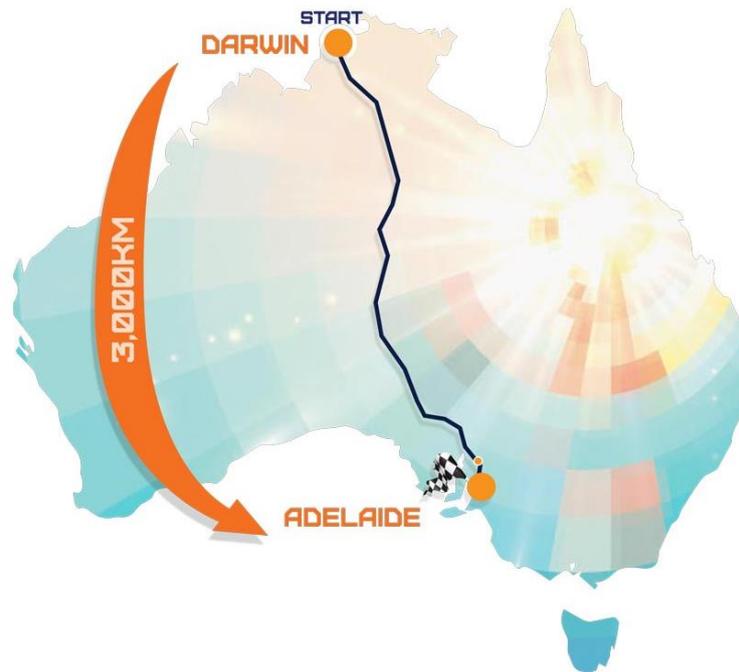


Figure 5. The traditional Bridgestone World Solar Challenge route.

For instance, Stella Lux, name of the car designed by a Dutch team, can reach a range of 1,000 km on a sunny day in the Netherlands. Overall, Stella Lux generates more energy than it consumes, which makes it energy positive. Excess energy may be returned to the power grid, making an important energy contribution for society requirements

Although major research must be conducted towards the improve of solar cells' and batteries' efficiencies, this seems to be the right path for progress. Especially in areas with high solar irradiation, such as California and Florida in the USA or southern European countries, such as Spain, Italy and Greece.

Indeed, this competition encourages engineers from all over the world to do research and improve energy efficiencies. The improvement made throughout the past few years, makes it seem realistic to find a feasible solution for commercial development.



Figure 6. Formula Sun Grand Prix logo

There are competitions with a similar theme, that take place in the USA, such as the Formula Sun Grand Prix (FSGP). FSGP is an annual solar-car race that takes place each year at a different location. In July 2019 it will be held in Austin, Texas on closed loop race tracks. The race dynamics is based on a three-day race, where the team whose car drives the most laps wins. In this race, teams from colleges and universities throughout North America design, build, test, and race solar-powered vehicles.



Figure 7. Formula Sun Grand Prix teams.

Solar Gators team is focused on designing, building and racing a solar car that will compete in the Formula Sun Grand Prix in July 2019. Solar Gators is a University



of Florida's student organization, driven by passionate student engineers and designers that aim to raise sustainability awareness amongst their peers, community and ultimately the world.



*Figure 8. Solar gators 2018 team picture.*

### ***2.3 ELECTRICAL SYSTEM OVERVIEW***

---

As previously introduced, this dissertation will describe the design process of a section of the electrical subsystem of the solar car. In particular, the connection between the solar panels and the batteries will be developed, considering the characteristics of the motors.

The whole electrical system is depicted in the next schematic.

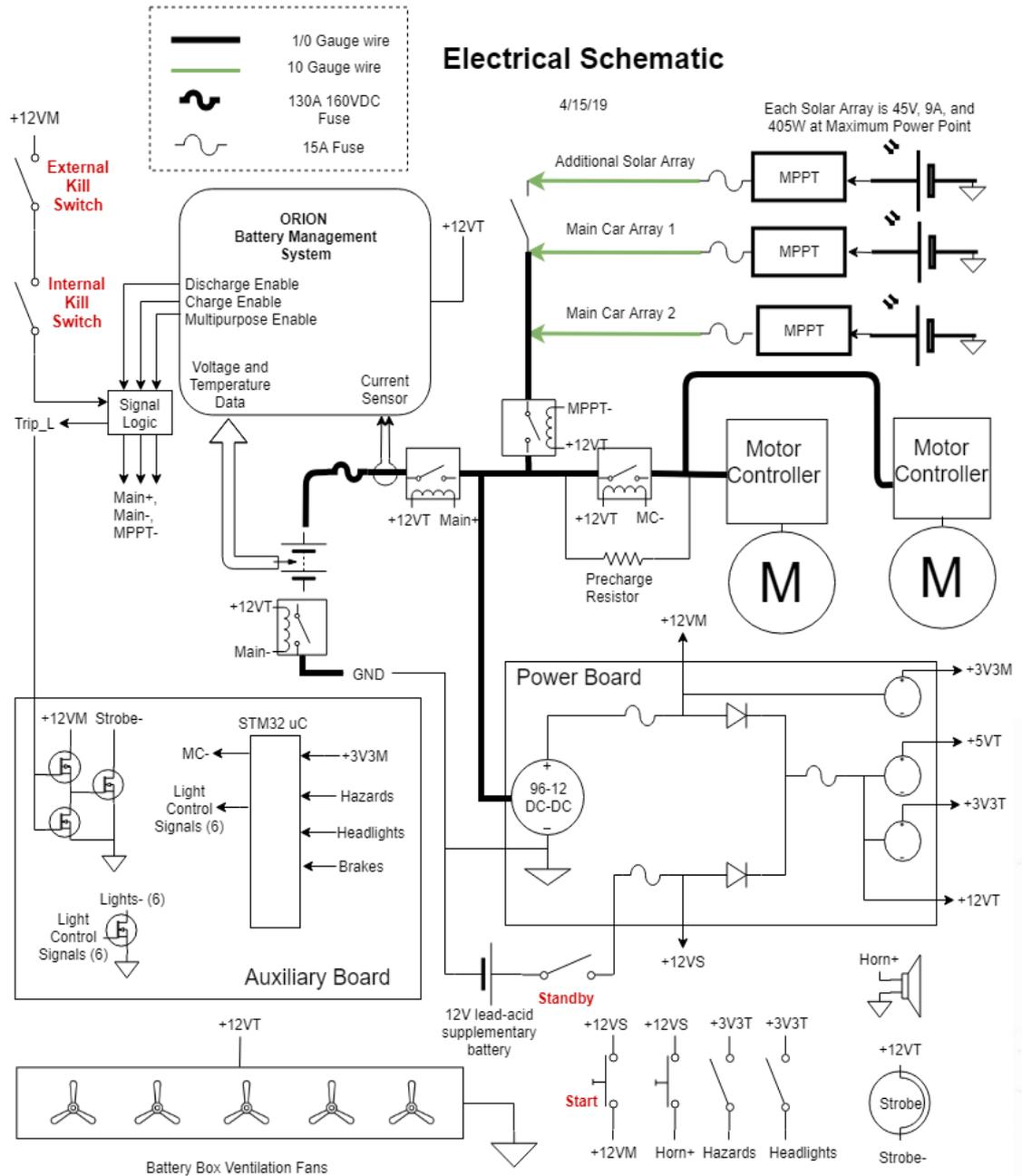


Figure 9. Electrical system schematic.

The MPPT subsystem is based on three MPPTs, two placed inside of the vehicle and an additional one that will be external to the car and will be used to charge the cars' batteries when the car is motionless. The motors are 96 Volts and will define the batteries and MPPT 's output voltage. There are three solar arrays, two of them

will be placed on the car's surface. Each array is 45 V, 9A and provides a maximum power point of 405W. The MPPTs aim to work at that maximum point, to yield the highest energy efficiency to improve the vehicle's autonomy.

The functional Block Diagram on the next image, shows a more visual overview of the vehicle's electrical subsystem.

### Functional Block Diagram

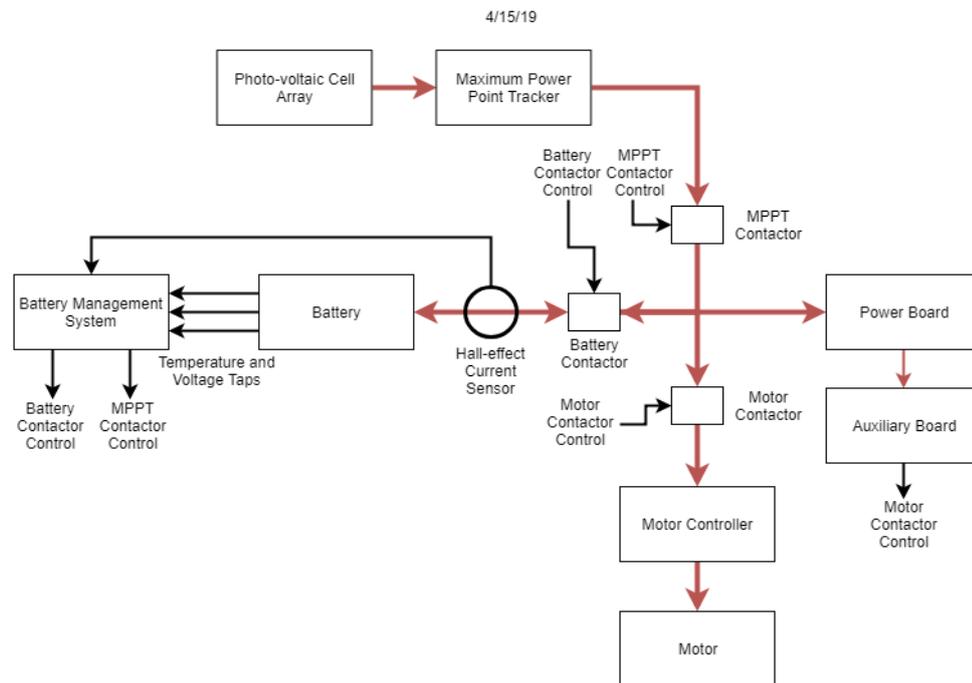


Figure 10. Functional Block Diagram.

Once the whole system has been shown, the MPPT will be described more deeply.

## 2.4 MPPT OVERVIEW

The next few lines will describe the MPPT functioning, why an MPPT is required and how the hill climbing algorithm works.

## 2.4.1 MPPT DEFINITION

The acronym MPPT stands for “Maximum Power Point Tracker”. It is a device that takes energy from solar arrays as an input and outputs a constant DC voltage, targeting the maximum energy. The output voltage is commonly used to charge batteries. Usually, a high end MPPT is close to 100% efficient (usually oscillates between 95% and 99%).

## 2.4.2 WHY DO WE NEED AN MPPT?

The main reason to use an MPPT is to improve the autonomy of the car. If the solar array were directly connected to the battery, the point of operation would not be the optimum. The Maximum Power Point is the single point that yields the highest efficiency.

In the hypothetical case the solar array was directly connected to a load, the battery would only use around 31% of its capacity.

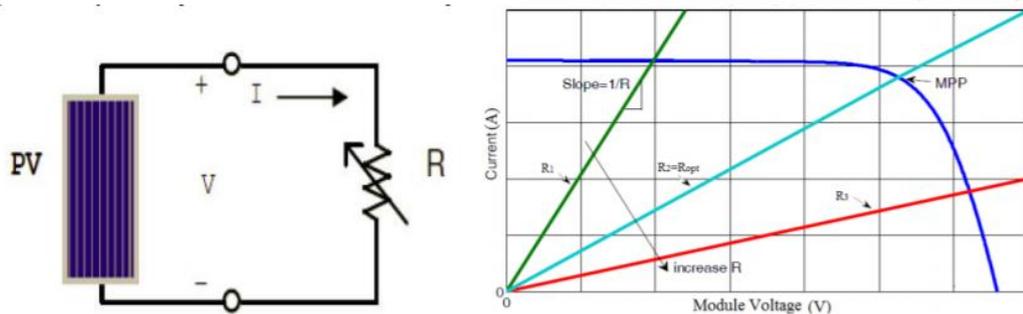


Figure 11. To the left, circuit of a PV array directly connected to a load; to the right, I-V curve of a solar panel with different loads

There is an empirical curve that shows the non-linear relationship between the current and the voltage flowing through a load directly connected to a solar panel.



This blue curve depends on the characteristics of the solar array. The intersection between the resistance linear function and the blue curve gives the operation point. The MPPT algorithm can modify the equivalent load seen by the solar cells, to make it the optimal load that would lead to the maximum power point. This point provides the maximum energy to charge the battery and therefore is the optimal point of operation.

The equivalent load can be expressed as:

$$R_{equiv} = (1 - D)^2 R_{load}$$

This explains why by changing the duty cycle of the MPPT, depending on the load resistance, which in this case will be the battery resistance, that could change depending on the moment of operation, the battery load and the battery's characteristics.

### 2.4.3 HOW DOES THE MPPT WORK?

The MPPT is composed of two main blocks; the algorithm that reaches the maximum power point and the buck and boost converter that adjusts the voltage to the one required by the battery.

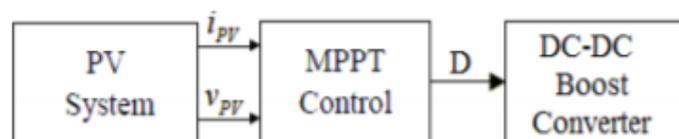


Figure 12. MPPT Block modules

The MPPT can work as a buck converter or a boost converter, depending on the final application, for instance, the battery requirements. For the configuration that will be described in this paper, the MPPT will work as a boost converter. A boost converter converts a DC input voltage into a higher value of output voltage. The gain or boost ratio is known as the output value, over the input value. It is usually seen as a black box.

The MPPT's gain is controlled with a transistor that regulates the duty cycle.

The duty cycle is the relationship between the time connecting and disconnecting the input and output modules. For instance, the transistor works at a 20% of duty cycle if the system is connected twenty percent of the time.

There is a linear relationship between the current and voltage input and output.

The current relationship can be described in terms of voltage or the duty cycle as:

$$\frac{I_{out}}{I_{in}} = \frac{V_{in}}{V_{out}} = 1 - D$$

Moreover, the equivalent circuit can be expressed as:

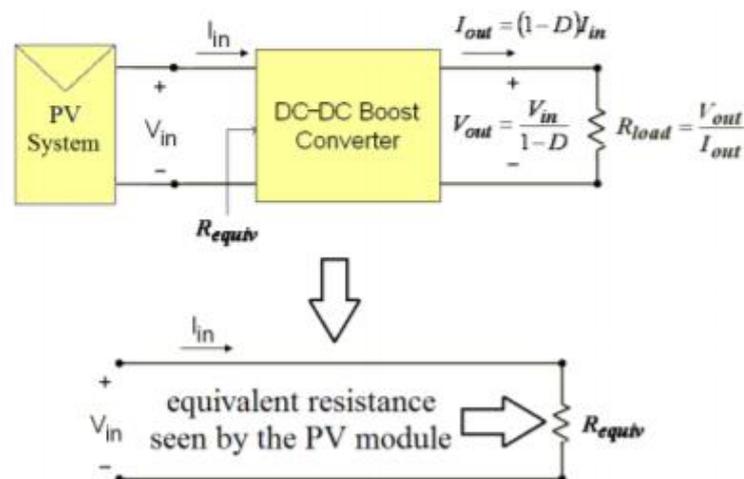


Figure 13. Equivalent circuit of an MPPT.



In the previous circuit, the DC-DC Boost converter, also known as MPPT, is pictured as a black box.

The equivalent resistance can be easily guessed and expressed as a relationship of the duty cycle and the load resistance.

$$R_{equiv} = \frac{V_{in}}{V_{out}} = (1 - D)^2 R_{load}$$

The duty cycle can also be expressed in terms of  $R_{equiv}$  and  $R_{load}$ , as follows:

$$D = 1 - \sqrt{\frac{R_{equiv}}{R_{load}}}$$

Solar cells are a certain type of diodes that follow an I-V curve characteristic and a power curve. For each type of solar cells, the MPP matches with the point where the maximum power is achieved.

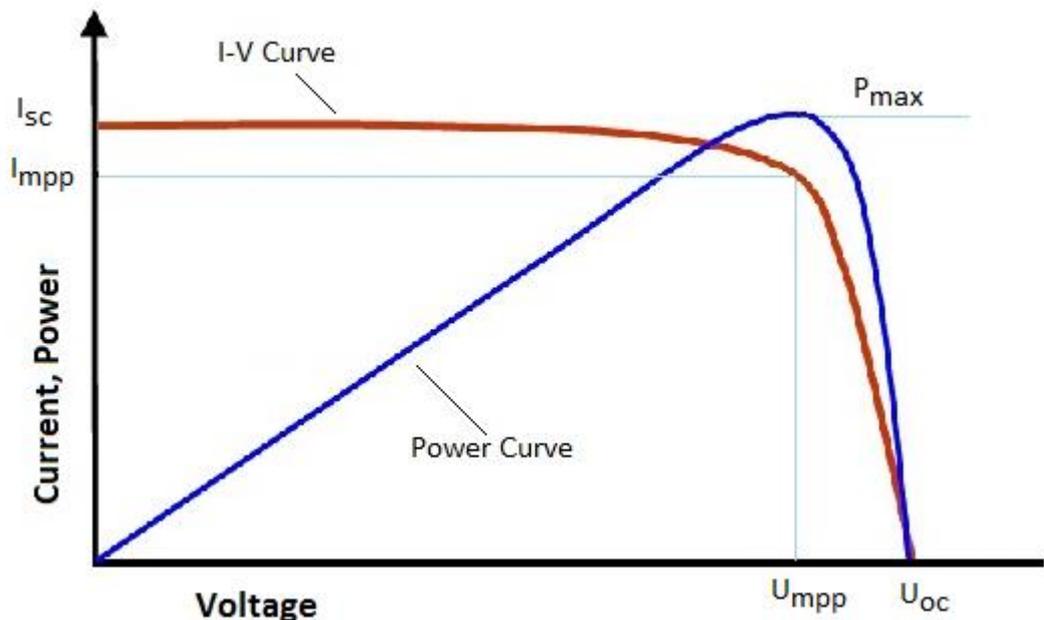


Figure 14. I-V and Power curves

To control the solar array's operating point, the gain of the boost converter must be changed real-time, using a programmed firmware that calculates the optimum point and is run by a microcontroller. Some people refer to the specific algorithm used as the "MPPT" and to the hardware as the boost converter. The feedback relationship between the two can be shown in the following diagram.

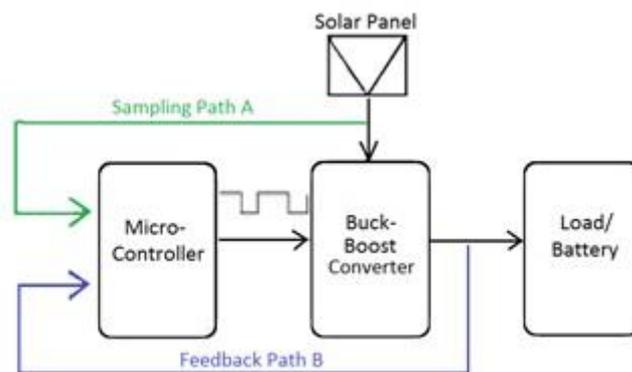


Figure 15. Double path feedback for the MPPT algorithm.

Although the hardware is important to achieve good results, a good algorithm is also required. Poor results will be obtained if a bad algorithm is used, regardless of the quality of the hardware.

There are several MPPT methods that can be used to track the MPPT successfully. One of the simplest and most effective methods that are very commonly used is the P&O or Hill Climbing Technique. This method requires low computational demand and yields good performance. This technique samples the current and voltage of the output and calculates the power. The microcontroller alters the voltage of the PV panel by a small magnitude  $\Delta V$ , resulting in a change of output power that is closer to the MPP. The control keeps continuously readjusting the voltage targeting the MPP.

When the MPP is found, if a dip in the power is experienced, a change in the opposite direction is triggered. This has an oscillatory behavior around the MPP.

P&O method is commonly known as Hill Climbing Method, as it climbs the power curve towards its maximum point.

The following table summarizes the technique:

Perturbation	Change in Power	Next Perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

Figure 16. Summarize of P&O Technique. Source: [http://www.ijirset.com/upload/2016/july/69\\_Comparison.pdf](http://www.ijirset.com/upload/2016/july/69_Comparison.pdf)

The process can also be summarized with the next flow chart.

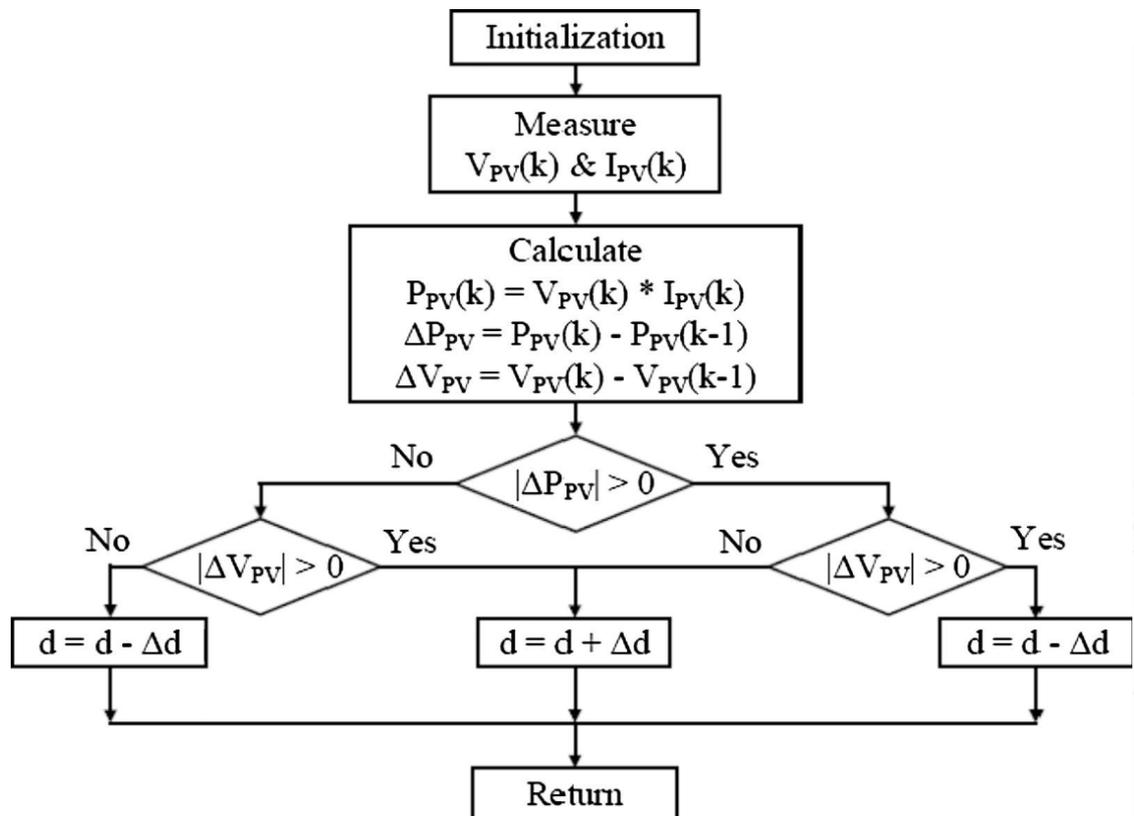


Figure 17. Flow Chart of the P&O Method.

The MPPT algorithms account for factors such as variable irradiance and temperature to achieve the best performance in terms of maximum energy efficiency. There is a direct relationship between the solar irradiance and the maximum power point that can be observed in the following curves.

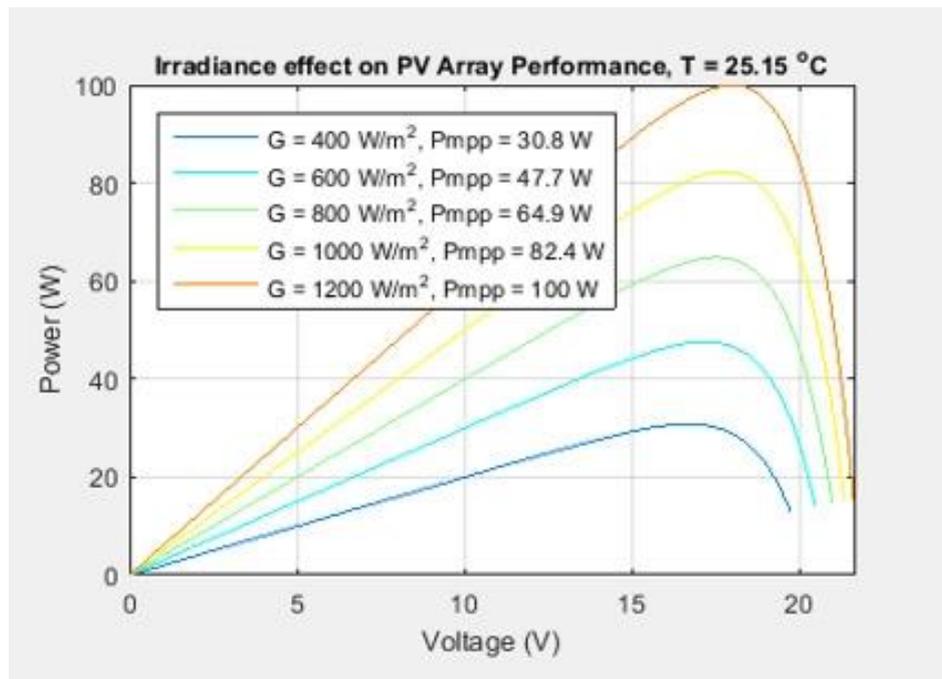


Figure 18. Power curves in terms of solar irradiance for a fix temperature.

#### 2.4.4 WHAT ARE THE GOALS FOR THIS SYSTEM?

The Solar Gators team purchased two different models of MPPTs. One was called the Racemax - Maximizer by AERL and the other one was called Photon 1's by Dilithium Power Systems. The Photon 1 was actually created by an engineer who was a scrutineer in the 2018 summer FSGP/ASC competition. Unfortunately, after some tests and deep analysis, it could be concluded that the Racemax couldn't handle the current output at MPP, so only the Photon 1's were eligible for the vehicle. The main goals for this project involve defining the parameters for the



MPPT subsystem depending on the available engines and the solar panels donated to the team. Furthermore, the MPPT setting and programming is also targeted in this project.

## ***2.5 MPPT CONFIGURATION***

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The manufacturer has a GUI user interface to configure the MPPT to its parameters. The manual for the user is in the link <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1> and will be also included in this chapter.

Although the manual uses a different programmer, the ICD2, the programmer used was the PICKit3, as that is the one physically available. Despite this small change, the other steps were strictly followed up to a successful completion of the configuration process.

The microprocessor used was the dsPIC33FJ64GS606, the same as the one used in the user guide.



Figure 19. Pick it 3.

All electrical subsystems report telemetry through a 500Kbps CAN bus, so the firmware must be set to it. The Pickit 3 is an ICSP output (In Circuit Serial Programmer) that we directly connected to the MPPT instead of using the adaptor mentioned in the manual.

### ***2.5.1 INSTRUCTIONS TO LOAD FIRMWARE***

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These instructions provide guidance for loading firmware onto Photon MPPTs. The information was provided by the supplier and can also be found on the following link <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>.

Downloaded .hex program files can be loaded onto MPPTs via the 6 pin RJ11 connector using a Microchip ICD2, ICD3 or PICKit3 (with RJ11 adapter) programmer and using MPLAB software (It is recommended to use the version v8.92).



---

Important information that must be considered:

The configuration file currently has configuration data entered for these serial numbers:

1, 2, 27, 28, 29, 30, 31, 32, 33, 48 and above

If your device is not on that list, please contact us at [info@dilithiumpower.com](mailto:info@dilithiumpower.com) if you wish to update your device's firmware.

Initial Steps:

1. Install the program MPLAB
2. Connect your chosen programmer
3. Open the program MPLAB
4. The program interface is shown in the next image:

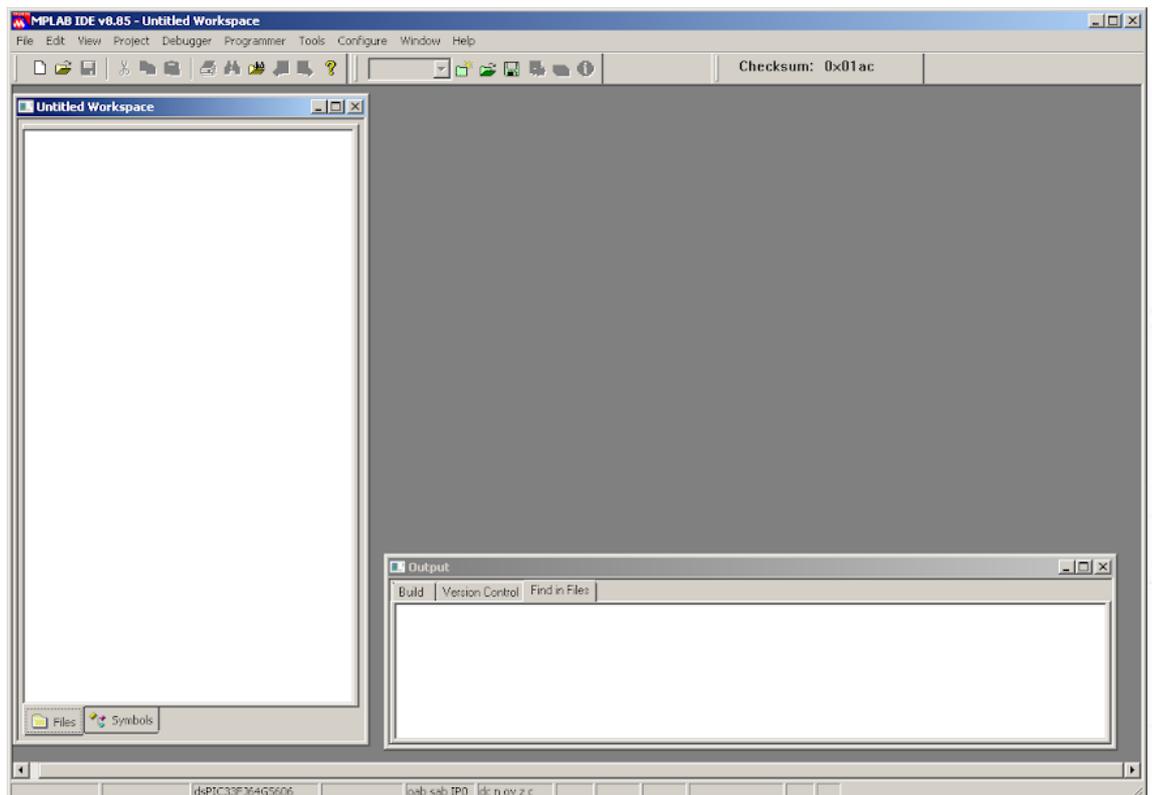


Figure 20. . Screenshot of the interface. Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>



4. Select the option Configure -> Select Device
5. Now select dsPIC33FJ64GS606 from the drop down menu.

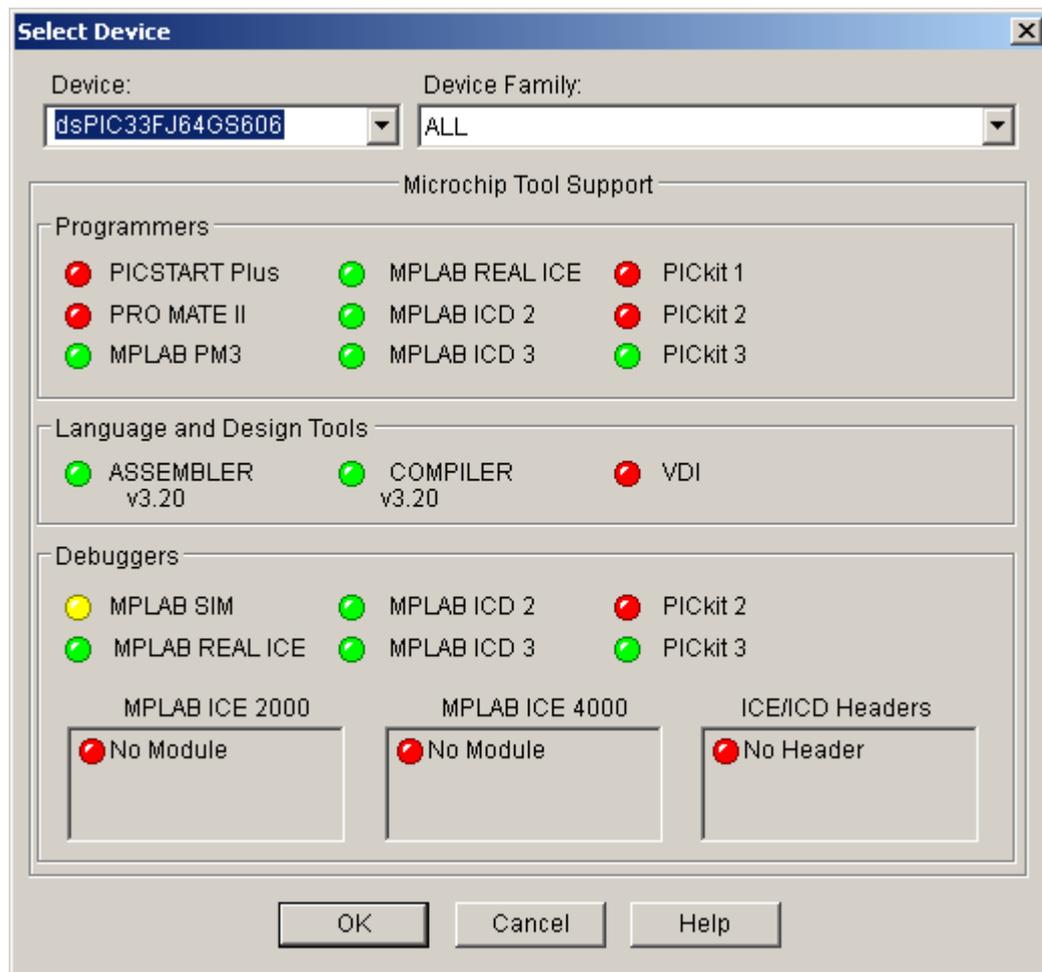


Figure 21. Screenshot of the microcontroller settings. Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>

For this guide the ICD2 programmer was used:



Figure 22. Connection of the Photon 1 MPPT to the programmer. Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>

1. Click Programmer -> Select Programmer -> ICD2

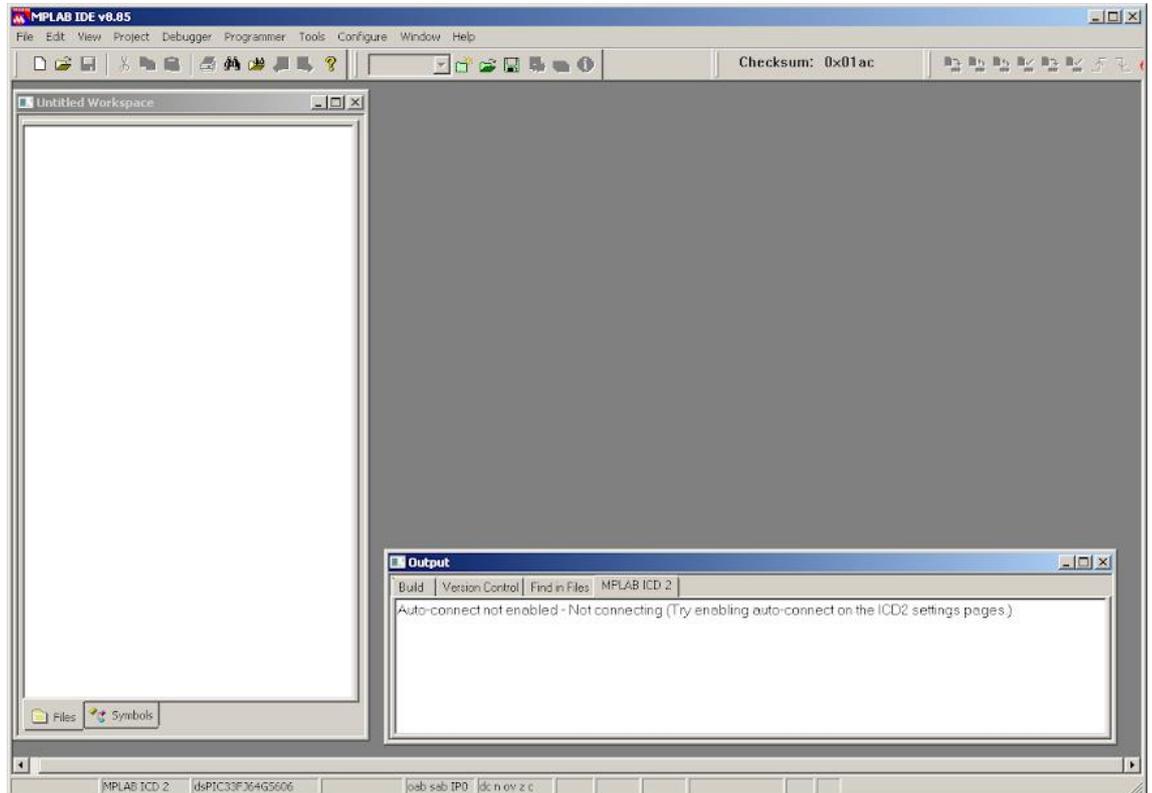


Figure 23. Screenshot of the interface once the programmer and microcontroller are both set.  
Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>

2. Now click Programmer -> MPLAB ICD2 Setup Wizard.
3. There will be a popup window, where USB as the COM Port must be both specified.
4. In the next window, tick the box "MPLAB IDE automatically connects to the MPLAB ICD 2".
5. Click through next.



6. Once you close the popup window, the ICD2 (or the programmer used) will try to connect to the device. You may get the popup warning 'ICDWarn0046', which is not a concerning issue. In that case, click OK.

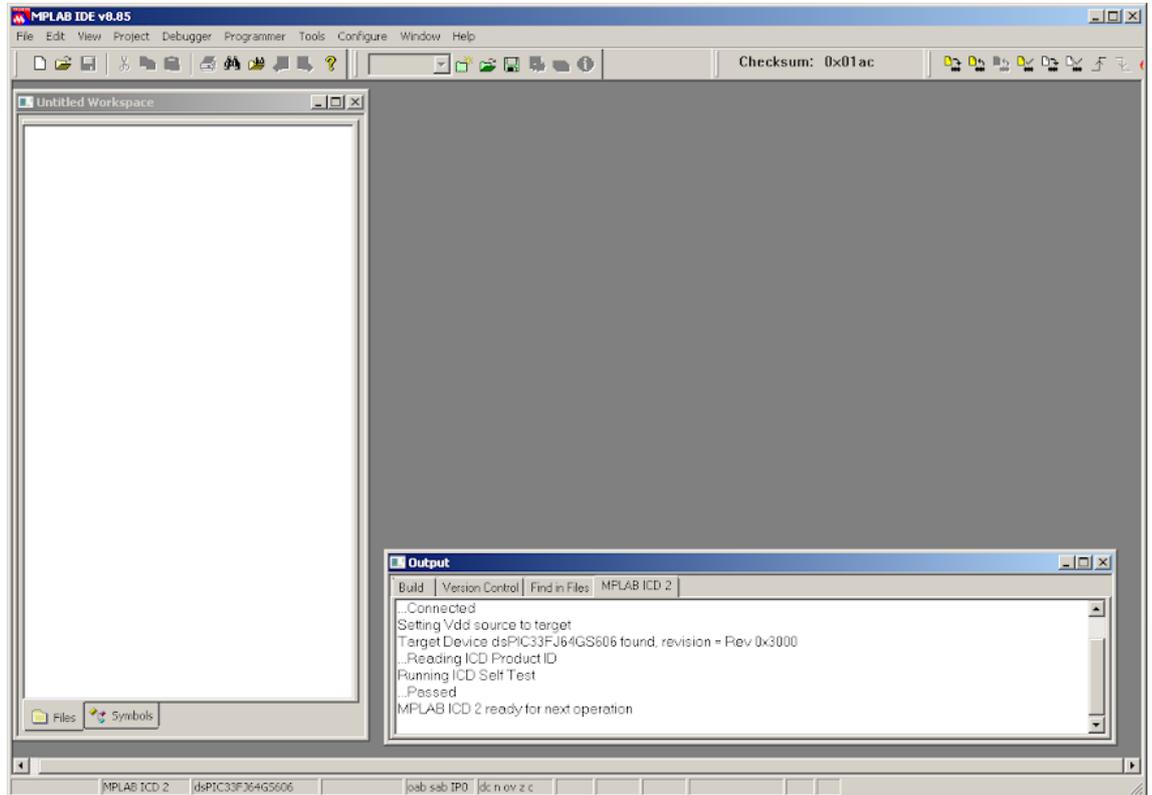


Figure 24. Screenshot of the output. Source:<https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>

7. Click File -> Import

8. Select the “. hex” program file that you want to load

9. Now click on Programmer -> Program

10. Next click Programmer -> Release from Reset or simply unplug programming cable. The lights should start blinking again.



The MPPT should now be loaded with default parameters from the .hex file. Users will likely now want to run the MPPT Configuration and Monitoring GUI to update their unit with their own application parameters.

## 2.5.2 UPDATING CONFIGURATION

After updating MPPT firmware the configuration over CAN protocol must be updated. The maximum output voltage is limited by default to 100V. In addition, the voltage, current and temperature measurement are not calibrated at the initial configuration stage.

The Photon 1 will initially be loaded as serial number 1.

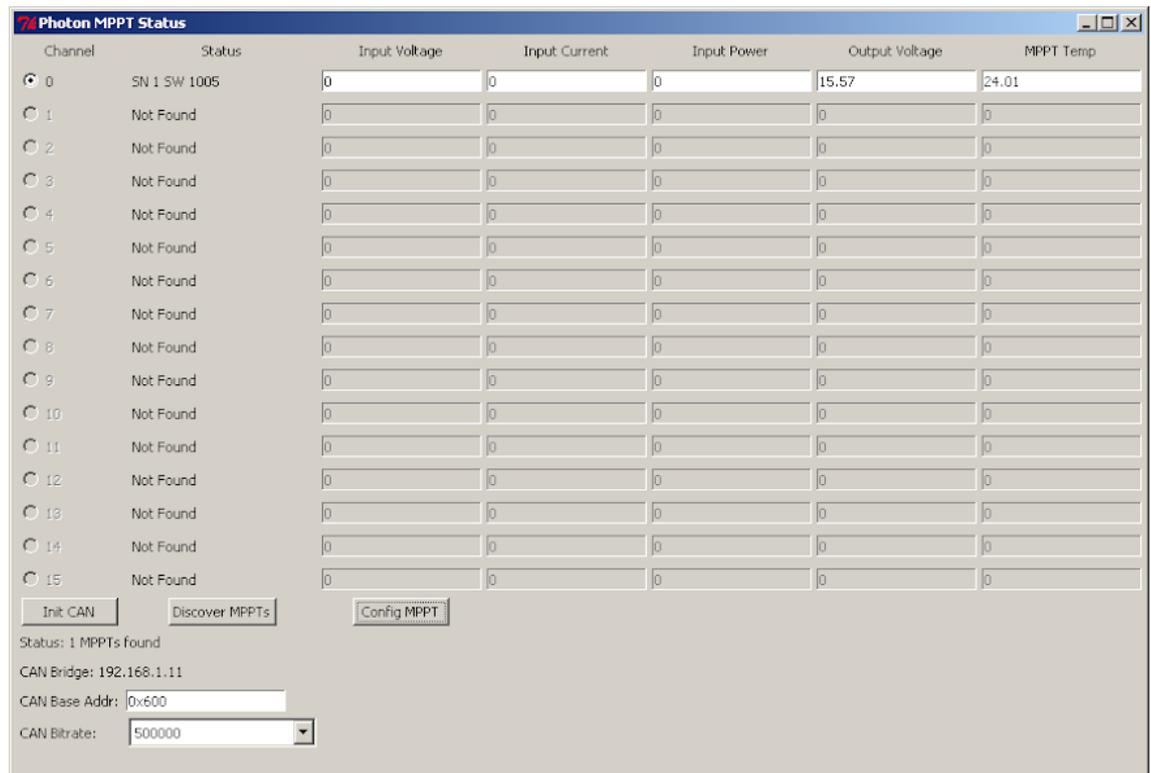


Figure 25. Screenshot of the MPPT status for the updating process.  
Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>



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Select the programmed MPPT and click Config MPPT. In the entry box 'SN to Write' type in the serial number of the Photon 1 and then click Load New Config. Once this step is reached, the program will pull the default values from the 'configuration.csv' file and load it onto the MPPT.



Parameter	Type	Current Value
serialNumber	int32	1
hardOutputVoltage	float	160.0
minOutputVoltage	float	0.0
maxOutputVoltage	float	100.0
constOutputVoltage	float	99.0
maxTemperature	float	110.0
hardCurrent	float	12.0
maxCurrent	float	12.0
scaleAmpsIn	float	16.5
offsetAmpsIn	float	0.0
scaleAmpsOut	float	16.5
offsetAmpsOut	float	0.0
scaleVoltsIn	float	200.0
offsetVoltsIn	float	0.0
scaleVoltsOut	float	200.0
offsetVoltsOut	float	0.0
constVoltageHyst	float	0.20000000298023224
safetyVoltageHyst	float	2.0
safetyCurrentHyst	float	0.25
safetyTemperatureHyst	float	5.0
thermistorBeta	float	3760.0
thermistorRo	float	50000.0
thermistorRbias	float	8060.0
thermistorTo	float	25.0
canBitrate	int32	500000
canBaseAddress	int32	1536
testMode	int32	0
POseconds	float	2.0
INCseconds	float	20.0
TRACKseconds	float	300.0
SWVersion	int32	1005
syncCurrentHi	float	3.0
syncCurrentLow	float	2.0
autoSendRate	float	0.0

Load New Config      SN to Write      48

Figure 26. Screenshot of the MPPT parameters, type and values at this stage.  
Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>



3. At this stage, the serial number should be matching the serial number previously picked.

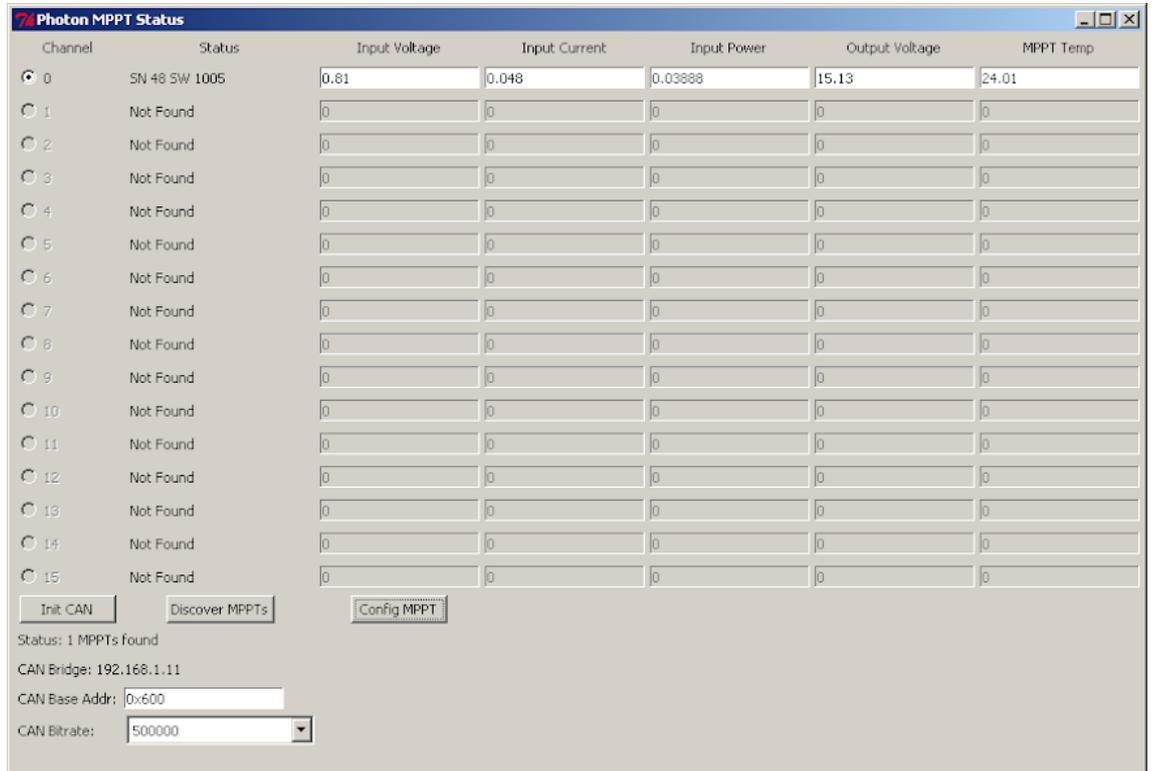


Figure 27. MPPT status at stage three. Source: <https://www.dilithiumpower.com/products/photon-1/loading-firmware-photon-1>

The configuration parameters should now match the parameters in the file 'configuration.csv'.



### **3. CHAPTER 3 RESULTS**

In this chapter the programmed changes in the configuration of the MPPT will be explained. Additionally, the results obtained in the main lab tests will be shown and deeply analyzed.

Due to the type of project developed, most of the results obtained will be related to the configuration of devices such as solar panels, batteries etc. These configurations depend on the motors and other race constraints, such as the battery weight.

This chapter will also include a deep study of the solar irradiation characteristics in Austin, Texas, in July, when the race will take place. It will hopefully provide an approximate overview of the energy input of the solar panels, despite the stochastic nature of the data analyzed.



### 3.1 MPPT ADJUSTED PARAMETERS

The MPPT Photon 1 interface will be used to adjust some parameters that should be adjusted to the car's characteristics.

An issue regarding the charging voltage is that the maximum voltage output from the MPPT is set to 100V. However, the charging maximum output voltage should theoretically be 110 V, as the final battery configuration is 26 in series, of 4.2 V of maximum charging voltage. This parameter was known as “constOutputVoltage” and has been changed manually to 105V; along with the parameter “maxOutputVoltage”, which has been changed to 106V as, in the end the configuration of the batteries was finally changed to 24 cells in series, due to the Battery Management Department specifications and adjustments.

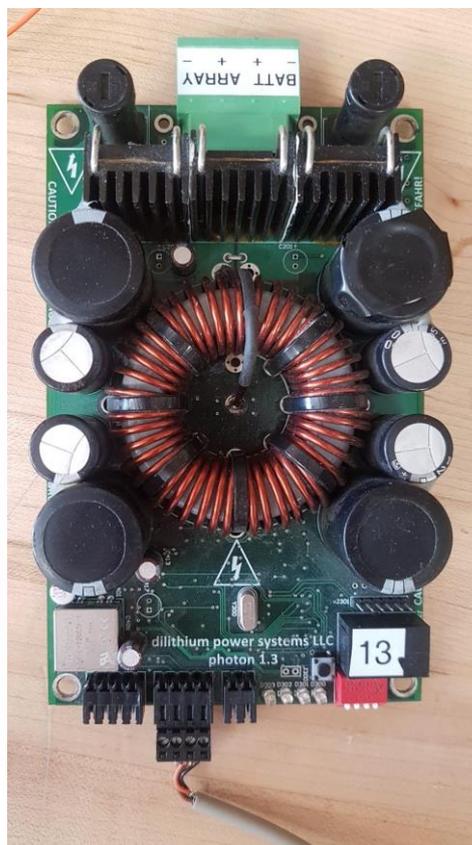


Figure 28. Picture of the Photon 1 .



### 3.1.1 GUIDE TO PROGRAM THE PHOTON MPPT

To change values from the MPPT the CANdapter Message Analyzer is used. This interface can be found on the following website, and it will be used to change the parameters of the MPPT:

<https://www.ewertenergy.com/products.php?item=candapter&page=utilities>

Click on the first link and download the setup utility, available for Windows 2000/XP/Vista/7/8/10.

Once downloaded, an interface like this should be seen.

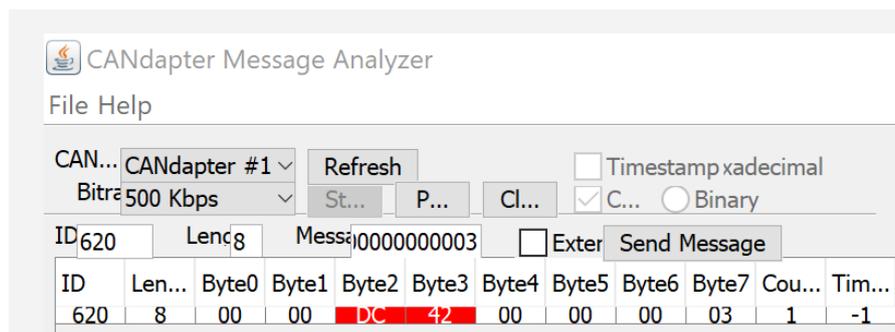


Figure 29. Screenshot of the CANdapter Message Analyzer.

In the following paragraphs, the different bytes of information of the message received by the MPPT will be described.

In the ID section, the reading, writing or base address code are typed.

The base address is 600, 620 indicates reading from the MPPT and 630 writing.

In the previous image, the Maximum output voltage is being read.

The default maximum voltage was set by default to 100V, the requirement in the system requires a 110 V maximum output voltage (for the charging state of the batteries). This parameter was changed, and the previous image shows it is correctly updated, as DC42 in little Indian, translated to decimal, is 110.

To read or write, the ID and message tabs will be changed.

The whole message has 16 numbers, 8 bytes.



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### 3.1.1.1 WRITING IN THE MPPT:

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The message written are the first 4 bytes (from 0 to 3), in little Indian. For instance, to change the maximum output value to 110V, the next steps were followed:

1. The last bit of the message gives the index of the parameter that must be changed.

On the next table, the parameters that can be changed are shown, along with their index numbers, which will be from 1 to 34, typed as the last character of the message.

Index Number	Parameter	Type of data
0	Serial Number	Int 32
1	Hard OutputVoltage	Float
2	minOutputVoltage	Float
3	OutputVoltage	Float
4	constOutputVoltage	Float
5	maxTemperature	Float
6	hardCurrent	Float
7	maxCurrent	Float
8	scaleAmpsIn	Float
9	offsetAmpsIn	Float
10	scaleAmpsOut	Float
11	offsetAmpsOut	Float
12	scaleVoltsIn	Float
13	offsetVoltsIn	Float
14	scaleVoltsOut	Float



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15	offsetVoltsOut	Float
16	constVoltageHyst	Float
17	safetyVoltageHyst	Float
18	safetyCurrentHyst	Float
19	safetyTemperatureHyst	Float
20	thermistorBeta	Float
21	thermistorRo	Float
22	thermistorRbias	Float
23	ThermistorTo	Float
24	canBitrate	int32
25	canBaseAddress	int32
26	testMode	int32
27	Poseconds	Float
28	INCseconds	Float
29	TRACKseconds	Float
30	SWVersion	Int32
31	syncCurrentHi	Float
32	syncCurrentLow	Float
33	autoSendRate	Float

Figure 30. Table of the different parameters that can be changed in an MPPT, along with their index number and type of data.

2. If the type of data is float, this step will need to be done. If the parameter is an integer type, the message can be written in decimal, changing the bytes' order (little Indian). With a decimal to binary decoder that can be found on this website ([http://www.binaryconvert.com/result\\_float.html?decimal=049049048](http://www.binaryconvert.com/result_float.html?decimal=049049048)) the number 110 was translated to floating point.

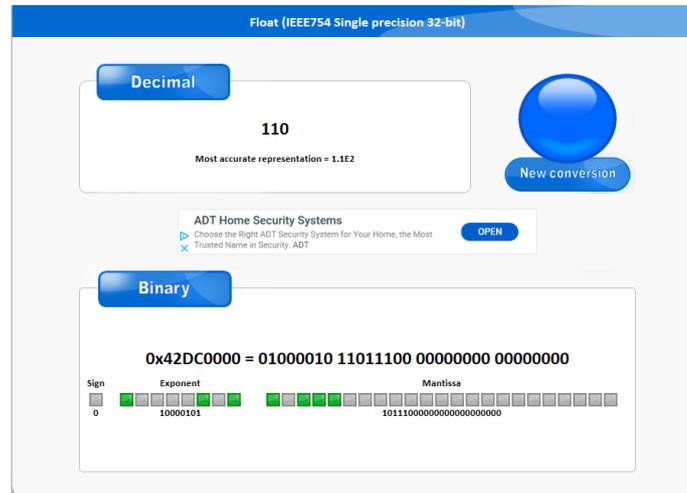


Figure 31. Screenshot of the translation from decimal to floating point.

3. The code 42DC is obtained. The communication with the MPPT is in little Indian, so the first bytes of the message will be 00 DC 42.
4. The next 3 bytes never change, 2D4E45.
5. The last byte indicates the index of the operation to be done. In this case, it is 3, as we want to change the maximum voltage output.

### 3.1.1.2 READING THE MPPT VALUES:

To read from the MPPT, the ID required is 620, and the message sent will be composed of 14 ceros, followed by the index number, 3 in the example shown above.

## 3.2 BATTERIES

The calculations for the battery's configuration give a flexible solution that can be adapted to the requirements of the race.



For this case, the batteries configuration is 16 in parallel with 24 in series. This configuration was estimated with a few calculations, described below.

Each battery has a nominal voltage of 3.7 V and a maximum voltage of 4.2 V. As the nominal voltage requirement is 96 V, a rough estimation of  $96/3.7$  would define the number of cells in series. The total number of cells is determined by weight regulations for the race, which allows a total of 430 batteries. The total amount of batteries divided by the number of batteries in series sets the 16 batteries in parallel. Taking into account all the constraints and Battery Management requirements, a few adjustments were made to finally conclude with the optimum configuration that leads to 16 batteries in parallel with 24 in series.

In the following images the battery modules can be seen. They were manually soldered according to the optimum configuration previously described.

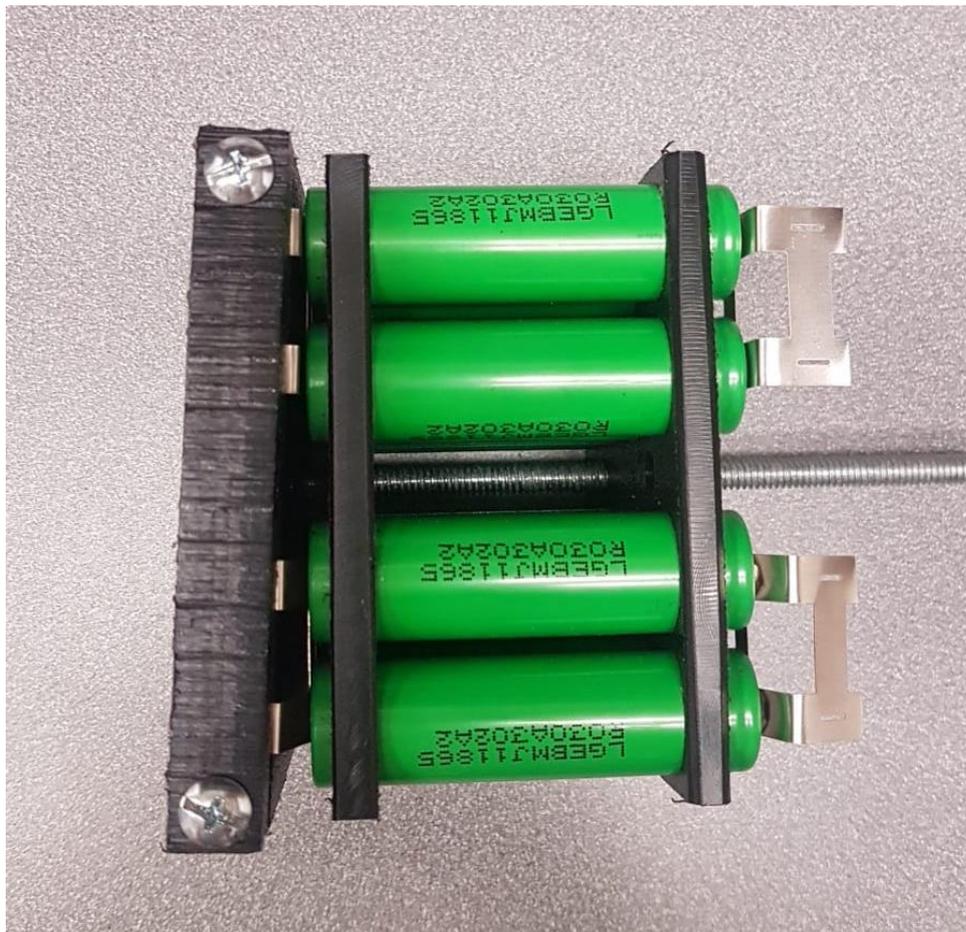


Figure 32. Lateral view of a battery module made with 16 battery modules in parallel.

The 16 batteries in series were soldered with metal stripes.

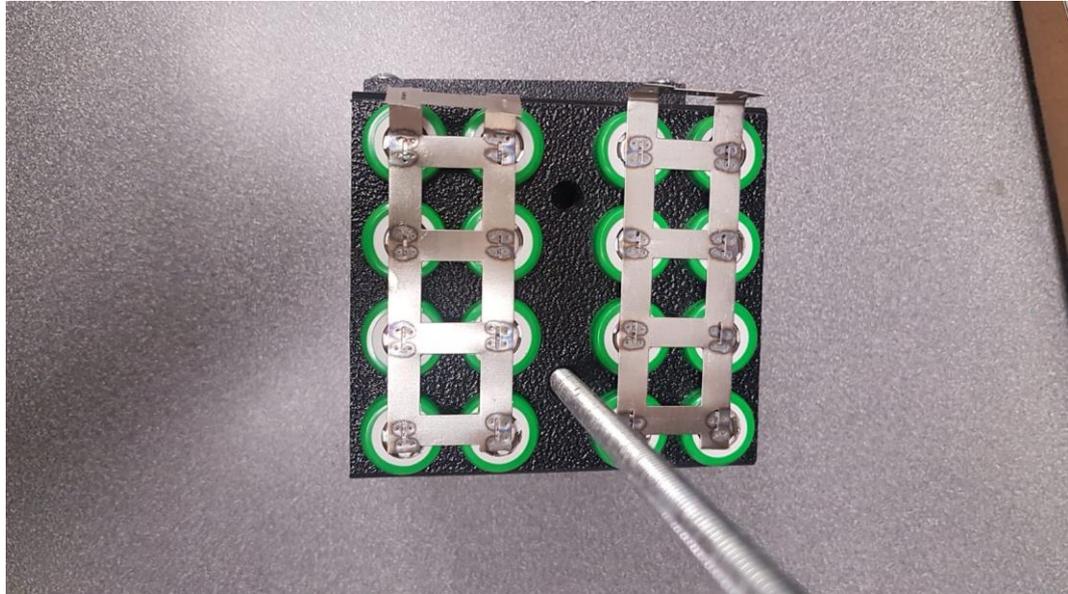


Figure 33. Base view of a single module of 16 batteries in parallel.

Finally, 24 modules were placed in series to create the desired configuration.



Figure 34. Overview of 10 modules in series, placed in a moving box.



### **3.3 SOLAR CELLS**

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The solar gators had an initial ideal plan, however adjustments had to be made throughout the process as some unexpected events happened along the way.

The solar car is designed with two solar panel modules on the car. Each module contains 81 solar cells in series, adding up the voltages, in order to be compatible with the battery voltage and the engines of 96V. During the breaks, the vehicles can be charged with additional solar cells in order to increase its autonomy during the racing periods. For this reason, an extra module of solar cells and MPPT composed of 81 solar cells in series will provide extra energy to the car and will be kept out of the vehicle.



*Figure 35. Picture of the solar panels facing the sun during a lab test.*



### 3.3.1 SOLAR PANELS EFFICIENCY STUDY

The following image shows the parameters used to calculate the curves. All these parameters were taken from the solar panels data sheet, attached at the end of the document.

The data sheet gives the parameters for 60 solar cells connected in series. For this reason, the voltage parameters in the data sheet have been changed. They have all been divided by 60, as the cells are connected in series, the current of one cell is the same as the one given in the data sheet.

The study was made with the initial configuration of 81 cells in series, to achieve the desired voltage configuration.

The image shows a software interface for configuring solar panel parameters. It is divided into two main sections: 'Array data' and 'Module data'.  
Under 'Array data', there are two input fields: 'Parallel strings' with a value of 1, and 'Series-connected modules per string' with a value of 81.  
Under 'Module data', there is a dropdown menu for 'Module:' set to 'User-defined'. Below it are several input fields:  
- 'Maximum Power (W)' with a value of 4.032.  
- 'Cells per module (Ncell)' with a value of 1.  
- 'Open circuit voltage Voc (V)' with a value of 0.67.  
- 'Short-circuit current Isc (A)' with a value of 7.7.  
- 'Voltage at maximum power point Vmp (V)' with a value of 0.56.  
- 'Current at maximum power point Imp (A)' with a value of 7.2.  
- 'Temperature coefficient of Voc (%/deg.C)' with a value of -0.281.  
- 'Temperature coefficient of Isc (%/deg.C)' with a value of 0.041.

Figure 36. General solar panels' parameters and configuration.

Based on a 1000 W/m<sup>2</sup> average sun irradiance, the following results were obtained, based on three different cell temperatures of 35, 45 and 65 degrees Celsius.

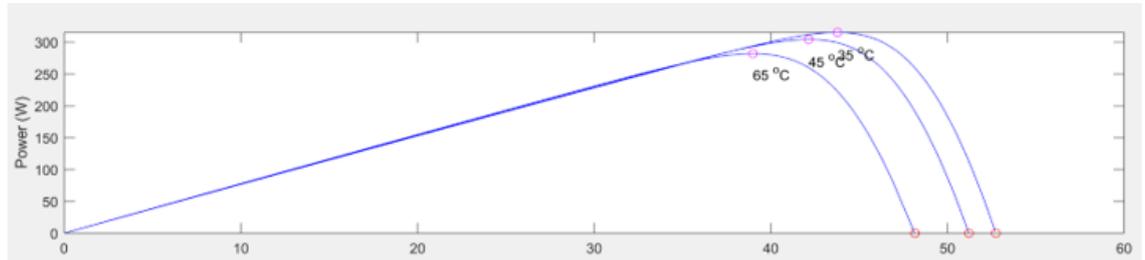


Figure 37. P-V Curves

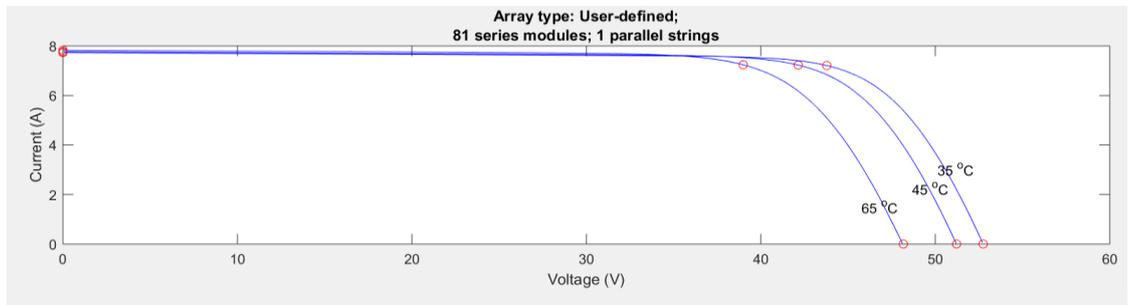


Figure 38. I-V Curves.

These graphs show the relationship between temperature and solar panels' efficiency, considering a constant irradiation. In the near future, the solar gators team is planning to build its own MPPT. For this reason and to maximize the energy efficiency, these factors affect very noticeably to the overall performance.

As it can be guessed from the graphs depicted, the temperature of the cells is an important factor regarding the energy efficiency of the modules. In future vehicles, there will be a sensor and a refrigerating system that will regulate the cells' temperature to maximize the energy efficiency.

The following function describes the hindering effect on the efficiency of an increase of temperature in the solar cells. A temperature below 35 degrees is not contemplated, due to the high ambient temperatures in July in Austin (where the race will be held). Future developments may lean towards a refrigerating system designed to boost power efficiency within a feasible range of temperatures.

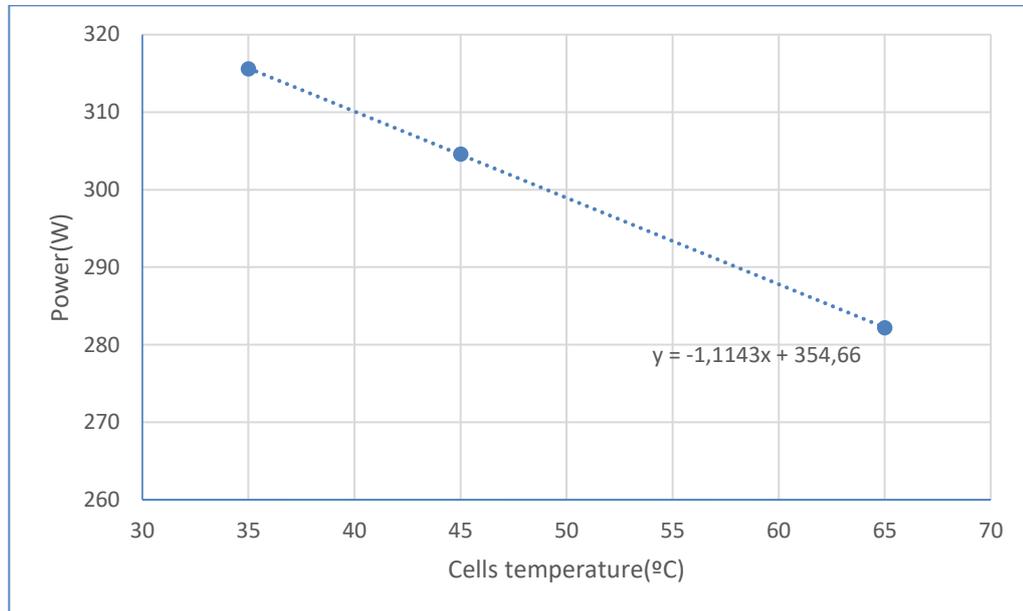


Figure 39. Power vs Temperature of the panel.

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### 3.3.2 SOLAR IRRADIANCE IN AUSTIN

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The race will take place in Austin, Texas. For future development and improvement of the MPPT process, the average daily data has been analyzed coming to the following results.

The normal radiation in a horizontal surface in Austin is shown in the following image, in KWh/m<sup>2</sup>/day.

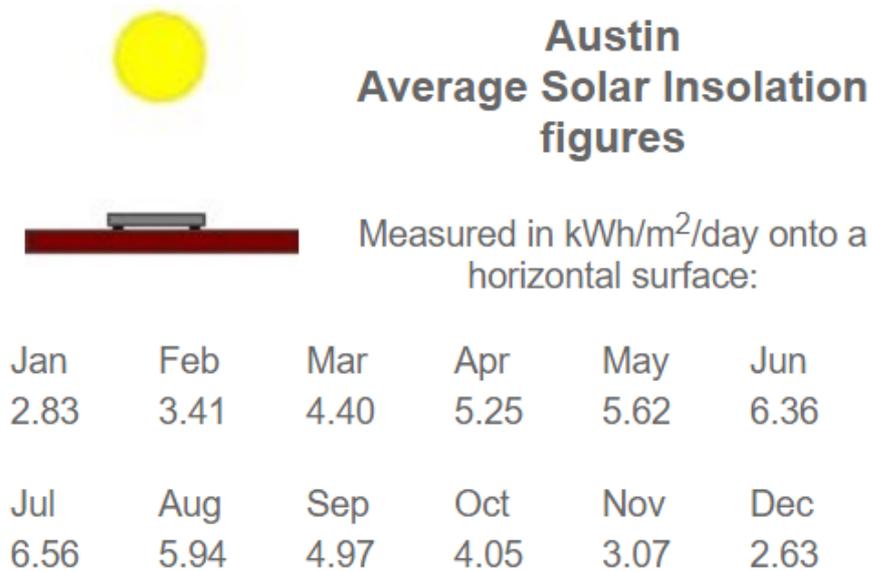


Figure 40. Normal irradiation on a horizontal surface in Austin.

The hourly radiation data was found in the database in the following link:  
[https://rredc.nrel.gov/solar/old\\_data/nsrdb/1961-1990/hourly/compressed/#T](https://rredc.nrel.gov/solar/old_data/nsrdb/1961-1990/hourly/compressed/#T)

The data is presented in compressed files, placed in the order shown in the next tables, taken from the manual, that can be found in the following link:  
<https://rredc.nrel.gov/solar/pubs/tmy2/PDFs/tmy2man.pdf>



**Table 3-1. Header Elements in the TMY2 Format  
 (For First Record of Each File)**

Field Position	Element	Definition
002 - 006	WBAN Number	Station's Weather Bureau Army Navy number (see Table 2-1)
008 - 029	City	City where the station is located (maximum of 22 characters)
031 - 032	State	State where the station is located (abbreviated to two letters)
034 - 036	Time Zone	Time zone is the number of hours by which the local standard time is ahead of or behind Universal Time For example, Mountain Standard Time is designated -7 because it is 7 hours behind Universal Time
038 - 044 038 040 - 041 043 - 044	Latitude	Latitude of the station N = North of equator Degrees Minutes
046 - 053 046 048 - 050 052 - 053	Longitude	Longitude of the station W = West, E = East Degrees Minutes
056 - 059	Elevation	Elevation of station in meters above sea level
FORTRAN Sample Format ( 1X,A5,1X,A22,1X,A2,1X,I3,1X,A1,1X,I2,1X,I2,1X,A1,1X,I3,1X,I2,2X,I4 ) C Sample Format: ( %s %s %s %d %s %d %d %s %d %d %d )		

Figure 41. Table of the header elements in the compressed files. Source: <https://rredc.nrel.gov/solar/pubs/tmy2/PDFs/tmy2man.pdf>

**Table 3-2. Data Elements in the TMY2 Format  
 (For All Except the First Record)**

Field Position	Element	Values	Definition
002 - 009 002 - 003 004 - 005 006 - 007 008 - 009	Local Standard Time Year Month Day Hour	 61 - 90 1 - 12 1 - 31 1 - 24	 Year, 1961-1990 Month Day of month Hour of day in local standard time
010 - 013	Extraterrestrial Horizontal Radiation	0 - 1415	Amount of solar radiation in $Wh/m^2$ received on a horizontal surface at the top of the atmosphere during the 60 minutes preceding the hour indicated
014 - 017	Extraterrestrial Direct Normal Radiation	0 - 1415	Amount of solar radiation in $Wh/m^2$ received on a surface normal to the sun at the top of the atmosphere during the 60 minutes preceding the hour indicated
018 - 023 018 - 021 022 023	Global Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1200 A - H, ? 0 - 9	Total amount of direct and diffuse solar radiation in $Wh/m^2$ received on a horizontal surface during the 60 minutes preceding the hour indicated
024 - 029 024 - 027 028 029	Direct Normal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	 0 - 1100 A - H, ? 0 - 9	Amount of solar radiation in $Wh/m^2$ received within a $5.7^\circ$ field of view centered on the sun during the 60 minutes preceding the hour indicated

Figure 42. Table of the data elements in the compressed files. Part 1. Source: <https://rredc.nrel.gov/solar/pubs/tmy2/PDFs/tmy2man.pdf>



**Table 3-2. Data Elements in the TMY2 Format (Continued)**

Field Position	Element	Values	Definition
<b>030 - 035</b> 030 - 033 034 035	Diffuse Horizontal Radiation Data Value Flag for Data Source Flag for Data Uncertainty	0 - 700 A - H, ? 0 - 9	Amount of solar radiation in Wh/m <sup>2</sup> received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated
<b>036 - 041</b> 036 - 039 040 041	Global Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	0 - 1300 I, ? 0 - 9	Average total amount of direct and diffuse illuminance in hundreds of lux received on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 1300 = 0 to 130,000 lux
<b>042 - 047</b> 042 - 045 046 047	Direct Normal Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	0 - 1100 I, ? 0 - 9	Average amount of direct normal illuminance in hundreds of lux received within a 5.7 degree field of view centered on the sun during the 60 minutes preceding the hour indicated. 0 to 1100 = 0 to 110,000 lux
<b>048 - 053</b> 048 - 051 052 053	Diffuse Horiz. Illuminance Data Value Flag for Data Source Flag for Data Uncertainty	0 - 800 I, ? 0 - 9	Average amount of illuminance in hundreds of lux received from the sky (excluding the solar disk) on a horizontal surface during the 60 minutes preceding the hour indicated. 0 to 800 = 0 to 80,000 lux
<b>054 - 059</b> 054 - 057 058 059	Zenith Luminance Data Value Flag for Data Source Flag for Data Uncertainty	0 - 7000 I, ? 0 - 9	Average amount of luminance at the sky's zenith in tens of Cd/m <sup>2</sup> during the 60 minutes preceding the hour indicated. 0 to 7000 = 0 to 70,000 Cd/m <sup>2</sup>
<b>060 - 063</b> 060 - 061 062 063	Total Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena at the hour indicated
<b>064 - 067</b> 064 - 065 066 067	Opaque Sky Cover Data Value Flag for Data Source Flag for Data Uncertainty	0 - 10 A - F 0 - 9	Amount of sky dome in tenths covered by clouds or obscuring phenomena that prevent observing the sky or higher cloud layers at the hour indicated

*Figure 43. Table of the data elements in the compressed files. Part 2. Source: <https://rredc.nrel.gov/solar/pubs/tmy2/PDFs/tmy2man.pdf>*

A deep analysis of the data delivered the hourly average Global Horizontal Radiation per square meter, considering five years of hourly data from the month of July, when the race will take place. The results are depicted in the following graph.

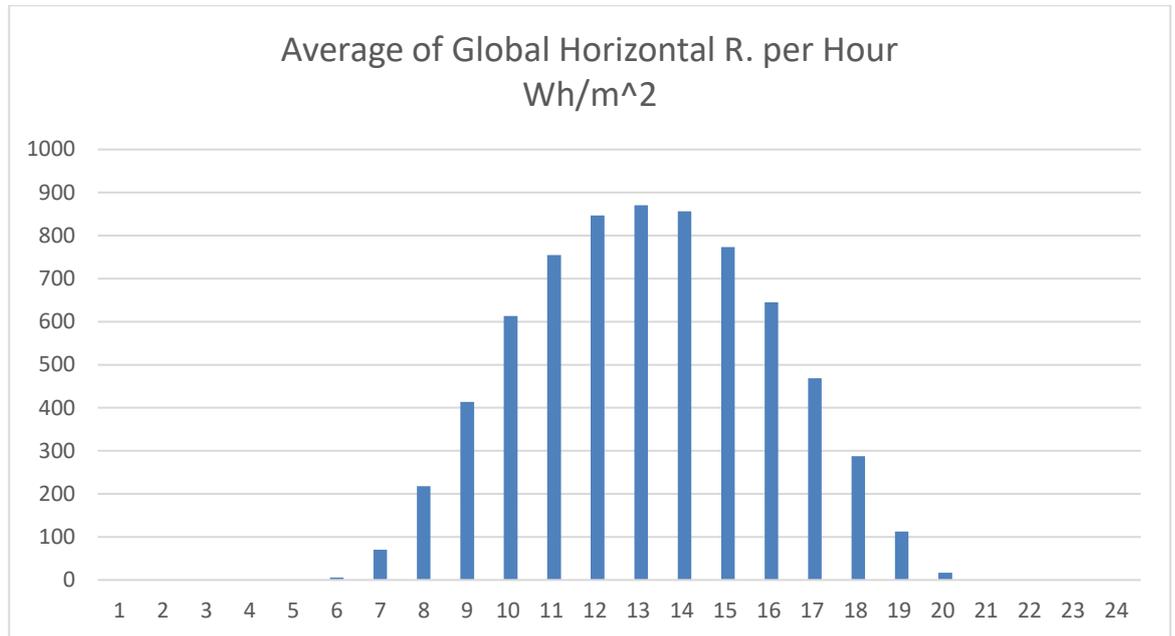


Figure 44. Hourly average Global Horizontal Radiation per square meter in Austin.

The peak hours of global horizontal radiation are concentrated within the center hours of the day, specially between 12pm and 2pm, when the average irradiation that hits a horizontal surface within the hour surpasses the 850 Wh /m<sup>2</sup>.

The following plots show the average, standard deviation and main layout of the radiation values for the hours of the day within 10:00 and 18:00 where main solar irradiance is encountered.

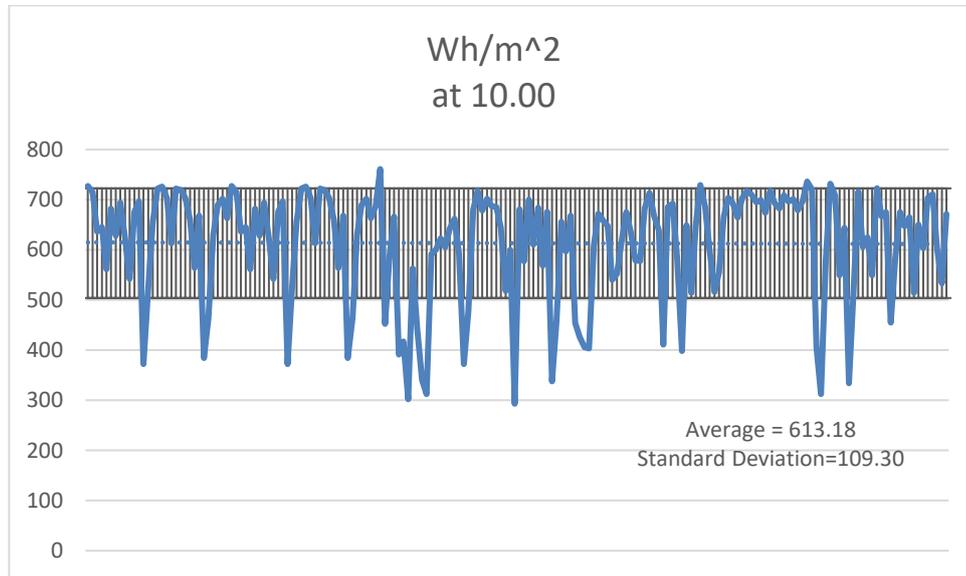


Figure 45. The average, standard deviation and main layout of the radiation values for 10:00.

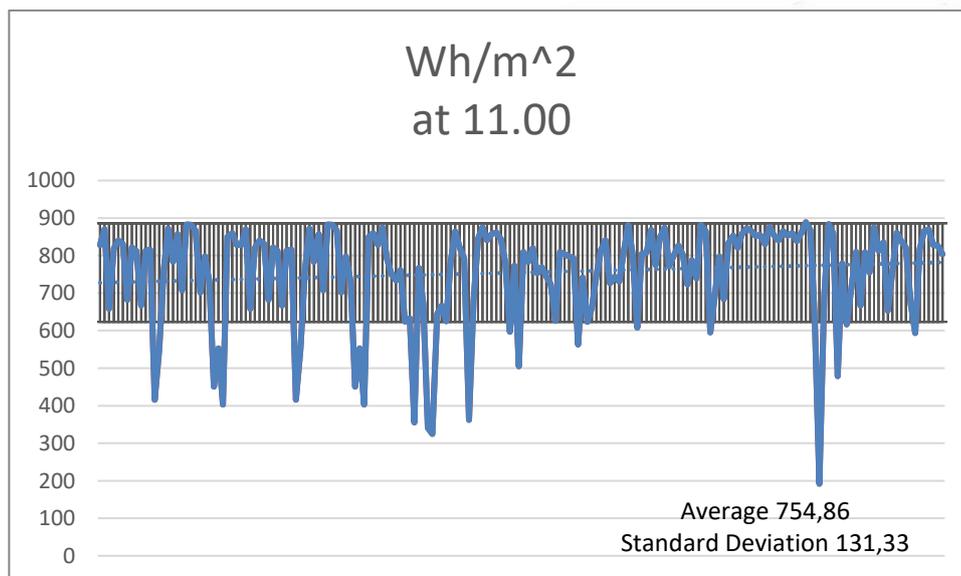


Figure 46. The average, standard deviation and main layout of the radiation values for 11:00.

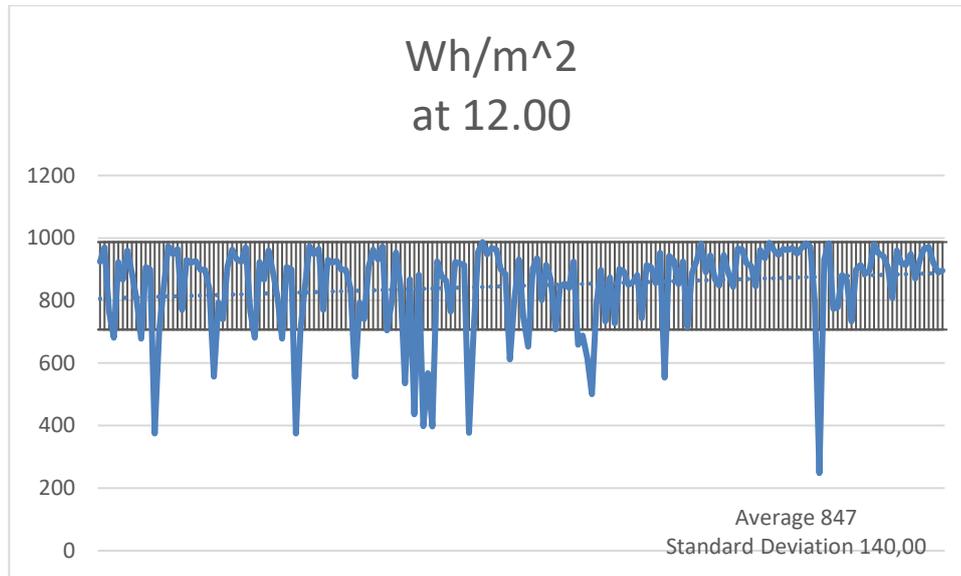


Figure 47. The average, standard deviation and main layout of the radiation values for 12:00.

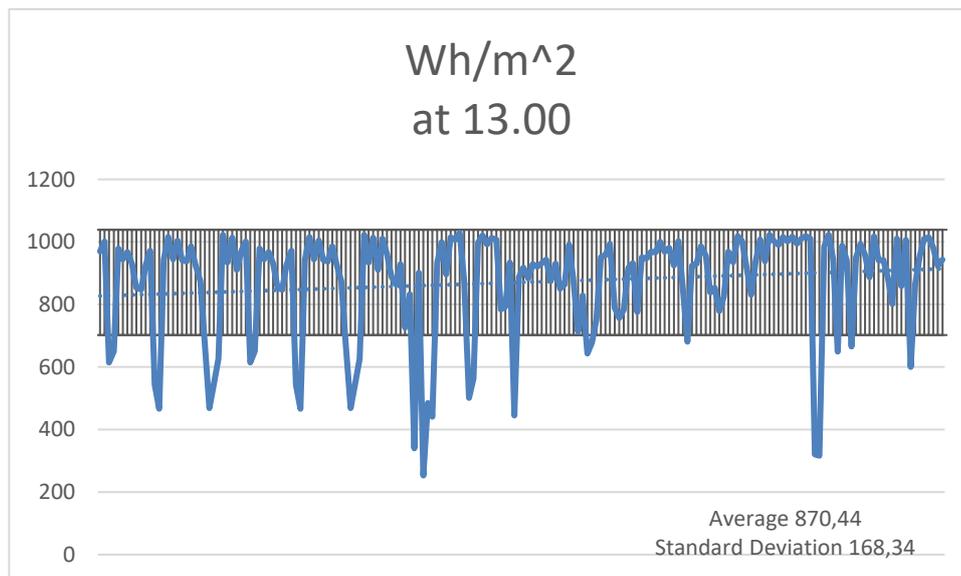


Figure 48. The average, standard deviation and main layout of the radiation values for 13:00.

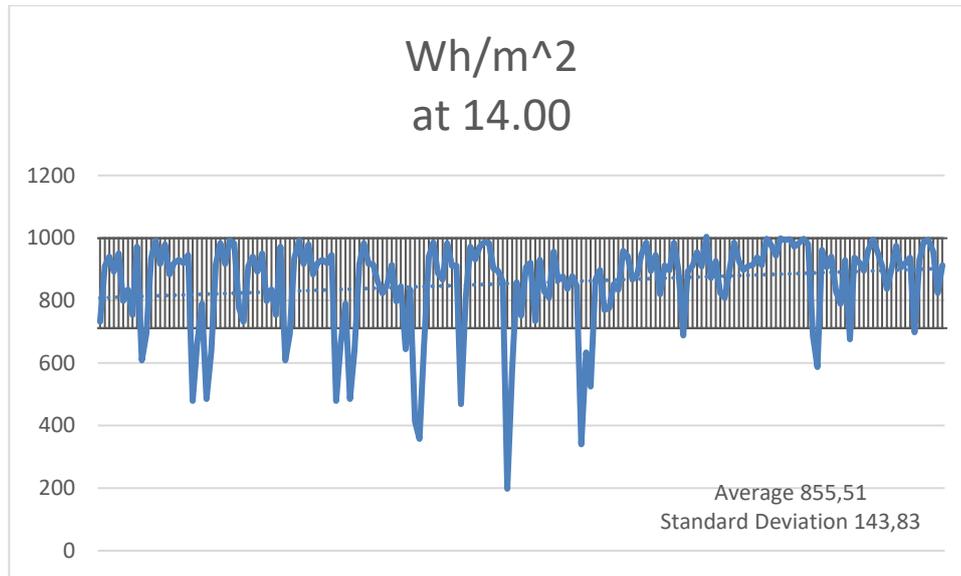


Figure 49. The average, standard deviation and main layout of the radiation values for 14:00.

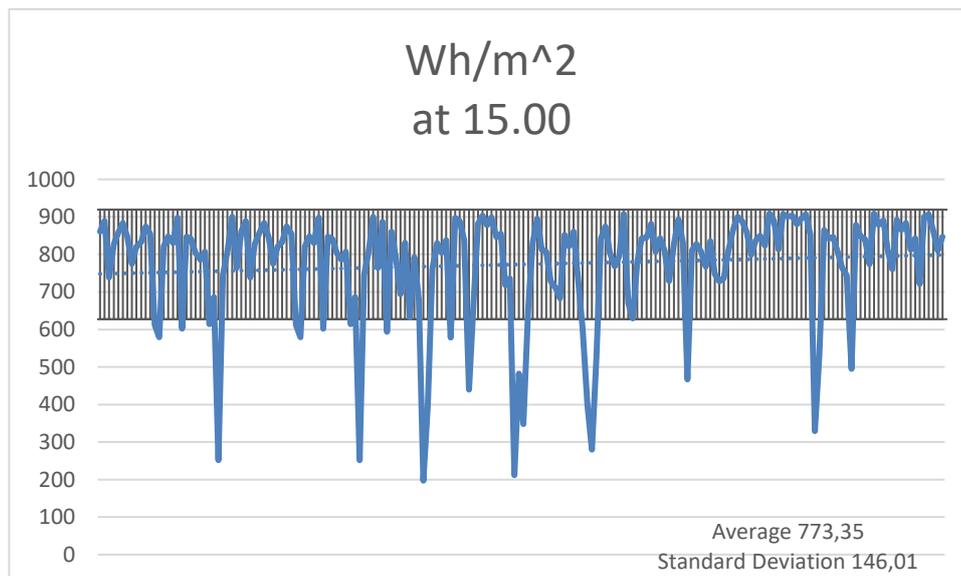


Figure 50. The average, standard deviation and main layout of the radiation values for 15:00.

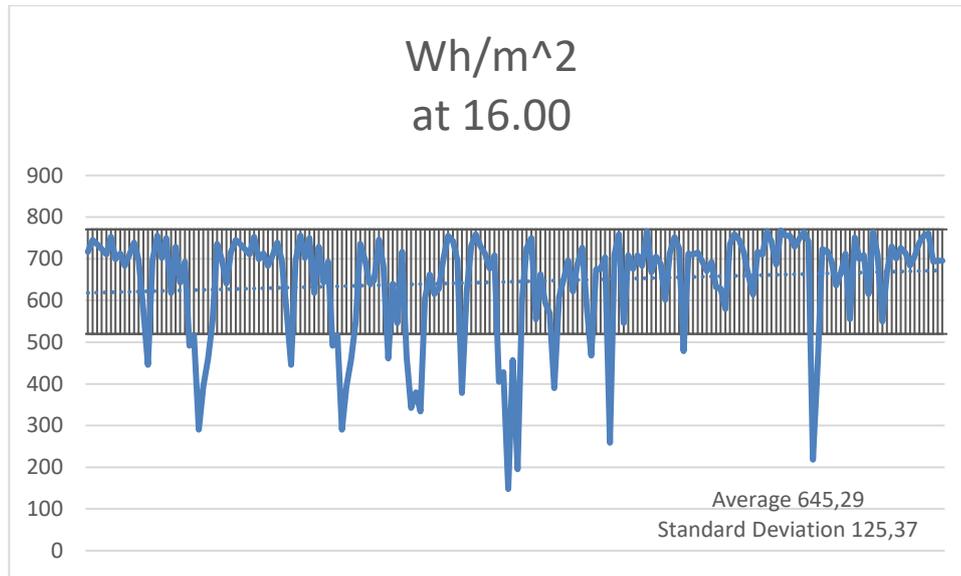


Figure 51. The average, standard deviation and main layout of the radiation values for 16: 00.

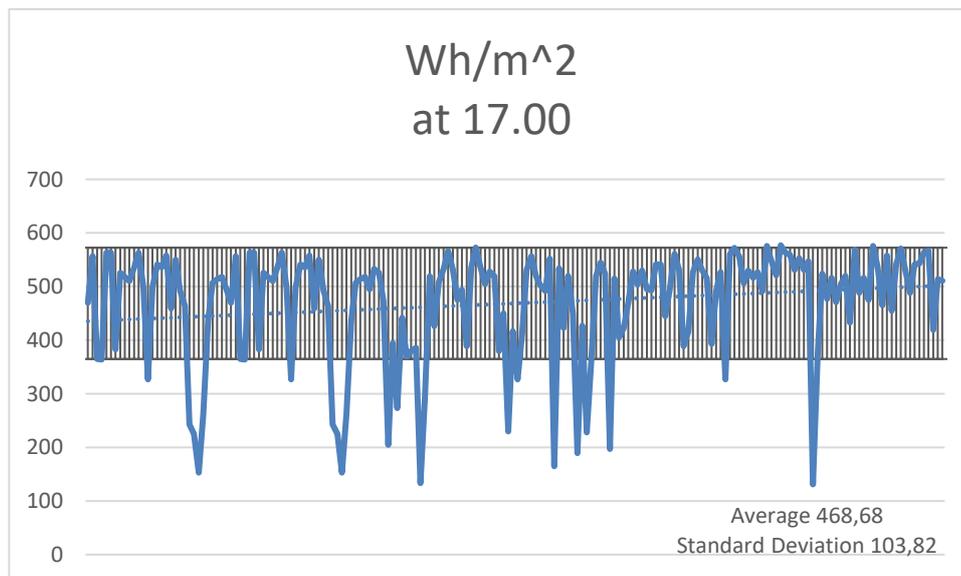


Figure 52. The average, standard deviation and main layout of the radiation values for 17:00.

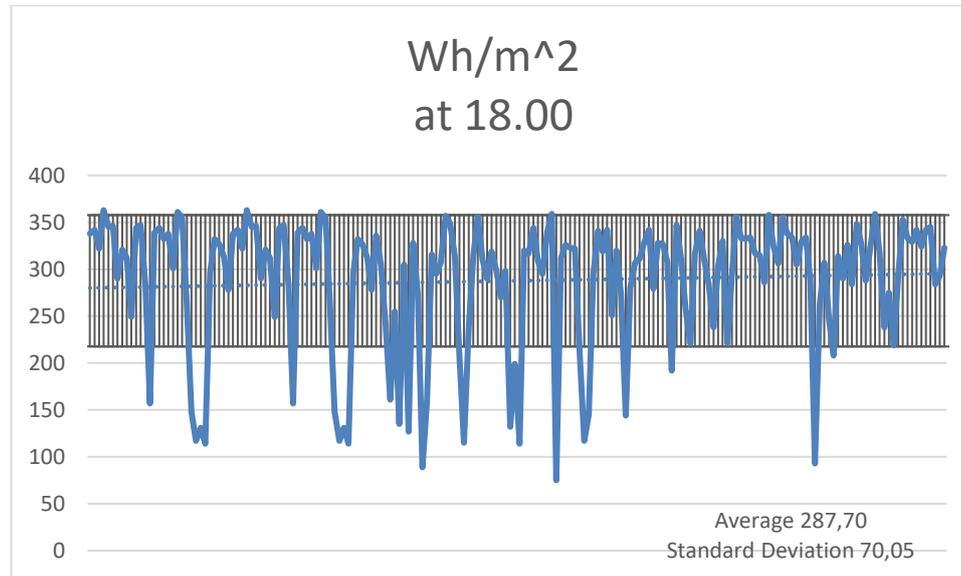


Figure 53. The average, standard deviation and main layout of the radiation values for 18:00.

The plots show a slightly unstable data, due to its stochastic nature. The data used for this analysis was the Global horizontal radiation, which accounts for both beam and diffuse radiation.

The combination of beam and diffuse shows the total radiation that could potentially hit the surface of the car, where the solar panels are placed.

For the analysis, the reflective radiation will not be considered. Reflected radiation describes sunlight that has been reflected off non-atmospheric objects such as the ground. Asphalt generally reflects around 4% of the light that hits it, which will be the case for the competition in Austin (surfaces such as lawns can reflect about 25%, but this is not likely to be the case in the race). Solar panels will very likely be tilted away from the reflected light's trajectory, therefore, reflected radiation will not account for a significant part of the sunlight striking the surface in question.

Beam radiation describes the solar radiation that travels on a straight line from the sun down to the surface of the earth.



Moreover, diffuse radiation refers to the scattered sunrays that have still made it to the surface of the earth despite the scattering effect of different factors in the atmosphere.

Direct radiation has a definite direction whereas diffuse radiation travels in all directions. When the radiation is direct, the sunrays are all travelling in the same direction. For this reason, an object can block them all at once, producing the shadow phenomenon.

The graphs previously depicted, are showing the global horizontal radiation, that accounts for both direct and diffuse radiation that hits the solar panels. The ratio of direct to diffuse radiation depends on the clearness of the sky. This factor can be predictable a few weeks in advance for the race, in order to adjust parameters and yield better efficiencies. When the sky is clear, during the hours at the middle of the day, the beam radiation accounts for most of the insolation striking the ground (around 85%), leaving the remaining radiation to the diffuse component (15%). As the sun goes lower in the sky, the amount of beam radiation decreases, until around 40% of the radiation that hits the ground is barely the diffuse component.

This first approach was made under the consideration of a clear; however, clouds, pollution and other factors may increase the percentage of the diffuse component. These factors may hinder the solar panels efficiency, reducing considerably the solar insolation.

In fact, the ratio of direct to diffuse is strongly dependent on latitude and climate. Unfortunately, these factors cannot be controlled, however, all the cars competing on the race will be under the same circumstances.

### ***3.4 LAB WORK GUIDE***

---

The following lines describe the procedure followed in the Energy Research lab.



Notes from Test made on the 18th of April in 2019, at 2:58 PM.

In order to test the system, we used 40 solar cells in series, an MPPT (Photon model) and a set of 4 batteries of 12 Volts.

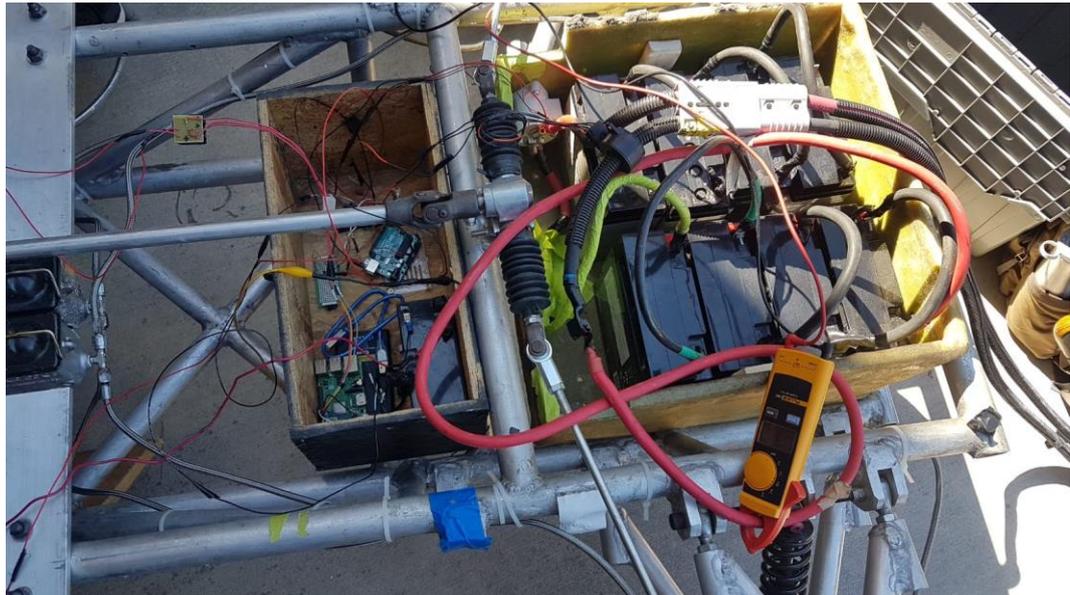


Figure 54. Picture of the cabling of the lab test.

When the batteries were connected directly to the array, the capacitors charged too fast, generating a very high charging current. The safety fuse from the battery blew, so it had to be replaced with a different one.

We pre-charged the output capacitor with the 8-ohm resistors in order to limit current, before the MPPT was connected, this way, we avoided blowing up the safety fuse from the batteries.

To get the steady state response, the resistors were removed. The maximum power point during the testing was a voltage of 19V and a current of 6.8A from the input of the MPPT. This means 129.2W of maximum power was obtained from the array, accounting the cable losses from the array to the MPPT. This data was obtained at 2:58pm at a sunny day with no clouds in the sky.

We obtained at the output of the MPPT 2.2 A of current and 53 V of voltage (MPPT in steady state). Therefore, the power to the batteries was  $2.2 * 53 = 116.6W$ . This



value accounts for the power going to the batteries, without considering the cable losses (from MPPT to the batteries).

The losses of the MPPT account for around 10% of the input voltage. ( $116.6/129.2$ )  
90.2% of the energy coming out of the array reached the batteries.



Figure 55. Picture of the different components used during the lab test.

#### Turn-on Procedure:

1. Take out In-line fuse currently in use (connected to MPPT)
2. Use a resistor to charge output to output capacitors
3. Once at desired voltage, disconnect batteries and insert fuse
4. Ensure solar array connection
5. Turn on (Photon model) MPPT

#### Turn-off Procedure:

1. Turn off MPPT
2. Disconnect solar array
3. Reverse order from Turn-on

4. Discharge input and output capacitors (to be safe).

### **3.4.1 LAB WORK COMPLICATIONS**

Unfortunately, while doing a testing, a Photon MPPT was seriously damaged and an alternative plan was required.

The input (CAN V+) is a port which should be tested with 12V DC Voltage. Instead, this port was connected to a 12V RMS, AC voltage supply. The CAN V+ signal is not delivering sensible voltages to other components; therefore, some diodes may have been damaged due to a current excess.

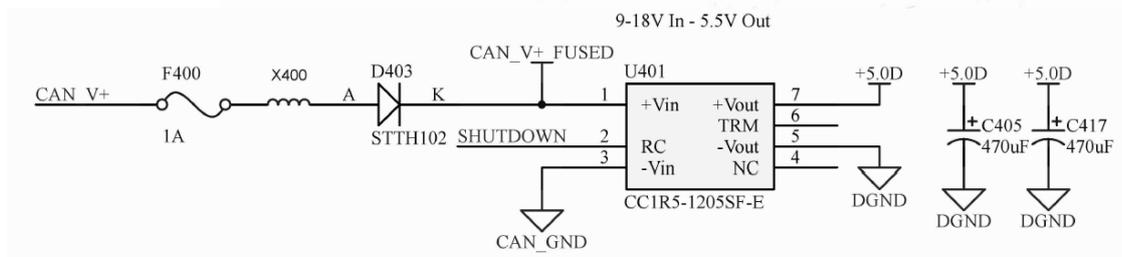
The CC1R5 module stopped working and the team had to contact the MPPT provider.

The CAN bus got overvoltage and it nuked the power circuits on the trackers. Fortunately, the power converter did not get fried as the upstream protection devices were not damaged (F400 Fuse).

The manufacturer suggested to pull off the dead TVS (Zener diodes) and then apply a lab supply directly to the car-side pins of the power converter to see if it powers up the unit. This way, the affected components were identified.

The full schematic of the Photon 1 MPPT is attached at the end of this document.

The specific module that was damaged is shown in the following image:



*Figure 56. Damaged module of the Photon 1 MPPT.*



Finally, the damages were identified. The D403 diode was burnt. Also, it was seen that the Zener D400 diodes in the image below were also damaged.

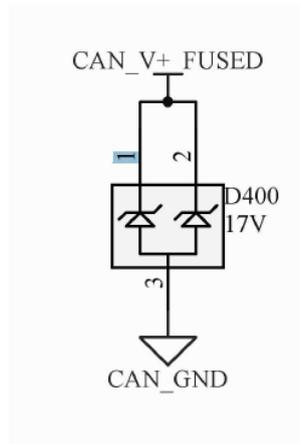


Figure 57. Zener diodes damaged during the MPPT Test.

A few weeks away from the competition, the most reasonable option is to find a third MPPT that can be used to power the external batteries with solar panels. This third subsystem, which is out of the car, could be either another Photon MPPT that would have to be purchased or two old AERL MPPT that can be programmed to work with 96V, but can only handle a maximum input current 6 A. As the maximum input current from the solar panels is 10 A, two MPPT should be placed in parallel.

It was also considered to fix the modules that were burnt, but there is a chance other modules were also affected and will hinder the vehicle's efficiency.



## CHAPTER 4 CONCLUSIONS

The thesis' conclusions can be summarized in the following bullet points:

- The use of MPPT improves significantly the energy efficiency. The same electrical system without an MPPT would round efficiencies of 30% whereas with an MPPT 90% efficiencies are easily attainable.
- The study conducted in this study varies significantly for each engine configuration. In this case, the engine used is 96 V and forced all the electrical system to be adjusted to it. The battery was programmed to give a maximum current and power that the motor could handle.
- Likewise, the solar cells were also configured so that their current, voltage and ultimately power matched the battery conditions after the MPPT'S adjustments. Their main design constraint was the vehicle's available surface.
- The whole system is in harmony to yield the best performance possible with the available resources.
- There could be better engines for this application, however, there are economical constraints. The engine was provided by one of the team's sponsors, as well as the solar panels. The batteries had to fulfil budget requirements, and the chassis and other physical components were recycled from an existent prototype.
- The vehicle's efficiency is strongly codependent on the solar irradiance and the temperature of the cells, for this reason further research must be conducted towards a refrigerating system for the solar panels and higher efficiencies in photovoltaic panels in order to increase the vehicle's autonomy.
- There is evidence to confirm that there is enough sun power potential to develop environmentally-friendly and energy self-sufficient vehicles. The future of vehicles leans towards renewable energies.



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## **CHAPTER 5                      FUTURE DEVELOPMENT**

Although the team owns off-the-shelf MPPTs which are very efficient, the goal is to have Solar Gators create our own in house built MPPT which fixes all the issues from the 2018-2019 engineering year.

To be specific the goals for the in house designed MPPT are:

- At least 90% efficiency
- Efficient Inductors in operation modes
- Low Drain resistance in transistor when on
- Efficient gate drivers
- Digital Isolation for signals
- Full telemetry system, ready to integrate into the rest of the car
- Easily firmware reprogrammable configuration
- 4-layer PCB design
- Use of Surface mount devices instead of only through hole devices
- Intelligent algorithm for maximum power point tracking
- Ability to handle up to 10 Amps or more
- Full understanding of how the MPPT works and how it works with the solar array and the battery pack



*Figure 58. Picture of the solar car without the solar panels in the lab.*



To achieve these goals, research needs to be done on the different algorithms available. We also need to experiment and test different firmware with the same hardware setup - same MPPT and solar cells - at roughly the same time under the sun or other light source.

There are also other goals to be reached but they may be unrealistic. For example, using a DSP chip instead of a regular microprocessor to speed up the MPPT algorithm. This is the case for the Photon 1's.

The rationale behind making a MPPT despite already having one is rooted in the culture and purpose of Solar Gators. The teams serve to not only compete but also provide a chance for students to learn and to get hands on experience with important skills. The MPPT is an important and useful project to that end.

Also, a custom built MPPT allows for much deeper understanding of how it works and can help with integrating with the rest of the system. This can provide insight when making strategies regarding how to race, where to set arrays of solar modules, and how to set up pre-race and post-race charging (where the top is taken off to be set at an angle to the rising or setting sun to maximize exposure).



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## ***PART 2 DATASHEETS***



## ***1.1 BATTERIES DATASHEET***

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*Prepared*

LGC MBD/MBDC

Oh, Kyung Su

## PRODUCT SPECIFICATION

**CONFIDENTIAL**

*Document No.*

LRB-PS-CY3450\_MJ1

*Date*

2014-08-22

*Rev*

1

*Approved*

LGC MBD/MBDC

Kim, Dong Myung

*Description*

Lithium Ion INR18650 MJ1 3500mAh

# PRODUCT SPECIFICATION

Rechargeable Lithium Ion Battery

Model : INR18650 MJ1 3500mAh



20 YOIDO-DONG YOUNGDUNGPO-GU,

SEOUL 150-721, KOREA

<http://www.lgchem.com>



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## 1. General Information

### 1.1 Scope

This product specification defines the requirements of the rechargeable lithium ion battery of LG Chem.

### 1.2 Product classification

Cylindrical rechargeable lithium ion battery

### 1.3 Model name

INR18650 MJ1

## 2. Nominal Specification

Item	Condition / Note	Specification
2.1 Energy	Std. charge / discharge	Nominal 3500 mAh Minimum 3400 mAh
2.2 Nominal Voltage	Average	3.635V
2.3 Standard Charge (Refer to 4.1.1)	Constant current Constant voltage End current(Cut off)	0.5C (1700mA) 4.2V 50mA
2.4 Max. Charge Voltage		4.2 ± 0.05V
2.5 Max. Charge Current		1.0 C (3400mA)
2.6 Standard Discharge (Refer to 4.1.2)	Constant current End voltage(Cut off)	0.2C (680mA) 2.5V
2.7 Max. Discharge Current		10A
2.8 Weight	Approx.	Max. 49.0 g
2.9 Operating Temperature	Charge Discharge	0 ~ 45 °C -20 ~ 60 °C
2.10 Storage Temperature (for shipping state)	1 month 3 month 1 year	-20 ~ 60 °C -20 ~ 45 °C -20 ~ 20 °C

### 3. Appearance and Dimension

#### 3.1 Appearance

There shall be no such defects as deep scratch, crack, rust, discoloration or leakage, which may adversely affect the commercial value of the cell.

#### 3.2 Dimension

Diameter: 18.4 +0.1 / -0.3 mm (Max. 18.5mm)

Height: 65.0 ±0.2mm (Max. 65.2mm)

### 4. Performance Specification

#### 4.1 Standard test condition

##### 4.1.1 Standard Charge

Unless otherwise specified, "Standard Charge" shall consist of charging at constant current of 0.5C. The cell shall then be charged at constant voltage of 4.20V while tapering the charge current. Charging shall be terminated when the charging current has tapered to 50mA. For test purposes, charging shall be performed at 23°C ± 2°C.

##### 4.1.2 Standard Discharge

"Standard Discharge" shall consist of discharging at a constant current of 0.2C to 2.50V. Discharging is to be performed at 23 °C ± 2 °C unless otherwise noted (such as capacity versus temperature).

##### 4.1.3 High Drain rate Charge/discharge condition

Cells shall be charged at constant current of 1,500mA to 4.20V with end current of 100mA. Cells shall be discharged at constant current of 4,000mA to 2.50V. Cells are to rest 10 minutes after charge and 20 minutes after discharge.

#### 4.2 Electrical Specification

Item	Condition	Specification
4.2.1 Initial AC Impedance	Cell shall be measured at 1kHz after charge per 4.1.1.	≤ 40 mΩ, without PTC
4.2.2 Initial Capacity	Cells shall be charged per 4.1.1 and discharged per 4.1.2 within 1h after full charge.	≥ 3400 mAh
4.2.3 Cycle Life	Cells shall be charged and discharged per 4.1.3 400 cycles. A cycle is defined as one charge and one discharge. 401st discharge power shall be measured per 4.1.1 and 4.1.2	≥ 80 % (of C <sub>min</sub> in 2.1)

## 4.3 Environmental specification.

Item	Condition		Specification
4.3.1 Storage Characteristics	Cells shall be charged per 4.1.1 and stored in a temperature-controlled environment at 23°C ± 2°C for 30 days. After storage, cells shall be discharged per 4.1.2 to obtain the remaining power*.		Power remaining rate ≥ 90% (P <sub>min</sub> in 2.1)
4.3.2 High Temperature Storage Test	Cells shall be charged per 4.1.1 and stored in a temperature-controlled environment at 60°C for 1 week. After storage, cells shall be discharged per 4.1.2 and cycled per 4.1.3 for 3 cycles to obtain recovered power**.		No leakage, Power recovery rate ≥ 80%
4.3.3 High Temperature and High Humidity Test	Cells are charged per 4.1.1 and stored at 60°C (95% RH) for 168 hours. After test, cells are discharged per 4.1.2 and cycled per 4.1.3 for 3 cycles to obtain recovered power.		No leakage, No rust Power recovery rate ≥ 80%
4.3.4 Thermal Shock Test	65°C (8h) ← 3hrs → -20°C (8h) for 8 cycles with cells charged per 4.1.1 After test, cells are discharged per 4.1.2 and cycled per 4.1.3 for 3 cycles to obtain recovered power.		No leakage Power recovery rate ≥ 80%
4.3.5 Temperature Dependency of Capacity	Cells shall be charged per 4.1.1 at 23°C ± 2°C and discharged per 4.1.2 at the following temperatures.		
	Charge	Discharge	Capacity
	23°C	-10°C	
0°C			80% of P <sub>ini</sub>
23°C			100% of P <sub>ini</sub>
60°C			95% of P <sub>ini</sub>

\* Remaining Capacity: After storage, cells shall be discharged with Std. condition (4.1.2) to measure the remaining capacity.

\*\* Recovery Capacity: After storage, cells shall be discharged with fast discharge condition (4.1.3), and then cells shall be charged with std. charge condition (4.1.1), and then discharged with Std. condition (4.1.2). This charge / discharge cycle shall be repeated three times to measure the recovery capacity.

#### 4.4 Mechanical Specification

Item	Condition	Specification
4.4.1 Drop Test	Cells charged per 4.1.1 are dropped onto an wooden floor from 1.0 meter height for 1 cycle, 2 drops from each cell terminal and 1drop from the side of cell can (Total number of drops = 3).	No leakage No temperature rising
4.4.2 Vibration Test	Cells charged per 4.1.1 are vibrated for 90 minutes per each of the three mutually perpendicular axis (x, y, z) with total excursion of 0.8mm, frequency of 10Hz to 55Hz and sweep of 1Hz change per minute	No leakage

#### 4.5 Safety Specification

Item	Condition	Specification
4.5.1 Overcharge Test	Cells are discharged per 4.1.2, and then charged at constant current of 3 times the max. charge condition and constant voltage of 4.2V while tapering the charge current. Charging is continued for 7 hours (Per UL1642).	: No explode, No fire
4.5.2 External Short - Circuiting Test	Cells are charged per 4.1.1, and the positive and negative terminal is connected by a 100mΩ-wire for 1 hour (Per UL1642).	: No explode, No fire
4.5.3 Overdischarge Test	Cells are discharged at constant current of 0.2C to 250% of the minimum capacity.	: No explode, No fire
4.5.4 Heating Test	Cells are charged per 4.1.1 and heated in a circulating air oven at a rate of 5°C per minute to 130°C. At 130°C, oven is to remain for 10 minutes before test is discontinued (Per UL1642).	: No explode, No fire
4.5.5 Impact Test	Cells charged per 4.1.1 are impacted with their longitudinal axis parallel to the flat surface and perpendicular to the longitudinal axis of the 15.8mm diameter bar (Per UL1642).	: No explode, No fire
4.5.6 Crush Test	Cells charged per 4.1.1 are crushed with their longitudinal axis parallel to the flat surface of the crushing apparatus (Per UL1642).	: No explode, No fire

## 5. Caution

Warning: Using the lithium ion rechargeable battery, mishandling of the battery may cause heat, fire and deterioration in performance. Be sure to observe the following.

### 5.1 Cautions for Using and Handling

- When using the application equipped with the battery, refer to the user's manual before usage.
- Please read the specific charger manual before charging.
- Charge time should not be longer than specified in the manual.
- When the cell is not charged after long exposure to the charger, discontinue charging.
- Battery must be charged at operating temperature range 0 ~ 45 °C.
- Battery must be discharged at operating temperature range -20 ~ 60 °C.
- Please check the positive(+) and negative(-) direction before packing.
- When a lead plate or wire is connected to the cell for packing, check out insulation not to short-circuit.
- Battery must be stored separately.
- Battery must be stored in a dry area with low temperature for long-term storage.
- Do not place the battery in direct sunlight or heat.
- Do not use the battery in high static energy environment where the protection device can be damaged.
- When rust or smell is detected on first use, please return the product to the seller immediately.
- The battery must be away from children or pets
- When cell life span shortens after long usage, please exchange to new cells.

### 5.2 Prohibitions

- Do not use different charger. Do not use cigarette jacks (in cars) for charging.
  - Do not charge with constant current more than maximum charge current.
  - Do not disassemble or reconstruct the battery.
  - Do not throw or cause impact.
  - Do not pierce a hole in the battery with sharp things. (such as nail, knife, pencil, drill)
  - Do not use with other batteries or cells.
  - Do not solder on battery directly.
  - Do not press the battery with overload in manufacturing process, especially ultrasonic welding.
  - Do not use old and new cells together for packing.
  - Do not expose the battery to high heat. (such as fire)
  - Do not put the battery into a microwave or high pressure container.
  - Do not use the battery reversed.
  - Do not connect positive(+) and negative(-) with conductive materials (such as metal, wire)
  - Do not allow the battery to be immersed in or wetted with water or sea-water.
-

### 5.3 Caution for the battery and the pack

Pack shall meet under condition to maintain battery safety and last long performance of the lithium rechargeable cells.

#### 5.3.1 Installing the battery into the pack

- The cell should be inspected visually before battery assembly into the pack.
- Damaged cell should not be used. (Damaged surface, can-distortion, electrolyte-smell)
- Different Lot Number cells should not be packaged into the same pack.
- Different types of cells, or same types but different cell maker's should not be used together.

#### 5.3.2 Design of battery pack

- The battery pack should not be connected easily to any charger other than the dedicated charger.
- The battery pack has function not to cause external short cut easily.

#### 5.3.3 Charge

- Charging method is Constant Current-Constant Voltage (CC/CV).
- Charging should be operating under maximum charge voltage and current which is specified in the product specification. (Article. 2.4, 2.5)
- The battery should be charged under operating temperature specified in the product specification. (Article. 2.9)

#### 5.3.4 Discharge

- Discharging method is Constant Current (CC).  
(In case of using the battery for mobile equipment, discharging mode could be Constant Power.)
- Discharging should be operating under maximum discharge current which is specified in the product specification. (Article. 2.7)
- Discharging should be done by cut off voltage which is specified in the product specification. (Article. 2.6)
- The battery should be discharged under operating temperature specified in the product specification. (Article. 2.9)

#### 5.3.5 Protection Circuit

- The protection circuit should be installed in the battery pack, charger.
- Charger or pack should have voltage sensing system to control over charge or discharge in order to maintain the battery's normal operating mode and protect cell imbalance.
- Charger or pack should have warning system for over temperature, over voltage and over current.

## 6. EXCLUSION OF LIABILITY

THE WARRANTY SHALL NOT COVER DEFECTS CAUSED BY NORMAL WEAR AND TEAR, INADEQUATE MAINTENANCE, HANDLING, STORAGE, FAULTY REPAIR, MODIFICATION TO THE BATTERY OR PACK BY A THIRD PARTY OTHER THAN LGC OR LGC'S AGENT APPROVED BY LGC, FAILURE TO OBSERVE THE PRODUCT SPECIFICATION PROVIDED HEREIN OR IMPROPER USE OR INSTALLATION, INCLUDING BUT NOT LIMITED TO, THE FOLLOWING:

- . DAMAGE DURING TRANSPORT OR STORAGE
- . INCORRECT INSTALLATION OF BATTERY INTO PACK OR MAINTENANCE
- . USE OF BATTERY OR PACK IN INAPPROPRIATE ENVIRONMENT
- . IMPROPER, INADEQUATE, OR INCORRECT CHARGE, DISCHARGE OR PRODUCTION CIRCUIT OTHER THAN STIPULATED HEREIN
- . INCORRECT USE OR INAPPROPRIATE USE
- . INSUFFICIENT VENTILATION
- . IGNORING APPLICABLE SAFETY WARNINGS AND INSTRUCTIONS
- . ALTERING OR ATTEMPTED REPAIRS BY UNAUTHORIZED PERSONNEL
- . IN CASE OF FORCE MAJEURE (LIGHTENING, STORM, FLOOD, FIRE, EARTHQUAKE, ETC.)

THERE ARE NO WARRANTIES – IMPLIED OR EXPRESS – OTHER THAN THOSE STIPULATED HEREIN. LG CHEM SHALL NOT BE LIABLE FOR ANY CONSEQUENTIAL OR INDIRECT DAMAGES ARISING OR IN CONNECTION WITH THE PRODUCT SPECIFICATION, BATTERY OR PACK.



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## ***1.2 SOLAR CELLS DATASHEET***

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# 60 CELL MONO-CRYSTALLINE PERC SOLAR MODULE WITH SMARTWIRE



**EPIQ**  
SOLAR PANELS

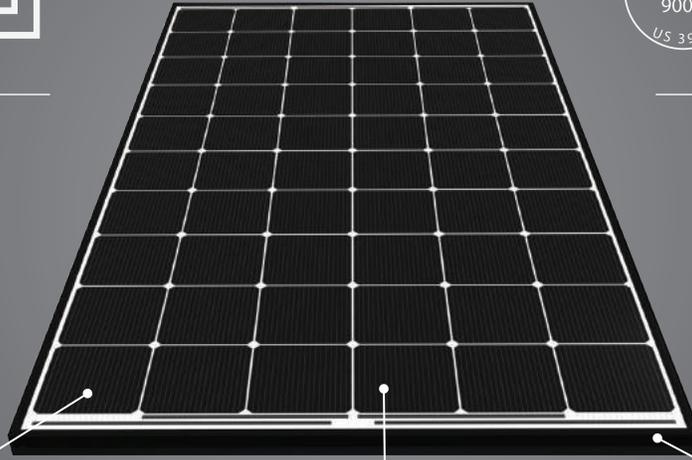
up to  
**310W**  
MONO-PERC



CERTIFICATIONS:  
IEC61215  
IEC61730  
UL1703  
Conformity to CE



**12**  
Year  
Product  
Warranty



**30**  
Year  
Performance  
Warranty

SmartWire Technology lessens the effects of micro-fractures and shading

Mono-crystalline PERC Busbar-less cells

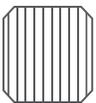
Anodized aluminum frame (Space Black or Metallic Silver)

## SMART FEATURES



### Superior Energy Production

Module efficiency up to **19.0%** achieved by utilizing the most advanced technology in the solar industry.



### SmartWire Technology (SWT)

The revolutionary process for connecting solar cells that outrivals busbars by spreading the electric current through 18 micro-wires.



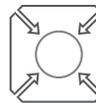
### Advanced PERC Technology

An advanced mono-crystalline cell which improves energy production by adding a special layer to capture more sunlight.



### Exceptional at low-light Conditions

The round shape of SmartWire reduces the wire shading by 25% and introduces a light trapping effect.



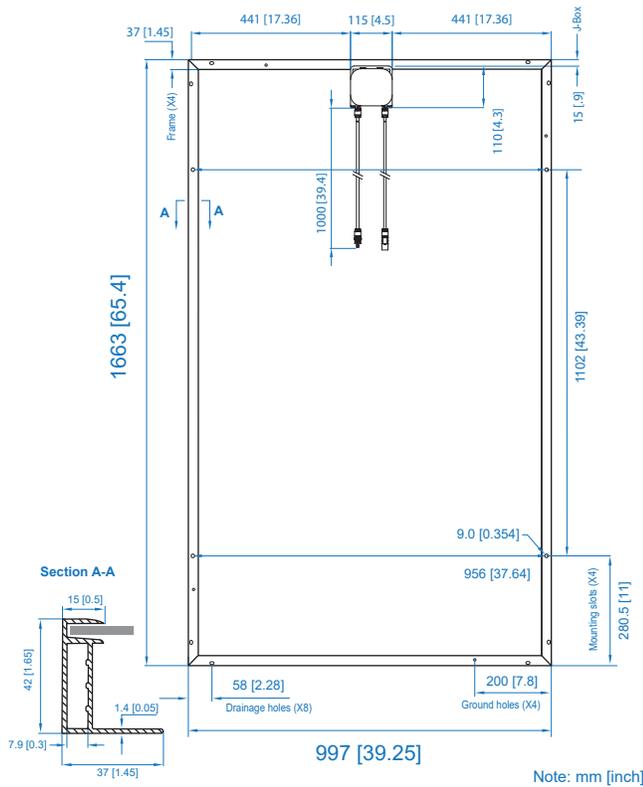
### Remarkable Connection Durability

SWT acts as a protective layer for the solar cell, ensuring reliable contact points for decades of consistent performance.



### Industry Leading Warranty

Accomplished with superior materials proven to perform better against potential induced degradation (PID).



### Mechanical Characteristics

Laminate Structure	Glass / TPO / Cells / TPO / Backsheet
Weight	Approx. 18 kg [40lbs]
Cell Type [mm]	Mono-crystalline PERC (156.75 mm)
Cell connection	60 cells (Serial)
Junction Box	IP65/IP67 with 3 Bypass Diodes
Cables Length	1m [39.4 in]
Connectors Type	MC4 Compatible
Moduel Dimensions	997 x 1663 x 42mm [39.25 x 65.4 x 1.65]
Encapsulant	(TPO) Hydrophobic
Front Load (Snow)	5400 Pa / 112.8 Psf
Rear Load (Wind)	3800 Pa / 79.4 Psf
Collection Pathways	18 Micro-wires
Glass Thickness	3.2mm [125] Anti-reflective Tempered Solar Glass (≥94% Transmittance)

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 www.solartechuniversal.com

### Electrical Characteristics STC

	STU- PERCB W-295	STU- PERCB W-300	STU- PERCB W-305	STU- PERCB W-310
Average Power	295W	300W	305W	310W
Max Module Efficiency (%)	18.1%	18.4%	18.7%	19.0%
Voltage at Max power (Vmp)	33.1V	33.4V	33.6V	33.9V
Current at Max power (Imp)	8.9A	9.0A	9.1A	9.1A
Open Circuit Voltage (Voc)	39.6V	39.9V	40.2V	40.6V
Short Circuit Current (Isc)	9.5A	9.5A	9.6A	9.7A
Operating Module Temperature	-40°C → 85°C			
Maximum System Voltage	1000V DC ( IEC + UL )			
Maximum Series Fuse Rating	20A			
Power Sorting	-0/+5W			

STC: Irradiance 1000 W/m<sup>2</sup>, module temperature 25 °C, AM=1.5; Best in Class AAA solar simulator (IEC 60904-9) used, power measurement uncertainty is within +/- 3%

### NOCT

	295W	300W	305W	310W
Max. Power at NOCT (Pmax)	215.6W	219.2W	222.9W	226.5W
Voltage Max. Power (Vmp)	30.3V	30.6V	30.8V	31.1V
Current Max. Power (Imp)	7.1A	7.2A	7.2A	7.3A
Open Circuit Voltage (Voc)*	36.9V	37.2V	37.5V	37.8V
Short Circuit Current (Isc)*	7.5A	7.6A	7.7A	7.7A

NOCT: 800 W/m<sup>2</sup> Irradiance, 20 °C ambient temperature, AM=1.5, wind speed 1 m/s  
 Values are based on RETC certified results from a light-soaked module.

### Temperature Characteristics

Nominal Operating Cell Temp. (NOCT)	45.3°C
Temperature Coefficient of Pmax	-0.366 %/°C
Temperature Coefficient of Voc	-0.281 %/°C
Temperature Coefficient of Isc	+0.041 %/°C

NOCT: 800 W/m<sup>2</sup> Irradiance, 20 °C ambient temperature, AM=1.5, wind speed 1 m/s;  
 NOCT values are based on RETC certified results. Based pm a 300w module

### Maximum Power at PTC

	273.4w	278.2w	282.9w	287.9w
Percentage of STC	92.7%	92.7%	92.8%	92.8%

### Certifications & Warranty

Safety and Aging	IEC61215
Mechanical and Structural Safety	IEC61730 / UL1703
Modules Fire Performance	Type 2 (UL1703)
Product Warranty	12 Years
Performance Warranty of Pmax	30 Years Linear*

\* 1st year 97%, 30th year 80%. Details of these warranties can be found at [www.solartechuniversal.com](http://www.solartechuniversal.com), under "Downloads"

### Shipping Configurations

	GP	HC	Trailer
Container Length	20'	40'	53'
Pallets Per Container	12	24	36
Modules Per Pallet	20	23	23
Modules Per Container	240	552	828





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**INDUSTRIAL ENGINEER MII**

# System Identification and control of MPPT DC-DC converters.

**SCHEMATICS**

Author: Nuria Santiso Serrano      Director: Dr Fazil Najafi

Coordinator: Tomás Gómez San Román

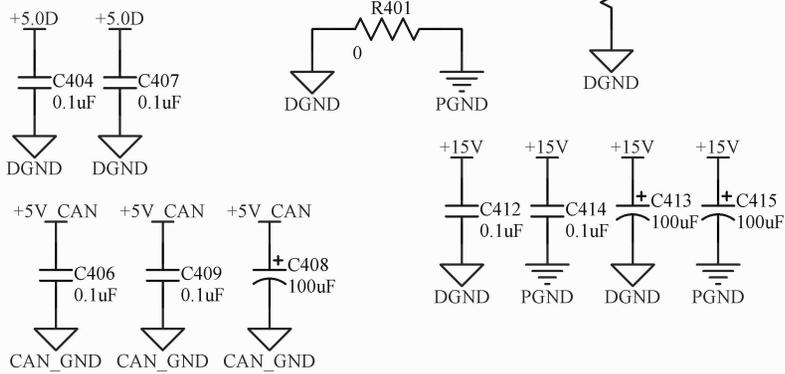
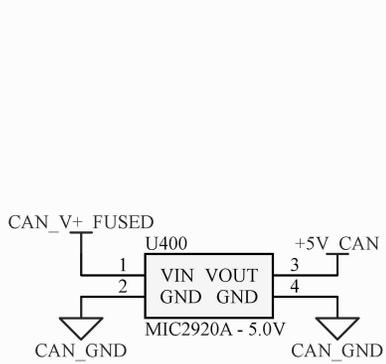
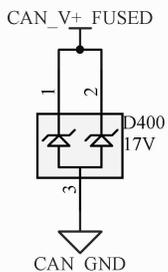
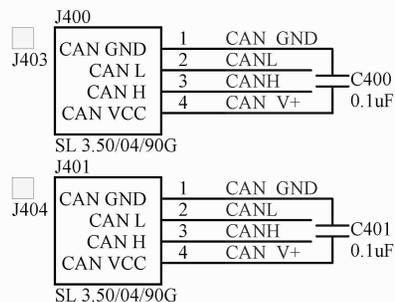
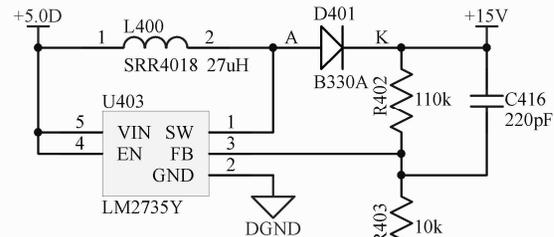
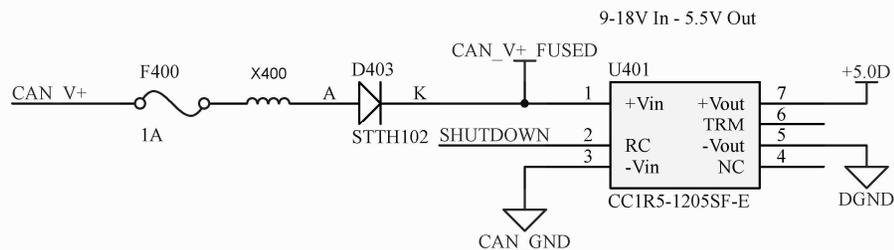
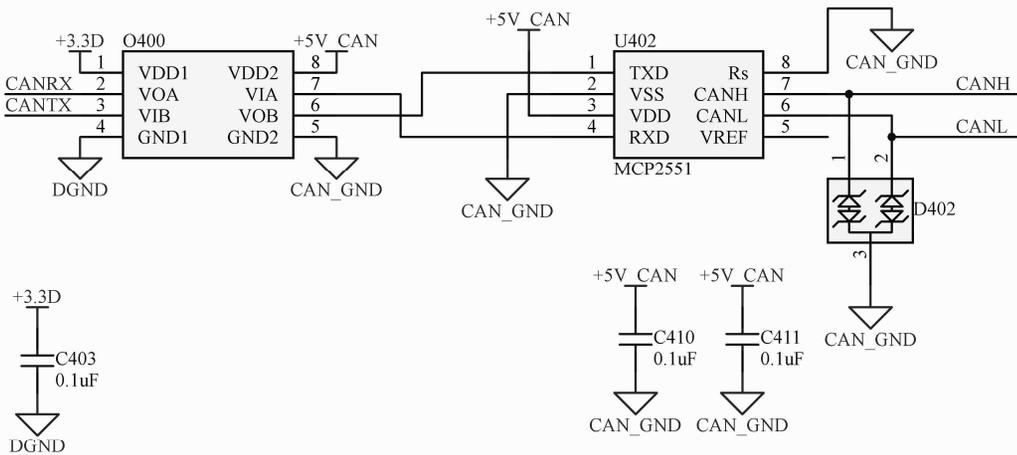
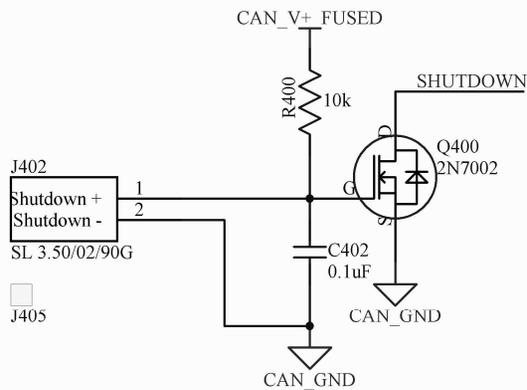
Madrid July 2019



## **PHOTON 1 MPPT SCHEMATICS**

Provided by the supplier

CAN Transceiver / Isolation



Title		
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**INDUSTRIAL ENGINEER MII**

# System Identification and control of MPPT DC-DC converters.

**BUDGET**

Author: Nuria Santiso Serrano      Director: Dr Fazil Najafi

Coordinator: Tomás Gómez San Román

Madrid July 2019



## **Budget index**

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<b>1.2 Electrical expenses .....</b>	<b>129</b>
<b>1.3 Mechanical expenses.....</b>	<b>132</b>
<b>1.4 Competition and travel expenses.....</b>	<b>134</b>



## CHAPTER 1 BUDGET

The purpose of the project is to learn while having fun designing a new concept car. The vehicle's development requires a lot of components that must be acquired through donations, sponsorships or family contributions. Despite the vehicle design and competition expenses, the struggle of organizing fundraisers to obtain the necessary funds for the project, the advantages outweigh the efforts.

The solar gators team has recycled some of the elements of the vehicle designed for the race in 2018.

### *1.3 GENERAL EXPENSES*

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The following table includes the expenses of the different departments in the 2018-2019 period.

Table 2. General expenditures

<b>Electrical</b>	\$7.511,00
<b>Mechanical</b>	\$2.801
<b>Competition/Logistics Fees</b>	\$10.200
<b>Motors</b>	\$26.000
<b>Budget Total</b>	\$46.512,00

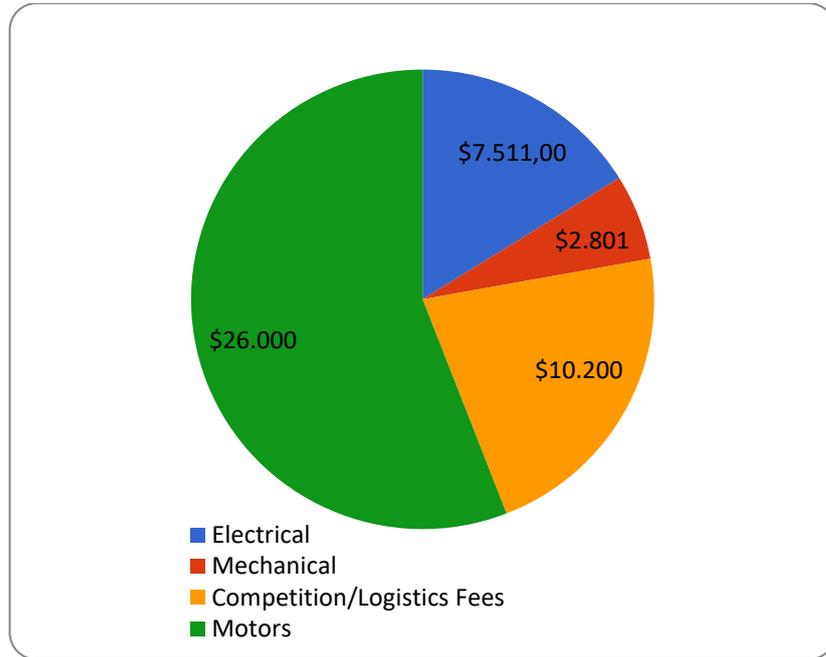


Figure 59. Graphical representation of the general expenses.

## 1.4 ELECTRICAL EXPENSES

The next table shows the breakdown for the electrical subsystem, for this year.

Table 3. Brakdown of the electrical expenses.

System	Part	Quantity	Cost Per	Cost
Relay Board	Bat => 12	2	100	200
	12 => 5	2	100	200
	Headers	20	4	80
	Transistors	50	1	50



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	PCB	1	50	50
	Fuses	20	2	40
	Microcontroller	3	15	45
	Switches	10	3	30
	Fans	10	5	50
	PCBs	4	25	100
			<b>Relay Total</b>	<b>845</b>
<i>Harnessing</i>	20AWG Wire	10	3,5	35
	16AWG Wire	50	3	150
	12AWG Wire	20	2,5	50
	10AWG Wire	20	2,5	50
	6AWG Wire	10	4,5	45
	1/0 Wire	20	5,5	110
	Main Fuses			400
	Fuses			100
	Power connectors			20
	Mischellaneous Connectors			100
	Wire Loom			50
			<b>Harness Total</b>	<b>1110</b>
<i>BMS</i>	VTap Harness	1	\$40,00	\$40,00
	CSense Hrns.	1	\$40,00	\$40,00



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	Main I/O Hrms.	1	\$35,00	\$35,00
	Thm.Exp. Hrms.	1	\$50,00	\$50,00
	PCB	5	\$25,00	\$125,00
	Transistors	10	\$1,00	\$10,00
	Switches	4	\$15,00	\$60,00
	Contactors	3	\$150,00	\$450,00
	uC	5	\$2,00	\$10,00
	uC Discovery Bd	1	\$15,00	\$15,00
	BMS IC	20	\$10,00	\$200,00
	Daughter PCB	25	\$10,00	\$250,00
	Mother PCB	2	\$50,00	\$100,00
	Temp. sensor	25	\$2,00	\$50,00
	CAN transceiver	3	\$2,00	\$6,00
	Digital Isolator	25	\$2,00	\$50,00
	R, C, etc	x	x	\$50
			<b>BMS Total</b>	<b>\$1.541,00</b>
<b>MPPT</b>	Current Sensor	6	20	120
	Transistor	30	1	30
	Transistor Driver	10	1,5	15
	Diode	10	1,5	15
	Capacitor	20	3	60
	Inductor	6	10	60
	Screw Terminal	10	2	20



	PCB	25	4	100
	MicoProcessor	5	4	20
			<b>MPPT Total</b>	<b>440</b>
<i>Battery Pack</i>	LG MJ1 Li-on Batteries	550	4,5	2575
	Box	1	500	500
	Other(connectors/fans)	1	500	500
			<b>Battery Total</b>	<b>3575</b>
<b>Electrical</b>				
<b>Total</b>				<b>\$7.511,00</b>

## ***1.5 MECHANICAL EXPENSES***

*The mechanical expenses are shown in the next table.*

*Table 4. Break down of the mechanical expenses.*

<b>System</b>	<b>Part</b>	<b>Quantity</b>	<b>Cost Per</b>	<b>Cost</b>
<i>Brakes</i>	Aluminum Stock	1	450	\$450
	Throttle	1	106	\$106
			<b>Brakes Total</b>	<b>\$556</b>



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<i>Rear Suspension</i>	Aluminum Stock	1	500	\$500
	Hardware	1	200	\$200
	Misc	1	100	\$100
			<b>Rear Susp Total</b>	<b>\$800</b>
<i>Steering</i>	6' Rod	1	100	\$100
	New Hardware	1	75	\$75
	New U-Joint	1	50	\$50
			<b>Steering Total</b>	<b>\$225</b>
<i>Body</i>	Nida-Core	1	\$500	\$500
	Epoxy Resin	1	\$300	\$300
			<b>Body Total</b>	<b>\$800</b>
<i>Solar Array</i>	FEP	1	\$300	\$300
	EVA	1	\$140	\$120
			<b>Solar Array Total</b>	<b>\$420</b>
			<b>Mechanical Total</b>	<b>\$2.801</b>



## ***1.6 COMPETITION AND TRAVEL EXPENSES***

The last table shows the competition and travel expenses.

<b>System</b>	<b>Part</b>	<b>Quantity</b>	<b>Cost Per</b>	<b>Cost</b>
<i>Comp Fees</i>	Track Fees	1	\$3.000	\$3.000
	Registration Fees	1	\$1.500	\$1.500
			Comp Fees Total	\$4.500
<i>Travel Expenses</i>	Food	1	\$1.000	\$1.000
	Gas	1	\$1.100	\$1.100
	Lodging	1	\$2.200	\$2.200
	Rental Cars	1	\$1.400	\$1.400
			Travel Expenses Total	\$5.700
			<b>Competition Total</b>	<b>\$10.200</b>



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