MPPT TRACKER S.M.K.B. EDITION

SOLARCOM TEAM

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Thanks

We are in special need to thank everyone who helped us. Particularly our team wants to thank the technical supervisor of our project Daniel Dixneuf, the management supervisors Philippe Fillatreau and Thierry Desmaison, all the international office beginning from Francois Saiz, Elodie Cassiau, Danielle Barthares, and the other staff of ENIT for their valuable advices and assistance.

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Keywords

SOLAR	REGULATOR	MPPT
PTHOTOVOLTAIC	CONTROL	IMPLEMENTATION
MATLAB	SOLID WORKS	MANAGMENT

Contents

1. Abstract

Solarcom is a French company that is dedicated to supply, through solar energy, remote telecommunication devices such as repeaters of fiber optics or phone antennas.

The project is commissioned by Solarcom for the EPS work team from ENIT, and consists in realize the design of a voltage regulator, based on maximum power point tracking algorithms (MPPT), to control the operating point of the power source formed by an array of photovoltaic panels, thus improving their performance and make effective control over the method and charge status of the battery.

First is done a management, is explained in the first chapter, how is managed the different resources during the time to finish the project in the deadline.

In the second chapter is made a little State of art to know how is the actual market in this area ant to decide the specifications and price target.

To make the design of the device is necessary to model the physical environment in which the voltage regulator work to validate step by step, through simulation, different algorithms and components which will be based regulator. The software chosen to realize the mathematical models of the different physical devices on which operation of voltage regulator depends is MATLAB 2010b, the models were made by modeling and simulation tool SIMULINK.

The hardware design of the device is implemented in Solid Works, and in this chapter is explained every component that is inside the device, how it function and why it's selected. In this chapter is showed all necessary to build it physically.

In the software design chapter is explained every function used to make the regulator functional and implemented it in microcontroller, the code is made in C++ language by Code Warrior for Mororolla.

2. Management

2.1 Introduction

Management is essential to get anything done efficiently, to make the best use of resources and to work through complexity. But also management has the responsibility to get us to the destination, completing a less creative, but equally challenging and demanding tasks. So, for that reason the project manager must have the ability to organize the team project to achieve a specific goal. Plus, it is approved that the delegation of each team member to an assigned task into the project leads to a good result for the project. Besides this successful result it has to be noticed that this delegation of the tasks never over extends the workload of one member of the team. Finally last but not least, one of the most important things that management provides to the work team is confidence and optimism about the outcome of the final procedure.

2.2 Objectives

Nowadays, solar energy consists one of the main sources that has the ability to supply with big amount of power, many types of loads (telecommunications, etc).Our project subject is about the loading regulation of a solar field. More specific about the project is the necessity to create a complete photovoltaic panel with all the simulations are needed which will be applied into the system, the MPPT algorithm. The benefits of this application we gain from this, are the more efficiency and traceability for the solar panels.

2.3 Clients

Our project is mainly a research project given by Enit in cooperation with the Solarcom enterprise. For this reason the most important things that our team has to do is to define the clients and the deliverables which we will see below. In this paragraph you can see the clients to whom we are responsible for giving them all the documents which are consider with the progress of our work.

- For all the technical reviews: Daniel Dixneuf (ENIT's professor)
- For all the management reviews: Philippe Fillatreau and Thierry Desmaison(ENIT's professors)
- For the final presentation: Enit and Solarcom

2.4 Deliverables

Using the term deliverables we describe the desirable results that should be delivered in a certain time. In our occasion, the deliverables we should give to our clients is all the work that has been done in all these four months, at the final presentation which will take place at the 23th of June. This work includes the main deliverables which are the following:

- Regulator prototype
- Final Report
- Archival work

2.5 Structure

One important thing is the definition of the main structure of the project. In order to define it, it is important to bear in mind the skills, the strengths and the weaknesses of each member of the team. Besides that it must be defined how many objectives our team has to accomplish so it will be easier to identify things like: a) Expected results, b) Necessary resources c) responsibilities d) risks of failure or alternative solutions.

Before the definition of each task it should be considered two things simultaneously:

- Client satisfaction(quality, cost, time)
- Project team satisfaction

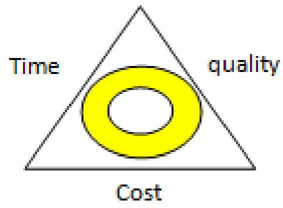


Figure 1

Taking into account all the above, it is important also to separate the project into several smaller work packages. This method allows organizing the management and the time better in order to reach the final goal. As a result of this method is a detailed analysis of the entire project into technical side, the management side and milestones.

<u>Technical Side</u>

- Hardware design
- Software design
- State of art
- Solar panel model
- Simulation of the solar panel model
- MPPT algorithm control
- Simulation of the MPPT algorithm control
- DC-DC converter
- Last version of charging a battery
- 3D model
- Complete simulation of the regulator
- Commercial paper
- Final report

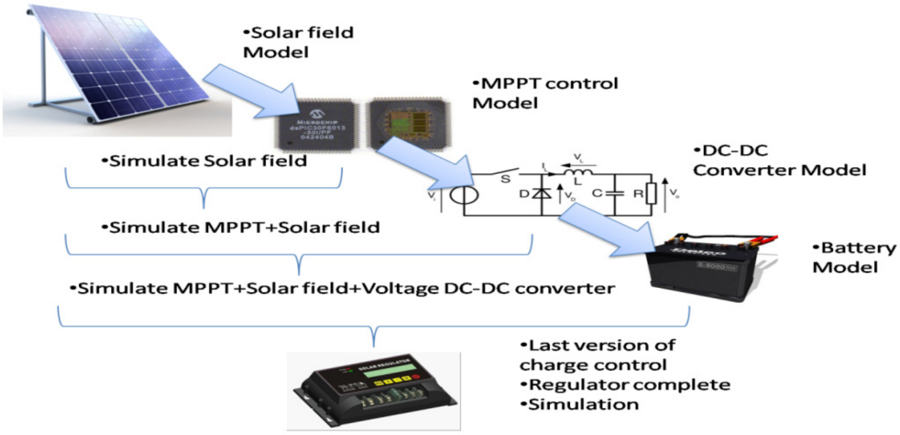


Figure 2

Management side

- Management planning
- Management monitoring
- Project tracking
  - Tracking Gantt
  - Tracking costs and deadlines
  - Critical path

Milestones (for more details see the annexe)

- 4 management reviews
- 2 intermediated reviews
  - Project review at 30/03/10
  - Project review at 19/05/10
- Final presentation at 23/06/10

2.6 WBS

The Work Breakdown Structure (WBS) consists a useful tool for project that helps to organize and define the total work scope of the project. The advantages of this tool that could be said are the facilitation of the progress measurement and the application of this method to more than 90% of projects, small or big projects. Besides that, the most important benefit is that defining smaller elements of the project –this means sub-tasks-it is easier to handle out the amount of work that should be done.

Working with our project, we are able to present in figure3 at the next page the definition of all the elements of the project. Their definition was made separating them to different levels, taking into account the importance of each one. The result of this strategy is clearly presented with the following diagram at the next page.

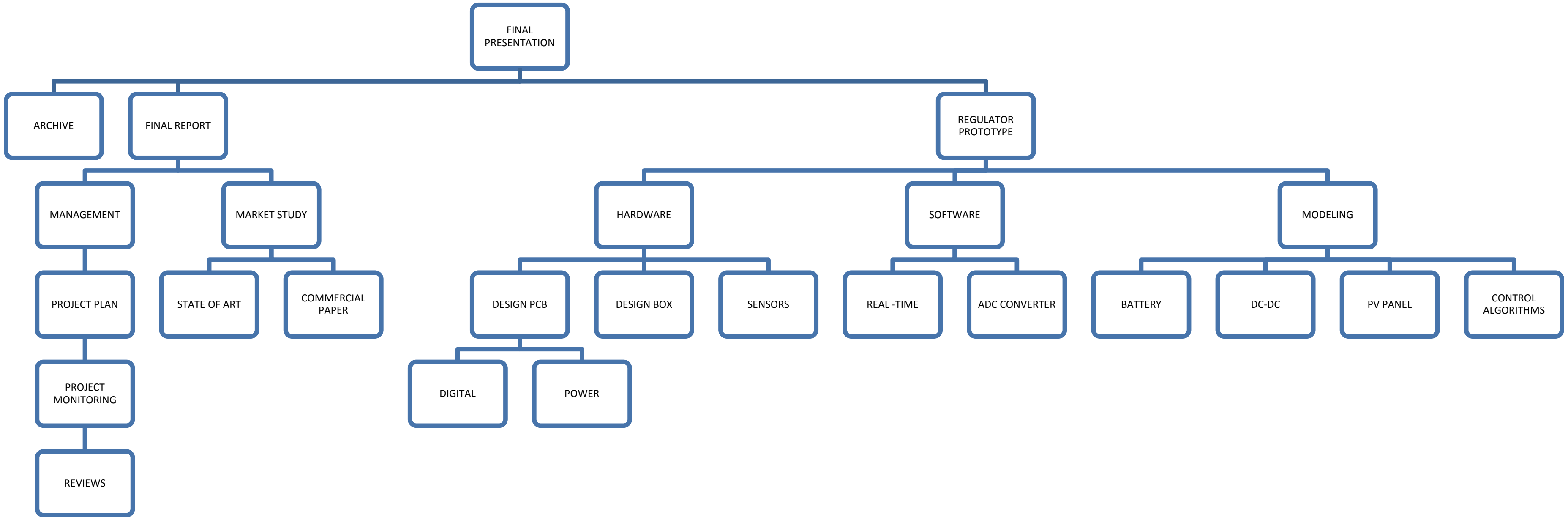

FINAL PRESENTATION
ARCHIVE
FINAL REPORT
REGULATOR PROTOTYPE
MANAGEMENT
MARKET STUDY
HARDWARE
SOFTWARE
MODELING
PROJECT PLAN
STATE OF ART
COMMERCIAL PAPER
DESIGN PCB
DESIGN BOX
SENSORS
REAL -TIME
ADC CONVERTER
BATTERY
DC-DC
PV PANEL
CONTROL ALGORITHMS
PROJECT MONITORING
DIGITAL
POWER
REVIEWS

Figure 3

2.7 Risks

A critical procedure inside a project is to identify and manage the risks. This belongs into the general risk management steps. This action offers to our team the ability to work with more efficiency and confidence, completing the project step by step.

It is easy to identify the risks by answering some questions considering about what is the main objective of the project, what are the resources that should be used and the proposed actions that should be taken to eliminate the risks. Taking into account all the above, it has been identified as risks, the final report for the regulator prototype and the effort is done to respect the given deadlines. Besides that, it is important to be referred that a successful project is when the result satisfies the client. As consider as the resources, they are separated into the human resources and the material resources. The human resources are the personal shortfalls (e.g. no knowledge for one subject), the absence of a team member during the project procedure because of an illness or an accident. After talking about the material resources, it could be said that they are the reliability of all the information which are collected during the period that the project lasts and all the software programs which are used, should be used legally from the team members.

As a conclusion, the work team should takes care some actions in order to prevent from appearing these risks or eliminate them if they are existing. These actions could be the flexibility between the human resources and that means the ability to cover this risk by working more and efficient. It can be also referred as critical action, the store of all the information into different storing devices or papers (reports, hard disk drive, and usb stick).

2.8. Project Planning

All the projects around the world are accomplished by making the project management. The project management brings about the successful completion of specific project goals and objectives. Having defined all the above and especially the deliverables, in our occasion the only useful tool that is in our hands is the Microsoft Office project (MS project). In the next lines and figures, it will be presented the most important results by using this software program.

2.8.1. Gantt Chart

The Gantt chart is a type of bar chart that illustrates a project schedule. A Gantt chart illustrates also the start and finish dates of the terminal elements. Gantt charts have become a common technique for representing the phases and activities of a project work breakdown structure (WBS), so they can be understood by a wide audience. At the next figure, it is clear to be seen the Gantt chart of our project.

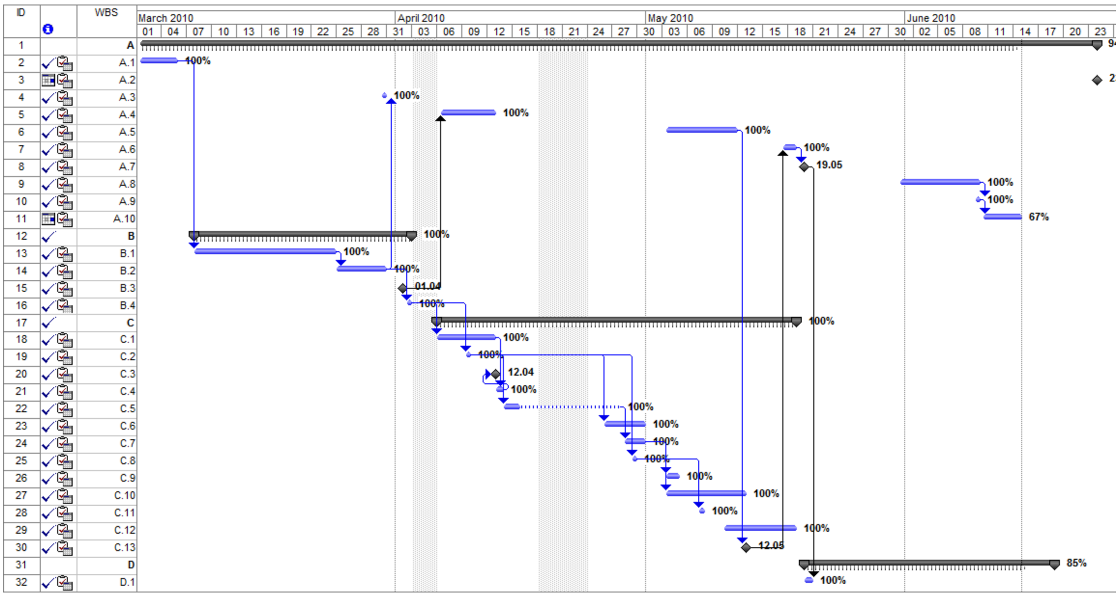


Figure 4

In figure 4 (for more details see the annex), we are able to derive information about the dates of each task and work package and also about the milestones that are defined.

2.8.2 Workload

Date	*Issue*	*Who*	*When*
15/03/10	Search information	All	24/03/10
18/03/10	EPS technical review	All	18/03/10
25/03/10	Select information	All	26/03/10
29/03/10	Management	All	
	• Ms project	Ahmed+Nikos	30/03/10
	• Intermediate review preparation	All	30/03/10
30/03/10	EPS 1st intermediate project review	All	30/03/10
31/03/10	EPS management review	All	31/03/10
02/04/10	EPS technical review	All	02/04/10
06/04/10	Management		
	• Project planning (Ms-Project)	Nikos+Ahmed	12/04/10
	• Management review preparation	Nikos+Ahmed	12/04/10
06/04/10	MPPT model	Didac+Martin	12/04/10
12/04/10	EPS technical review	Didac+Martin	12/04/10
13/04/10	MPPT model report	Didac	13/04/10
14/04/10	Dc-Dc converter	Didac	26/04/10
26/04/10	Model of battery	Martin+Didac	30/04/10
26/04/10	The way of charge	Martin+Didac	30/04/10
27/04/10	Report of Dc-Dc converter model	Didac	27/04/10
28/04/10	Simulation PV+MPPT+Dc-Dc	Didac	30/04/10
29/04/19	EPS technical review	All	29/04/10
03/05/10	Market study		
	• Products compare	Ahmed	18/05/10
	• State of art	Ahmed	28/05/10
03/05/10	Management		
	• Planning corrections	Nikos	11/05/10
	• Preparation for the mngt review	Nikos+Ahmed	11/05/10
	12_05_10	Martin	04/05/10
03/05/10	Mathematical model report of the solar panel	Didac+Martin	12/05/10
03/05/10	Simulation of the regulator	Didac+Martin	07/05/10
07/05/10	EPS technical review	Martin	18/05/10
10/05/10	Design coil (new task)	All	12/05/10
12/05/10	EPS mngt review	All	
13/05/10	Preparation for Intermed review 19_05_10	Ahmed	18/05/10
	• Market study report	Nikos	18/05/10
	• Management report	Didac+Martin	18/05/10
	• Technical report	All	19/05/10

19/05/10	EPS 2th intermed project review	Martin	28/05/10
20/05/10	Pre-design PCB & Box	Didac	20/05/10
20/05/10	Define the microcontroller	Didac	25/05/10
20/05/10	Select sensors	Didac	28/05/10
20/05/10	Make C code for µC (code warrior)	Didac	28/05/10
26/05/10	First conversion algorithm matlab → C	All	28/05/10
28/05/10	EPS technical review		
31/05/10	Management		
	• Project monotoring	Ahmed	08/06/10
	• Project tracking	Ahmed	09/06/10
31/05/10	Design PCB & Box	Martin	16/06/10
31/05/10	C code function of display	Nikos	02/06/10
31/05/10	C code function of ADC	Didac	31/05/10
01/06/10	Switch a relay drivers	Didac	04/06/10
03/06/10	Final C code µC	Nikos	10/06/10
07/06/10	Drivers design	Didac	07/06/10
08/06/10	Design digital PCB	Didac+Martin	11/06/10
09/06/10	EPS tech review	All	09/06/10
10/06/10	Preparation of mngt review 15_06_10	Ahmed	14/06/10
14/06/10	Report of hardware design	Didac	16/06/10
15/06/10	EPS mngt review	All	15/06/10
15/06/10	Software report	Nikos	18/06/10
17/06/10	PCB prints	Martin	18/06/10
16/06/10	Commercial paper	All	18/06/10
21/06/10	Preparation of the final presentation:		
	• Final report	All	22/06/10
	• Archival work	All	22/06/10
23/06/10	Final presentation	All	23/06/10

Figure 5

Doing the workload in a project, it consists the major help for all the members of the team. Each one of the work team is informed about the responsibilities and of course the assigned task that he has to do during the project.

2.9 Project monitoring

This section explains all the requirements needed for monitoring the project's progress. This includes technical and management process of monitoring, as well as the formal reporting requirements. It provides a guide for better practice for:

- Planning and conducting project review meetings.
- Centralize all information relating to the project.
- Preparing quality reports.
- Summarize the results and distribute to relevant stakeholders.

2.9.1 Tracking Gantt

Project monitoring should help, not hinder the project. Therefore, it is recommended to update the project progress at a given date:

- According to the predefined, important project milestones
- According to a predefined update frequency
- In relation to the handling of a particular critical problem

The tool that is usually used is the tracking Gantt in the MS-Project. The *Tracking Gantt* view provides a list of tasks and related information, and a chart showing baseline and scheduled Gantt bars for each task.

The baseline can be used to compare the original plan that has been done for the project with the actual course of the project. The *Tracking Gantt* view shows the tasks that should have been started earlier or later than they were planned, with the danger of exceeding their original budget, and lasting longer than the original planning.

In our project we defined two dates to update the project progress:

- Project status update as at 14/06/10

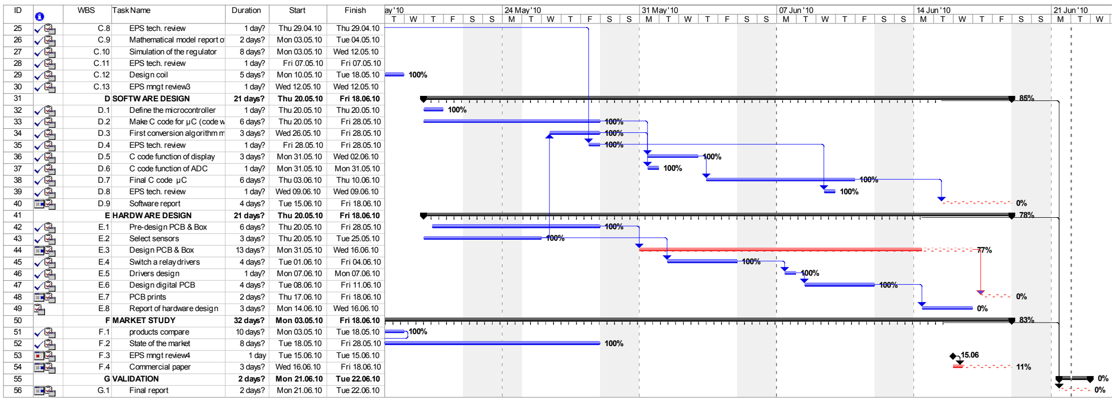


Figure 6

In figure 6(for more details see the annex), we are able to derive all the information about the tasks in the critical path and all the completed tasks until that date.

- Project status update as at 22/06/10

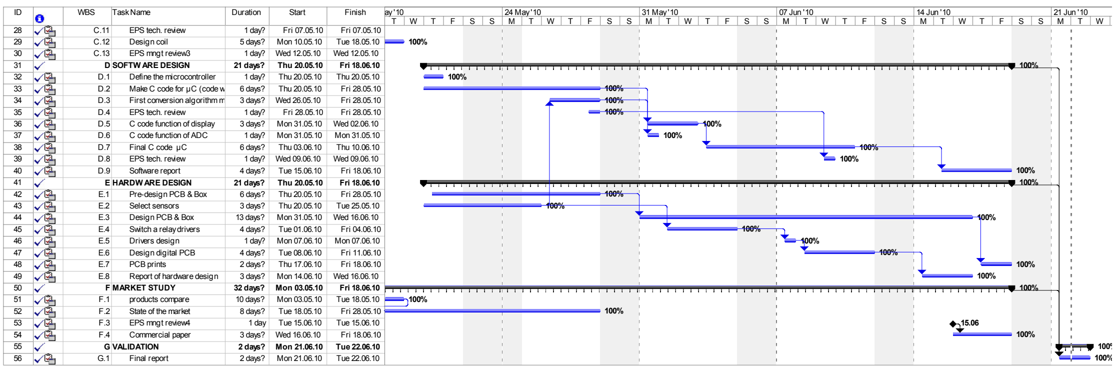


Figure 7

In figure 7 (for more details see the annex), we can see the difference between the two dates, which is ore in the critical path. So we can say that all the tasks are completed one day before the final presentation.

2.9.2 Results

It is well known that the management is very important for the procedure of a technical project. It directs the team members to take the good decisions during the project.

After that, there are technical, management reviews, simulations and validation for every step in the project. This project monitoring leads to some certain results, useful for import much information about it. Using the software program Microsoft Office project (MS Project), it is an important tool that enables all the team members to read all these information. At the next figures, it is presented some results about the management for the solarcom's project.

Dates			
Start:	Mon 1/3/10	Finish:	Wed 23/6/10
Baseline Start:	NA	Baseline Finish:	NA
Actual Start:	Mon 1/3/10	Actual Finish:	NA
Start Variance:	0 days	Finish Variance:	0 days

Duration			
Scheduled:	74 days?	Remaining:	0,42 days?
Baseline:	0 days?	Actual:	73,58 days
Variance:	74 days?	Percent Complete:	99%

Work			
Scheduled:	1.840,98 hrs	Remaining:	21 hrs
Baseline:	0 hrs	Actual:	1.819,98 hrs
Variance:	1.840,98 hrs	Percent Complete:	99%

Costs			
Scheduled:	$0,00	Remaining:	$0,00
Baseline:	$0,00	Actual:	$0,00
Variance:	$0,00		

Task Status		Resource Status	
Tasks not yet started:	1	Work Resources:	6
Tasks in progress:	3	Overallocated Work Resources:	0
Tasks completed:	52	Material Resources:	0
Total Tasks:	56	Total Resources:	6

Figure 8

In this figure 8, it is presented all the information for the duration of the project (duration), the total working hours (work), the total tasks in the project and the resources.

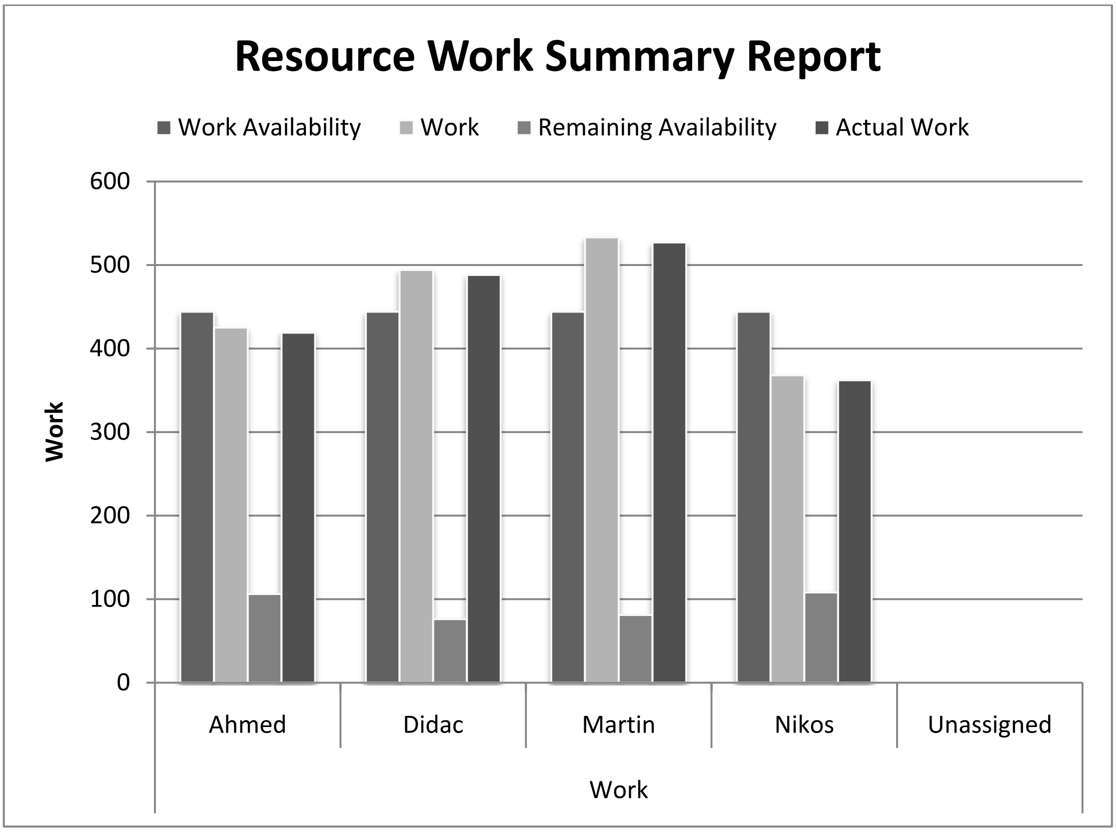


Figure 9

In the figure 9, the results is the summary of all the work that has been done during these four months for every member of the group. This diagram summarizes the total work availability, the work that has been done, the remaining work and the actual work. It is important to refer that the work is calculated in hours.

3. State of the Art

In this part of the project we have studied the prices of regulators which are already in existence and on the market in order to compare them with ours.

Considering the current state of affairs in the Gulf of Mexico, and the worlds' dependence upon oil and petroleum products for energy, the market of solar energies may be close to a large growth in the public domain. Currently, the market for solar regulators is largely centered in the private sector with large government contracts, providing power to stationed personnel in remote locations. However, as more people choose to 'go green', and as electricity and gas rates for the home rise, more homeowners will choose to adapt their homes to solar energy.

Energy products must work efficiently and properly, but where cost of the product is concerned, in order to bring solar energy further into the public domain, it must be more affordable for the average person. This is where our project, to create both an efficient and cost-efficient, solar regulator becomes evident.

In our study of the market, we realized that the price of the MPPT-rgulators depends on four different characters:

- Efficiency
- Maximum Charging Current
- Max. PV Off-Load Voltage
- Power

The different product compared are products of the following five companies:

- TrisStar
- Morningstar
- Steca Solar
- Esomatic
- Soltronic

Nº	Name	Price[€]	µ[%]	Imax[A]	Vin max offload[V]	Power[W]
1	TriStar MPPT-45	450	99	45	72	1200
2	TriStar MPPT-60	550	99	60	150	1600
3	SunSaver MPPT(morningstar)	226	97,5	15	75	400
4	MPPT 2010 Steca Solar	215	98	20	100	500
5	IVT MPPT(Esomatic)	150	97	30	60	600
6	MPPT100/20	260	97	20	95	600
7	Soltronic MPPT 7520	189	97,5	20	75	600

3.1 Comparison of the properties

3.1.1 Efficiency

The efficiency means that the output of the MPPT charge controller might vary continually to adjust for getting the maximum amps into the battery.

Therefore the efficiency can affect the price of the regulator, and as you can see on ***figure 10***, the price of regulators varies depending on the efficiency.

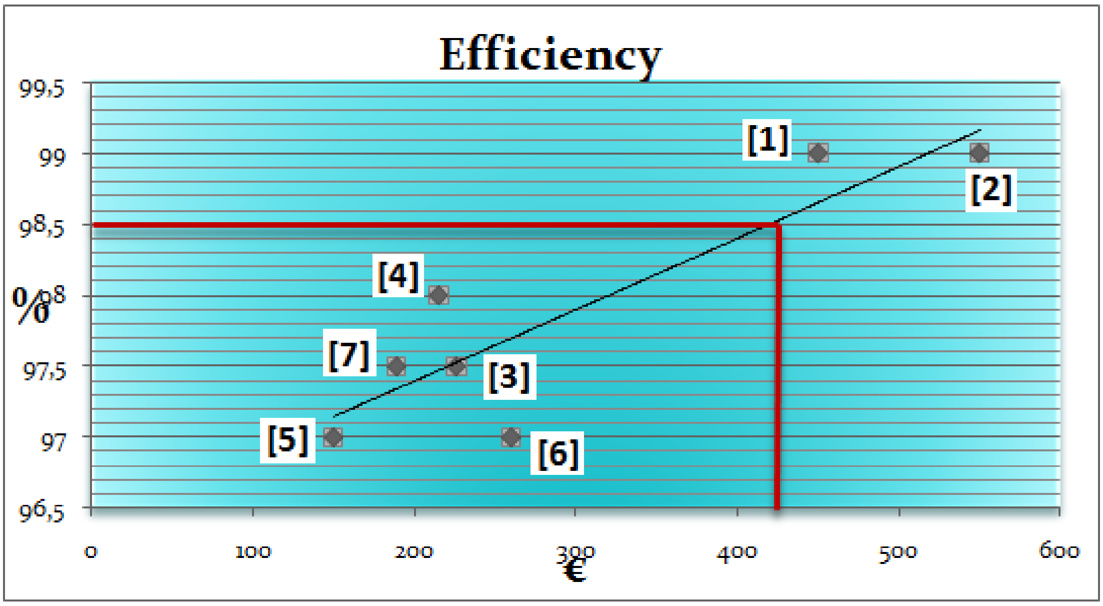


Figure 10

3.1.2 Maximum charging current

The maximum charging current is when the current limit phase of charging is flowing into the battery, because the battery voltage is below the set point. The charger senses this and sources maximum current to try to force the battery voltage up.

During the current limit phase, the charger must limit the current to the maximum allowed by the manufacturer to prevent damaging the batteries.

In our study of market, we found that the price is also dependent of the maximum charging current. On ***Figure 11*** you can see how the price increases depending on the current, with the exception of one product where the price is less than the other although he has 30A.

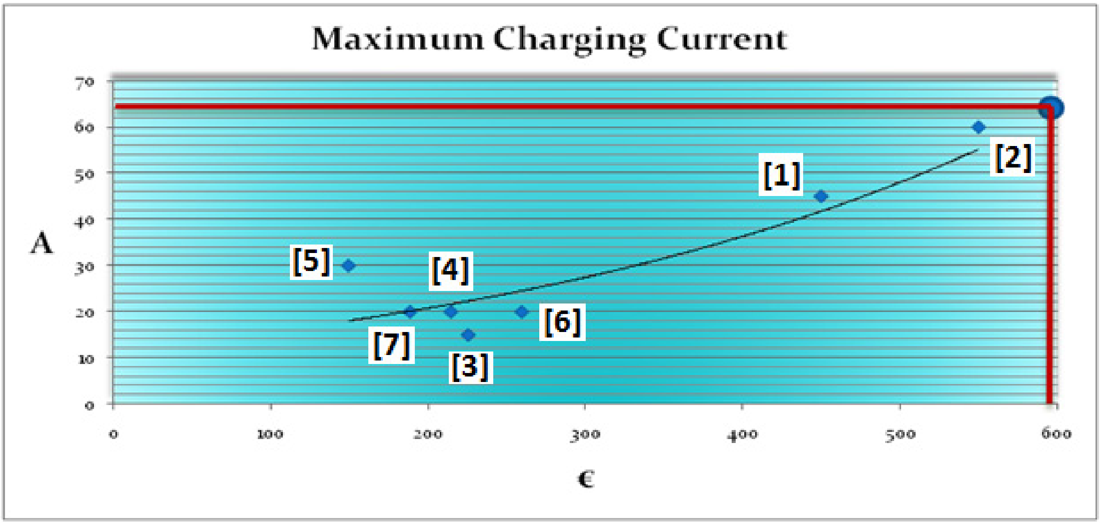


Figure 11

3.1.3 Max. PV Off-Load Voltage

Regulating the voltage of a transformer is a requirement that often arises in a power application or power System. Limit the dimension of the array that can be connected in the input.

The prices of the compared products are disposed depending the value of the voltage. ***Figure 12*** shows that the product designed should have the price of 200€ in comparison to the market in voltage topic.

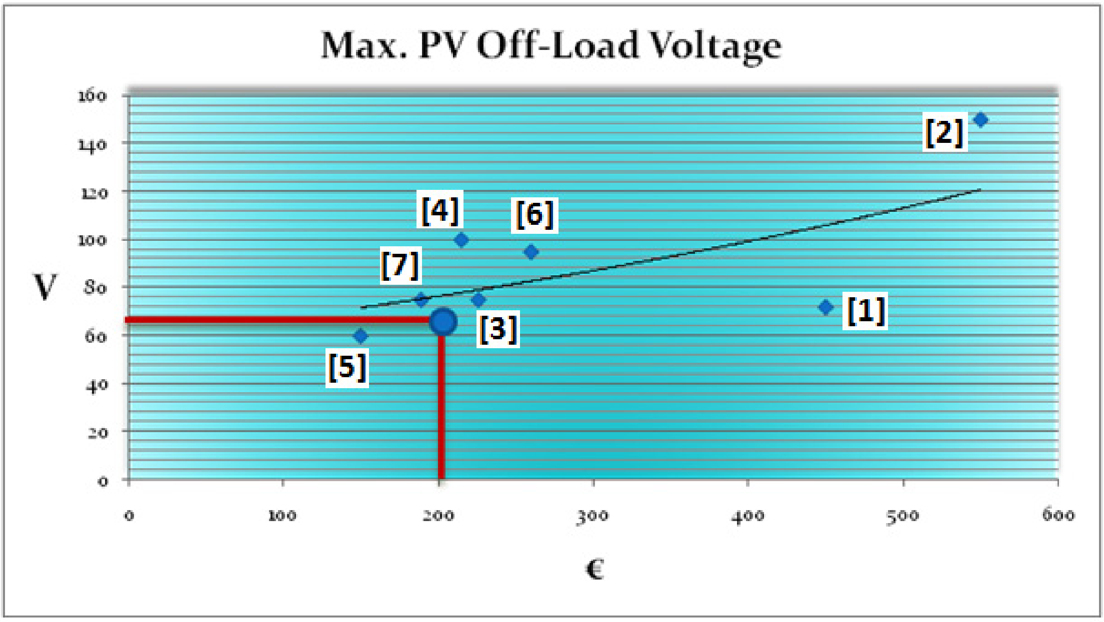


Figure 12

3.1.4 Power

This parameter means the power that can hold the regulator, most solar panels used with batteries are not operated at their output power, but are forced by the battery voltage to a lower-power output.

The designed product will employ Maximum Power Point Tracking to give more energy from the solar panels.

Therefore the price of the regulator increases with the increase of power. The graphic shows which price should be the regulator designed, because it will let the solar panel run at its most efficient voltage, extract the most power as possible, and charge the batteries at their voltage, with almost no loss.

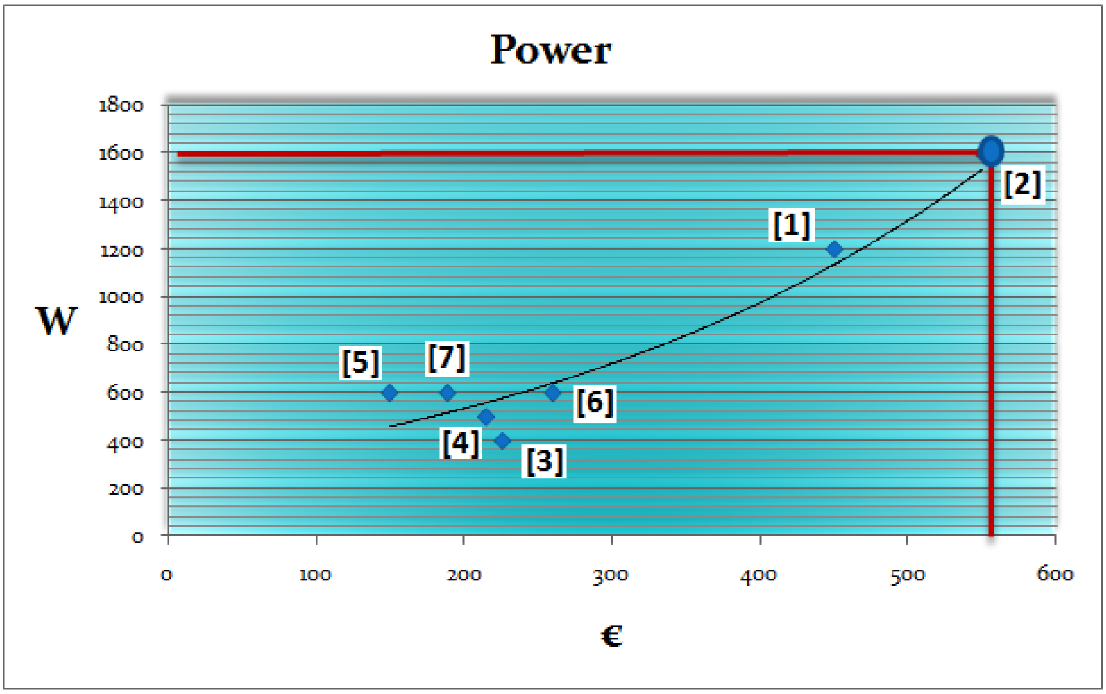


Figure 13

3.2 Conclusion

The product designed for Solarcom-Team of ENIT has been compared with other product already existing in the market with similar characteristics and technology to take an idea of the price that should be have the regulator designed in the actual market.

Efficiency	98.5%	420€
Output current	65A	600€
Max input voltage	63V	200€
Power	1600W	550€

For the Efficiency topic is, Solarcom-team regulator should acquire a value of 420€, for the maximum output current 600€, for the maximum input voltage 200€ and for the power 550€. This meant that to create an effective competence for the similar devices is necessary to increase the maximum input voltage to create a device with 500€ very competitive in the market.

4. Photovoltaic panel model

Mathematical model of photovoltaic (PV) panel is used to simulate regulator algorithm. The model represents properties of real solar panel and its reactions to external conditions such as changes of temperature, solar irradiance and it's possible to control its response by voltage.

4.1 Electrical model

For the purposes of simulation of controller is sufficient to use a one diode model shown on figure 14.

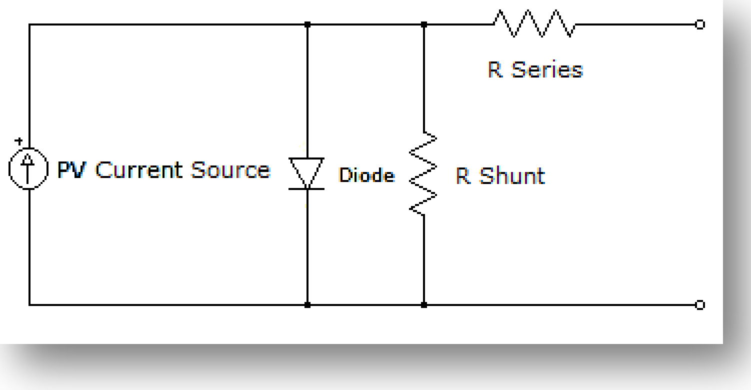


Figure 14 Diode model

4.2 Mathematical model

This model is defined in Simulink by equations of equivalent circuit

One cell model:

$$I = I_{PH} - I_{D1} - \frac{V + I \cdot R_S}{R_{SH}}$$

Panel and array model:

$$I = N_P \cdot I_{PH} - N_P \cdot I_{S1}(T)\left(e^{(V+I \cdot R_S)y} - 1\right) - N_P \cdot \frac{V + I \cdot R_S}{N_S \cdot R_{SH}}$$

Where:

I - Current of PV panel

R_S - Series resistance

I_{PH} - Current produced by solar irradience

R_{SH} - Shunt resistance

I_{D1} - Current of diode

N_S - Number cells multiplied by number of panels in series

V - Volatage of PV panel

N_P - Number cells multiplied by number of panels in paralel

Equations of: irradiance current, short circuit current, open circuit voltage, diode dark saturation current.

$$I_{PH} = I_{SC}(T) \cdot \frac{\lambda}{\lambda_{REF}}$$

$$I_{SC}(T) = I_{SCREF}\left(1 + K_{ISC}(T - T_{REF})\right)$$

$$V_{OC}(T) = V_{OCREF}\left(1 + K_{VOC}(T - T_{REF})\right)$$

$$I_{S1}(T) = I_{S1REF}\left(\frac{T}{T_{REF}}\right)^{\frac{3}{A_1}} e^{E_{GAP} \cdot y * \left(\frac{1}{T} - \frac{1}{T_{REF}}\right)}$$

$$y = \frac{q}{A_1 \cdot kB \cdot T}$$

T_{REF} - Reference temperature 298,15 °K
T - Actual temperature of PV panel
I_{SC} - Short circuit current of PV panel
V_{OC} - Open circuit voltage of PV panel
I_{S1} - Diode saturation current
λ - Solar irradience
E_{GAP} - Band gap of silicon semiconductor
q - Elementary electron charge
kB - Boltzman constant
K - Temperature constant
$_{REF}$ - at reference temperature

Computation of diode dark saturation current from boundary conditions.

$$T = T_{REF}; V = V_{OC}; N_S = 1 \rightarrow I = 0$$

$$0 = I_{PH} - I_{S1}\left(e^{V_{OC} \cdot y} - 1\right) - \frac{V_{OC}}{R_{SH}}$$

$$I_{S1}\left(e^{V_{OC} \cdot y} - 1\right) = I_{PH} - \frac{V_{OC}}{R_{SH}}$$

$$I_{S1} = \frac{I_{PH} - \frac{V_{OC}}{R_{SH}}}{e^{V_{OC} \cdot y} - 1}$$

4.3 Simulink model

From this equations it was made Simulink model of PV panel

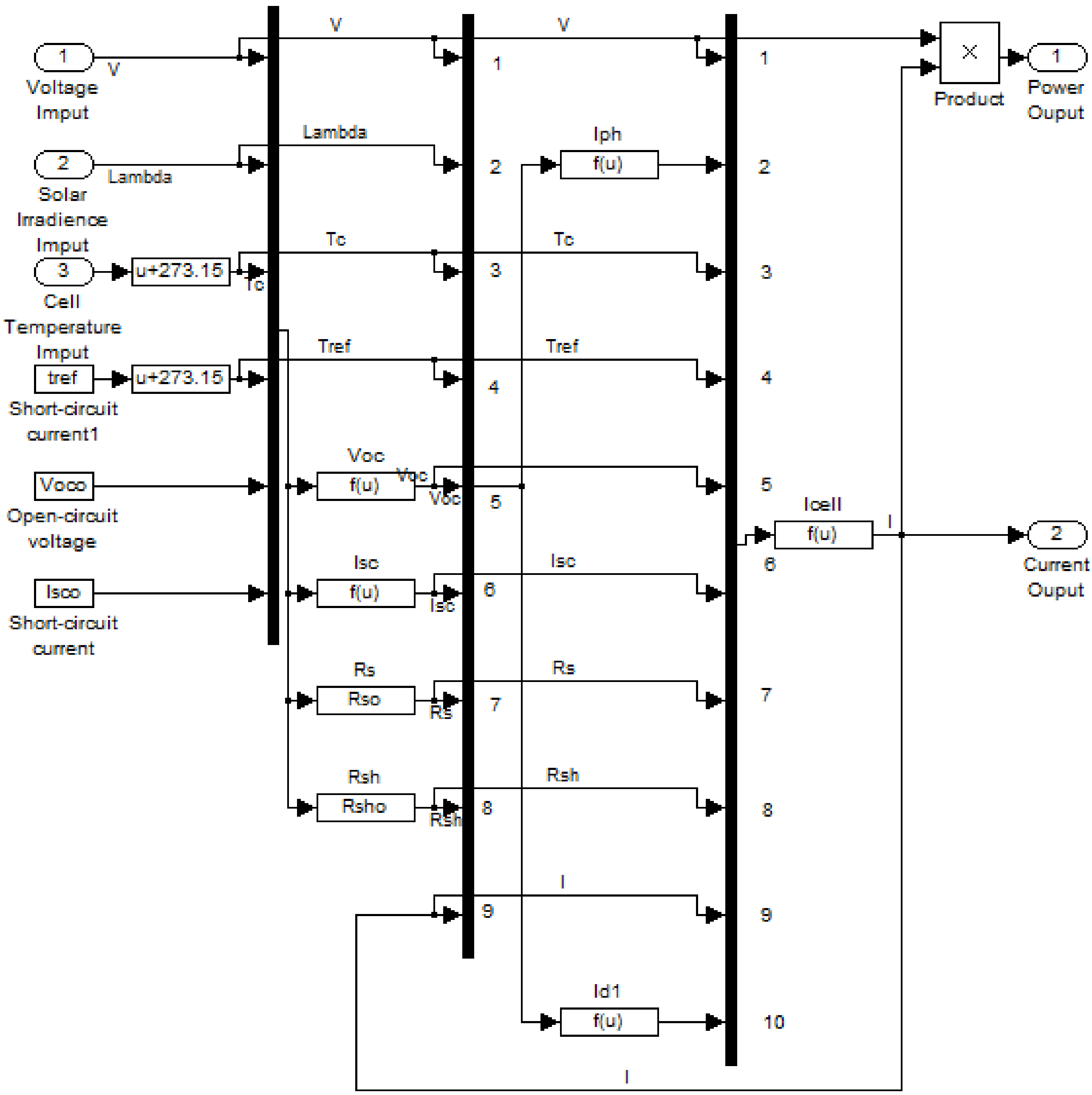


Figure 15 Simulink PV model

From model was made subsystem which is used to simulate other regulator parts, this model can be setup by setup window.

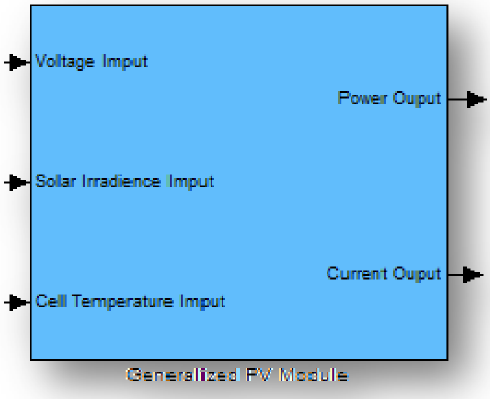


Figure 16 Simulink subsystem of generalized PV module

To could change panel easily has been created a mask with different parameters that can be changed.

This setup is divided to three sections, basic setup, advanced setup and constants.

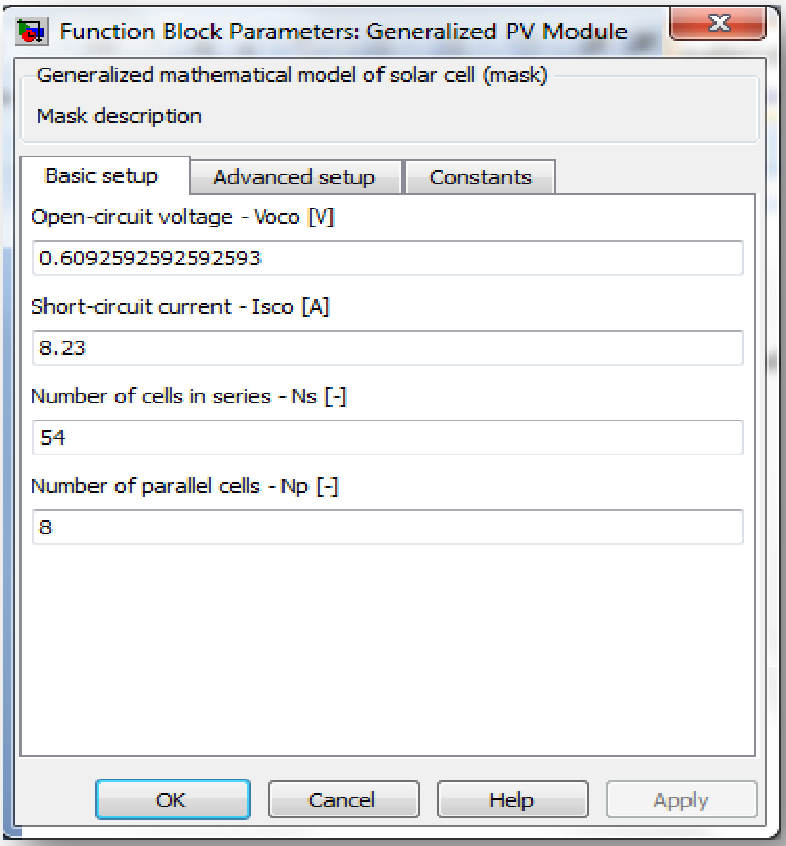


Figure 17 Subsystem setup

4.4 Simulation and validation

On figure 18 and 19 is comparison of real PV panel characteristic and simulink mathematical model of PV panel characteristic.

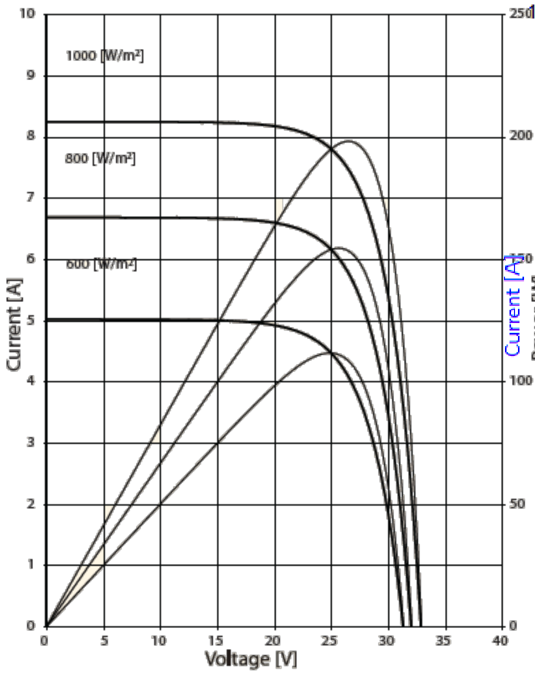


Figure 18 Real PV panel characteristic

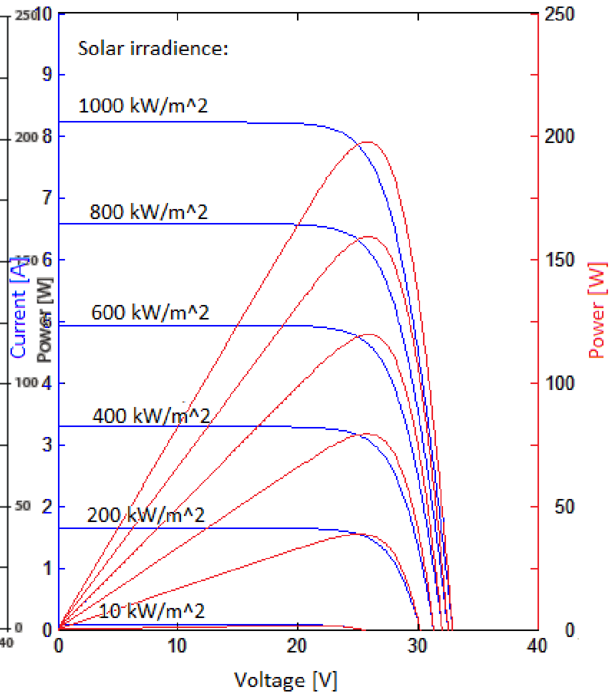


Figure 19 Simulink model characteristic

The photovoltaic panel simulated the correct function is verified looking at the data sheet characteristics and can be used to show and verify the next devices that depends for PV panel like a source.

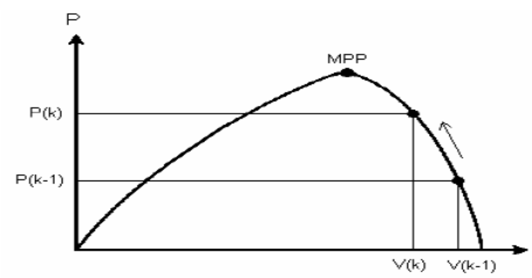
To show more information about the simulated solar field see data sheet in annex.

5. Maximum power point algorithm design

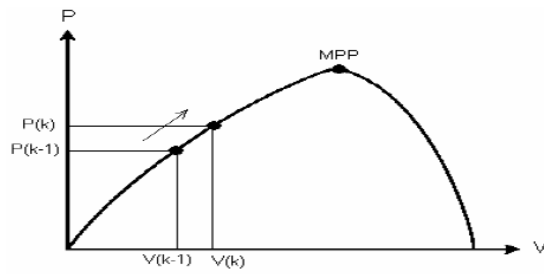
This section has developed a new method for detecting the maximum power point of the photovoltaic panel to get the best possible performance, this is named dPdV.

5.1 Basic study

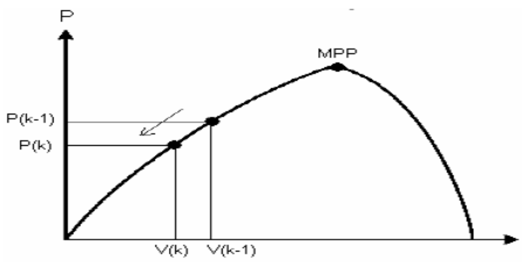
There are four different possible cases



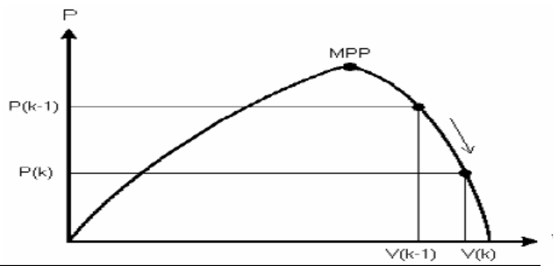
Decreasing the voltage of the photovoltaic panel increase the service panel power



Increasing the voltage of the photovoltaic panel increase the service panel power



Decreasing the voltage of the photovoltaic panel decrease the service panel power



Increasing the voltage of the photovoltaic panel decrease the service panel power

Figure 20, 4 possible cases to study

These four cases can be summarized in table 1 (+ increase, - decrease)

	S1	S2	S3	S4
Voltage	+	+	-	-
Power	+	-	+	-
Consign	+	-	-	+

Then the algorithm only needs this operation to make a decision:

$$Consign = \frac{dP}{dt} \cdot \frac{dV}{dt}$$

5.2 Code designed to implement the algorithm dPdV

The control id directly connected to the switch, for this reason the output is translated in 0 or 1, when a 0 is in the switch gate, there is Voc in the panel and Vbat when it's a 1.

Switching between this points, controlling the duty cycle though the MPPT algorithm it's possible to select a voltage in the panel, that have the desired result.

```
function y = fcn(dpdv,Volt)
if (dpdv>0)
    Volt=-1;
end
if (dpdv<0)
    Volt=1;
end

y = Volt;
```

5.3 Matlab model of dPdV MPPT algorithm

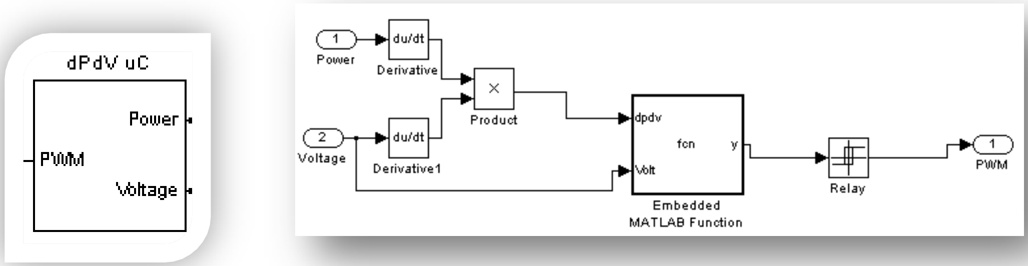


Figure 21 Simulink block diagram

First is implemented the operation necessary to make a decision, and in the embedded function there is the code of the algorithm, see figure 21.

5.4 Test of MPPT algorithm

To test the MPPT algorithm modeled, has been selected a changing irradiance source to see the algorithm tracking in the maximum power point in different cases.

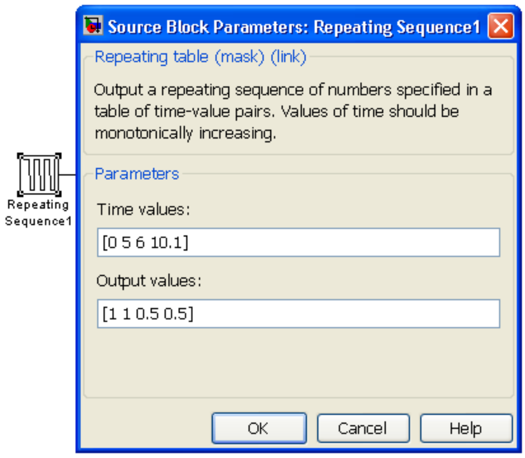


Figure 22 Setup of source in MPPT simulation

From the second 6 to 10 the irradiance will be the half.

The figure 23 shows the maximum point tracking power, in 1 second can be at some distant point in the MPPT found.

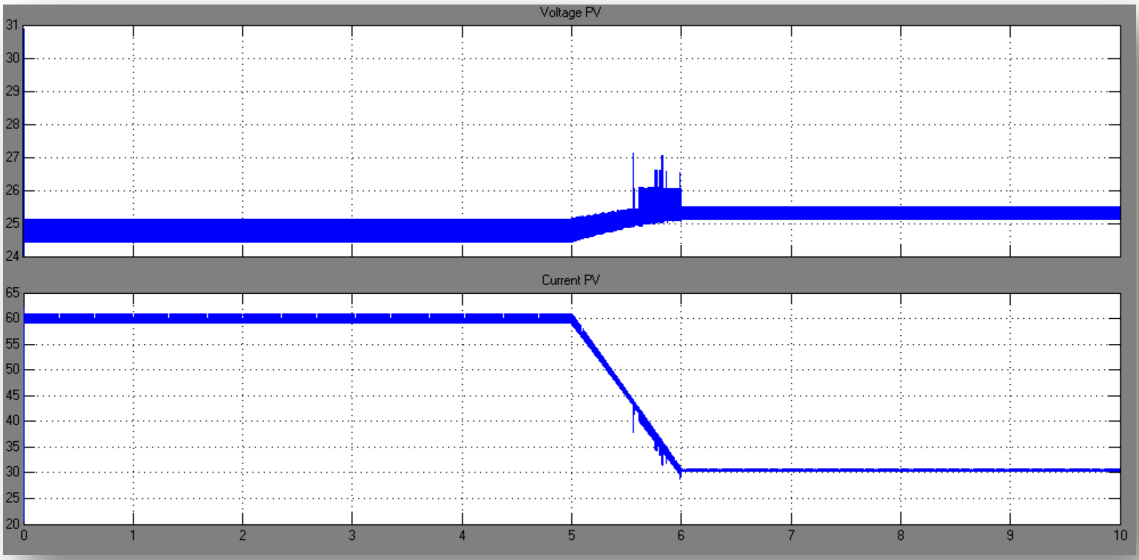


Figure 23 State of PV panel

This picture shows the response of the DC-DC converter for the changes in the panel to charge the battery.

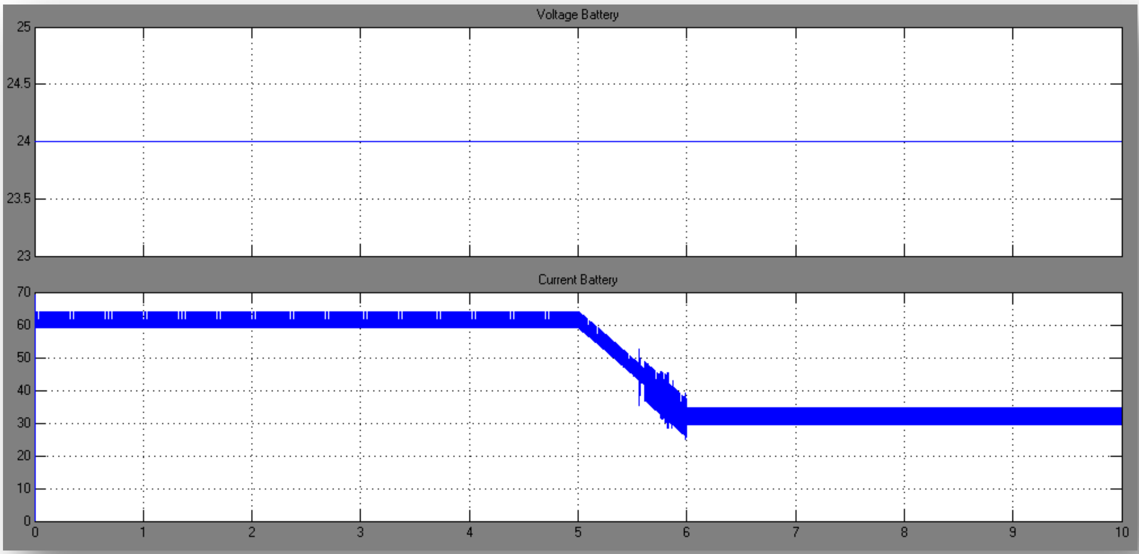


Figure 24 output controlled current

6. Voltage Regulator design

6.1 Modeling DC-DC converter

To control the photovoltaic power system is necessary to use a DC-DC converter, the most adequate is the Buck converter, its operation is to reduce the input voltage, the figure 25 shows the topology used.

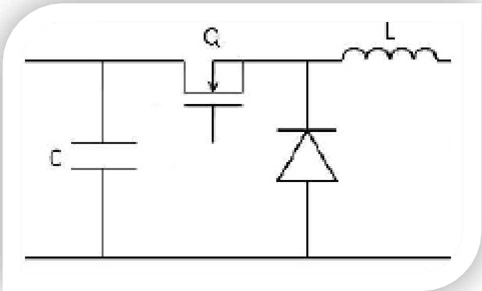


Figure 25 Buck Converter

By differential equations that define the behavior of the buck converter of figure, has been created the simulink model.

$$L\frac{di_L}{dt} = V_C \cdot D - V_{BAT}$$

$$C\frac{dV_C}{dt} = I - i_L \cdot D$$

Where i_L is the current of the battery, I is the current of the photovoltaic field, V_C is the voltage of the photovoltaic field and D is the PWM parameter control {0,1}.

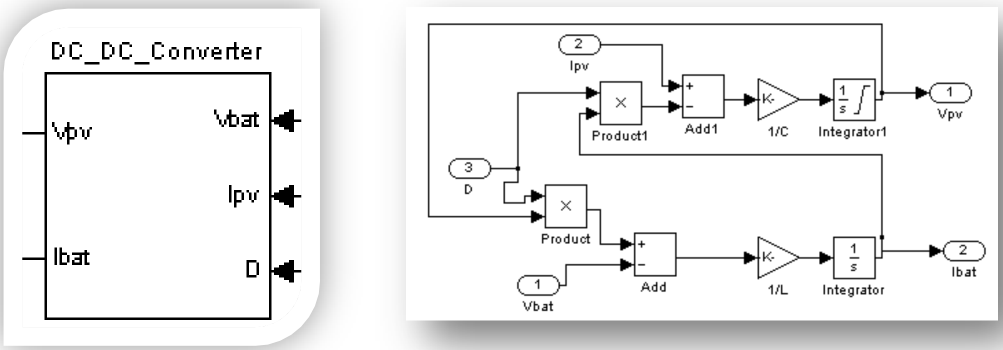


Figure 26 Simulink block diagram of DC-DC converter

6.2 Simulation of DC-DC converter

The object of the first simulation that have done it's for validate only the static part of the model, choosing a constant duty cycle to validate the equation.

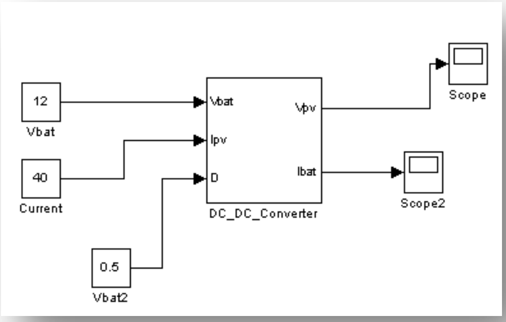


Figure 27 Validation of mathematic model

With a constant in Duty Cycle parameter 0.5, the voltage of the battery will be the half of the panel and the current the middle, Pin=Pout.

Voltage of photovoltaic field:

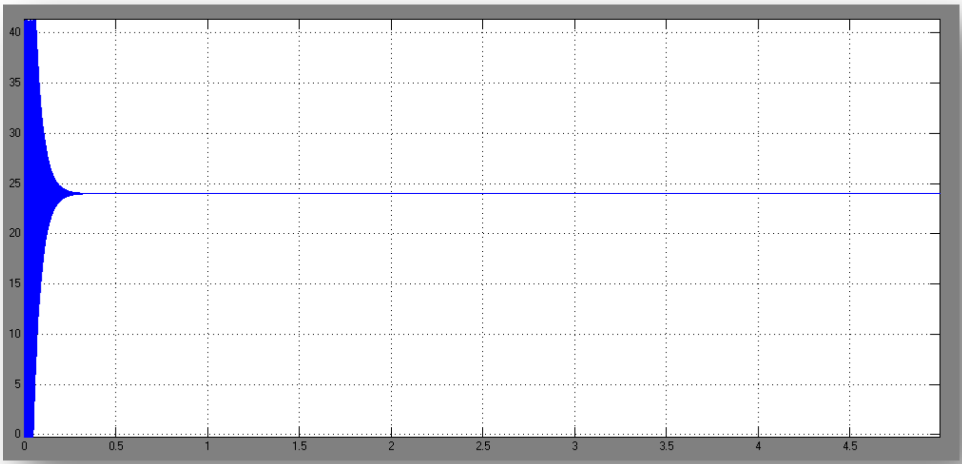


Figure 28 Voltage of PV panel

Current of Battery:

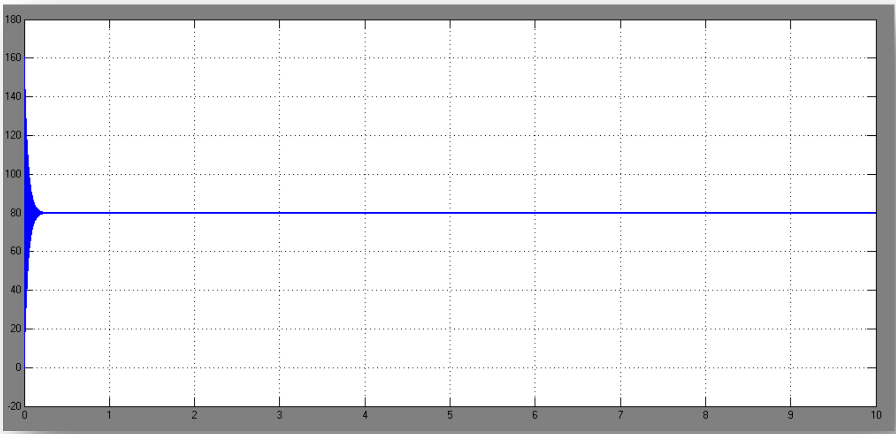


Figure 29, Output regulator current

With the buck converter modeled is necessary to design a PWM control to monitore the maximum power point while interacting with the power zone of the panel with Switch.

6.3 Design of PWM control

The PWM controller is based on the tracking algorithm point of maximum power of PV panel with a small modification on the output that result in changes in the voltage of the panel changes the pulse width (duty cycle) for control via Switch.

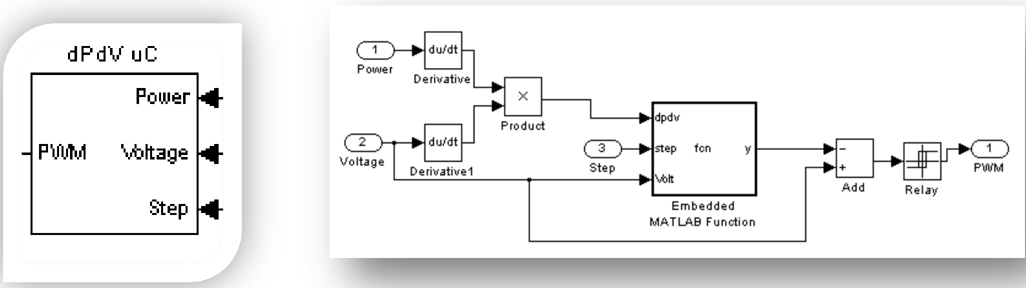


Figure 30 PWM control block diagram

6.4 Simulation of DC-DC converter in PV panel

To check the operation of the designed controller has performed the simulation with the photovoltaic panel with the MPPT algorithm, see figure 31.

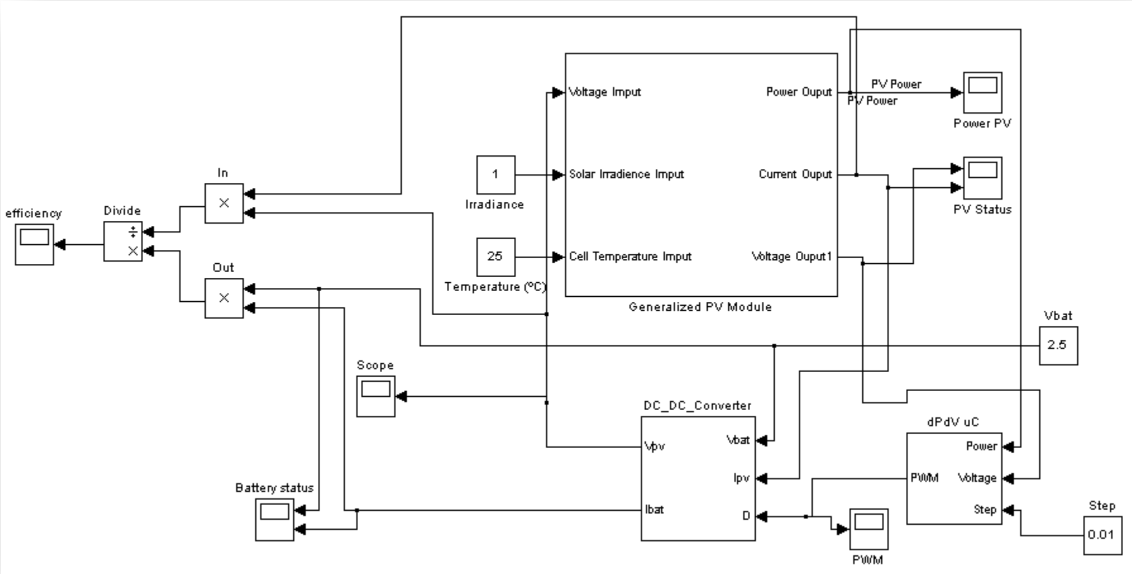


Figure 31, DC-DC converter complete simulation

The simulation is also useful for designing the values of inductance and capacity of the condenser and coil of Buck converter.

The simulations are performed to constant battery voltage, irradiance and temperature, 12V, 1000Wh/m2/day and 25ºC. The step of increment of the controller is defined to 0.01 and the frequency of the microcontroller 40kHz.

The complete system consists of six solar panels located in parallel, to perform the final design of the different components of the DC-DC converter is performed with complete system simulation.

6.5 Capacitor design

The capacitor needed it's a power capacitor not normal, it's necessary to support big currents, the next equation represents the current that will cross the capacitor.

$$I_C(A) = \frac{P}{Ns \cdot V_{PV}} = \frac{1600W}{2 \cdot 32.9V} = 24.31A$$

The typical parameter that explains the maximum current that can cross the capacitor is in efficacy value, then.

$$I_{Cef} = \sqrt{\frac{1}{T}\int I^2\,dt} \approx \frac{1}{3} I_C$$

The capacitor selected needs to support 8.1A, and the maximum voltage of the panel array is 60V, see figure 32.

Vishay BCcomponents Aluminum Capacitors, 101/102 PHR-ST

Power High Ripple Current Screw Terminals

Figure 32 Capacitor

ELECTRICAL DATA AND ORDERING INFORMATION FOR 101 SERIES										
U_R (V)	C_R 100 Hz (μF)	NOMINAL CASE SIZE Ø D x L (mm)	I_R 100 Hz 85 °C (A)	I_{LS} 5 min (mA)	ESR max. 100 Hz (mΩ)	Z max. 20 kHz (mΩ)	STANDARD HIGH POST M5 DISC		HIGH CURRENT M6 DISC	
							ST ORDERING CODE MAL2101......	ST BOLT NUT ORDERING CODE MAL2101......	ST ORDERING CODE MAL2101......	ST BOLT NUT ORDERING CODE MAL2101......
63	4700	35 x 60	5.9	0.59	42	25	18472E3	58472E3	-	-
	6800	35 x 60	6.6	0.86	38	25	18682E3	58682E3	-	-
	6800	35 x 80	7.3	0.86	30	19	28682E3	68682E3	-	-
	10 000	35 x 80	8.1	1.26	27	19	18103E3	58103E3	-	-
	10 000	35 x 105	8.8	1.26	22	14	28103E3	68103E3	-	-
	15 000	35 x 105	9.7	1.89	19	14	18153E3	58153E3	-	-
	15 000	50 x 80	12.1	1.89	16	11	28153E3	68153E3	-	-
	22 000	50 x 80	11.1	2.77	19	15	18223E3	58223E3	-	-
	22 000	50 x 105	14.3	2.77	12	9	28223E3	68223E3	-	-
	33 000	50 x 105	12.9	4.16	14	12	18333E3	58333E3	-	-
	33 000	65 x 105	16.5	4.16	9	6	28333E3	68333E3	48333E3	88333E3
	47 000	65 x 105	15.6	5.92	10	8	18473E3	58473E3	38473E3	78473E3
	47 000	76 x 105	18.6	5.92	8	6	28473E3	68473E3	48473E3	88473E3

6.6 Coil design

The equation to model the function of inductor is:

$$V_L = L\frac{di_L}{dt} \rightarrow V_L = L\frac{\Delta i_L}{\Delta t}$$

Then, working in 40kHz:

$$L = \frac{V_{BAT}\Delta T}{\Delta i_L} = 24\frac{\Delta \mathrm{T}}{\Delta i_L} = 24\frac{25 \cdot 10^{-6}}{5} = 125 \cdot 10^{-6}H = 125\mu H$$

The power inductor needed is 125uH 70A, it will be made manually because is so expensive in the market (see coil design chapter).

6.7 Functional DC-DC converter simulation

For a quick and precise response regulator have been adjusted inductance and capacitance values in 140uH and 10mF standard.

In this section have been simulated the operation of the entire system, grouping of photovoltaic panel (2x4), DC-DC converter and tracking algorithm for maximum power point.

The model of the panel simulated is Sharp MD-198UC1 with 198W polycristaline sylicon.

The power maxium result is 1486W in 70ms, see figure 33.

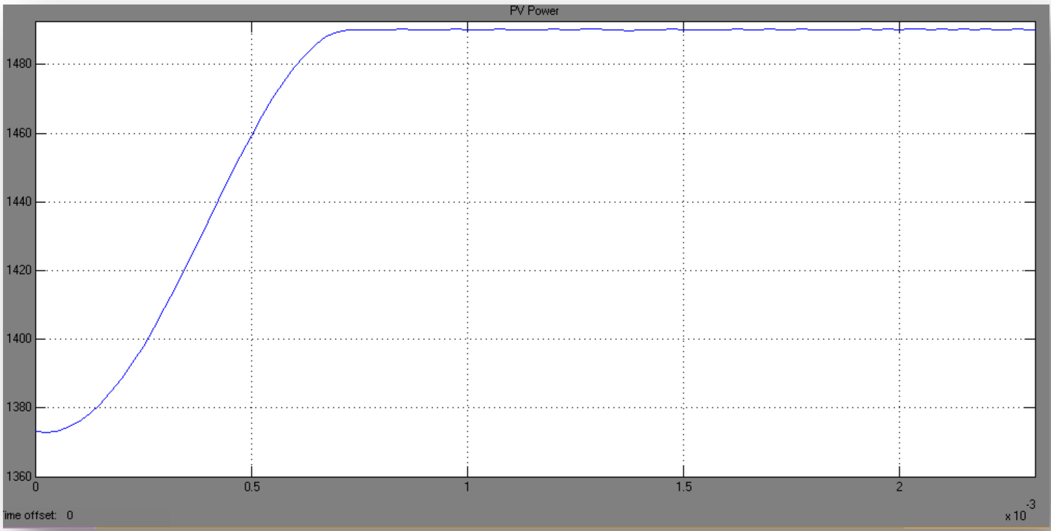


Figure 33 PV panel Power with MPPT algorithm

State of the panel, the MPPT in finded in 70ms, 49V, the voltage beguin in 54V for the charge of the coil and capacitor, and the picture shows that is quickly going to the MPPT, see figure 34.

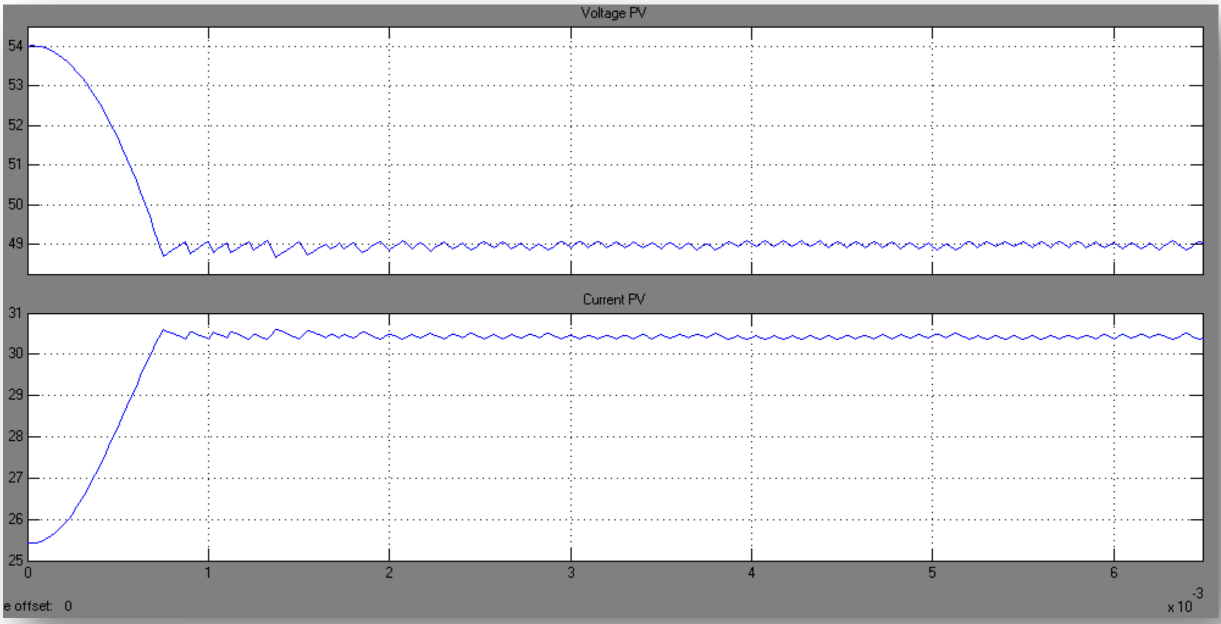


Figure 34 Panel state with MPPT algorithm

State of battery, the maxium battery current 62±2.5 A, is beginning to charge at the maxium current in 70ms, see figure 35.

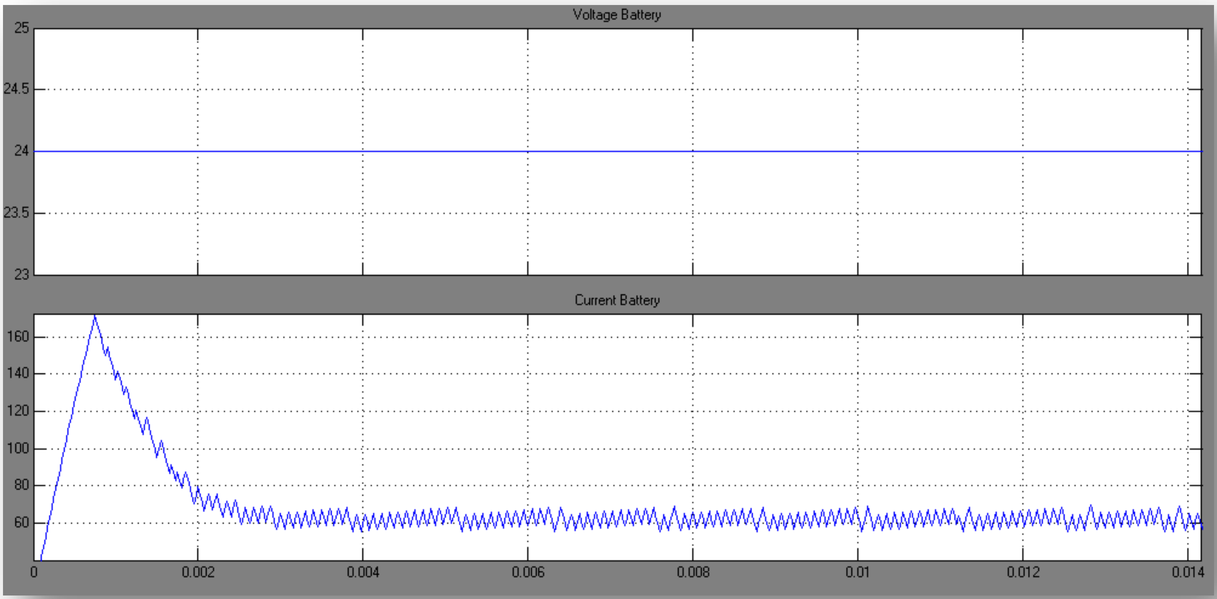


Figure 35 Output Regulator

The PWM control is responsible for carrying the panel to the point of maximum power by the high frequency switching switch, see figure 36.

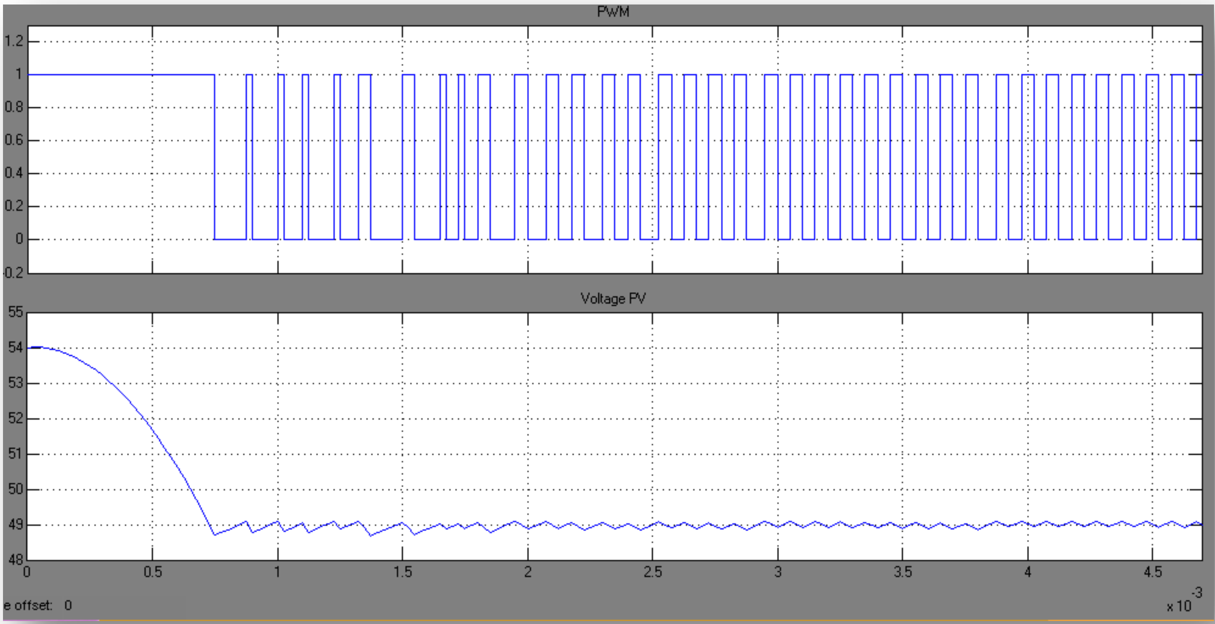


Figure 36 PWM control

7. Coil design

For smoothing the output current of the regulator is necessary to use coils. Coil parameters needed to be 0.125 mH at 65 A current at maximum output deviation of plus or minus 5%. Power Coil with such parameters is not on the market or its price is too high. For this reason it is necessary to propose a specific power coil.

7.1 Steps to design the coil

Computation was made by core selection procedure from company Magnetics for cores made from MPP material.

Only two parameters of the design application must be known: required inductance and the DC current. By the following procedure was determined the core size and number of turns.

7.1.1. The choice of the number of coil cores

Because was necessary to reduce inductance to one core, was chosen tree cores for coil.

$$L_1 = \frac{L}{N_{CORES}} = \frac{0{,}125\text{mH}}{3} = 0{,}041667\text{mH}$$

7.1.2. Computation the product of LI^2

$$L_1 I^2 = L_1 \cdot I^2 = 0{,}041667\text{mH} \cdot (66{,}6\text{A})^2 = 185{,}185\text{mHA}^2$$

Where:

L = inductance required with DC bias (mH - millihenrys)

I = DC current (A - amperes)

7.1.3. Selection of core from "core selection chart"

From MPP core selection chart on figure 37 was chosen core 55908.

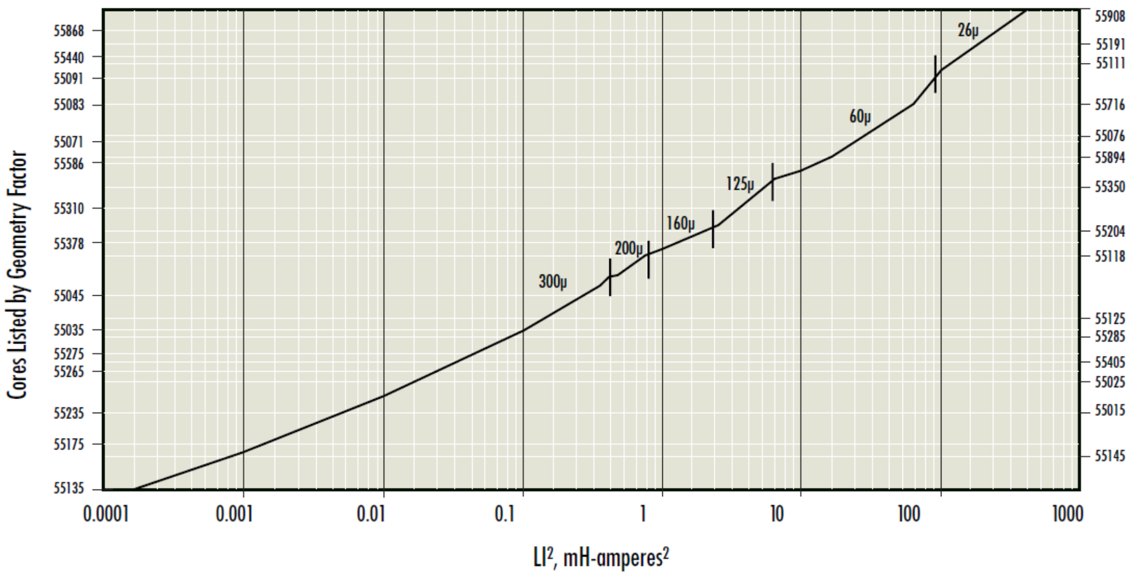


Figure 37 MPP core selection chart

7.1.4. Core properties from datasheet

Permeability

$$\mu = 26Hm^{-1}$$

Nominal inductance of core

$$A_{L1} = 37 \pm 8\% nH/Turn^2 \rightarrow A_{L1MIN} = 37\, nH/Turn^2 * 0{,}92 = 34{,}04\, nH/Turn^2$$

Nominal DC resistance

$$R_{MAG} = 0{,}0345\Omega/mH$$

Path length

$$l_e = 19{,}61cm$$

7.1.5. Number of turns needed

$L_1 = 0{,}041667mH$

$$turns = \sqrt{\frac{L_1}{A_{L1MIN}}} = \sqrt{\frac{0{,}041667mH}{34{,}04\, nH/Turn^2}} = 34{,}99 \approx 35$$

The magnetizing force (DC bias)

$$H = \frac{turns \cdot I}{l_e} = \frac{35 \cdot 66{,}6A}{19{,}61cm} = 119A \cdot Turn$$

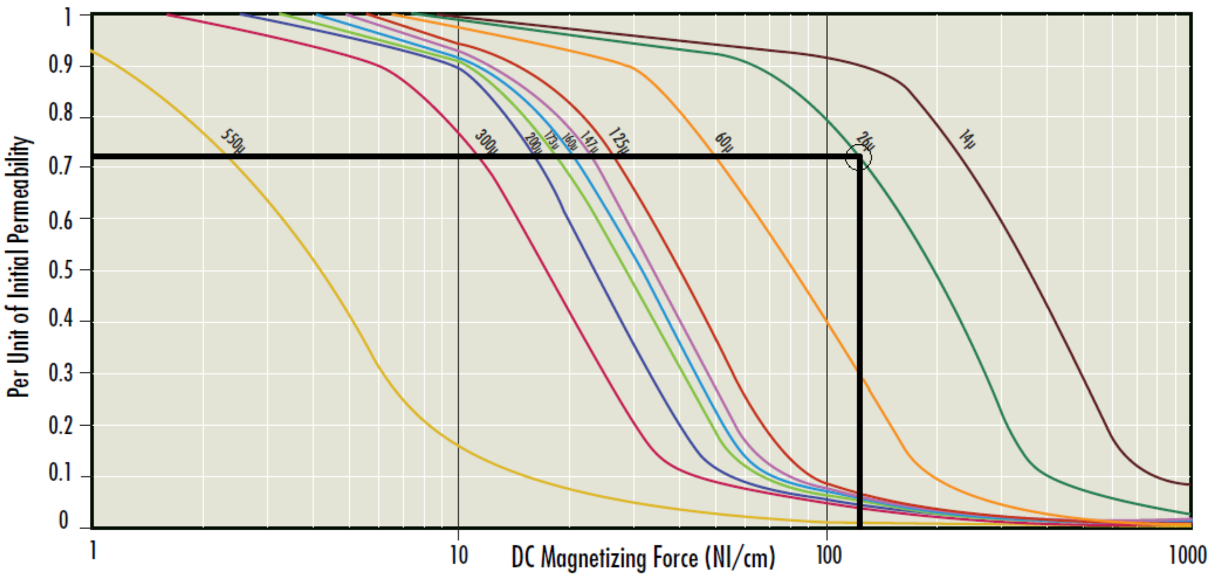


Figure 38 Permeability versus DC bias curves for MPP cores

From figure 38 was chosen Per Unit of Initial Permeability 0.73 and was used to correct number of turns.

$$turns_{Real} = \frac{turns}{0{,}73} = \frac{35}{0{,}73} = 47{,}95 \approx 48$$

7.1.6. Choosing of wire

$$A = \frac{I}{J} = \frac{66{,}6\overline{6}A}{3\,A/mm^2} = 22{,}2\overline{2}mm^2$$

$$d = \sqrt{\frac{S \cdot 4}{\pi}} = \sqrt{\frac{22{,}2\overline{2}mm^2 \cdot 4}{\pi}} = 5{,}319mm \rightarrow \text{Choosing of wire } 5{,}5\text{mm with isolation}(\approx \text{AWG } 4)$$

7.2. Analysis of the preceding result yields

7.2.1. Real magnetizing force (DC bias)

$$H_{REAL} = \frac{turns_{REAL} \cdot I}{l_e} = \frac{48 \cdot 66{,}6A}{19{,}61cm} = 163A \cdot Turn$$

7.2.2. Choosing of Real Per Unit of Initial Permeability

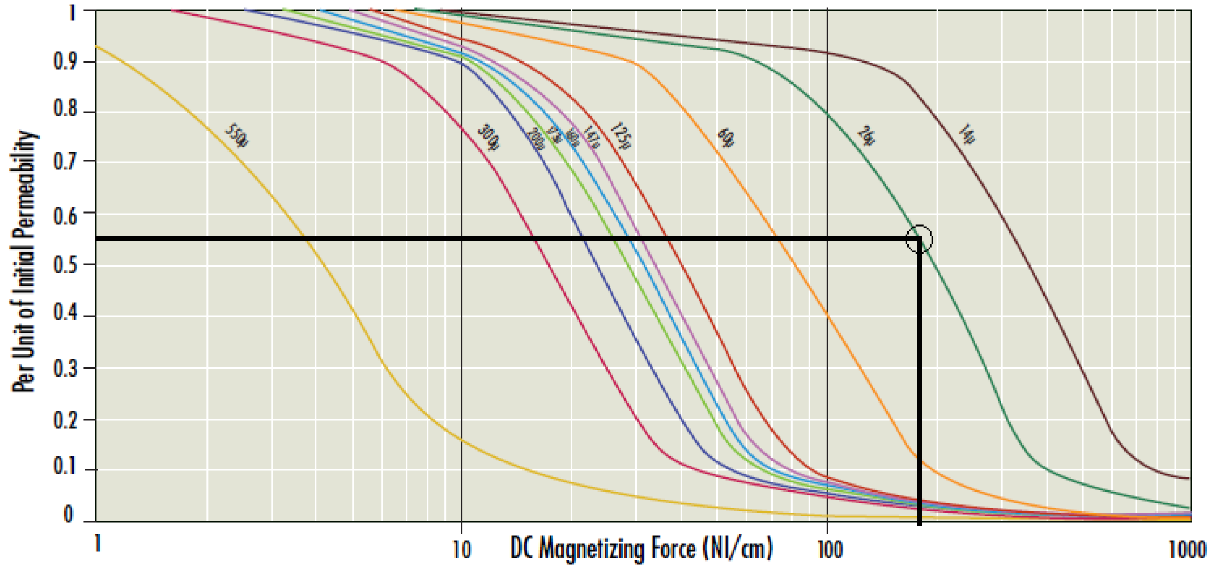


Figure 39, Permeability versus DC bias curves for MPP cores

From figure 39 was chosen Real Per Unit of Initial Permeability 0.55 and was used to correction of minimal inductance of core

7.2.3. Correction of minimal inductance of core

$$A_{L1MINREAL} = A_{L1MIN} * 0{,}55 = 37\,nH/Turn^2 * 0{,}55 = 20{,}35\,nH/Turn^2$$

7.2.4. Minimal inductance of coil

$$L_{1REAL} = A_{L1MINREAL} \cdot turn_{REAL}^{\;2} = 20{,}35\,nH/Turn^2 \cdot 48^2 \cdot 10^{-6}\,mH/nH = 0{,}0468864mH$$

$$L_{REAL} = L_{1REAL} \cdot N_{CORES} = 0{,}0468864mH \cdot 3 = 0{,}140mH$$

7.2.5. Calculation of winding factor of core

Total window area of core

$$W_A = 1799mm^2$$

Area of wires

$$A_{WIRES} = A \cdot turn_{REAL} = 22,2\overline{2}mm^2 \cdot 48 = 1066,6\overline{6}mm^2$$

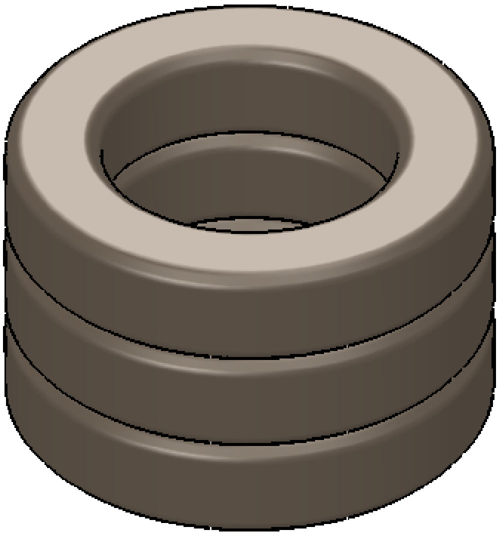
Winding factor of core

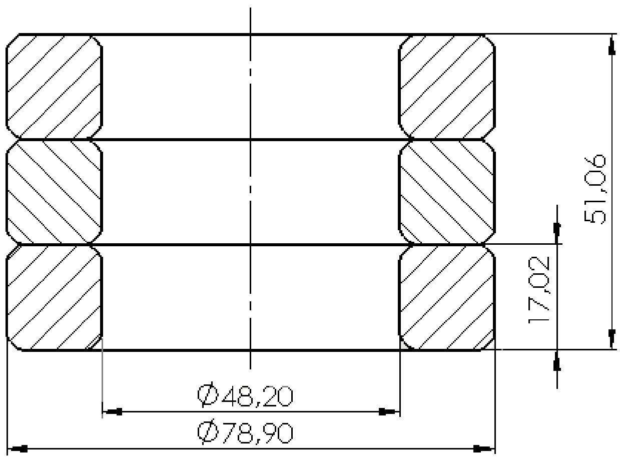
$$f_W = \frac{A_{WIRES}}{W_A} \cdot 100\% = \frac{1066,6\overline{6}mm^2}{1799mm^2} \cdot 100\% = 59,3\%$$

7.3 3D Model

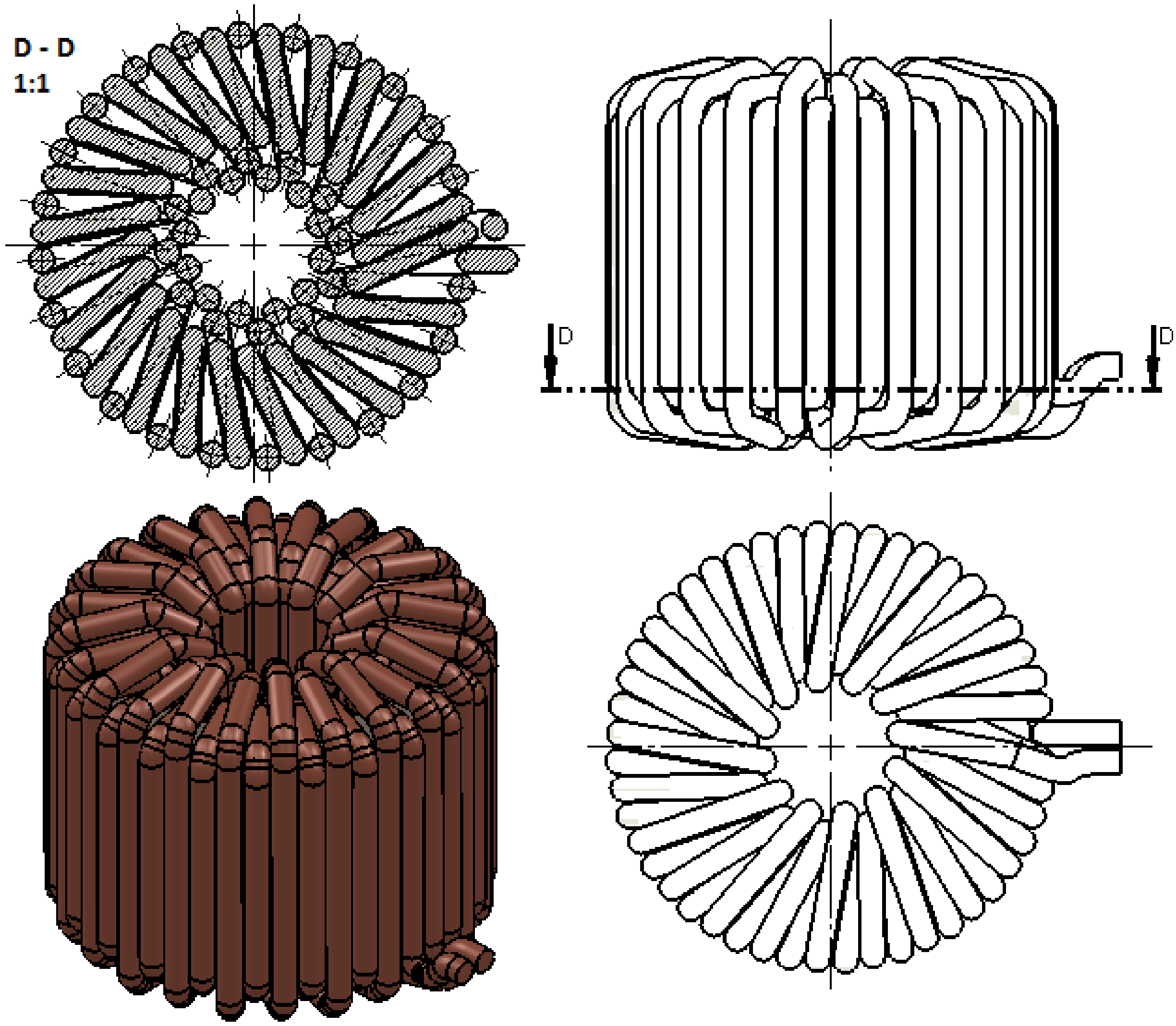
7.3.1. 3D model of cores of inductor

Dimension of cores are from datasheet of core (in annex)





7.3.2. 3D model of inductor



7.4 Results

Minimum calculated inductance of coil 0,140mH

Maximum diameter 89 mm

Maximum height 78mm

Weight approximately 2.67 kg

Minimal diameter of core of copper wire 5,3mm

8. Complete model

In this report is explained the last algorithm implemented in the microcontroller in charge to control the state of the panel as a function of the charge state battery.

8.1 Irradiance sun cycle model

To simulate the complete system in the real weather conditions has been modeled the irradiance sun cycle (kWh/m2/day). The equation that defines the day irradiance sun cycle is:

$$Irradiance(kwh/m^2/day) = e^{-\frac{(x-12)^2}{8}}$$

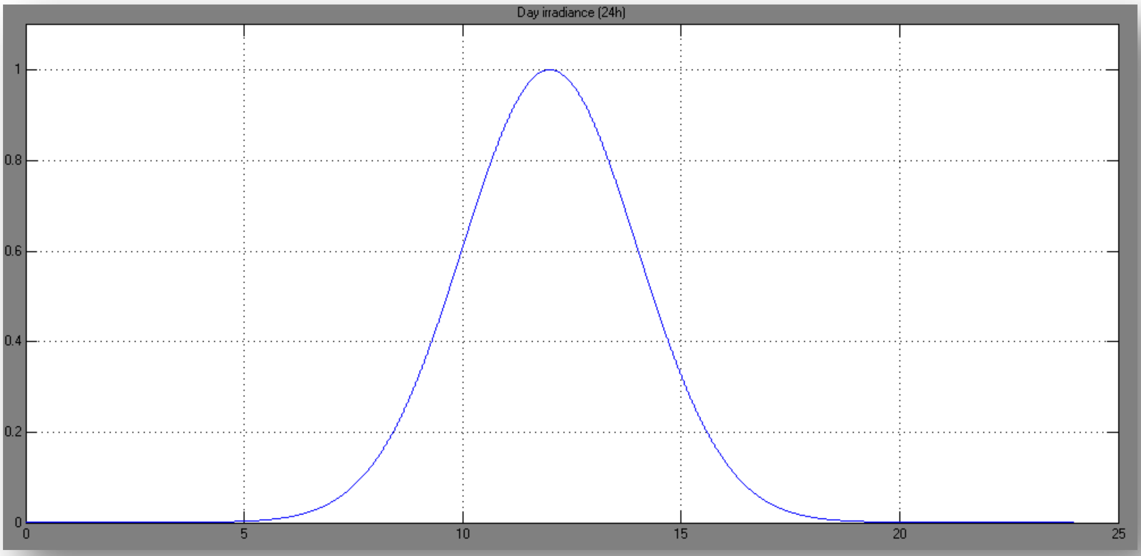


Figure 40, Irradiance solar cycle

8.2 Battery characteristics

The battery modeled and selected is a lead-acid battery, the characteristics shown below are typical of a high-capacity battery, but in order to perform a simulation has been manually tweaked only the values associated with the carrying capacity of the battery. The battery simulated has 100 times less capacity than the real.

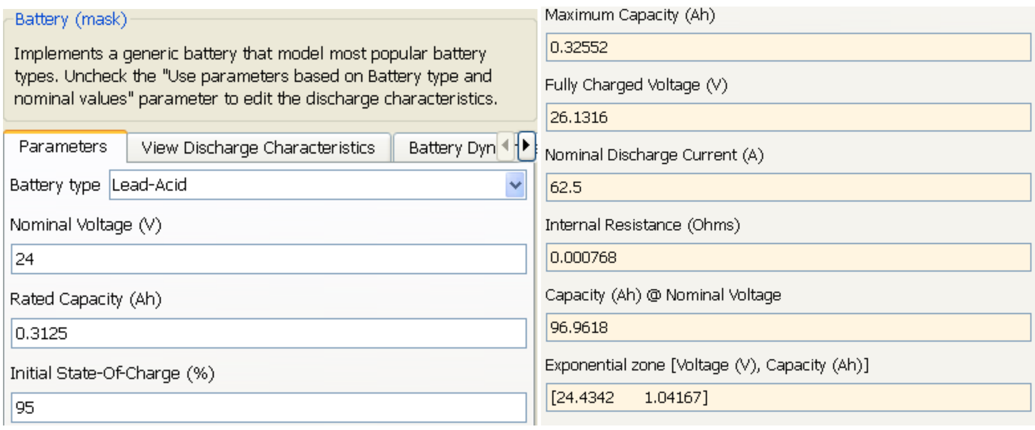


Figure 41, Battery mask

8.3 Battery model

The figure 42 shows the model of a battery, implementing the different equations that define the function of a battery, have an input by current and response with the voltage that determines the level of charge of the battery.

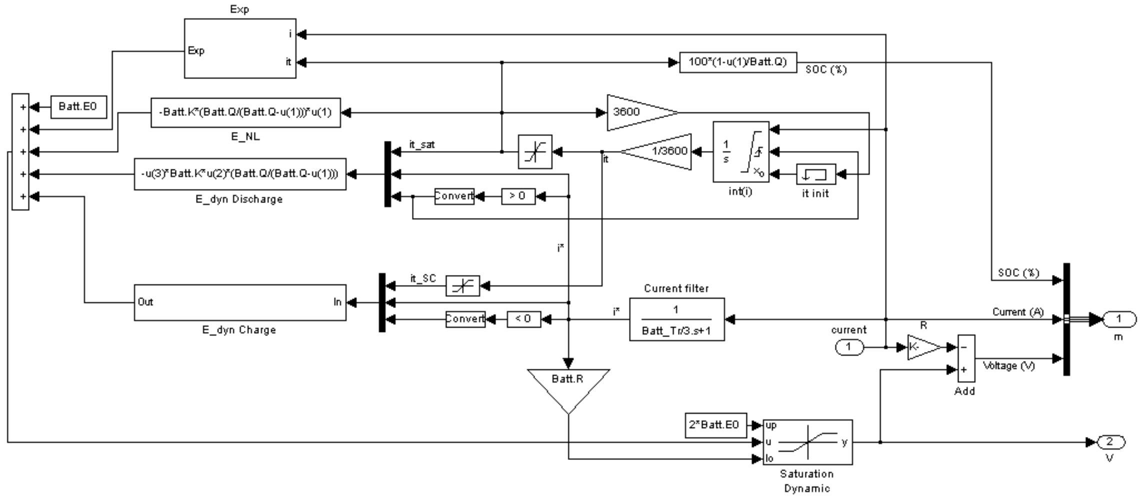


Figure 42, Simulink battery block model

8.4 Simulation of battery

In this part has been simulated only the charge and discharge of the battery to find the points of voltage and select the levels to cut the charger.

8.4.1 Discharge cycle

Figure 43 shows a cycle of discharge of the battery, in green there is the % of charge of the battery and in blue the voltage of the battery.

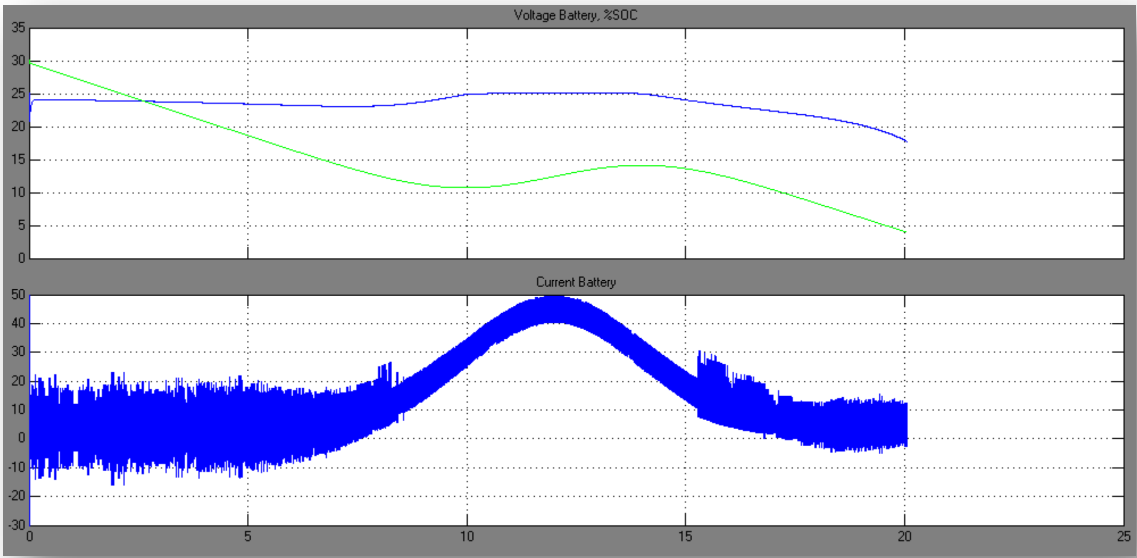


Figure 43, Discharge cycle

The lower limit with a maximum discharge of 10%, corresponds to Vbat=22.5V.

8.4.2 Charge cycle

The figure 44 shows a charge cycle of the battery.

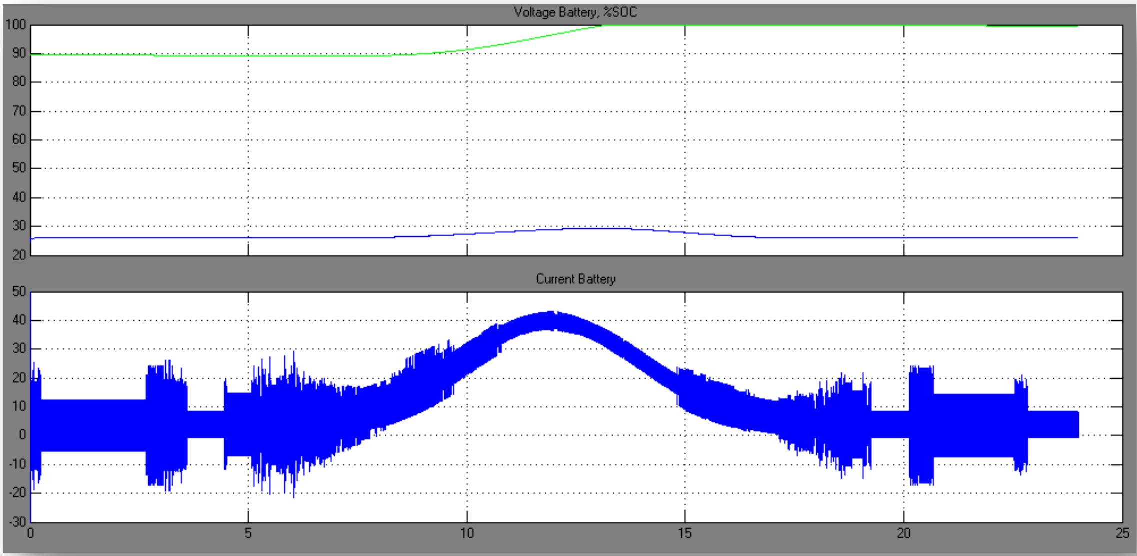


Figure 44, Charge cycle

The battery is full charged when the voltage of the battery is Vbat=29.5V.

With the model of the irradiance sun cycle, the battery, and selected the levels that it works is possible to design the algorithm to control the charge of the battery.

8.5 Control battery algorithm

This part is designed to change the panel state in function of the necessity of the battery and is created following the next rules.

- When the battery is 10% of his capacity, and there is not irradiance to supply the load (night), the battery cut the transmition of power to the load though a mechanical switch (relay), to not be destroyed.
- When the battery is full, the output power of the regulator should be the power necessary to supply the load plus the power to maintain the battery full.
- When the battery is between 10% and full, is charged though MPPT, at maximum power.

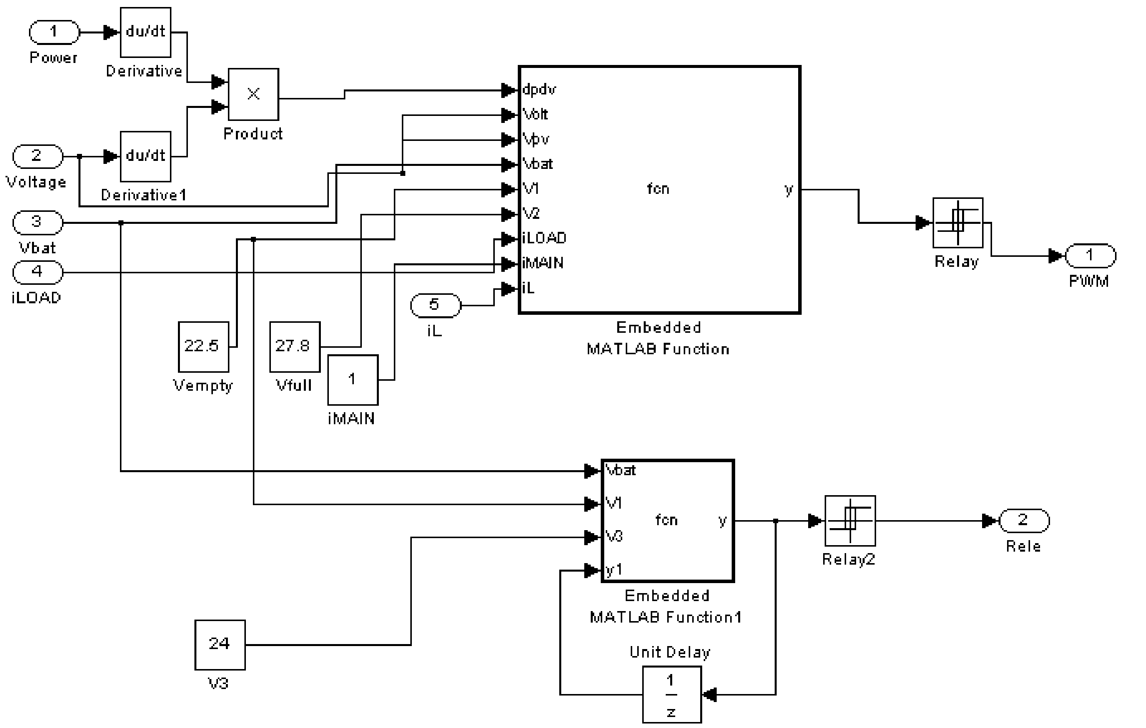


Figure 45, Block diagram of uC software

8.5.1 Supply algorithm

```
function y = fcn(dpdv,Volt,Vpv,Vbat,V1,V2,iLOAD,iMAIN,iL)
if (Vpv>Vbat)%sunshine
    if ((V1<=Vbat)&&(Vbat<=V2))%level to charge

        if (dpdv>0)% MPPT()
            Volt=-1;
        end
        if (dpdv<0)
            Volt=1;
        end% MPPT end
    end
    if (Vbat>=V2)%full level
        if (iL<(iLOAD+iMAIN))%MAINTAIN()
            Volt=1;
        end
        if (iL>(iLOAD+iMAIN))
            Volt=-1;
        end
    end
end
y = Volt;
```

8.5.2 Cut load algorithm

```
function y  = fcn(Vbat,V1,V3,y1)

if  Vbat<V1
    Vbat=-1;
end
if y1==-1 && Vbat<V3
    Vbat=-1;
end

y = Vbat;
```

8.6 Maintain the charge

In this part has been done the simulations of the complete system when is going to full the battery, to validate the maintain algorithm. With a load current of 5A and maintain current of 1A.

8.6.1 Constant irradiance

Selecting a constant source of irradiance 1.1kWh/m2/day. The charge of the battery begins in 95%, and begins to charge in the MPPT.

When the battery is full, Vbat=29.5V, the algorithm to charge the battery is changed to the maintain algorithm, the current of the battery goes to 1A (maintain current) and the load is supplied, see figure 46.

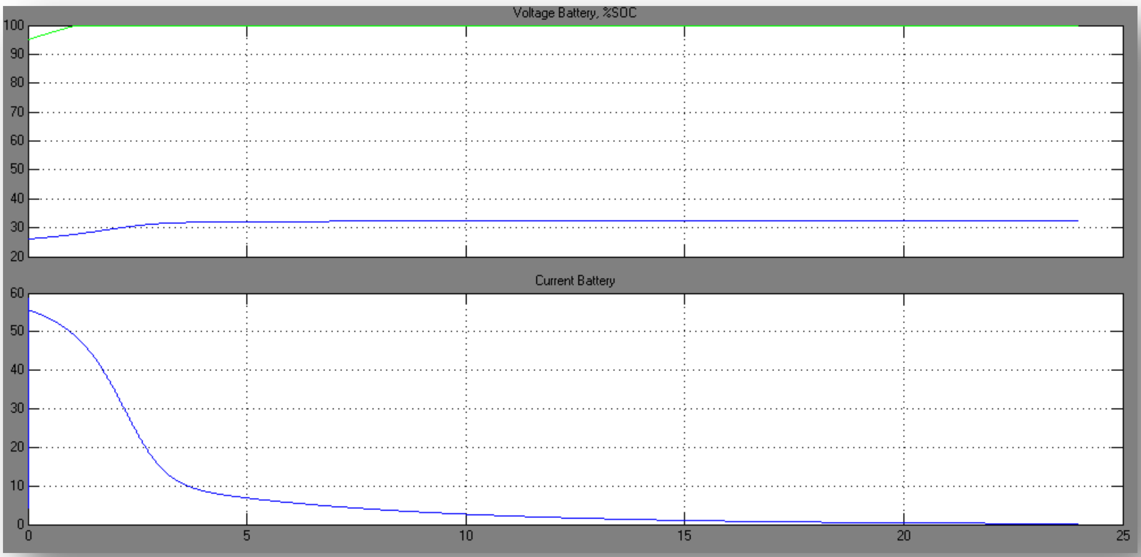


Figure 46, State of battery, maintain algorithm with constant irradiance

The control of the panel is correct, increase the voltage from the MPPT to reduce the output current to the one that is necessary to supply the load and maintain the battery charge, when it cross the regulator, see figure 47 and 48.

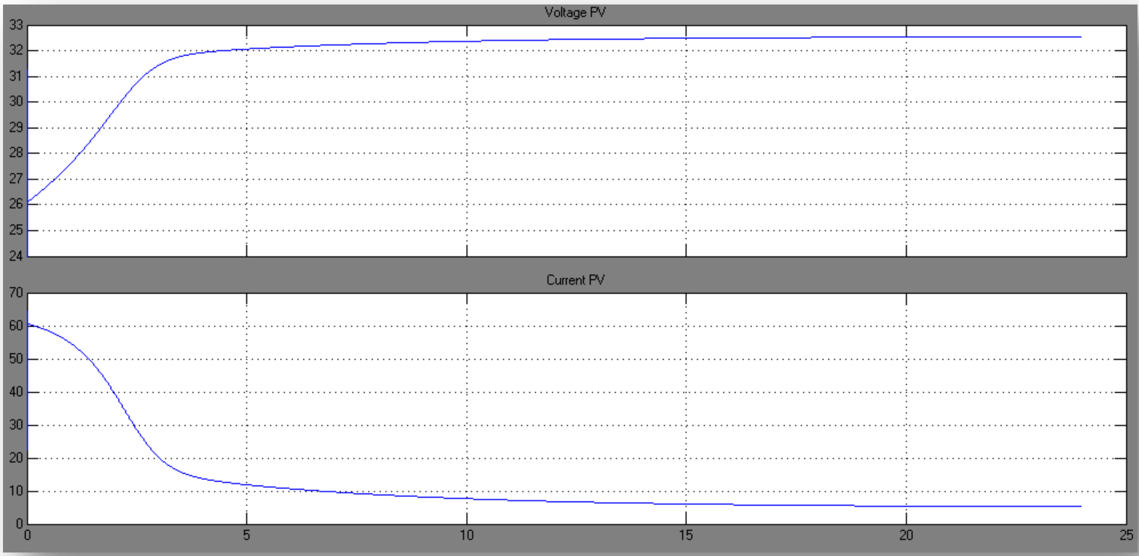


Figure 47, State of PV panel, maintain algorithm with constant irradiance

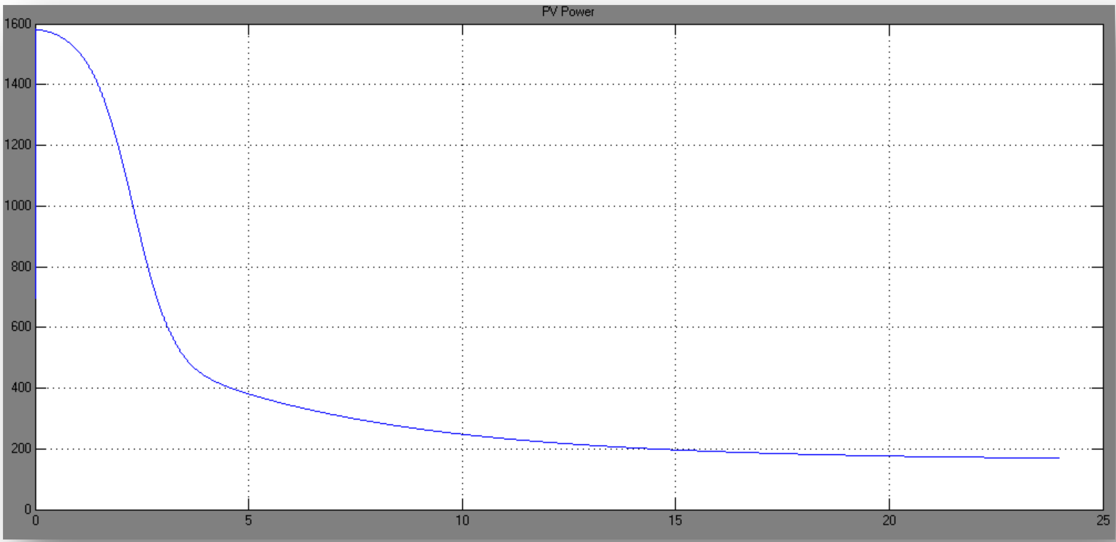


Figure 48, PV panel, maintain algorithm with constant irradiance

8.6.2, During irradiance solar cycle

Selecting the model of the sun in source of irradiance with 5A of load, 1A of maintain current and beginning with the battery at 80% of charge. During the night, or the hours of low irradiance the load is supplied by the battery, and its discharged a little bit, when the sunshine appear, increase the irradiance incident in the panel and charge the battery.

When the battery is full, change the MPPT algorithm to maintain algorithm, decrease the current until maintain current, and the sequence repeat, see figure 49.

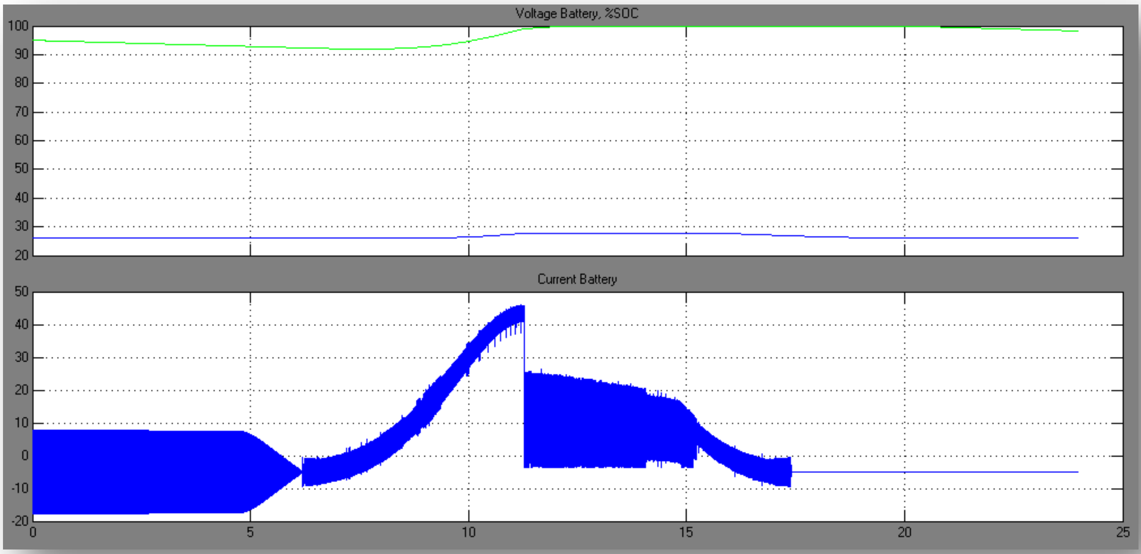


Figure 49, Battery status, maintain algorithm during solar cycle irradiance

In the next picture there is the state of the photovoltaic panel, all the time in the MPPT. But when the battery is full increase the voltage to reduce the current, see figure 50 and 51.

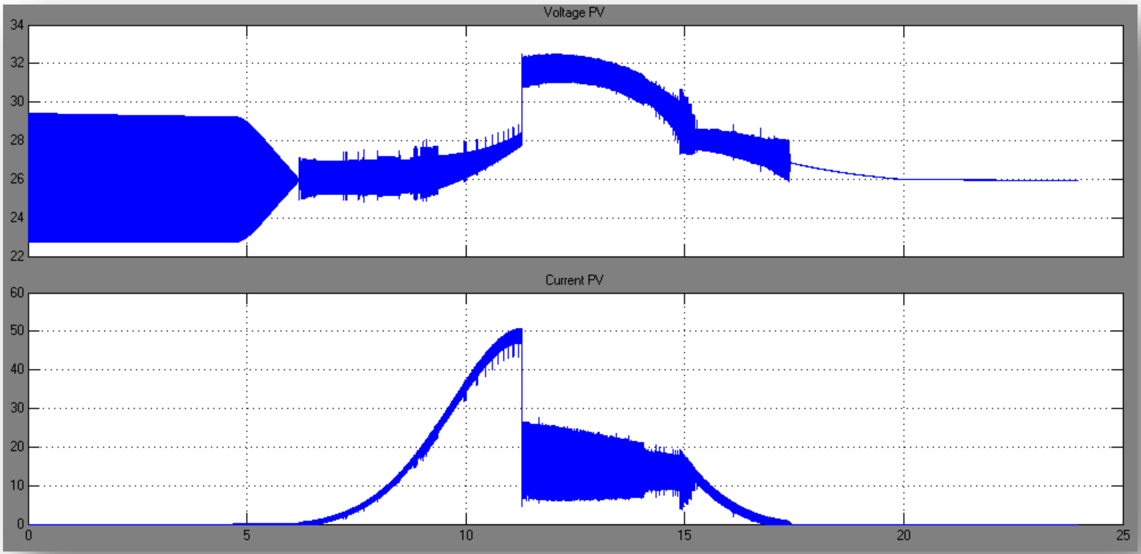


Figure 50, PV status, maintain algorithm during solar cycle irradiance

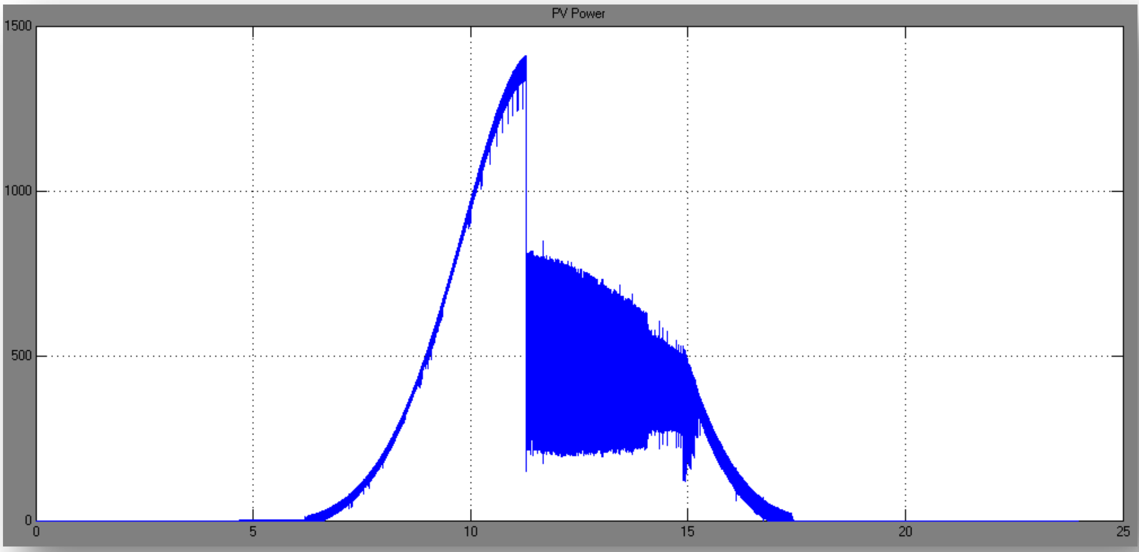


Figure 51, PV panel power, maintain algorithm during solar cycle irradiance

8.7 Cut of load

In this section has been done the simulation to verify the function of the algorithm in charge to protect the battery, if the battery is discharged more than the parameter discharge maximum capacity, can be destroyed.

To prevent a batteries will discharged more than normal should disconnect from the load, thus avoiding the continuous unloading and loading is allowed only. To implement this protection is situated a power relay between the load and battery controlled by the algorithm cut load.

The simulation parameters were: load current=30A, %charge=15%, Vempty=22.5V and Vsafety=24V.

This critical load is unusual, but is selected to take the battery to limit and to could simulate the battery in a critical state.

The figure 52 shows different parts, when the voltage arrives discharging at the lower limit (22.5V), the load is cut for the battery to protect it. Then, with the little current of the panel, the battery is charged a little bit.

When the voltage is stabilized again at a security level of voltage (24V), reconnects the load, and continuous discharge of the battery.

When high levels of irradiance are present in the photovoltaic panel, charges the battery at high speed, this cycle is repeated again for the next day.

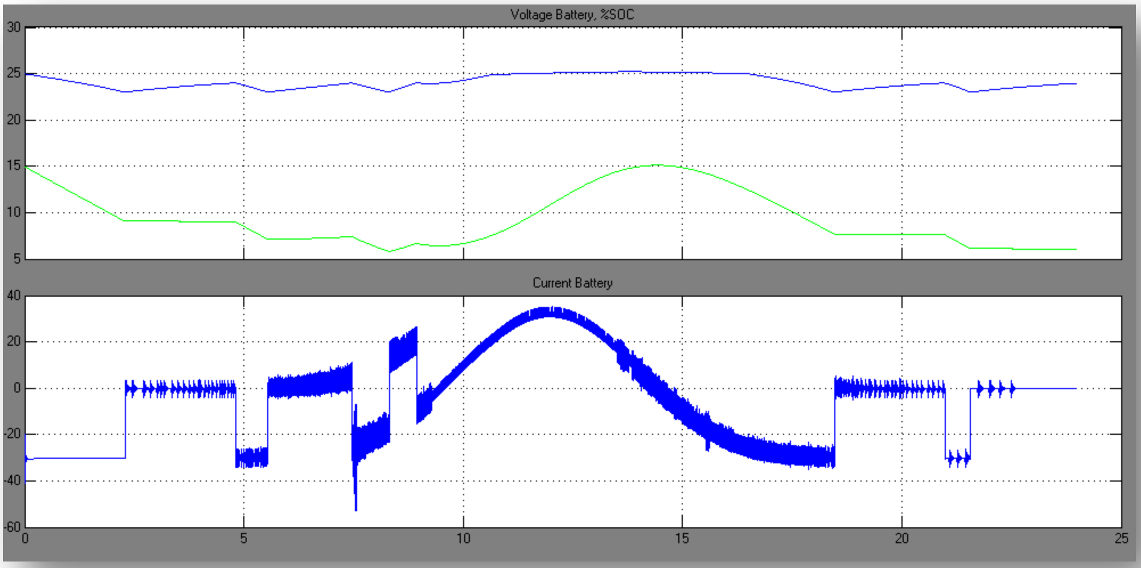


Figure 52, State of battery, cut load algorithm

The picture shows the current that cross the relay during the day, when the battery is at the empty limit, the relay cut the supply of the load to safe the battery, see figure 53.

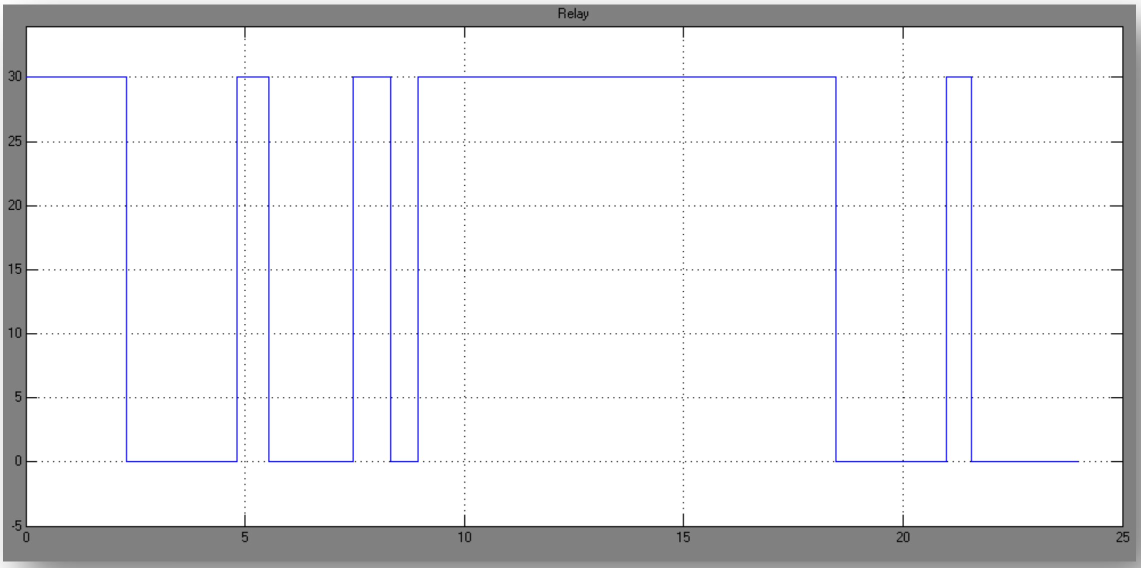


Figure 53, Relay cuts the load

The figures 54 and 55 show the response of the panel from the changes of the load and the solar irradiation day cycle.

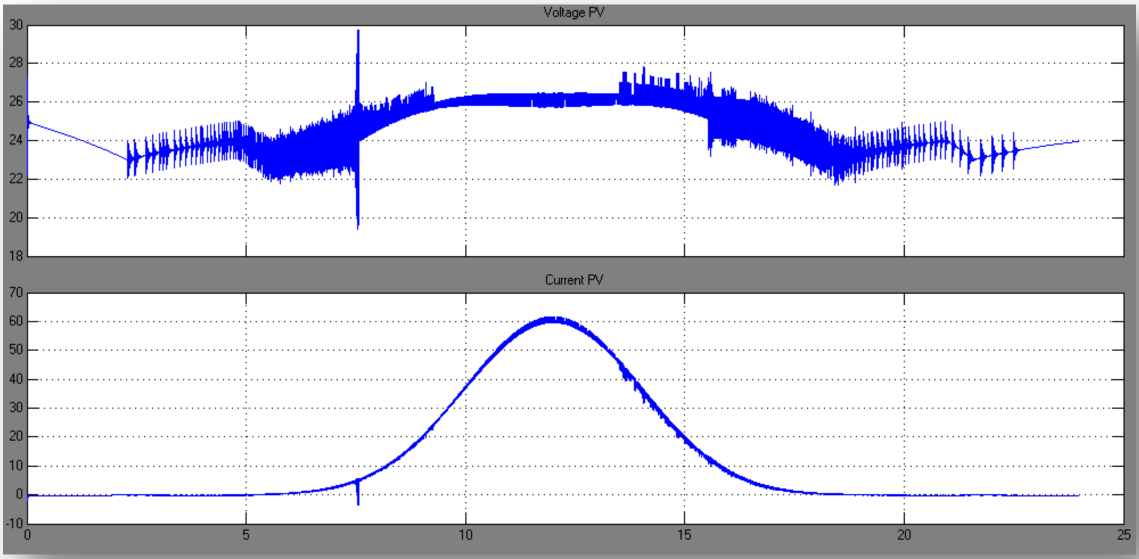


Figure 54, State of PV panel, cut load algorithm

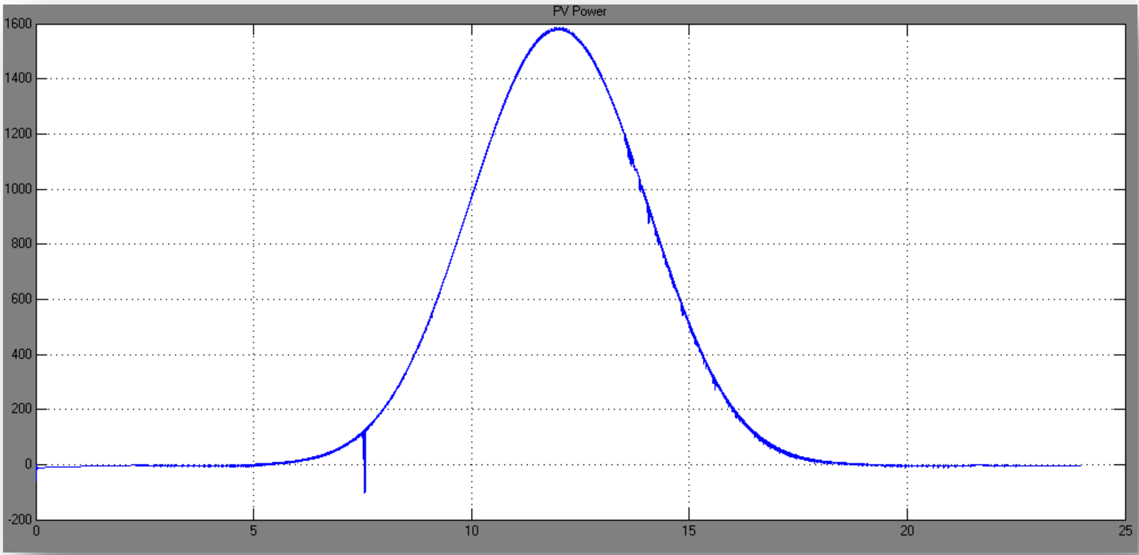


Figure 55, PV module power, cut load algorithm

9. Regulator device pre-design

9.1 Box

Size of box was affected by coil as a biggest part of regulator assembly and predicted size of printed circuit board. As can be seen on figure 56 the box maximum dimensions are 110mm x 200mm x 92mm (width x length x height). The maximum dimensions of coil are: diameter 89 mm and height 78mm.

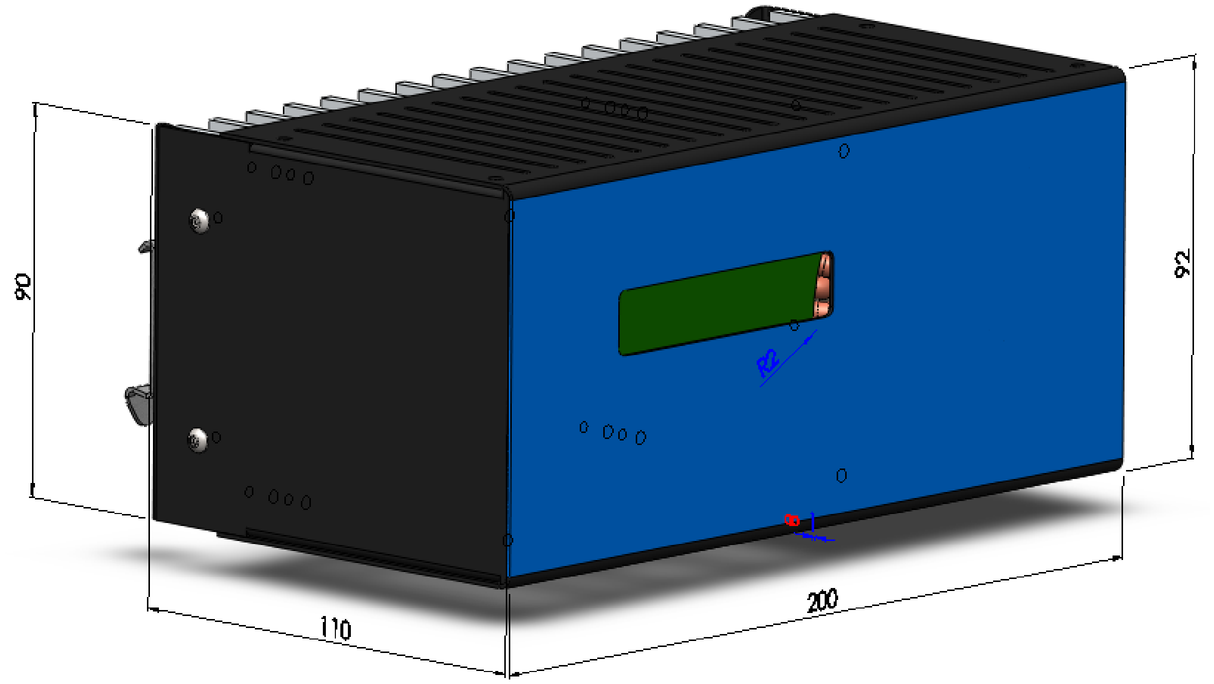


Figure 56, Box outside dimensions

9.2 Cooler

Main part of box is cooler, which is used as a base for other parts and it's too important for cooling switch.

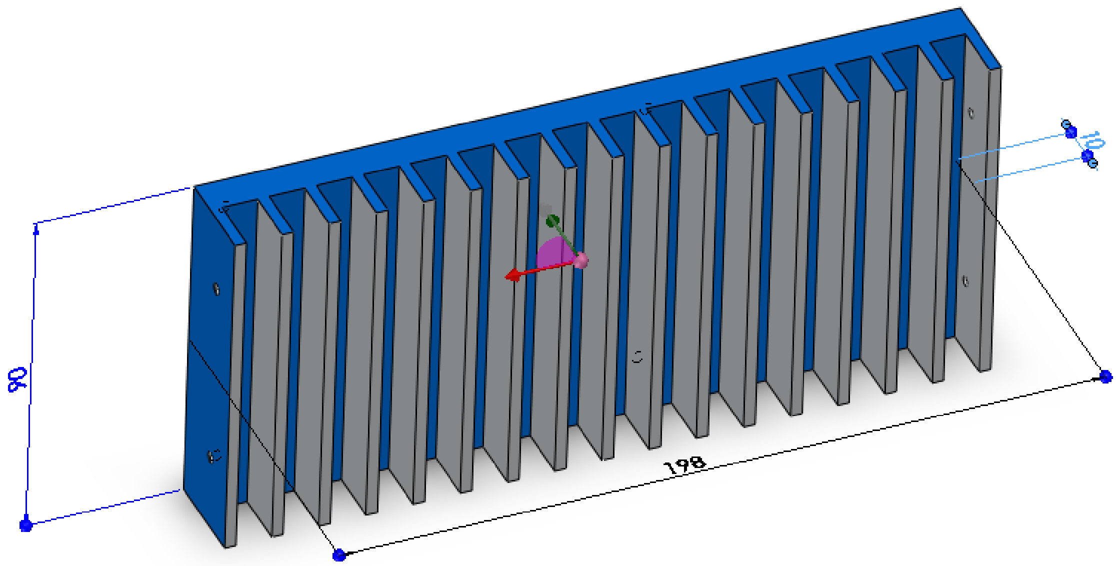


Figure 57, Cooler

9.3 Sheet metal parts box

Other boxing will be made from sheet metal parts.

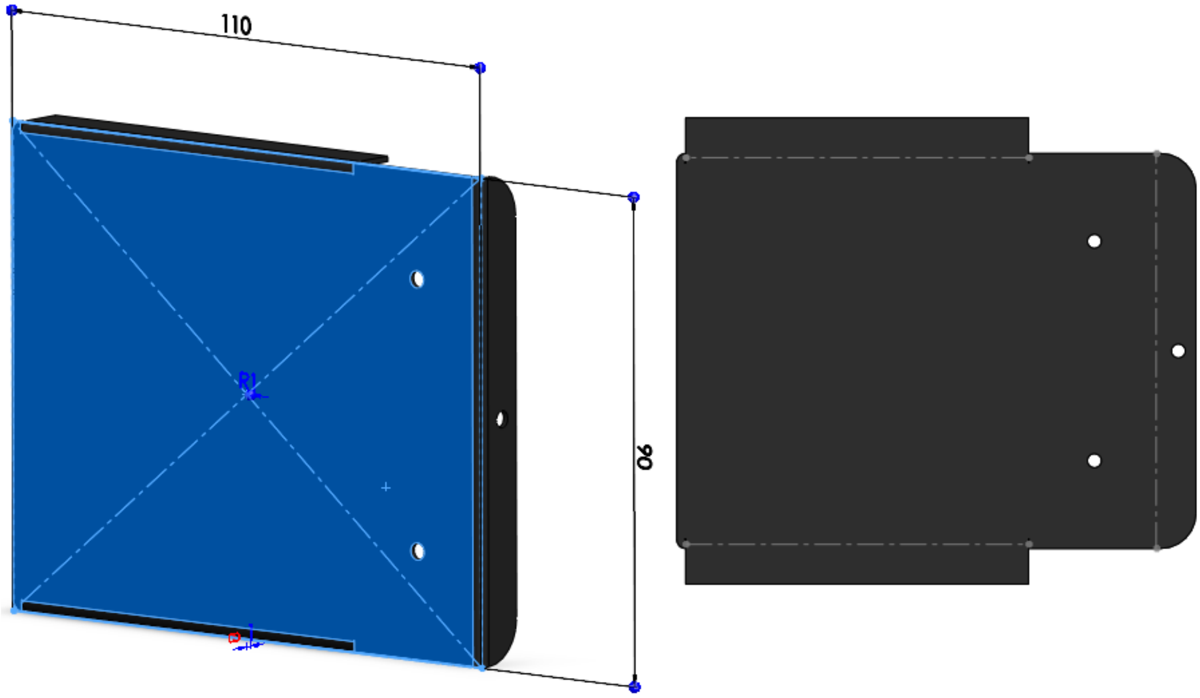


Figure 58, Side sheet metal part

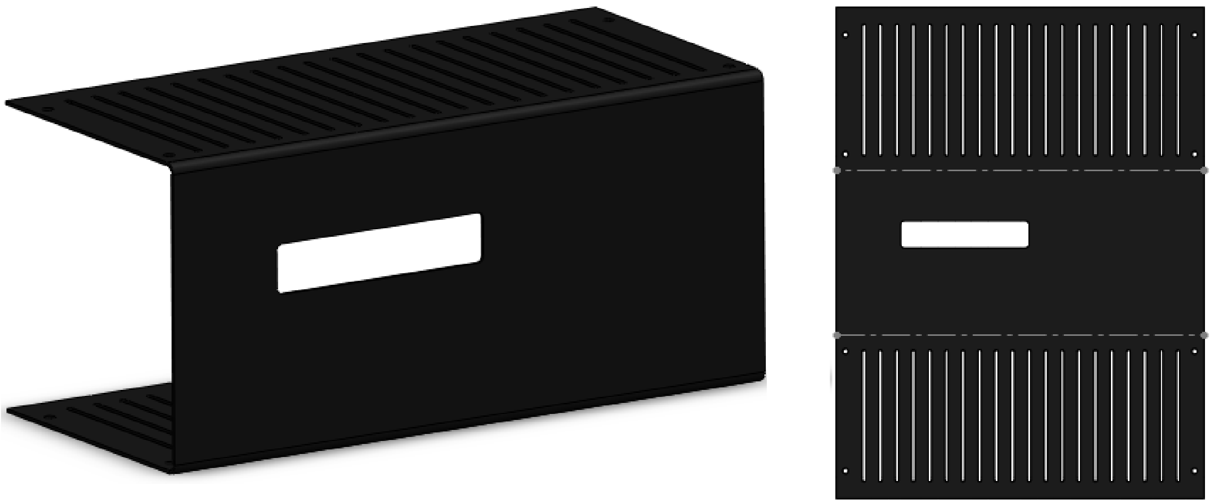


Figure 59, Front sheet metal

The cooler and the sheet metal parts will be made from aluminum 5052-H32. This aluminum alloy has tensile strength of 230 MPa, thermal conductivity 137 W/(m*K) and density only 2680 kg/m^3.

This material is used for example in applications include electronic chassis, tanks, pressure vessels etc... It has good formability, maintains high corrosion resistance and weld ability.

By using same material for all chassis will be prevent from electro-galvanic corrosion in wet and aggressive environment for example near see or petroleum industry.

9.4 Inside the box

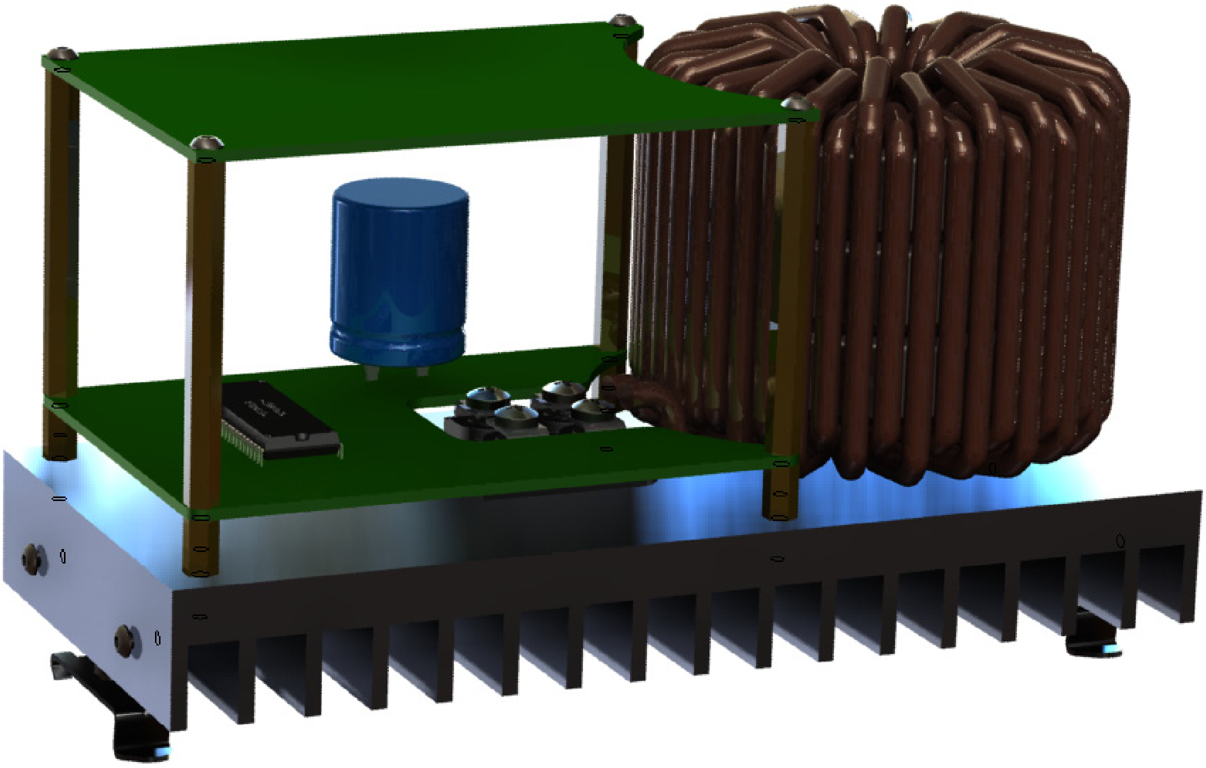


Figure 60, Render of inner parts

As is shown on figure 60, printed circuit board shapes are affected by parts such as coil or switch. For connecting and assembling are used normalized or mass produced screws.

Weight of all predesigned assembly is 3.7 kg and its represent most of all weight of complete assembly.

10. Results of Modeling

In this part of Project, modeling and simulating, have been made functional models of all devices and physical systems that interact in the project: irradiance solar cycle, PV module, microcontroller maximum power point tracking algorithm and load and battery charge control, DC-DC converter reducer type (buck) and battery.

Each and every one of them has been tested separately and together, in static and dynamic tests. Therefore, the results of the simulations verify the correct design of the photovoltaic panel regulator device and the designs of control algorithms to be implemented in the microcontroller.

The next chapters is explained how its done the hardware design, BOX and PCB's, software design, algorithms and functions implemented in uC, and an economical paper.

The next chapters explain how is maked the hardware design, power and digital PCB, the components selected to make it, the software design, translation of algorithms to C code, create the functions to manage display and ADC converter etc.

11. Hardware design

In this chapter is explained and designed all the components necessaries to make the regulator, the block diagram of the figure 61 shows all the important components that are used.

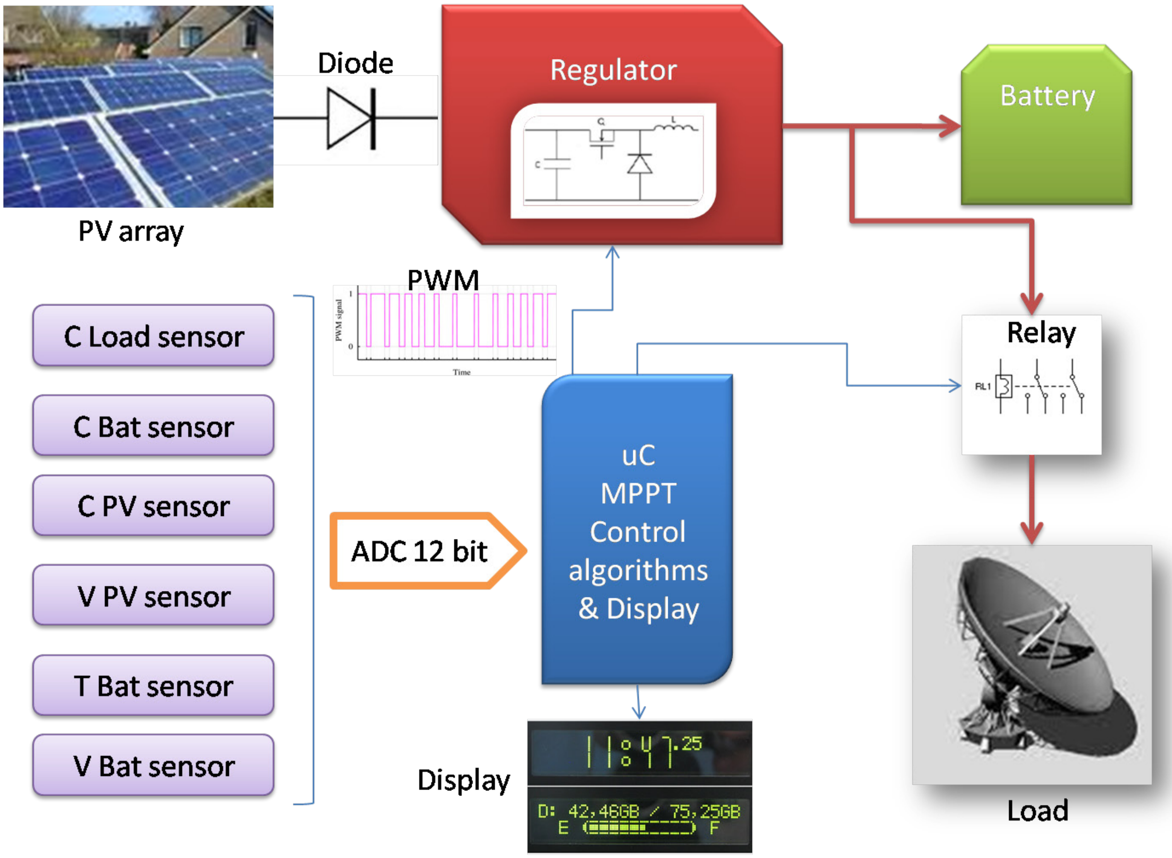


Figure 61, Block diagram of hardware components

The components necessary to finish the device are: 3 current sensors, 2 voltage sensors, 1 temperature sensor, 1 switch, 2 power diodes and 1 power relay. The capacitor and coil have been designed in regulator chapter design.

11.1. Voltage sensor

To measure the voltage of the panel and the battery and realize a feedback for the uC, is necessary to monitor this voltages, the way designed to implement this voltage sensors is explained in this chapter.

11.1.1 Electrical model

The electrical model selected to function like a voltage sensor is showed in figure 62, is composed by a resistor divisor. The input voltage is between 0 and 100V, for the design, and the output that is needed is between 0 and 5V. Is selected a small capacitor in the output of the voltage sensor to use it like a filter for the fluctuations in the power line sensed.

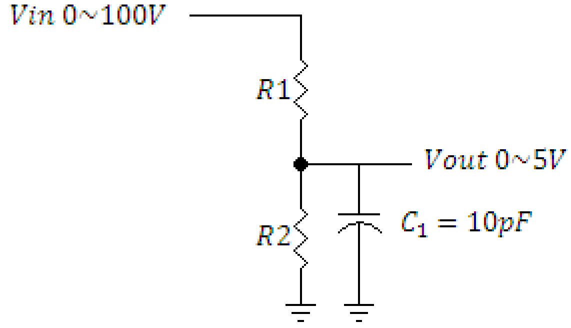


Figure 62, Electrical voltage sensor model

11.1.2 Resistors design

To reduce the current and the loses in the voltage sensor, have been chosen a very big impedance in the first resistor, the second one have been designed to satisfy the rules explained before.

$$R1 = 100k\Omega$$

The equation that represents the function of the electric circuit is:

$$V_o = V_{in} \cdot \frac{R2}{R1 + R2}$$

Then:

$$R2 = \frac{V_o \cdot R1}{(V_{in} - 1)} = \frac{5 \cdot 10^5}{(100 - 1)} = 5.05k\Omega \cong 5k\Omega$$

11.1.3 Result

The sensor resultant is a block that convert an input between 0 and 100V to an output between 0 and 4.76V, because is selected a normalized resistor of 5kΩ at the maximum power it dissipates 9.5mW and there is a capacitor of 10pF at the output to filter the switching currents and connect with uC. The figure 63 represents the characteristics of the sensor.

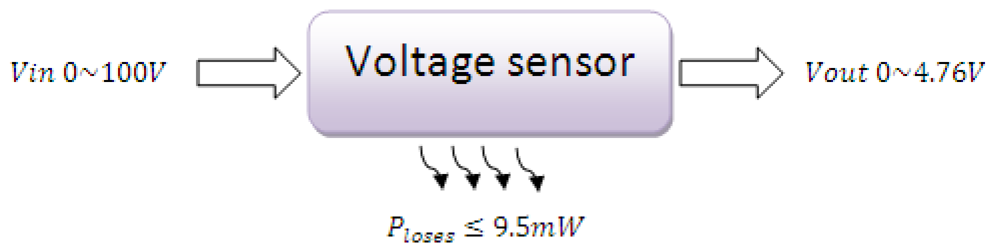


Figure 63, Voltage sensor characteristics

11.2. Current sensor

The current sensor is a critical part, because is connected in the power line and is a better solution search for an integrated circuit in charge to do this thing that design a sensor using passive components.

11.2.3. Characteristics

The Current Sensor that has been selected is ACS755xCB-100, the most important characteristic is that can support 100A in the power pins and have low loses. The typical characteristics are summarized in figure 64.

Characteristic	Symbol	Test Conditions	Min.	Typ.	Max.	Units
Primary Sensed Current	I_P		0	–	100	A
Supply Voltage	V_{CC}		4.5	5.0	5.5	V
Supply Current	I_{CC}	V_{CC} = 5.0 V, output open	6.5	8	10	mA
Output Resistance	R_{OUT}	I_{OUT} = 1.2 mA	–	1	2	Ω
Output Capacitance Load	C_{LOAD}	VOUT to GND	–	–	10	nF
Output Resistive Load	R_{LOAD}	VOUT to GND	4.7	–	–	kΩ
Primary Conductor Resistance	$R_{PRIMARY}$	I_P = +100A; T_A = 25°C	–	100	–	μΩ
Isolation Voltage	V_{ISO}	Pins 1-3 and 4-5; 60 Hz, 1 minute	3.0	–	–	kV

Figure 64, Typical characteristics of current sensor

The package is showed in figure 65, have two power pins, that are connected in the power line, and the three digital pins are Vcc GND and OUT, the typical supply necessary to function is 5V and the out pin is directly connected to uC analog port.

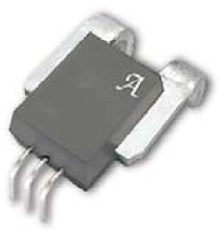


Figure 65, Current sensor package

11.2.2. Response

The step response of the current sensor is showed in figure 66, there is in yellow the power line, step of 50A, and the response in mV is quickly and precise.

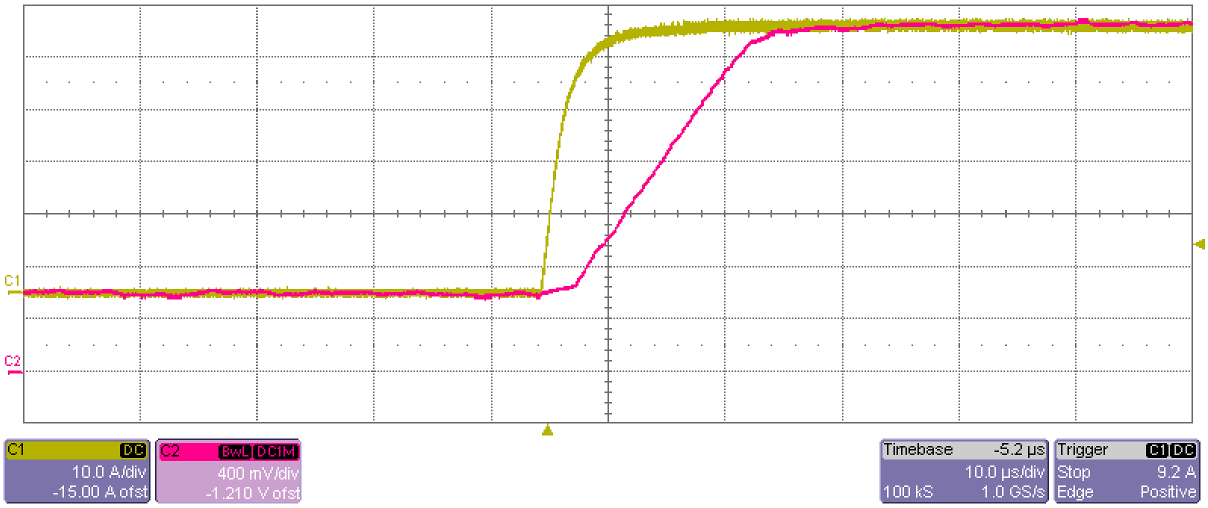


Figure 66, Step response of current sensor

To show more information about the sensor see data sheet in annex.

11.3. Temperature sensor

The temperature of the battery can be a problem, because if it's so high the acid, that the battery is composed, can start to boil and the battery can be destroyed.

To safe this possibility is designed a function inside the control part that is in charge to control if the temperature of the battery arrive at the limit established, to monitor this variable is necessary the use of a temperature sensor in shape of probe, to connect in the battery and use it like a peripheral to send the necessary information.

The temperature sensor that has been selected is a Pt-1000 named ESMB-12, the typical characteristics and the shape of the package is showed in figures 67 and 68.

Code number	**087B1184**
Designation	**Pt 1000 Universal sensor**
Min. temperature	**0 °C**
Max. temperature	**100 °C**
Time constant	**20 s**
Material	**18/8 stainless steel / 2,5m PVC cable**
Enclosure	**IP54**
Electrical connection	**2-wire cable (2 x 0,2 mm2)**
Mounting	**For pipe or flat surface or in pocket**
EAN	**5702421064566**

Figure 67, Table of characteristics of temperature sensor

Figure 68, Probe of temperature

The temperature sensor is based in a Pt1000, the resistance characteristic is showed in figure 69, this sensor, is supplied with a constant 5V, the current that cross the Pt1000 change with the temperature linear with the resistance. To monitor these changes in voltage is necessary to connect the sensor through a divisor bridge topology, see figure 70.

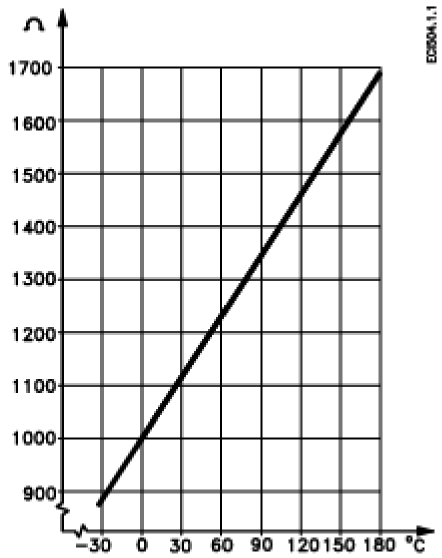


Figure 69, Resistance characteristic of Pt1000 ESMB-12

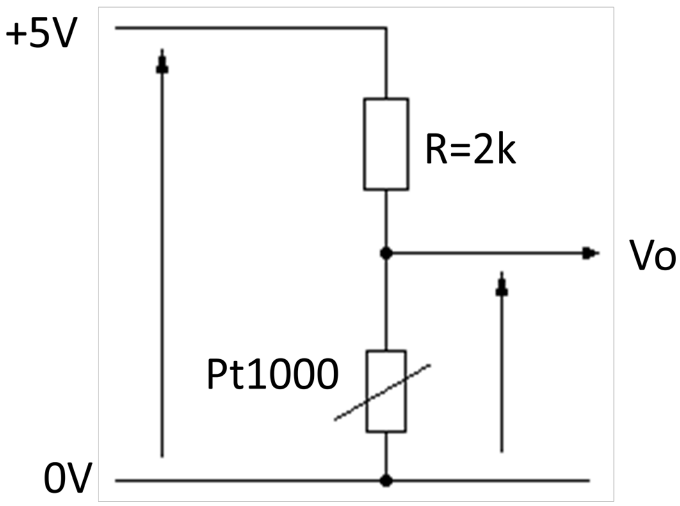


Figure 70, Connection temperature sensor

With this connection the information is codified in the voltage of the Pt1000.

The equation that determines the function of this sensor is:

$$Vo(V) = \frac{Vcc \cdot Pt1000}{R + Pt1000} = \frac{5}{\frac{2 \cdot 10^3}{Pt1000} + 1} V$$

The curve of the sensor is in figures 71 and 72 .

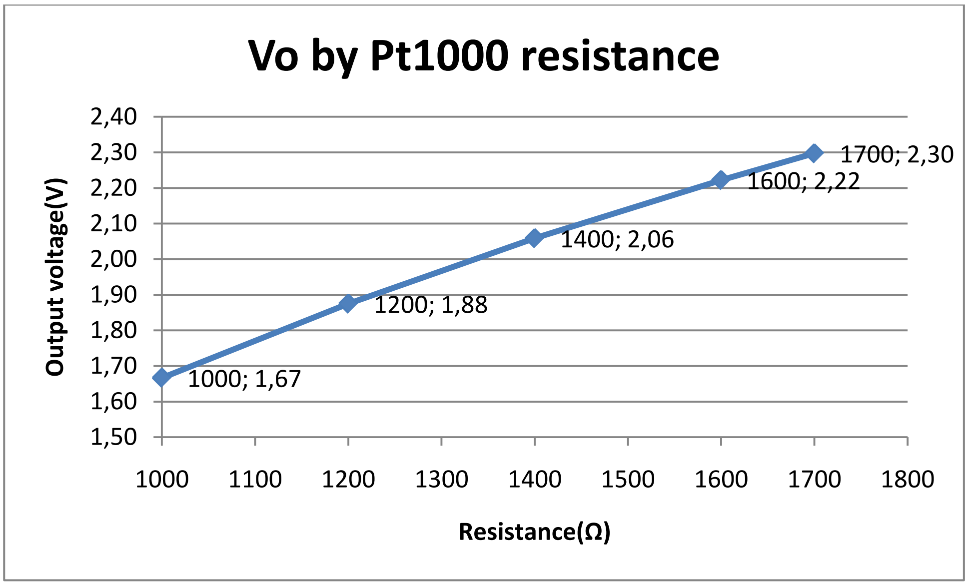


Figure 71, Temperature sensor curve resistance

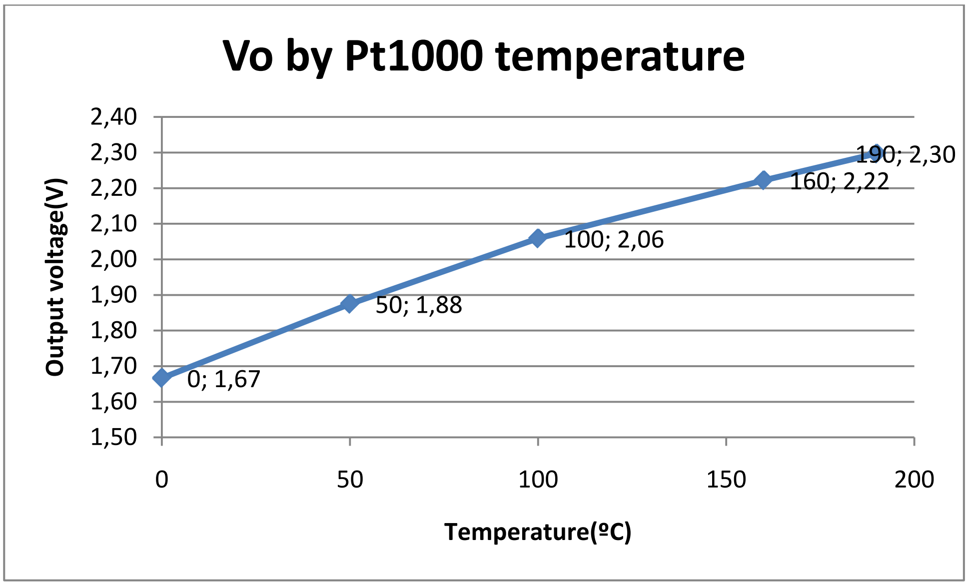


Figure 72, Temperature sensor curve temperature

To show more information about the sensor see data sheet in annex.

11.4. Switch

The switch is a critical part of the regulator, is in charged to control the voltage of the PV array switching between open circuit voltage, characteristic of panel, and battery voltage and it is controlled by PWM output of uC though a driver.

The device more indicated to realize this task is a Power Mosfet for its lower loses and the big switching frequency, the Ixis Power is the company selected to provide the Power Mosfet for the prices and performance of their devices.

11.4.1. Preliminary Technical Information

Features

- International standard packages
- Fast intrinsic diode
- Avalanche Rated
- Low Q and Rds ON
- Extended FBSOA

Advantages

- Low gate drive requirement
- High power density
- Fast switching

Applications

- Load switches
- High side switches
- Low voltage applications such as automotive, DC & DC converters
- Inverters and battery chargers
- Audio and Medical applications

11.4.1. Characteristics

For the correct function of the regulator is necessary to support the maximum levels of the power line that it will be work. The maximum current is 66A because it's a regulator of 1.6kW and the maximum voltage is 60V in the case that the do an array of more than 2 panels in serial. The maximum frequency of the PWM output of uC is 40 kHz. The last characteristic is a heavy package, is necessary to be able to connect the power line cables, 22mm2 size.

The device that has been chosen is a Power Mosfet P-channel, and the typical characteristics are summarized in figure 73, the maximum voltage in drain is 65V and supports 120A between drain and source, the typical resistance at 25 degree is 0.01Ω.

IXTP120P065T

- V_{DSS} = - 65V
- I_{D25} = - 120A
- $R_{DS(on)} \leq 10m\Omega$

IXYSPOWER
Efficiency Through Technology

PolarP™ and TrenchP™ Summary Table

Part Number	Vdss (max) V	Id @ Tc=25°C (A)	Rds(on) @ Tc=25°C (Ω)	Ciss (pF) typ	Qg (nC) typ	trr @ Tc= 25°C (ns)	R(th)JC (°C/W)	Pd (W)	Package
TrenchP P-Channel Power MOSFETs									
IXTA32P05T	-50	-32	0.036	1975	46	26	1.5	83	TO-263
IXTP32P05T	-50	-32	0.036	1975	46	26	1.5	83	TO-220
IXTA140P05T	-50	-140	0.008	13500	200	53	0.42	298	TO-263
IXTP140P05T	-50	-140	0.008	13500	200	53	0.42	298	TO-220
IXTH140P05T	-50	-140	0.008	13500	200	53	0.42	298	TO-247
IXTA28P065T	-65	-28	0.045	2030	46	31	1.5	83	TO-263
IXTP28P065T	-65	-28	0.045	2030	46	31	1.5	83	TO-220
IXTA120P065T	-65	-120	0.01	13200	185	53	0.42	298	TO-263
IXTP120P065T	-65	-120	0.01	13200	185	53	0.42	298	TO-220
IXTH120P065T	-65	-120	0.01	13200	185	53	0.42	298	TO-247
IXTA24P085T	-85	-24	0.065	2090	41	40	1.5	83	TO-263
IXTP24P085T	-85	-24	0.065	2090	41	40	1.5	83	TO-220
IXTA96P085T	-85	-96	0.013	13100	180	55	0.42	298	TO-263

Figure 73, Typical characteristics of Power Mosfet

The package selected is showed in figure 74, it’s a heavy package with big screws to connect with safety the power line and have the integrated cooler under the package perfect to connect with the principal cooler of the regulator box.

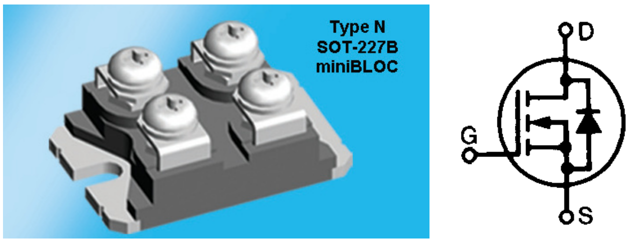


Figure 74, Package and symbol of Power Mosfet

To show more information about the Power Mosfet see data sheet in annex.

11.5. Diode

To keep the discharge of the battery trough the panels during the night and complete the function of the DC-DC converter is necessary two power diodes with high electrical characteristics and low loses.

The diode selected to make this functions is an parallel agrupation of VF40100C with isolated package. The technical applications, information and characteristics are summarized in the next points.

11.5.1. Preliminary technical information

PRODUCT BENEFITS

- Low Losses
- Low Noise Switching
- Cooler Operation
- Higher Reliability Systems

- Increased System Power
- Density

PRODUCT FEATURES

- Ultrafast Recovery Times
- Soft Recovery Characteristics
- Popular ITO-220AB Package
- Low Forward Voltage
- Low Leakage Current
- Avalanche Energy Rated

PRODUCT APPLICATIONS

- Anti-Parallel Diode
- Switch mode Power Supply
- Inverters
- Free Wheeling Diode
- Motor Controllers
- Converters
- Inverters
- Snubber Diode
- PFC

11.5.2. Characteristics

This diode is made by two diodes in parallel, and has an isolated package, see figure 75. The typical characteristics of the diode are summarized in the figure 76.

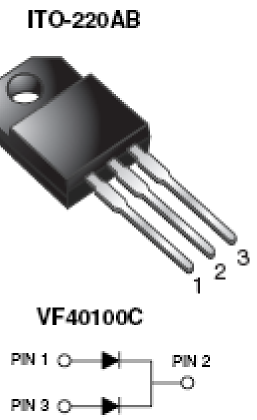


Figure 75, Diode isolated package

PRIMARY CHARACTERISTICS	
$I_{F(AV)}$	2 x 20 A
V_{RRM}	100 V
I_{FSM}	250 A
V_F at I_F = 20 A	0.61 V
T_J max.	150 °C

Figure 76, Diode typical characteristics

One of the most important characteristic of this diode is the current that can cross it with very low loses, the figure 77 shows this characteristic, to reduce the loses in the diodes is designed a matrix of 2 diodes in the input, to cut the panel in night, and three in the output to discharge the coil in the battery. Every diode is composed by 2 diodes, this meant that there are 4 diodes in 2 packages in the input and 6 in 3 packages in the output.

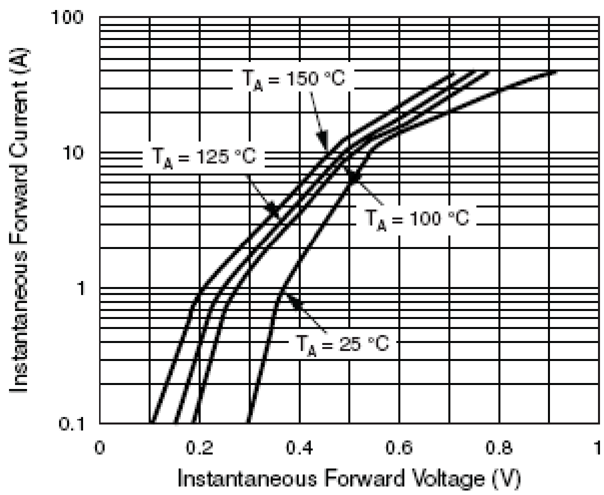


Figure 77, Typical Instantaneous Forward Characteristics Per Diode

To show more information about the power diode see data sheet in annex.

11.6 Regulator 5V

To supply all the integrated circuits from digital PCB, power PCB, sensors etc, is necessary a regulator that convert the voltage of the battery to 5V, this converter will be located in the power PCB, and provides energy to all the IC's.

11.6.1. Characteristics

The Regulator selected is the typical LM78M05V from National Semiconductor with TO-220 package, see figure 78, and the typical characteristics are showed in figure 79.

TO-220 Power Package (T)

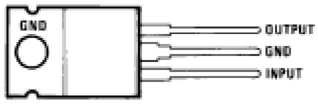


Figure 78, 7805 Regulator 5V package

National Semiconductor

LM341-5.0, LM78M05C

Unless otherwise specified: V_{IN} = 10V, C_{IN} = 0.33 µF, C_O = 0.1 µF

Symbol	Parameter	Conditions		Min	Typ	Max	Units
V_O	Output Voltage	I_L= 500 mA		4.8	5.0	5.2	V
		5 mA ≤ I_L ≤ 500 mA P_D ≤ 7.5W, 7.5V ≤ V_{IN} ≤ 20V		4.75	5.0	5.25	
$V_{R\ LINE}$	Line Regulation	7.2V ≤ V_{IN} ≤ 25V	I_L = 100 mA			50	mV
			I_L = 500 mA			100	
$V_{R\ LOAD}$	Load Regulation	5 mA ≤ I_L ≤ 500 mA				100	
I_Q	Quiescent Current	I_L = 500 mA			4	10.0	mA
ΔI_Q	Quiescent Current Change	5 mA ≤ I_L ≤ 500 mA				0.5	
		7.5V ≤ V_{IN} ≤ 25V, I_L = 500 mA				1.0	
V_n	Output Noise Voltage	f = 10 Hz to 100 kHz			40		µV
$\frac{\Delta V_{IN}}{\Delta V_O}$	Ripple Rejection	f = 120 Hz, I_L = 500 mA			78		dB
V_{IN}	Input Voltage Required to Maintain Line Regulation	I_L = 500 mA		7.2			V
ΔV_O	Long Term Stability	I_L = 500 mA				20	mV/khrs

Figure 79, Typical characteristics of 7805 5V Regulator

11.6.2. Connection

The connection between 5V regulator and the rest of circuit is showed in figure 80. In the input of the regulator is connected the battery, with a capacitor to smooth the current and protect the IC. The 7805 convert the voltage of the battery to 5V that show in the output, and in this pin is connected all the supplies of the PCB's like uC, sensors etc.

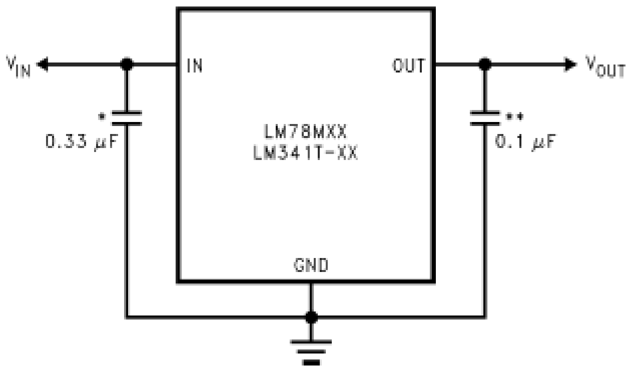


Figure 80, Connection of 7805 5V Regulator

To show more information about the LM78M05C 5V Regulator see data sheet in annex.

11.7. Analog to digital Converter (ADC)

The algorithm designed to control the PV panels, work in a frequency of 40kHz, this mean that every 25us, a control sign is in the switch. In the other hand, to function the algorithm is necessary to manage 6 analog sensors; this meant that in 25us all the analog signals must be converted to digital and the entire algorithm calculated by the uC. The uC is not able to do this, because only have one ADC integrated and need 15us for every conversion.

This problem has been solved though the use of an external ADC and connected to the uC like a peripheral. The IC selected to realize this task is ADS7864 from Analog Devices.

11.7.1. Electrical characteristics

All specifications T_{MIN} to T_{MAX}, $+V_A = +V_D = +5V$, V_{REF} = internal +2.5V and f_{CLK} = 8MHz, f_{SAMPLE} = 500kHz (unless otherwise noted).

PARAMETER	TEST CONDITIONS	ADS7864Y			ADS7864YB			UNIT
		MIN	TYP	MAX	MIN	TYP	MAX	
Digital Input/Output								
Logic Family			CMOS			CMOS		
Logic Levels:								
V_{IH}	I_{IH} = +5µA	3.0		$+V_D$ + 0.3	3.0		$+V_D$ + 0.3	V
V_{IL}	I_{IL} = +5µA	–0.3		0.8	–0.3		0.8	V
V_{OH}	I_{OH} = –500µA	3.5			3.5			V
V_{OL}	I_{OL} = –500µA			0.4			0.4	V
External Clock		0.2		8	0.2		8	MHz
Data Format			Binary Two's Complement			Binary Two's Complement		
Power-Supply Requirements								
Power Supply Voltage, $+V_A$, $+V_D$		4.75	5	5.25	4.75	5	5.25	V
Quiescent Current, $+V_A$, $+V_D$				10			10	mA
Power Dissipation				50			50	mW

Figure 81, Electrical characteristics of ADS7864

11.7.2. Preliminary technical information

FEATURES

- 6 Simultaneous Sampling Channels
- Fully Differential Inputs
- 2us Total Throughput per Chanel
- No missing Codes

- Parallel interface
- 1MHz Effective Sampling rate
- Low power: 50mW
- 6X FIFO

APPLICATIONS

- Motor control
- Multi-Axis positioning systems
- 3-Phase power control

11.7.3. Function

The ADC have 6 analog channels to convert, and is capable to convert 2 channels simultaneously because have two ADC implemented inside.

The first step is the choice of the operation mode, for this application has been selected FIFO mode, because is necessary to convert signals and read it from the internal memory of ADS7864 at the same time. When the mode is selected is necessary to manage which channel is going to be converted, the order of the channels, the figure 82 shows how it can be chosen.

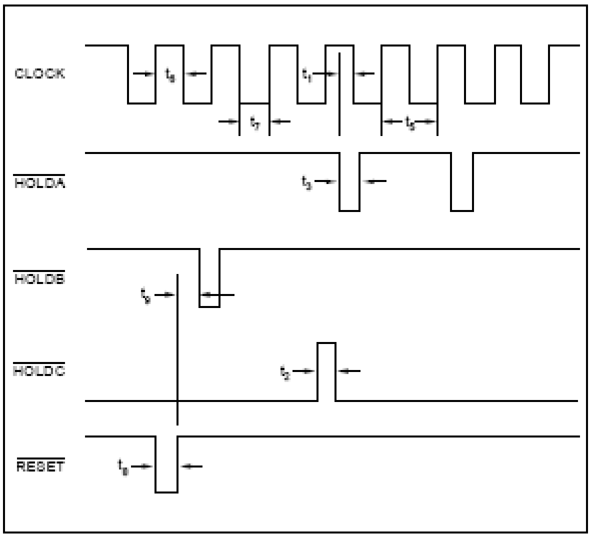


Figure 82, Sample and Hold control signals example

All start with a reset, and trough the control signals HOLDX, is possible to do the schedule of the signals that is going to be converted, in this case, the conversion will begin with channel B, after that channel C and after 2 times channel A, in every channel there are two signals converted simultaneously, in total 6 signals.

The FIFO and conversion is managed though BUSY and RD signals, the figure 83 shows how this signals function.

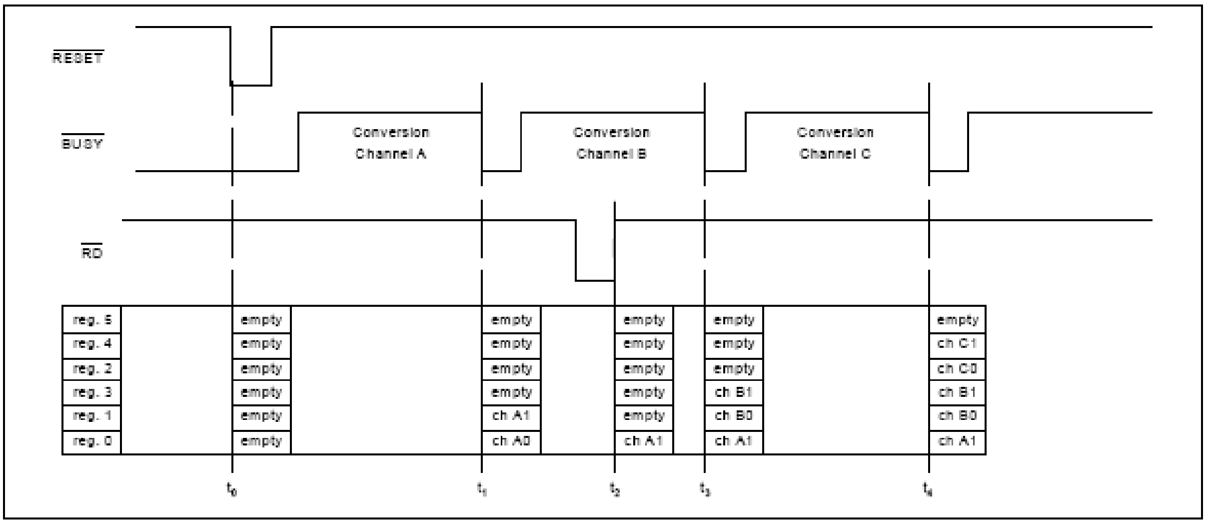


Figure 83, FIFO example

Start with RESET, that erase all the memory registers of FIFO, when is selected a channel to convert, in this case first A second B and finally 3, the signal BUSY it's at high level during the conversion, when it finish, return to low level and this meant that there are two signals converted in the FIFO, A0 and A1 for channel A, to refresh the output and send the digital information to the uC must be an impulse in RD signal, when this occurs this data is erased from the FIFO and is sent through the digital outputs. The figure 84 shows the structure of the information sent from the ADC device though digital output to the uC.

Valid Data	3-Bit Channel Information	12-Bit Data Word

Figure 84, Output data structure

For our purpose is only necessary the 12 data bits, because the manage is done with the uC and all the time is known the sensor precedence of the data.

The software that controls the ADC device is explained in software chapter.

11.7.4. Connection

The external ADC is connected like in the figure 85, in the ports from 27 from 48 is connected directly the sensors, the device is supplied with 5V from the regulator, the control signals are connected directly to the uC and the same with the digital outputs.

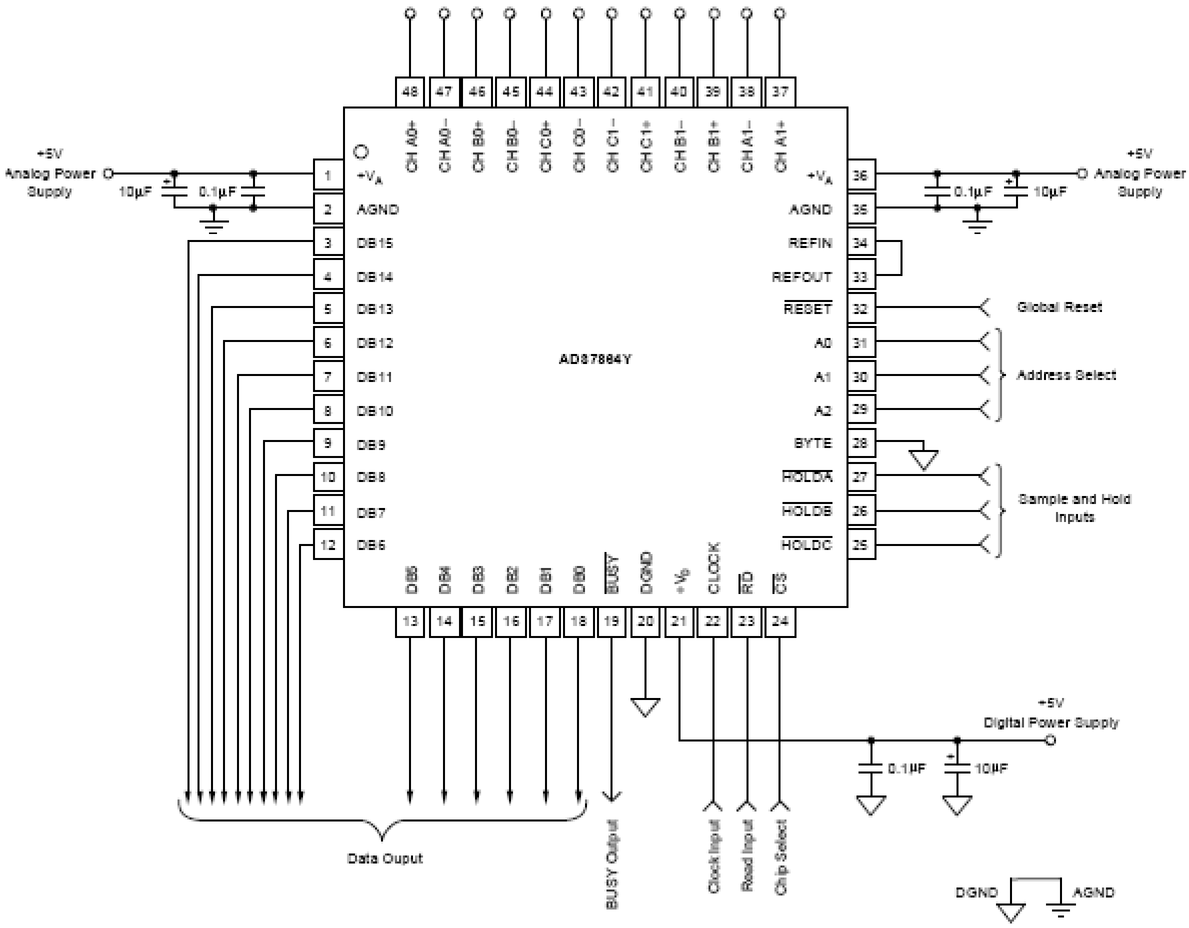


Figure 85, Connection of ADS7864

For more information about ADS7864 show the data sheet in annex.

11.8. Drivers

To be effective the control consigns that send the microcontroller, through the outputs, to the power line is necessary to increase the energy of these signals. To solve this problem have been designed drivers to connect between power line and microcontroller.

11.8.1. Power Mosfet driver design

To open or close the power Mosfet is necessary to put a voltage between gate and source of -10V and a level of charge of 240nC. This meant that is necessary a floating supply for the driver because the reference (source) is changing in the time between 0 and -60V (maximum).

The electrical circuit to connect the driver to the switch is showed in figure 86.

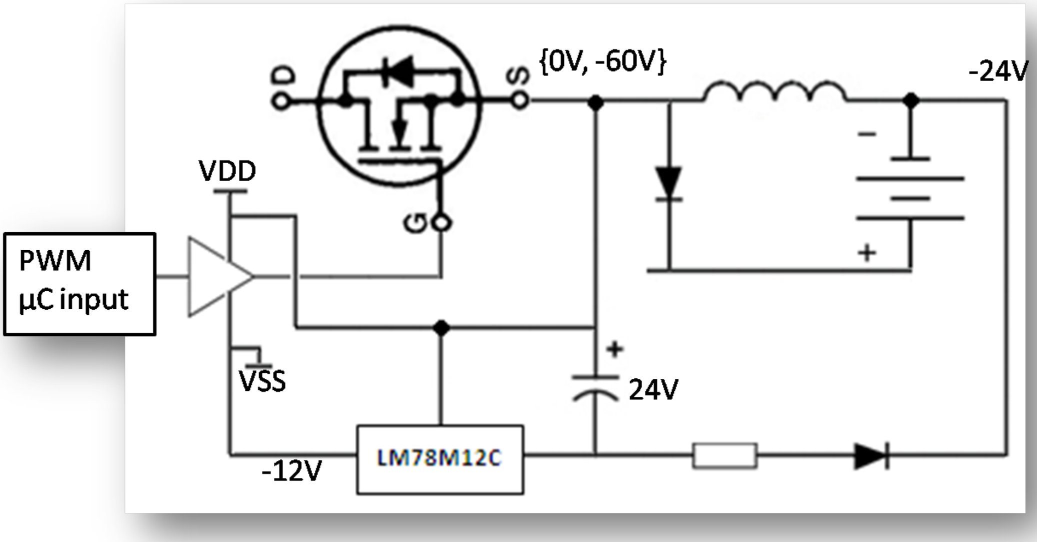


Figure 86, Driver Power Mosfet Schematic

With this topology, the driver is always supplied with 12V and is able to apply the voltage and current necessary to change the state of the Power Mosfet.

The capacity of the capacitor determines the speed of the system and the resistor limit the current that cross the diode.

The energy of the capacitor is:

$$E_1 = \frac{1}{2} C {V_0}^2$$

The energy necessary to change the state of the Power Mosfet is, see figure 87:

$$E_0 = QV$$

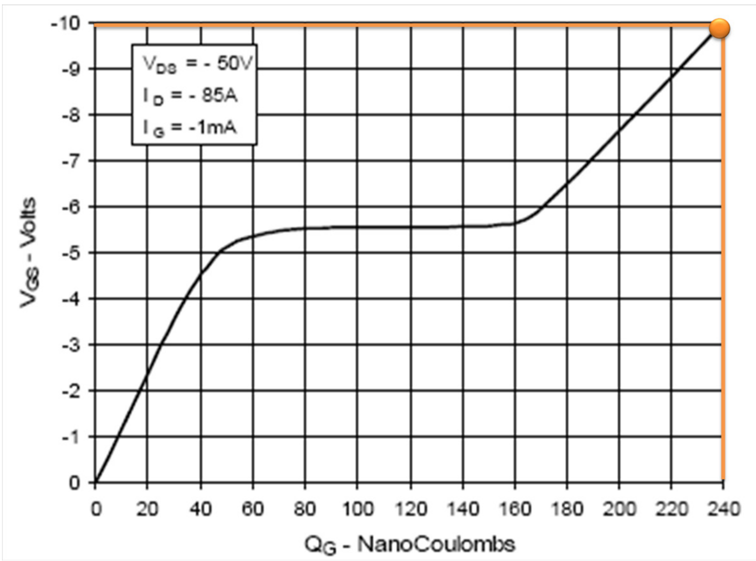


Figure 87, Gate charge

Q=240nC and Vgs=-10V

Then the energy total:

$$E_2 = \frac{1}{2}C{V_0}^2 - QV$$

E2 is too:

$$E_2 = \frac{1}{2}C{V_1}^2$$

When V1 is capacitor voltage discharged and V0 when is charged.

The minimum capacitor necessary is:

$$C_{min} = 12.6nF$$

To be sure multiply this capacity by a factor of security:

$$C = C_{min} \cdot 10 = 126nF$$

Normalizing:

$$\boldsymbol{C = 150nF}$$

With a choice of 50mA of current limited in the diode, the resistor is:

$$\boldsymbol{R} = \frac{V}{I} = \frac{24V}{50mA} = \mathbf{480}\Omega$$

The 12V regulator selected is LM78M12C, to see more details about the regulator show data sheet in annex.

The driver selected is ADP3630 from Analog Devices, is supplied with 12V and is able to send an output of 2A.

The typical characteristics al showed in figure 88.

Parameter	Symbol	Test Conditions/Comments	Min	Typ	Max	Unit
SUPPLY						
Supply Voltage Range	V_{DD}		9.5		18	V
Supply Current	I_{DD}	No switching, INA, $\overline{INA}$, INB, and $\overline{INB}$ disabled		1.2	3	mA
Standby Current	I_{SBY}	SD = 5 V		1.2	3	mA
UVLO						
Turn-On Threshold Voltage	V_{UVLO_ON}	V_{DD} rising, T_A = 25°C	8.0	8.7	9.5	V
Turn-Off Threshold Voltage	V_{UVLO_OFF}	V_{DD} falling, T_A = 25°C	7.0	7.7	8.5	V
Hysteresis				1.0		V
DIGITAL INPUTS (INA, $\overline{INA}$, INB, $\overline{INB}$, SD)						
Input Voltage High	V_{IH}		2.0			V
Input Voltage Low	V_{IL}				0.8	V
Input Current	I_{IN}	0 V < V_{IN} < V_{DD}	−20		+20	µA
SD Threshold High	V_{SD_H}		1.19	1.28	1.38	V
		T_A = 25°C	1.21	1.28	1.35	V
SD Threshold Low	V_{SD_L}	T_A = 25°C	0.95	1.0	1.05	V
SD Hysteresis	V_{SD_HYST}	T_A = 25°C	240	280	320	mV
Internal Pull-Up/Pull-Down Current				6		µA
OUTPUTS (OUTA, OUTB)						
Output Resistance, Unbiased		VDD = PGND		80		kΩ
Peak Source Current		See Figure 20		2		A
Peak Sink Current		See Figure 20		−2		A

Figure 88, Typical characteristics of driver ADP3630

The diode selected for this application is 1N5401 from Fairchild Semiconductor, with a maximum reverse voltage of 100V and maximum direct current 3A.

To see more information about the driver or the diode see data sheet in annex.

11.8.2. Relay driver

To switch the relay it's not enough the control signal that send the microcontroller, is necessary to amplify this signal with power. In the specifications of relay is written that is necessary for the model of 5V, 80mA to charge the coil and create the magnetic field to close the contact.

The driver designed to realize this function is showed in figure 89.

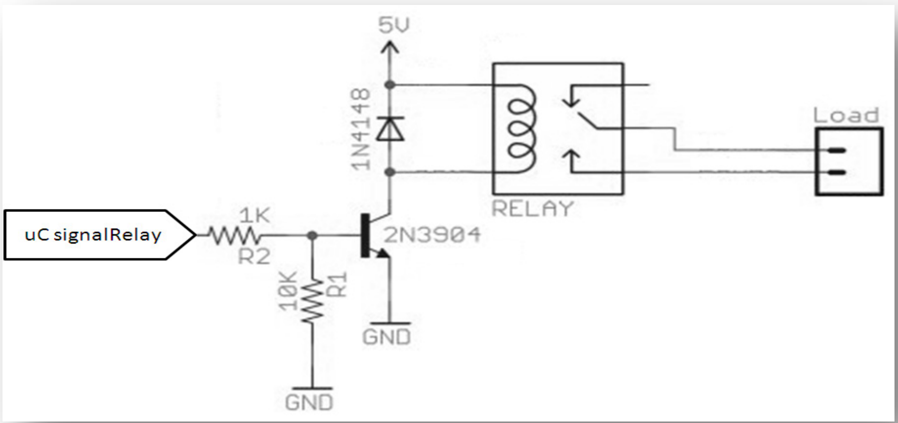


Figure 89, Relay driver

This driver is composed for a pair of resistances that create a voltage sufficient to turn on the transistor 2N3904 that make a current between collector and emitter of 200mA, enough to close the contact of the relay. When the signal of microcontroller is a zero, there is no voltage between base and emitter and the transistor is open. The coil is discharged by the diode 1N4148.

11.9. Display

The display is used to show the state of the regulator in real time in the front of the package of the regulator, the display selected is MC1602F-SYR from EVERBOUQUET, and the module is made by a matrix with 2 lines and 16 characters in every one, see figure 90.

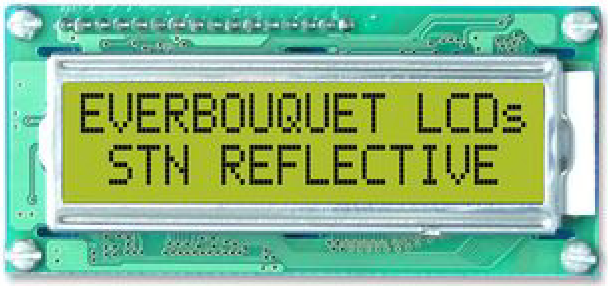


Figure 90, LCD display

11.9.1. Description of characteristics

STN LCD MODULE 2X16
Number of Digits / Alpha: 32
Character Size: 4.86mm
Supply Voltage: 5V
Display Mode: Reflector
Width, display area: 85mm
Height, display area: 36mm
Operating Temperature: 0 ° C to +50 ° C
Width (external): 85mm
Length / Height: 36mm
Active Area Height: 16mm
Color, font: Yellow
Color, font: Green
Polarization Display: Reflective
Height, character: 4.86mm
Width, character: 2.96mm
Width, active area: 64.5mm
Lines, numbers: 2
Number of colors: 1
Number of digits: 16
Resolution: 5 x 7 Dots + Cursor
Display Technology: STN
Temperature, storage max: 70 °C
Temperature, storage min: -20 °C
Supply Voltage D.C.: 5V
Voltage, supply max: 6V
Interface Type: Parallel
Character Type: Dot Matrix + Cursor

11.10. Power PCB

In this PCB is designed all the power line, the Buck regulator, coil, capacitor, power diodes, Power Mosfet, drivers, sensors, the connection to the outside and the supplies for the digital PCB. The communication between PCB's is made through a PATA connector and is sent the values of the 6 sensors and the supply and reference for the integrated circuits.

In figure 91, 92 and 93 is showed the PCB designed for the power line.

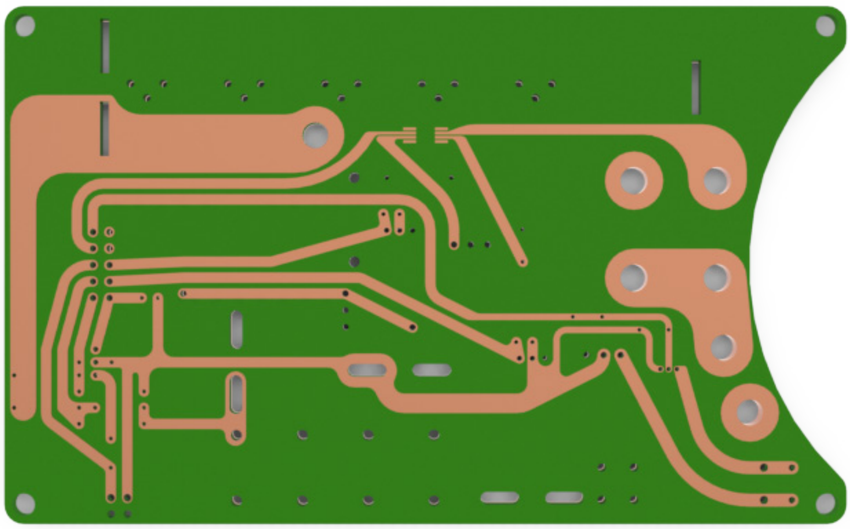


Figure 91, Top Power PCB

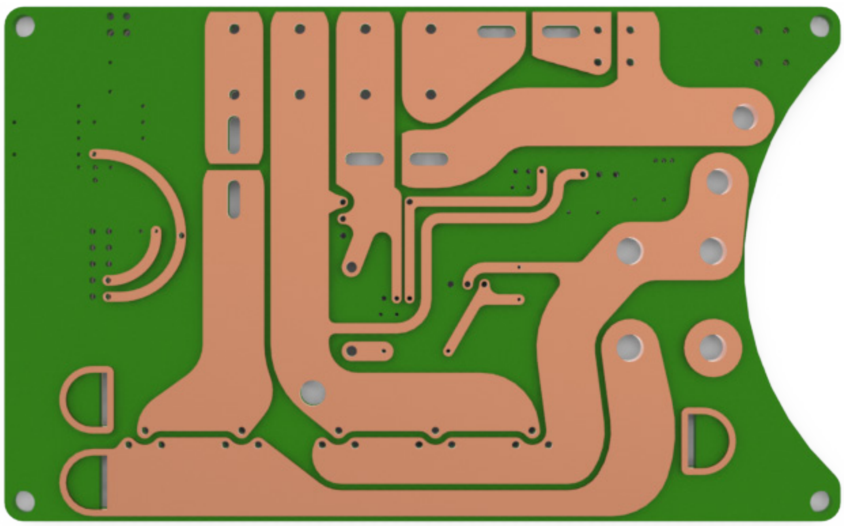


Figure 92, Bottom Power PCB

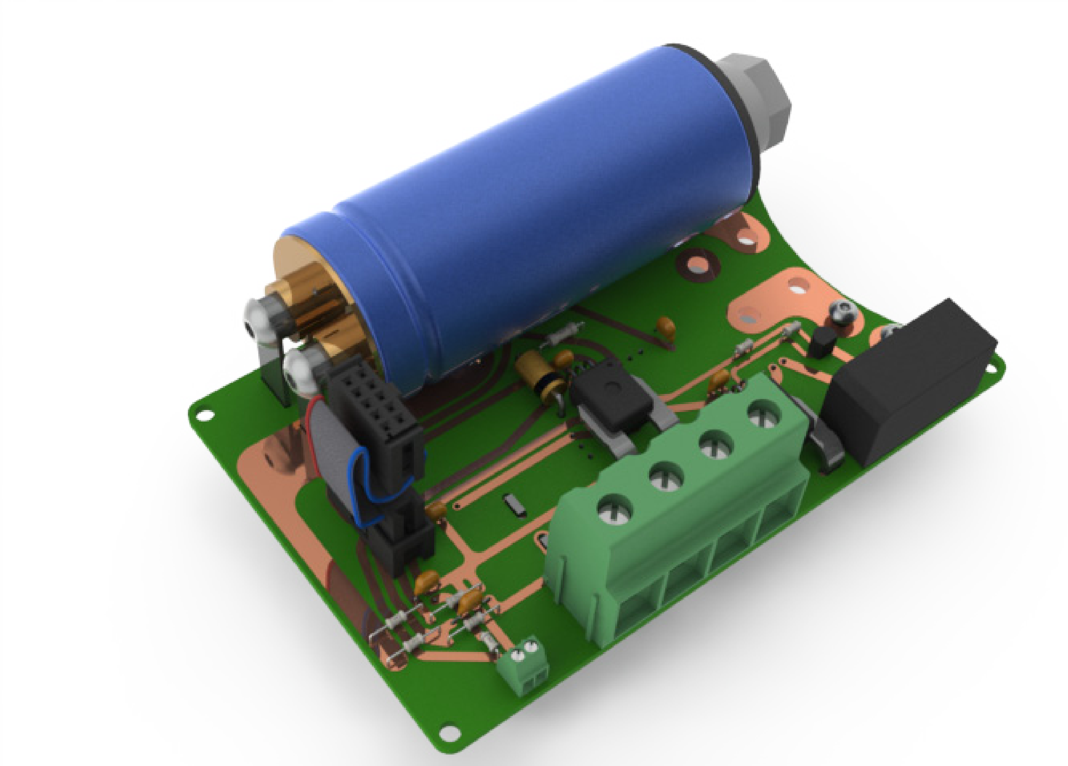


Figure 93, Complete Power PCB

11.11. Digital PCB

In this PCB is designed the digital part, all that something in common with the microcontroller, like display, ADC converter or reset button. This PCB is the mind of the device and control all the power line.

The figures 94 and 95 shows the Digital PCB.

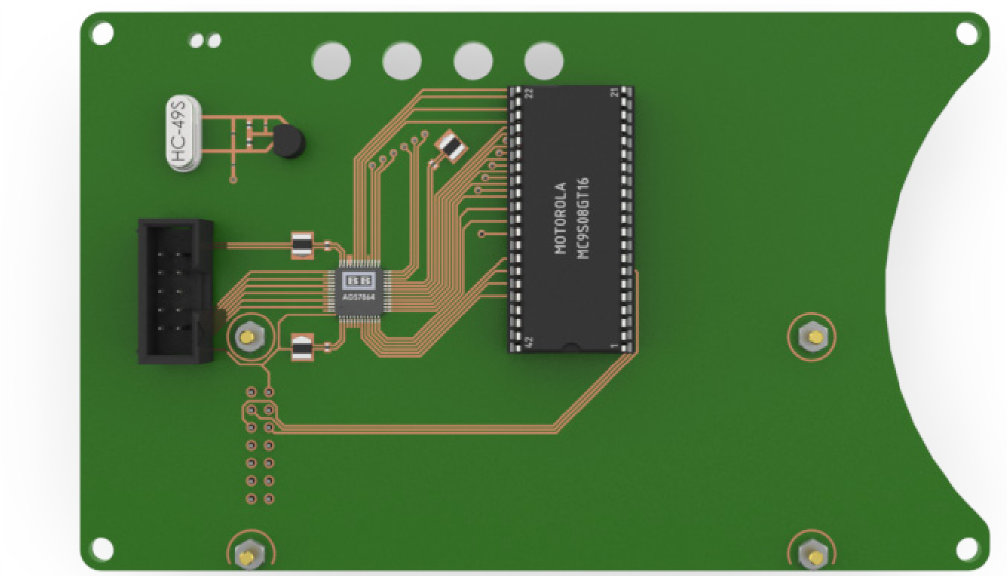


Figure 94, Bottom Digital PCB

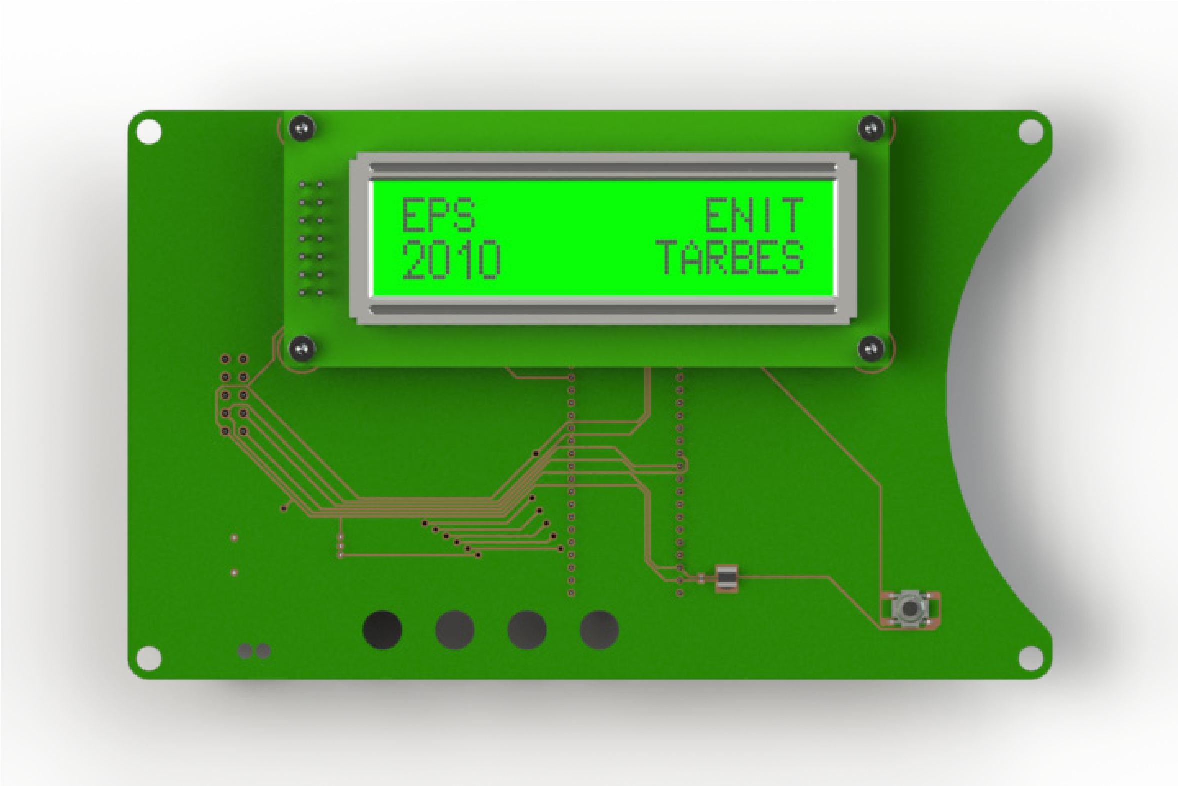


Figure 95, Top Digital PCB

11.12. Box

In this chapter is showed the box where is stored the PCB's, and is composed by aluminum and in the back have the cooler, se figure 96.

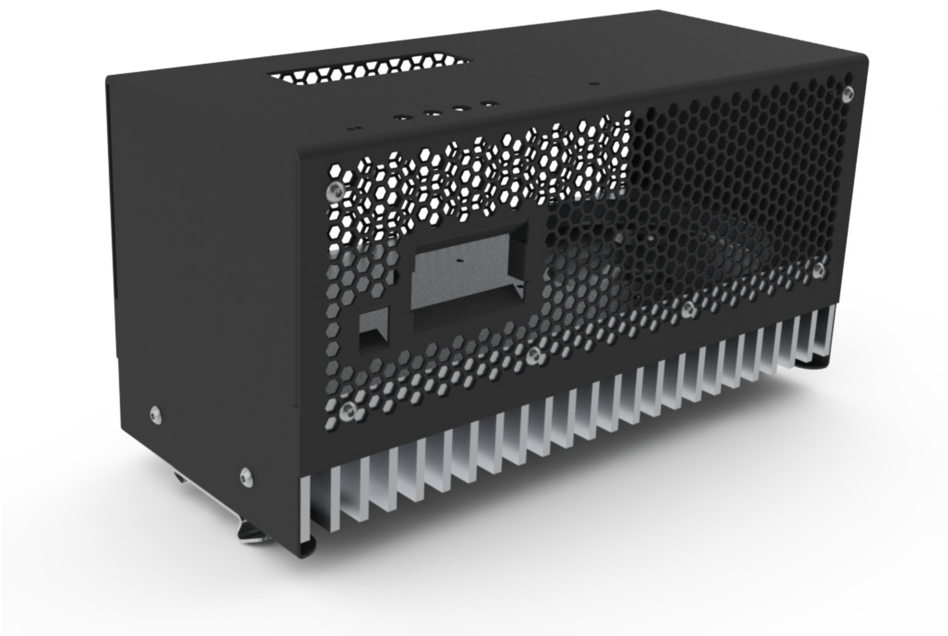


Figure 96, Box and cooler

11.13. Complete device

This chapter shows the final device implemented, see figures 97 and 98.

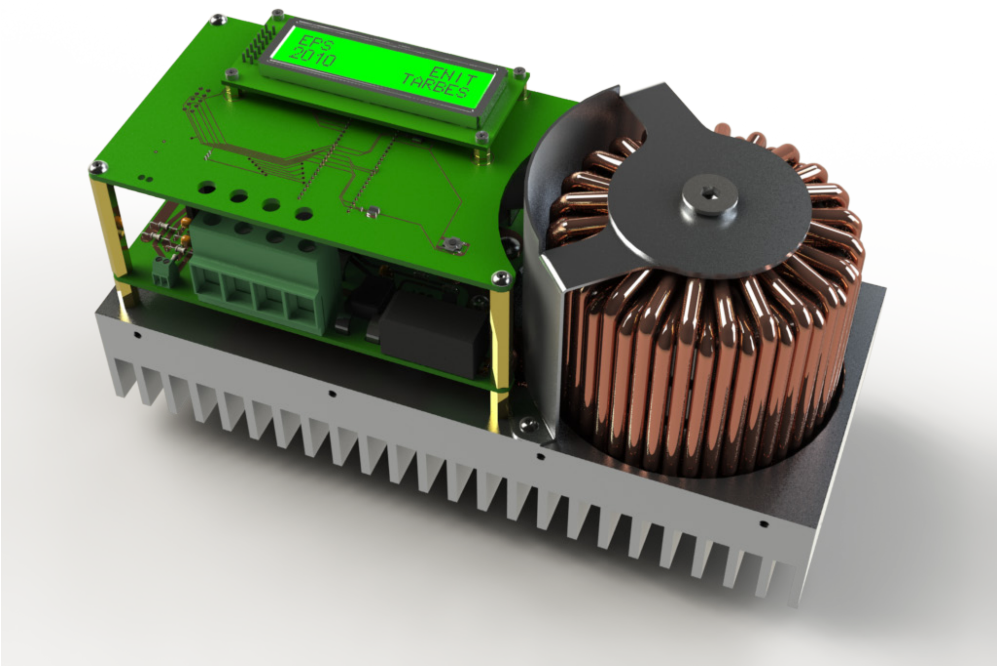


Figure 97, Device without box

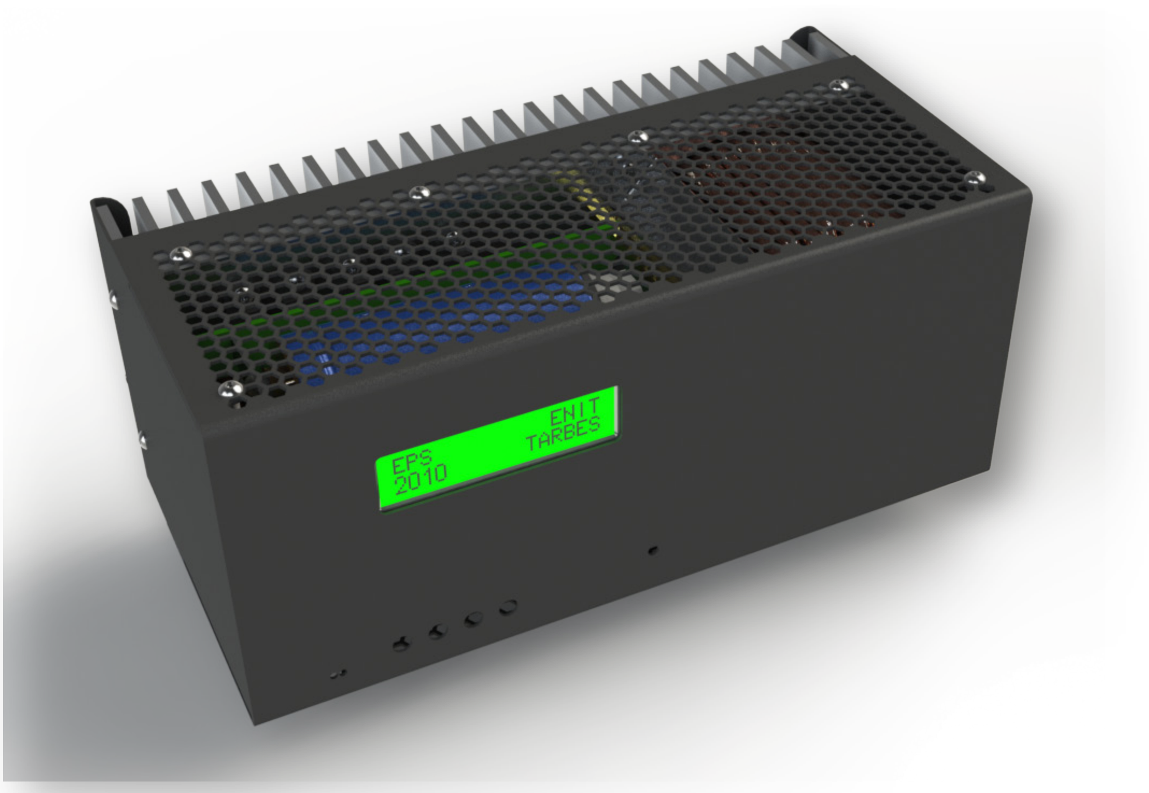


Figure 98, Complete Device

11.14. Loses

In this chapter is calculated the loses of the compete device to know the efficiency of the prototype and if is made in the correct way.

11.14.1. MOSFET

The loses of the power Mosfet are divided in two parts, when the switch is ON, there are loses for connection and between connection and disconnection there are loses by commutation, when the switch is OFF there are not loses.

The time to switch between OFF and ON is 32ns and the time for ON to OFF is 82ns, the resistance between drain and source is 12mΩ, these parameters are specified in the data sheet of Power Mosfet. The calculation is done in the worst case, when all work at maximum, With a voltage in the array of panels of 60V and a current of 24A, and in the coil 60A and 24V, all working at 40kHz, period of 25us.

Loses by commutation:

$$\boldsymbol{P_{COM}} = \frac{V_{DS} \cdot I_D}{2T}(T_{ON} + T_{OFF}) = \frac{36V \cdot 60A}{2 \cdot 25 \cdot 10^{-6}}(32 \cdot 10^{-9} + 82 \cdot 10^{-9}) = \mathbf{4.9}\boldsymbol{W}$$

Loses by conduction

$$\boldsymbol{P_{CON}} = \frac{1}{T}\left(I_D{}^2 R_{DS(ON)} T_{ON}\right) = \frac{1}{25 \cdot 10^{-6}}(60^2 \cdot 12 \cdot 10^{-3} \cdot 0.54 \cdot 25 \cdot 10^{-6}) = \mathbf{23.32}\boldsymbol{W}$$

Total

$$\boldsymbol{P_{MOSFET}} = \mathbf{28.228}\boldsymbol{W}$$

11.14.2. Power diodes

The diodes are composed by arrays of diodes in parallel, the power diode in the source of the Power Mosfet is made by 6 diodes, every one support a current of 10A in the worst case, the Duty cycle in MPPT is 0.54 and the characteristic of voltage of the diode is showed in figure 99.

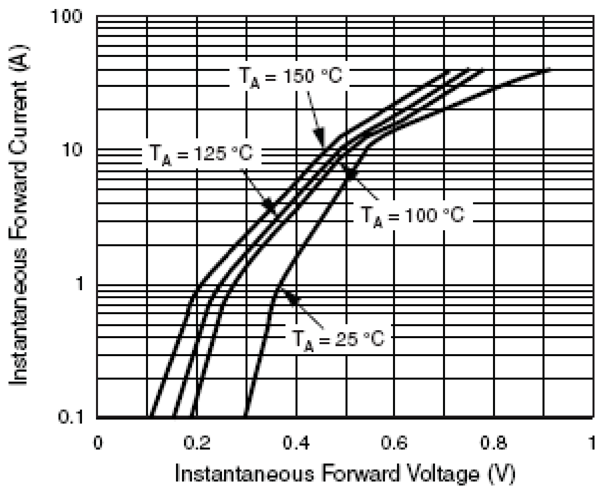


Figure 99, Voltage in diode

In this case, with a current of 10A for every diode working in a temperature of 100ºC, there is a voltage of 0.5V.

$$\boldsymbol{P_{DIODE(S)}} = I \cdot V_D \cdot (1 - D) = 60A \cdot 0.5V(1 - 0.54) = \mathbf{13.8W}$$

For the power diode connected in the drain of the Power Mosfet.

This diode is made by an array of 4 diodes in parallel, the current that cross everyone is 6A, and works in a voltage of 0.45V, see figure 86.

$$\boldsymbol{P_{DIODE(D)}} = I \cdot V_D = 24A \cdot 0.45V = \mathbf{10.8W}$$

11.14.3. Others

In this part is contemplated all the other low loses parts, like integrated circuits, DC-DC converters for supply them, drivers, the coil and little components like resistors and capacitors.

The loses are estimations always worst than the reality but approximated.

Other components	Loses
Integrated circuits	800mW
DC-DC converters	2W
Drivers	2W
Coil	4W
Little components, C, R	200mW
TOTAL	**10W**

11.14.4. Total loses

The total loses are summarized in figure …, this shows the worst case of efficiency of the regulator designed and it's only approximately 1 hour a day, maximum irradiance hour, in the other hours the efficiency is better.

The figure 100 shows graphically the loses in the device.

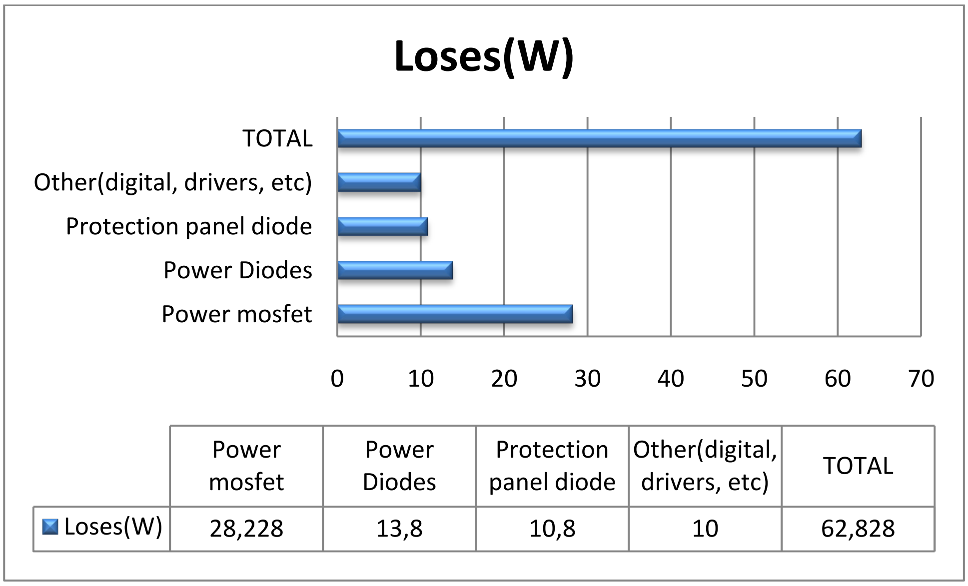


Figure 100, Prototype loses

The global efficiency of the regulator in the worst case is:

$$\mu = 96.1\%$$

This shows the efficiency of the prototype, the next steps before implementation are work on PCB and components to reduce loses.

12. Software design

This chapter explains the functions designed that implements the function of the regulator simulated and designed in Matlab Simulink. To create a functional device is necessary more functions than only the control algorithms, like ADC converter control or display function.

To create the functions in the Microcontroller has been used Code Warrior software and C language, to explain the functions in this chapter has been used flux diagrams to be easier to understand and explain it, to show the real code compiled and implemented in the device see the annex.

12.1. Device selected

The microcontroller selected is a Motorolla 8 bits 42pins not SMD, MC9S08GT60, the reason of this selection is for the facilities of Motorolla and the efficiency of this model is enough for the application, the figure 101 shows the package of the microcontroller selected.

The most important thinks that are used in this microcontroller are the digital common ports (5 ports) and 16 bit timer to create Real time interrupts.

Figure 101, MC9S08GT60

For more information about this device, show MC9S08GT60 data sheet in annex.

12.2 Structure

This chapter explains the structure followed to create the different functions that compose the complete software implemented in the microcontroller in charge to control the regulator, see figure 102.

Regulator
Initializations (Libraries, Port map, I/O, constants, Vectors)
Algorithms ➢ **MPPT** ➢ **Maintain** ➢ **Cut load by charge** ➢ **Overtemperature**
Analog to Digital Converter ➢ **ADC control** ➢ **Save data** ➢ **Convert to physical units**
Real time ➢ **Setup timer** ➢ **RSI**
Display

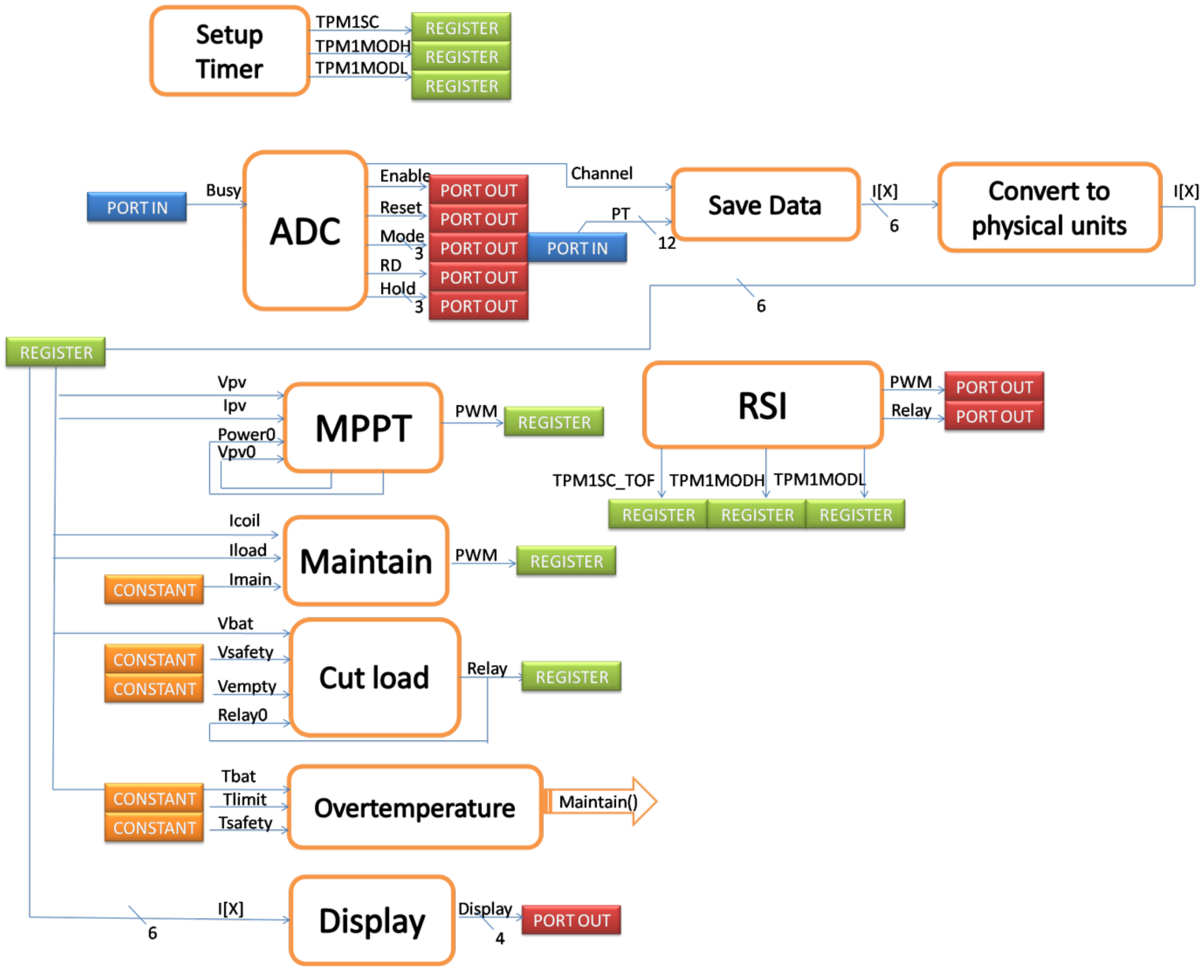


Figure 102, Complete software system

12.3 Main

This part of the code is the principal code and is only in charged to call the functions with a particular schedule, the idea is to call first the initialization of the timer, to start counting the 25us, after that, full the vector of external information from the sensors, later, the execution of the algorithm and finish with the refresh of the display.

The main code is explained in figure 103 though a flux diagram.

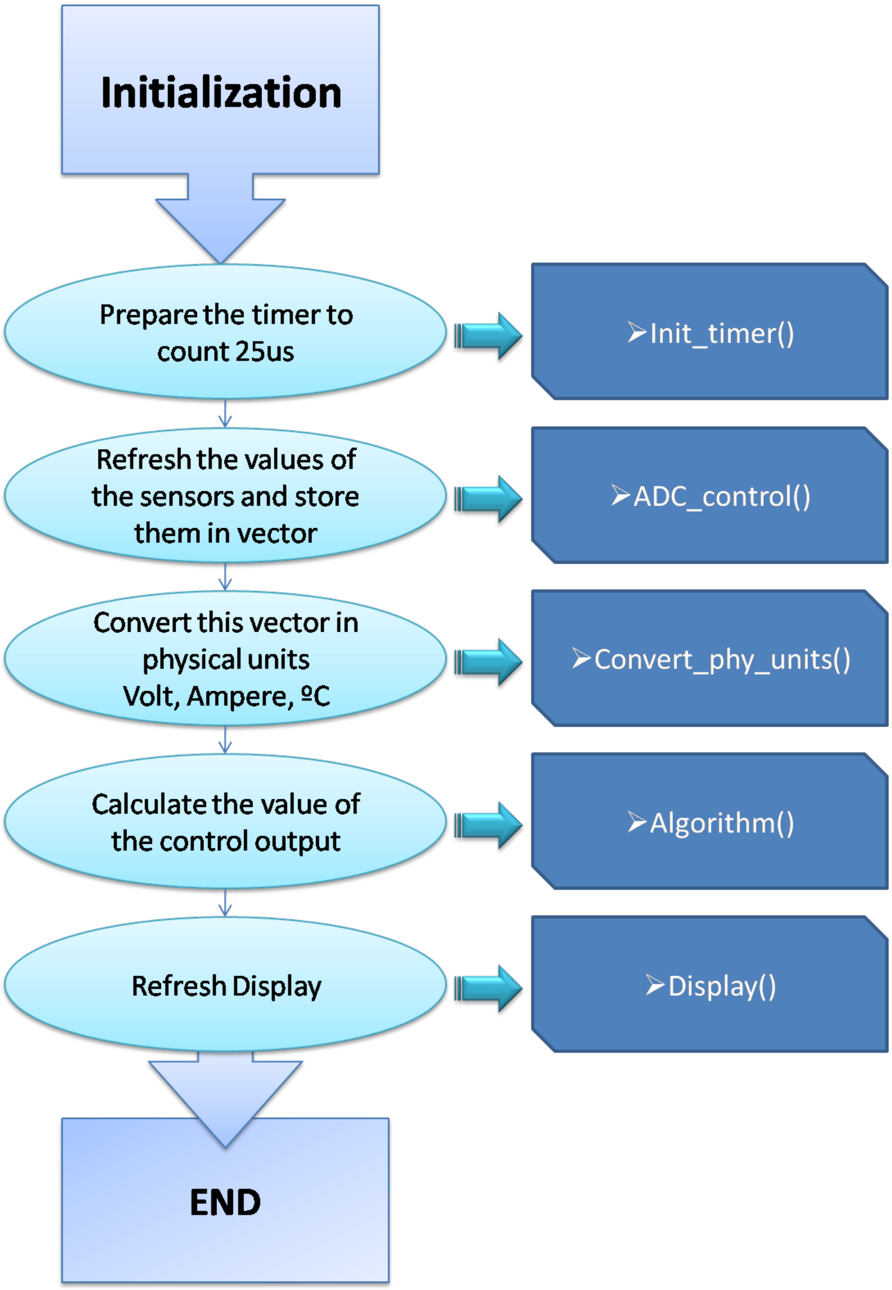


Figure 103, Main flux diagram

12.4 Control algorithm functions

In this chapter is explained every function used to implement the control algorithm designed in the previous chapters and how is translated in C code.

12.4.1. MPPT

This function, when is called, is in charge to calculate the next point of the status of the PV panel to increase the power that can provide it.

In figure 104 is showed the I/O schematic and figure 105 explains how is made in C code.

To show the real code implemented in microcontroller see annex.

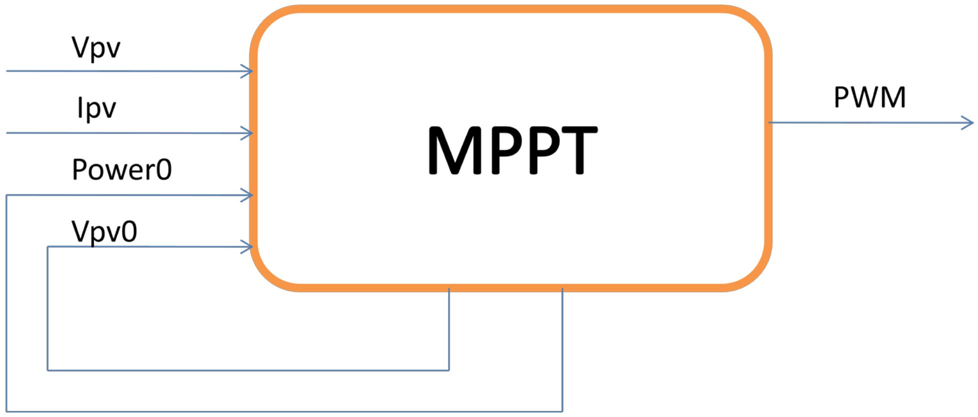
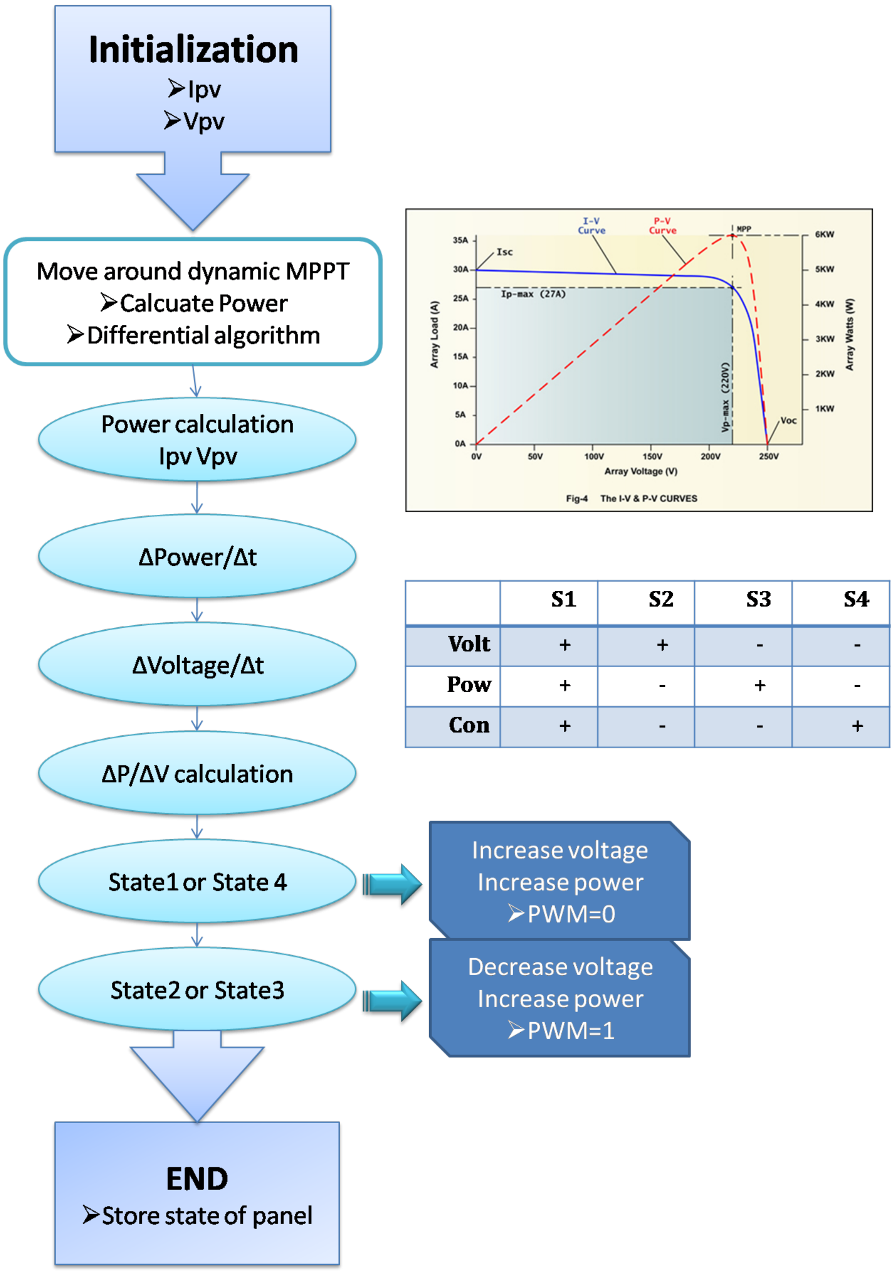


Figure 104, I/O MPPT



	S1	S2	S3	S4
Volt	+	+	-	-
Pow	+	-	+	-
Con	+	-	-	+

Figure 105, MPPT function

12.4.2. Maintain

This function is in charge to control the current that supply the load and the current that maintain the charge of the battery when it is full. The idea is to follow a consign to control the panel that make at the output a current enough to supply and maintain battery and load.

The I/O schematic is showed in figure 106 and C code algorithm implemented in microcontroller is explained in figure 107 though a flux diagram.

Figure 106, I/O Maintain

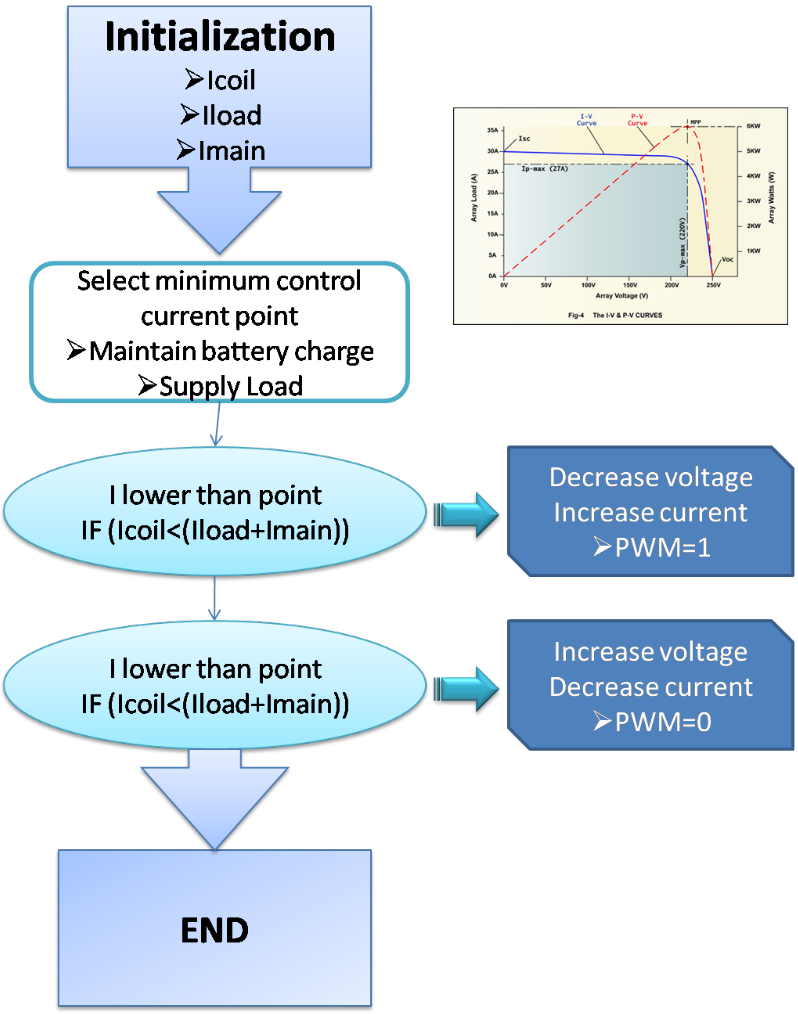


Figure 107, Maintain flux diagram

12.4.3. Cut load by charge

This function is in charge to protect the battery of overdischarges, the idea that if follows is monitor, every time that is called, the state of charge of the battery and cut when the level is critical.

Figure 108 shows I/O schematic and figure 109 explain the C code implemented in microcontroller though a flux diagram.

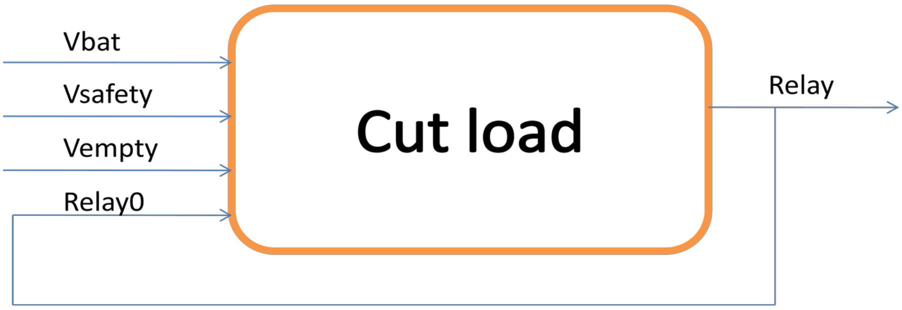


Figure 108, I/O Cut load

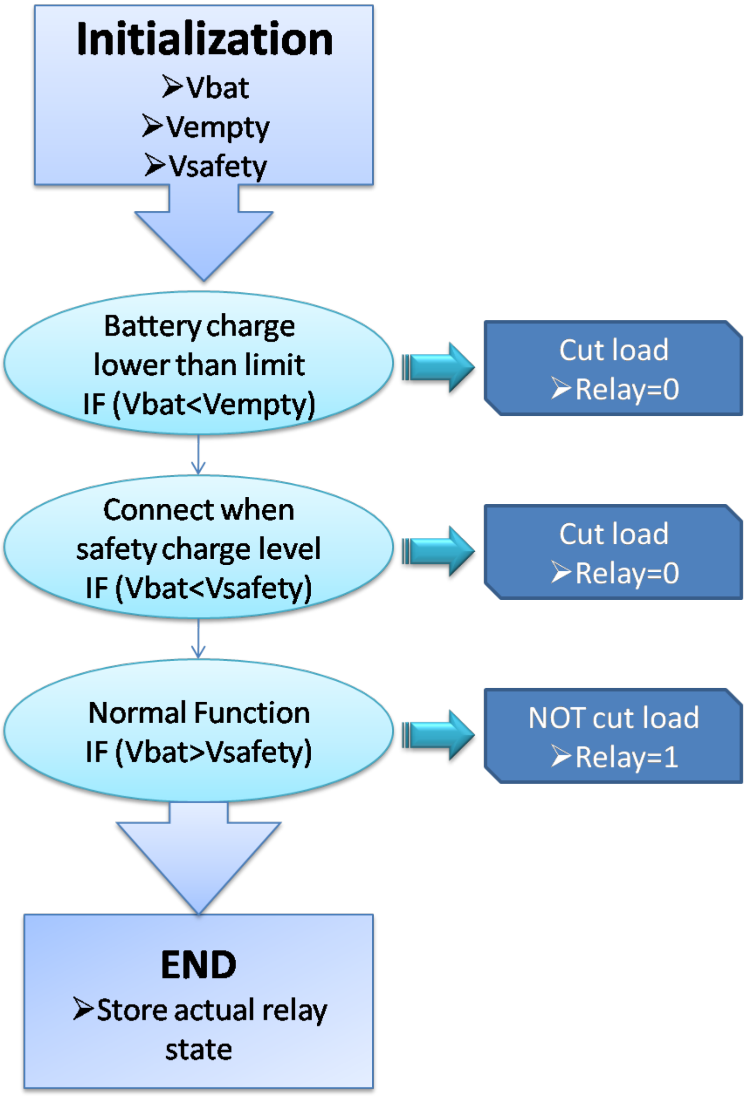


Figure 109, cut load by charge function

12.4.4. Overtemperature

This function is optional, and can be selected for the user to use it or not because it use an external temperature sensor that can be connected or not, and the other parts of the device can function without this one.

When the battery receive a bulk continuous charge, the acid that is allocated inside can tart to boil, to protect the battery of overtemperature, when this is detected, the control of the system switch to maintain state.

Figure 110, I/O

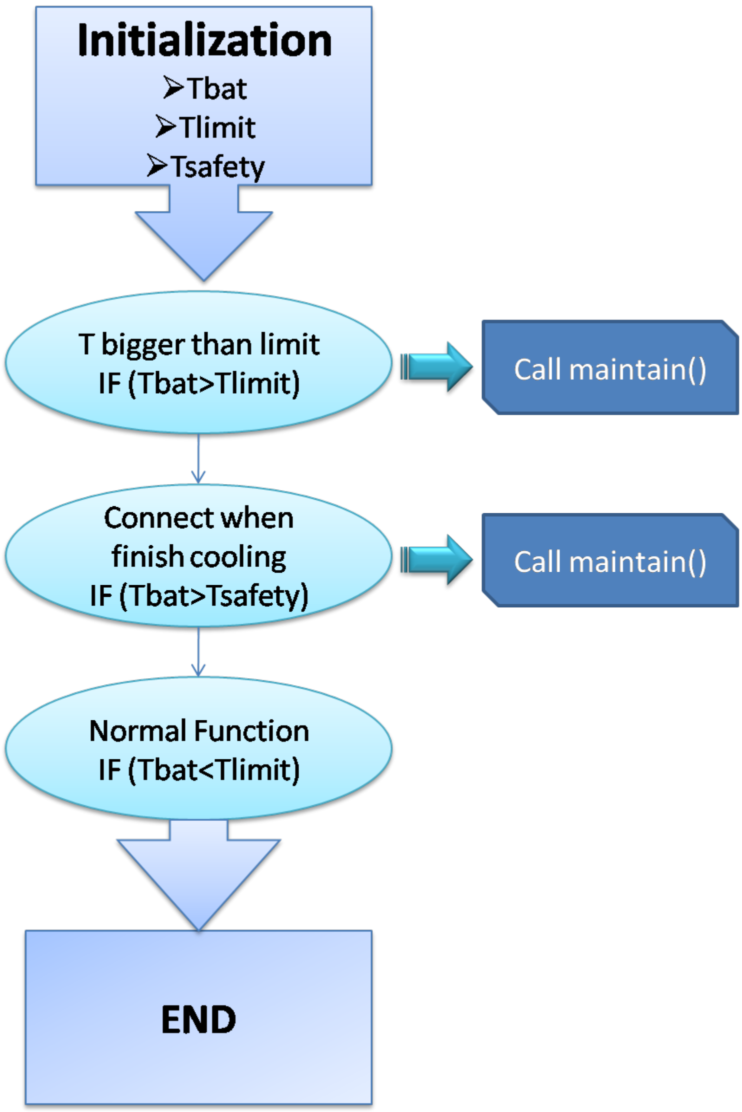


Figure 111, Overtemperature function

12.5 ADC functions

The sensors provides an analog signal that is necessary to convert in digital to be used for the microcontroller, to make this is used an integrated circuit analog to digital converter (ADC) to that provides this signal in digital like peripheral.

12.5.1. ADC control function

This device is managed by the microcontroller trough control signals. The I/O schematic, figure 112, and the function implemented in microcontroller that control the external ADC is explained in figure 113 through a flux diagram.

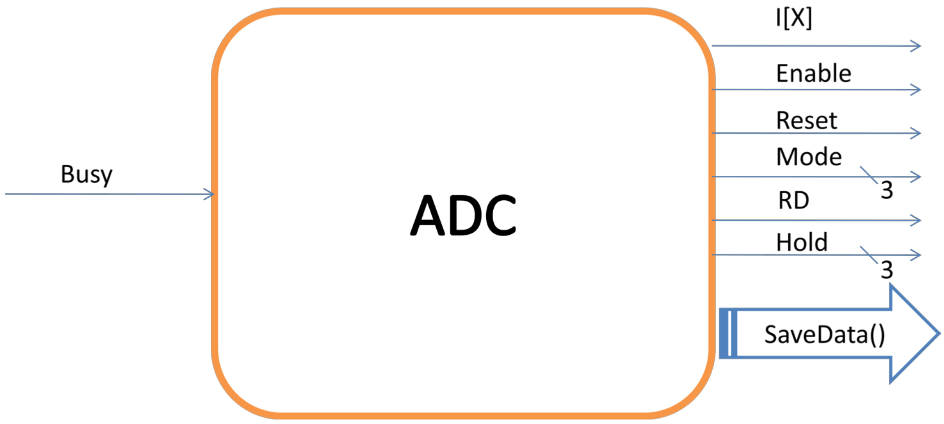


Figure 112, I/O ADC

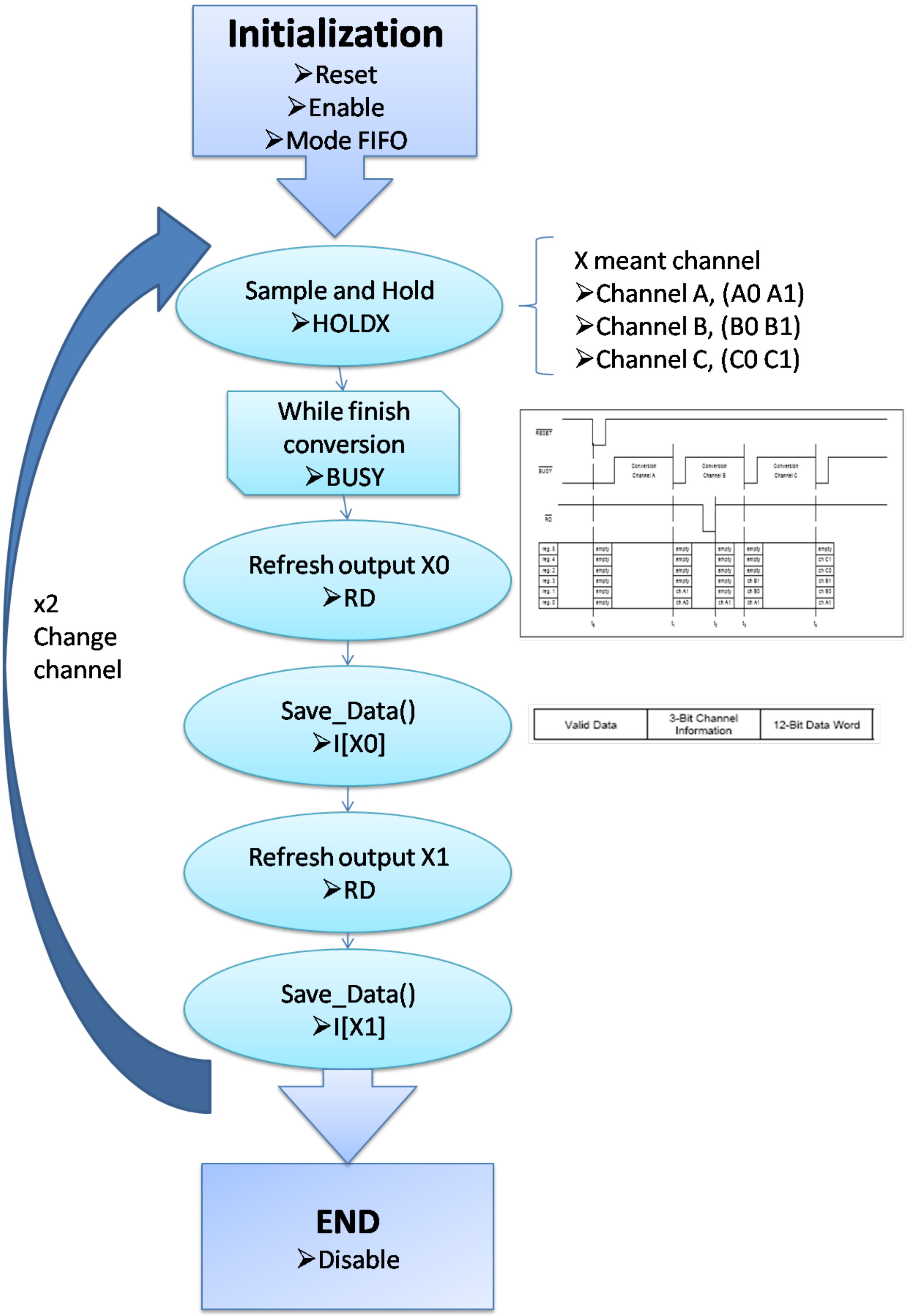


Figure 113, ADC control function

12.5.2. Save data function

This function is created to store the information that provides the analog to digital converter, the information is sent in parallel way, using 12 ports of microcontroller. This function read this ports and manage the information to store the data in an integer database of microcontroller.

The I/O diagram is showed in figure 114 and the function implemented in the microcontroller is explained in figure 115 through a flux diagram.

Figure 114, I/O save data

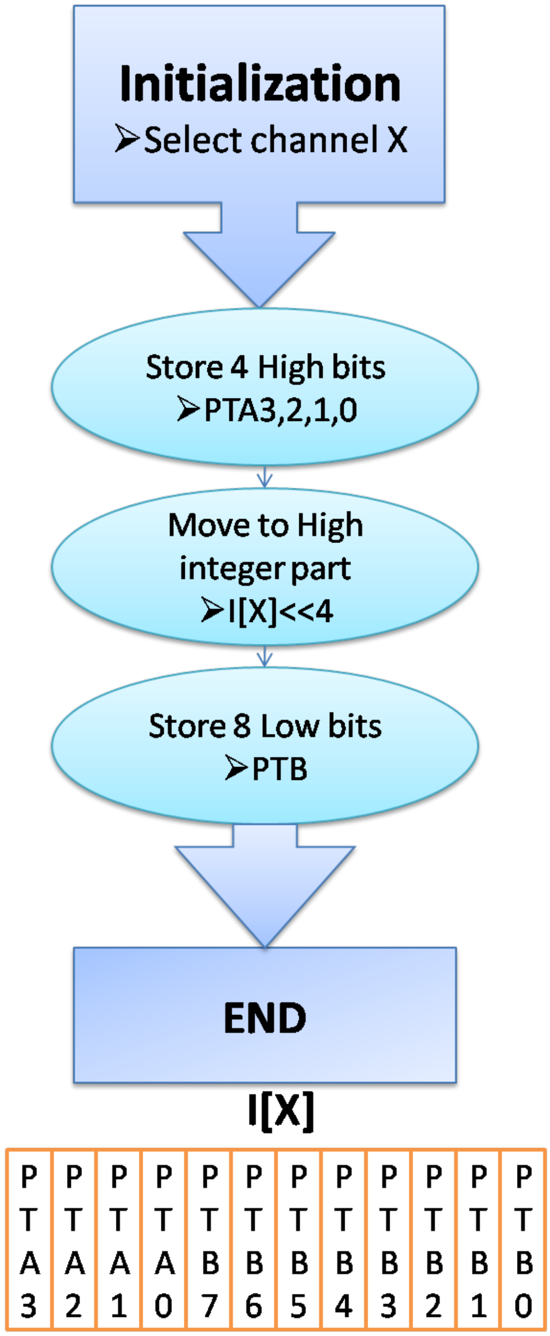


Figure 115, Save data function

12.5.3. Convert to physical units

The data that is stored in the microcontroller is a binary word of 16 bits that represents a number between 0 and 5V, to make a control of the state of the system is necessary to convert it in the physical unit that comes.

a) Voltage sensors

The information is codified in a signal between 0 and 4.7V, where the 0 correspond to 0V and the 4.7 correspond to 100V. The ADC is supplied with 5V, then, 5V represents the binary word of 12 bits FFF in hexadecimal. Then is possible to make the curve that represents the function of this sensor, see figure 116.

The binary word that correspond is 100V, 4.7V codified is:

$$B(integer) = \frac{4.7 \cdot 4096}{5} = 3850\ int \rightarrow F0A\ hex$$

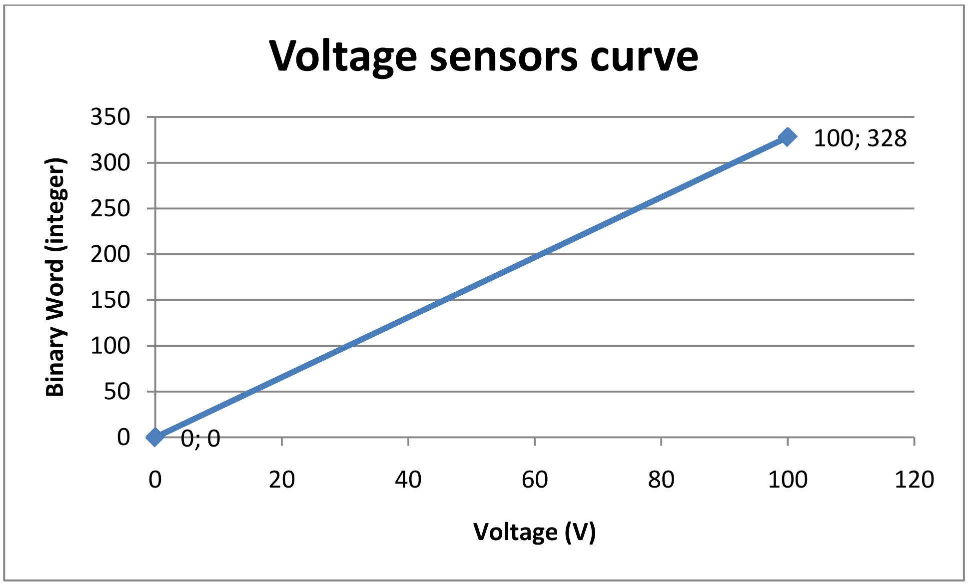


Figure 116, Voltage sensors curve

With this curve it's easy to calculate the factor of linearity to determine inside the software the physical variable codified in the binary word.

$$m = \frac{dy}{dx} = \frac{\Delta y}{\Delta x} = \frac{3850}{100} = 38.5$$

The equation that converts the binary word to the physical units is:

$$\boldsymbol{Physical\ Voltage(integer) = \frac{Binary\ Word(integer)}{38.5}}$$

The real resolution of this conversion is:

$$Resolution = 1LSB = \frac{100}{3850} = 0.026V$$

b) Current sensors

The output of the current sensors codifies a current between 0 and 100A in a voltage between 0 and 400mV.Then is easy to calculate the curve for current sensors, see figure 117.

$$B(integer) = \frac{0.4 \cdot 4096}{5} = 328(integer)$$

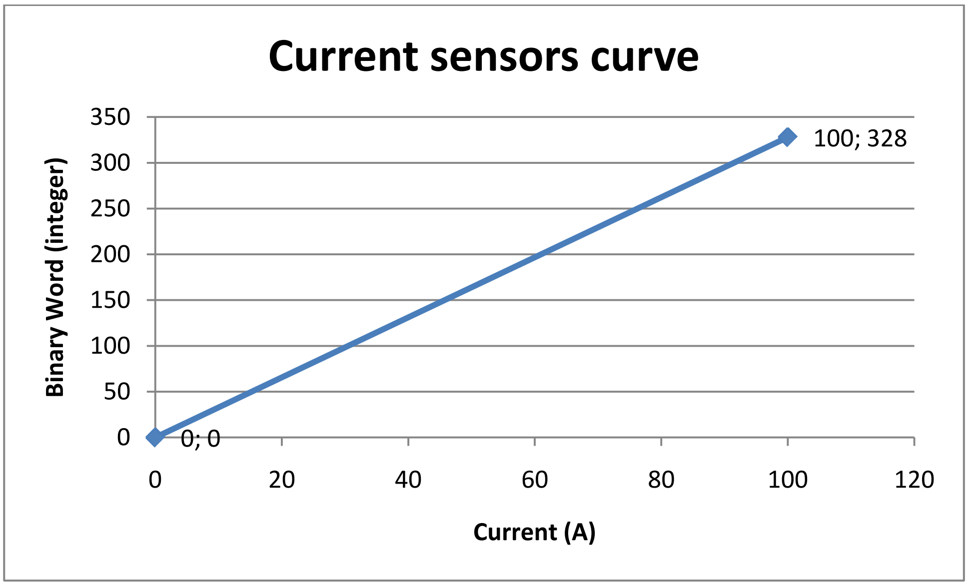


Figure 117, Current sensors curve

The linear parameter that connects the physical variable with the binary word is:

$$m = \frac{dy}{dx} = \frac{\Delta y}{\Delta x} = \frac{328}{100} = 3.28$$

The equation that converts the binary word to the physical units in the current sensor is:

$$\boldsymbol{Physical\ Current\ (integer) = \frac{Binary\ Word\ (integer)}{3.28}}$$

The resolution in the current sensor is:

$$Resolution = 1LSB = \frac{100}{328} = 0.3A$$

c) Temperature Sensor

The range of output voltage of the temperature sensor is between 1.67 and 2.3 that correspond from 0 to 225ºC, the digital numbers that correspond to this maximum and minimum values are:

$$Bmin(integer) = \frac{1.67 \cdot 4096}{5} = 1368(integer)$$

$$Bmax(integer) = \frac{2.3 \cdot 4096}{5} = 1884(integer)$$

Then, the curve of the sensor in digital is, figure 118:

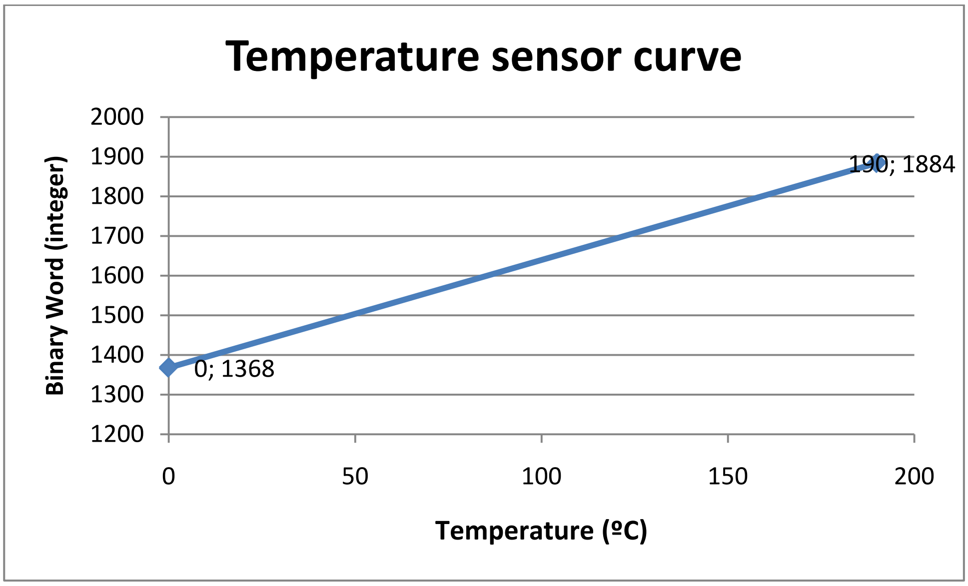


Figure 118, Temperature sensor curve

The linear parameter that connects the physical variable with the binary word is:

$$m = \frac{dy}{dx} = \frac{\Delta y}{\Delta x} = \frac{1844 - 1368}{190} = 2.5$$

The equation that converts the binary word to the physical units in the temperature sensor is:

$$\boldsymbol{Physical\,Temperature\;(integer)} = \frac{\boldsymbol{Binary\,Word\;(integer) - 1368}}{\boldsymbol{2.5}}$$

The resolution in the temperature sensor is:

$$Resolution = 1LSB = \frac{190}{1844 - 1368} = 0.4ºC$$

The I/O diagram is showed in figure 119 and the code implemented in the microcontroller is explained in figure 120 though a flux diagram, first is converted to physical units the two voltage sensors, positions 0 and 1 of the table, after that, the three current sensors, positions 2, 3 and 4 of the table and finish with the temperature sensor, position 5.

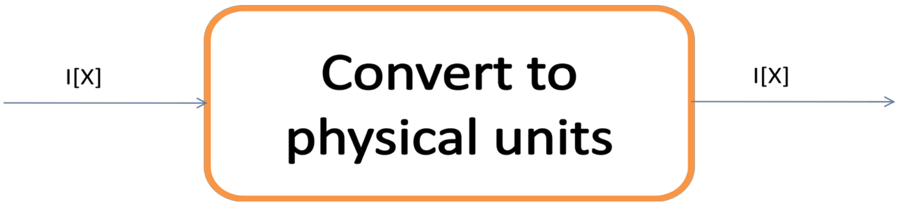


Figure 119, I/O Convert to physical units

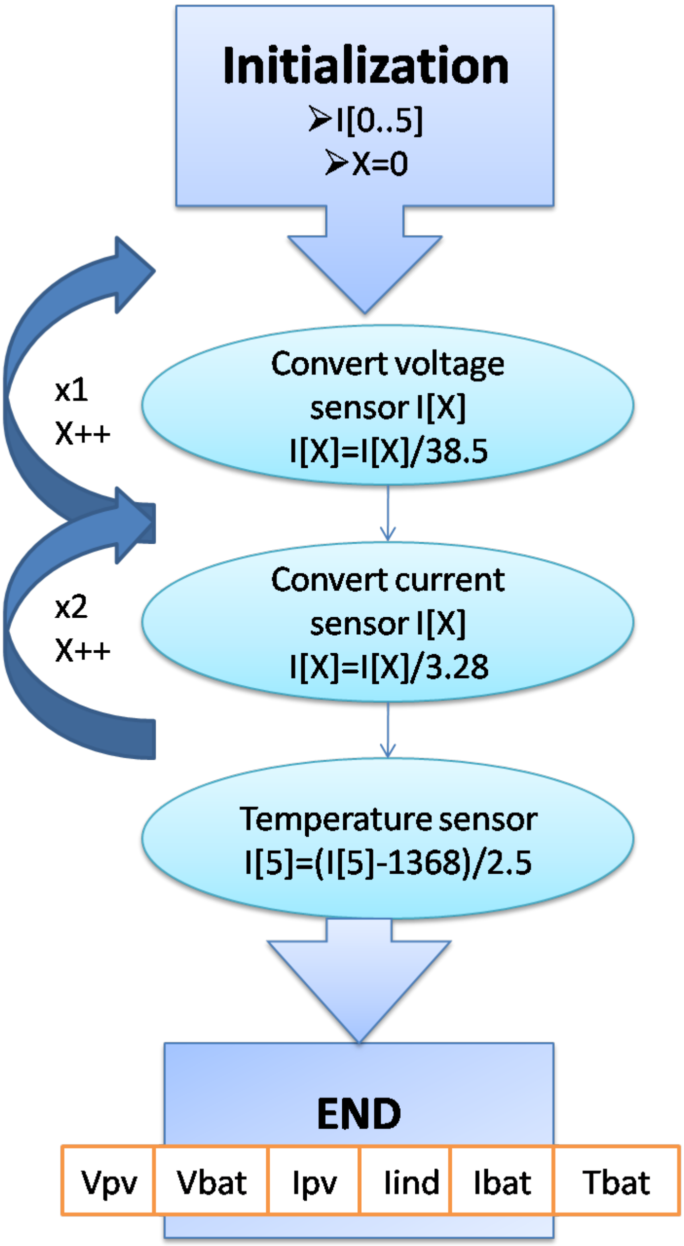


Figure 120, Flux diagram of Physical conversion function

12.6 Real time function

This function is in charge to launch an interrupt with a frequency of 40kHz to realize a periodic control of the switch, this is composed by two parts, to count the time is used timer 1 of microcontroller and a the routine of service interrupt refresh the outputs of the regulator when it overflows.

The internal clock of the microcontroller is working in a frequency of 40MHz, this meant that every 25ns there is a tick in the clock. Is needed every 25us one overflow of the timer to make an interrupt with a frequency of 40kHz. Then, is necessary to count 1000 ticks.

The timer 1 is a timer of 16 bits, this meant that can count from 0 to FFFF hex ticks. 1000 ticks in hexadecimal is 3E8 hex, then, is easy to calculate the number to put in the microcontroller to count 1000 ticks.

$$\boldsymbol{Timer\ value = FFFF - 3E8 = FC17}$$

If the timer start to count every time in FC17, there will be one overflow every 25us, and interruptions with a frequency of 40kHz.

The I/O diagrams are showed in figures 121 and 122 and the code implemented in microcontroller to realize this function is explained through a flux diagram in figure 123.

Figure 121, I/O Setup timer

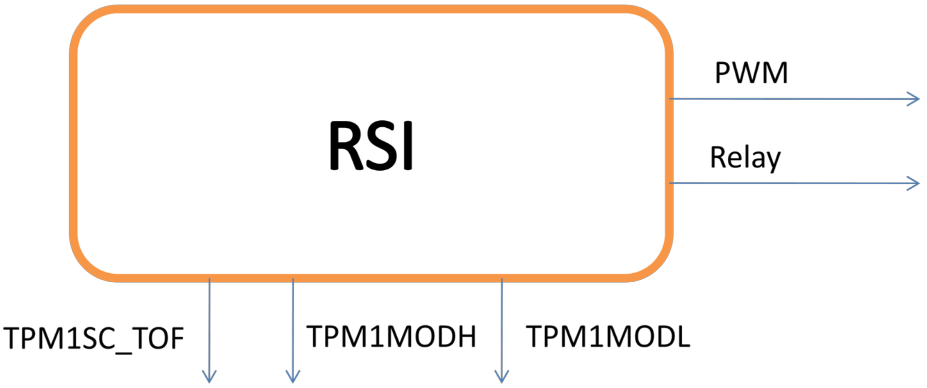


Figure 122, I/O RSI

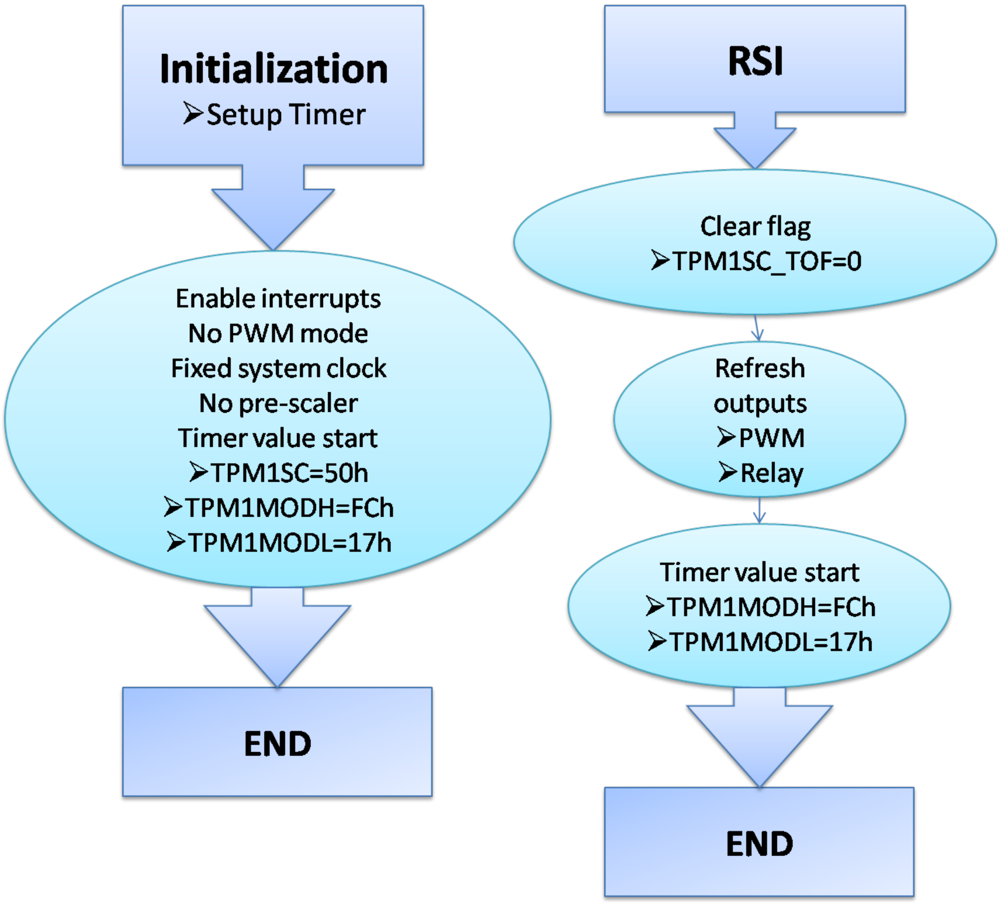


Figure 123, Real time function and RSI

12.7 Display function

To show to the user like an interface the state of the regulator is used a display, the flux diagram that explain the control function designed in C code is showed in figure 124.

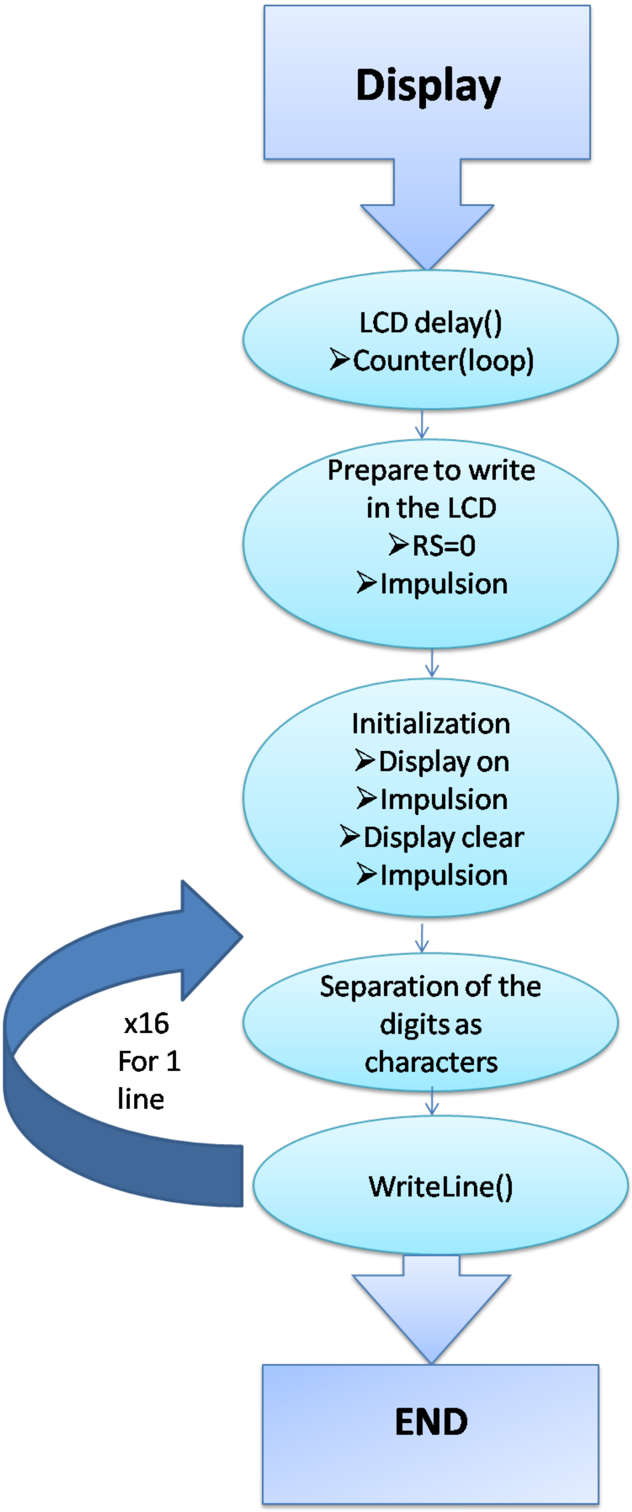


Figure 124, Display function

13. Conclusion

For the Design & Simulation have been done the models of irradiance solar cycle, PV panel, µC algorithm (control battery and MPPT), DC-DC converter and Battery and have been tested static and dynamic, separately and together. This verifies the correct function of the design of the regulator and the control algorithms.

For the implementation is made the Software that implements the control algorithms, ADC control, real time function, display and for hardware have been done all the necessary to build the device, digital PCB and power PCB, box.

With all this designs and reports has been created the design of a new device to control PV panels and extract them more efficiency using MPPT algorithms. The name of the device is MPPT TRACKER S.M.K.B. EDITION.

MPPT TRACKER S.M.K.B. EDITION	
Power	1.6kW
Vpv max	63V
Vbat nominal	24V
Maximum current charging	66A
Efficiency	96_98%
Dimensions	230x114x100mm
Weigh	4.6Kg
Display interface	
Diode protection integrated	
Smooth coil integrated	
MPPT algorithms technology	
Power Mosfet technology	
Fast Direct Interrupt Controller	
Low loses	

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Management

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- **Language:** French
- **ISBN-10: 2754004009**
- **ISBN-13: 978-2754004008**

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