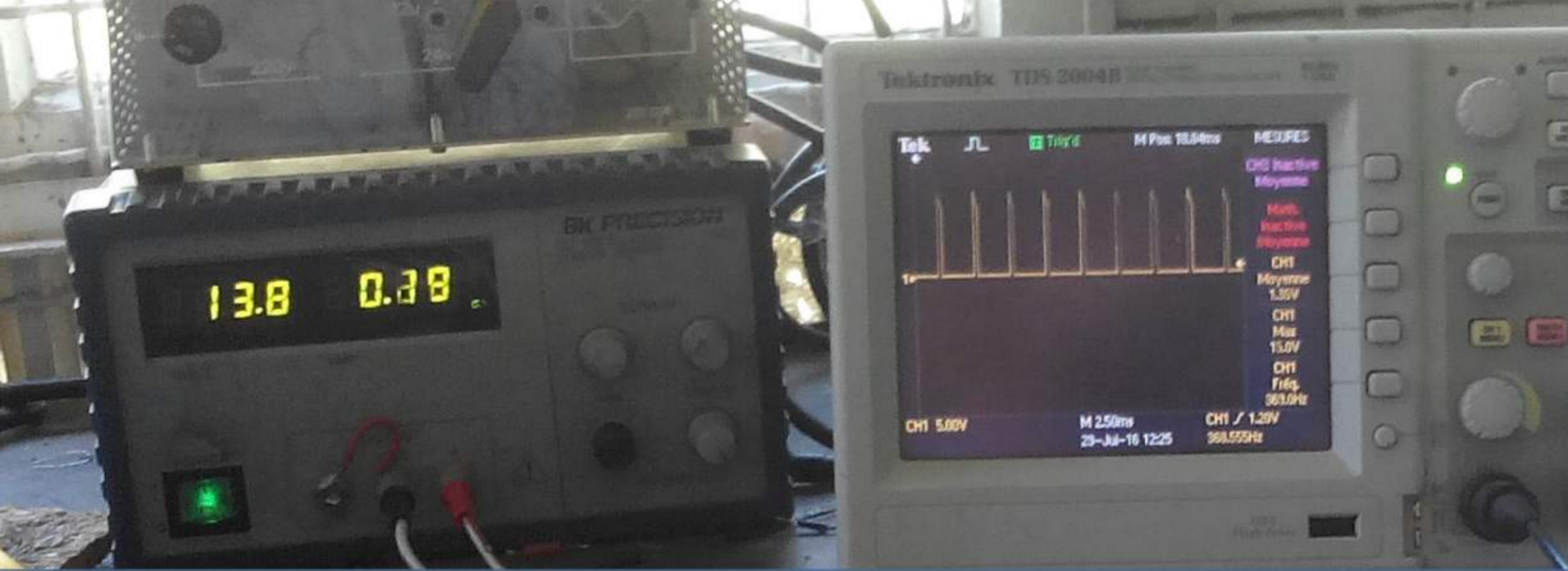
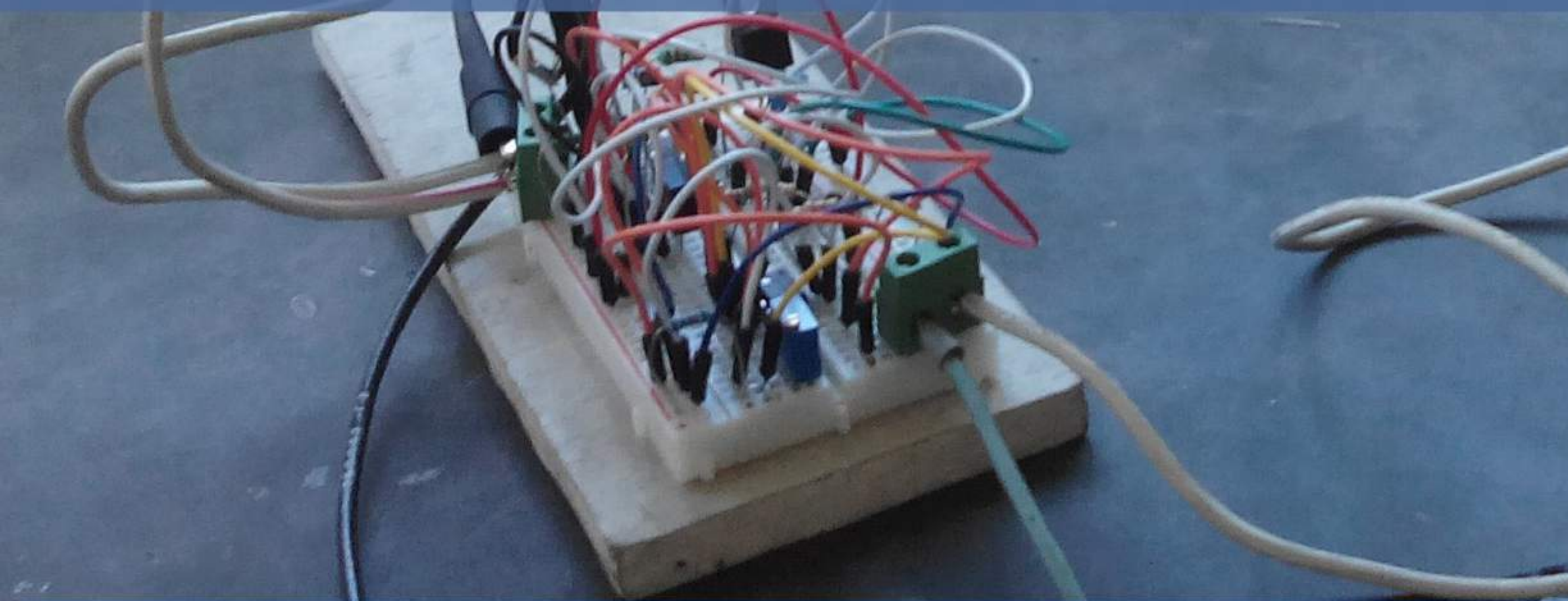


Designing your own charge controller

First prototype for Wind Turbine installations in

isolated areas

Clément Gangneux



TI'ÉOLE ÉNERGIES ÉOLIENNES
Réseau Tripalium
Wind EMPOWERMENT

This project was done under the supervision of Jay Hudnall, André Andretta and Luiz Fernando Lavado Villa with the financial support of WindEmpowerment, Ti'éole and Wisions. Is has been running between April and September 2016.

For any questions or remark regarding the project, please contact me : `clem.gangneux@gmail.com`.

January 17, 2017

Contents

1. Introduction

The installation of a small wind turbine without grid connection requires the use of a battery and a charge controller. This unit is a safety system for the turbine, protects and allows a better use of the battery and therefore extends the lifetime of the installation. The charge controllers available on the market are expensive and often difficult to acquire in developing countries. This manual propose a prototype of a charge controller for small wind turbine systems in 24 or 48 Volts (For a 12 Volts system, jump to section 5.3).

1.1 The project

This prototype of a charge controller is the outcome of a project that has been running between April and September 2016 by members of **WindEmpowerment**. It is an organization for the development of locally built small wind turbines. In this network, the Piggott wind turbine has become a standard because its construction requires basic materials, tools and skills. Thanks to the simplicity of its design and its open source license, it has been promoted all over the world and particularly in countries where electricity supply is not available or affordable.

1.2 A work in progress

This manual is part of a cooperative process. Each reader is free to take over the system described in it : understand, comment, test, modify the design of this charge controller to build his own. Please share your results and improvements to make this project go forward. As this project is making his first steps, the presented charge controller comes without any warranty. Please be careful while using it : it is highly recommended to test it with a safety system before installing it.

> **Note** If you have any question, remarks about the design, if you want to report a malfunction or share your improvements on the device, please send an email to `clem.gangneux@gmail.com`, `luizlavado@gmail.com` and `jay@tieole.com`. ■

2. Why using a charge controller ?

And here we go for a bit of theory ! This part is to understand quickly the operations made by the charge controller. We'll try to focus on the basics, but you still need some skills in electricity to understand. If you are lost, no worries, you can still build a regulator by following the instructions in the chapter 3.

2.1 Charging Lead-Acid batteries

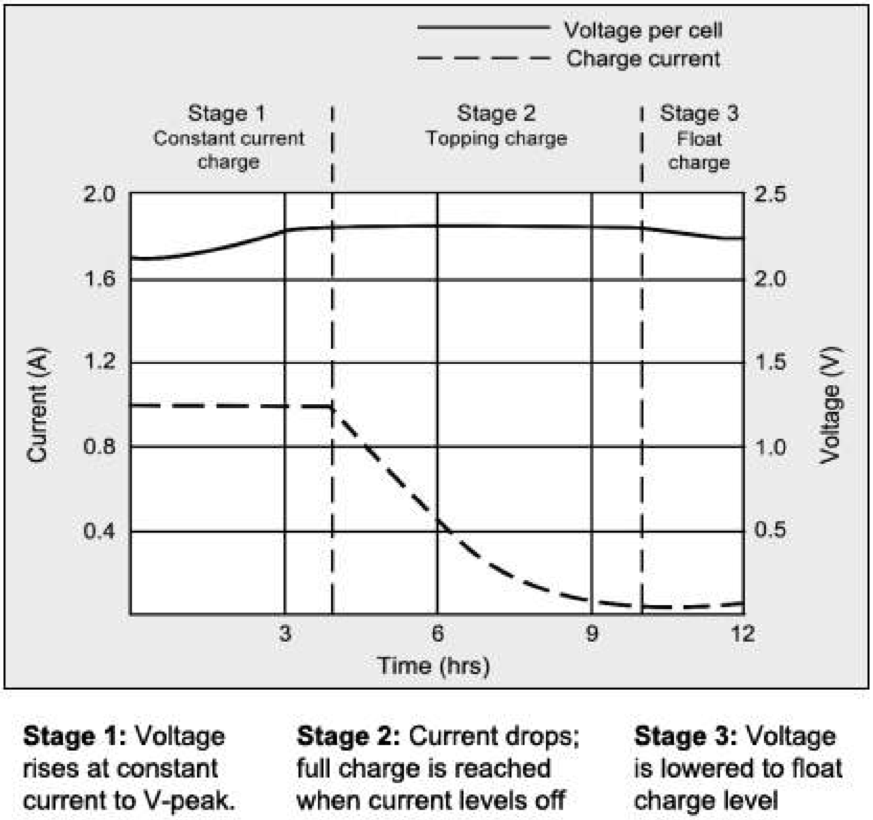


Figure 2.1: Charge stages of a lead acid battery

Lead acid batteries should be charged in three stages shown in figure 2.1 :

1. **Constant-current charge or bulk** During this stage the battery charges to about 70 percent in 5–8 hours. The voltage of the battery slowly increases (from around 11.5 to 14.5 Volts for a 12 Volts battery).
2. **Topping charge** When a certain voltage is reached, it has to remain constant for another 7-10 hours. During this time, the remaining 30 percent is filled with a smaller charge current.
3. **Float charge** It compensates for the loss caused by self-discharge by applying a really small charge current.

The topping voltage also called absorption voltage is usually between 13.8 Volts and 14.5 Volts for 12 Volts Lead Acid batteries. Its value always figure on the documents provided by the battery manufacturer. As many chargers, the charge controller does not feature float charge. Once fully charged through saturation, the battery should not dwell at the topping voltage for more than 48 hours and must be reduced to the float voltage level. This is especially critical for sealed systems because they are less tolerant to overcharge than the flooded type. Charging beyond the specified limits turns redundant energy into heat and the battery begins to gas. This shouldn't happen with a wind turbine due to the intermittent nature of its production but in certain cases (strong constant wind with small consumption), this can be an issue.

2.2 The role of a charge controller

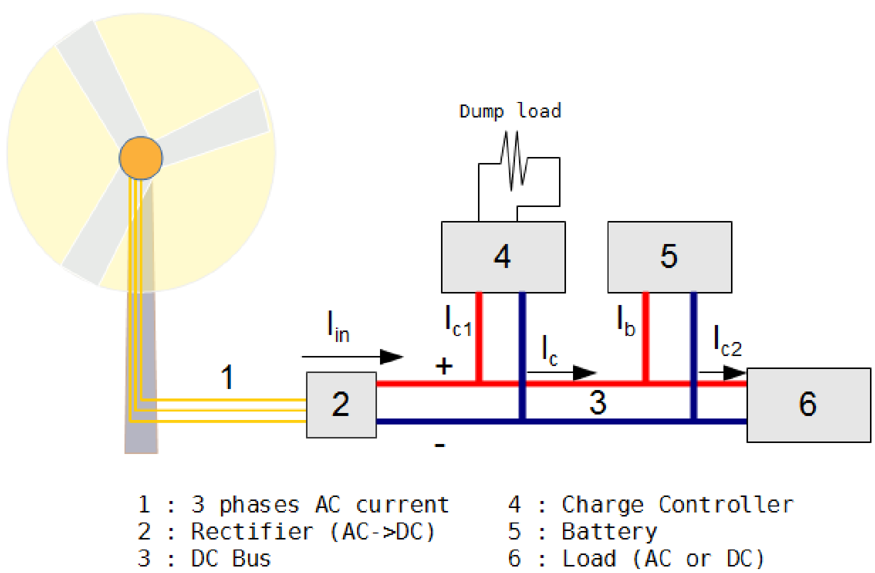


Figure 2.2: Schematics of an installation with a battery

A classic installation of a small wind turbine is shown in figure 2.2. The charge controller is directly connected to the electrodes of the batteries which constitute the DC-bus and it has two roles :

- Ensure the best use of the battery by being as close as possible to the constant current constant voltage (CC/CV) charge method described in section 2.1.
- Protect the wind turbine by making sure it will never freewheel and therefore spin at high speeds which could damage the machine. This is why a dump load is used rather than simply opening the circuit (this method is used when using solar panels).

So, the controller "watches" the battery voltage until it reaches the topping voltage. When it happens, the regulator starts sending some current to the dump load. As the battery is increasingly being charged, the current in the resistor increase, and so the current sent to the battery decrease. This way, its voltage remains constant.

2.3 How does it work ?

The charge controller uses a Pulse Width Modulation (PWM). What it means is that the system watches the battery voltage and gives as an output a binary signal (either it is switch ON or OFF). This signal works at a frequency of 300 Hz and stays ON during a certain time then OFF. The duty cycle correspond to the percentage of time ON. This duty cycle is piloted by the circuits depending on the battery state of charge so that its voltage remains constant. Then, this signal controls the connection of the dump load with transistors. The different steps of the signal processing is presented on figure 2.3. The first curve shows the battery voltage. When it exceeds the topping voltage, then the duty cycle starts increasing and the Pulse signal starts emitting and therefore the dump load is connected. The connection of the dump load will decrease the voltage of the battery until it remains at the topping voltage, the duty cycle then remain at its value.

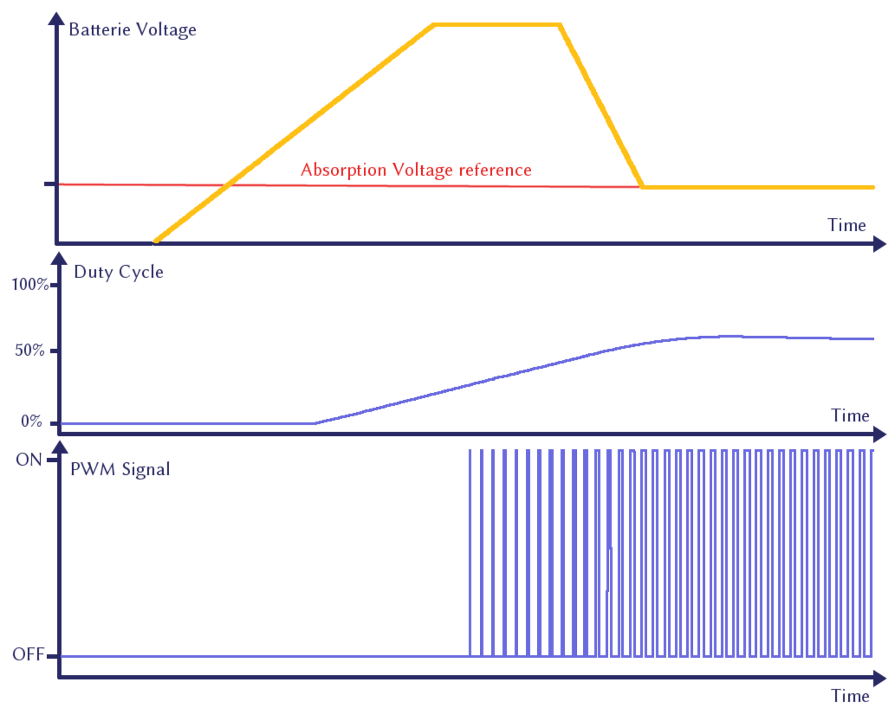


Figure 2.3: How a PWM works

More simply, the charge controller just works like a switch which is constantly open and closed when the regulation is needed. The duty cycle δ defines the percentage of time when it is ON. It is presented on figure 2.4 where I_e represents the current provided by the turbine which is distributed between the battery, the load and the dump load when it is regulating.

Note The different parts of the controller (measurement, signal processing ...) needs some power to work. That is why another part of the circuit is made to feed the different devices. Its role is to use the battery voltage which is often moving and quite high to a smaller fixed value.

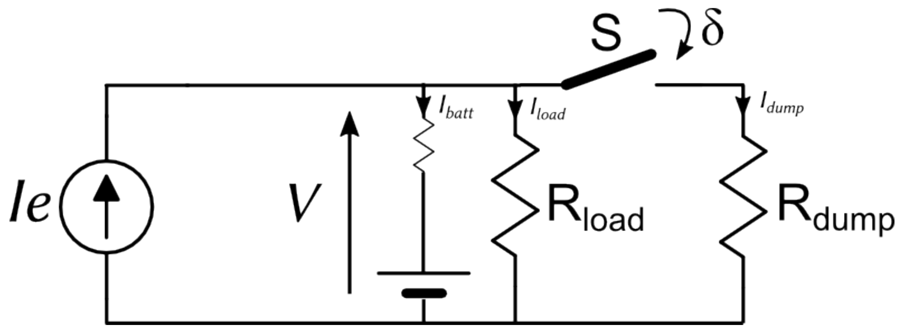


Figure 2.4: Charge controller seen as a controlled switch

The feeder block of the controller gives around 14.6 Volts. ■

2.4 Characteristics

The charge controller has the following characteristics :

Variable	Value
Operating input voltage	20 V to 100 V DC
Max input current	50 A
Frequency of the PWM	300 Hz

3. Fabrication

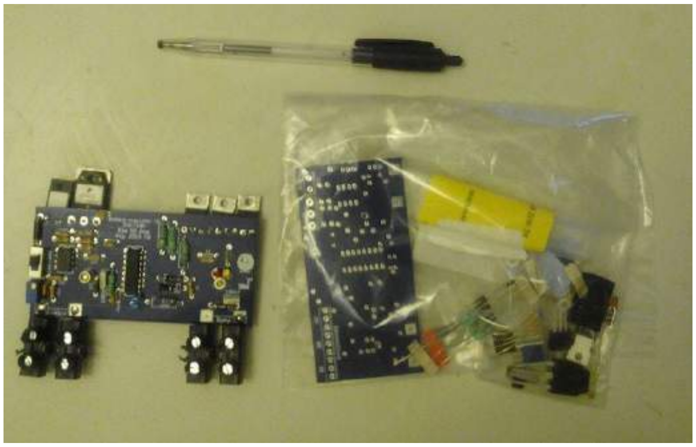


Figure 3.1: The final controller next to a fabrication kit

To build your own charge controller, you need some material :

- A soldering iron
- A multimeter - an oscilloscope is even better !
- A stabilized voltage source : this is more than useful when you are working with electronics !
- The printed board of the controller
- the different components. The list of components can be found in section 5.1.

To get the PCB and/or the components, you can either get them as a complete kit or print it / buy it yourself. Please contact WindEmpowerment for more information.

> **Note** Working with power electronics requires an extra care with voltage ratings and short circuits. Please be careful when manipulating power systems. Any tests should be conducted after considering all the safety issues possibly involved. ■

3.1 Step 1 : Soldering

First, you can solder all the components on the board. Here are some hints to achieve this with serenity :

- Try to identify all the items and their value. For the resistors, you can use the figure 3.2 to find their value. Don't confuse the different values of the capacitors (10 nF and 100nF) and the Zener diode (which reference is 1N5353) with the other diodes. All values are written on the chip, for more details, you can refer to the circuits and components map in section 5.1.
- Start with the smallest components and end up with the biggest ones. There is 5 components on the other side of the chip. Those are the components that release the most heat. You can bend them to fix them on a heat sink as shown in fig 3.3. Put those components at last so it won't bother you.
- Watch out for the orientation of the components : the ones that matters are the diodes (Normal, Zener and LED), the transistors (`T1`, `Q6`, `Q7` and `Q8`) and the integrated circuits (`U3` and `IC1`). The figure 3.4 can help you to not make any mistakes.

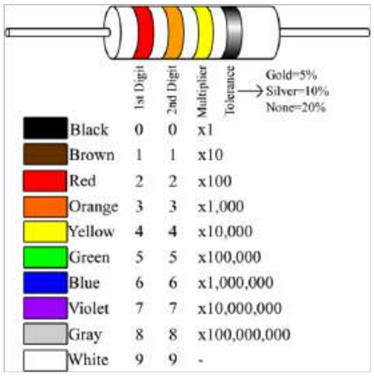


Figure 3.2: Electrical color code reminder

Figure 3.3: Example of an installation on a heat sink

- The two holes on the board are made to put support legs on it. They are provided with a plastic ring to make sure there is no contact with the circuits of the board.
- The 4 pads `(-Vdc+)` and `(Dump)` are for the connections. They have been made to solder a small piece of metal on it in order to plug a screw terminal on it as shown in figure 3.5. It is also possible to screw the hole a bit bigger in order to put banana jack holders.
- Watch out not to create any short circuits while soldering. You can check the connection with a multimeter.

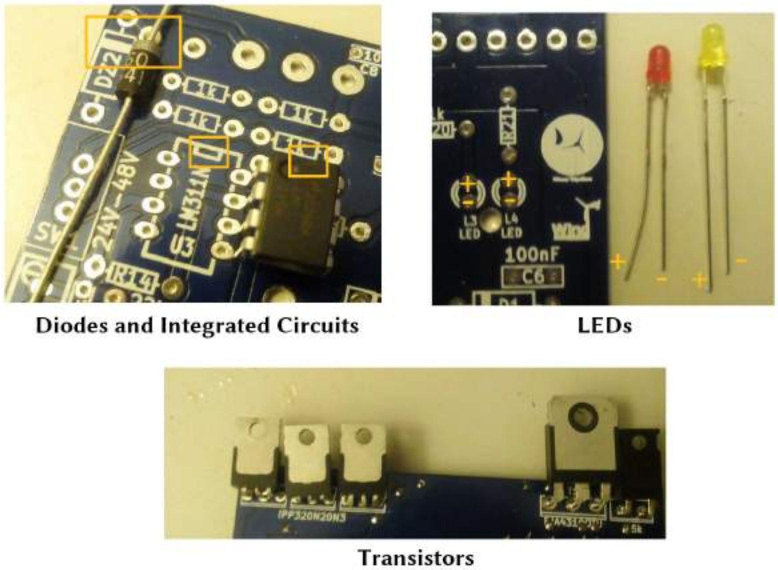


Figure 3.4: Orientation of the different components

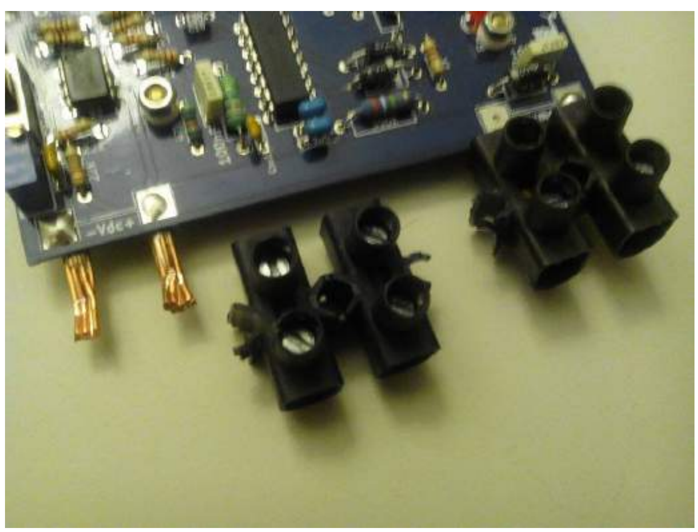


Figure 3.5: Example of connection with terminal blocks

3.2 Step 2 : Testing and calibration

Before feeding the chip with power, it is recommended to check with care the connections of the chip and to be sure there is no short circuits. We are going to test the circuit step by step.

3.2.1 The DC supply

As explained forward, different devices of the chip need a feeder and a part of the circuit is made to give a stabilized source of current. To test it :

1. Connect the controller to a stabilized voltage source connected to terminal `(-Vdc+)` without connecting anything on the other terminal `(Dump)`.

   Note When there is no dump load connected, the current which flows through the controller is really low. If the current is higher the 500 mV, there is an assembly issue. ■

2. Bring the voltage to around 20 Volts. The LED L3 should start to light up.

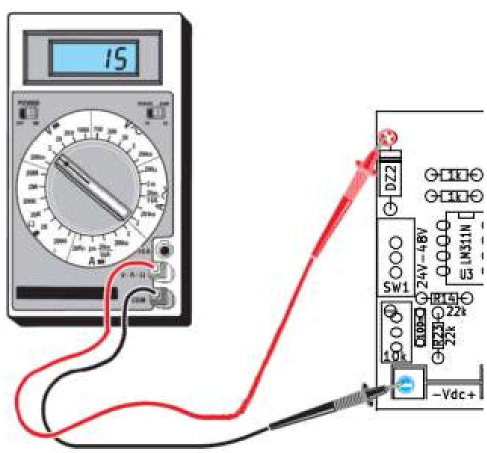


Figure 3.6: How to measure the supply voltage

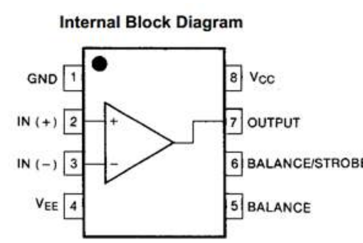


Figure 3.7: The different pins of the LM311

3. Check the voltage between the ground and the cathode of the Zener diode (see figure 3.6) with a Voltmeter or an oscilloscope. The voltage should be between 13 and 16 Volts.
4. Try to play a bit with it. If you change the value of the voltage, the supply should remain constant. If you go below 20 Volts, it starts decreasing.

3.2.2 Output of the comparison

The first step of the signal processing is a comparison between the measurement of the voltage of the battery and a reference. The reference stay constant while the control of the measurement voltage is made by the trimmer `POT1`. This comparison is made by the Operational Amplifier `U3`. Its different pins are shown in figure 3.7 : the comparison is made between `IN (+)` and `IN (-)` the result of this comparison is given by the pin 7 `OUTPUT`.

1. Place the switch `SW1` on the position 24 V so that you can test the system in its 24 Volts function. Feed the controller with a voltage between 20 and 30 Volts.

2. **Measure the reference voltage** : Measure the voltage between the ground and the pin 2 of the Op Amp and note the value. When you change the input voltage, the reference voltage should remain constant.
3. **Measure the measurement voltage** : Connect your Voltmeter between the ground and the pin 3 of the Op Amp. When you change the input voltage of the Controller, the measurement voltage should change as well. As a first setting, you can feed the controller with a certain voltage (for example 27 Volts which could correspond to the topping voltage of a battery). Change the measurement voltage by turning the trimmer and set it at the same value at the reference voltage.
4. **Measure the ouptut** : Measure the voltage between the pin 7 and the ground while you are shifting the input voltage around the topping voltage you have chosen. The output of the Op Amp is revered compared to the input voltage, it should behave like this :

Input Voltage `Vdc`	Output of the Op Amp
Below the topping voltage	9 to 12 Volts
At the topping voltage	4 to 8 Volts
Above the topping voltage	0 to 1 Volt

Figure 3.8: Measure of the PWM with an oscilloscope

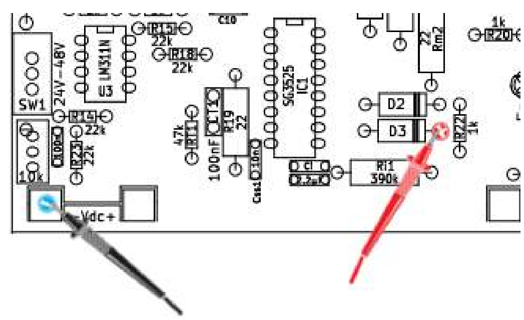


Figure 3.9: Measure of the output of the SG3525

3.2.3 Pulse Width Modulation

The PWM is driven by the device `IC1` which is an integrated circuit called SG3525. It takes the value of the previous step and adapt the value of the duty cycle. You can watch the output of this step with an oscilloscope as shown in figure 3.8.

1. With the same settings of switch and trimmer as before, feed the controller with a stabilized voltage source.
2. Measure the voltage between the ground and the output of the SG3525 (cf figure 3.9).
3. Play with the input voltage to see when the controller triggers. The signal should be at zero when we are below the topping voltage and it should jump to a pulse which is ON 100% of the time when you cross the topping voltage. Because there is no dump load connected, the system cannot regulate the voltage and therefore the duty cycle doesn't stabilize to a certain value but jump from 0 to 100 %.
4. You can fine the tuning of the topping charge with the trimmer.

> **Note** If you want to use the controller in a 48 Volts installation, you can calibrate it in the 48 V mode or set the topping voltage at half its value in the 24 V mode. ■

5. You can switch to the 48 V mode while the input voltage is around 30 Volts. The duty cycle should jump from 100% to 0 %.

Congrats ! You have achieved the calibration of your controller ! Now we can do some testings with a dump load.

3.2.4 Test with a dump load

Now serious business begins because we are putting some electric power on the controller.

1. Plug a dump load to the terminal `(Dump)`. Choose a value of resistor between 1 and 20 Ω that can dissipate up to 10 Amps.
2. Measure the output of the SG3525 with an oscilloscope.
3. Play with the input voltage. When you reach the topping voltage, the controller should increase the duty cycle of the PWM signal and start to send some current to the dump load. As a consequence, the voltage should be reduced and stay around the value of the topping charge. Once again, you can tune the topping voltage with the trimmer. Be sure, that the voltage won't overcome the voltage given by the battery manufacturer. When you are pleased with your tuning, your charge controller is ready to install.

4. Installation

The figure 4.1 shows an example of an installation. The controller is attached on a heat sink : the 5 components on the bottom of the controller have to be attached with material shown in figure 4.2. On this installation, we use the same heat radiator for the controller and the diode bridge rectifier. `(-Vdc+)` is connected to the DC bus and `(Dump)` is connected to the dump load. Once the controller is installed, keep watching the battery voltage to see if the controller triggers at the good value.

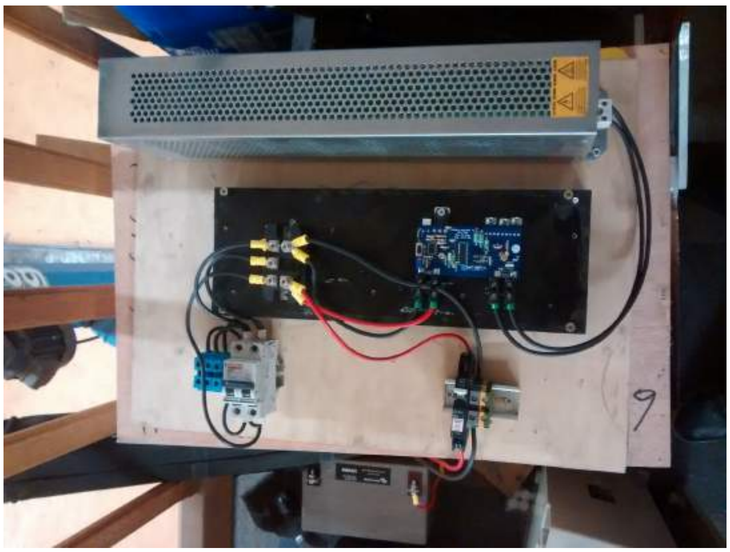


Figure 4.1: Example of an installation of the controller

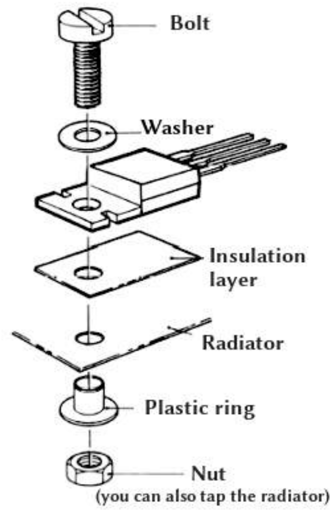


Figure 4.2: How to fix a component to the heat sink

Note It is recommended to install at first this controller with a commercial one. The topping voltages can be set in order that the commercial controller triggers only in case of malfunction. ■

5. To go further

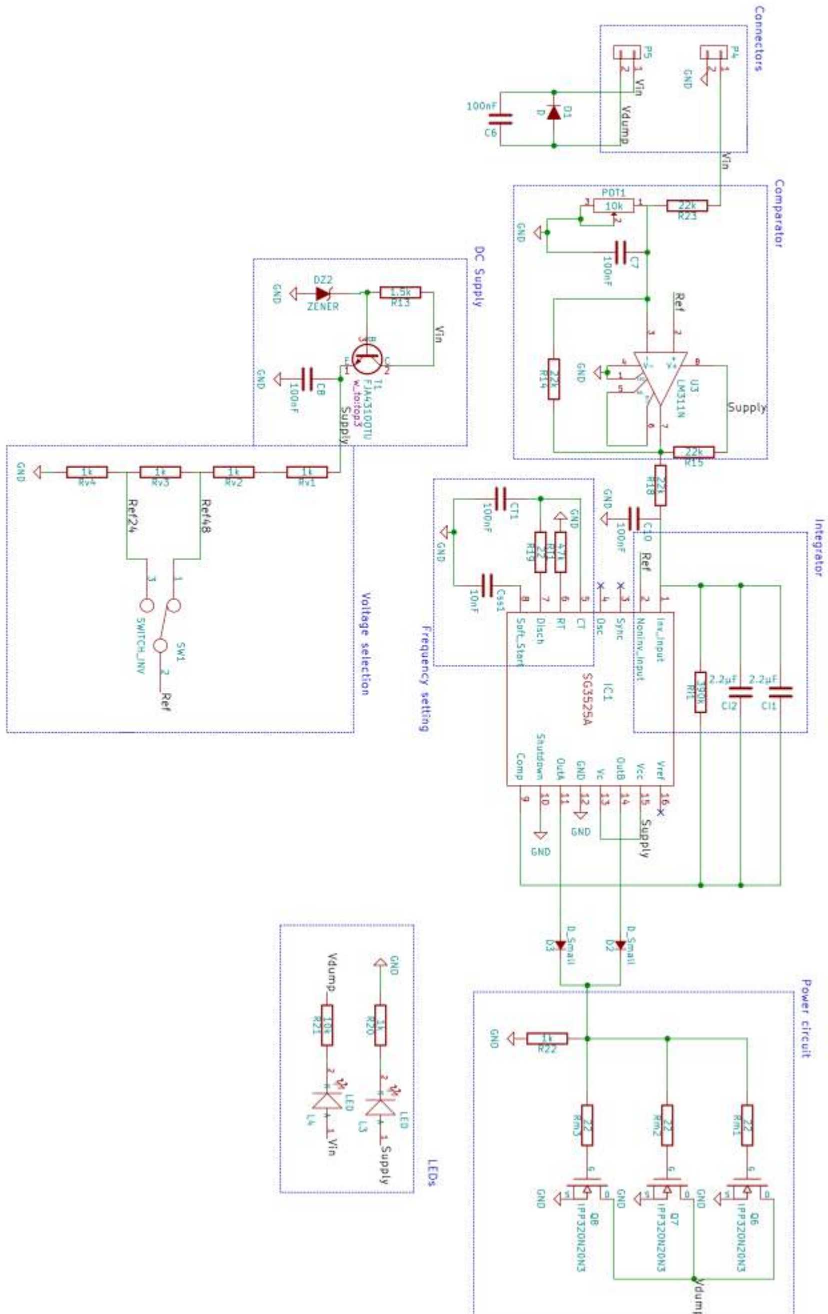
5.1 Appendix

Here are some documents that can be useful for building your charge controller. Some of those documents can be found on the website of WindEmpowerment.

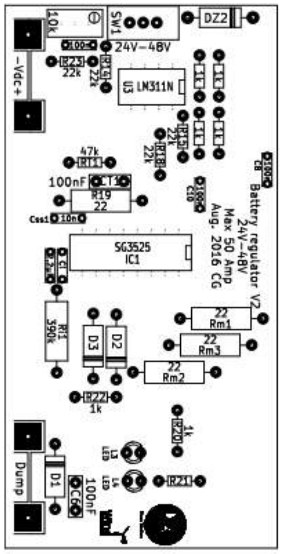
5.1.1 List of the components of the controller

Composant type	Name on the cheap	Model	Value	Quantity
Diodes				
Diode Schottky	D1 D2 D3			3
Diode Zener	DZ2	1N5353B	16 V	1
Red LED	L3			1
Yellow LED	L4			1
Condensators				
Radial Condensators	Ci		2.2u	2
	C6 C7 C8 C10 Ct1		100n	5
	Css		10n	1
Resistors				
Power resistor TO - 220	R13	AP821	1.2k / 1k / 1.5k	1
Resistors	Rm R19		22	4
	Rv R20 R22		1k	6
Trimmer	Pot1	T93YA103KT20	10k	1
Resistors	R21		10k	1
	R14 R15 R18 R23		22k	4
	RT1		47k	1
	Ri		390k	1
Transistors				
Transistor NPN	T1	FJA4310OTU	-	1
Mosfet	Q6 Q7 Q8	IPP320N20N3		3
Autres				
SG 3525	IC1	SG 2525		1
AOP	U3	LM311		1
Switch	SW1	MFP1220		1
Dominos				2*2

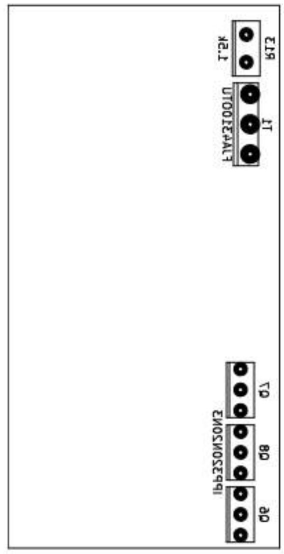
5.1.2 Schematics of the circuit


Connectors
Comparator
DC Supply
Voltage selection
Frequency setting
Integrator
Power circuit
LEDs
SG3525A
LM311N

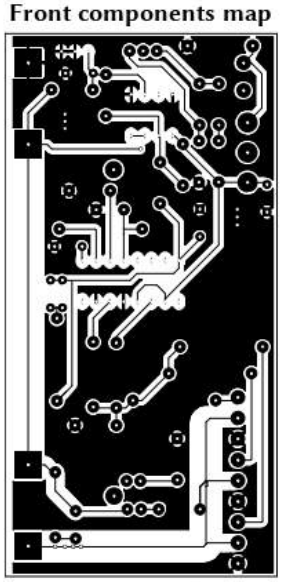
5.1.3 Map of the PCB



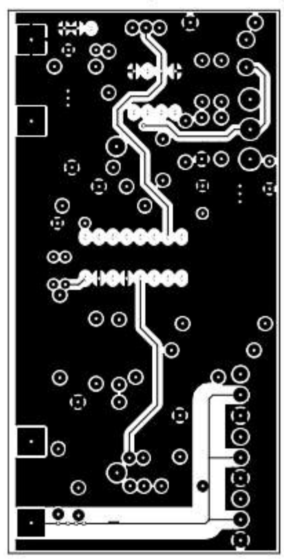
Front components map



Bottom components map



Front copper layer



Bottom copper layer

5.1.4 Web ressources

- The website of WindEmpowerment : http://windempowerment.org/
- Hugh Piggott's blog : http://scoraigwind.co.uk/
- The website of Tripalium, a french network for self constructed small wind turbines : http://www.tripalium.org/
- For more informations on the batteries and how to charge them : http://batteryuniversity.com/

5.2 Detailed design of the charge controller

In this section, you will find more information on the general design of the charge controller, in order to go more into details into its principle of working. The overall circuit uses an Integrated Circuit which drives the PWM : the SG3525. It is a wide used integrated circuit, first designed by *Texas Instrument* and now by many other manufacturers. A small documentation on how to use the SG3525 can be found on http://tahmidmc.blogspot.fr/2013/01/using-sg3525-pwm-controller-explanation.html. The circuit can be divided into 5 parts.

5.2.1 DC supply

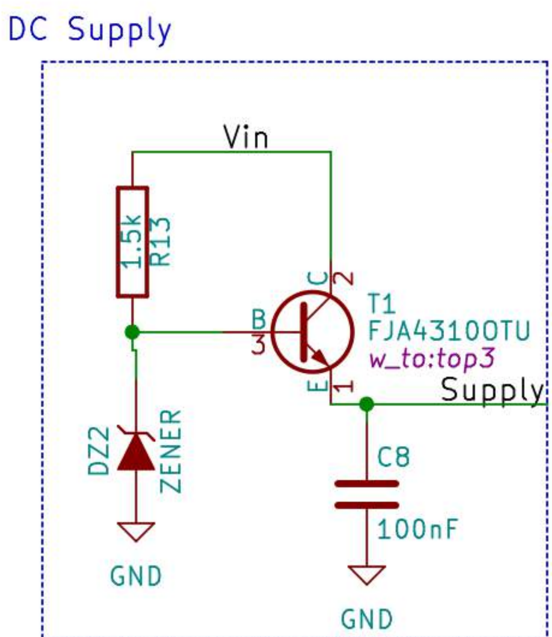


Figure 5.1: Schematics of the DC supply part

The DC supply is used to power some components such as the Op Amp and the SG3525 and is also used to give a reference for the voltage measurement. The input is the DC Bus and the output gives a stabilized voltage of 15 V. It can work with a input from 20 V to 100 V and gives a maximum of 200 mA.

5.2.2 Voltage selection

The voltage selection module aims to select the voltage reference we are using. The reference is given by a simple voltage divider. It gives a voltage of 10 Volts for the 48 V mode and 5 Volts for the 24 V mode.

5.2.3 Comparator

The first part of the signal processing is a comparator which uses an operational amplifier to compare the battery voltage with our reference. A trimmer enable a fine setting of the reference. The output

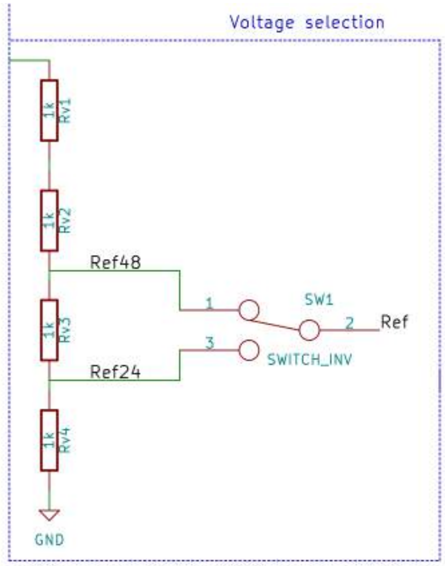


Figure 5.2: Schematics of the voltage selection part

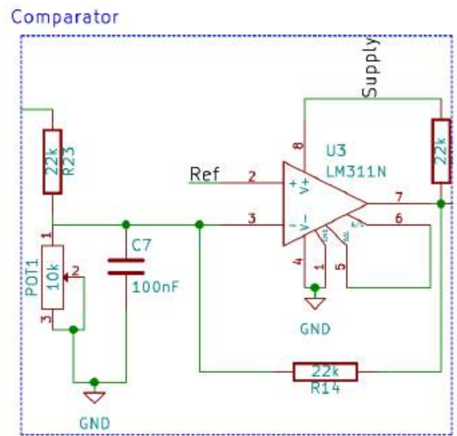


Figure 5.3: Schematics of the comparator part

of this stage is a voltage higher than V_{Ref} if the battery voltage is lower than the reference and lower than V_{Ref} if the voltage is higher than the reference as seen on figure 5.4.

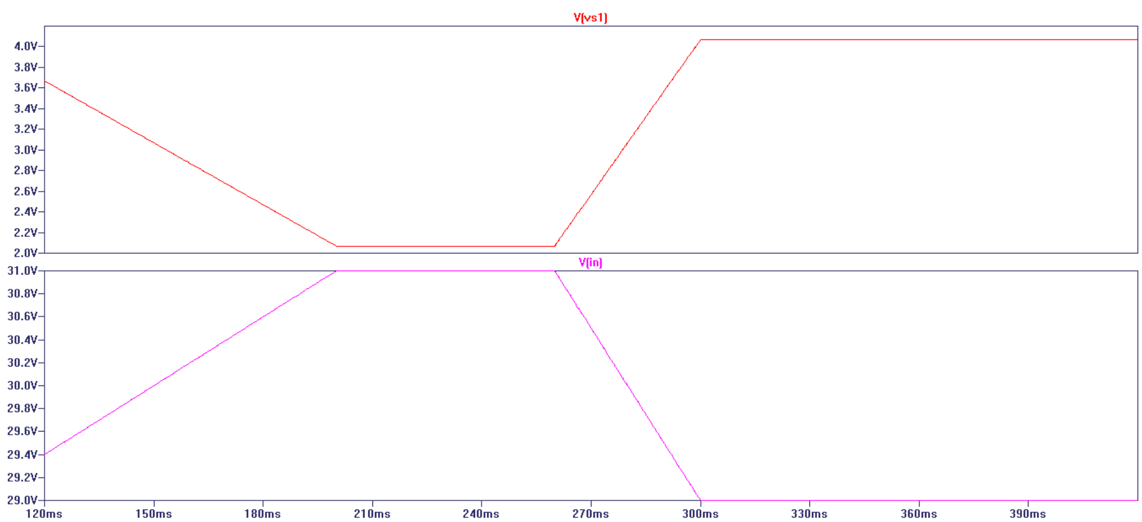


Figure 5.4: Simulation of the output of the comparator stage (in red) compared to the battery voltage (in pink) for a voltage reference of 29 V and where V_{Ref}=4 V

5.2.4 SG3525 driver

We need to integrate the signal in order to keep increasing the duty cycle of the PWM if the voltage stay higher than the reference. Moreover, if the voltage stabilizes at the value of the reference, the duty cycle need to remain constant. We use an inverting integrator with the Op Amp contained in the

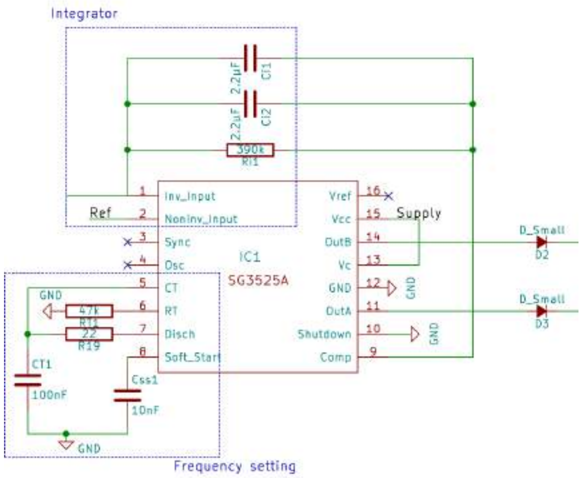


Figure 5.5: Schematics of the SG3525 driver

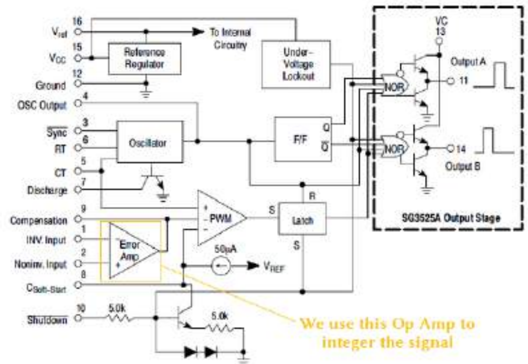


Figure 5.6: Representative block diagram of the SG3525

SG3525 as we can see on figure 5.6.
An overview of the output of this second stage is shown in figure 5.7.The blue curve represent the output of this inverting integrator. This output will directly drive the duty cycle of the PWM : a signal of 0 Volts leads to no regulation and a signal greater than 5 Volts correspond to a duty cycle of 100 %. We can see that the value of this signal stabilize in this experiment around 1.7 V when the battery voltage is close to the reference.

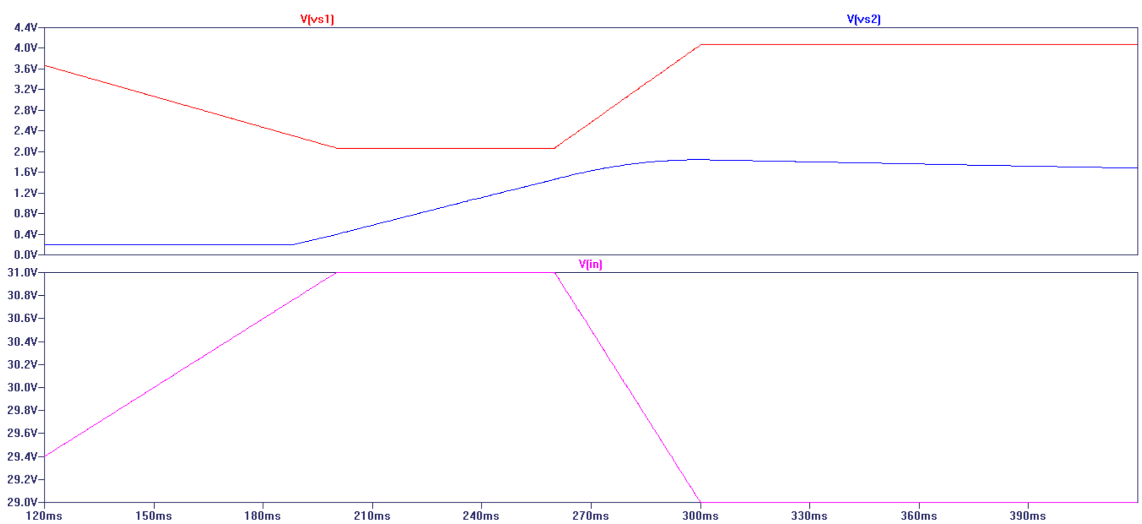


Figure 5.7: Simulation of the output of the integrator

The setting of the frequency of the PWM is given by :

$$f_{PWM} = \frac{1}{C_T(0.7R_T + 3R_D)}$$

In this case we decided to use a frequency of 300 Hz : the frequency doesn't need to be very high and it correspond to the working frequency of the *Tristar*.

5.2.5 Power circuit

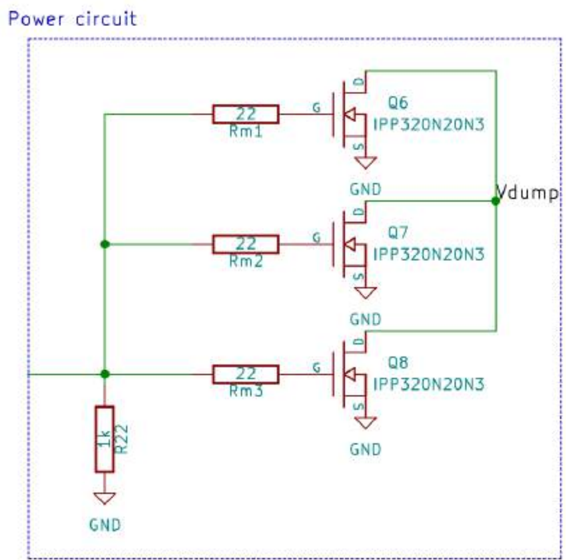


Figure 5.8: Schematics of the power circuit

The power circuit uses a Mosfet transistor that works at 200 V and 34 A. We will put 3 of them in parallel in order to support a maximal current of 100 A, maximal required current being 50 A.

Note If you have any question, remarks about the design, if you want to report a malfunction or share your improvements on the device, please send an email to `clem.gangneux@gmail.com`, `luizlavado@gmail.com` and `jay@tieole.com`. ■

5.3 12 Volts charge controller

Because of technical issues, the controller presented here works only for 24 and 48 Volts systems. It is yet possible to redesign it in order that it works with a 12 Volts system. The circuit has already been done (see figure 5.10) but no PCB has been designed. The circuit is simpler than the 24/48V one. It should be possible to do some modifications on the PCB presented in this manual to have a 12 Volts system by using this circuit.

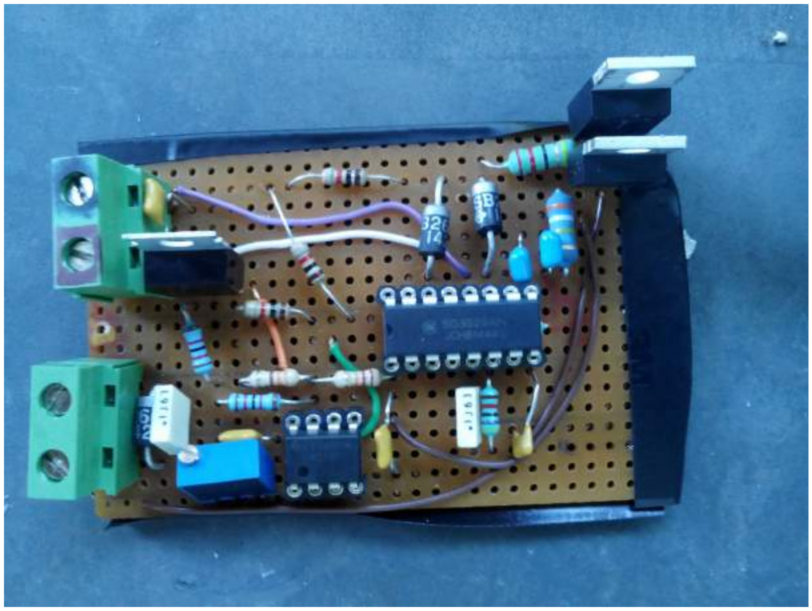


Figure 5.9: Picture of a working 12 Volts prototype

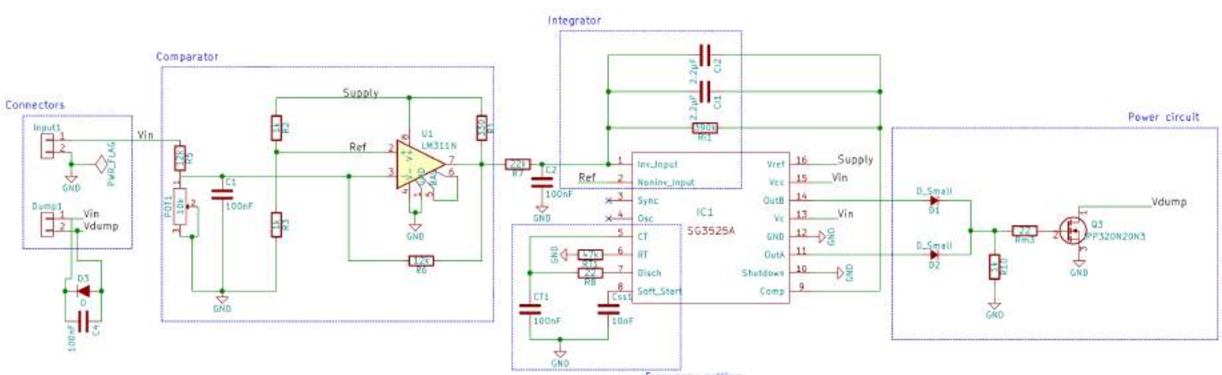


Figure 5.10: Schematics of the circuit of a 12 Volts regulator