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UNIVERSIDAD PONTIFICIA
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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

"POWERING A WATER QUALITY MONITORING SYSTEM"

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Madrid

Junio de 2019

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Fdo.: Luis Navarro Velasco Date: 27/05/2019

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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

"POWERING A WATER QUALITY MONITORING SYSTEM"

Autor: Luis Navarro Velasco

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Madrid

Junio de 2019

ALIMENTACIÓN DE UN SISTEMA DE MONITORIZACIÓN DE LA CONTAMINACIÓN DEL AGUA

Autor: Navarro Velasco, Luis.

Director: Jiang, Jing.

Entidad Colaboradora: CERSE.

RESUMEN DEL PROYECTO

1. *Introducción*

La Entidad Colaboradora, CERSE (Center for Environment Restoration and Sustainable Energy) con sede en el campus de Urbana-Champaign de la Universidad de Illinois, planteó un proyecto para monitorizar la contaminación del agua en lagos y ríos en tiempo real. La solución propuesta consiste en diseñar un barco autónomo (de aproximadamente 1 metro de longitud) dotado de sensores y herramientas de localización y comunicación que le permitan no solo tomar muestras para generar datos de contaminación del agua, sino también enviarlos a un servidor web para poder valorarlos en tiempo real y poder así alertar a la población sobre la seguridad en el consumo del agua.

Este barco está dotado de un circuito electrónico formado por distintos componentes como un GPS y un GSM, que le permiten llevar a cabo su función. Para el correcto funcionamiento de dicho sistema, la empresa debe alimentar cada uno de sus componentes cumpliendo sus diferentes especificaciones de potencia y durante el tiempo necesario para que éste pueda llevar a cabo sus funciones, las cuales durarán como mínimo un día, tras el cual el barco será llevado a tierra firme.

Este proyecto pretende solucionar este problema de potencia planteado. Para ello se diseñará el sistema de alimentación para el proyecto de la empresa CERSE, de modo que la electrónica tenga la energía suficiente para funcionar durante este tiempo especificado por la empresa. El principal reto que plantea este proyecto es que, ya que el barco se va a encontrar navegando, el sistema de potencia debe ser "inalámbrico", es decir, debe ser capaz de funcionar sin estar conectado a la red eléctrica. Los componentes de este sistema de potencia deben ser ligeros ya que, cuanto más pesen, más energía consumirá el barco a la hora de moverse y, por tanto, podrá estar menos tiempo navegando. Además de ser ligeros deben ser de reducido tamaño, ya que deben poder ser introducidos junto con el resto de componentes en el pequeño barco del proyecto global.

2. *Objetivos*

Los objetivos de este proyecto son los siguientes:

1. Implementar un panel solar capaz de cargar el paquete de baterías.
2. Diseñar un paquete de baterías que permita alimentar el sistema durante el tiempo especificado por la empresa.
3. Controlar el estado de carga del paquete de baterías, para que la empresa tenga en todo momento información sobre cuánta carga le queda al mismo.
4. Diseño de un sistema de protección para las baterías para evitar daños durante la carga y descarga de las mismas.
5. Diseñar un circuito de potencia para alimentar la electronica del barco del proyecto global.

3. *Metodología:*

Este proyecto se desarrollará siguiendo tres fases:

Fase 1: Estudio y selección de los diferentes componentes del sistema.

Fase 2: Construcción el sistema físico.

Fase 3: Verificación el correcto funcionamiento del sistema.

A continuación, se explicará el desarrollo de cada una de las fases mencionadas:

2.1. *Fase 1: Estudio y selección de los diferentes componentes del sistema*

El primer paso a seguir para desarrollar este proyecto, es el estudio del problema que se plantea y el diseño de un sistema que cumpla las especificaciones de la empresa. Tras realizar dicho estudio, se llegó a la conclusión que el sistema necesita estar dotado de los siguientes componentes:

i) **Paquete de baterías**: este componente permitirá almacenar la energía que se proporcionará al sistema. Se deben realizar cálculos de potencia, de tal manera que el conjunto de baterías elegido proporcione energía al sistema durante el tiempo especificado por la empresa. Para la elección de las baterías, se ha tenido en cuenta no solo el presupuesto sino también el peso y tamaño de las mismas que, como ya se ha mencionado anteriormente, es una especificación crítica en este proyecto. Las baterías elegidas, así como la potencia de las mismas se presentan en la sección de resultados de este resumen.

ii) **Contenedor de baterías**: para mayor seguridad y facilidad de ensamblaje del paquete de baterías, se introducirán las mismas en unos contenedores de plástico. Estos componentes contienen metal en su interior para poder realizar la conexión entre las baterías, lo cual nos permitirá crear conexiones en serie entre las mismas. De este modo, no solo permitirán aislar las baterías del exterior para que no se produzcan cortocircuitos, sino que además facilitarán la conexión de las mismas para crear el paquete deseado.

iii) **Panel solar**: este componente nos permitirá cargar las baterías durante el día. De este modo, podremos aumentar la potencia total del sistema, de manera que se pueda alimentar la electrónica del proyecto durante un periodo de tiempo más largo. Al igual que en el caso de las baterías, se ha escogido un panel solar ligero y de reducido tamaño. Además, este componente estará en la parte superior del barco mientras navega, lo cual implica que hay riesgo por salpicadura de agua, lo cual se debe tener en cuenta a la hora de elegir el panel solar para el proyecto. El panel solar elegido, así como la potencia adicional que proporciona al sistema se presentan en la sección de resultados de este resumen.

iv) **Sistema de protección de baterías: BMS y Controlador de carga**: todo paquete de baterías necesita estar dotado de un sistema de protección que nos permita asegurarnos que el paquete de baterías está funcionando en condiciones de trabajo seguras, ya que de lo contrario las baterías pueden ser dañadas o incluso, en casos extremos, arder y suponer un peligro para el resto del sistema. El BMS (Battery Management System), permitirá obtener el estado de carga de las baterías (también denominado SOC), y realizar balanceo entre las diferentes celdas del paquete de baterías. Esto último significa igualar la carga de las baterías que, al estar conectadas en serie, no todas reciben la misma energía, por lo que después de varios ciclos acaban teniendo estados de carga distintos, lo cual puede dañar las celdas al producirse sobrecargas o sobredescargas.

El controlador de carga será la conexión entre el paquete de baterías, el panel solar y el circuito de potencia (que estará conectado a la carga a alimentar), y protegerá el paquete total de sobrecargas, sobredescargas y que se pierda potencia de las baterías a través del panel solar cuando este último no esté suministrando potencia.

v) **PCB (Printed Circuit Board)**: el circuito de potencia que permitirá adaptar la tensión y corriente de las baterías a los requerimientos del resto de componentes a alimentar del proyecto mayor y obtener los datos del estado de carga de las baterías se desarrollará en una PCB, que será la misma en la que se encontrarán dichos componentes que se pretenden alimentar. En esta PCB estará incluido también el BMS, y además incluirá un microcontrolador ATmega328p, diodos, resistencias y dos reguladores de tensión. Estos dos reguladores de tensión serán de salidas de 5V y de 3.3V respectivamente.

La conexión de los diferentes componentes se muestra a continuación en el diagrama de bloques del sistema:

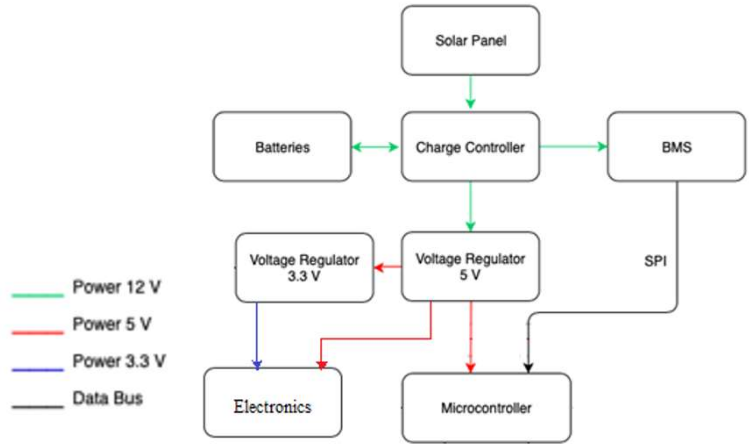

Figure 1: Diagrama de bloques

2.2. *Fase 2: Construcción del sistema físico*

Una vez conocidos los componentes necesarios y las especificaciones que debe cumplir cada uno, se inicia una búsqueda de los componentes para poder así adquirirlos y construir el sistema final.

Los componentes elegidos para este proyecto son los siguientes:

i) **Paquete de baterías**: se adquirieron baterías de Li-ion 18650 de 3.7V y 11000mAh cada celda. Se escogió este tipo de celdas debido a que presentan un buen equilibrio entre tamaño, peso y potencia. El paquete total de baterías consta de un total de 3 baterías en serie, lo cual proporciona una tensión total de 11,1V y un amperaje de 11Ah. Además, este tipo de baterías se puede cargar hasta un máximo de 4,2V cada celda, lo cual implica que el voltaje total, cuando están completamente cargadas, sea de 12.6V.

Figure 2: Celda individual

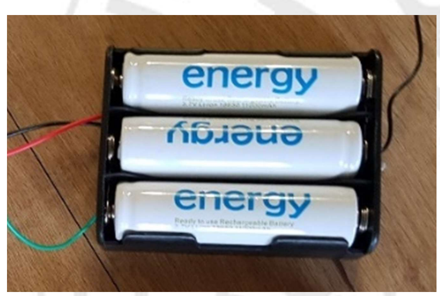

Figure 3: Paquete de baterías

ii) **Contenedor de baterías**: permite crear las asociaciones en serie fácilmente, evitando exponer las bornas de las baterías al exterior. Además, para posibilitar la conexión de cada celda individualmente al BMS, se soldaron dos cables más (verde y negro), que se conectan a las bornas de las celdas que no tenían conexión al exterior originalmente. Dichos cables se pueden observar en la Figure 3. A continuación, se muestra el contenedor de baterías original.

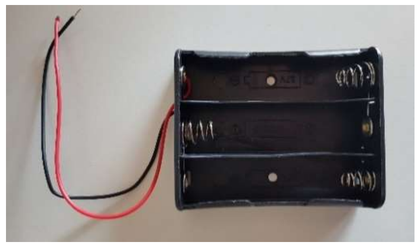

Figure 4: Contenedor de baterías original

iii) **Panel solar:** el panel solar elegido tiene una potencia nominal de 10W, con una tensión nominal de 17,3V. Tal y como se comentó en el apartado anterior y debido a la aplicación dee este sistema, debe ser resistente al agua, y por ello el componente elegido tiene una resistencia al agua de norma IP65, es decir, es resistente ante salpicaduras. Además, es de reducido tamaño (33cm de largo), lo cual permitiría incluir en el barco un total de hasta 3 de estos paneles en caso de que en un futuro aumente la demanda de potencia del proyecto completo diseñado por la entidad colaboradora.

Figure 5: Panel solar

iv) **Sistema de protección de baterías: BMS y Controlador de carga**

(1) **BMS**: el componente elegido permite conectar hasta 7 baterías en serie. Además, tiene comunicación SPI (Serial Peripheral Interface), la cual nos permitirá comunicarlo con el microcontrolador y obtener así los datos del estado de carga de las baterías. El componente elegido es el LTC6810G-2 de la empresa Analog Devices.

Figure 6: BMS

(2) **Controlador de carga:** el componente elegido admite una entrada de hasta 40V, que se adapta perfectamente a la tensión nominal de 17,3V proporcionada por el panel solar. Además, tiene una salida de corriente continua con un máximo de 10A, lo cual garantiza que las baterías sean cargadas con valores de corriente seguros para las mismas (ya que el valor máximo de corriente al que pueden ser cargadas es 11A). Este componente protege el paquete de baterías garantizando que, si el nivel de las mismas supera los 12,6V, se desconectan del panel solar, de forma que no sufran por sobrecarga; si la tensión de las baterías es inferior a 10,5V no permite descargarlas más, aislando las mismas de la carga. El componente elegido posee además una pantalla que proporciona datos acerca de la tensión de las baterías y de la corriente que fluye del panel solar a las baterías y de estas últimas a la carga. Dicho componente es el CMG-2410, y se muestra en la siguiente figura:

Figure 7: Controlador de carga

v) **PCB:** la placa fue diseñada usando el software de diseño EAGLE. Consta del BMS, el microcontrolador, los dos reguladores de tensión ya mencionados, resistencias, condensadores y diodos. El microcontrolador elegido es el ATmega328p debido a que cumple los requerimientos del proyecto, la cuales se presentan más adelante en este documento en el "Project Report". Los componentes los podemos ver soldados sobre la PCB en la Figure 8, y sus especificaciones se detallan en la parte 1 del "Document I: Project Report", de este mismo documento.

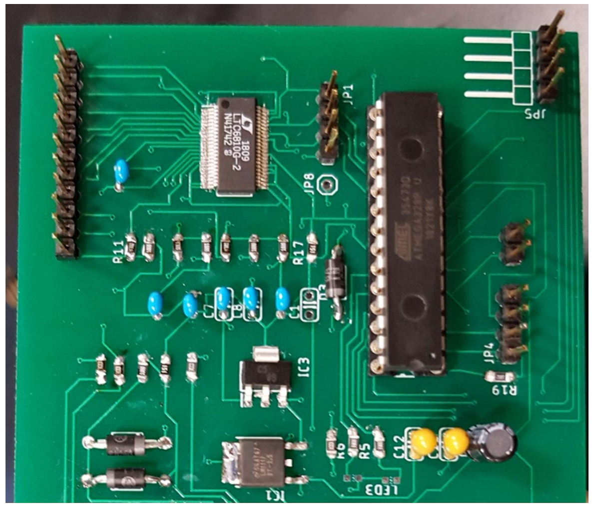

Figure 8: PCB

El resultado final del sistema es el siguiente:

Figure 9: Sistema completo

2.3. Fase 3: Verificación del correcto funcionamiento del sistema.

La pantalla del controlador de carga permite fácilmente comprobar el correcto funcionamiento del sistema, ya que especifica la corriente que fluye del panel solar a las baterías, la que fluye de las baterías a la carga y la tensión de las baterías. Con estos datos podemos saber si la alimentación funciona correctamente. Además, podemos verificar que los reguladores de tensión están funcionando según lo esperado midiendo la tensión y corriente de salida con un multímetro.

El BMS se debe programar a través del microcontrolador, utilizando comunicación con protocolo SPI. De este modo, podremos no solo configurar el BMS correctamente, sino también recibir los datos del estado de carga de las baterías. El programa necesario para obtener dichos datos y para configurar el chip es proporcionado por la empresa en su página web, la cual se indica en las referencias.

Ya que este microcontrolador es el mismo utilizado por Arduino, podemos utilizar el software del mismo para comprobar mediante el puerto serie que se están recibiendo los datos correctamente. Para poder programar más fácilmente el microcontrolador, no se ha soldado a la PCB, sino que se ha soldado a la misma un adaptador que permite introducir el microcontrolador y extraerlo cuando sea necesario. De este modo, el microcontrolador se puede extraer del PCB e introducirlo en la placa de Arduino para programarlo más fácilmente.

3. *Resultados:*

Tras llevar a cabo la verificación del sistema, se puede afirmar que funciona según lo esperado, y que cumple las especificaciones del proyecto.

Nota: en este apartado se muestran resultados de cálculos que se desarrollan en la parte 2 del "Document I: Project Report", que tiene por título "Calculations".

El consumo total del circuito de potencia diseñado junto con la carga que se está alimentando, es de 0,4Ah y 12V, es decir, 4,8Wh. Ya que la potencia de las baterías es de 11Ah a 12V, es decir, 132Wh. Esto implica que las baterías, sin acción del panel solar (es decir, en un día nublado o durante la noche), pueden alimentar la carga durante un total de 1 día y 3 horas. Esto significa que, aún en días en los que el panel solar no proporcione potencia al sistema debido a tiempo desfavorable, se cumplirá la especificación de la empresa de que la electrónica del barco pueda funcionar durante al menos1 día.

En un día soleado, el panel solar podrá proporcionar la suficiente energía a las baterías para alimentar el sistema durante 10,41h. Esto implica que, ante días soleados, la electrónica se podrá alimentar durante alrededor de 2 días antes de que se descarguen las baterías por completo.

En cuanto al coste total en componentes, se ha conseguido un precio total reducido dado el número de componentes que forman el sistema. El coste total de todos los componentes (exceptuando la PCB ya que se compartiría con el circuito de electrónica que se pretende alimentar del proyecto global), es de 76.21$, es decir, unos 67€.

4. *Conclusiones*

Tal y como se puede observar tras los resultados finales del proyecto, el sistema se adecúa a los requerimientos de la empresa colaboradora, ofreciendo una solución ligera, de reducido tamaño y de precio asequible, que consigue alimentar cada uno de los componentes electrónicos del proyecto global según sus diferentes especificaciones de potencia.

Este proyecto tiene la potencia esperada, sin embargo, si aumentara la demanda de potencia del proyecto global debido a un crecimiento del mismo, se podrían añadir más baterías e incluso hasta dos paneles solares más, ya que son de reducido tamaño y tendrían suficiente espacio en el barco del proyecto global.

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POWERING A WATER QUALITY MONITORING SYSTEM

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Collaborating Institution: CERSE.

PROJECT ABSTRACT

1. *Introduction:*

The Collaborating Institution, CERSE (Center for Environment Restoration and Sustainable Energy) located at the Urbana-Champaign campus of the University of Illinois, proposed a project to monitor water pollution in lakes and rivers in real time. The proposed solution consists of designing an autonomous boat (approximately 1 metre long) equipped with sensors and location and communication tools that allow it not only to take samples to generate water pollution data, but also to send them to a web server in order to assess them in real time and be able to alert the population about the safeness of water consumption.

This boat is equipped with an electronic circuit formed by different components such as a GPS and a GSM, which allow it to carry out its function. For the correct functioning of this system, the company must power each one of its components meeting their different specifications of power and during the necessary time so that the boat can carry out its duties, which will last at least one day, after which it will be taken to mainland.

This project aims to solve this power problem. For this purpose, the power supply system will be designed for the CERSE project, so that the electronics have enough energy to operate during this time specified by the company. The main challenge posed by this project is that, since the boat is going to be sailing, the power system must be “wireless", i.e. it must be able to operate without being connected to the grid. The components of this power system must be lightweight because the heavier they are, the more energy the boat consumes when moving and therefore the less time it can spend sailing. In addition to being light they must be of reduced size, since they must be able to be introduced together with the rest of components in the small boat of the global project.

2. *Objectives*

There are various objectives for this project:

1. Implement a solar panel capable of charging the battery pack that will be installed in the boat.
2. Design a battery pack that can power the boat for the period of time specified by the company.

3. Control the state of charge of that battery pack, so that we can know at all times the amount of power left that is available.
4. Design a system that protects the batteries to avoid damaging them when charging nor discharging.
5. Create the power circuit to power the electronics of the boat. This will allow us adapt the power supplied by the batteries to the requirements of the different modules of the major project to be powered.

3. *Methodology:*

This project will be developed in three different phases:

Phase 1: Studying and selecting the different components of the system.

Phase 2: Building the system.

Phase 3: Testing the system.

The development of each of these phases will be explained below:

2.1. Phase 1: Studying and selecting the different components of the system

The first step to follow to develop this project is the study of the problem that arises, and the design of a system that meets the specifications of the company. Following this study, it was concluded that the system needs to be equipped with the following components:

i) **Battery Pack**: this component will store the energy that will be supplied to the system. Power calculations should be made so that the chosen battery pack provides power to the system for the time specified by the company. For the choice of the batteries, not only the budget should be taken into account, but also the weight and size of the batteries which, as already mentioned above, is a critical specification in this project. The chosen batteries and their power specifications are presented in the results section of this summary.

ii) **Battery holder**: for greater security and ease of assembly of the battery pack, they will be placed in plastic containers. These components contain metal inside to facilitate the connection between the batteries, which will allow us to create series connections between them. By doing this, not only will the batteries be isolated from the outside so as not to cause short circuits, but this will also make it easier to connect them to create the desired package.

iii) **Solar panel**: this component will allow us to charge the batteries during the day. Thanks to the solar panel, we will be able to increase the total power of the system, so that the electronics of the project can be powered for a longer period of time. As in the case of the batteries, a small, lightweight solar panel has been chosen. In addition, this component will be at the top of the boat while sailing, which implies that there is a risk of splashing water, which should be taken into account when choosing the solar panel for the project. The chosen solar panel as well as the additional power it provides to the system are presented in the following sections of this summary.

iv) **Battery Protection System: BMS and Charge Controller**: Every battery pack needs to be equipped with a protection system that ensures that the battery pack is working under safe working conditions, as otherwise the batteries may be damaged or even, in extreme cases, burn and pose a danger to the rest of the system. The BMS (Battery Management System), will allow to obtain the state of charge of the batteries (also called SOC), and perform balancing between the different cells of the package. The latter means equalizing the charge of the batteries which, being connected in series, do not all receive the same energy, so that after several cycles they end up having different states of charge, which can damage the cells as overloads or over-discharges occur. The charge controller will be the connection between the battery pack, the solar panel and the power circuit (which will be connected to the load to be powered), and will protect the battery package from overcharges, over-discharges and loss of battery power through the solar panel when the latter is not supplying power.

v) **PCB**: the power circuit that will allow the voltage and current of the batteries to be adapted to the requirements of the rest of the components to be powered from the major project and to obtain data on the state of charge of the batteries will be developed in a PCB, which will be the same one in which the components to be powered will be found. This PCB will also include the BMS, an ATmega328p microcontroller, diodes, resistors and two voltage regulators. These two voltage regulators will have outputs of 5V and 3. 3V respectively.

The connection between the different components is shown in the following block diagram:

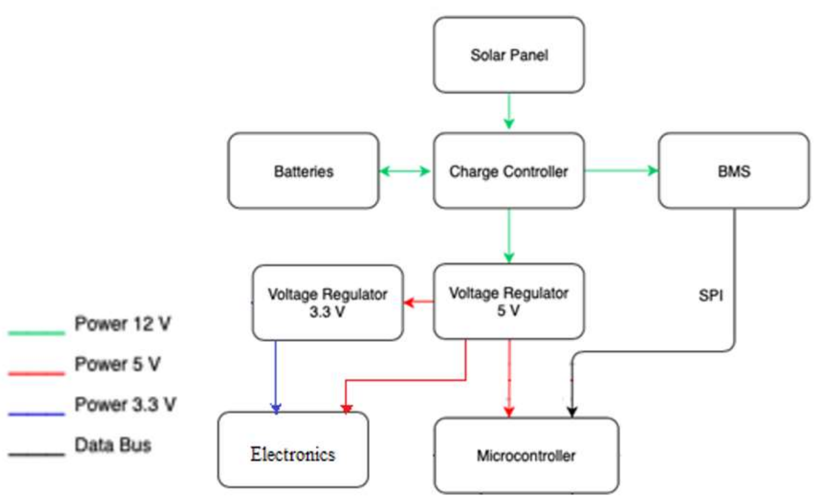

Figure 1: Block diagram

2.2. Phase 2: Building the system

Once that the research on which components should be used is completed and known the specifications of each component, we fall into the second stage, which consists on looking for specific components and buying them to later build the system.

The chosen components are the following:

i) **Battery Pack**: 18650 Lithium-Ion batteries of 3.7V and 11000mAh (each cell) were purchased. These cells were chosen due to their good balance between size, weight and power. The total battery pack consists of a total of 3 batteries in series, providing a total voltage of 11.1V and an amperage of 11Ah. In addition, this type of battery can be charged up to a maximum of 4.2V per cell, which means that the total voltage when fully charged is 12.6V.

Figure 2: Battery cell

Figure 3: Battery Pack

ii) **Battery holder**: allows to connect 3 batteries in series easily, and avoids exposing the battery terminals to the outside. In order to do the connections between each battery cell and the BMS, two more wires were soldered to the battery holder (green and black), as can be seen in Figure 3. In Figure 4, the original battery holder (before soldering the wires) is presented.

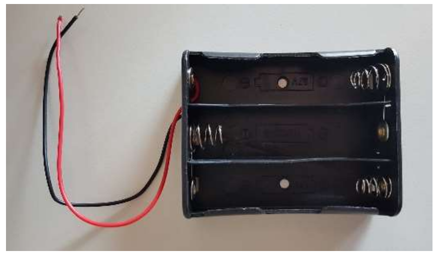

Figure 4: Battery holder

iii) **Solar Panel:** the chosen solar panel has a power of 10W, with a maximum voltage of 20V. As mentioned in the previous section, it must be resistant to water, which is why the component chosen has an IP65 water resistance, i.e. it is resistant to splashes. In addition, it is small in size (33cm long), which would allow a total of up to 3 of these to be included on the boat in case extra power wants to be added to the project at a later date.

Figure 5: Solar panel

iv) **Battery Protection System: BMS and Charge Controller:**

(1) **BMS**: the chosen component allows up to 7 batteries to be connected in series, and can balance the charge between them. In addition, it has SPI communication, which will allow us to communicate it with the microcontroller and thus obtain the data of the state of charge of the batteries. This component is the LTC6810G-2 from Analog Devices.

Figure 6: BMS

(2) **Charge Controller:** the chosen component supports an input of up to 40V, which is perfectly works fine with to the nominal voltage of 17.3V provided by the solar panel. In addition, it has a direct current output with a maximum of 10A, which guarantees that the batteries are being charged with safe current values. It protects the battery pack by ensuring that if their level exceeds 12.6V, they are disconnected from the solar

panel, so that they do not suffer from overload and, if the voltage of the batteries is less than 10.5V does not allow more discharge, isolating them from the load. The chosen component also has a screen that provides data about the voltage of the batteries and the current flowing from the solar panel to the batteries and from the latter to the load. This component is CMG-2410, and is shown in the following figure:

Figure 7: Charge Controller

v) **PCB:** this component was designed using EAGLE design software. It consists of the BMS, the microcontroller, the two voltage regulators already mentioned and resistors and capacitors. The microcontroller chosen is the ATmega328p because it meets the requirements of the project and has been used for previous projects. The components can be seen soldered on the PCB in Figure 8, and their specifications are detailed in part 1 of Document 1: Project Report, of this same document.

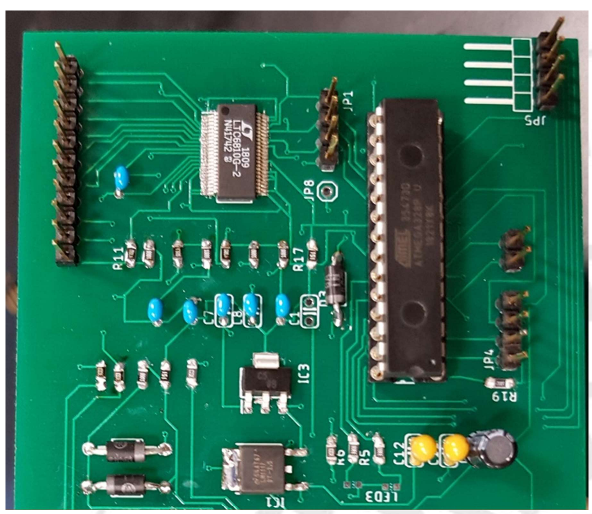

Figure 8: PCB

The final result of the whole system is the following:

Figure 9: Complete system

2.3. Phase 3: Testing the system

The display of the charge controller allows to easily check the correct functioning of the system, as it specifies the current that flows from the solar panel to the batteries, the current that flows from the batteries to the load and the voltage of the batteries. With these data we can know if the power supply is working properly. In addition, we can verify that the voltage regulators are operating as expected by measuring the output voltage and current with a multimeter.

The BMS must be programmed through the microcontroller, using SPI communication. By doing this, we both configure the BMS correctly and receive the data of the state of charge of the batteries. The program necessary to obtain these data and to configure the chip is provided by the company on its website, which is indicated in the references.

Since this microcontroller is the same one used by Arduino, its software can be used to check through the serial port that the data is being received correctly. In order to be able to program the microcontroller more easily, the PCB has not been soldered, but rather an adapter has been soldered to it that allows the microcontroller to be inserted and removed when necessary. In this way, the microcontroller can be removed from the PCB and inserted into the Arduino board for easier programming.

3. Results:

After carrying out the verification of the system, it can be stated that it works as expected, and that it meets the specifications of the project.

Note: This section shows the results of calculations developed in Part 2 of Document I: Project Report, entitled Calculations.

The total consumption of the power circuit designed together with the load being powered is 0.4Ah and 12V, i.e. 4.8Wh, and the power of the batteries is 11Ah at 12V, i.e. 132Wh. This means that the batteries, without the action of the solar panel (i.e. if it was cloudy every day), can power the charge for a total of 2 days and 7 hours. This means that even on days when the solar panel does not provide power to the system due to unfavorable weather, the company's specification that the ship's electronics should operate for 2 days will be met.

On a sunny day, the solar panel will be able to provide enough energy to the batteries to power the system for 10.41h. This means that, with favorable weather, the electronics can be powered for around 2 days before the batteries get completely discharged.

As for the total cost in components, a reduced total price has been achieved given the number of components that make up the system. The total cost of all the components (except the PCB as it would be shared with the electronic circuit of the major project that is intended to be powered), is $76.21

4.Conclusions:

As can be seen after the final results of the project, the system adapts to the requirements of the Collaborating Institution, offering a lightweight, small size and affordable solution, which has proven to power each of the different components in the major project meeting the power specifications of each one of them.

This project has the expected power, however, if the power demand of the major project increased due to the growth of the project, more batteries could be added and even up to two more solar panels could be added, as they are small and the boat would have enough space for them.

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GRADO EN INGENIERÍA EN TECNOLOGÍAS INDUSTRIALES

TRABAJO FIN DE GRADO

"POWERING A WATER QUALITY MONITORING SYSTEM"

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Junio de 2019

DOCUMENT I: PROJECT REPORT

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TABLE OF CONTENT

1. PROJECT REPORT

PART 1: PROJECT REPORT

TABLE OF CONTENT

1. INTRODUCTION

The USGS (U. S. Geological Survey) has estimated that each person uses up to 130,000 liters of water per year. A large part of this consumption is for drinking and hygiene. Water companies, consumers and environmental scientists need to know the state of water resources in order to take action if water pollution levels increase unexpectedly, given the importance of drinking water to people's health. Water pollution is a bigger problem than we think. Actually, it causes more deaths than any war. Every year more and more people die from water pollution. The WHO (World Health Organization) has estimated that 1.7 million children under the age of 5 die each year due to environmental pollution, and a large percentage of these deaths are caused by the consumption of contaminated water *[1]*.

The company CERSE (Center for Environment Restoration and Sustainable Energy) is aware of the major problem posed by the contamination of this natural resource, and wants to make sure that the water consumed is safe. This led them to develop the following project: a boat that analyzes the water in lakes and rivers and sends alerts in real-time if the water is not drinkable. This boat (around 1m long) will be deployed in lakes and rivers and will remain there for a period of time obtaining data on water pollution. In order to obtain this data, the ship is equipped with sensors, which will obtain all the necessary information to determine the levels of water pollution. This boat will move to different points specified by the company in those lakes and rivers, and gather data on water pollution in all those different points.

Note: in this paper, this larger project designed by the company will be noted as 'the major project'.

The objective of this company is to create a system that can not only gather all these data, but also send it to a web page, in order to obtain real-time information on the location of the boat and water pollution. To do this, they need a modular electronics system. All these modules need to be powered, so a power system needs to be created.

While carrying out its duties the boat will be away from the shore, which means it cannot be connected to the grid. This is one of the problems that the company has to face, as it implies that the power system to be designed will have to be transported by the ship.

The objective of this project is to design the power system for the electronics of this vehicle so that it meets the specifications of the company and allows the boat to carry out its tasks. In addition, information on the state of charge of the batteries will be provided to the company. This information will be sent to the microcontroller, and then to the cloud (for this project it will only be sent to the microcontroller). This will allow them to know at all times how much battery is left, so they can bring the boat back before it runs out of battery.

All of these objectives should be completed with a system designed with the minimum cost and minimum size (as it has to fit in the 1m long boat) and minimum weight, as the more these component weight, the more power will be needed to move the boat from one point to another.

2. OBJECTIVES

There are various objectives for this project:

6. Implement a solar panel capable of charging the battery pack that will be installed in the boat.
7. Design a battery pack that can power the boat for the period of time specified by the company.
8. Control the state of charge of that battery pack, so that we can know at all times the amount of power left that is available.
9. Design a system that protects the batteries to avoid damaging them when charging nor discharging.
10. Create the power circuit to power the electronics of the boat. This will allow us adapt the power supplied by the batteries to the requirements of the different modules of the major project to be powered.

3. METHODOLOGY

This project will be developed following three different stages:

1. Carry out a study of the different components.
2. Build the physical system.
3. Test the system and check its correct functioning.

For this Project, each component will be presented separately, showing the study of each of them, the chosen component for the real system and the final results presented by the component.

4. DESIGN

The first step to follow to develop this project is the study of the problem that arises, and design a system that meets the specifications of the company. Following this study, it was concluded that the system should be equipped with the following components:

i) **Battery pack**: this component will store the energy that will be supplied to the system. It should be as light and less bulky as possible, as it has to fit in the 1m long boat of the major project.

ii) **Battery holder**: for greater security and ease of assembly of the battery pack, the batteries will be inserted into plastic containers. These components contain metal inside to be able to make the connection between the batteries, which will allow us to create serial connections between them. In this way, not only will the batteries be isolated from the outside, but they will also make it easier to connect the battery cells between them to create the desired battery pack.

iii) **Solar panel**: this component will allow us to charge the batteries during the day. This means that the electronics of the project will be powered for a longer period of time before the batteries run out of charge.

vi) **Battery protection system: BMS and charge controller**: battery packs always need to be provided with a protection system that ensures that batteries are working under safe working conditions, as otherwise they may be damaged or even in extreme cases, burn and pose a danger to the rest of the system. The BMS (Battery Management System), will allow to obtain the state of charge of the batteries (also called SOC), and perform balancing between the different cells of the package. The latter means equalizing the charge of the batteries. The charge controller will be the link between the battery pack, the solar panel and the power circuit (which will be connected to the load to be powered), and will protect the battery pack from overcharges, over-discharges and loss of battery power through the solar panel when the latter is not supplying power.

iv) **PCB**: the PCB, which will be the same one on which the components of the electronic circuit of the major project to be powered will be found, will hold the power circuit. It will allow us not only to adapt the voltage provided by the batteries to the requirements of each component of the circuit to be powered, but will also allow the connection between the BMS and the microcontroller of the major project to enable the acquisition of the state of charge of the batteries.

Note: the block diagram of the system, which specifies how all the components have been connected to each other, can be found later in this document, in the section entitled Final System.

What follows is the study, selection and results of each component are presented individually.

I. BATTERY PACK

STUDY OF THE COMPONENT

In the present, batteries are the cheapest way to store energy. There are different types of batteries depending on the material they are made of. Some of the most common are Lithium Polymer, Lithium-Ion and Lead Acid. The first step is to understand which battery parameters must be taken into account to make the right choice. These parameters are the following:

- Composition: as mentioned above, there are different types of batteries depending on the chemical component of which they are made. Each chemical component behaves in a different way, which makes the batteries have different qualities. The first difference that can be found is the nominal voltage that a cell has, and also in the discharge curve that follows the battery. We can see a comparison of the main types in the following graph:

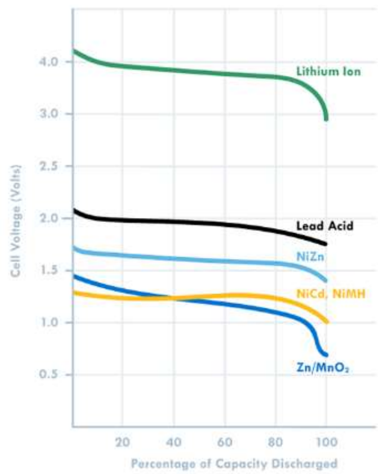

Figure 1: Discharge curves for each type of battery [2]

- <u>Capacity:</u> the capacity of a battery is measured in ampere hours (Ah). What this measure shows is how many amps a battery can provide continuously in an hour until it is completely discharged. To increase this capacity, it is sufficient to place batteries with the same nominal voltage in parallel, and thus the total capacity will be the result of the sum of the batteries placed in parallel.

- <u>Discharging ratio:</u> some batteries can be discharged with a higher power than the rated one, i.e. they can provide an amperage per hour greater than that specified by the capacity of the battery. The discharging ratio is specified by the letter C. This feature allows us to increase the power provided by our battery, however, the discharge time will be proportionally reduced. For example, if the battery gives us the option of being discharged at 2C, it can be discharged at twice the specified ampere hours, but only for half the time (half an hour).

- <u>Temperature:</u> this is the temperature range in which the battery operates safely. This is an important parameter, since in case the batteries are working outside this temperature range, they could be damaged, or even explode or burn. This parameter is especially critical in projects where the batteries are working in locations with extreme temperatures or in small enclosed spaces (which is the case with this project), where the heat released by the batteries could heat the space that encloses them to temperatures higher than the maximum allowed by the batteries.

- <u>Primary or secondary:</u> primary batteries cannot be recharged, but must be replaced when completely discharged, while secondary batteries can be recharged.

- Cost: depending on the composition of the battery, the cost of this component changes. For example, the lead ones have a very reduced cost.

- Size and weight: as mentioned before, for this project size and weight are critical specifications. Depending on the type of battery, the size and weight vary greatly, for example, lead-acid batteries are very heavy and take up a lot of space while lithium batteries are light and small.

DESIGN OF THE COMPONENT

Once these parameters and the pros and cons of each type of battery were known, it was decided that the type of battery to be used in this project is Lithium-Ion. This decision is based on several points. The first one is that this type of batteries are very light, and provide a large power with a small cell size, which allows to build a pack of batteries of reduced size and weight, but with a great power rating. In addition, the great availability of these batteries in the market allows to find a battery with the desired specifications and with very affordable prices.

Now that the battery composition has been chosen, the next step is to create the battery pack with the desired power. The first thing to bear in mind is that Lithium-Ion batteries have a nominal voltage of 3.7V, being able to reach a maximum voltage of 4.2V when fully charged (as can be seen in Figure 1). This data is necessary to see how many batteries in series we will place to obtain the desired voltage.

The first thing we should know is that, by placing the batteries in series (joining the positive pole of one of them with the negative pole of the next) we will be adding their voltage and, if we place them in parallel (joining the positive and negative poles of each battery with each other), we will be adding their capacities (their amps per hour). With this in mind, we will first look for the needed voltage. The decision of the voltage used for this battery pack is made together with the decision of the chosen solar panel, as well as the charge controller. The choice of these two components, which is specified later in this document, leads us to create a 12V battery pack, i.e. 3 batteries in series.

The last step to finish designing the battery pack is to make an approximate calculation of the power consumption of the system, as it will be needed in order to determine the capacity that the batteries should have. The result of these calculations, which are shown in the Calculations section of this document, indicates that in order for the batteries to power the system uninterruptedly for a full day before being completely discharged, which was a company specification, a total of at least 9.6Ah will be required.

These calculations lead to the decision to buy 11Ah Lithium-Ion batteries, and create a package consisting of 3 batteries in series, which provides 12V and 11Ah. The batteries are type 18650, and are shown in the following image.

Figure 2: Battery cell

II. BATTERY HOLDER

DESIGN OF THE COMPONENT

Due to the battery configuration mentioned above, and the fact that the battery pack needs to be assembled, it was concluded that this project needed to include a battery holder that keeps the batteries together and connected to each other. In addition, another objective of creating a battery holder is to prevent the battery poles from being exposed. For this, the best solution is to use a battery holder that facilitates the serial connection of the batteries. The chosen component is as follows:

Figure 3: Battery holder

As it can be seen in the image above, this component contains the internal connections necessary to connect the batteries in series.

This component will be connected to the charge controller with the two output cables (red and black) that can be seen in Figure 3. Each battery cell also needs to be connected individually to the BMS, in order to be able to carry out the charge balancing and getting the state of charge of each of the cells that form the battery pack. In order to be able to do those connections, two more cables have been welded to this battery holder (green and black), as can be seen in Figure 4.

In deciding to use this component, it was also taken into account that it barely adds extra size to the battery pack, and its very little weight does not increase the weight of the system.

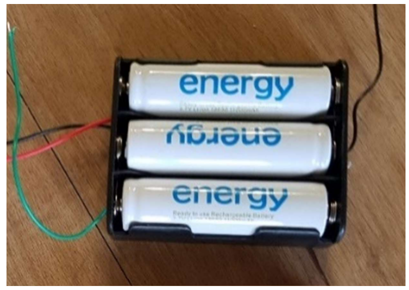

Figure 4: Battery pack

III. SOLAR PANEL

STUDY OF THE COMPONENT

One of the objectives of this project is to create a power supply that would allow us to charge the batteries while the boat is carrying out its tasks in lakes and rivers. This, coupled with the project's ecological approach, led to the decision of using a solar panel. Solar energy is becoming more and more popular. The cost of one of these panels is increasingly reduced, and the variety offered in the market is increasing. The fact that solar energy was chosen instead of other renewable energies such as wind energy is due to the fact that, in addition to being able to produce a greater amount of energy at a lower cost, the solar panel will not affect the aerodynamics of the boat.

The functioning of the solar panel for practical purposes is as follows. The solar panel receives an amount of sunlight, and depending on how much light it receives, it produces a higher or lower DC voltage. This voltage varies between 0 (when there is total darkness) and the nominal voltage of each solar panel (when there is intense sunlight). One thing to keep in mind is that, when the solar panel is not producing energy, it becomes a passive element, that is, if it is connected directly to the batteries, it will consume energy from them. This is one of the reasons why we need to place a control system such as a charge controller, between the batteries and the solar plate. The design of the charge controller is shown later in this document.

The parameters to study when choosing the solar panel are the following:

- Open circuit voltage (VOC): this is the voltage at the solar panel's terminals when no load is connected.

- Short circuit current (ISC): it is the current in the panel when no load is connected, and the solar panel terminals are connected to each other.

- Maximum power (MP): it is the maximum power that the solar plate can generate. It occurs at the elbow of the curve shown in Figure 5.

- Nominal voltage: this voltage is the maximum at which the solar panel works when a load is connected to it. This voltage is lower than the open circuit voltage, for example, for a 12V solar panel, the open circuit voltage is about 22V, and the nominal voltage is about 17V. There are solar panels of many sizes and voltages, but the most common with the size needed for the project and the power required are 12V or 24V.

- Efficiency: the typical efficiency value of solar panels is around 16-17%. A solar panel is considered to be a high efficiency one if it exceeds 19% of efficiency.

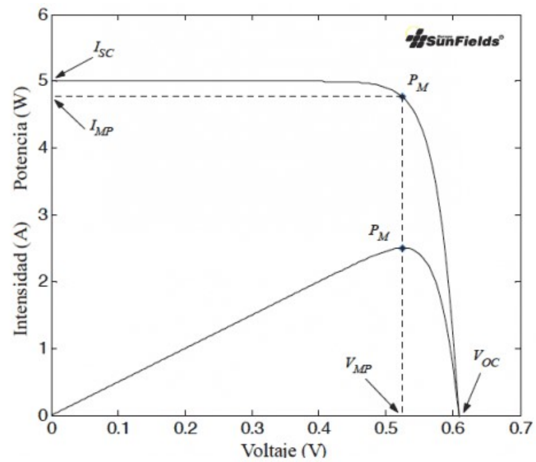

Figure 5: Voltage vs current curve in a solar panel [4]

DESIGN OF THE COMPONENT

After analyzing the power results presented in the Calculations section of this document, and after knowing the budget for the components specified by the company, it was decided that the solar panel chosen for the project is the following:

Figure 6: Solar panel

The solar panel chosen has a nominal power of 10W, and a nominal voltage of 17.3V and an open circuit voltage of 22V, so it is a solar panel designed to charge 12V batteries. In addition, it is small in size (33cm long) which makes it perfect for this project, as the boat is only 1 meter long. This reduced size means that if the power demand of the major project increases in the future, up to two more panels like this can be added, meeting the size specifications.

Another factor that adds to the choice of this solar panel as suitable for this project is that, because it will be located on top of the boat while sailing, the solar panel must be designed to resist water splashes, as it can receive water impact while the boat sails to collect the data. This chosen solar panel has IP65 waterproof protection, which makes it perfectly adapted to the working conditions of this component.

This solar panel provides solution for the power system that requires a small number of batteries, since only 3 batteries are needed in series to achieve a total of 12V. In addition, it is a solution with a very reduced cost, as the total cost of this solar panel together with a charge controller is $33.51.

IV. BATTERY PROTECTION SYSTEM

Using a battery pack for an extended period of time and performing multiple charge cycles before being replaced or individually charge the battery cells requires a battery protection system. There are many ways in which this protection system can be designed, but all of them go through controlling battery overcharges and over-discharges, and additionally monitoring temperature and other parameters.

For this system, it was decided that the battery pack should be protected against overcharges and over-discharges. Another objective is to do charge balancing between the different cells that form the battery pack. Temperature will not be monitored, as it does not place a problem for the battery pack in this project, as the boat will be in constant contact with the water and therefore will be cooled at all times.

This battery protection system consists of two components: BMS and Charge Controller, which will be developed below.

1) BMS

STUDY OF THE COMPONENT

The BMS (Battery Management System) is an electronic component that allows to protect and monitor batteries. Currently in the market there are multiple solutions of this type. There is a wide range of prices and system complexities. The BMS makes sure that the batteries are working under safe conditions, avoiding harmful operating points for them. In addition, in some cases they allow to know the state of charge of each cell of the battery pack.

As for the components that we can find in the market, we can differentiate them in 2 types: components that are acquired as an electronic board to which only the batteries have to be connected and components of chip type, which consist of an electronic component that has to be soldered to a PCB together with the pertinent components for a correct connection (which is the one used for this project). As you can guess, the second type is more complex to design, as not only the chip has to be chosen, but also the design the PCB circuit has to be carried out.

The decision of designing the BMS in this second way is due to the fact that a more complete protection system can be achieved at a lower price. BMS that are purchased as an already designed electronic board increase a lot in price if they include the possibility of balancing charge between the cells. With a chip-type component we can perform this action without buying a high-priced component.

DESIGN OF THE COMPONENT

Since the charge controller protects the battery pack as a whole from overcharges and over-discharges, what is sought with the BMS in this project is to be able to monitor each cell, obtaining the state of charge of each one of them in order to detect possible faults in individual cells and also to provide the company with the state of charge of the battery pack. With the goal of increasing the cell protection, another aim for this component is to carry out cell balancing. This will avoid overcharging individual cells in the long term, since, after many charging cycles of a set of batteries in series, some of them get charged more than others, thus creating an imbalance of charges that can cause some to overcharge, and so damage those cells.

For this project, the BMS needs to monitor and balance 3 cells. The BMS chosen is the LTC6810G-2. It has the capacity to monitor up to 7 cells in series and perform charge balancing between them. In addition, it has communication with SPI protocol, which allows not only to program the component communicating it with the microcontroller, but also allows us to send to the microcontroller the data relative to the state of charge of each cell.

Figure 7: BMS

The schematic of the final circuit designed is shown in the second document of this project, entitled Schematics. The batteries will be connected to cells 1-3 in the BMS, as shown in the figure below, where each cylinder represents one cell in the battery pack.

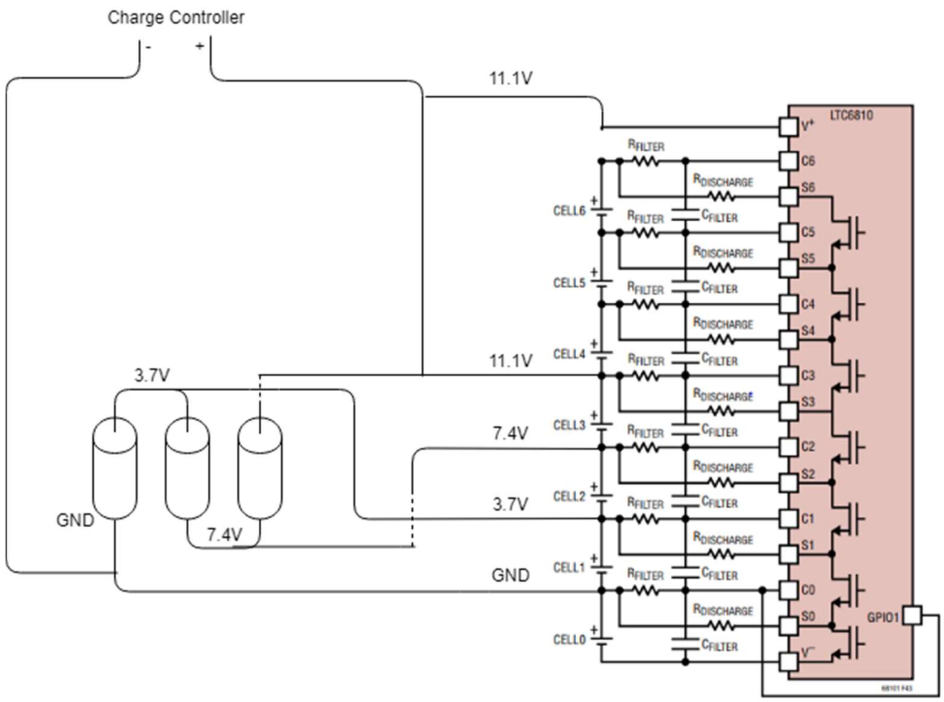

Figure 8: Connection between the battery cells and the BMS

As for the values of the resistors and capacitors necessary to connect the batteries to the BMS, the values (whose calculations are shown in the alculation section of this document) are the following:

R_{filter}= 100Ω C_{filter}=100nF $R_{discharg}$ =37Ω

The functionality of R_{filter} and C_{filte} is to filter the current coming from the batteries, so that the signal at the input of the BMS pins is as clean as possible. As for $R_{discharge}$, its functionality is to make possible the balancing between the cells of the battery pack.

<u>OBTAINING THE SOC AND CONFIGURING THE BMS</u>

The SOC (state of charge) of the batteries, will be obtained by the BMS, which will collect the needed data. This data will be sent to the microcontroller of the major project. In order to do this, we need to connect both components and communicate them through SPI protocol. The connections of these two components can be found on the second document of this project, entitled Schematics. Furthermore, communicating these two components will allow us to configure the BMS through the microcontroller.

The SPI protocol allows us to send this information in a fast and secure way. The coding needed to carry out this communication is provided by the developer of the BMS, and can be found in reference *[6]*. Also, in order for this communication to work, the right connection needs to be done. This means that the MISO, MOSI, SS and SCK of each component may be connected to those of the other component. The functionality of each of these ports is the following:

- MOSI: stands for Master Out Slave In. It allows the microcontroller (which is the master of this communication) to send data to the BMS (which is the slave). Through this port, the microcontroller will configure the BMS and ask this component to send the needed information, which will be sent through the MISO.
- MISO: stands for Master In Slave Out. This port allows the BMS to send data to the microcontroller. The data sent will be the state of charge of the batteries and the state of the BMS, i.e. if it is working properly.
- SCK: this is the clock that both components will follow in order to communicate with the same frequency. This clock is provided by the Microcontroller, and the BMS follows its frequency.
- SS: stands for Slave Select. This port allows to have various slaves connected to one same master in SPI communication. The slave select is activated by the master, and specifies to the slaves who has to receive the message sent and send a response. In this project, only the BMS will be connected to the microcontroller, so no connection is needed for the Slave Select port.

2) CHARGE CONTROLLER

STUDY OF THE COMPONENT

The charge controller is the second and last of the components whose purpose is to protect the batteries. The decision to use this component was based on the idea that it is necessary to have a component that controls the energy flow between the solar panel, the batteries and the load. This component needs to have various functionalities.

First it should, as just mentioned above, create a safe connection between the solar panel and the batteries. The first idea to have in mind is that, when the solar panel provides less power than the one that the batteries have at that moment, it behaves like a load. This means that, when it is not sunny enough, the batteries would lose power through the solar panel, and thus, would run out of charge sooner. The charge controller needs to avoid this, by disconnecting the batteries from the solar panel when this situation occurs, to avoid increasing the power consumption.

Second, it should protect the batteries from overcharging. When it is sunny, the solar panel will charge the batteries. Each Lithium-Ion battery cell can be charged up to 4.2V. If charged more, they will get damaged or even burn. To avoid this situation, the charge controller needs to disconnect the solar panel and the batteries when the latter are fully charged.

Last, this component needs to protect the batteries from over-discharge. Lithium-ion batteries can get damaged if discharged under 3.5V. This situation can shorten their lifetime, and even reduce their capacity in short-term. The charge controller avoids this by disconnecting the batteries and the load when the charge of the batteries is lower than a certain level of charge.

DESIGN OF THE COMPONENT

This component should meet the requirements just mentioned, and also the power specifications of the chosen solar panel and batteries. Having in mind all of these specifications, the chosen component is the CMG-2410, which can be seen in the following Figure:

Figure 9: Charge Controller

This component allows an input of up to 40V, and provides a dc output that allows to properly charge the batteries. It also has an overcharge voltage threshold of 12.6V, which means that disconnects the solar panel from the batteries when the charge of the latter goes beyond that voltage. Furthermore, it has an over-discharge voltage of 10.5V, which means that it disconnects the batteries from the load when the charge of the batteries goes under that voltage.

This charge controller is also equipped with a 5V dc output (the two USB that can be seen in the Figure), and an on/off button and an LCD. The LCD provides information on the voltage of the batteries, the current flowing from the solar panel to the batteries and the current flowing from the batteries to the load. All these information makes the verification of the system easier, as the power tests can be carried out by analyzing the information given by this component.

V. PCB

DESIGN OF THE COMPONENT

The PCB will have various components that will allow us to carry out two different tasks: adapting the power provided by the batteries to the power specifications of the components of the major project to be powered and getting the SOC of the batteries. After carrying out a study of the components that should make up the PCB, it was concluded that the following components are needed:

- BMS: its study and specifications are detailed above.
- Microcontroller: this component will allow us to configure the BMS and to get the information of the SOC of the batteries from it. As for the major project a microcontroller is needed, the same one will be used to carry out this configuration and data gathering. The chosen component is the ATmega328p, which is the same microcontroller used on the Arduino board. For an easier programming of this component, it has not been soldered directly to the PCB. A socket has been soldered instead, so that the microcontroller can be inserted an extracted from the PCB, and inserted into the Arduino board to program it. This reduces the number of components needed in the PCB, as no circuit is needed to program the microcontroller.

- Linear voltage regulators: within the components of the major project that are going to be powered, two types of power requirements can be found: components that require a voltage of 3.3V and those who require a voltage of 5V. This means that two different voltage regulators are needed. These are connected in series, i.e. the 5V one's input is the voltage from the batteries, and to its output the components that require an input of 5V and the 3.3V voltage regulators are connected. By doing this, the input voltage of the 3.3 voltage regulator is 5V, and to its output, the components with a required input of 3.3V will be connected.

When all the components have been chosen, the datasheets of each of them has to be studied in order to design the needed circuit for the correct functioning of each of them. The circuit of the PCB was designed using the EAGLE software. The schematics with the connections of each component are shown in the second document of this project, entitled Schematics.

The final result of the PCB is the following:

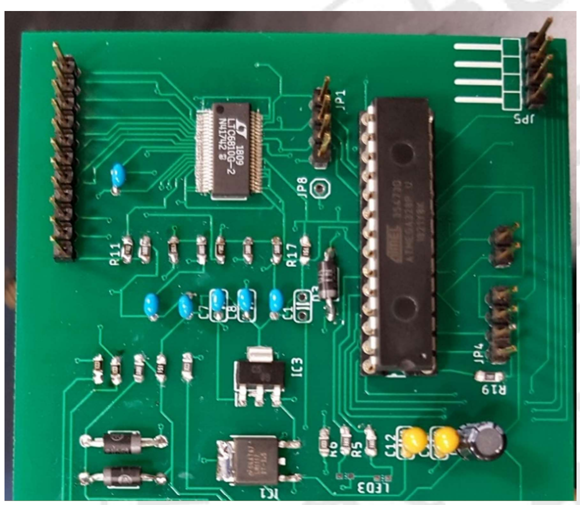

Figure 10: PCB

5. FINAL SYSTEM

A reduced cost, light and small-size power system has been designed, meeting all the specifications that the company had for this project. As it can be seen throughout the document, all of the objectives that were presented in the objectives section of this document have been fulfilled.

The connection between the different components of the system is presented in the block diagram of the final system:

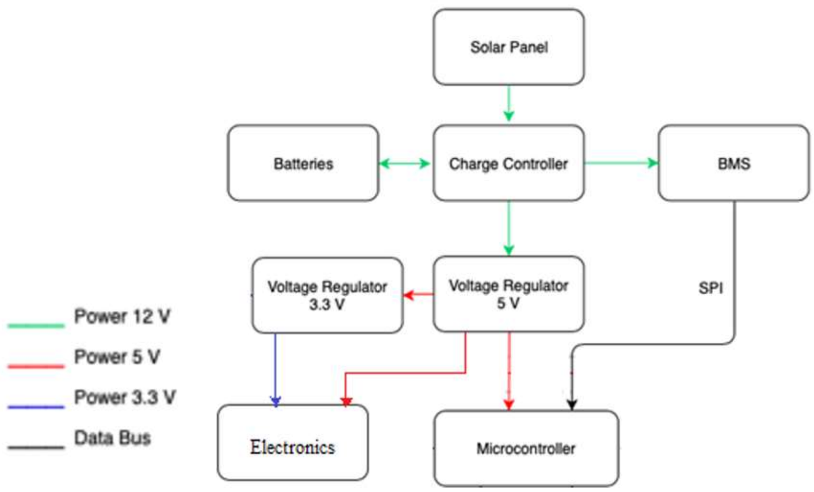

Figure 11: Block Diagram

The final result of the designed system is the following:

Figure 12: Final result

This system can power the electronics of the boat of the major project for at least one day when it is not sunny, and for up to 2 days when sunny. It also allows to charge the batteries using clean energy through the solar panel, so no power is needed from the grid.

Also, the protection systems for the batteries work properly, keeping them safe by making sure that they are working in the right working conditions. The state of charge of each battery cell is sent properly to the microcontroller using SPI communication, and allows the company to know at all times that the batteries are working fine and how much charge they have left.

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2. CALCULATIONS

PART 2: CALCULATIONS

TABLE OF CONTENTS

1. BATTERY PACK'S AND SOLAR PANEL'S POWER

It was tested that the power consumption of the system of the major project that is being powered is 0.4Ah at 12V, which makes a total of:

$$\text{Power consumption} = 0.4Ah*12V = 4.8Wh \quad (1)$$

This means that, the total power that this project's batteries need to supply after a whole day is the following:

$$\text{One day power consumption} = 4.8Wh*24h = 115.2W \quad (2)$$

Knowing this power consumption, we can now calculate the minimum power specifications for the battery pack. For this calculation, we need to have in mind that the company needs the system running for at least one day before getting the boat back to land, and so, that's the minimum time that the battery pack's charge should last.

As the decision on the system's voltage was made to be 12V due to the ease of finding cheaper solar panels and charge controllers that meet the specifications of the project, we can now calculate with the results in equation (2) and this 12V the capacity that the batteries need to have:

$$\text{Minimum capacity} = \frac{115.2Wh}{12V} = 9.6Ah \quad (3)$$

This is the minimum capacity that the batteries should have in order to meet the specifications of the company. After looking into components on the internet, 11Ah batteries were found, and thought to be the right ones for this project. With this battery capacity, we can now calculate the power that the battery pack has:

$$\text{Power} = 12V*11Ah = 132W \quad (4)$$

With the result in equation (4) and equation 1, the time that the batteries can power the load before running out of charge can be calculated as follows:

$$\text{Time before charging} = \frac{132}{4.8Wh} = 27.5h = 1 \text{ day and } 3.5h \quad (5)$$

As we can see, the chosen batteries meet the specifications of minimum power specified by the Collaborating Institution for this project.

The next step is to calculate the power that the solar panel can provide to the system. As the company stated, a good specification for the solar panel would be to add 8 more hours of power a day to the system when the weather is favorable, i.e. when it is fully sunny for the whole day. In order to add those extra hours of power per day, the solar panel needs to provide the following power to the batteries:

$$\text{Power for 8 hours} = 4.8\text{Wh}*8\text{h} = 38.4\text{W} \quad (6)$$

Knowing this power rating, we fall into the calculations of the total power needed for the solar panel. The solar panel will provide full power when it is fully sunny. Assuming that there are 5 hours of full sun on average per day, the power rating of the solar panel needs to be at least the following:

$$\text{Solar panel's power} = \frac{38.4W}{5h} = 7.68\text{Wh} \quad (7)$$

This means that the solar panel needs to have at least a power of 7.68W in order to meet the specifications. The solar panel that was finally used for the project has a total power of 10W, so it fulfills the requirement.

As a last power calculation, let's obtain the number of hours of power that the solar panel can provide during a day when it is fully sunny:

$$\text{Powering time} = \frac{10W*5h}{4.8Wh} = 10.42\text{h} \quad (8)$$

As we can see from the result of this equation, after a sunny day, the solar panel will provide the batteries enough energy to power the system for almost 10 and a half more hours. The solar panel is a crucial component of this system, as it will provide almost half of the power needed in one day if the day if sunny, and so, increase a lot the power rating of the system.

One way in which the power consumption of the system could be reduced is getting a charge controller with no screen. Despite that, this screen was very useful for this project as it showed in an easy manner that the system worked as expected and so, made the testing a lot easier.

2. BMS's RESISTORS AND CAPACITORS

As stated earlier in this document, the BMS is the component in charge of balancing the charge between the different cells that form the battery pack. In order to complete that task, it needs some resistors and capacitors at the input from the batteries, to adapt the power getting into it and filter that power and which can be seen in Figure 8.

Three components are to be calculated: the discharge resistor, the filter resistor and the filter capacitor. As stated in the datasheet of this component *[6]*, the filter capacitor and the filter resistor should have the following values:

$R_{filter} = 100\ \Omega$ $C_{filter} = 10\ \text{nF}$

Also, in the same datasheet on reference *[6]*, the following formula are found to obtain the value of the discharge resistor:

$$Balance\ Current = \frac{\%SOC_{Imbalance} * Battery\ Capacity}{Number\ of\ hours\ to\ balance} \quad (9)$$

$$Discharge\ Resistor = \frac{Nominal\ Cell\ Voltage}{Balance\ Current} \quad (10)$$

Let's use equation 9 to calculate the balance current. The first thing to have in mind is that this current should not be over 150mA, as this would produce a big amount of heat in the BMS, which can damage the component.

$$Balance\ Current = \frac{5\% * 11Ah}{5h} = 110\ mA \quad (11)$$

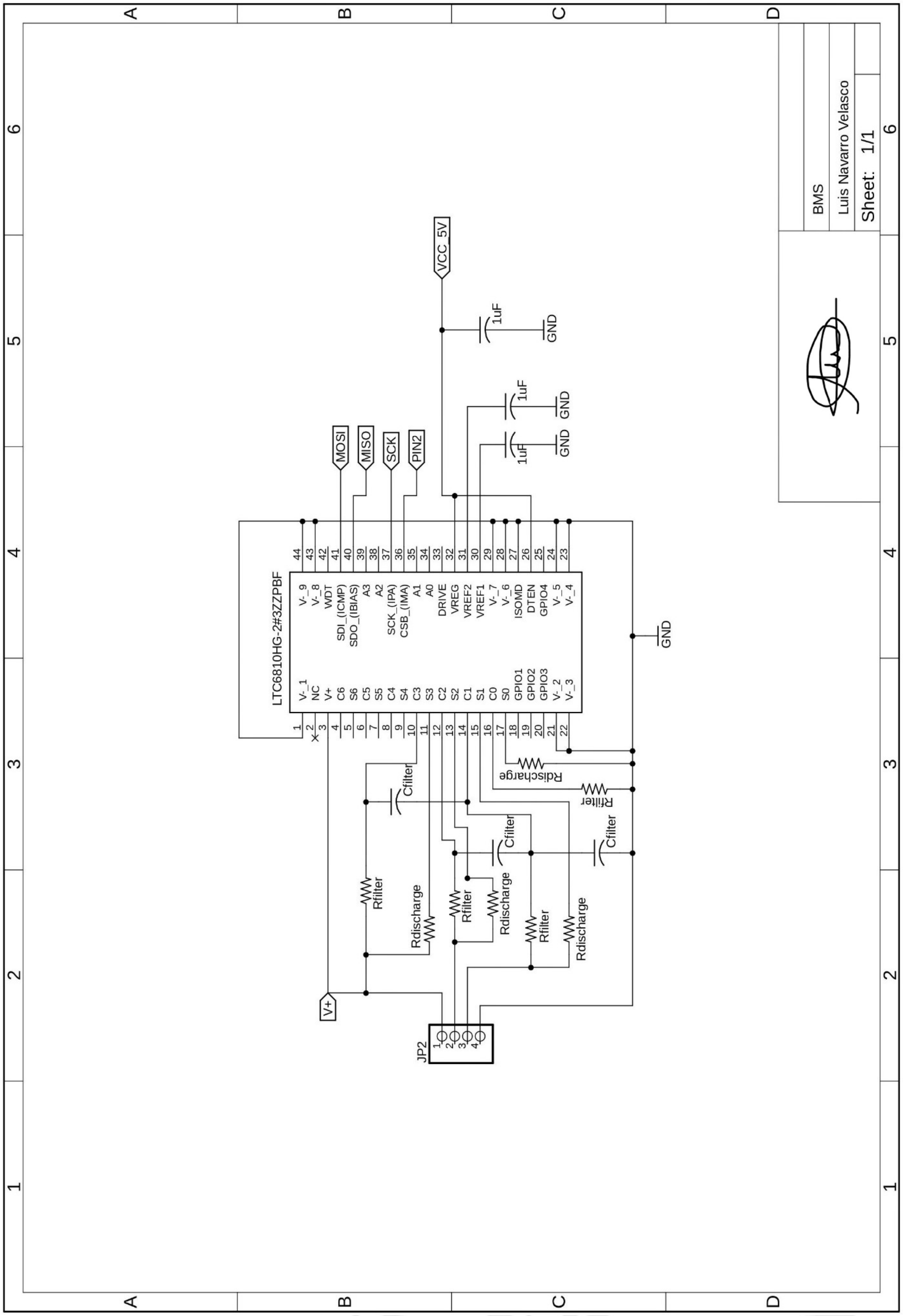
This value of balance current is safe, as it is not higher than the specified 150mA. This would mean that with the 11Ah batteries in this project, the BMS will be able to balance an imbalance of 5%, i.e. will be able to equalize the charge between two batteries when the difference between them is equal to 5% of their total charge, in 5 hours' time. The final step is to obtain the value of the discharge resistor, using equation (10) and the result in equation (11):

$$Discharge\ Resistor = \frac{3.7V}{0.110A} = 33.63\ \Omega$$

DOCUMENT II: SCHEMATICS

DOCUMENT II: SCHEMATICS

TABLE OF CONTENTS



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Luis Navarro Velasco
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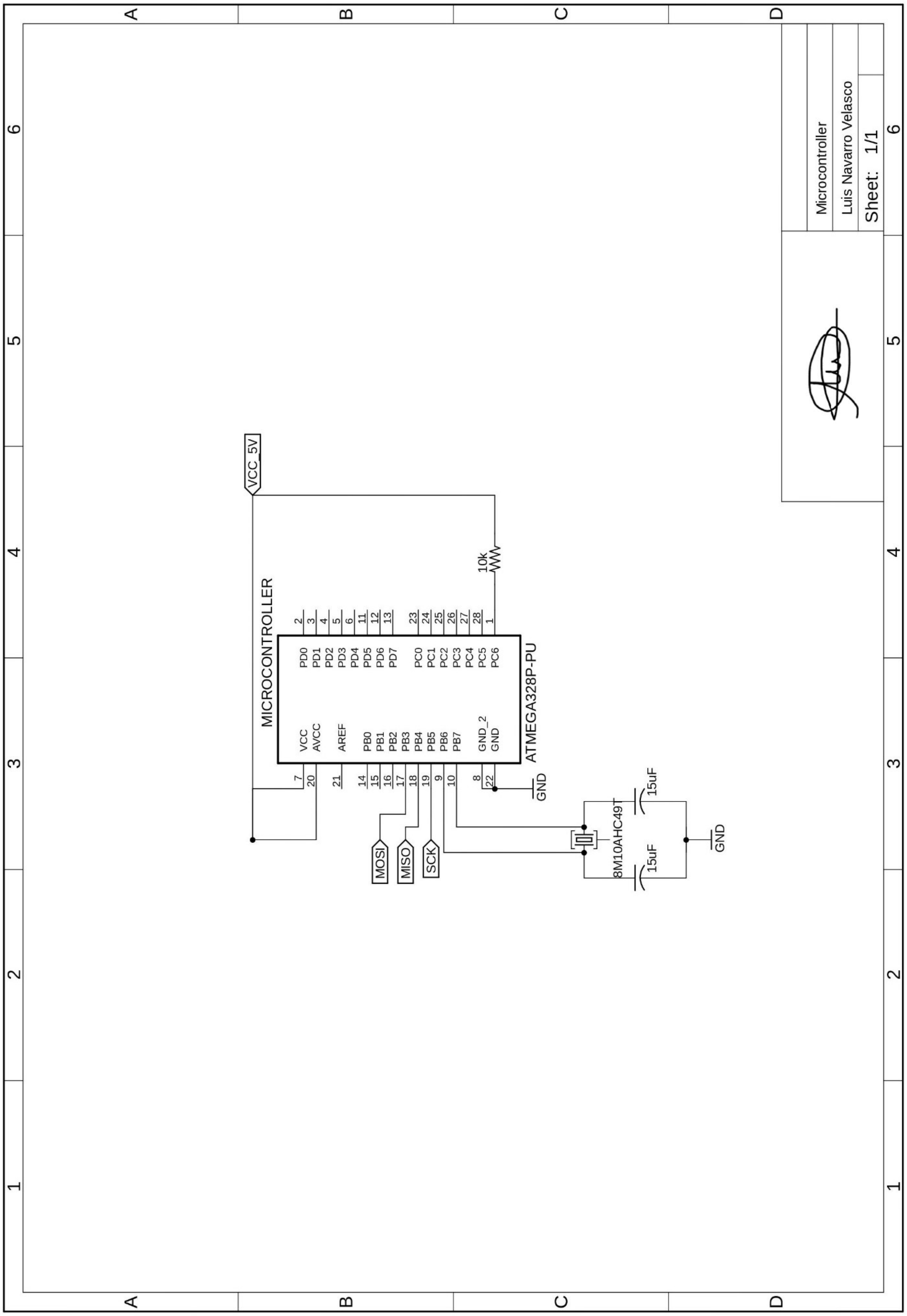
MISO
SCK
PIN2
GND
1uF
Cfilter
Rfilter
Rdischarge
JP2
V+



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10k
VCC
AVCC
AREF
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PB1
PB2
PB3
PB4
PB5
PB6
PB7
GND_2
GND
PD0
PD1
PD2
PD3
PD4
PD5
PD6
PD7
PC0
PC1
PC2
PC3
PC4
PC5
PC6
MOSI
MISO
SCK
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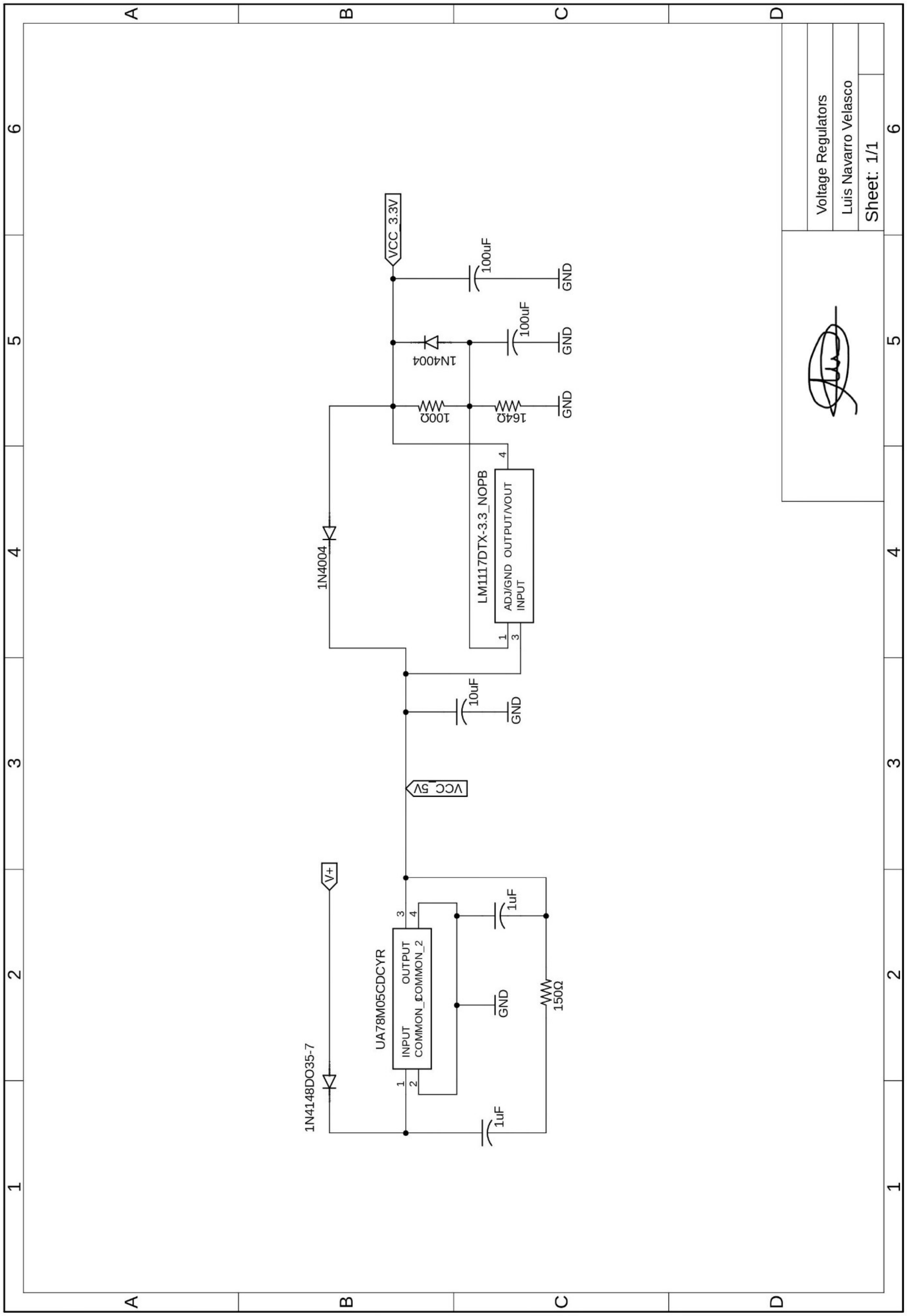
GND
Microcontroller
Luis Navarro Velasco
Sheet: 1/1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ADJ/GND
INPUT
OUTPUT/VOUT
1N4004
10uF
GND
VCC_5V
V+
UA78M05CDCYR
INPUT
COMMON_1
OUTPUT
COMMON_2
1uF
GND
150Ω
1N4148DO35-7
1uF
Voltage Regulators
Luis Navarro Velasco
Sheet: 1/1

DOCUMENT III: BUDGET

DOCUMENT III: BUDGET

TABLE OF CONTENTS

1. INTRODUCTION

Cost is always one of the main variables to take into account when developing a project. A good balance between cost and quality is what every project tries to achieve. Those projects in which this balance is optimize, are the ones that will produce the maximum profit.

In this document, the budget of the project will be presented. All of the components in this project have been bought online, so the prices are the ones corresponding to each component at the time when they were bought, and are shown in dollars, which is the currency used to pay those components. No labour cost will be shown for this part. In the section entitled References, the webpage where each component was bought is specified.

2. BUDGET

The cost of each component is shown in the following table:

Component	**Part number**	**Quantity**	**Cost**
BMS	LTC6810HG-2	1	$16.04
Microcontroller	ATMEGA328P-PU-ND	1	$1.24
Solar Panel and Charge controller	b) ECO-WORTHY 10w c) CMG-2410	1	$33.66
Batteries	18650 11Ah 3.7V Li-Ion	8	$11.83
Battery holder	3-Slot 3.7V 18650 Battery storage box	4	$6.99
5V voltage regulator	UA78M05CDCYR	1	$0.65
3.3V voltage regulator	LM1117DTX-3.3/NOPB	1	$1.48
Resistors and capacitors	-	-	$4.15
Diodes	1N4148WT	1	$0.174
Total			**$76.21**

Table 1: Cost

Note: the cost of the PCB is not included in the list of components, as the same PCB would be used for this project and for the major project, so it would add no additional cost to the major project. If this component wants to be included for the total cost, it would add up 22$ to the final price (including delivery costs).

Note: the delivery cost has not been included in the price of the BMS, the microcontroller, the diodes, the capacitors nor the resistors, as these costs depend on where the components are sent and how fast they need to be delivered.

3. REFERENCES

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