



ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA
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GRADO EN INGENIERIA ELECTROMECAÁNICA,
ESPECIALIDAD ELÉCTRICA

SMART MANAGEMENT OF INDIVIDUAL BATTERIES

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MADRID
JUNIO 2016

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Fdo Jaime Gayá Fuertes

SMART MANAGEMENT OF INDIVIDUAL BATTERIES

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Entidad Colaboradora: University of Illinois at Urbana-Champaign.

RESUMEN DEL PROYECTO

INTRODUCCIÓN

La tecnología se está desarrollando de forma mucho más rápida que en los siglos pasados, lo que supone un aumento del consumo energético en todo el mundo y la búsqueda de patrones que permitan una mayor eficiencia y sostenibilidad. Una de las soluciones a este problema supone el desarrollo de energías renovables. Esta solución conlleva unos problemas como son una fuente de energía intermitente, con producción de energía en momentos no deseados (los picos de producción de energía eólica se suelen dar por la noche) por lo que impide una dependencia de solo energías no convencionales. Una de las soluciones a este problema supone el almacenamiento de energía en baterías para poder llevarla a los picos de consumo. Este sistema es caro y poco eficiente, pero el desarrollo de nuevas baterías como la de ion de litio llevado a una escala de uso particular puede solucionar este problema.

El proyecto consiste en una idea para fomentar este tipo de baterías particulares que supone una inversión relativamente pequeña para el consumidor pero que permite infinidad de ventajas, tanto para él como para el desarrollo de red eléctrica a la que permitirá estar más adaptada a los nuevos tiempos. Esta idea consiste en el desarrollo de un software que supone la creación de un app para que el cliente disponga de la información relativa al consumo eléctrico en su casa y pueda comprar o vender energía de forma automatizada o a libre elección de usuario. También supone el desarrollo de un hardware que reconstruirá el escenario a pequeña escala para permitir transacciones entre baterías particulares y con la red para probar la efectividad de la medida.

METODOLOGÍA

Para alcanzar los objetivos propuestos se siguió los siguientes procedimientos:

- Diseño de desarrollo de un hardware donde el objetivo es simular un escenario real llevado a pequeña escala donde distintos usuarios podrían interactuar con el mercado. Para ello se diseño y construyó la conexión entre distintas baterías de ion de litio mediante distintas herramientas usadas en la electrónico de potencia como boost converter o buck converter (para minimizar perdidas en el intercambio energético al elevar la tensión en el proceso de intercambio). Además también se desarrolló un rectificador para conectar las baterías con la red. Finalmente se diseñó y construyo un cargador de batería usando circuitos integrados.
- Diseño de una aplicación web donde el usuario tenga información accesible del mercado energético de una forma fácil de entender. Esta aplicación contiene información del precio de la energía eléctrica en tiempo real, el precio máximo estimado del día y el mínimo, así el consumo medio de la vivienda por día. También dispone información de de la batería para que cada usuario pueda determinar de cuanta autonomía dispone y el precio al que ha acumulado dicha energía. Finalmente también hay un apartado donde permite al consumidor automatizar un proceso de carga para comprar la energía al menor precio posible (esto es en horas valles) y cargar el coche eléctrico (si se dispone de él) de la misma forma. En esta aplicación no solo se regula el proceso de compra sino también de venta energética si se dispone de módulos de producción de energía (como por ejemplo paneles solares). Esta energía se puede automatizar para venderla en momentos picos donde la energía adquiere un valor máximo.
- La conexión entre la aplicación y el hardware se realiza a través de arduino que se encarga de encender/apagar relés para iniciar el flujo de energía el tiempo estimado hasta finalizar la transacción.

RESULTADOS

El diseño se llevó a cabo mediante el diseño de PCBs realizadas en Eagle y simulados en LTSpiceIV para el hardware y para el software se usó como lenguaje de programación CSS, HTML Y PHP. Se construyeron en total 3 módulos (un rectificador, un boost converter y un buck converter) y para la batería se utilizó 3 baterías 18650 de 3.7 V cada una con una capacidad máxima de 3200 mAh de química ion de litio. La lectura de las magnitudes de la batería (tensión, capacidad, corriente, temperatura) fue llevada a cabo mediante el lector de baterías BQ34Z100-EVM. Las conexiones con el software se llevaron a cabo mediante la Wifi shield de Arduino donde se interactuaba tanto para enviar información a la web como se adquiría información para empezar las transacciones en el mundo físico

El sistema era capaz de cargar energía de la red cuando era requerido pero siempre con las condiciones de seguridad pertinentes al tratarse de una batería relativamente peligrosa en el proceso de carga y descarga y esta a su vez era capaz de transmitir la energía a otro módulo.

El coste total del proyecto fue de \$205,11 excluyendo las PCB que fueron cortesía de Electrical and Computer engineering Lab, perteneciente a University of Illinois at Urbana Champaign.

El proyecto era una prueba de concepto, no una herramienta de uso real, debido a las magnitudes que tendría en el mundo real (baterías de entorno \$3000-\$3500 y unas dimensiones de 1302 mm x 862 mm x 183 mm). Sin embargo si es extrapolable al mundo real, ya que el sistema de control simplemente abría que sobredimensionarlo para manejar la potencia adecuada. En este proyecto, para acercarlo más a la realidad, los factores leídos por la batería se multiplican por una constante para acérca los a las lecturas que se leerían en un sistema de tamaño real.

CONCLUSIONES

Aunque el sistema no pudo ser terminado, si se pudo hacer unas primeras aproximaciones y se pudieron manejar los módulos diseñados en el hardware, así como una total implantación de la aplicación, pero con una competitividad ajustada del módulo de arduino al pasar las lecturas del Wifi a la aplicación. Una de las razones de ello fue la alta interferencia de aparatos electrónicos que nos encontramos en el laboratorio y la

dificultad de los protocolos de actuación del Wifi Shield. Por ello hubiera podido ser más aconsejable utilizar el módulo Ethernet en vez del Wifi.

A pesar de ello consideramos que es una herramienta de gran aplicación en países donde el autoconsumo y este tipo de utilidades está permitida (En algunos países de la Unión Europea en la actualidad legal estos sistemas).

La implantación de estas tecnologías en hogares particulares puede suponer el éxito de distintas estrategias de eficiencia energética que se han llevado en el pasado pero que no han tenido éxito, como son el *valley filling* y el *load shifting*. Además supondría una disminución de inversión pública en el desarrollo de las Smart Grid al fomentar el desarrollo de sistemas de almacenamiento energético por capital privado y una mayor intervención de la gente y de la conciencia popular en el siguiente paso de desarrollo energético. Este se puede ver acentuado con el desarrollo del coche eléctrico, elemento también observado en este proyecto.

SMART MANAGEMENT OF INDIVIDUAL BATTERIES

ABSTRACT

INTRODUCTION

The technology is developing much faster than in past centuries, representing an increase of energy consumption worldwide and search for patterns that allow greater efficiency and sustainability. One solution to this problem involves the development of renewable energy. This solution involves some problems such as an intermittent source of energy, with energy production in unwanted moments (peak wind energy production often occur at night) so prevents dependence on non-conventional energy only. One solution to this problem involves storing energy in batteries to carry it consumption peaks. This system is expensive and inefficient, but the development of new batteries such as lithium ion carried a scale of particular use can solve this problem.

This project is an idea to encourage this type of individual batteries which is a relatively small investment for consumers but allows plenty of advantages, both for himself and for the development of the future electric network that will allow to be more adapted to the new times. This idea leads the development of a software that involves creating an app for the customer so they can have information related to the electricity consumption at home and where they can buy or sell energy in an automatic or manual mode. It also involves the development of a hardware that will rebuild the stage to allow small-scale transactions between batteries and the network to test the effectiveness of the idea.

METHODOLOGY

To achieve these objectives, the following procedures are followed:

- Design and develop a hardware where the goal is to simulate a real scenario led a small scale where different users might interact with the market. For this purpose, designed and built the connection between different lithium-ion batteries using various tools used in electronic power as boost converter or buck converter (to minimize losses in the energy exchange by stepping-up tension in the exchange

process). In addition, a rectifier was also developed to connect the batteries to the network. Finally, it was designed and built a battery charger using integrated circuits.

- Design a web application where the user has the energy market information accessible in an easy way to understand. This application contains information of the price of electricity in real time, the estimated maximum price and minimum price and the average consumption of housing per day. It also has the battery information so each user can determine how much autonomy has and the price at which the energy in their batteries has been accumulated. Finally, there is also a section which allows the consumer to automate a charging process to buy energy at the lowest possible price (this is in hours' valleys) and load the electric car (if available) in the same way. This application not only allow the buying process but also the sale of energy is regulated if there are available modules of production of energy (such as solar panels). This energy can be automated to be sold at peak times when energy prices takes a maximum value.
- The connection between the application and the hardware is done through Arduino that is responsible for turning on / off relays to start the flow of energy the estimated time to complete the transaction

RESULTS

The design was done by designing PCBs made in Eagle and simulated in LTSpice for the hardware, and for the software was used as programming languages: CSS, HTML and PHP. It was built in total 3 modules (rectifier, a boost converter and buck converter) and for the battery was used 3 modules of 18650 Battery, 3.7 V each with a maximum capacity of 3200 mAh of lithium ion chemistry. For reading the magnitudes of the battery (voltage, capacity, current, temperature) it was carried out by the battery reader BQ34Z100-EVM. Connections to the software were carried out by Arduino Wi-Fi shield, which interacted both to send information to the web as well as acquired information from the user interface to interact with the physical world.

The system was capable of charging power from the grid when it was required but always with the proper safety conditions as li-ion chemistry is a relatively dangerous battery in the process of loading and unloading, and this in turn was able to transmit power to another module.

The total project cost was \$205,11, excluding PCBs that were courtesy of Electrical and Computer Engineering Lab, part of University of Illinois at Urbana Champaign.

The project was a proof of concept, not a tool of actual use, due to the magnitude that would have in the real world (batteries will cost around \$ 3000- \$ 3500 with dimensions of 862 mm x 1302 mm x 183 mm). However, it is extrapolated to the real world, as the control system that just opened oversized adequate power to handle. In this project, to bring it closer to reality, factors read by the batteries are multiplied by a constant to move them to the readings that would have be read in a system of actual size.

CONCLUSIONS

Although the system could not be finished, it was done the first approximations and it could handle the modules designed in hardware, as well as full implementation of the application, but with a tight competitiveness module Arduino passing readings Wife the application. One reason for this was the high interference of electronic devices that were in the laboratory and the difficulty of the protocols of wireless Shield. Therefore, it would have been more advisable to use the Ethernet module instead of the Wi-Fi shield.

Nevertheless, we consider it a tool widely used in countries where consumption and this type of utilities is permitted (In some countries of the European Union these systems are not legal right now).

The implementation of these technologies in private households can mean the success of different energy efficiency strategies that have been carried out in the past but have not been successful, such as the valley filling and load shifting. In addition, it would be a decline of public investment in the development of Smart Grid to promote the development of energy storage systems of private capital and a greater involvement of people and the popular consciousness in the next step of energy development. This can be seen accentuated with the development of the electric car, also observed element in this project.



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1.INTRODUCTION

1.1 AIM OF THE PROJECT

The technology is developing much faster than in past centuries, representing an increase of energy consumption worldwide and search for patterns that allow greater efficiency and sustainability. One solution to this problem involves the development of renewable energy. This solution involves some problems such as an intermittent source of energy, with energy production in unwanted moments (peak wind energy production often occur at night) so prevents dependence on non-conventional energy only. One solution to this problem involves storing energy in batteries to carry it consumption peaks. This system is expensive and inefficient, but the development of new batteries such as lithium ion carried a scale of particular use can solve this problem.

This project is an idea to encourage this type of individual batteries which is a relatively small investment for consumers but allows plenty of advantages, both for himself and for the development of the future electric network that will allow to be more adapted to the new times. This idea leads the development of a software that involves creating an app for the customer so they can have information related to the electricity consumption at home and where they can buy or sell energy in an automatic or manual mode. It also involves the development of a hardware that will rebuild the stage to allow small-scale transactions between batteries and the network to test the effectiveness of the idea.

This project is a possibly alternative to the current energy trade market in the world, and aims towards achieving consumer-level trade of energy within a network of batteries. The battery devised allows a user to see the energy utilization and remaining battery charge, and project the information to a cloud- based energy market system. This cloud system allows different users connected within a grid of batteries to buy or sell energy depending on their future energy requirements. Our system successfully establishes this trade between two different batteries depending on the user's requirements. There continues to

be room for improvement by establishing this energy trade system between a larger network of batteries.

1.2 STATEMENT OF PURPOSE

The energy market today is a very oligopolistic one in the sense that a few suppliers completely dominate the market. The current power structure requires consumers to tap energy from a central grid directly without being able to track their own energy consumptions. As a result, most consumers are unable to foresee their energy expenditure as they are usually billed after consumption.

Our project aims at providing the proof of concept of a central energy system where energy can be traded freely in the market between different consumers. This is achieved with the use of a battery connected to each household to provide a detailed breakdown of the amount of energy being used up within each local household. This system will store all details on a cloud-based server thereby allowing numerous users to exchange information and data about their energy demands and supply in a convenient and user-friendly manner. As a proof of concept, our system would include 3-4 batteries connected together in a grid. The user will be able to interact with the smart- box through a web-based user interface environment to buy or sell (transfer) energy within the network of batteries.

1.3 OBJECTIVES

The objectives, goals and features of the project are summarized in the following points:

1.3.1 Goals and benefits

- Model the idea of a renewable energy society.
- Enable consumer level energy trade within the market.
- Peak shifting of the energy in the electric market.
- More efficient way of energy utilization.

- Economical solution to the current energy trade market.
- Real time energy and cost analysis.

1.3.2 Functions and features

- Real time tracking of battery capacity and power consumption.
- Transfer energy flexibly within a network of batteries.
- Central cloud system - graphical analysis of current energy usage.
- User interface for projecting energy demand and supply.

1.4 TOOLS

For this project different tools and softwares were used. For simulating all the circuits, it was used LTspiceIV, [1] a free software from Linear Technology which allow us a lot of flexibility for implantation and simulation of almost any scenario. Also it was chosen because Linear Technology give us the opportunity to request free samples reducing the overall price of the project.

The microcontroller was Arduino MEGA, which was connected with a Wi-Fi Shield for connecting the Arduino with the user interface and Internet. The reasons of choosing it was for the wide number of outputs, the good relationship of cost-benefits, the use of the shield, which works better with a Mega rather than an Arduino Uno and a wider frequency range in case we want to control the converters.

For designing the software, which consists in an online app, the language used was HTML for the main user interface page, CSS for the design of the pages and PHP for interact both with Internet and Arduino.

2. DESIGN

Our Project was divided in two main entities, as shown in the block diagram below. A hardware which consists on a battery and some converters, and a software, which main parts are a user interface, a database server, a market data and a computing algorithm. In the figure below is explained the connections between all the modules.

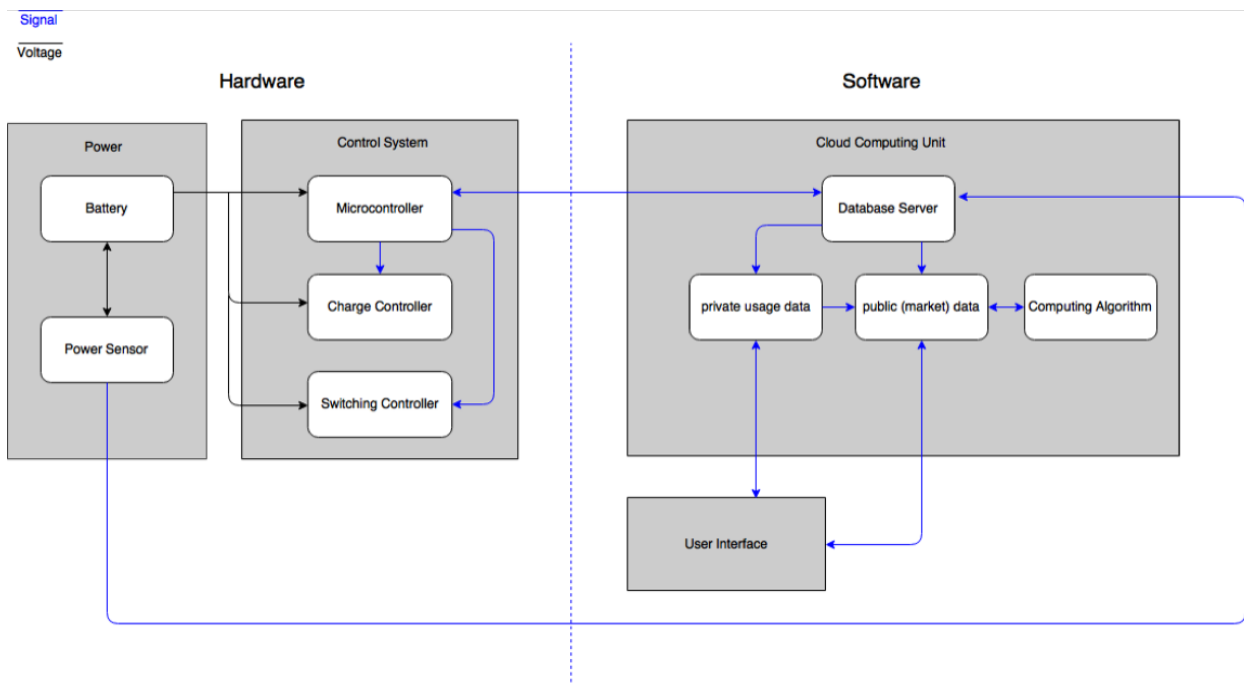


Figure 1. High-level block diagram

2.1 HARDWARE

The following pages show the hardware part and the connections between the grid and the batteries and within the batteries.

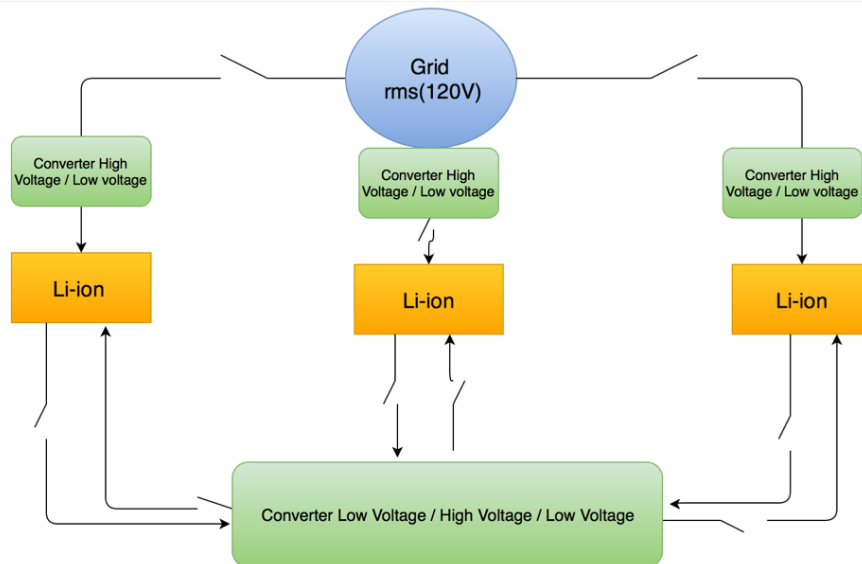


Figure 2. Power system Process Flow

2.1.1 Rectifier

This component converts the voltage and the current from an AC wave to DC. The input signal will be transform to low voltage through a transformer. This component will have some a full wave rectifier, made by the diode bridge. The full wave rectifier works as follows:

When the AC wave has a positive value, D1 and D2 conduct current (short-circuit with a small voltage drop). In the same way, if the input signal has a negative value, D3 and D4 will be 'activate'.

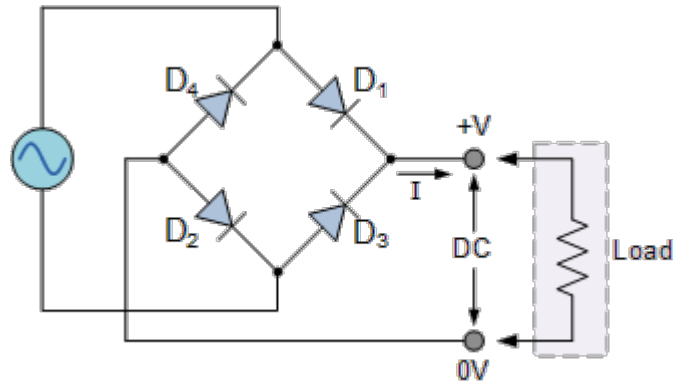


Figure 3. Full bridge rectifier (Electronics Tutorial, 2016)

After this step the wave will be positive, but it won't be a DC wave. A capacitor used in the output of the diodes bridge will filter and will ensure as a dc value on the load.

The rectifier connects the battery charger and the grid. The input is a sine signal and the output is a dc signal with a small ripple. The output signal has the requirements of the input signal for the battery charger (for more information see the Battery Charger section (2.1.2)). It is responsible for converting 120 V RMS AC voltage into 14 V.

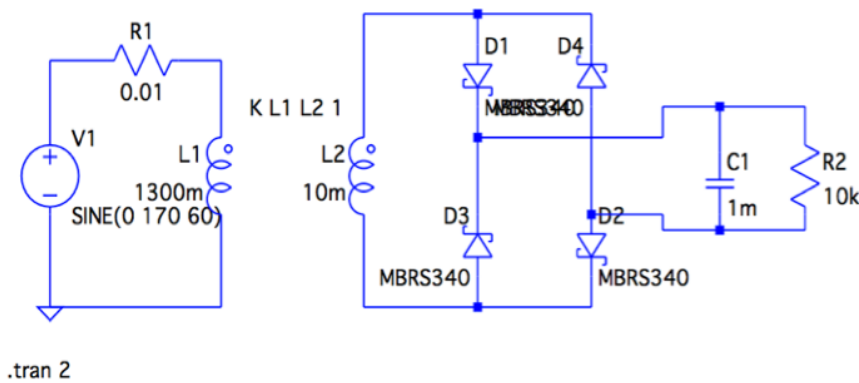


Figure 4. Rectifier

The following equations are the basics for the design of the Rectifier:

$$V_{in} = 120 \text{ V (rms)} \quad \& \quad V_{out} = 14 \text{ +/ - } 1\text{V} \quad (1)$$

$$\text{Transformation ratio} = \frac{N1}{N2} = \frac{120 * \sqrt{2}}{14} \approx 12 \quad (2)$$

The transformer must deal with at least 7 A (peak value of the input current) and finally was chosen a transformer with a transformation ratio of 10, due to the difficulty of find a transformer with the desirable transformation ratio. Also it is desirable to step up the output voltage for an offset produce for the battery charger voltage drop that it wasn't consider in equation (1) and equation (2). More information about this will be explained in the following point.

The transformer was a Mouser transformer¹ with the following characteristics:

Input Voltage (VAC)	100, 120, 220, 240
Frequency (Hz)	50, 60
Series Output (VAC)	24 @ 4.17 A
Parallel Output	12 V @ 8.33 A

Table 1. Transformer characteristics.



Figure 6. Photo of the transformer



Figure 5. Transformer connections

The connection will be in parallel that allows us the desire voltage with our current below the maximum level of the transformer.

¹ The table 1 only shows the basic information about the transformer, for further information see the next references [2].

2.1.2 Battery Charger

This project uses an integrated circuit as a battery charger. The chip chosen was LT 1513 [3] from Linear Technology because it can provide more than 1 A at 14 volts and the max input voltage is 30 V. Furthermore, it can charge more than 1 cell (it is going to be used for up to 3) and it has a really good voltage accuracy for rechargeable lithium batteries.

The figure 7, designed in LTspiceIV, shows the battery charger circuit with most of the connections. The output voltage of the Rectifier will be connected to Vin and the Pin SHDN² wouldn't be connected for this specific situation. The output is voltage source which represents the behavior of the battery.

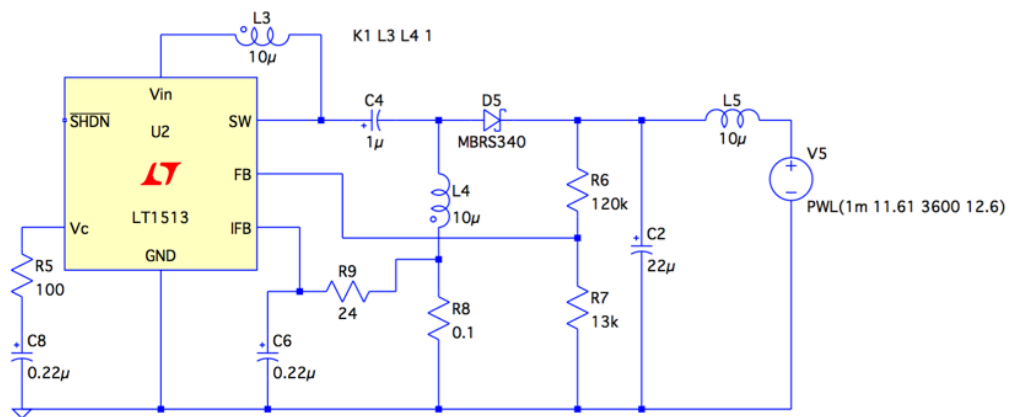


Figure 7. Battery charger Circuit

² This pin can be used for shutdown and/or synchronization. It defaults to a high ON state when floated.

The following calculations show how the main part of the circuit was calculated. The input signal is around 14-15 V and came from the rectifier. This value sets the max current to around 1.15 A, as it is shown in the figure 8.

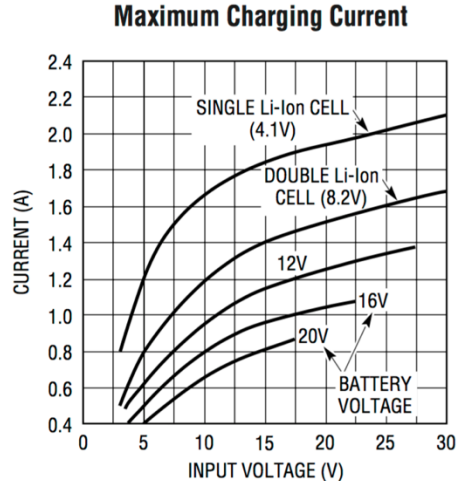


Figure 8. Current-Voltage Relationship

The output voltage is controlled by a divide resistor (R_6 & R_7). The equations are given in the following lines:

$$V_{battery} < V_{out} \text{ and } V_{battery} \leq 12.6 V \rightarrow$$

$$\rightarrow V_{out} \text{ will be designed for a value of } 12.8 V$$

The output voltage is determined by the following equation:

$$R_6 = \frac{R_7 * (V_{battery} - 1.245)}{1.245 + R_2 * 0.3\mu A} \quad (3)$$

For a proper use of the IC, the value of the input voltage might be bigger than the battery voltage:

$$V_{battery} < V_{out} \text{ and } V_{battery} \leq 12.6 V$$

If the battery is discharge, the voltage will be 9 V whereas while it is full charged the value will be 12.6 V

$$\text{If } V_{battery} = 12.6 V \rightarrow R_6 = 112.75 K\Omega \quad (4)$$

$$\text{If } V_{battery} = 9 V \rightarrow R_6 = 77 K\Omega \quad (5)$$

$$R_6 = 120 K\Omega > 112.75 K\Omega \quad (6)$$

The resistor chosen had a value of $120\text{ K}\Omega$, which fits all the requirements and ensure as the output voltage could be 12.8 V at any moment.

The following figures show the theoretical values of the voltage and the current of both the rectifier and the battery charger when they are connected. The simulations were carried out by LTspiceIV.

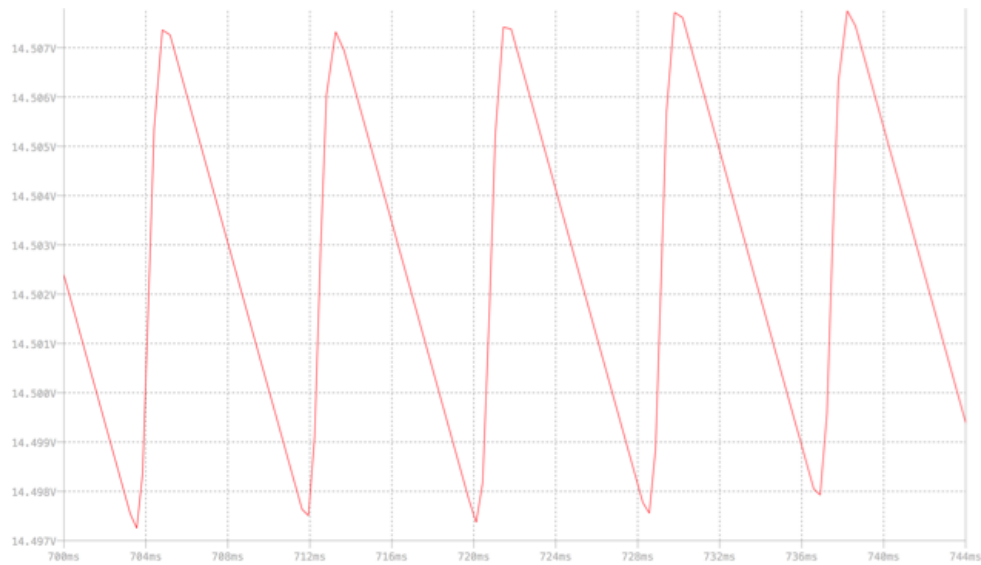


Figure 9. Input voltage into the battery charger (Output voltage of the rectifier)

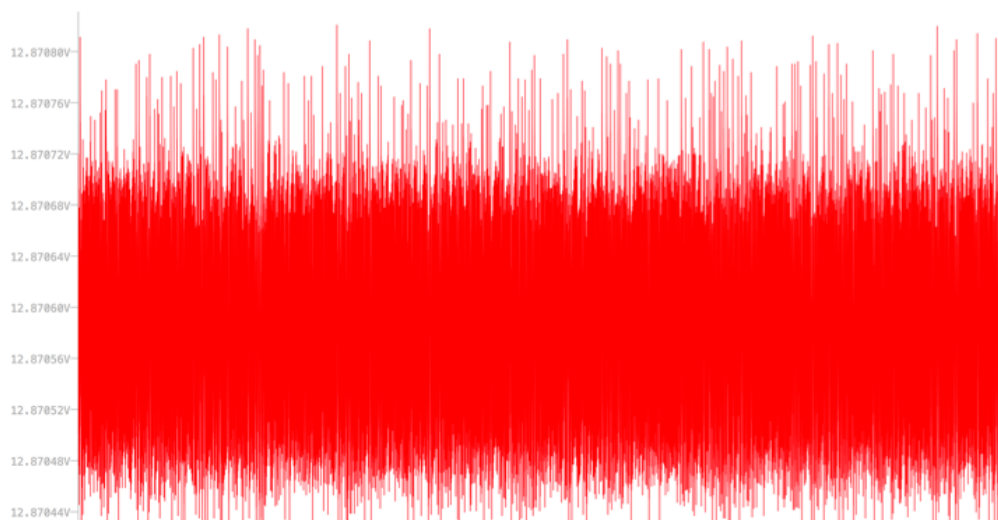


Figure 10. Output voltage of the battery charger (vacuum test)

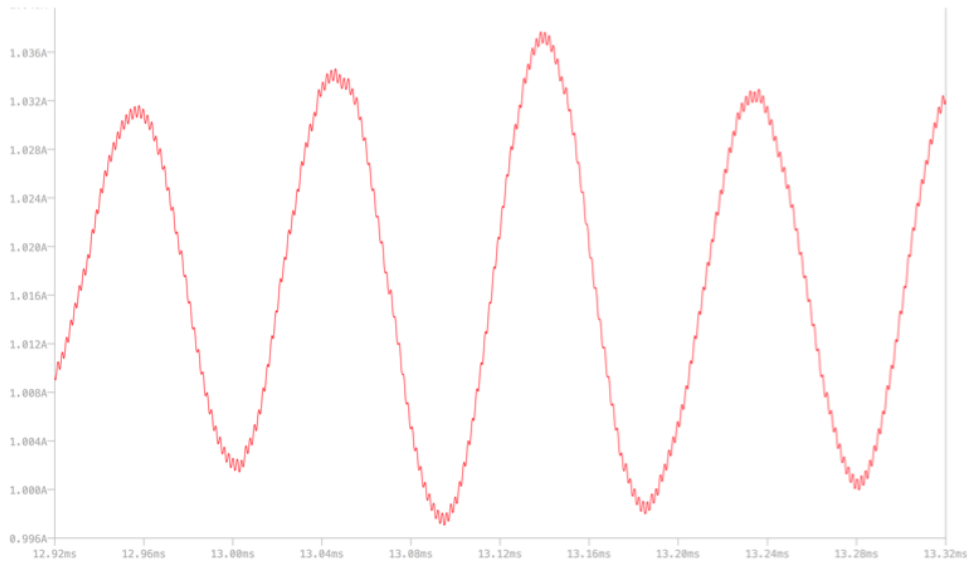


Figure 11. Output current of the battery charger (when a battery is connected)

As it can be shown, in Figure 8 the output voltage is above 12.6 Volts. The IC will control the input voltage at every moment into the batteries within a value between 9 Volts and 12.6 Volts. This system is designed to avoid any values more than 12.8 Volts for safety issues. See battery section for further information.

2.1.3 Boost converter

This Component connect two different DC voltage, where $V_2 > V_1$. It will step up the voltage and step down the current. The functioning of the converter is based in storing energy in the inductor in two different steps [WART]:

- 1.Switch is on (diode will switch off): the current goes through the inductor and the energy stored in it will increase.
- 2.Switch is off (diode will turn on): The inductor and the power source will be in charge of providing the circuit the needed current.

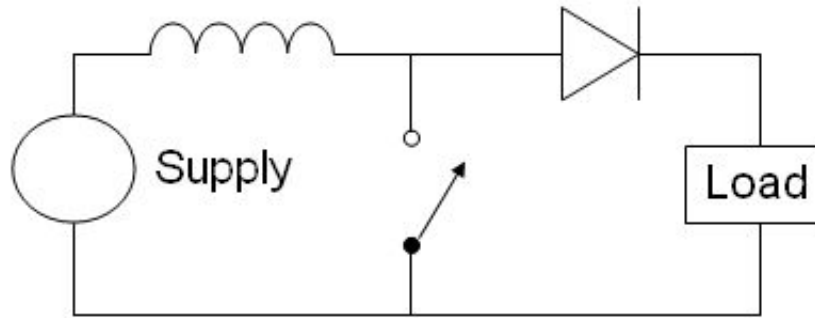


Figure 12. Boost Converter (Wikipedia, 2012)

This element is used for connecting the batteries. As the batteries are not connected through the grid, we will connect them directly (It was not possible to give back energy to the grid for the bad quality of the AC signal. we couldn't obtain that all the harmonics requirements). In order to obtain higher efficiency from the system, the voltage will rise so that the current may fall, thereby minimizing the losses in the overall system.

For having a good overall efficiency of the system a microchip was purchased from linear technology rather than designing and connecting with Arduino. The efficiency can reach easily a value above 85 % (it depends of the current).

The chip used was LT 8580,[4] which allows 1.5 A at a clock frequency of 1.5 MHz³ and an input voltage between 2.55 and 40 V. This is really useful because it allows a constant output whereas the input can change (the input voltage come from the battery and it can change between 9 and 12.6 V).

The basic equations for this component are them who control the output voltage and current. The voltage is proportionally to R4 and the current to R3. The rest of the chosen values can be found in the references[4].

The following figure shows the circuit for the chip. The input was the battery at a nominal voltage and the output a resistor used only for tests conditions.

³ See the datasheet for further information [4]

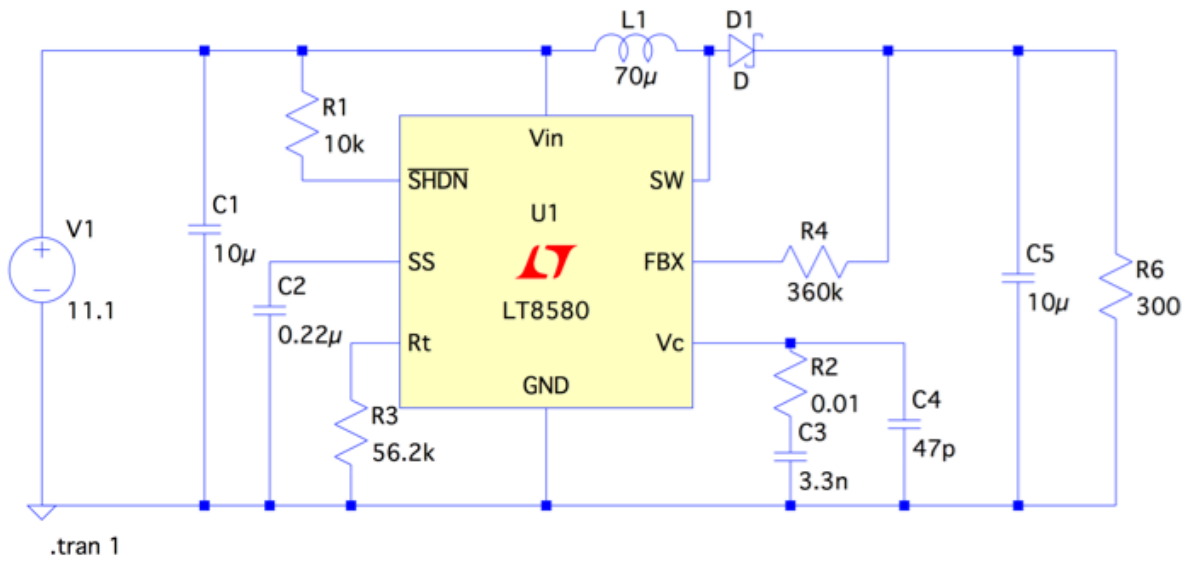


Figure 13. Boost Converter Circuit (chip LT8580)

$$R_{\text{FBX}} (R_4) = \frac{(V_{\text{out}} - 1.204 \text{ V})}{83.3} = \frac{30 - 1.204}{83.3} = 345 \text{ K}\Omega \quad (7)$$

$$R_t (R_3) = 56.2 \text{ K}\Omega \rightarrow 1.5 \text{ MHz} \quad (8)$$

The output voltage of the boost converter is a value around 30 V. This value has been chosen randomly based on a value that can decrease the losses (we can reduce the losses of transmission almost to 50%) but it is still low voltage so it doesn't represent a dangerous voltage.

The output voltage is represented in figure 14. As it was only a test simulation we weren't concerned for the current, so it wouldn't be represented. The current will be determined for the next stage, which will be connected in series with this converter.

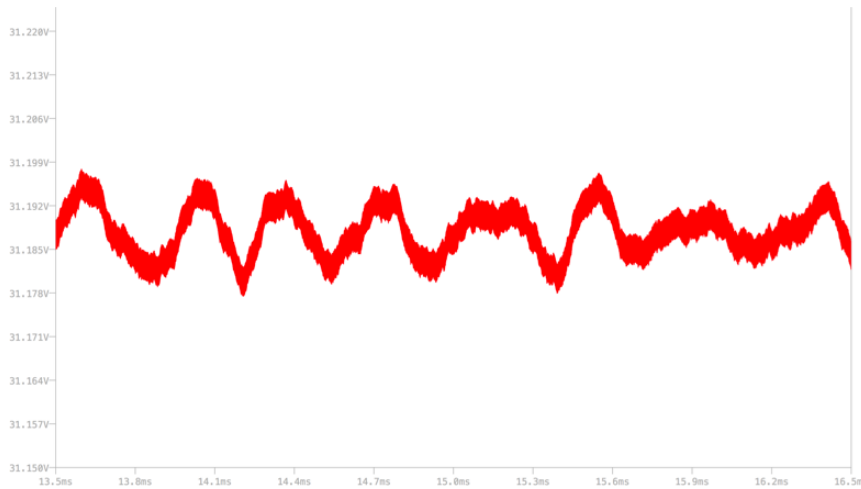


Figure 14. Output voltage of the boost converter

Although it can be seen the voltage is a bit higher than it was expected. The reason is because R_4 has a value of $360\text{ K}\Omega$ because there weren't resistors of $345\text{ K}\Omega$. This output doesn't change the specifications of the system because the chip used in the buck converter allow us a steady output, regardless the input.

2.1.4 Buck Converter

This Component connect two different DC voltage, where $V_1 > V_2$. It will step down the voltage and step up the current between the high voltage module and the battery [WART].

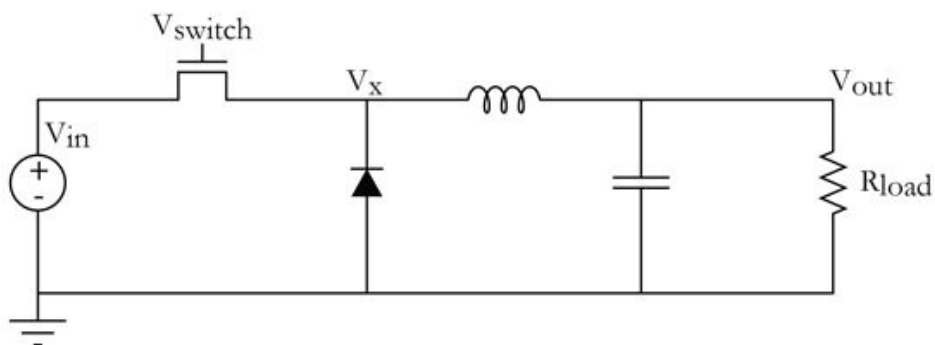


Figure 15. Buck Converter (Mike Thomson, 2011)

The functioning of the converter is based in storing energy in the inductor in two different steps:

1. Switch is on (diode will switch off): the current goes through the inductor and the energy stored in it will increase.
2. Switch is off (diode will turn on): The inductor will be the one in charge of providing the circuit the needed current, which was charged during the step 1.

The voltage that reaches the battery will be relatively high because it will come from the Boost Converter (around 30 V). To charge the battery we need to step down the voltage. For doing this, we will be using a buck converter to reach the desire voltage and then a battery charger, same as the one used in the rectifier (LT1513), because we need the same requirements and specifications.

The chip used for the Buck converter is LT 8609 and has the following features: Input voltage between 3- 42 V, 2 A of max current and an efficiency above 90 %. The output voltage will be constant controlled by a divide resistor so we have not be concerned about the small variations of the input voltage.

The output voltage will be around 14-15 V for the same reason as the rectifier i.e. to get around 1 A into the charging process.

The following equations shows how to reach the desirable output voltage⁴:

$$R_3 = R_2 \left(\frac{V_{out}}{0.782} - 1 \right) \quad \& \quad R_2 = 69 \text{ K}\Omega \quad (9)$$

$$R_3 = 1180 \text{ K}\Omega \quad (10)$$

The circuit is shown in the figure below, with an input of 31 V (the output of the boost converter) and as output a resistor for tests conditions. The battery charger (LT1513) will replace the resistor R_5 with the same parameter as it was shown in the point 2.1.2. Please see that section for further information.

⁴ For more information about the equations please see the reference [5]

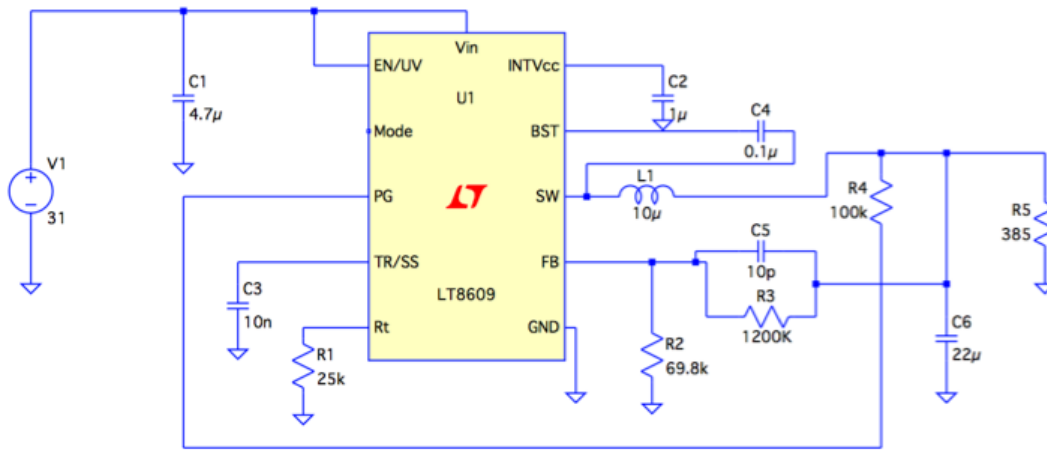


Figure 16. Buck Converter Circuit (chip LT8609)

Following the same scheme as the previous stage, the output is represented in figure 17. The voltage has a ripple of $7e-4$ (almost zero) with a maximum value of 12.21959 V. At this stage we are not concern about the current, because it will be determined by the battery charger, not by the converters.

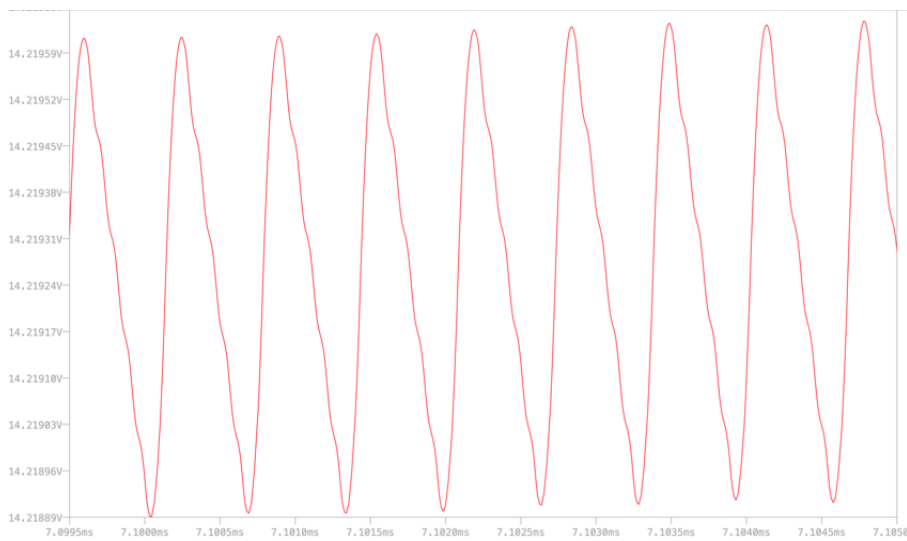


Figure 17. Output voltage of the buck converter

2.1.5 Li-ion Battery

Li-ion batteries are the current batteries in the new technologies such as Tesla Powerwall or similar devices. For this reason, the battery chosen was li-ion batteries (in this way we can try the most similar scenario).

For this project it will be used 3 Li-ion cells each one with a nominal voltage of 3.7V, minimum voltage of 3 V and a max voltage of 4.2 V. The capacity of each cell is 3600 mAh. For getting a wider flexibility and reducing the cost it will be used 18650 cells with a chemistry of BRC (Built-in Resistance compensation) li-ion.



Figure 18. Single li-ion cell

The connection will be in series so the battery will have the following characteristics:

MAGNITUDE	VALUE
NOMINAL VOLTAGE	11.1 V
MAX VOLTAGE	12.6 V
MIN VOLTAGE	9 V
DISCHARGING CAPACITY	3600 mAh

Table 2. Battery characteristics



Figure 19. Batteries connected in series

The li-ion batteries have some outstanding features such as high energy density but it is a relatively unsafe process if it not controlled. In the worst case, the battery can burn.

For solving this problem, some techniques have been developed to ensure everything is going as required⁵:

- Designing a battery charger that cannot overcome 12.8 V (The battery is designed for up to 12.6 V, a higher value could harm the chemistry)
- Use a battery gas gauge that is reading the voltage and the current and if something unexpected happen turn off the charging process.
- Controlled the flow of current with an Arduino and some relays. The relay allows to the user to be safe in case of accident.
- During the charging process the battery was inside a lipo-sack in case and accident can occur.

⁵ It was followed all the indications of *Safe Practice for Lead Acid and Lithium Batteries*, by Spring 2016 Course Staff

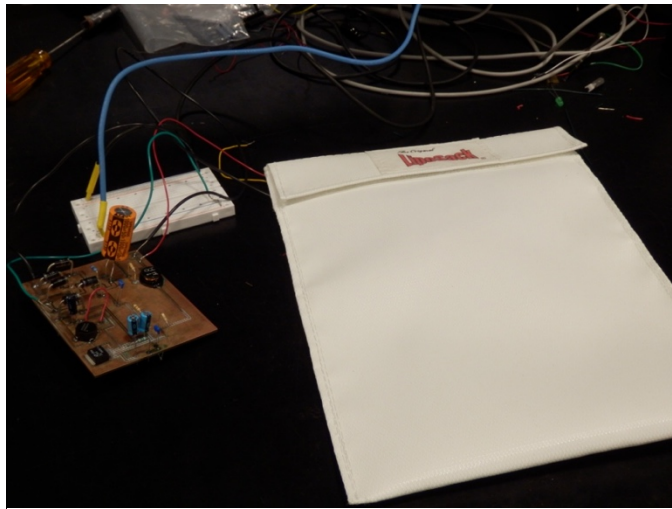


Figure 20. Charging process within a lipo-sack

The charging process has two stages:

1. Constant current.
2. Constant voltage.

This process can be seen in the Figure 21.

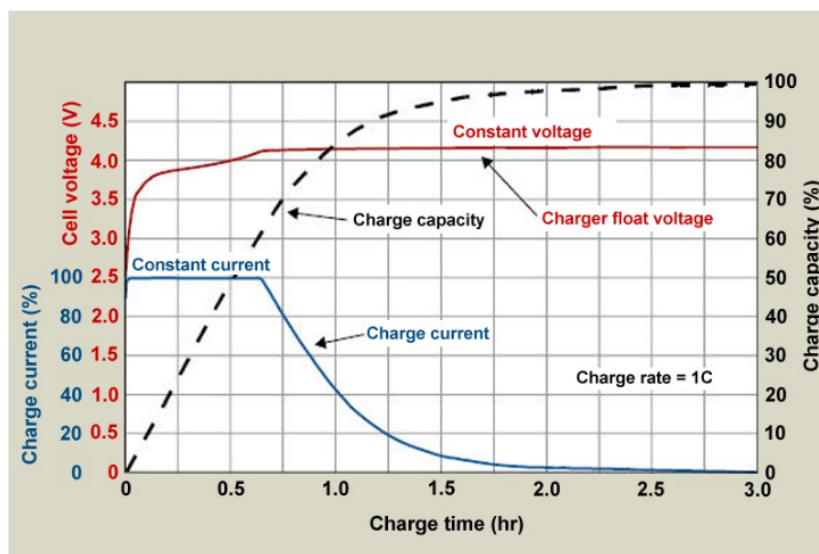


Figure 21. Charging characteristics

For a proper charging process, the current must decrease and the voltage should reach the maximum voltage quickly, remaining in that number during the process. As non on this process is linear, it cannot be measure the capacity in a relationship between capacity-current or capacity-voltage. A power sensor was used for this requirement.

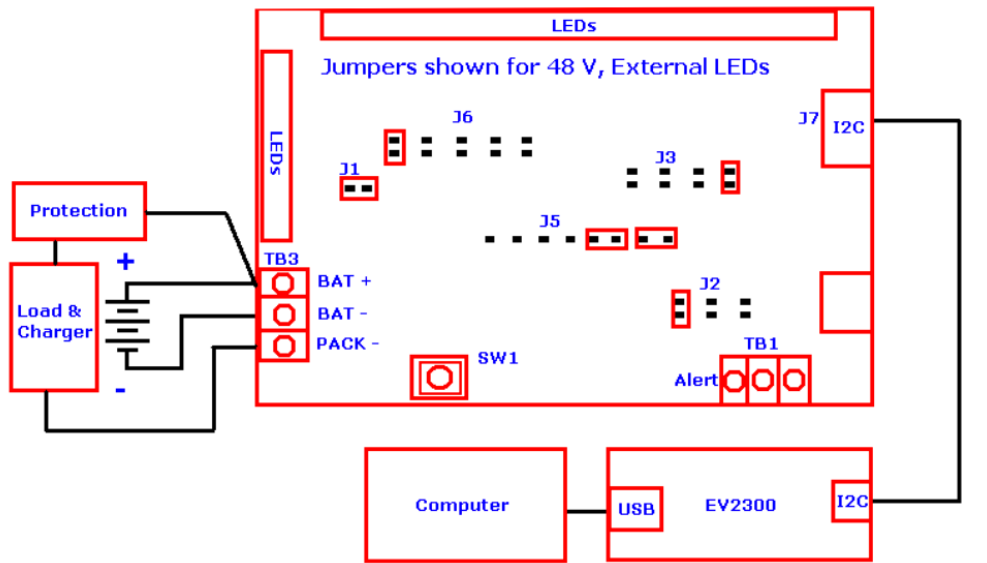
2.1.6 Switching Controller (Relay)

This component controls the flow of the energy, allowing energy to go out or come in from the battery. The switching controller receives its inputs from the Arduino. These inputs determine whether the buck/boost or the rectifier should be working so that energy can be transported based on the user's requirements. The elements chosen was a relay, so the user can be safe although it can manipulate a lot of energy.

2.1.7 Power Sensor

The power sensor system comprises of a battery fuel gauge, specifically the BQ34Z100-EVM [6] Wide Range Impedance Track™ Enabled Battery Fuel Gauge Solution. This gas gauge module, connected to the Li-Ion batteries, provides details about the battery capacity by using its using Patented Impedance Track Technology for batteries from 3 V to 65 V. The gas gauge system also provides outputs to the microprocessor (Arduino Mega) through the I2C communication port.

In this manner, the Arduino receives the real-time battery capacity for further trade computations.



The gas gauge module receives operational power from the same battery providing the
Figure 22. BQ34Z100-EVM Connections

information. The J7 port in the module (Fig. 2) serves as the I2C communication port. This EVM module is primarily used to conduct performance testing on batteries in order to evaluate their performance. In such case, the module is connected to a computer via an I2C bus - EV2300. But due to the presence of I2C communication lines in our microcontroller, we neglected the EV2300 module due to cost analysis.

Figure 23. and Appendix A provide further information about procedures and requirements while securing the communication between the microcontroller and the gas gauge module.

2.1.8 Microcontroller

This component, as mentioned above, comprises of the Arduino Mega 2560 [7] along with the Arduino Wi- Fi-Shield 101. A battery of 3.7V, generally derived from the same battery powering the trade, powers the microcontroller. This component is responsible for interacting with the power sensor system to obtain information about the battery consumption. The Arduino is programmed to specifically access register values corresponding to the gas gauge chemistry data, which is secured using the

Wire library for enabling I2C communication between the BQ34Z100-EVM and the Arduino.

The Arduino projects this information to the database server using the Wi-Fi shield. In a vice versa system, the Arduino also receives inputs regarding market transactions from the cloud database, and switches on the energy trade process between the specific batteries involved in the trade. The software layer provides further details about the communication with the cloud-based system.

The following figure provides the flow chart depicting the relationship between the different hardware and software layer entities.

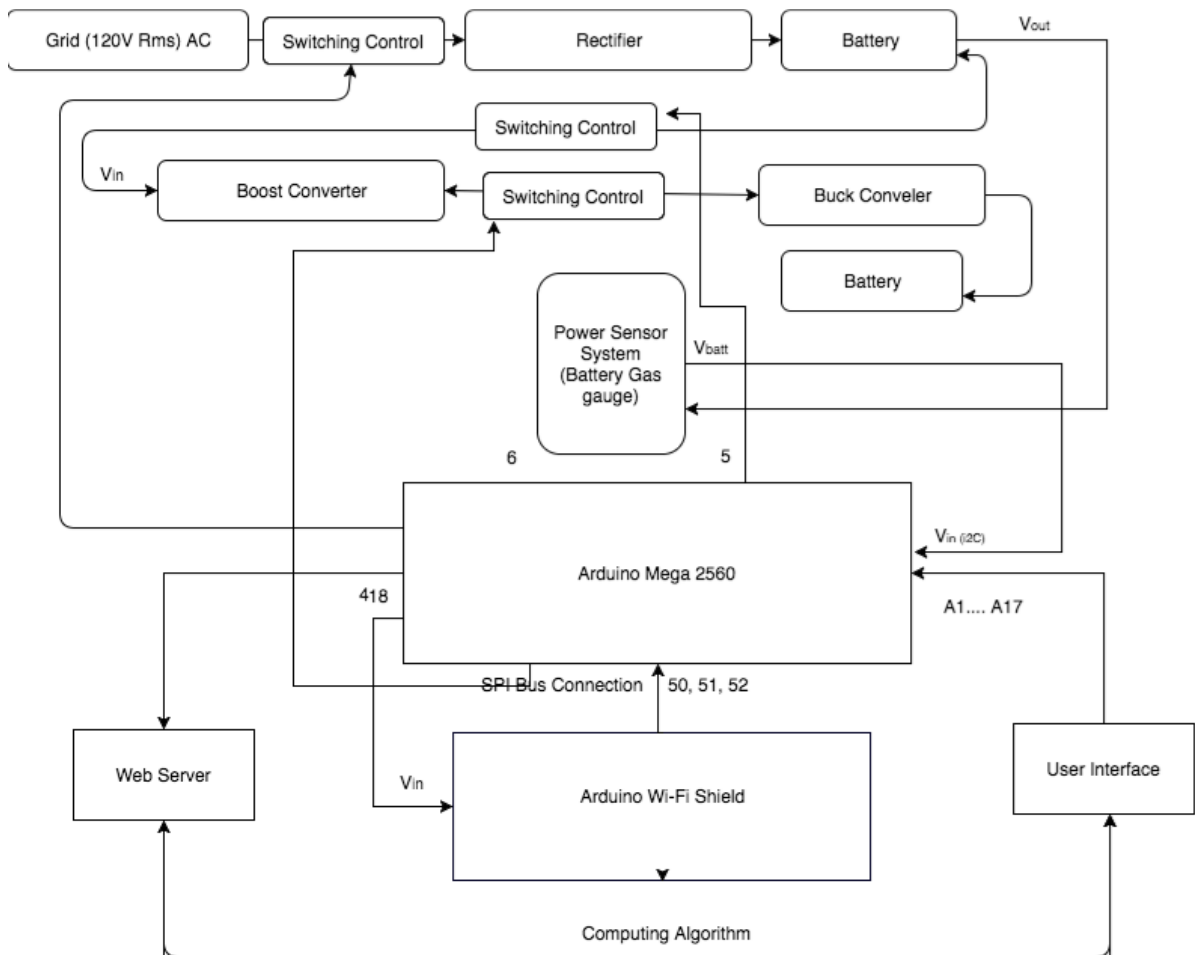


Figure 23. Microcontroller connections

2.2 SOFTWARE

The idea of this section is to design a web application where the user has the energy market information in an easy way to understand. This application may contain information of the price of electricity in real time, the estimated maximum price and minimum price and the average consumption of housing per day. It also has the battery information so each user can determine how much autonomy he/she has and the price at which the energy in their batteries has been accumulated. Finally, there is also a section which allows the consumer to automate a charging process to buy energy at the lowest possible price (this is in hours' valleys) and load the electric car (if available) in the same way. This application not only allow the buying process but also the sale of energy is regulated if there are available modules of production of energy (such as solar panels). This energy can be automated to be sold at peak times when energy prices takes a maximum value.

This section is designed for two different scenarios:

1. A scenario created specifically for this project, where the user can trade directly between them and they only can buy energy from the grid, but they cannot sell energy to the grid. The price will be set up in an artificial way and it is only a proof of concept due to the magnitude of this project. The idea with this is only see if the project is suitable.
2. A real scenario where the users can buy and sell energy from the grid, creating algorithms that use the real price of the energy and where the user can buy (sell) energy from (to) the grid. This represents the idea of the project but cannot be implement with our resources. For this reason, only was designed the software, whereas for the scenario 1 it was designed both the hardware and the software.

In every section is specified the scenario related.

2.2.1 Arduino Wi-Fi Shield

The Arduino Wi-Fi Shield [8] is plugged to the microcontroller as described above. However, this component could also be considered as part of the software system because

its function is highly related to the server and the database. The main function of this shield is to keep the data transmission between the web server and the local micro controller. The Wi-Fi shield sends the data retrieved from the power sensor to the server and update the database. Besides, this shield also keeps receiving and reading the response from the sever, so that the micro controller could detect the trading status of the the users, and then change its output to start/stop the energy transmission.

The microcontroller can be used for both scenarios.

2.2.2 Cloud Computing Unit

The cloud contains the following major components:

2.2.2.1 Database Server

This component refers to the main software station where all the information stored by the battery is transferred. Our database server stores the real-time power measurements transmitted by the microcontroller via the Arduino Wi-Fi Shield. We choose MySQL as our database, since it is open source and has a high compatibility with different operating systems.

The cloud database has two components associated with it namely Private Usage data and Public Usage data; allowing the users to decide what information about their batteries do they wish to publicize to the energy market.

The Database Server can be used for both scenarios.

2.2.2.2 Private User Data

This component refers to that part within the main database that contains data pertaining to the local energy usage within each battery. Based on all the information provided by the power sensor to the database, the private data is implemented as a personal energy profile for each user to categorically analyze their energy usage. Depending on the energy consumption, each user can decide how much energy do they wish to purchase or sell.

The private user data table from the user interface retrieves these user inputs in order to perform an energy trade.

The outputs generated from the private user data are stored as saleable or demanded energy within the Public (Market) data for all the users within the network to view. This information is only for a proof of concept, but it wouldn't have this structure in a real application. As we cannot sell energy to the grid and we are not going to use the energy for a real purpose, we are going to trade between batteries simulating a real market where the batteries are different clients that can trade within them. Although this is not the real idea, only the first iteration, a table where we can store all the information may be useful for having a better vision and a better performance of the project.

Figure 24. is part of the private user table in our database, each row refers to the information of one battery, the entity 'userid' is the primary key of this table and the 'trading status' shows whether the battery is during an energy transaction.

userid	voltage	charge_amount	category	remaining	sell_available	buy_available	trading_status	reading_status	username
1	12.6	6.6	Lipo	0.68	0.18	0.15	1	0	zh
2	11.1	6.6	Li ion	0.75	0.25	0.25	1	0	jm
3	12.6	6.6	Li ion	0.5	0	0.45	0	0	sn

Figure 24. Private market data table

2.2.2.3 Public (Market) Data

This component, as the name suggests, refers to the assimilated market data from all the individual users connected within the shared energy network. It is stored within the cloud system as a central point of information for the entire trade-taking place. The inputs to these components essentially included energy packets that are either demanded or available for supply within the market, depending on the private user data for each user.

The market data also has a dependent computing algorithm in order to efficiently handle trade between different customers present in the market. The output of the Public market table is displayed to all the users who request to view the market. The data in table is also used by the computing algorithm to set the the market price and recommend the current lowest price of the energy block within the network.

The same as the private user data, this section is created for the proof of concept, not for

a real use. As we cannot trade with the grid and we can only get energy from it, we are going to trade both with the grid and within the batteries (although as it was explained the idea was trading only with the grid). For creating a competent simulated market, each battery would have an ideal price, which is not real, and the algorithm will buy the lowest price.

Figure 25. displays part of the public market table, each row corresponds to one energy block, and the entity ‘tradeid’ is the primary key of this public market table.

tradeid	userid	voltage	charge_amount	name	category	available	trade_type	price
1	1	12.6	6.6	zh	Lipo	0.25	sell	7.5
2	2	11.1	6.6	jm	Li ion	0.2	sell	7.5
3	1	12.6	6.6	zh	Lipo	0.05	sell	7.5

Figure 25. Public market data table

2.2.2.4 Web Server

A web server is needed for our project since we set up a website as the user interface, so that the server could be able to process the requests sent from the users. Considering about the high cost of leasing or purchasing a server, we decide to make use of the web hosting provided by our university. Also it was used our laptops as personal webserver so it could avoid that problem.

A website domain, which provides the port of the HTTP requests. The website domain represents its unique IP address which corresponds to a specific web hosting. The web hosting connected to the web server behaves like an online virtual machine where we could upload and store the files needed for the website. Our website domain is *eventclicker.web.engr.illinois.edu*. and also *localhost:8888* when our laptops were used as Web Server.

Our laptops were used as a web server for the computing algorithm for a real case, whereas it was used the university domain for the computing algorithm used for the project. For further information, see the next section.

2.2.2.5 Computing Algorithm

2.2.2.5.1 Computing algorithm for the project (Scenario I)

This central software algorithm performs a list of computations in order to efficiently handle trade in the market. The most important function of this component is to keep a constant track of the demand and supply created as a result of the changes in the market price. As a result, the inputs for the algorithm are taken from the public data function block. The algorithm triggers a trade when a complete transaction takes place whereby a buyer and a seller are matched for a transaction of energy.

Furthermore, there is another significant algorithm that performs computations about the current price in the market depending on the net demand and supply created within the network. It also projects the minimum cost of energy available in the market and provides both the supplier and the consumer with an updated scenario of the energy market.

Figure 26 is the flow chart that displays the communication of the database server and user interface. The information data of each battery from the power sensor should have been stored in the database. Now this flowchart shows how the cloud-computing unit processes the request from the user interface. Moreover, the microcontroller keeps listening to the relative entity and will enable the charge controller & switching controller when it detects that the current state meets the criteria for energy transmission. Then also after the energy transmission, the user interface will display the updated information of the battery.

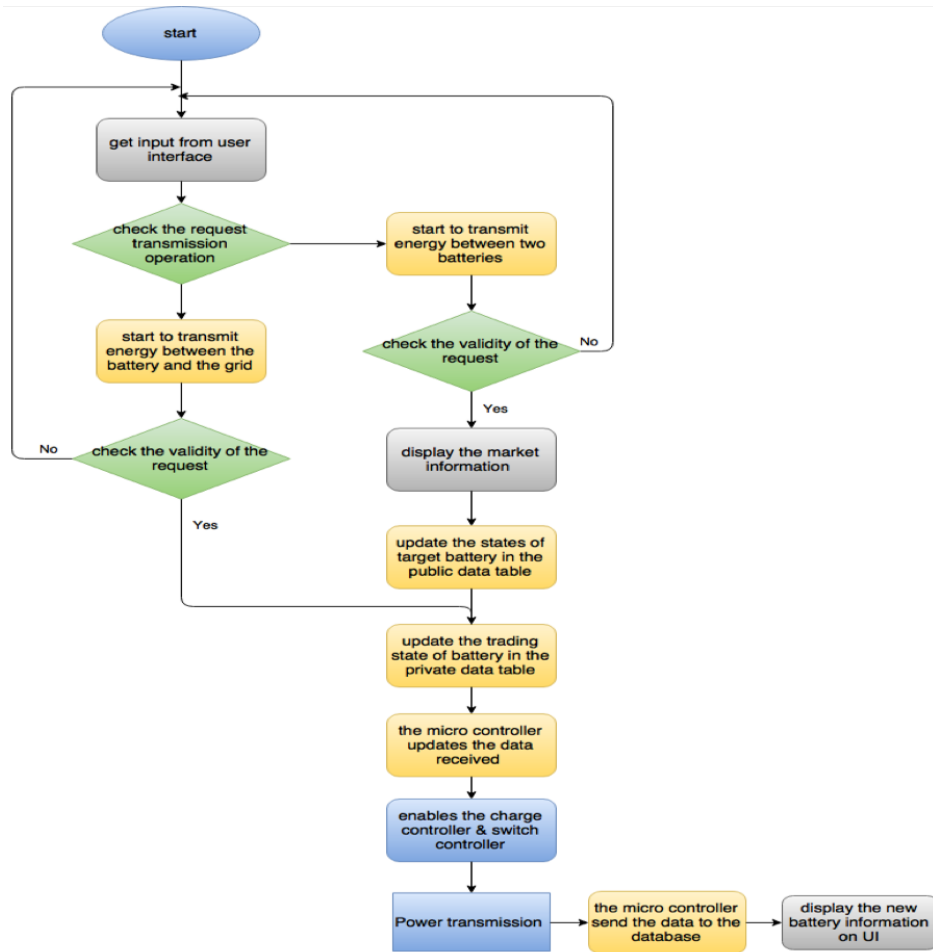


Figure 26. Interaction between Server and UI

2.2.2.5.2 Computing algorithm for a real case (Scenario II)

As it was explained before, this algorithm simulates a real case, and not something specific for this project, and it tries to buy the energy at a minimum price.

1. The first thing it does is take the the actual energy price at every hour and save it in MySQL (Our database).
2. Then it prints in the user interface the current price for the energy and the maximum and minimum price of the energy, so the user can have a reference about if the price is high or low.
3. At the same time, the fuel gas gauge it is reading the parameters of the battery so the user can have an idea about the remaining battery they have and how much autonomy they he/she still have.

4. Once all the information is stored in our database, the user has two options:
Buy the energy when they want or establish an automatic process.
5. If he/she chooses a manual process, the trading starts right now.
6. Otherwise, the algorithm finds the hours where the energy is cheaper and waits until it reaches them for buying the energy.
7. In this way the user can store the energy at the cheapest price possible.
8. If applicable, the user can also sell energy to the grid using the same idea, automatizing the process where the algorithm would find the maximum price so the profit can be maximized.
9. In case of having an electric car, this process can be repeated using other price values, the specifics for the electric car.

2.2.3 User interface

A web application will be created as the user interface, which displays the data to the user and allows each user to interact with the market data. This component refers to the web-based platform that allows each user to make several trade decisions after analyzing their energy use. The web application will evaluate the validity of the user's request and lead the user to finish the transaction. The interface first interacts with the private data to make a decision about a possible trade based on the personal energy consumption data.

Furthermore, the user interface interacts with the public market table when the energy trade is confirmed between two different batteries or the battery and the grid. After confirmation from the user interface, the output of the transaction algorithm provides the inputs to the microprocessor within the control system to begin the energy flow process between the batteries. The purchase process can be both manual or automatic.

Figure 27 shows the profile page of the user interface, displaying the information stored in the private user table, with correct units. The navy-bar on the top could lead the user to jump to different pages with corresponding functions. These figures are taken from the real scenario (scenario II)

The different pages are:

1. Market: it shows the basic information of the market and the price of the energy

storage in your battery.

2. Your battery: it shows the basic information of your battery.
3. Sell your energy: it allows the user to sell energy in a manual or automatic mode.
4. Buy energy: it allows the user to buy energy in a manual or automatic mode.
5. Charger your car: Same as buy energy but using different parameter.
6. Red Eléctrica: Direct access to the webpage of Red Eléctrica.

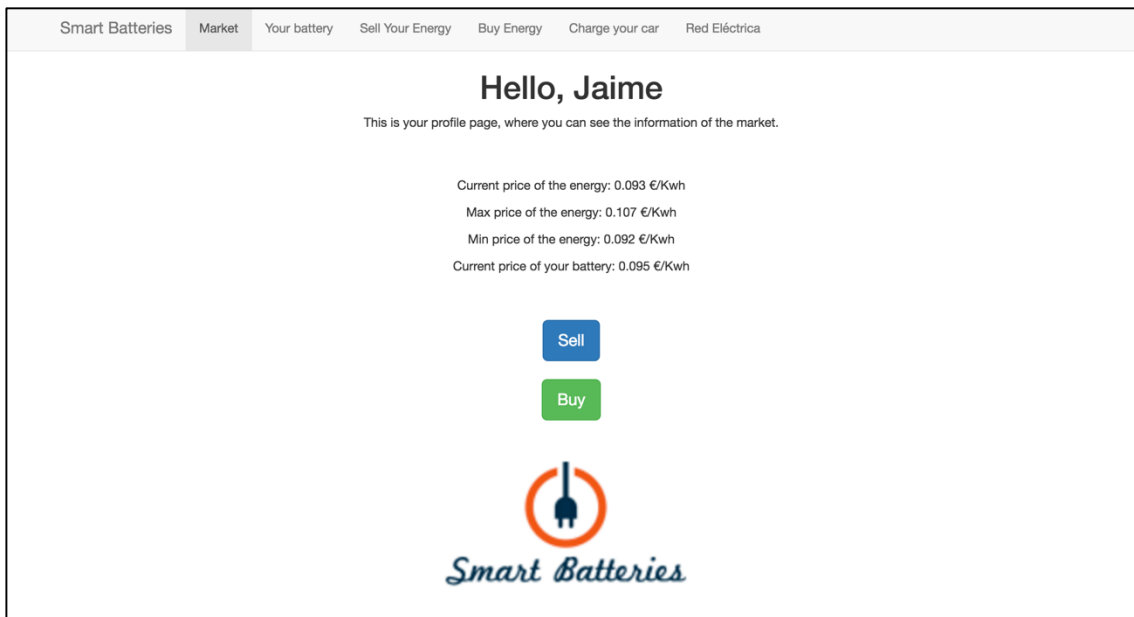


Figure 27. Market page of UI

It is also shown some others functions so it can be given the main idea of the User Interface behavior. The client will have at every moment actual information of their price, the transaction is being realizing, the price you buy the energy at and some other relevant information.

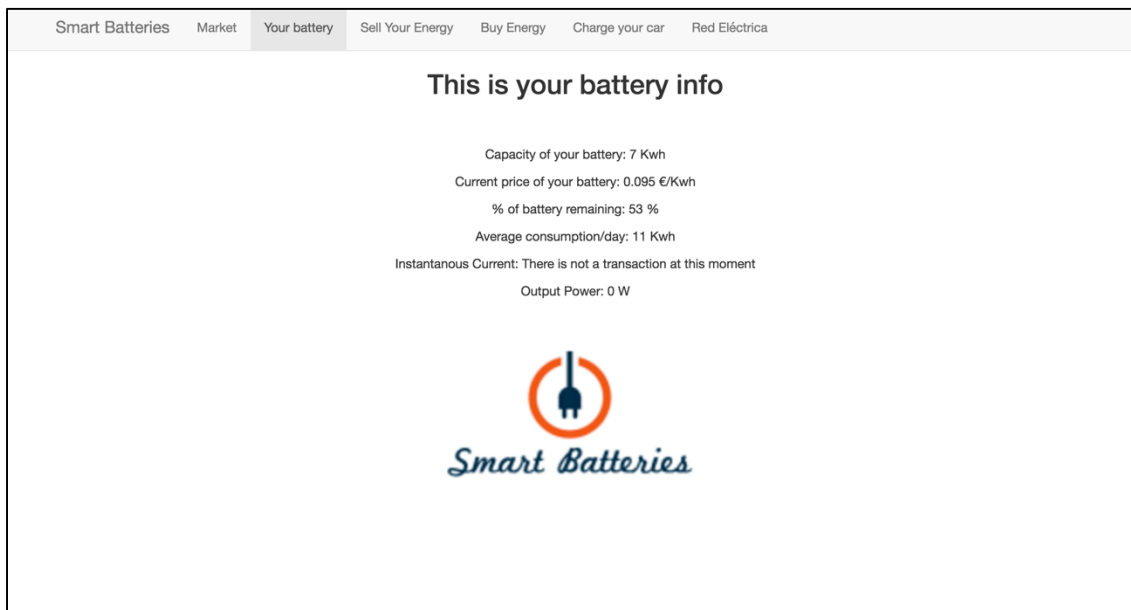


Figure 28. Your battery page of UI

There is also a section for charging the electric car. The idea is the same, the main difference is the algorithm uses other values (there is a special price for electric vehicle). All the purchase process can be automatized so the algorithm can find the minimum price.

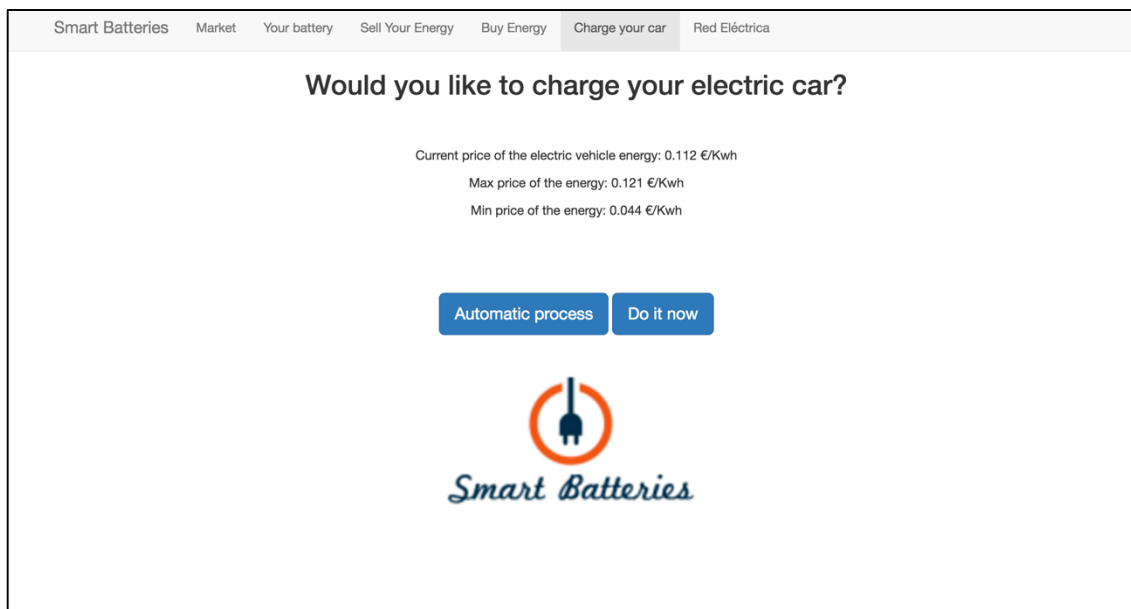


Figure 29. Charge your car page of UI

3. PCB

The following pages shown how the hardware was designed and printed. All the circuits in this project were integrated in a PCB which were designed using EAGLE and then printed in the ECE supply store, courtesy of ECE lab. For each PCB were used two layers. The red one was printed on the top of the board and the blue one in the bottom. This legend was used for all this section.

3.1 PCB Design & Printing

As it was explained before, for this project were realized three different modules: A rectifier, a boost converter and a buck converter. Some of these modules were designed with the battery charger.

3.1.1 Rectifier & Battery Charger

The first module designed was the rectifier. As it was a relatively simple design it was also integrated with the battery charger. The width of the path change in this board because of Scotty diodes (used for minimize the losses), which can cause that the peak of the current can reach up to 7 A, although the average current was around 1 A. After the rectifier the current had a DC value so the width can be reduced a lot as the peak current was only 1.2 A.

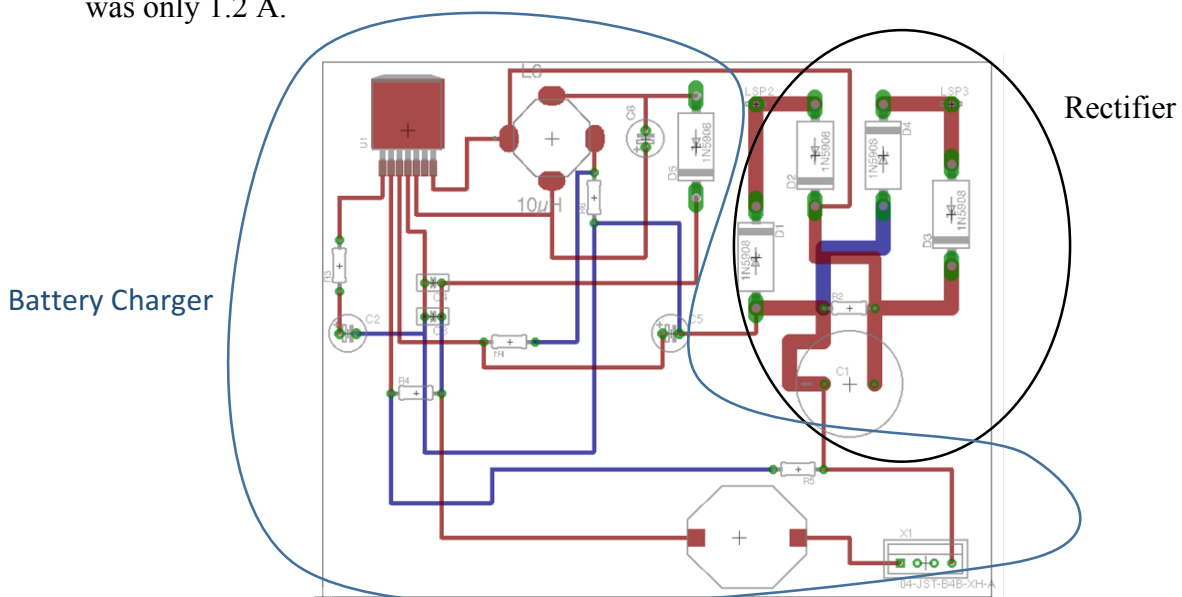


Figure 30. Rectifier and battery charger designed in EAGLE

Figure 30 shows the design of the PCB in EAGLE. The printed board is represented in the following figures. It is shown both the top and the bottom layers.

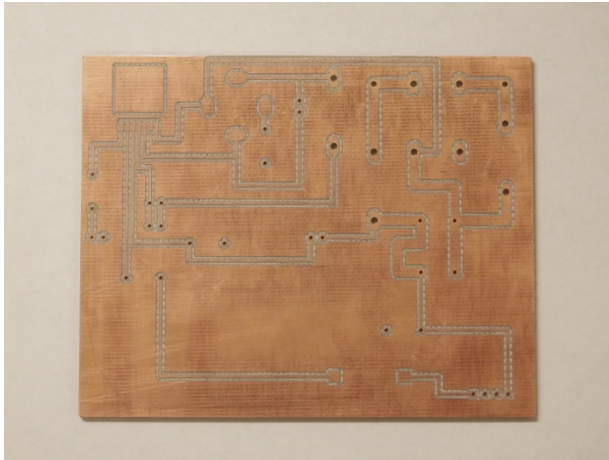


Figure 32. Top layer of the PCB

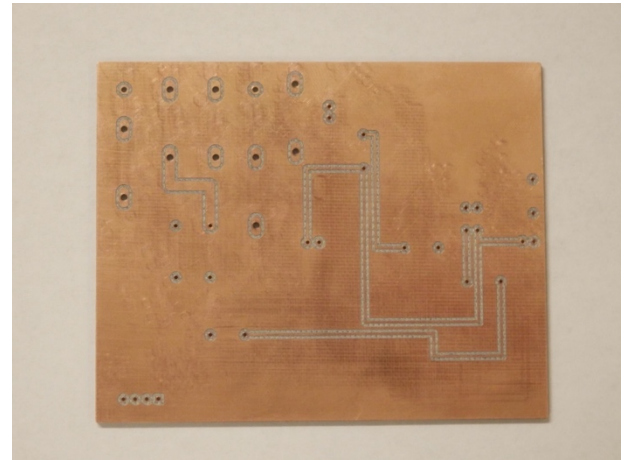


Figure 31. Bottom layer of the PCB

After printed the PCB the next step is to solder all the elements such as resistors, capacitors, diodes or some chips⁶. The process for soldering was always insert flux, (so it can clean the board all allow an easier solder) and then solder the elements with tin and a welder. The final result can be shown in the figure below.

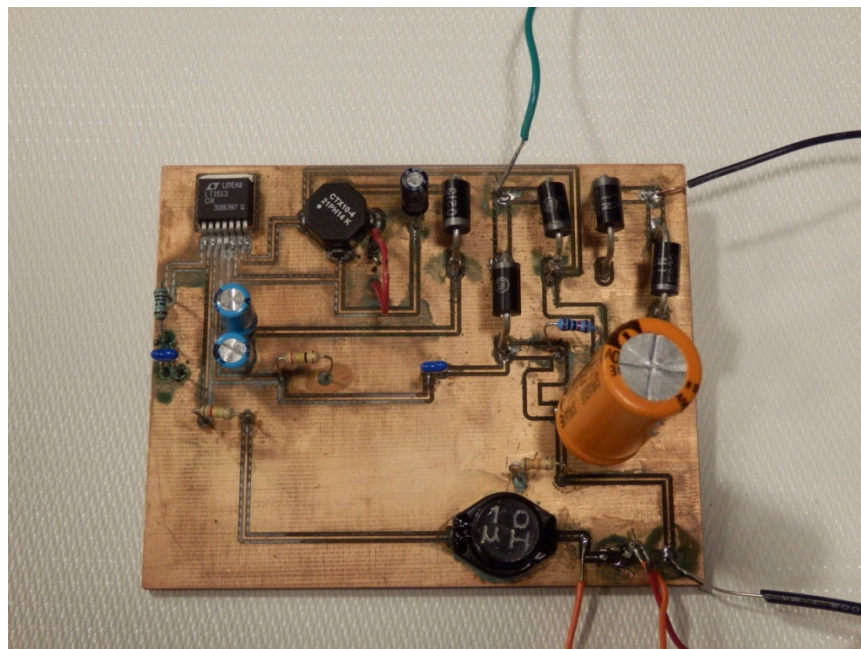


Figure 33. Rectifier and battery charger PCB soldered

⁶ All the elements have been chosen base on the considerations of the datasheet of LT1513 [3].

3.1.2 Boost Converter

The next module is the boost converter. The boost converter was only a stage between different batteries so it is not necessary to couple the battery charger. The main element is the chip LT 8580 and an inductor. The following figure shows the model realized in EAGLE before printing with the same legend. Red color for the top layer and the blue one for the bottom. As all the process uses DC power (it comes from the battery) and the voltage is step-up, the current is small so the width is relatively smaller than the previous board.

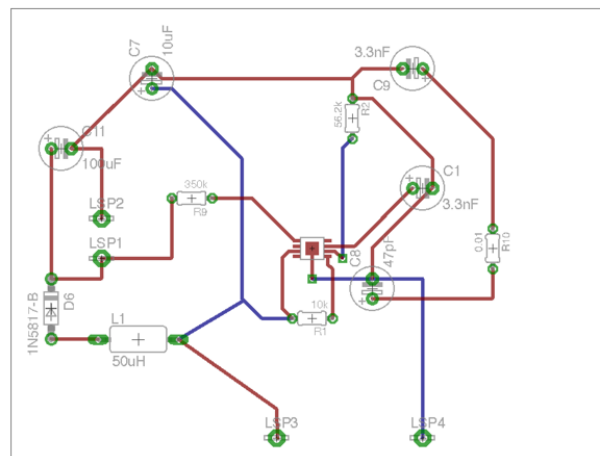


Figure 34. Boost converter designed in EAGLE

Figure 34. shows the design of the PCB in EAGLE. The printed board is represented in the following figures. It is shown both the top and the bottom layers.

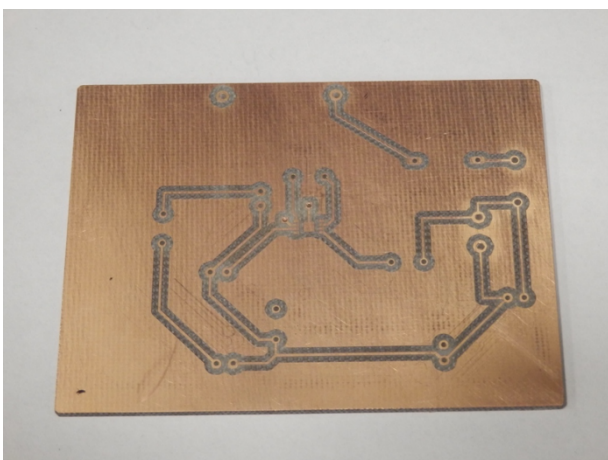


Figure 36. Top layer of the PCB

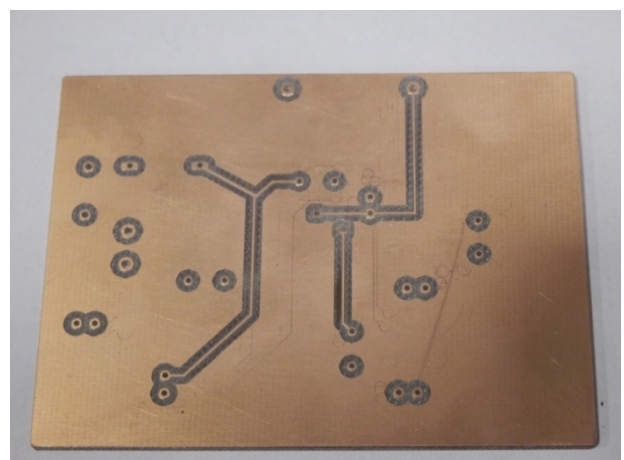


Figure 35. Bottom layer of the PCB

For soldering the PCB was followed the same steps explained in the previous section. The selection of resistors, capacitors and coils were made according the datasheet of the chip LT8580 [4].

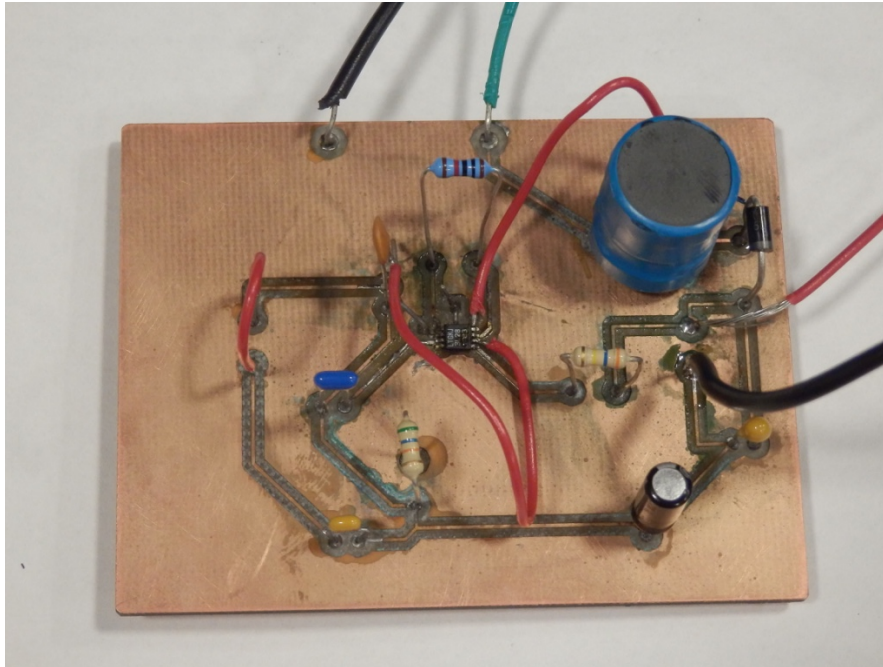


Figure 37. Boost converter PCB soldered

3.1.3 Buck Converter & Battery Charger

The final step of the trading process is a buck converter that step-down the voltage so it can charge another battery again. This PCB has both a buck converter and the battery charger. The battery charger is the same used with the rectifier, as long as all the batteries have the same characteristics. The width of the buck converter's path is really narrow because the chip is really small and a bigger path means a short-circuit around the chip. The design in EAGLE is shown in the following figure with the same scheme and legends explained in the previous sections. Color red for the top layer and blue one for the bottom. This board was way far the most complex in the design due to the high number of elements involved and the difficulty of solder some of the elements.

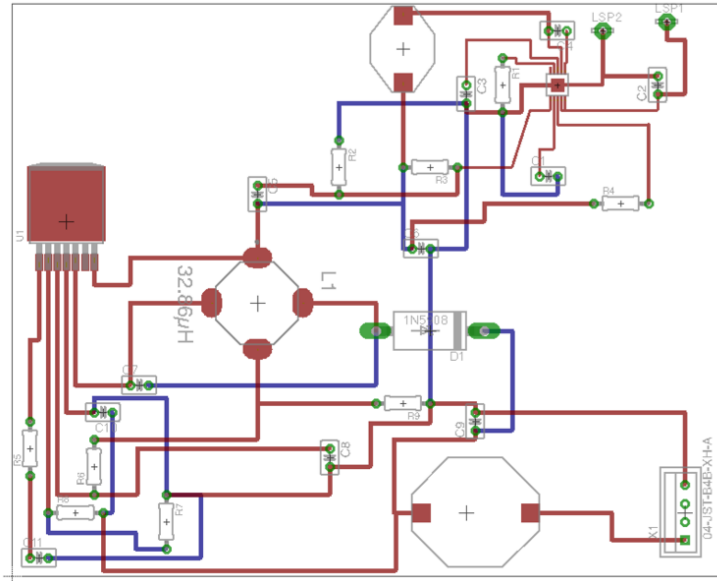


Figure 38. Buck converter designed in EAGLE

Figure 38. shows the design of the PCB in EAGLE. The printed board is represented in the following figures. It is shown both the top and the bottom layers.

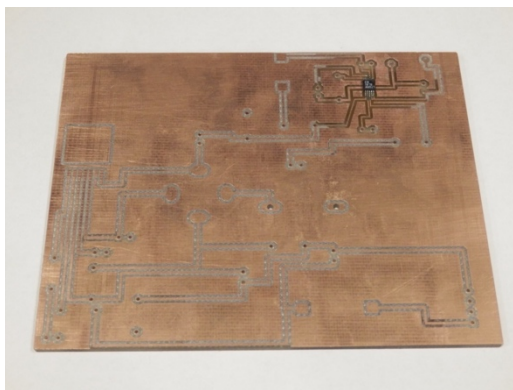


Figure 40. Top layer of the PCB

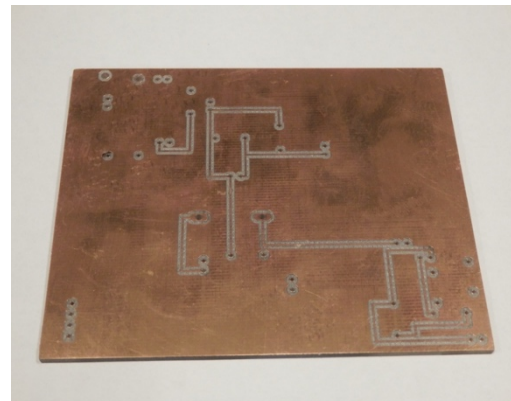


Figure 39. Bottom layer of the PCB

Finally, and closing this section the next figure represents the buck converter. It is only solder the buck converter but the battery charging is missing. The reason of that is for the bad behavior of this board. The main problem was it step-down much more than it was expected. The battery charging process, as it was explained, it is a relatively dangerous process and everything must be under control. For this reason, it was finished the board and part is missing. For further information, see Appendix A.

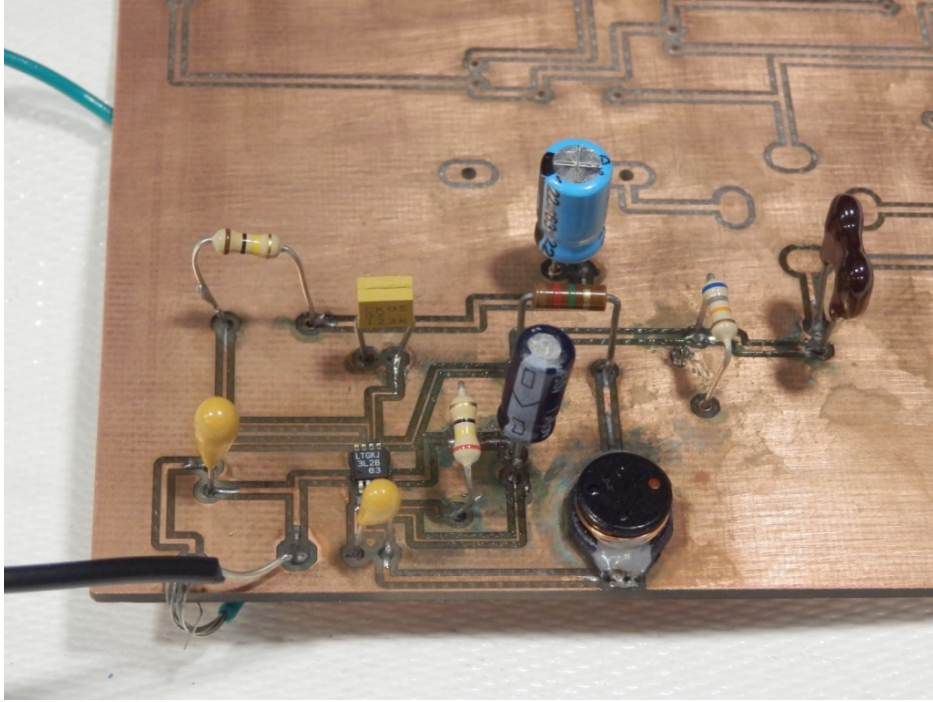


Figure 41. Boost converter PCB soldered

4. DESIGN VERIFICATION

In this section is explained what we got and what we reach in the project. All the modules are specified and the goals are commented.

4.1. POWER SYSTEM

The power system was in charge of controlling the transactions between the grid and the battery and within the batteries. This system tried to get the maximum efficiency. The goal of this system was: to get 14 V at the input of the battery charger and 12.8 and the input of the battery.

The power system failed in the some of this requirements. Although the grid can charge the battery we couldn't send energy between batteries. The reason of this was because the converters weren't working. Both chips didn't step up or step down the voltage at the level we request so we couldn't connect the two batteries.

For further information, please refer to the requirements and verification table in Appendix A.

4.2. POWER SENSOR & MICROCONTROLLER

The Wi-Fi shield communication is established successfully by exchanging basic data packets between the Arduino Mega 2560 and the cloud-based database. Furthermore, the user inputs successfully activate the relay depending on the value within the database, thereby proving that the Arduino is functional with the web server.

However, the I2C communication between the BQ34Z100-EVM and the Arduino Mega could not be established. This is due to the missing component EV2300. Upon enquiry with the supplier, we were able to realize that the I2C bus (EV 2300) is a necessary entity not just for setting up the computer program, but also to sync the chemistry data algorithm within the gas gauge. As the gas gauge remains non- configured without the right installation using a computer system, the choice of our gas gauge remains faulty rendering

the requirements useless.

For further information about the specific requirements and testing procedure, please see the Appendix A.

4.3. CLOUD COMPUTING UNIT

Our cloud computing unit mainly consists of the web server, database and the computing algorithms.

4.3.1. Web Server

Since we applied a website domain and take use of the server from the university, we didn't make a specific requirement and verification for the web server since this is the very first step before all the software function could work. And our database, user interface and micro controller (Wi-Fi Shield) are all successfully connected to the server.

4.3.2. Database Server

The tables in the database correctly store the information, and the stored data is updated properly with the input values. For details on the specific requirements and testing procedures, please see the Appendix A.

4.3.3. Computing Algorithm

The transaction algorithm is able to set the trading status correctly; and the computing algorithm with the price is able to set the market price correctly and help user to determine the current lowest price. For details on the specific requirements and testing procedures, please see the Appendix A.

4.4. USER INTERFACE

The user interface correctly display the information data stored in the database. And it checks the validity of the input from the users and send the request to the server properly. For details on the specific requirements and testing procedures, please see the Appendix A.

5. COSTS

This section is divided in two parts: the cost of the materials and the cost of the labor of the engineering work.

5.1 PARTS

All the parts used in this project can be summarized in the following table:

<i>Part</i>	<i>Manufacturer</i>	<i>Retail Cost (\$)</i>	<i>Bulk Purchase Cost</i>	<i>Actual Cost (\$)</i>
<i>LT1513</i>	Linear Technology	5.45	4.80	0 ⁷
<i>LT8580</i>	Linear Technology	3.70	2.59	0 ⁶
<i>LT8609</i>	Linear Technology	3.57	2.50	0 ⁶
<i>18650 li-ion cell (x2)</i>	Ultra Fire	6.07	6.07	30.35
<i>Relay</i>	Songle	8.99	8.99	8.99
<i>Coupled inductors</i>	Mouser	6.06	4.45	12.12
<i>Battery holders</i>	Mouser	4.36	2.67	13.08
<i>Battery holder</i>	Mouser	2.26	1.41	6.78
<i>Arduino and Wi-Fi Shield</i>	Adafruit	95.00	95.00	95.00
<i>Resistor, inductor, capacitors, etc.</i>	ECE supply shop	--	--	--
<i>Transformer</i>	Triad Magnetics	38.79	29.09	38.79
<i>Total Cost</i>				205.11

Table 3. Parts cost

⁷ It was provided by Linear technology at a cost of 0.

5.2 LABOR

The Labor cost is calculated as follows: The rate of an engineering in the market, by the numbers of hours and by a factor of 2.5, same as it is calculated in a company. The following table represents this calculation.

<i>Student</i>	<i>Rate (\$/hour)</i>	<i>Hours</i>	<i>Total (\$)</i>
<i>Somnath Deshmunkh</i>	35	250	21,875
<i>Ziheng Wu</i>	35	250	21,875
<i>Jaime Gayá</i>	35	250	21,875
<i>Total</i>	35	750	65,625

Table 4. Labor cost

The overall cost of this project was $\$205.11 + \$65,625 = \$65,810.11$. If the engineers working on this project are working pro-bono on account of the philanthropic application, the cost is then reduced to the cost of materials, $\$205.11$. However, the university provides us some funds, and the final price was $\$166.32$. Specially thanks to ECE shop for printing the PCB at a cost of 0. As long as the project is created in a larger number can be reduced to $\$172.85$ (15% less).

6. CONCLUSIONS

The next section explains some conclusions of our project, our accomplishments, uncertainties and our ethical compromise.

6.1 ACCOMPLISHMENTS

During the span of the semester, we were able to learn a great deal about different steps involved within hardware and software development from a product design standpoint. Despite facing several technical and logistical challenges, we were able to achieve most of the functionalities for the software part, thereby enabling a smart-grid energy system that allows consumers to analyze and project their energy consumptions.

Although the system could not be finished, it was done the first approximations and it could handle the modules designed in hardware, as well as full implementation of the application, but with a tight competitiveness module Arduino passing readings Wife the application. One reason for this was the high interference of electronic devices that were in the laboratory and the difficulty of the protocols of wireless Shield. Therefore, it would have been more advisable to use the Ethernet module instead of the Wi-Fi shield.

Furthermore, we are completely aware of the different shortcomings in our product design, and intend on fixing the system for further development.

6.2 UNCERTAINTIES

Our system finally failed to create independent energy-sharing between the network of selected batteries. There were several unforeseen challenges that lead to the possible non-completion. A few of the batteries supplies posed testing challenges, as they were not fit for usage due to their low-voltage ratings. Furthermore, the gas gauge module chosen missed an essential component that was vital to obtain the battery-chemistry data for real-time energy sharing.

Also, as mentioned before in the design section, our output voltages during testing

appeared to be very different from our expected values.

6.3 ETHICAL CONSIDERATIONS

During the course of the project, we have adhered to the following guidelines from the IEEE Code of Ethics [IEEE1] as relevant to us.

1. To accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

We ensure that all procedures relating to the product design and development will be conducted with the highest level of concern to avoid any form of hazards in the laboratory.

2. To avoid real or perceived conflicts of interest whenever possible, and to disclose them to affected parties when they do exist;

We will highlight all instructions relating to the application and design of the product in the final product manual, including any concerns relating to the electrical design, power or heat intake.

3. To be honest and realistic in stating claims or estimates based on available data;

We will provide citations of sources used during the project, and will be completely honest about any data values involved during the development.

4. To improve the understanding of technology; its appropriate application, and potential consequences;

The main idea of our project aims towards innovating the field of power distribution and related applications. We will clearly highlight the different applications of our product, including any limitations of operation

5. To avoid injuring others, their property, reputation, or employment by false or malicious action;

We ensure to treat all our colleagues and resources with utmost respect and honor.

6. To maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

We promise to assist in any technical development only after acquiring all the related information or knowledge about the topic in concern

7. To reject bribery in all its forms;

We will not indulge in any form of bribe or malpractices of form.

6.4 FUTURE WORK

After observing the benefits of this project, we consider it a tool that can be widely used in countries where consumption and this type of utilities are permitted (In some countries of the European Union these systems are not legal right now).

Also, we consider that the implementation of these technologies in private households can mean the success of different energy efficiency strategies that have been carried out in the past but have not been successful, such as the valley filling and load shifting. In addition, it would be a decline of public investment in the development of Smart Grid to promote the development of energy storage systems of private capital and a greater involvement of people and the popular consciousness in the next step of energy development. This can be seen accentuated with the development of the electric car, also observed element in this project.

For all this reason, we think this idea has a lot of potential and should be continue. Although the next step could be design a functional module, the next step must be a better and and improved software. The hardware for this project was only designed for educational use and as a proof of concept, but the software could have useful applications in the real world. It could also be designed a hardware but in a real scale for a connection between a real battery and the grid.

Another step could be design a system for implement an energy source such as solar panels and designing and algorithm for it, as the current algorithm is mainly for buying energy, not for sale energy.

Appendix A: Requirements and Verification Table

The following tables explain what were reached in the project and how was the verification process. If the verification status says Y(ES), it means that goal was reach. Otherwise it says N(O).

Hardware systems

	Requirement	Verification	Verification Status
Linear Rectifier	1) Output voltage 14 +/-0.2 V 2) Max ripple 0.4 V 3) Output current 1.4 +/- 0.2 A	1. Verification Process for Item 1: (a) Attach 10-ohm Resistor as load (b) Plug AC/DC rectifier unit into the grid (c) Ensure output voltage it is about 14 V +/- 0.2V 2. Verification for item 2 (a) During process 1 attach an oscilloscope (b) Ensure the ripple is under 0.4 V 3. Verification for item 3 (a) During process 1 ensure the current is between V_{out}/R (should be approx 1.4) +/-0.2A	1. Y 2. Y 3. Y
Boost Converter	1)Input voltage: 11.1 V 2) Output voltage: 28+/- 1 V 3) Max ripple 2 V	1. Verification Process for Item 2: (a) Attach 39-ohm Resistor as load (c) The voltage should be 28	1) Y 2) N

	<p>4) Output current 0.7 +/- 0.1 A</p>	<p>V +/- 1V</p> <p>2. Verification for item 3</p> <p>(a) During process 1 attach an oscilloscope</p> <p>(b) Ensure the ripple is under 2 V</p> <p>3. Verification for item 4</p> <p>(a) During process 1 ensure the current is between V_{out}/R (should be approx. 0.7 A) +/- 0.1A</p>	<p>3) N</p> <p>4) N</p>
Buck Converter	<p>1) Output voltage 12.8 +/- 0.2 V</p> <p>2) Max ripple 0.4 V</p> <p>3) Output current 1.2 +/- 0.2 A</p>	<p>1. Verification Process for Item 1: (a) Attach 10-ohm Resistor as load</p> <p>(b) Ensure output voltage remain above 12.6 at every moment</p> <p>2. Verification for item 2</p> <p>(a) During process 1 attach an oscilloscope</p> <p>(b) Ensure the ripple is under 0.4 V</p> <p>3. Verification for item 3</p> <p>(a) During process 1 ensure the current is between V_{out}/R (should be approx 1.3A) +/- 0.2A</p>	<p>1) Y</p> <p>2) N</p> <p>3) N</p>

<p>Power sensor</p>	<p>1) Accuracy of: Voltage battery Capacity remaining Current</p>	<p>1. Verification for item 1:</p> <p>(a) Before testing the gas gauge, we must ensure that the battery made using a combination of single Li-Ion 18650 batteries is functional. The battery pack is connected using banana cables to the multimeter in order to ensure that the battery voltage is close to 11.1V which is the desired value.</p> <p>(b) Connect the battery gas gauge module to each battery, and connect the SDA and SCL wires from the gas gauge module to the arduino I2C communication lines (SDA and SCL). Run the developed code in order to test that the initial value of the charge capacity of the battery is maximum.</p> <p>(c) Discharge the battery with a current of 3.3 A during 1 hour. Measure with the gas gauge: the capacity remaining must be around 50% and the current 3.3A</p> <p>(e) Check the value read by the Arduino Mega connected to the gas gauge to ensure the correct battery details are received</p> <p>(f) After ensuring individual performance of each battery, connect the batteries to an analog mux, and their subsequent outputs to the gas gauge battery input, thereby</p>	<p>1) Y</p>
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		retrieving battery information from both batteries by manipulating the select bit using the arduino. This ensures that both batteries work consistently using a single gas gauge module.	
Li-ion Battery	<p>1) Li-ion battery 11.1 v 3600mah</p> <p>3 18650 Li-ion batteries Max voltage: 12.6 volts Min voltage: 9 volts</p> <p>2) Each battery must store 3600mAh, -360 mAh tolerance, of charge at 11.1 V</p>	<p>1.Verification for item 1:</p> <p>(a) Draw 0A and measure voltage. It should measure a value between 9 and 12.6 Volts</p> <p>2. Verification Process for Item 2:</p> <p>(a) Attach 10 ohms resistor bank as load</p> <p>(b) The output current should be around 1.1 A.</p> <p>(c) Ensure the current is almost constant. (As the load is linear it must be constant)</p> <p>(d) After 3 hours at least 3200 mAh has been extracted. At that point the battery should continue giving power.</p>	<p>1) Y</p> <p>2) Y</p>

Battery Charger	<p>1) The input voltage it a value around 14 +/-02 V</p> <p>2) The voltage of the battery must be a value between 9 and 12.6 V</p> <p>3) The battery is a li-ion 11.1 V The max voltage is 12.6 V and the minimum is 9 V. Ensure the voltage is always within the limits.</p>	<p>1) Measure the input voltage</p> <p>2) Measure the voltage of the battery</p> <p>3)</p> <p>a) Connect the charger battery and introduce the li-ion battery into the liposack and have in consideration all the safety issues. Measure the voltage every 2 min.</p> <p>b) The battery should increase the voltage after few minutes of charge.</p>	<p>1) Y</p> <p>2) Y</p> <p>3) Y</p>
Relay	<p>1) Relay connected to the Arduino</p>	<p>1) Verification for item 1.</p> <p>(a) Attach a load to the relay</p> <p>(b) When the relay receives information from the Arduino, turn it on. The led associate must be on</p> <p>(c) Otherwise, the led must be off</p>	<p>1) Y</p>

Table 5. Hardware systems R&V table

Software systems

	Requirement	Verification	Verification Status
Control System (Microcontroller)	<p>1) Be able to set up wireless transmission with the cloud system in order to send and receive data properly</p> <p>2) Notify the charge controller to set the voltage based on the input and request (output) voltage.</p> <p>3) Enable the switching controller to decide which battery to be used and set the direction of energy transmission (AC/DC or DC/DC)</p>	<p>1. Wi-Fi Connection Setup:</p> <p>(a) Attach the Wi-Fi Shield to the Arduino Mega 2560 microcontroller</p> <p>(b) Connect the Wi-Fi Shield to the wireless network which operate under 802.11b and 802.11g specifications</p> <p>(c) Enable all the connections with the appropriate wiring as explained in the Arduino Wi-Fi Shield page</p> <p>(d) Program the Arduino to output data onto a database server with a particular HTTP address</p> <p>(e) Send a known data packet through the arduino to the cloud platform to check if the server is receiving the information</p> <p>(f) Send a known data packet from the cloud based UI system and check if the arduino can obtain the correct value from the corresponding database entry</p> <p>2) Connection to the Charge Controller:</p> <p>(a) Check that the logic of the microcontroller code correctly activates the right analog signals</p>	<p>1) Y</p> <p>2) Y</p> <p>3) Y</p>

		<p>corresponding to the batteries in trade. In order to do this, first compile the created arduino code and upload it into the arduino.</p> <p>(b) Attach LEDs in series with the charge controller activation node such that the LEDs light up when 2 batteries get connected. Ensure that the LEDs have significant tolerance to handle high current</p> <p>3) Connection to Switching Controller:</p> <p>(a) Check that the logic of the microcontroller code correctly powers the AC/DC or the DC/DC switch within the switching controller</p> <p>(b) Connect LEDs in series with the switch for debugging if the correct node has been powered between 2 batteries for determining current flow direction</p>	
<p>Cloud Computing Unit</p>	<p>1) Store the energy information (power voltage, percent usage, etc.) for each user in the database.</p> <p>Ex: Voltage: 10V, Charge amount: 6.6 Ahr, remaining percentage: 90.1%, Selling Availability: True, etc.</p>	<p>1. Database server</p> <p>(a) Create a test data packet</p> <p>(b) Send the data to the server, and the received data should be automatically stored in the database</p> <p>(c) Visit the website as a client, post the exact correct test data and request to output the data</p>	<p>1) Y</p> <p>2) Y</p> <p>3) Y</p> <p>4) Y</p>

	<p>2) A database for network, updating the network energy information</p> <p>Ex: The user sells 30% of energy in the battery, when 20% has been bought, the market displays only 10% is available</p> <p>3) Algorithm for setting the market price $P(g)$ based on net energy availability.</p> <p>Ex. Each buying request will raise the market price by 0.5 cents/kwh to its current price. And the selling request does the opposite.</p> <p>4) Algorithm to determine the lowest price and make recommendation.</p> <p>Ex: The price of energy in the grid varies from 1 to 10 cents/kwh based on time (ex. sin function + offset).</p> <p>If $P(g) > 5$, buy from house with 5 cents/kwh</p> <p>Otherwise, buy from the grid with $P(g)$</p>	<p>from the database</p> <p>(d) Use the database command to compare the previously stored data with the sent data, check if the data received (stored in the database) is the same as the data sent to the server</p> <p>2. Verify the data transmission from private usage data to public data</p> <p>(a) Create a test data packet in the private data table, but not in the public data</p> <p>(b) In the private data side, manually change the status of trading entities (ex. Via selling option to sell 30% energy from remaining available etc.) to make sure it meets the criteria needed for the public data.</p> <p>(c) Request to output the private data we just modified. If the test data we modified in the private data could be found in the public side, then it means the data transmission from private side to the public side has already taken place. A piece of data which includes the selling information will be posted on the selling page. And the public data in the market page also have been updated.</p> <p>(d) After finding the test data in the public data table, compare the data in the public and the</p>	
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		<p>private tables to check if the data transmission has completely taken place.</p> <p>3. Computing Algorithm</p> <p>(a) Create a test data packet in the public data table, request for a trade, post it to public.</p> <p>(b) Create another piece of data which meets the trading criteria of previous data created in (a); this will be the buyer in the later step. Mark down the market price</p> <p>(c) Post another piece of data to the public. This should not meet any available request based on the algorithm, since the above two should have already matched up.</p> <p>(d) Now change the trading status of the buyer (start to buy).</p> <p>(e) Assume the transaction is done, search</p> <p>through the public data, check if the seller information is updated. (ex. Available remaining percent: 30% to 10%) The completed transaction data should be set to Invisible, and therefore should not show up in the searching result.</p> <p>(f) Go to the private data table of the seller and the buyer, check if the data information has been</p>	
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		<p>updated. (ex. From 30% to 50%)</p> <p>(g) Check the updated market price after the trade is the price we expected. Since there is less sellers now, the market price should be higher than before.</p> <p>4. Computing Algorithm part2</p> <p>(a) Create a function to simulate the varying energy price from the grid based (ex. Price varies from 1 to 10 cents/kwh)</p> <p>(b) Create a constant price for energy from house (ex. 5 cents/kwh)</p> <p>(c) When the market price is higher than the energy price from house, make a request to buy energy, the recommendation should suggest user to buy from the house with the lowest price, which is 5 cents/kwh here.</p> <p>(d) When the grid price is cheaper, repeat the request in part(c), the recommendation output should be: buy from the grid.</p>	
User Interface	<p>1) Display the information (voltage, energy charge, power, remaining percent) of each battery.</p> <p>2) Display the market information (demander, supplier, target amount,</p>	<p>1. Display the information</p> <p>(a) Create a test data packet in the private data block.</p> <p>(b) Request to get the data from the database server</p> <p>(c) Display the downloaded data, check if the data match with the</p>	<p>1) Y</p> <p>2) Y</p> <p>3) Y</p>

	<p>etc.) of the network</p> <p>3) Send trading request (buy/sell) to server based on user inputs</p>	<p>test data created in the database</p> <p>(d) Repeat steps (a) to (c) but create the test data in the public data table instead.</p> <p>2. Send trading request</p> <p>(a) Create a test data packet in the private data table, but not in the public data</p> <p>(b) Send the trading request with required inputs (ex. status: sell, percent available: 15%, etc.)</p> <p>(c) Search in the private data table to check if the data has been updated correctly.</p> <p>(d) Do the steps (c) and (d) in the data transmission part in the verification part of Cloud Computing Unit to check if the private data information has been posted to the public.</p>	
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Table 6. Software systems R&V table

APPENDIX B: ARDUINO CODE

As an example, in this appendix will be shown some of the most relevant Arduino codes. For this sample, it is shown the code for connecting the Wi-Fi with the server. The code is based on a code of J. Vanderwall. It is not the whole code, just some parts as an example.

```
// Read some paramaters

void readRemainingCapacity()
{
  Wire.beginTransaction(BQ34Z100);
  Wire.write(0x04);
  Wire.endTransmission();

  Wire.requestFrom(BQ34Z100,1);

  unsigned int low = Wire.read();

  Wire.beginTransaction(BQ34Z100);
  Wire.write(0x05);
  Wire.endTransmission();

  Wire.requestFrom(BQ34Z100,1);

  unsigned int high = Wire.read();

  unsigned int high1 = high<<8;

  remain_cap = high1 + low;
}
```

```

void readVoltage()
{
  Wire.beginTransmission(BQ34Z100);
  Wire.write(0x08);
  Wire.endTransmission();

  Wire.requestFrom(BQ34Z100,1);

  unsigned int low = Wire.read();

  Wire.beginTransmission(BQ34Z100);
  Wire.write(0x09);
  Wire.endTransmission();

  Wire.requestFrom(BQ34Z100,1);

  unsigned int high = Wire.read();

  unsigned int high1 = high<<8;

  voltage = high1 + low;
}

Wire.beginTransmission(BQ34Z100);
Wire.write(0x0c);
Wire.endTransmission();

Wire.requestFrom(BQ34Z100,1);

unsigned int low = Wire.read();

Wire.beginTransmission(BQ34Z100);
Wire.write(0x0d);

```

```

Wire.endTransmission();

Wire.requestFrom(BQ34Z100,1);

unsigned int high = Wire.read();

unsigned int high1 = high<<8;

batt_temp = high1 + low;

batt_temp = 0.1*batt_temp;    // Each bit is 0.1K, so we have a value in Kelvins
batt_temp = batt_temp - 273.15;    // Convert to degrees Celsius
}

//Calculate the Power flow

float PowerDraw(float volt, float current)
{
    volt = volt/1000.0;
    current = current/1000.0;
    float power = volt*current;
    return power;
}

//Print the information

void setup()
{
    Serial.begin(9600);
    Serial.begin(57600);
    Wire.begin();
}

void loop()
{

```



```
readRemainingCapacity();
Serial.print("Remaining Capacity: ");
Serial.print(remain_cap);
Serial.println(" mAh");

readVoltage();
Serial.print("Battery Pack Voltage: ");
Serial.print(voltage);
Serial.println(" mV");

power_draw = PowerDraw(voltage,avg_current);
Serial.print("Power Draw: ");
Serial.print(power_draw);
Serial.println(" W");

Serial.print("\r\n");

delay(5000);
}
```

APPENDIX C: HTML CODE

The following code is an example for the User interface code. It has been used HTML, CSS and PHP language. The code is not the whole code, just the man body for being used as an example of the market page:

//The next lines show the navbar on the top

```
<div class="container">
  <div class="navbar-header">
    <a class="navbar-brand" href="#">Smart Batteries</a>
  </div>
  <div>
    <ul class="nav navbar-nav">
      <li class="active"><a href="market.php">Market</a></li>
      <li><a href="yourbattery.php">Your battery</a></li>
      <li><a href="SellEnergy.php">Sell Your Energy</a></li>
      <li><a href="BuyEnergy.php">Buy Energy</a></li>
      <li><a href="ChargeCar.php">Charge your car</a></li>
      <li><a href="https://www.esios.ree.es/en/pvpc"> Red Eléctrica </a></li>
    </ul>
  </div>
</div>
</nav>
```

//The next lines show the main body of the user interface, where all the information can be found.

```
<center>
  <div class="column">
    <p>Events You Host: </p>
  </div>
  <div class="col-md-6">
```

```

    <p>Events You Attend: </p>
</div> -->
<div class="row-md-6">
    <p>Current price of the energy:
    <?php
        $currentPrice = file_get_contents('http://localhost:8888/currentprice.php');
        echo $currentPrice;
    ?>
    €/Kwh </p>
</div>
<div class="row-md-6">
    <p>Max price of the energy:
    <?php
        $maxPrice = file_get_contents('http://localhost:8888/maxprice.php');
        echo $maxPrice;
    ?>
    €/Kwh </p>
</div>
<div class="row-md-6">
    <p>Min price of the energy:
    <?php
        $minPrice = file_get_contents('http://localhost:8888/minprice.php');
        echo $minPrice;
    ?>
    €/Kwh </p>

</div>
<div class="row-md-6">
    <p>Current price of your battery: -- €/Kwh </p>

</div>
</div>
</center>
</div>

```

```
<br><br>
<div>
  <center>
    <div class="row">

// The following lines shows the configuration of the bottoms

    <form action="SellEnergy.php">
      <button class="btn btn-lg btn-primary" type="submit" onclick="sell_energy()"
value="sell"> Sell </button>
    </form>
    <br>
    <form action="BuyEnergy.php">
      <button class="btn btn-lg btn-success" type="submit" onclick="buy_energy()" >
Buy </button>
    </form>
  </div>
</center>
```

References

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