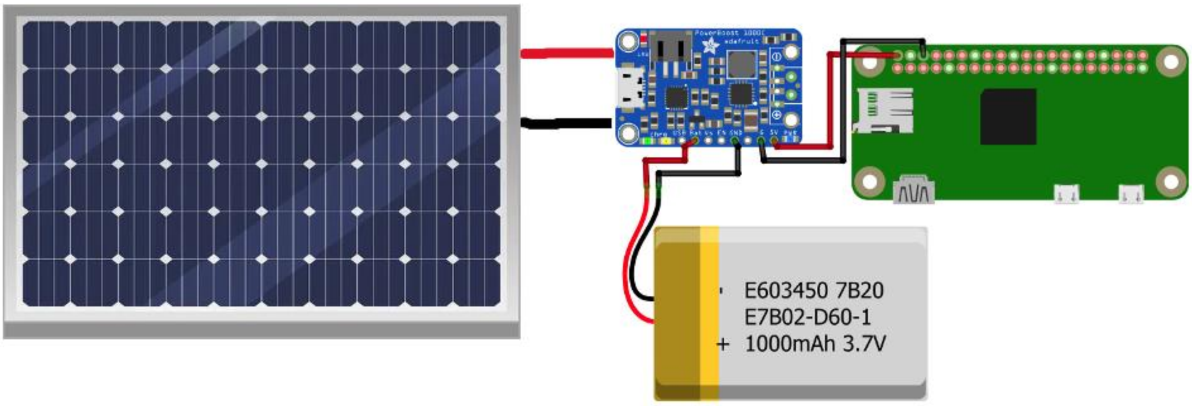
Universidad de La Laguna

Solar system by Raspberry Pi



Student: Aythamy Pérez Moyano

Abstract

The present project gathers the specifications and requirements necessary for the selection of a series of electronic devices to carry out the integration of an autonomous solar electronic module using the Raspberry Pi platform. Thanks to this board, a series of HDR images can be processed remotely and uploaded to a database through 4G connectivity, achieved through the SIM7600E-H module. To achieve this, both systems need to have a constant power supply, made by an independent module of generation and accumulation of solar energy, which will have the specific parameters that allow the complete system to have enough energy in isolation.

Content

Table of figures

Introduction

An autonomous energy system is one that is not connected to the electrical grid, so that it can count on sufficient energy to operate independently. For this, it is necessary to take advantage of some of the resources available in the environment to generate the electrical energy demanded by this system, so that it can operate with the appropriate energy requirements.

The resource chosen for this particular project is precisely the reason for which the installation of the same device is intended in this exact area: solar energy. In this way, the total energy efficiency provided is even greater by having an autonomous and isolated system that can operate without the need to demand energy from the electrical grid.

This is an abundant resource in the space where the system is to be installed, resulting in a good alternative for its power supply. In this way, it provides a complete system that improves energy efficiency in a broader way by not requiring energy consumption through the grid and providing valuable information for improving the efficiency of the solar panels in the same area.

However, since this is a nearly constant consumption and a limited resource, sufficient storage capacity is needed to regulate the energy that will be demanded by this system. The advantage results in that the highest energy load occurs precisely when the abundance of the energy resource is higher, since its installation will be in a solar park for the correct realization of the predictions.

Thus, each of the autonomous generation systems (one for each load circuit) is composed of the following elements, and the specific specifications of each of them can be consulted individually in the corresponding annexes:

- Solar panel 6 W
- Charge regulator *bq24074*
- Batteries type LiPo 18500

The charging system, i.e. the one intended to be powered by autonomous generation, includes each of the following elements:

- Raspberry Pi (models 3B and 4).
- HD camera
- SSD hard disk
- 4G HAT SIM7600E-H 4G modem

The following is a description of each of the elements that make up both systems, and the necessary interaction between them to establish the electrical connection and be able to provide power in an adequate way.

Description of systems

Consumer system (load)

The main objective of this project is to provide an isolated and autonomous electricity generation system (in the absence of network and connectivity) so that it is possible to feed the electrical load demanded by the output circuit, and at the same time, to have enough energy to restart the system if necessary.

The following schematic image shows the symbolic arrangement of the elements of both systems, being able to identify the generator system formed by the board, the regulator [2] and the battery (of different characteristics), and the main system can be identified as the Raspberry board, which would be used together with the rest of the auxiliary elements connected to it: a camera, an SSD hard disk and a HAT 4G modem. In the following image you can see the complete set of elements installed on the board, and which would result in the complete system to be powered:

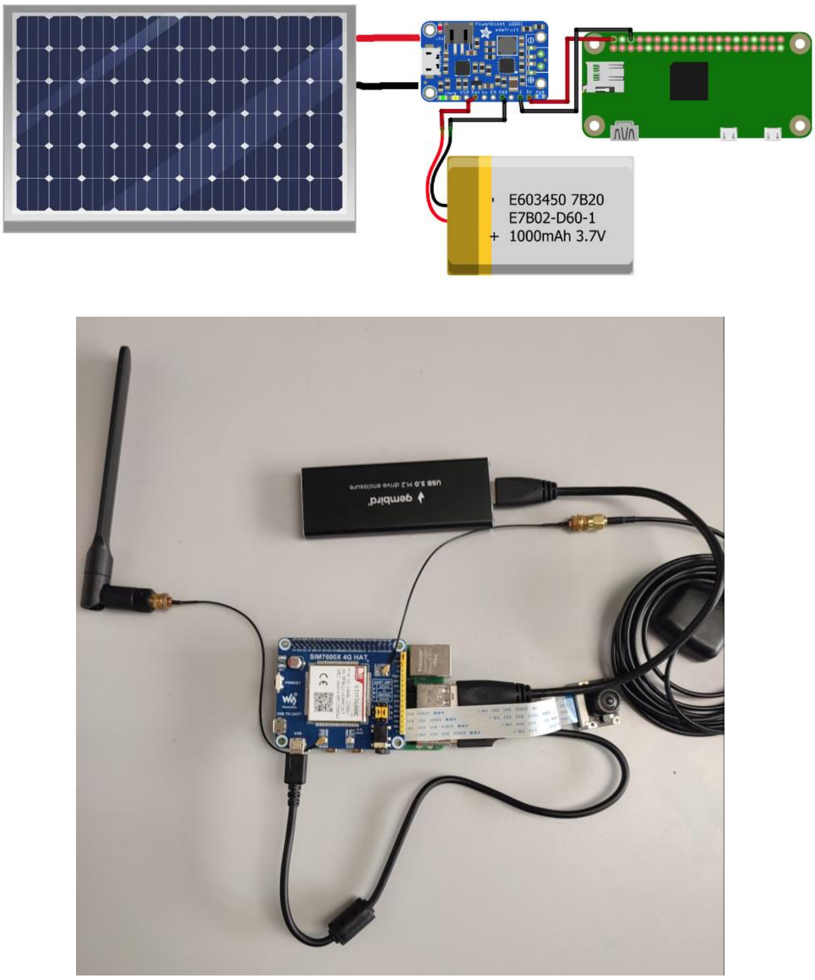


Figure 1: Connection diagram and system to be supplied

The Raspberry Pi board is a device that functions as a small-board computer, i.e. as a single-board computer (SBC), which makes it very affordable, making it perfect for educational projects related to computing. (Raspberry Pi ORG, 2022)

This system is controlled by the Raspberry Pi computer board (models 3 and 4), connected to a camera, a 4G HAT modem and an SSD hard drive. The complete system as a whole setting up its image capture function and its corresponding upload to a server via 4G connectivity produces a load curve as follows:

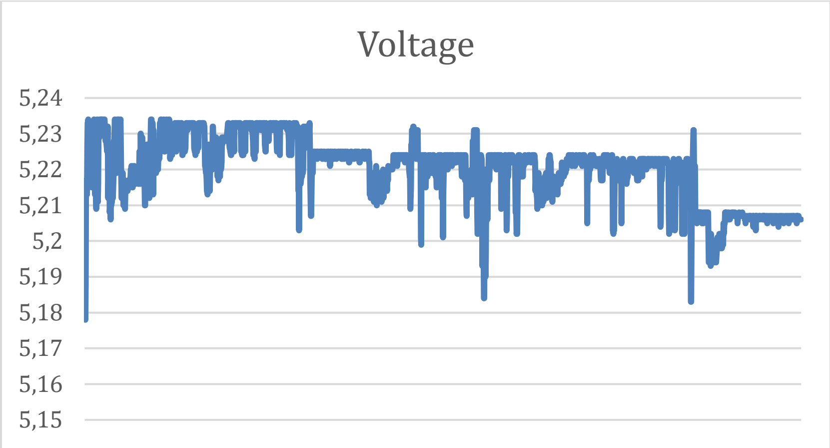


Figure 2: Full-load voltage measurements by UM25C

While in the hibernation or "idle" state, different consumption data is obtained, with lower average power due to the computational cost of the process. The data during this state can be observed in the following graphs, in which the only appreciable voltage peak corresponds to the processing of the 4G connection through the modem:

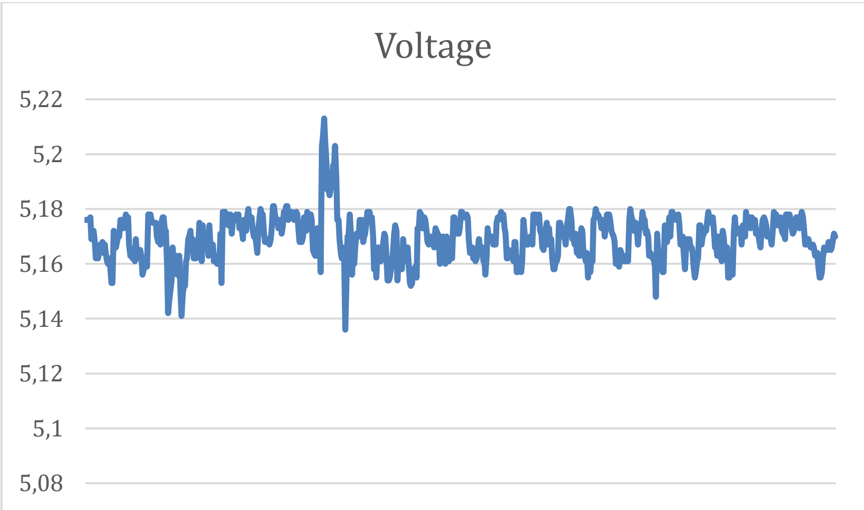


Figure 3: Voltage measurements by UM25C

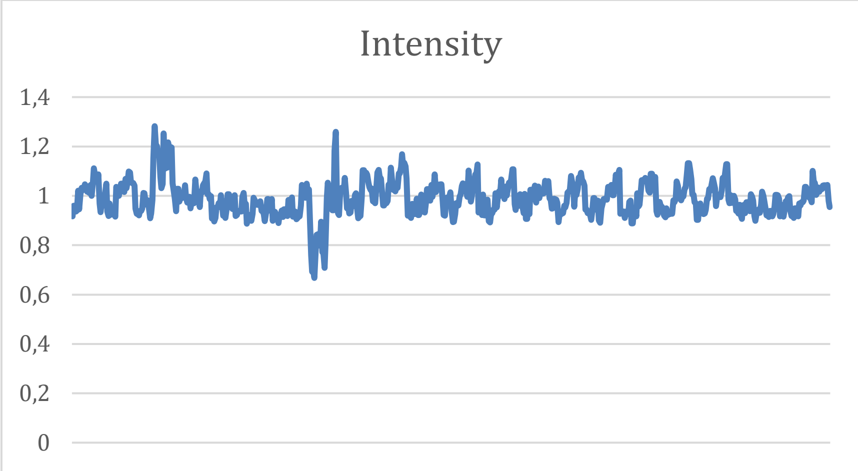


Figure 4: Intensity measurements using UM25C

The device used for the measurements was the USB tester, specifically the UM25C. This tester has Bluetooth connectivity, so that the reading data could be downloaded to a computer and synthesized using Python, so it is the actual load curves of the system operating at full capacity with the elements that contribute to its operation and when the board is not performing any activity, i.e., in "idle" or rest mode.

In this way, knowing the consumption of the complete system, both at full load and in hibernation state, it is possible to start the necessary calculations to size the necessary components that result in the proper operation of the generator system. Using this information, we proceed to the calculation of the elements to establish the power supply autonomously by means of the accumulation system with batteries. That is why the batteries must be sized to support the desired autonomy, using the consumption data for the calculations.

Generator system

The generation system to be implemented consists of the integration of a small photovoltaic panel that, together with the corresponding charge regulator, can provide an adequate current to recharge the lithium batteries, which in turn will be the ones feeding the charging circuit (Raspberry). This accumulation system consists of a module of 18500 LiPo batteries connected in parallel.

Before specifying the configuration of the energy system, it is necessary to carry out an exhaustive study of the electrical demand of the system to be powered (load). That is why a brief summary of the different components of both systems is made, and the different consumptions stipulated and measured for the same are exposed.

To start sizing the generator system, it is necessary to specify the dimensions of the solar panel required in order to establish the adequate power, both to the batteries and to the fed system. That is why the electrical demand of the system to be fed must be known with the appropriate measurements, and through electrical calculations, determine what power to choose for the construction of the generator system.

As it has been observed, the system at full load consumes an average of 1'3 Ah and 5'2 V. This is equivalent to an average power used of 6.7 Wh, so just to make the charging circuit work during the first 12 hours of the day (between 8:00 and 20:00) it will be necessary to provide a minimum power of 82 Wh for the correct electrical operation of the system.

To achieve the proper recharge of the batteries chosen for the accumulation system, it will be necessary to provide extra energy, i.e., energy that will not be used to power the charging system, and that is also sufficient to ensure that the batteries are well recharged and can withstand the desired hours of autonomy. The selected battery capacity will be specified at a later date. For the time being, in order to effectively recharge the batteries, a minimum of 100 Wh more will be needed, with a total of 182 Wh produced in the first 12 hours of the day.

The generator selected for integration in this system is the generator marketed by "incoingenieros" [3] with a generated power of 15 W provided at 6 V. This guarantees a generation according to the values intended to be transmitted to the system, and on a sunny day should ensure both adequate recharging of the batteries and power supply to the charging system.

However, it is proposed to make use of a panel that can provide a higher power output, since it is necessary to take into account days in which, due to cloudiness or extreme temperatures, the power output may be different. In addition, this avoids losses due to faulty wiring and electrical circuits, while supplying the batteries with sufficient power to be optimally charged.

The specifications of the chosen board can be consulted in the corresponding annex.

Figure 5: Polycrystalline solar panel

Accumulation system

The accumulation of the energy captured by the solar panel is one of the most important factors to be taken into account in order to provide sufficient autonomy to the rest of the components. This is possible by means of a battery module connected in parallel, which consists of devices made up of electrochemical cells that convert the stored chemical energy into electric current.

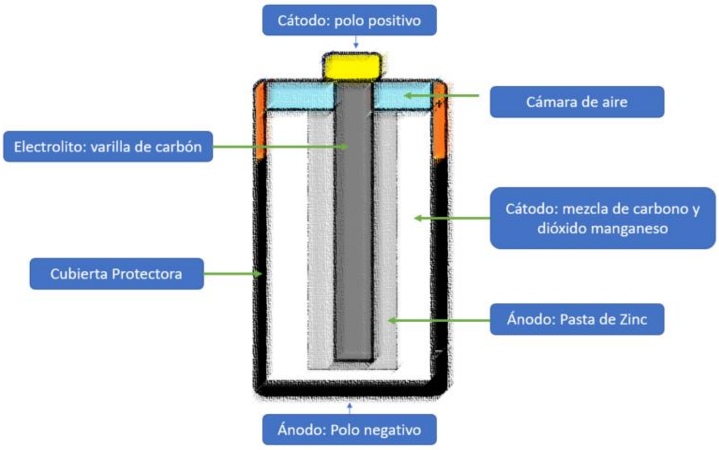


Figure 6: Elements of a battery [4]

Each cell, therefore, will have a positive electrode, or cathode, a negative electrode, also called anode, and the electrolyte that allows the ions to move between the two electrodes [4]. The movement generated by the electromagnetic attraction of the ions is what allows current to be generated to power an electrical circuit.

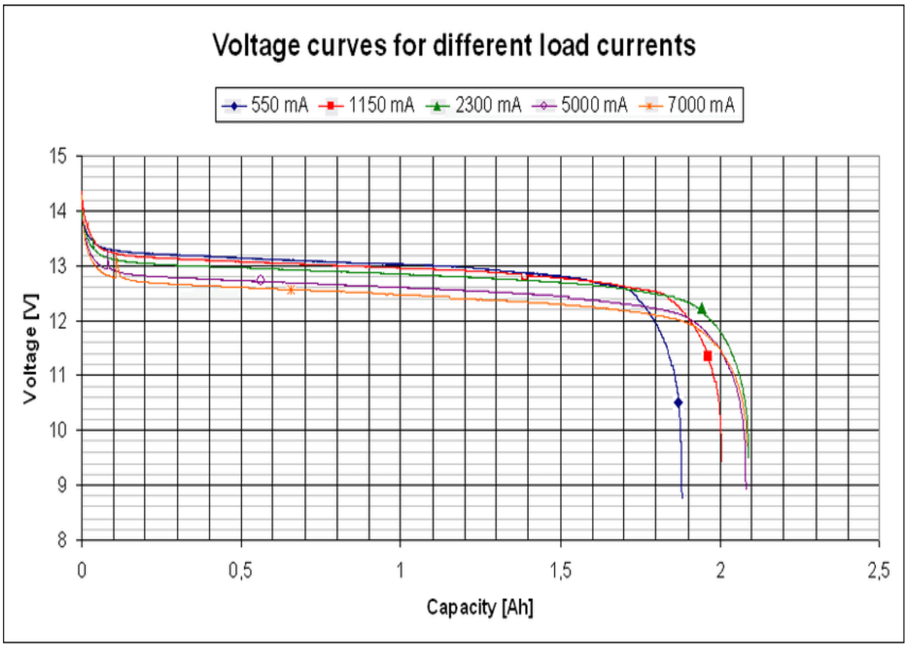


Figure 7: Voltage - Capacity curves

There are several types of energy storage systems. The best known are probably the lead-acid batteries used in automobiles, which are composed of two lead electrodes in a sulfuric acid solution that acts as electrolyte.

Type	**Energetic density (W/kg)**	**Voltage (V)**	**Nº recharges**	**Charge time (h)**	**Self-discharge (% monthly)**
Pb	30-40	2	1000	8-16	5
Ni-Fe	30-55	1,2	>10.000	4-8	10
Ni-Cd	48-80	1,25	500	10-14	30
Ni-Mh	60-120	1,25	1000	2-4	20
Li-ion	110-160	3,7	4000	2-4	25
Li-Po	100-130	3,7	5000	1-1,5	10

Table 1: Characteristics of different types of batteries

The most widely used type of battery today is the lithium-ion battery: these use a graphite anode and a cathode of cobalt oxide, triphilin or manganese oxide. This is a relatively recent technology and provides higher energy density, with better discharge capacities for longer life and no memory defects. Voltage data related to the charge capacity of these batteries are as follows:

- At full charge: 4.2 - 4.3 V.
- At nominal load: 3.6 - 3.7 V
- At low load: 2.65 - 2.75 V

The batteries used for the storage circuit of the present project are the so-called lithium polymer (LiPo) batteries, which are a variation of lithium ion (Li-ion) batteries, with very similar characteristics and offering higher energy density as well as higher discharge rate. As they have the lowest memory effect, they are the most suitable for a project of this type. [5]

In order to choose the correct amount and disposition of the batteries, it is needed to calculate by the consumption needs and the autonomy required. The calculations made to know the total amount of energy required to be suplied are as follows:

	Magnitude	Units
Consumption	1,4	A
Time	12	h
Result	16,8	Ah
Consumption	1	A
Time	12	h
Result	12	Ah
Total consumption (24 h)	28,8	Ah

Rounding, the total amount of Amps-hour to supply is about 30 Ah per day. So the total accumulation system needs to be able to grant this quantity. Specifically, the batteries chosen for their parallel connection and, therefore, the accumulation of their capacity without varying the output voltage, are those marketed by Adafruit, with a capacity of 10050mAh. The maximum recharge current for these batteries is 3000 mA, which is in accordance with the maximum output current of the selected panel. [6]

Figure 8: Adafruit 10050 mAh Battery

To know the total quantity of batteries needed to be connected in parallel, in order to achieve the autonomy required by the system, the next calculations are made:

	Magnitude	Units
Daily Ah required	30	Ah
Maximum days of autonomy	4	days
Ah required x Autonomy days	120	Ah
DoD (Depth of Discharge)	0,8	%
Ah required / DoD	150	Ah
Battery Ah rating choosed	10,05	Ah
Battery capacity / Choosen Battery Ah ra	14,925	Nº
Result (Number of batteries in parallel)	15	Batteries

Charge regulator

The solar panel is responsible for transforming the solar irradiance received into electrical power. Therefore, the energy produced will fluctuate, making it difficult to maintain a constant value of the net electricity produced at all times. This results in peaks (sudden rises) or ramps (drops) of the energy produced by the panel, being a risk for the electrical components powered in this way, since this variation in the power supply can lead to certain failures of the implemented components.

That is why it is really necessary to install a certain electrical component to control these fluctuating parameters of voltage and current, so as to provide a constant and safe value of the same and to establish the energy in a stable manner at all times. This element is the charge regulator, which must be of adequate dimensions to achieve the establishment of the electrical connection between both systems, generator and consumer. This element will be, therefore, in charge of charging the lithium batteries chosen for the energy storage system provided by the solar panel, and at the same time, use the energy already accumulated in these batteries to feed the consumer system with the energy required by it at all times.

Normally, charge controllers use different stages for charging a battery system, depending on the state of the batteries and the power generated by the panel at each moment. This provides some adaptation to the operation of the batteries themselves, while avoiding possible overcharging. This occurs because the regulator uses different stages to control the energy, so that the voltage, the main indicator of the charge level, is measured and used by the regulator to determine how to provide the current to be stored, while an overvoltage protection prevents higher electrical magnitudes from damaging the storage system.

The different stages that can take place are as follows:

- Bulk stage: this is the stage in which the maximum possible current is provided, until the first voltage limit is reached, charging the battery approximately 90 % at this point. Depending on the storage system chosen, the voltage limit can vary greatly, being 12.6 V for most of the battery systems used, but depending exclusively on the sum of the nominal voltages of each of the cells used to store energy connected in series.

- Absorption stage: the charging rate is decreased until the total charge is completed. The voltage reached in this stage will be the maximum available voltage reached in the Bulk stage and the maximum capacity provided by the battery, delimited by the absorption limit.

- Float stage: the voltage decreases as the injected current decreases so that the battery filling can be completed safely.

There are different types of solar charge controllers, differing mainly in the way each determines the charging of the storage system:

- PWM solar charge regulators: these regulators decide the charge based on the state of the battery and the power generated at any given moment, working at the same nominal voltage as that used by the batteries. What they use to top up the battery are voltage pulses.

- MPPT solar charge regulators: this type of regulators are responsible for supplying electrical energy using the voltage at maximum power of the panel, thus making the most of the energy without stressing the batteries. However, it is not advisable to use this type of regulators in installations using values lower than 24V and 60 cells.

Specifically, with the chosen system, the device marketed by Adafruit bq24074 is suitable. This device consists of two main components: a DC/DC converter, which transforms the voltage emitted by the solar panel (between 5 and 10 V) to the voltage required for the correct charging of the batteries (3.7 V) and a battery charge regulator type TP4056 [7].

The following image shows the behavior of the selected charge regulator for different IV curves, demonstrating that this regulator works as an MPPT:

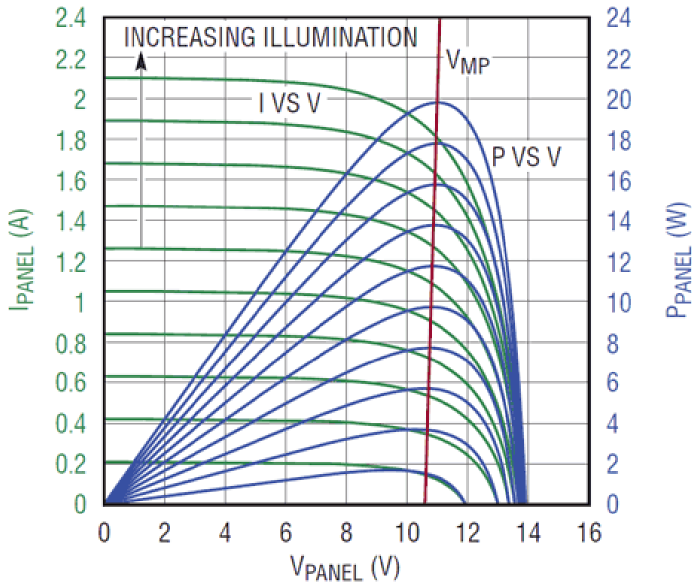


Figure 9: Establishment of VMP for different IV and PV curves [8]

This chip, compared to its predecessor (*MCP73871*), is a charge regulator with several modifications that give it a dynamic stability that prevents the oscillation that can occur between current and voltage that can cause some kind of incident in the system load. The new *bq24074* charger is specially designed for this type of situations, solving them by entering the Input Dynamic Power Management Mode (Input DPM), which consists precisely in detecting when the generation falls below 4.5 V, decreasing (or increasing if necessary) the charge rate, so that the voltage remains above 4.5 V almost automatically. The following image shows an example of the input in this mode:

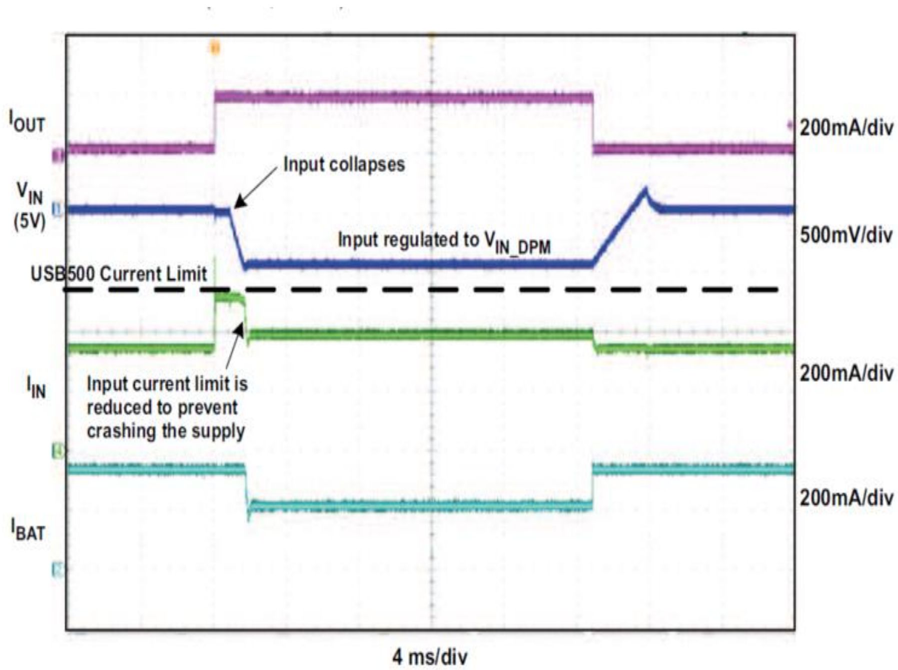


Figure 10: bq24074 Input DPM setting

Once the connection between the panel and the batteries is established through the charge controller, the next step is to use this same controller circuit to establish the connection between the energy storage system and the system to be powered: the Raspberry Pi board. In this way, the same charge controller can directly connect the batteries to the board by establishing a simple USB power cable, providing stable battery power for proper operation. The connection with the batteries is established through the outputs provided for this purpose (LiPo), while the input to which the energy captured by the chosen solar panel will arrive will be the one established through the "Jack" header. In the following image you can see this component:

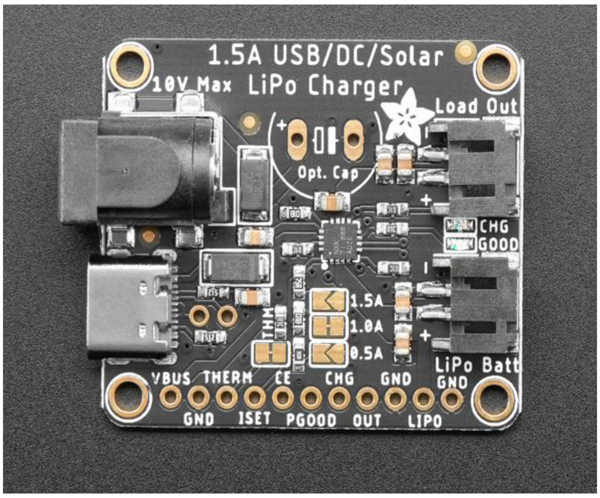


Figure 11: Charge controller bq24074

However, as the voltage provided by the batteries is 3.7 V and the voltage required for the operation of this system is 5 V, a final intermediate element is necessary to increase the output voltage of the storage system. It is a chip that allows to control the voltage, in case the one provided by the batteries is different from the one required by the system to fully operate. It is a voltage booster device, commonly called "Booster", which consists of a boost converter that, through the use of transistors and the frequency of the analog electrical signal, act as if they were small transformers, allowing to vary these levels of voltage or intensity.

For the operation of the present system it is proposed the use of one of these devices that is marketed by Adafruit, since it is an element widely used and improved over time by this same company. The name of the component that is suitable for the present project turns out to be the *PowerBoost 1000 Charger* [10], it admits an input voltage between 2 and 24 V, and can offer an output voltage between 5 and 28 V, being its maximum output current of 2 A, which is suitable for the circuit in question according to the calculations made for the consumption of the system.

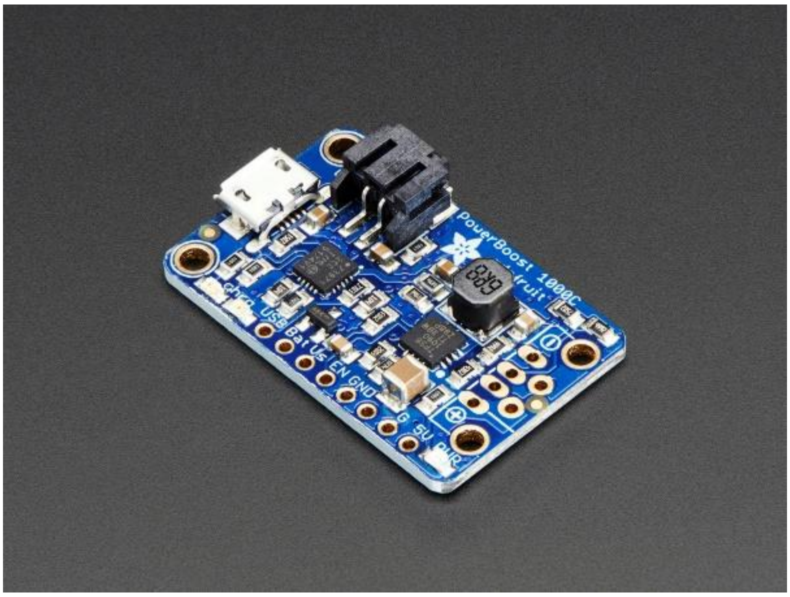


Figure 12: PowerBoost1000 Charger

Conclusions

In conclusion, the project would contribute to the improvement of the energy efficiency of a solar farm by measuring the state of the sky through the Raspberry Pi platform. This, in addition, would integrate its own power generation through the generator circuit explained, taking advantage of the abundant energy availability in the area where the project is intended to be installed.

In this way, previous knowledge about electronics, power electronics, electrical components, data analysis, programming and determination has been strengthened. The commissioning of the set described in the project could not be tested in practice mainly due to the lack of most of the electronic components, which would be the determining step to know the behavior of the set.

The calculations made for the knowledge of the generation needs have been possible thanks to the acquisition of the USB tester, by means of which it has been possible to choose the rest of the components of the generator circuit.

It is expected that the circuit can be useful in its integration for the improvement of energy efficiency in solar parks, or that it can serve as a reference for the improvement of this type of systems.

References

[1]: Raspberry Pi ORG. (2022). *Raspberry Pi*. From **https://www.raspberrypi.org/**

[2]: Ramirez, R. (2021). *Circuit Basics*. From https://www.circuitbasics.com/how-to-make-a-solar-powered-raspberry-pi/

[3]: IncoIngenieros. (2022). *IncoIngenieros web*. From https://incoingenieros.eu/panel-solar-policristalino-6v-15w/#

[4]: SolElectro. (2022). *Sol Electro Shop*. From https://solectroshop.com/es/blog/x-n71

[5]: Prometec. (2022). *Prometec*. From https://www.prometec.net/elegir-bateria-lipo/

[6]: Adafruit. (2022). *Adafruit 10 Ah battery*. From **https://www.adafruit.com/product/5035**

[7]: Hwlibre. (2022). *TP4056 charger*. From https://www.hwlibre.com/tp4056/?utm_source=feedburner&utm_medium=feed&utm_campaign=Feed%3A+hwlibreweb+%28Hardware+libre%29

[8]: Adafruit. (2022). *Adafruit bq24074.* From https://learn.adafruit.com/adafruit-bq24074-universal-usb-dc-solar-charger-breakout/design-notes

[9]: Circuit Basics. (2022). *How DC-DC converters work*. From https://www.circuitbasics.com/what-are-dc-dc-converters/

[10]: Adafruit. (2022). *PowerBoost 1000.* From https://www.adafruit.com/product/2465

Appendix I: Inventory of elements

Solar panel 6V 15 W: https://incoingenieros.eu/panel-solar-policristalino-6v-15w/#

Adafruit 10050 mAh Battery: **https://www.adafruit.com/product/5035**

MPPT Solar Charge Regulator: https://www.adafruit.com/product/4755

PowerBoost 1000 Charger: https://www.adafruit.com/product/2465

Appendix II: Datasheets

Solar panel

Panel solar fotovoltaico altamente eficiente que convierte la energía solar en energía eléctrica. Ideal para cargar batería de 3,7 V de proyectores solares led y otros dispositivos electrónicos.

Sus células solares son altamente eficientes y logran convertir hasta el 19,5% de la energía solar en energía eléctrica.

Ecológico: un panel solar que reducirá los costes de la factura de energía eléctrica y ayuda a frenar las emisiones de carbono.

El panel fotovoltaico dispone de un cable de 3m con conector DC y protección IP65 a prueba de agua.

Ampliamente utilizado en casas y carreteras rurales, calles residenciales, aceras, parques industriales, parques, jardines, calles, plazas, etc.

Especificaciones:

- Material: Silicio policristalino
- Color: negro
- Voltaje de funcionamiento: 6V (puede ser utilizado para cargar la batería de 3,7 V)
- DC puerto: 5521
- Temperatura de funcionamiento: 0 a + 50 °C
- Longitud del cable: 300 cm
- Tamaño del producto: 35 * 35 cm

Peso	1,220 kg
Dimensiones	350 × 17 × 350 cm
Marca	Ledbox
Interior/Exterior	Exterior
Protección IP	IP65
Certificados	CE, ECORAEE, RoHS

Battery

Technical Details

- Nominal Capacity
  - Minimum: 9500mAh
  - Typical: 10050mAh Standard discharge (0.2C) after Standard charge
- Nominal Voltage 3.7V
- Charging Cut-off Voltage 4.2V
- Discharge Cut-off Voltage 2.5V
- Standard Charge
  - Constant Current 0.2C
  - Constant Voltage 4.2V 0.01 C cut-off
  - Charge Time : Approx 8.0h
- Maximum Constant Charging Current 3000mA
- Standard Discharge Discharge at 0.2 C to 2.5V
- Maximum Continuous Discharging Current 3000mA
- Operating Temperature Charge 0 ~ 45℃
- Discharge –20 ~ 60℃
- Storage Temperature -20 ~ 45℃ for 1Month -10 ~ 35℃ for 6Months
- Storage Voltage 3.7-3.85V

Product Dimensions: 66.6mm x 55.3mm x 18.7mm / 2.6" x 2.2" x 0.7"

Product Weight: 148.0g / 5.2oz