SOLA GRATIA FARM PITCHED PROJECT

Design Document

28 DE FEBRERO DE 2020

PROJECT 73

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Summary

1. INTRODUCTION

1.1. Problem and Solution Overview

Sola Gratia Farm is a charity organization that donates at least 10% of its production to hunger programs. The farm does not invest a lot of money on improving their items, they depend on major cases from external donations. In the case of the electricity the get it from the Ameren Line which comes from the church. This line has a capacity of 75A, however, an electrician that talk with the farmers told them to not overload the line above 70A to avoid tearing up the breakers. Currently, they have on their facilities two coolers, one greenhouse and one high-tunnel, a wellhead and a shed. Inside these places, there are located heaters, lights, fans and compressors which take power from the line. During a full test of use, it was found that the line was running at 37-38 A, those numbers could increase during the items' start-up, the moment in which they demand the greater amount of energy.

The problem arises at the moment they want to add a new third cooler and new heaters and fans. The heaters and fans won't be a problem as the amount of energy they demand are much smaller in comparison with the energy demanded by the cooler. The electrician that talked with the farmers estimated that adding these new items to the farm will cause an overload on the line being above the 70A of maximum capacity. Again, our field of study is the start-up period.

The solution we suggest is trying to reorganize the electrical installation of the farm making it more efficient and less dependent on the Ameren Line. To achieve that we have thought of adding solar panels and batteries to supply extra energy to the farm's items. Moreover, we plan to include a current limiter to avoid exceeding the maximum capacity of the line. The batteries and solar panels will be monitor by a microcontroller which, with the help of a Hall Effect current sensor, can measure the current over the line, the one supply by the solar panels and by the batteries. With this, the microcontroller will be able to activate/deactivate MOSFETs to reduce the current through the line and take the needed current from the batteries and the solar panels.

1.2. Visual Aid

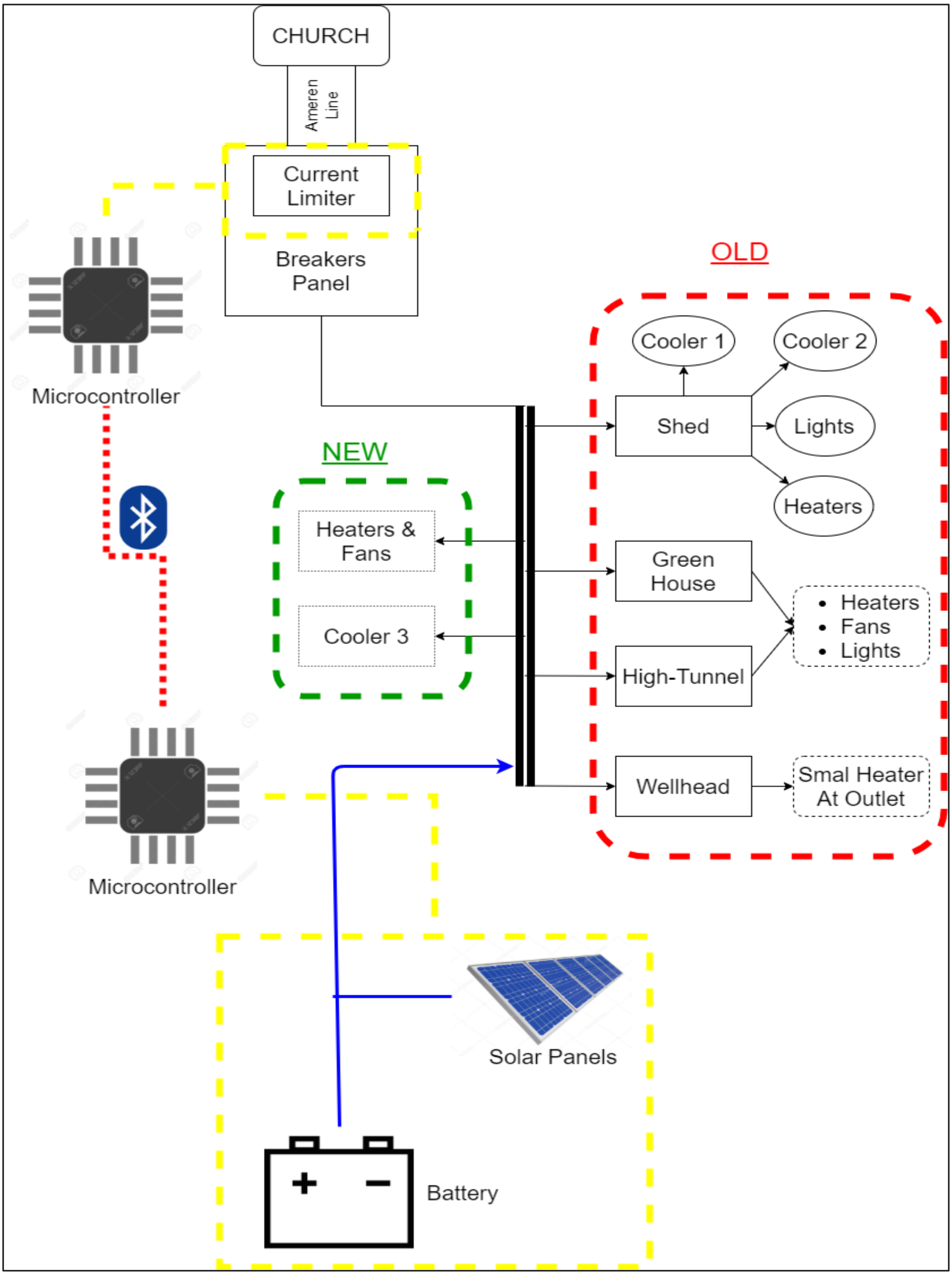


Figure 1: Visual Aid Schematic

1.3. High-level requirement list

- Remaining the line at a maximum of 70A without overloading it. Being able the third cooler they need.
- Make the installation efficient reducing the amount of current through the line if the solar panels and batteries are able to supply part of the demanded energy. The microcontroller should take care of this.
- Efficient choice of the solar panels making the installation cheaper and useful.

2. DESIGN

2.1. Block Diagram

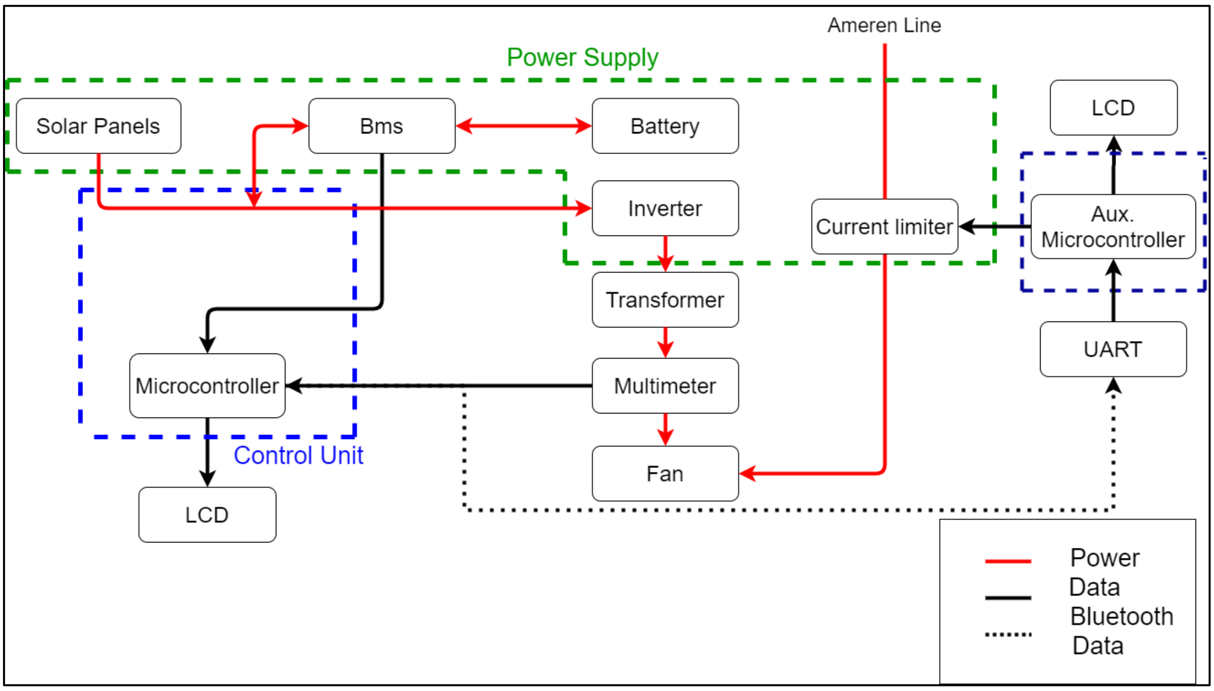


Figure 2: Block Diagram

2.2. Subsystems

2.2.1. Power Supply

2.2.1.1. Current Limiter:

The current limiter will be placed just before the breakers' panel to avoid exceeding the maximum capacity of the line, 70A. The input will be connected to the current supply, in this case, the Ameren Line, and the output to the breakers' panel. To achieve this goal, we are going to use a TRIAC as an AC switch to allow current during that part of the cycle when the voltage is below the limit we are going to set. For this, we will make use of a current sensor just before the TRIAC. The current sensor will be measuring current every time, and at the moment it reached the level we have set, the microcontroller will send a 0 to open the TRIAC and stop flowing current, during the allowed window under the current limit the microcontroller will send a 1 to the TRIAC to close the switch and allow the current flow. So with this implementation loads will not be working at their 100% of their efficiency, however, they will be complemented with the current supplied by batteries and solar panels.

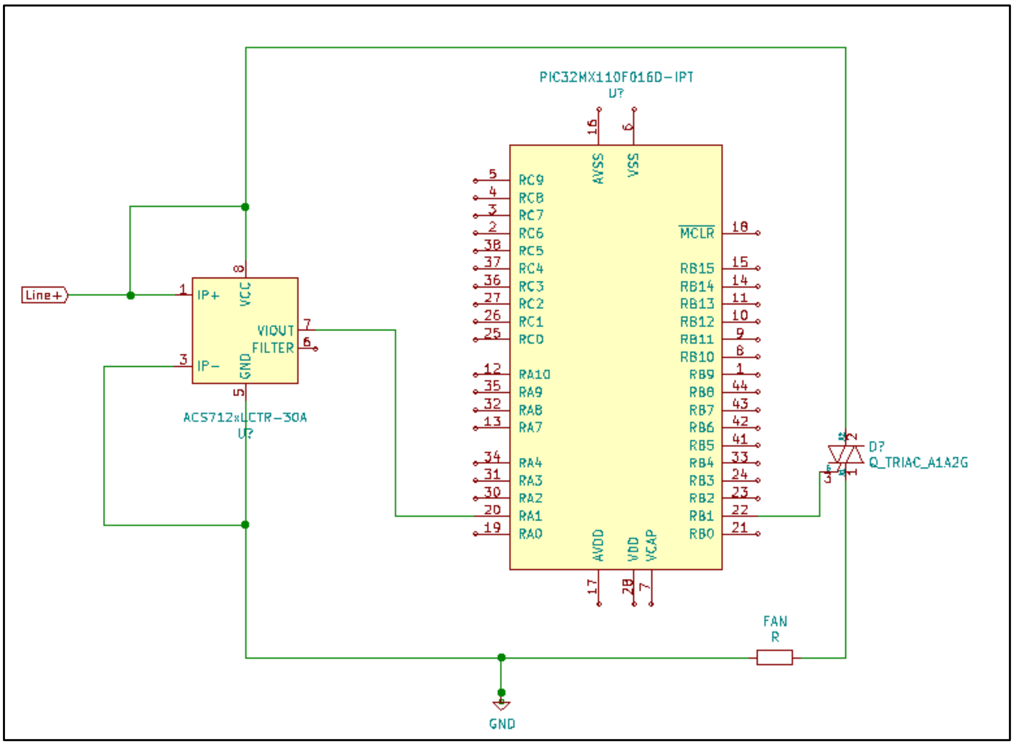


Figure 3: Current Limiter Schematic

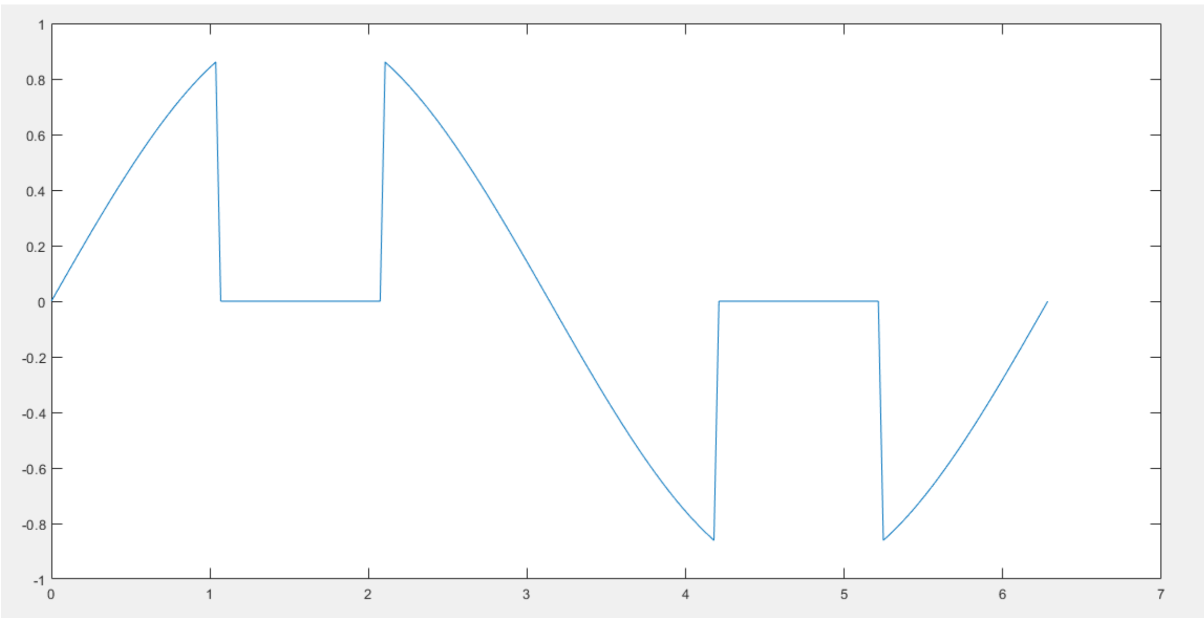


Figure 4: Current's graphic after limiter

Table 1

Requirement	Verification
Avoid overloading the line over the current limit set by the microcontroller	Checking the LCD and/or using a digital ammeter during the demo.

2.2.1.2. Photovoltaic Solar Panels:

Depending on the electric power consumption we will choose the panels that fit better. There are three types of silicon solar panels, monocrystalline, polycrystalline and thin-film amorphous.

	Monocrystaline Panels	Polycrystaline Panels	Thin Film Panels
Type			
Efficiency	14% – 18% cell efficiency	12% – 14% cell efficiency	5% – 6% cell efficiency
Temperature Tolerance	0% +5%	-5% +5%	-3% +3%
Life Time	25-30 year life span	20-25 year life span	15-20 year life span
Durability	Hail resistant 25 year P & M	25 year P & M warranty	25 year P & M warranty

Figure 5: Photovoltaic Solar Panels Types' Comparison

Although the monocrystalline one seems to be the most efficient one we will choose the polycrystalline because of its price as it is cheaper than the monocrystalline and it still works well.

Table 2

Requirement	Verification
Produce energy to reduce the current that comes from the line	Discharging the batteries and checking in the multimeter the current that will only be produced by the solar panel

2.2.1.3. Batteries:

Depending on the electric power consumption we will choose a bigger set of batteries or if the consumption is relatively low we will choose smaller ones. There are 3 types of batteries:

- Lead Acid: These batteries are the cheapest ones and have been used for off-grid energy systems for decades. they have also a small Depth of discharge and are heavy

- Lithium-Ion: They are commonly used in energy storage devices at home. the have longer lifespan and bigger Depth of discharge than the Lead acid ones. As a disadvantage, they are more expensive than the Lead acid ones.

- Saltwater. These batteries don’t contain heavy metal relying instead on saltwater electrolytes. Their recycling process is easier than the one of the lithium and lead acid batteries.

As we can see in the next image this is the comparison of the cost, the lifespan, and the DoD.

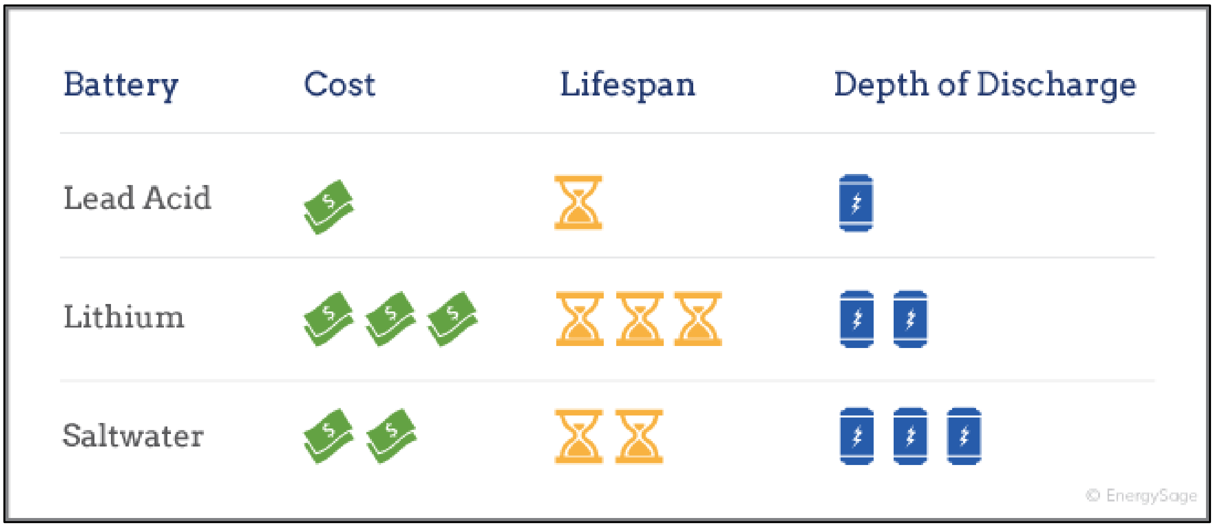


Figure 6: Batteries Types' Comparison

We are planning to use Lithium Ion batteries because, as we can see in the previous image, they offer the best characteristics.

Table 3

Requirement	Verification
Help solar panels supplying the load	Covering the solar panel so that all the current that we will check in the multimeter will be produced by the batteries
Be able to be charged by the solar panel	Disconnecting the load, all the current will be dedicated to charge the batteries, so checking the voltmeter we will see the batteries’ levels increase

2.2.2. Sensors

2.2.2.1. BMS:

Battery Management System is an electronic device that allows you to protect the batteries when charging them. Batteries don't discharge at the same rate, because of that we can not assume to charge them at the same rate, here is when the bms acts protecting those batteries that are already fully charged.

Table 4

Requirement	Verification
Protect the batteries while the charging cycle	Charge the batteries and see how they first start charging fast and when they are getting full they get charged slower, not getting overloaded
Send a signal to the microcontroller when the batteries are fully charged	Check in the microcontroller if the data has been received via SPI.

2.2.2.2. Multimeter:

We will use an ACS712 module working with the PIC microcontroller. This sensor will be placed right after the inverter to measure the amount of current we are drawing from solar panels and batteries. We have to distinguish in a day when we have the maximum supply (usually at midday) and when we are not producing energy form the solar panels. Moreover, to monitor how much energy are we producing on those cloudy days. The sensor will provide information to the microcontroller that will use to decide whether to take the energy from the batteries or the solar panels and how much. We can include an LCD to display the current flowing at the moment, to make it easier for future new changes on installation or just for checking how much we are drawing.

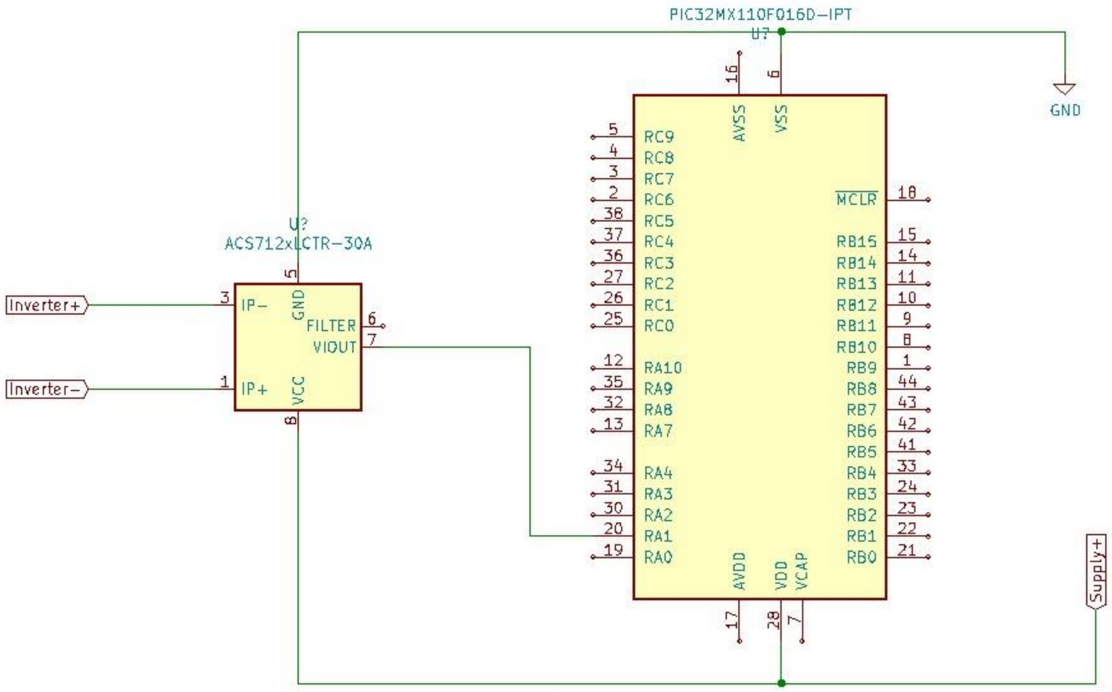


Figure 7: Multimeter Schematic

Table 5

Requirement	Verification
Being able to measure accurately current after the inverter	Checking with a digital ammeter during the demo

2.2.2.3. VOLTAGE CIRCUIT SCALER FOR VOLTMETER:

We are using a voltmeter to know the battery levels. The microcontroller will read the input voltage through one of its analog pins and convert it to a 10-bit digital number with his internal ADC. The microcontroller can work only with voltages under 5V, that's why we need this circuit to scale down the voltage input. With this measure, the microcontroller will decide when drawing current from both solar panels and batteries or only from solar panels.

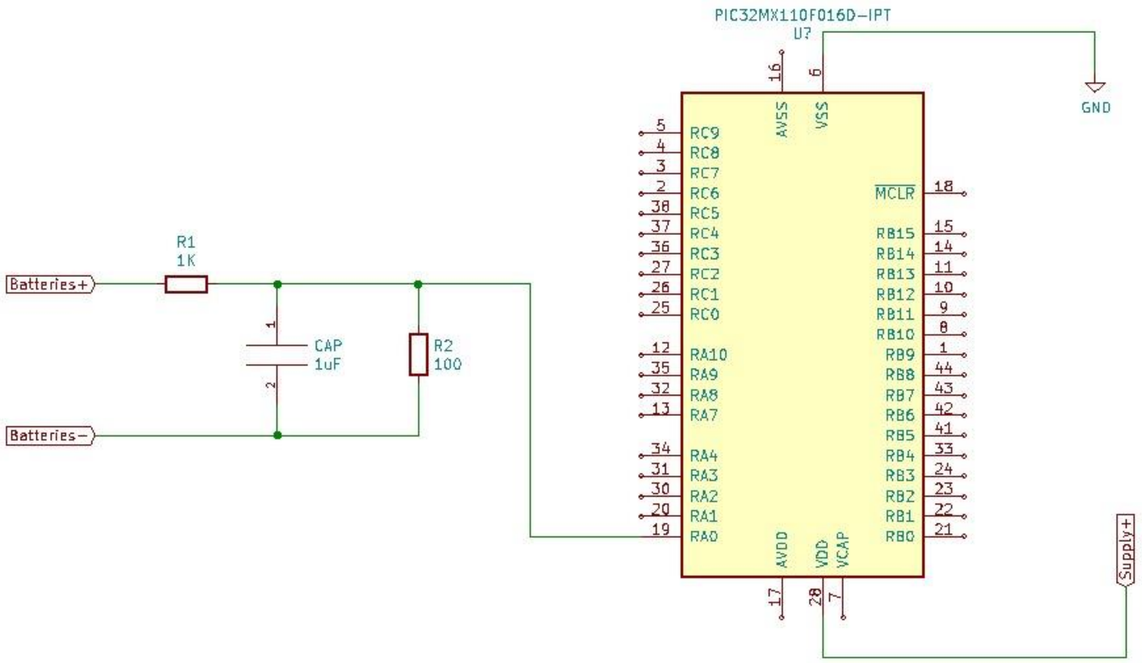


Figure 8: Voltmeter Pin Conections

Table 6

Requirement	Verification
Being able to measure the batteries' levels	Checking with a digital voltmeter during the demo

2.2.3. Control Unit

2.2.3.1. Main Controller:

The microcontroller will be handling all the possible states of the line, the solar panels, and the batteries. The controller will receive information from the BMS in a data bus, to avoid overcharging those batteries that are already fully charged. Moreover, it will receive data from the multimeter and decide then how much current to draw from the line by sending this data to another microcontroller located near the current limiter in the breakers' panel. We are planning on using a Raspberry Pi, we will be more accurate when designing hardware.

Table 7

Requirement	Verification
Implement an FSM to control the whole device	Checking the multimeter and voltmeter when are we drawing current from.
Receive data from the BMS to control if the batteries are fully charged or not	Checking in the microcontroller the received data and during the demo with a digital voltmeter/ammeter the results are correct
Receive data from the multimeter about the current drawn after the inverter	
Receive data from the voltmeter about the batteries' levels	
Send the current limit we want to establish to the secondary microcontroller via Bluetooth	Check in the secondary microcontroller the data has been received
Send to the LCD all the data gathered and calculated	See in the LCD the data is correct.

2.2.3.2. Secondary Controller:

The reason for using this microcontroller is to avoid connecting the current limiter, which is located in the breakers' panel, with the main microcontroller that will be located somewhere near the solar panels. To communicate both microcontrollers we are planning to use an UART module that will connect them via Bluetooth. This microcontroller will receive from the main one data related to the current limit and it will be placed on the digital potentiometer of the current limiter.

Table 8

Requirement	Verification
Receive the current limit from the main microcontroller via Bluetooth	Check in the microcontroller the received data and in the demo with a digital ammeter that the data is correct

2.2.4. OTHERS

2.2.4.1. DC TO AC INVERTER:

Batteries and solar panels produce energy in DC, while coolers, heaters, and compressors demand energy in AC. That's why we need to include an inverter to join both parts of the circuit. The DC-AC converter will be structured in three parts. Firstly, a rectifier circuit, then places a fixed voltage and thirdly an inverter circuit made of MOSFETs. The suggested diagram has been taken from Power Electronics class.

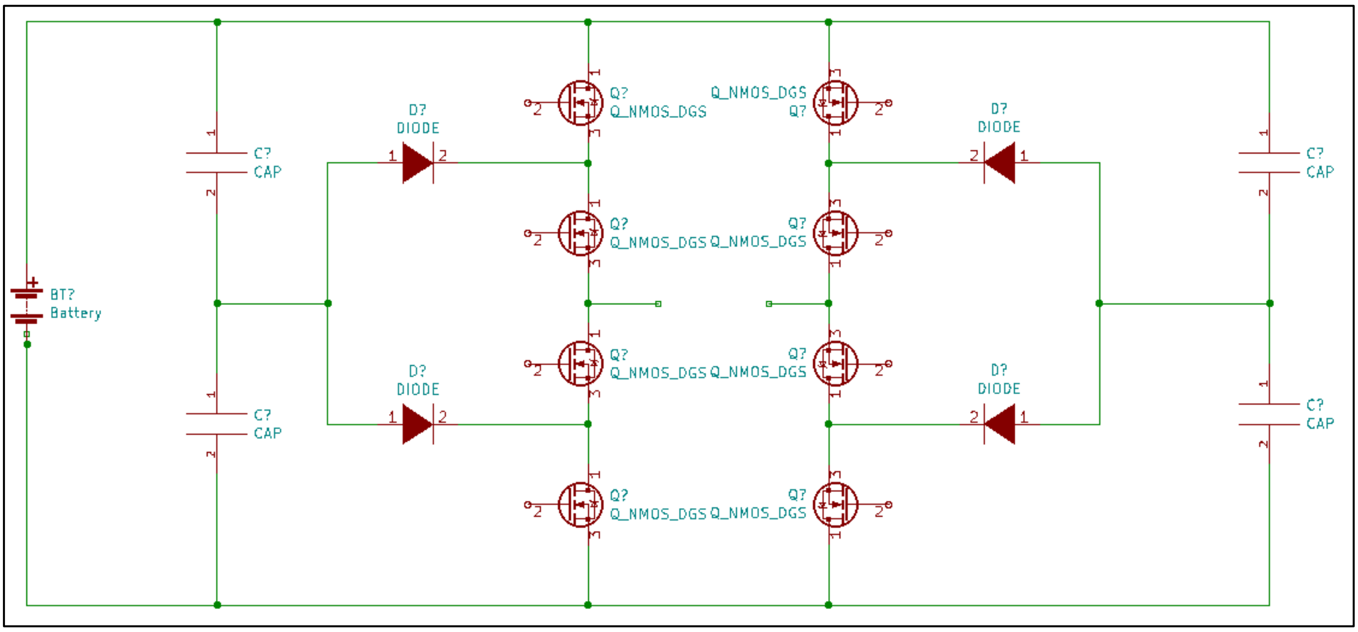


Figure 9: Inverter Schematic

Table 9

Requirement	Verification
Transform the DC current from the batteries and solar panel into AC current	Check the multimeter and see if its measuring AC current
Transform 20V from DC part into 120V for the AC part	Check if the load works correctly or by checking with a voltmeter during the demo

2.2.4.2. LCD:

We are using some LCDs to display the current we are drawing from Ameren Line that the microcontrollers are setting, as well as the current drawn from the batteries and solar panels. Moreover, we can display battery levels.

Table 10

Requirement	Verification
Display correctly the data received from the microcontroller	See on the screen the data and in the microcontroller check if the data displayed is correct

2.2.4.3. UART MODULE:

This module will be connected to both the main microcontroller and the secondary microcontroller to make connections possible between them. Both devices will receive and transfer data via BlueTooth.

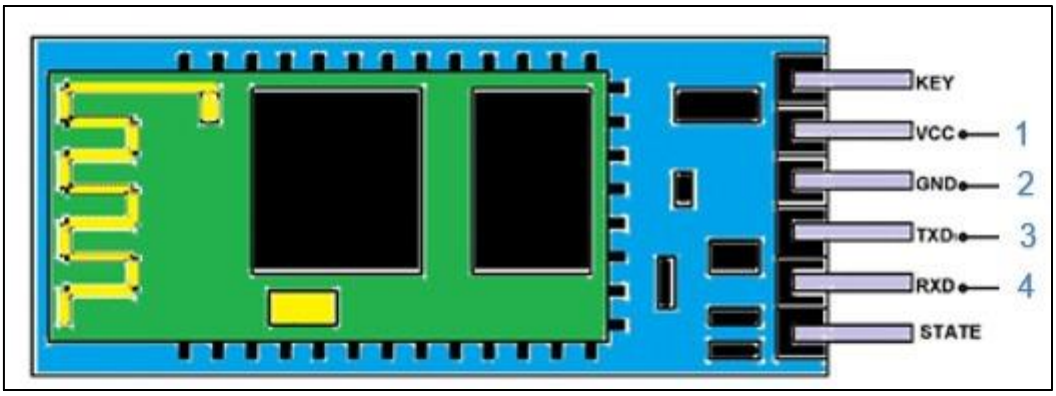


Figure 10: UART Schematic

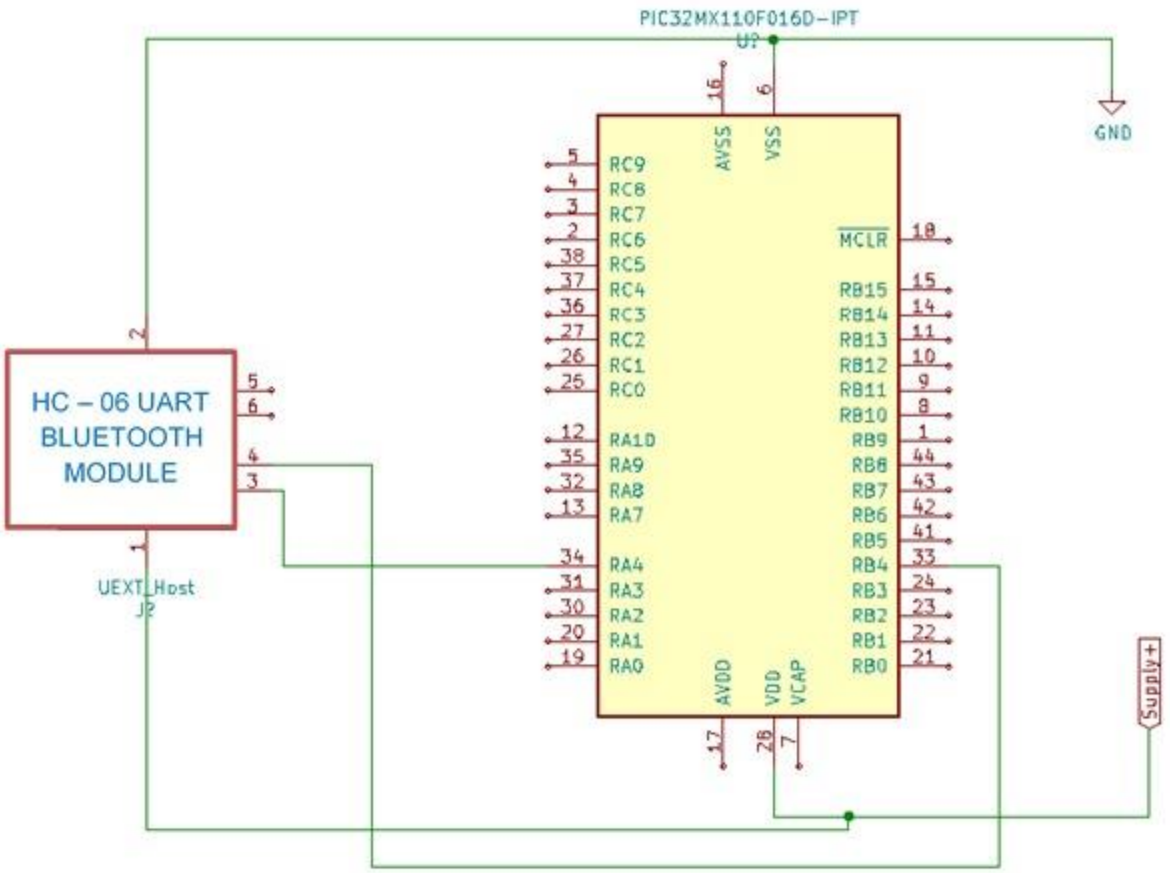


Figure 11: UART Schematic(2)

Table 11

Requirement	Verification
Being able to transfer/receive data via bluetooth	Check in both microcontrollers we are receiving the data

2.3. Flow Chart

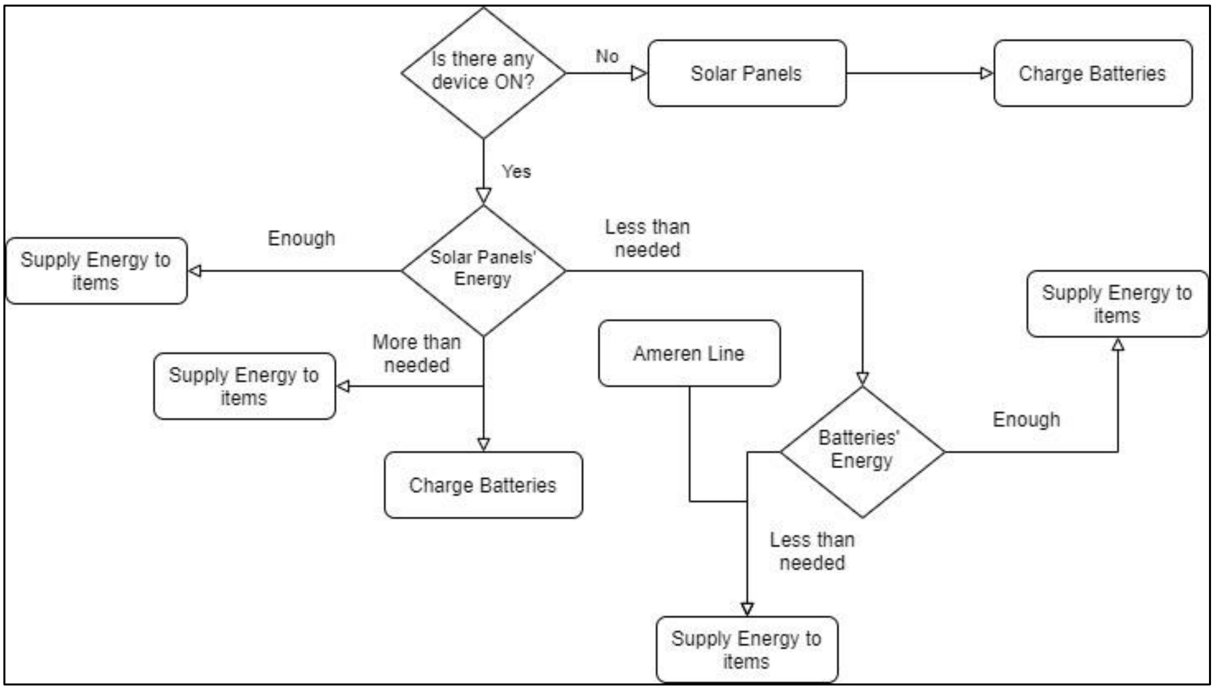


Figure 12: FSM Flowchart For Microcontroller

3. TOLERANCE ANALYSIS

The critical device of our project is the multimeter placed right after the batteries. This module is giving critical information to the microcontroller that then will be used to decide how much current are we limiting on the input of the breakers' panel. For that reason, we need to know that the current is flowing is exactly the one the multimeter is measuring.

- Case 1: We are measuring less current than the one actually flowing.
  - Let's say we need 90A demanded from the farm devices, we have batteries fully charge and the multimeter is measuring 40A after the inverter. The microcontroller is going to set the current limit in the breakers' panel at 50A which is the difference between both data. In fact, let's say the real current flowing after the inverter is 60A instead of 40A as the multimeter has measured. At this point, we are supplying the farm line with 110A, 20A over the demanded one which will lead to potential damage all the connected devices to the line

- Case 2: We are measuring more current than the one actually flowing.
  - This is the opposite side. At this point we will think we are handling the demanded current while, indeed, we are drawing less current than the one needed. This leads to devices not working properly which is a critical issue for the farm that can not afford heaters or fans stop working because this will lead to rotten food and having lots of losses.

The ACS712 module has some characteristics that affect the total error of the sensor.

- The product of the linear IC amplifier gain (mV/G) and the noise floor for the Allegro Hall-effect linear IC leads to voltage noise that makes appear some errors. Typical peak to peak noise voltage at standard sensitivity and 25ºC is 7mV.
- The degree to which the voltage output from the sensor varies in direct proportion to the primary current through its full-scale amplitude. Non-linearity appears when we reach the limits of the multimeter, which lead to imprecisions.

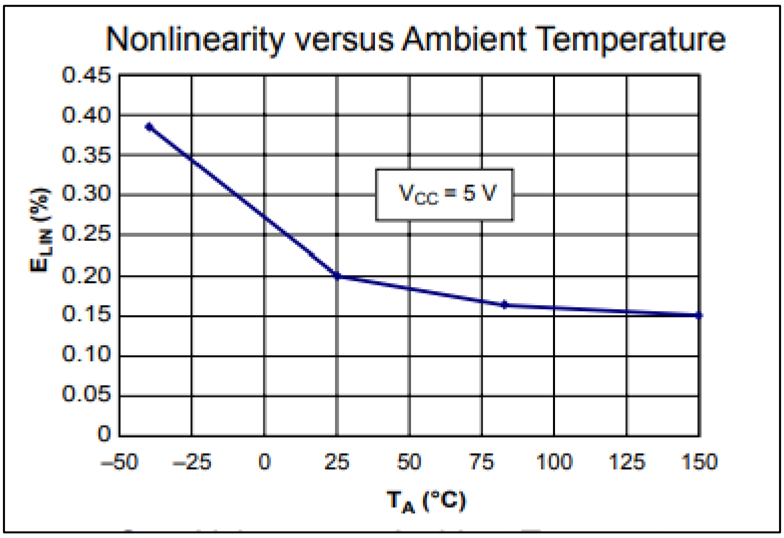


Figure 13: Non-linearity vs. Temperature (ACS712 Module)

- Resolution or radiometric sensitivity refers to the number of digital levels used to express the data collected by the sensor. The ratiometric change in sensitivity is defined as:

$$100\left(\frac{Sens_{VCC} / Sens_{5V}}{V_{CC} / 5\ \mathrm{V}}\right)$$

Figure 14: Resolution formula by change in sensitivity

Accuracy is divided into four areas:

1. 0 A at 25°C. Accuracy of sensing zero current flow at 25°C, without the effects of temperature.
2. 0 A over Δ temperature. Accuracy of sensing zero current flow including temperature effects.
3. Full-scale current at 25°C. Accuracy of sensing the full-scale current at 25°C, without the effects of temperature.
4. Full-scale current over Δ temperature. Accuracy of sensing full-scale current flow including temperature effects.

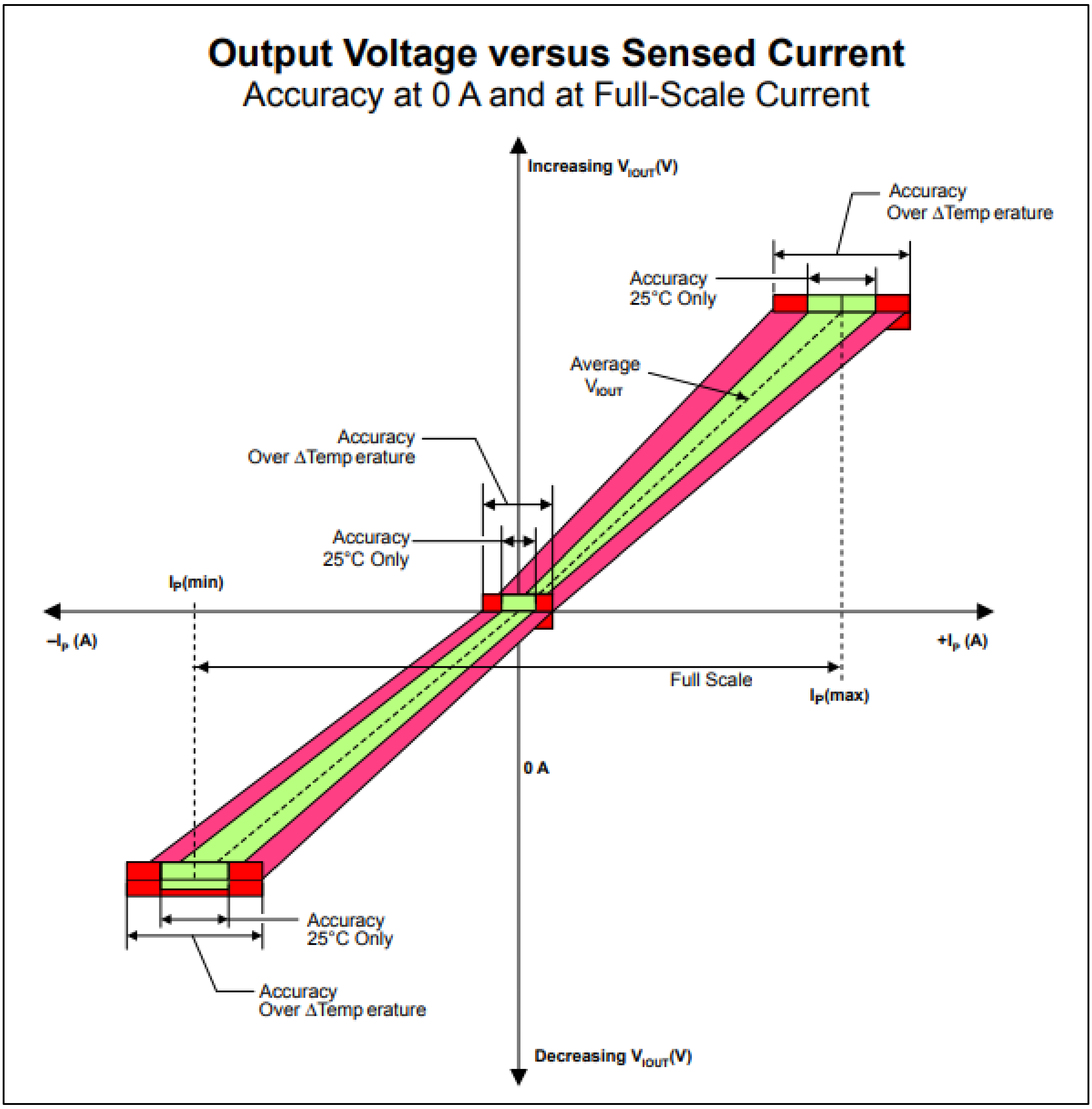


Figure 15: Output Voltage vs. Sensed Current

This sensor has an optimized accuracy range from -30 to +30A. Sensitivity depends, as I said before, on the ambient temperature and the sensed current, as a standard over a full range of current at 25ºC the sensor has a sensitivity between 64 and 68 mV/A. Overall, has an output total error of +-1.5% in the sensing current.

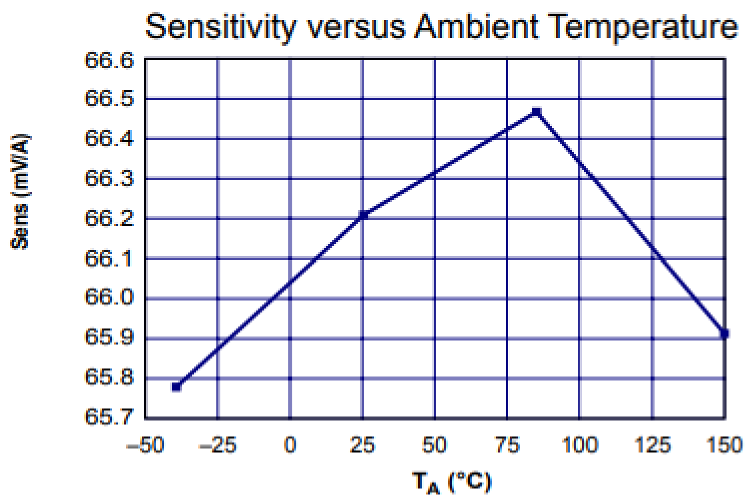


Figure 16: Sensitivity vs. Ambient Temperature

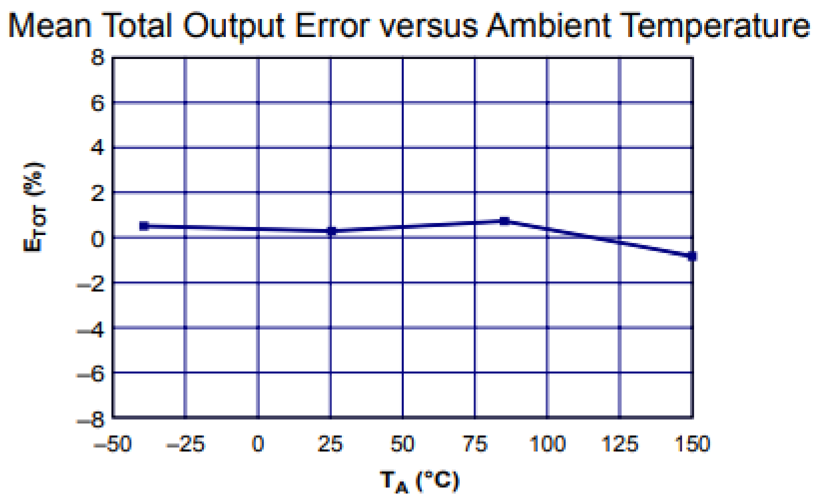


Figure 17: Mean Total Output Error vs. Ambient Temperature

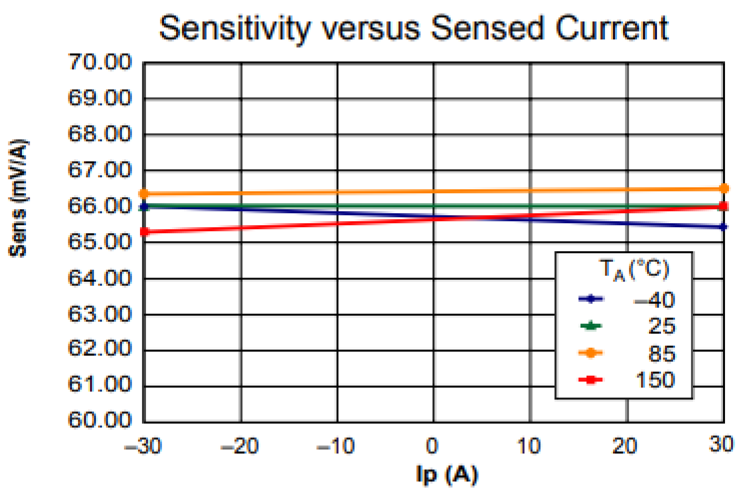


Figure 18: Sensitivity vs. Sensed Current

Trying to improve the sensitivity of the sensor and deleting as much as we can the total output error, it could be advantageous to add a simple RC filter to the output of the sensor. Such a lowpass filter improves the signal-to-noise ratio, and therefore the resolution, of the sensor output signal. The ACS712 contains an internal resistor, a filter pin connection to the printed circuit board, and an internal buffer amplifier. With this circuit architecture, we can implement a simple RC filter via the addition of a capacitor from the filter pin to the ground.

4. Cost Analysis & Schedule

4.1. Physical Components

Table 12

Component	Model	Cost
Solar Panel	ECO-WORTHY 10W 12V	$38.50
Battery	Ugood_ 2019 DC 12V 6800-18000mAh Super recargable Li-ion batería de litio Pack + US Plug	$23.00
BMS	LTC6810HG	$28.58
Inverter	Peaks 4000W 12V TO 110/220V AC Inverter Solar Power Inverters - 220V	$29.44
Current Limiter	ACS712 Bridgold BTA41-600B, 40A, 600V, TRIAC	$8.19
Circuits for measure voltage and current	Resistors: 1K Ω,100Ω Capacitors: 1μF	$1.62
Multimeter	ACS712	$7.19
Main controller	Raspberry Pi 3A+	$38.33
Secondary controller	Pic32MX	$6.28
UART Module	HC-06 Bluetooth UART Communication Module V2.4	$7.99
LCD	Geekcreit® IIC / I2C 1602	$2.44*2=$4.88
Fan	Honeywell HT900E4	$19.95
TOTAL		**$213.95**

4.2. Labor Hours

Table 13

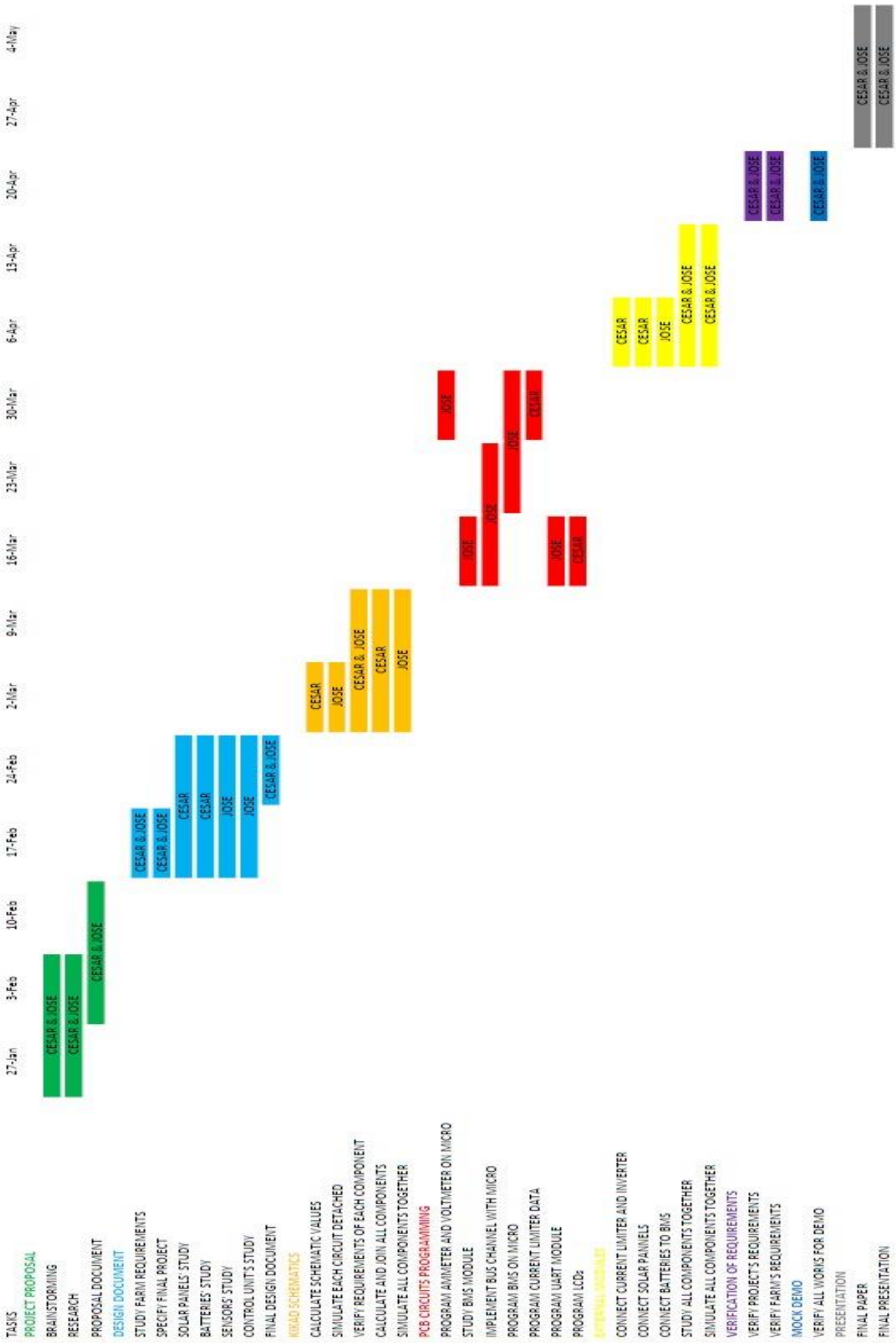
Function	Estimated hours(h)	Cost($)
PCB Design	25	750
Battery design	25	750
Bluetooth Calibration of UART module	30	900
Solar panel study	25	750
Charger study	20	600
Programing the FSM of the Control Unit	25	750
Building the system	35	1050
SUBTOTAL	185	5550
TOTAL	**185**	**13875**

4.3. Total Costs

Table 14

SUBTOTAL: COMPONENTS	$213.95
SUBTOTAL: LABOR HOURS	$13875
TOTAL	**$14088.95**

4.4. SCHEDULE



TASKS
PROJECT PROPOSAL
BRAINSTORMING
RESEARCH
PROPOSAL DOCUMENT
DESIGN DOCUMENT
STUDY FARM REQUIREMENTS
SPECIFY FINAL PROJECT
SOLAR PANELS' STUDY
BATTERIES' STUDY
SENSORS' STUDY
CONTROL UNIT'S STUDY
FINAL DESIGN DOCUMENT
KIKAD SCHEMATICS
CALCULATE SCHEMATIC VALUES
SIMULATE EACH CIRCUIT DETACHED
VERIFY REQUIREMENTS OF EACH COMPONENT
CALCULATE AND JOIN ALL COMPONENTS
SIMULATE ALL COMPONENTS TOGETHER
PCB CIRCUITS PROGRAMMING
PROGRAM AMMETER AND VOLTMETER ON MICRO
STUDY BMS MODULE
IMPLEMENT BUS CHANNEL WITH MICRO
PROGRAM BMS ON MICRO
PROGRAM CURRENT LIMITER DATA
PROGRAM UART MODULE
PROGRAM LCDs
CONNECT CURRENT LIMITER AND INVERTER
CONNECT SOLAR PANNELS
CONNECT BATTERIES TO BMS
STUDY ALL COMPONENTS TOGETHER
SIMULATE ALL COMPONENTS TOGETHER
VERIFICATION OF REQUIREMENTS
VERIFY PROJECT'S REQUIREMENTS
VERIFY FARM'S REQUIREMENTS
MOCK DEMO
VERIFY ALL WORKS FOR DEMO
PRESENTATION
FINAL PAPER
FINAL PRESENTATION
27-Jan
3-Feb
10-Feb
17-Feb
24-Feb
2-Mar
9-Mar
16-Mar
23-Mar
30-Mar
6-Apr
13-Apr
20-Apr
27-Apr
4-May
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JOSE

5. Ethics and Safety

A potential unethical issue could be the misuse of the extra power supplied by either the batteries or the solar panels. The objective of these devices is to supply power to the third cooler and not to make a profit from it making at the same time an overload of the line. Since we have said before we can sell the extra power that solar panels produce but only in the case there is enough to feed the cooler.

Another threat could be selling the project to a third person/company and again make a profit of it. Or even take advantage of this project by realizing the profitable issue of the project, stopping using all of this to charity and profiting themselves.

The main risk of the project could have failures during the implementation and development of the design that could make the near areas to the cooler a dangerous place. We have to control every detail to avoid this to happen.

Apart from the implementation, there are other external risks that we can not handle but we can control as the batteries behavior, which can have unforeseen failures.

6. References

[1]“Autosolar.” Autosolar, 21 Feb. 2018, autosolar.es/blog/aspectos-tecnicos/las-dudas-mas-comunes-sobre-el-autoconsumo-energetico-fotovoltaico. https://autosolar.es/blog/aspectos-tecnicos/las-dudas-mas-comunes-sobre-el-autoconsumo-energetico-fotovoltaico

[2] “How to Choose the Best Battery for a Solar Energy System.” EnergySage, 22 Feb. 2020, www.energysage.com/solar/solar-energy-storage/what-are-the-best-batteries-for-solar-panels/.

[3] R-B, “PIC-Based Digital Voltmeter,” Embedded Lab. [Online]. Available: http://embedded-lab.com/blog/pic-based-digital-voltmeter-dvm/.

[4] “Battery management system (BMS) diagrams, integrated circuits and designs,” Battery management system (BMS) diagrams, integrated circuits and designs | TI.com. [Online]. Available: http://www.ti.com/solution/battery-management-system-bms?variantid=14011&subsystemid=17260.

[5] fuentes, I. (2020). Instrumento de medición para fuentes. [online] Electgpl.blogspot.com. Available at: http://electgpl.blogspot.com/2015/09/instrumento-de-medicion-para-fuentes.html

[6] Naylampmechatronics.com. (2020). Tutorial sensor de corriente ACS712. [online] Available at: https://naylampmechatronics.com/blog/48_tutorial-sensor-de-corriente-acs712.html

[7] Circuitdigest.com. (2020). Digital Ammeter Circuit using PIC Microcontroller and ACS712. [online] Available at: https://circuitdigest.com/microcontroller-projects/digital-ammeter-circuit-using-pic16f877a-acs712

[8] Components101.com. (2020). HC 06 Bluetooth module pinout, features & datasheet. [online] Available at: https://components101.com/wireless/hc-06-bluetooth-module-pinout-datasheet

[9] kemisa.es. (2020). Voltímetro digital display LCD. [online] Available at: https://www.kemisa.es/es/circuitos-con-pic-microcontroladores/27-voltimetro-digital-display-lcd.html

[10] PIC Microcontroller. (2020). A brief overview of Allegro ACS712 current sensor. Part 2 - Interface the sensor with a PIC microcontroller. [online] Available at: https://pic-microcontroller.com/a-brief-overview-of-allegro-acs712-current-sensor-part-2-interface-the-sensor-with-a-pic-microcontroller/

[11] CALEFACCIÓN SOLAR Y ENERGÍAS RENOVABLES. (2020). CÓMO ELEGIR BATERÍAS PARA PANELES SOLARES. [ONLINE] AVAILABLE AT: http://calefaccion-solar.com/como-elegir-baterias-para-paneles-solares.html