ELO 5 REPORT

3.3. CF Greyling

OCTOBER 23, 2017

SCE

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3.3.1 Scope of Work

In the following Figure 1below the system operational architecture of the group can be seen. In this architecture I am responsible for the parts lined in blue. That is the solar panel, mains 220V input (if there is enough funds at the end of the project once all essential components have been acquired), solar charge controlling, the battery and the switching between power supplies in the system.

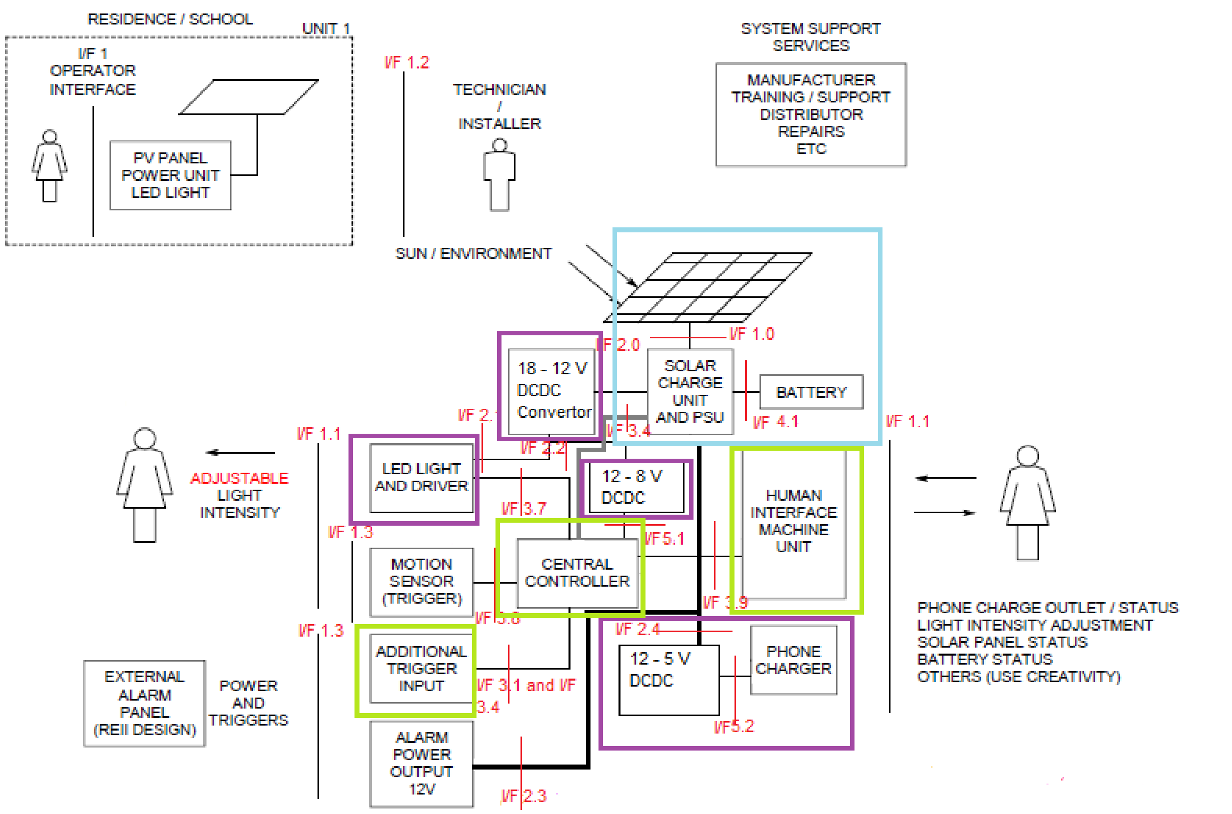

Figure 1: System operational architecture of the whole group

This can also be represented as the following sub system in Figure 2 below. In the Figure 2 the basic layout of the system can be seen once more in the blue lines.

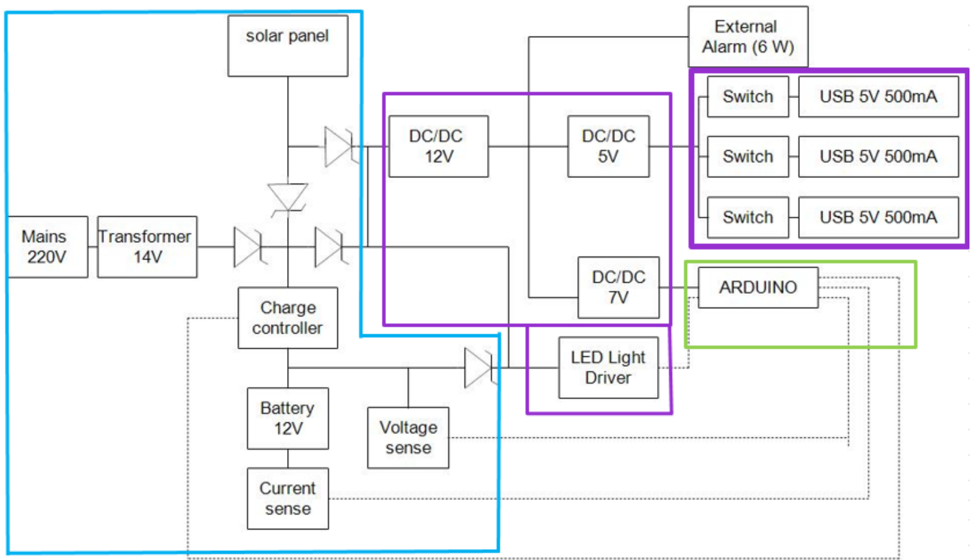

Figure 2: Sub system architecture

Unit Breakdown (Functional Architecture of Circuits):

The individual unit breakdown can be seen in the Figure 3 below. However the design changed and therefore so did the individual architecture. Therefore the interface and unit referencing was not made from this architecture

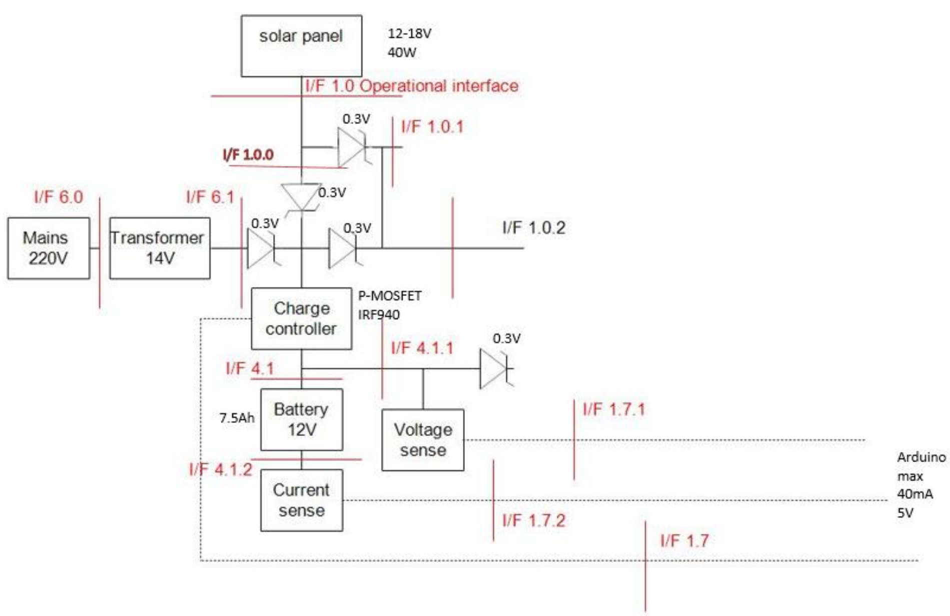

Figure 3: CF Greyling Individual Unit breakdown rev1

The final subsystem architecture with interfaces and unit numbers can be seen in the Figure 4 below. The architecture in Figure 4 is used to for the referencing of interfaces throughout the design of the subsystem.

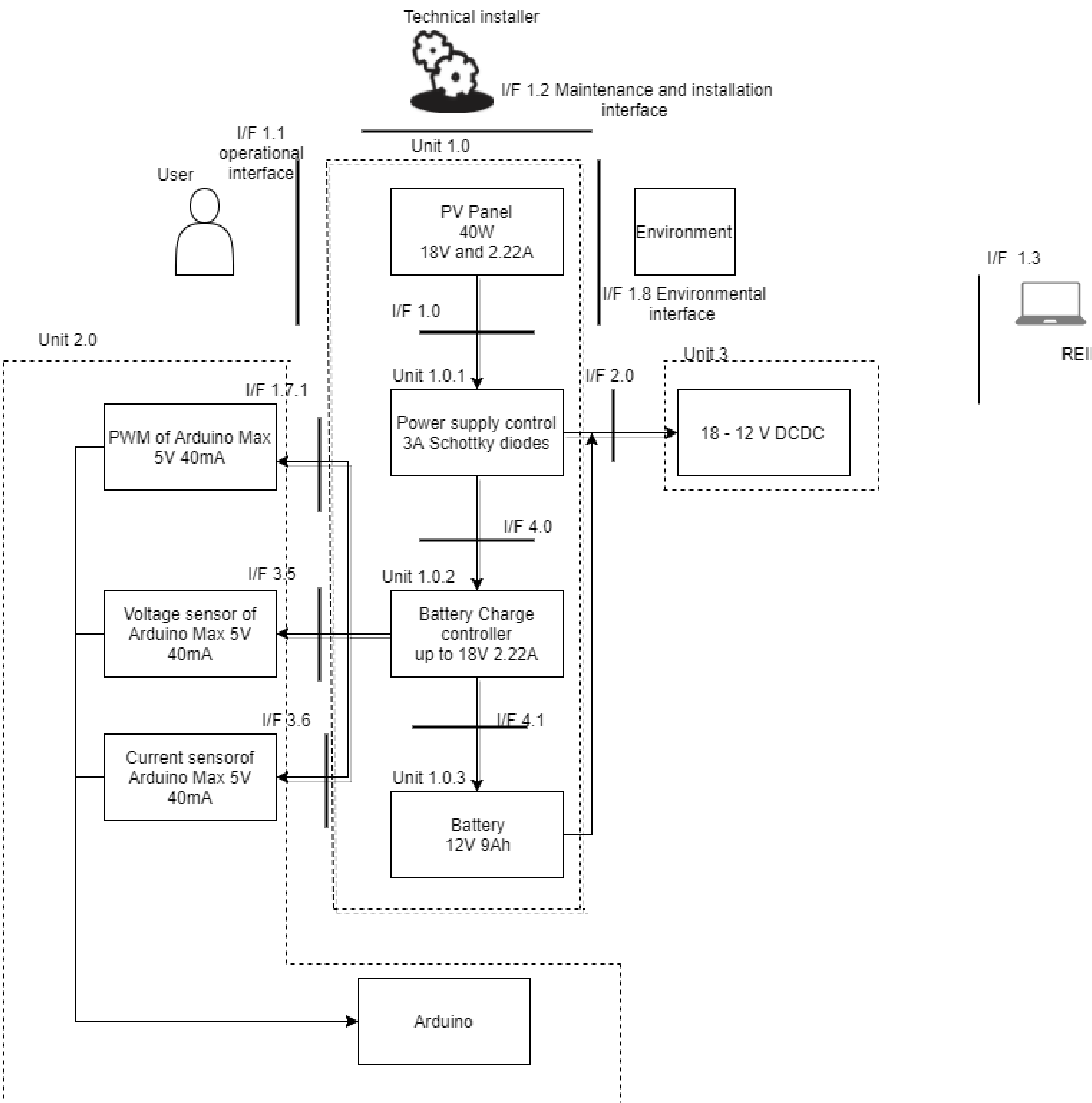

Figure 4: Sub system interface and architecture

Scope:

For this project the scope of work is divided between technical, project management, design, documentation and research scope for the work.

3.3.1.1 Research

Research must be done on the following subjects as in the work scope:

- Battery characteristics and application
- Charge controller
    - P channel MOSFET application in circuit
    - Voltage sensing for Arduino using voltage divider with capacitor for filer of noise and diode to for spike protection for the Arduino pins
    - Current sensing for Arduino using voltage divider with capacitor for filer of noise and diode to for spike protection for the Arduino pins
    - Arduino pin application notes
        - Minimum and maximum voltage that can be applied to pin
        - Minimum and maximum current that can be applied to pin
        - Maximum output signal
    - NPN transistor characteristics
- Circuit switching with Schottky diodes
- Solar Panel
- Transformer for mains 220V AC supply (if applicable)
- Transorb use for lightning protection
- Fuses for circuit protection

3.3.1.2 Project management

- Ensure the project stays on track of the timeline
- Hold meetings and take notes
- Do work allocation for the group and keep progress report of the group's progress

3.3.1.3 Design

Do the:

- Rough Circuit design
- Basic wire diagram
- Simulation in LTspice

For the following elements of the design:

- Charge controller circuit
    - Voltage sensor for Arduino

  - Current sensor for Arduino
  - PWM for Arduino connection to controller
- Switch between different sources with Schottky diodes
- Circuit connecting the sources
  - Solar panel
  - Battery
  - Mains 220V

3.3.1.4 Technical

The following technical aspects must be addressed:

- Battery
- Charge controller
- Solar panel
- Mains 220V source (if applicable)
- Switching between power sources with diodes
- Connection to Arduino

3.3.1.5 Documentation

- Compile the Design portfolio
- Do individual ELO 5
- Minutes for meetings in class
- Notes during class
- Requirement listing
- Simulations and results for the above mentioned aspects in the design section.
- Datasheets/ application notes
- Drawings of circuit and device (Hand and software)

3.3.1.6 Parts of the circuit the member is responsible for:

I am responsible for the following interfaces of the system, the interfaces can be seen in Figure 3 below.

- Solar panel – Interface 1.0

  - Basic characteristics
    - 40 W
    - 18 V
    - 2.22 A
- Mains (If applicable) – Interface 6.1
- Diode circuit power switching – Interface 1.0.0
    - Interface 1.0.1
    - Interface 1.0.2
    - Interface 1.0.3
- Charge controller – Interface 4.0 (to Arduino - Interface 1.7 – with SJ du Plessis)
  - Voltage sensor to PV panel – Interface 3.6 (to Arduino - with SJ du Plessis)
  - Voltage sensor at battery - Interface 3.5 (to Arduino - with SJ du Plessis)
- Battery – Interface 4.1

3.3.2 Assumptions and Constraints

The assumptions and constraints are tabulated in the following Table 1 below.

Table 1: Assumptions and constraints CF Greyling

Assumptions	Constraints
The project building will be finished with in time.	3rd year has many difficult subjects that demand a lot of time away from the design subject.
Assume the heat sink for the P-MOSFET will allow for enough heat deprivation for the system to work continuously	Heating up of components because of incorrect calculations will cause the components in the circuit to blow.
Financial assistance to build project	Only R 1500 to build the whole project
Alarm panel load	12V and 6W needed from system to run the panel

Transorb lightning protection	Transorb is effective but has limited characteristics and may prove not to be enough for the circuit leaving the whole circuit to blow up.
Switching between power sources with diodes	Each diode will take approximately 0.3 V this could make the voltage output too small for the system
Assume all components will be bought with finances provided by the NWU	Components are very expensive adding taxes and shipping cost especially from overseas may mean going over budget.
Assume project will be done before 28 October to prevent working on project during exam	Work load is excessive as the second semester of 2017 is decidedly shorter than other semesters.
Assume the diodes in voltage and current sensing circuit will protect the Arduino	Very large spike or some malfunction of the diodes will cause the damage to the Arduino
Assume the PMOS will accurately start up from signal with PWM from Arduino	A lot of factors working in on system that could affect the output.
Assume solar panel will load the battery each day highly efficiently	Weather and dust may affect the efficiency of the solar panel greatly.

3.3.3 Discipline-Specific Engineering Methodology

For the project discipline-specific engineering methodology is used to manage tasks to improve on the speed and difficulty of the project. These methodologies such as function diagrams, simulations, architecture of systems and, so on allows the system to be broken down onto more understandable section that improve the effectiveness of design and testing of the systems.

The following discipline-specific steps where followed during the project:

a. Communication

Throughout the whole project communication between the team members, power block and alarm system, and the members and Prof Holm is a key aspect to effective project management. Whether it is verbal, written or nonverbal communication, clear and concise communication during consultations and meetings deter unnecessary misunderstandings and confusion that could delay or set back the project.

b. Documentation

During the project documentation was held of all the aspects of the project to form as both a log and proof of the different aspects of the project and its management throughout the projects duration.

The following discipline-specific steps where followed during the project:

1. Problem analysis

After the project scope was provided to the team, the team analysed the project both as:

a. Individuals
b. Team.

To assess what the project consists of and what the demands where of the project in general.

2. System breakdown

After the basic problem analysis of the project was completed, the system was broken down in two ways namely:

a. a functional analysis of the system; and
b. a functional architecture of the system.

3. General research of system
   a. Once it was established what the different components of the system each member did some general research for the project to become more informed of the different aspects of the design.
   b. General idea formed of who will do which work
4. Choose system

After general research the most efficient system was chosen for the project. By analysing the specifications set by the client and lecturer. This is part of communication to between the client, lecturer and the group in the form of:

a. Meetings between the members for system integration

   b. Lectures in class, where the requirements and specifications where communicated by the lecturer.
5. Work allocation

Once a general idea was formed of how much work each aspect of the design would be the work was allocated among the team with the understanding that should one members work become more than originally estimated the other members will help to lighten the load so as to have an equal distribution between the members for the work. Each member would then be responsible for their own part (subsystem) of the project and then there would be a joint responsibility once integration of the system begins.

Work breakdown of the project was completed with:

   a. Functional analysis of the project
   b. Functional architecture as in the project management documents where each members work is divined. Where the system was then broken down in subsections to simplify the design process.
      a) In the functional architecture the subsystems where organised in units which were then connected to other subsection by the use of interfaces
      b) In the subsystems of the functional architecture the ratings of the units were divined for an easier overall view of the system.
6. Research on subsystem

Once the work was subdivided between the team members each member could start extensive research for their own subsystem to determine what aspects to keep in mind when designing there parts of the project.

   a. Research was done by each member on their subsystem
   b. With interfaces between the members it was necessary to do combined research on how the subsystems would act together.
7. Wiring diagram

After the research was completed diagrams of the circuit was made:

   a. First a concept wiring diagram of the overall system was completed, without any subsystems, this was completed during a lecture.

   b. Then a sub system wiring diagram was completed by each member.
   c. These sub system wiring diagrams where then combined to create a detailed wiring diagram of system. From which a concept design was then made

8. Power Budget

A power budget was created to determine how much load would be on the system at what time during its operational cycle.

   a. Each member created a list of their power supply and/or consumption
   b. A member in the team then created the combined power budget of the system

9. Financial Budget

A financial budget was made for the project, limited by the R1500 set by the NWU. For the compilation of the financial budget:

   a. Each member was responsible to do research for their own sub system to determine from which manufacturer they could get components and which would present the cheapest viable option for the project.
   b. Once each member has completed this, a meeting was held to determine which components would be bought and which components would have to be changed and/or changes in the design to compensate the budget, in order that a less expensive route could be followed.
   c. Once the decision on which major components would be bought the rest of the financial budget was allocated.

10. Concept design

Once the wiring diagrams where completed with integrated subsystems were established:

   a. Each member created a concept design of their subsystem and analysed
   b. This design was then tweaked and improved upon throughout the design process. Using the design skills acquired during studies thus far.
   c. Then the subsystem concept designs where combined to form a combined concept design of the system.

11. Decide on design

From the concept design fine tuning and meetings a design for the system was decided on. Each subsystem details were up to each member.

12. Calculations

Once a general design was established calculations where done to determine the detailed design values of the different components within the subsystem to ensure the correct operation of the subsystem. This was done on two part:

a. the calculation of correct values for the components to have the desired voltage and current in specific circumstances in the circuit
b. the other calculations where safety calculations for the different components to ensure that the components do not undergo to much strain or heat depending on the aspect that would cause it to fail first.

These calculations where made using both the knowledge acquired during studies such as for the MOSFET in the circuit, as well as knowledge about the components and other aspects which were acquired during the research into the subsystem.

13. Detailed design

Once all the correct values for the components where determined the detailed design of the:

1. Subsystem was made by each member of their own subsystem. In which each of the components and there values are set out in detail.

14. Simulations

Once the detailed design was completed the simulations of the subsystem could be made to determine whether the circuit would work successfully before building the circuit on the strip board. This allows for easy cheap system analysis and troubleshooting of the circuit to determine if there are any unforeseen problems with the system. Simulations of the circuit was done using Ltspice a free simulation package that provides basic simulation capabilities. However some of the components in the simulation software does not have the correct values or are not quite the same components as those the designed circuit makes use of. Therefore the simulation only provides an estimation of how the circuit would operate in real circumstances once built. To make the simulation more realistic I searched for other simulation packages to simulate the circuit in but these other simulation packages where ether unjustifiably expensive for one simulation in the project or featured some components in greater detail with more accuracy but did not have some of the components at all, which would have made the simulation impossible to run as some of the components in the circuit would be utterly missing.

15. Order and buy the components

During this stage it became clear that some components where very expensive and others would have an extensive shipping time. Therefore application of management skills in terms of project time management and financial management had to be applied to the circumstances. For components that would cause us to go over budget cuts and reorganization had to be made, such as the 220V ac mains power supply that would have needed a transformer to connect to the system. After calculating the cost of the core components and determining that it would be too expensive, and as it was just an optional extra the decision had to be made to cut the mains power transformer from the project in favour of the core components of the project. Once this decision was made changes were made to the design to remove the power supply from the system.

16. Circuit board layout design

To help with the circuit board layout I used the Fritzing software to make a preliminary design of the circuit using the stripboard tool to place the components and replace them until a satisfactory circuit emerged. Which lessens the risk of having the re-solder the circuit because of incorrect layout in the board.

17. Receive components

We received the components we were waiting for that had still been in transportations.

18. Build circuit

Once the most of the components had been received for the circuit building could begin. Some of the components where not exactly those that had been ordered therefore before building could commence further simulations had to be run to determine whether these components could be used for the in the circuit.

Once the design was set out the circuit was soldered using the equipment in the Thevenin laboratory provided by the NWU for the engineering students. Taking care to follow the correct safety measures while soldering the circuit as well as being careful as not to damage the components in the circuit by burning them accidently with the soldering iron.

19. Test circuit

Once the circuit was soldered I tested by first inspecting all the connection of the circuit to ensure that no short circuit connection where made. Then checked all the soldering points to ensure that they were in fact soldered fast to the board. Then I tested the circuit by connecting the Arduino to the charger to give the PWM and then measuring the voltages of the nodes and discovered that an incorrect connection was made in the circuit design.

20. Redesign layout of circuit

To ensure that no thither error where made in the layout of the circuit board I unsoldered the circuit and re-laid it to both fix the incorrect point and bring the grounds closer together to form a tighter circuit.

21. Rebuild circuit

Once the circuit was re-laid I rebuilt the circuit by soldering it onto a strip board this time improving it by using less solder and by bring the ground of all the components closer together.

22. Testing

Once the circuit was rebuilt, the circuit was once more tested, first visually to inspect all the node connections to ensure that there are no short circuits and then the individual components and their solder connection to the board to ensure that they are secured to the board and making connection. Lastly the voltages of the nodes where measured.

23. Control box

Place the final project in a box for mounting and safekeeping.

24. Demonstration

Finally the project was demonstrated to the lecturer.

3.3.4 Function of hardware

From the following functional analysis of the operational flow in Figure 5 below the general function of the charge controller and the Schottky diodes can be seen.

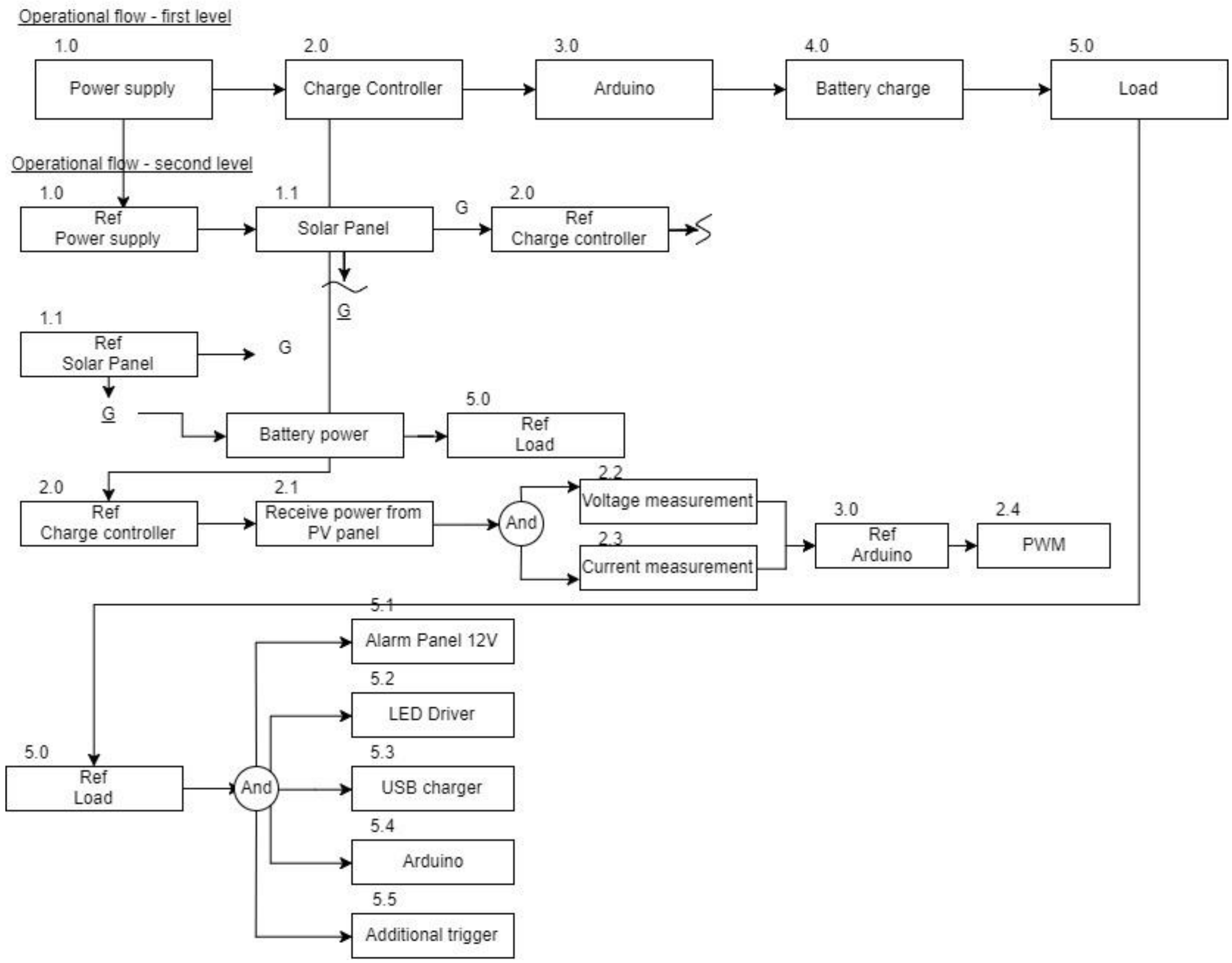

Figure 5: Operational functional flow diagram CF Greyling

3.3.4.1 Charge Controller

The charge controller is used to charge the battery from the solar panel, this is done by means of switching with a MOSFET. In the following Figure 6 below the simplified charge controller circuit can be seen. For the charge controller a P-channel enhancement mode MOSFET is used to switch the charging on as for a P channel MOSFET to switch on the voltage at the gate must below that of the source voltage and when the P channel MOSFET is on the current flow is from the source to the drain which will allow the battery to charge as can be seen in the schematic below, the drain is connected to the battery and the source to the solar panel. The gate of the MOSFET is connected to the Arduino for pulse width modulation (PWM). But as the Arduino can only handle 5 V we place a NPN transistor as well as the R4 resistor to protect the Arduino from harm. The resistor R3 between the gate and the source of the MOSFET is used as a pull up as the gate and source act as a week capacitor in a P channel MOSFET. The diode D1 is a 10V Zener diode that is used to protect the circuit from spikes. The capacitor C3 is used to filer some noise from the circuit. Voltage divider s at R5, R6 and R1, R2 are used to give input the Arduino pins so the Arduino can measure the voltage before and after the MOSFET to allow for PWM calculations during the charge of the resistor.

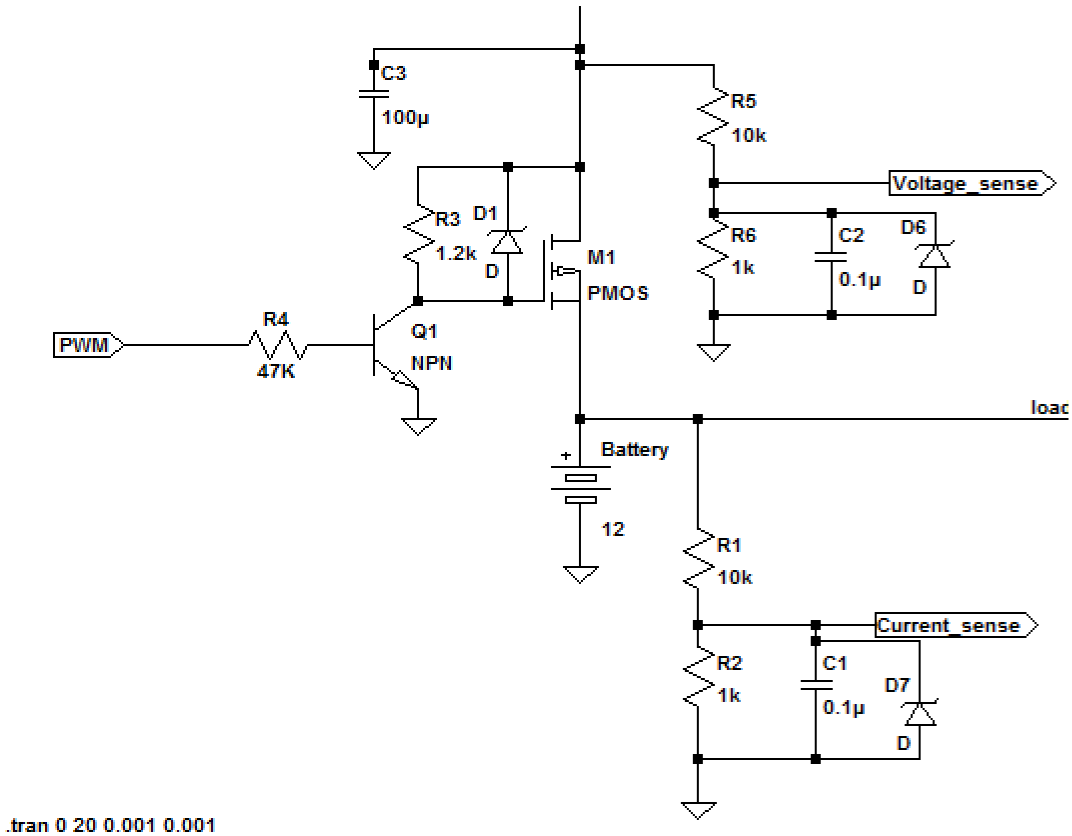

Figure 6: Simplified charge controller circuit

3.3.4.2 Schottky Switching

In the system, the power supplied to the system will come from two power sources, the PV panel and the battery. During operation only one of the two power sources will supply power at a time to the load. When the PV panel is online the power will be supplied from the PV panel to the load and it will also charge the battery if the battery is in need of a charge. In the case that the PV panel is not functional, e.g. it is night or the sky is too over cast to allow for power generation, then the power for the load will come from the battery. This is accomplished by the following circuit addition in the block diagram below in Figure 7: diode switching Hardware function.

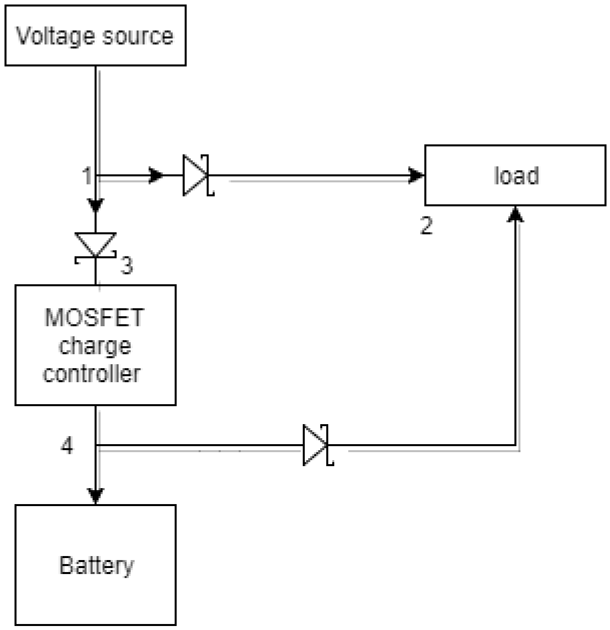

Figure 7: diode switching Hardware function

The diodes used to stop the current flow are 3A Schottky diodes as Schottky diodes are quick acting and ideal for this application. The Schottky diode between point 1 and 3 in the Figure 7 above, is used to stop the battery and/or the MOSFET from providing current to the PV panel when the PV panel is not providing power. The diode lets the current flow in only one direction. The Schottky diode between point 4 and point 2 allows there to be only current flow from the battery to the load and prevents the battery from charging from the load. The Schottky diode at the connection between the points 1 and 2 stops the current from flowing back from the load to the PV panel when the PV panel is not providing power to the system.

3.3.4.3 PV panel

The photovoltaic panel (PV panel) will act as the main power source for the whole system. The PV panel will both provide power to the load and charge the lead acid battery, the system will run on at night. The general characteristics of the PV panel is as follow:

- General
    - Weight 4.4 kg
    - Dimensions : 530x670x25mm
    - Number of cells: 36
    - Polycrystalline solar cell
- Electrical Performance at STC

  - Maximum power Voltage: 18V
  - Maximum Power Current: 2.22A
  - Open circuit Voltage : 22.1V
  - Short circuit Current: 3.06A
  - 40 Watt
- Limits:
  - Operate Temperature: -40 to 85 degrees Celsius
  - Maximum system Voltage 1000V DC

The panel will be installed on the roof, facing at an angle towards the peak of the sun at midday.

3.3.4.4 Battery

In the system the 12V 9Ah lead acid battery will act as a backup source for the circuit. In the case that the sun is not shining i.e. at night or when it is overcast, the battery will provide power to the loads, which are the 12V 6W alarm panel, 5V USB charger, 12V LED light and the 7V Arduino. In the case that the battery is draining more than desired because the sun had perhaps not shined for a few days. Then the non-essential components of the load such as the LED light and the USB charger will be disconnected from the battery to conserve power. In such a case only the alarm panel, for security measures, and the Arduino for functional measures will be provided with power from the battery.

3.3.5 Simulations

3.3.5.1 Design 1

The first design of the system of the charge controller and the power supplies connected to the load can be seen in the **Error! Reference source not found.** below. Where the solar panel voltage is represented by an 18V DC voltage power supply and the mains power is represented by a 14V DC power supply which would be the output of the mains power supply transformer connected to the circuit. The load on the system is represented by the 1k Ohm resistor R(8) at the right on the simulation. The load on the system would include the alarm panel, USB charger, LED driver and the Arduino power requirements.

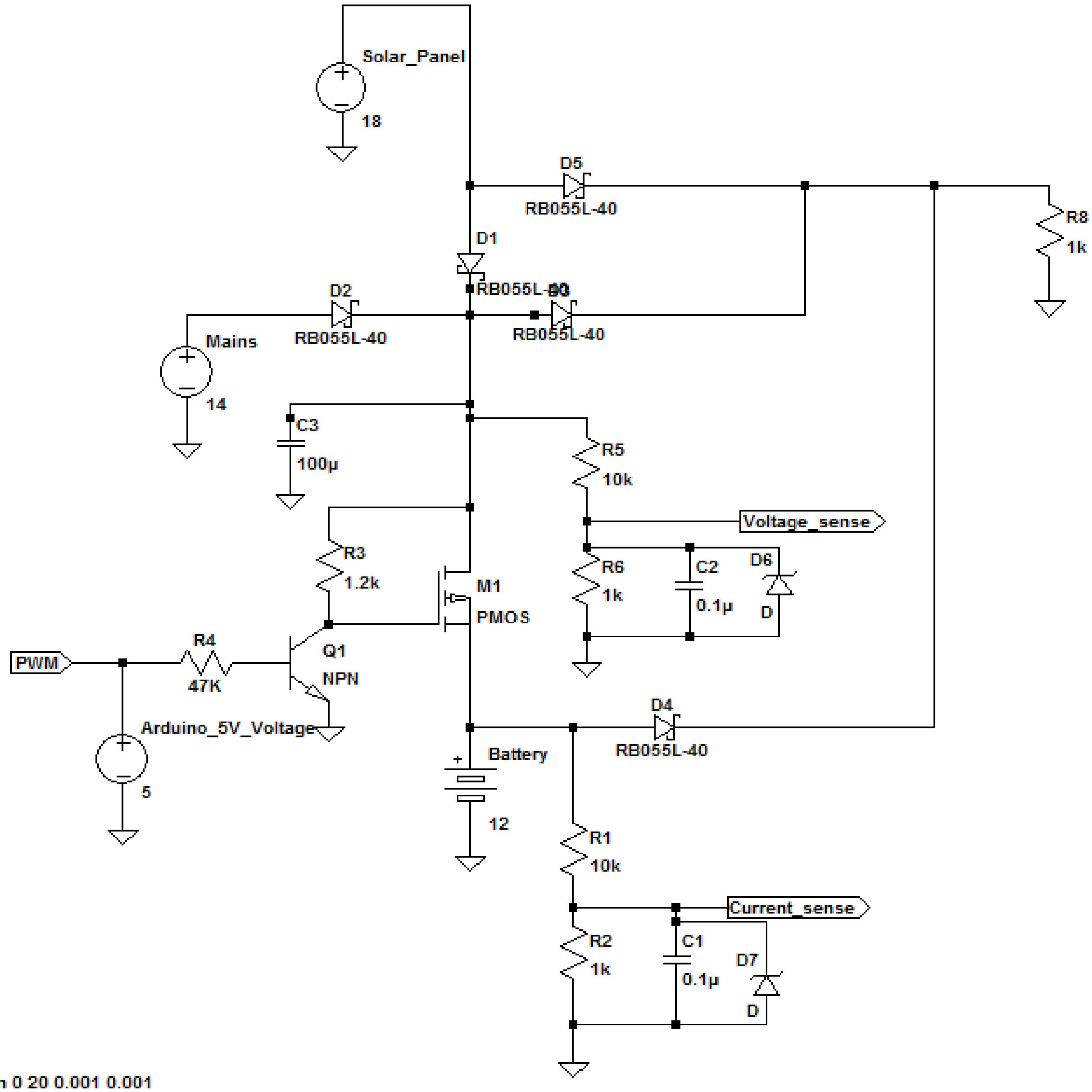

Figure 8: LTspice simulation of the charge controller circuit

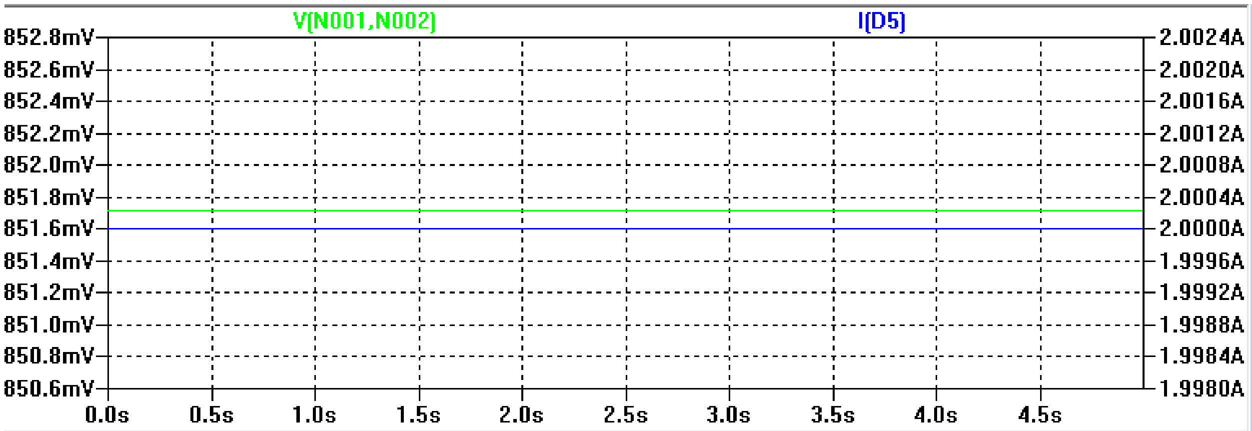

Figure 9: Voltage drop from solar panel to diode 5

In the figure above the voltage drop over the diode D5 between the solar panel positive node and the load can be seen as well as the current flowing through the diode D5. The voltage is represented by the green line and the current is represented by the blue line.

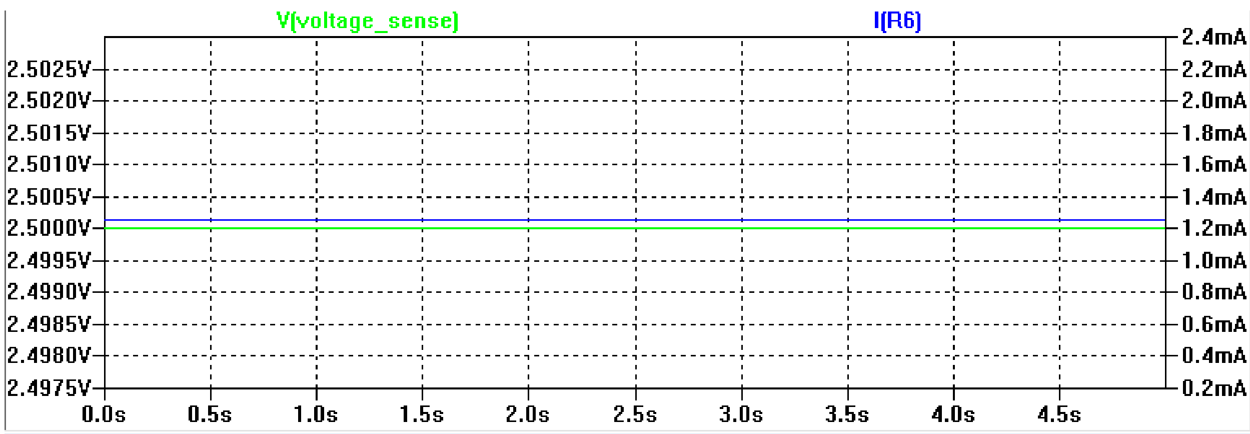

Figure 10: Voltage sensor voltage and current through the resistor 6

In the figure above the graph of the voltage sensor output can be seen, both the voltage output that will go to the I/O pin of the Arduino, which is represented by the green line in the graph above. The blue line in the graph above is represents the current through the resistor R6 as can be seen in the Figure 8 above. In the Figure 11 below the current sensor measurement graph of the simulation is shown. Where the blue line is the voltage output of the current sensor that will be provided to the Arduino I/O pin to measure the voltage at the battery. In the graph below the green line represents the current through the resistor R2 and is measured in mA. Lastly the red line the graph below is the current through capacitor C1.

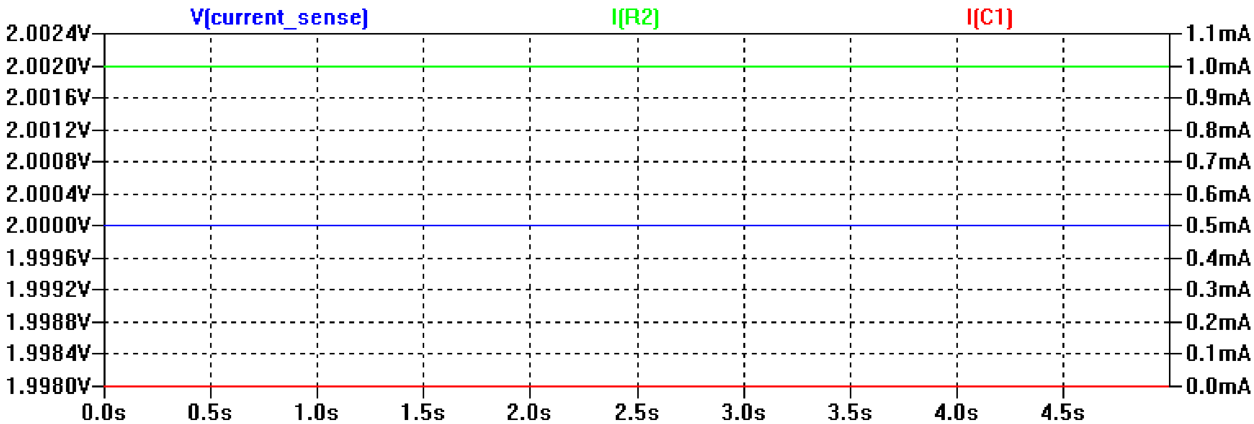

Figure 11: Voltage of current sensor and the current through the R2 and Capacitor 1

3.3.5.2 Design 2

A decision was made to remove the mains 220V source from the design as the budget did not allow for a transformer. The design changed to the following circuit below in Figure 12, below.

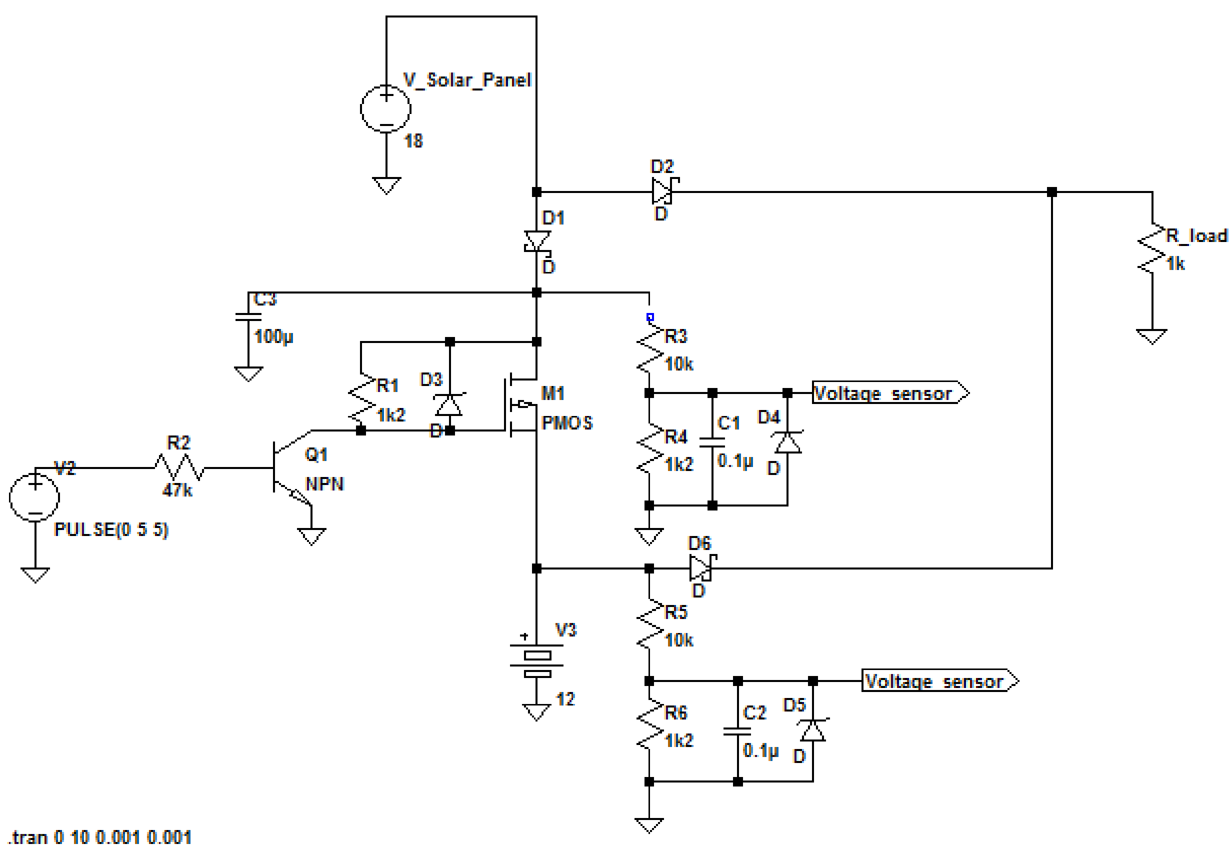

Figure 12: Final simulations circuit for charge controller

In the above figure of the simulation in Ltspice a P channel MOSFET is used to switch the solar panel power to the battery to charge the battery. This is done by a pulse provided by the Arduino via pulse width modulation, in this simulation however a DC voltage pulse is simply used to simulate the pulse from the Arduino. This pulse is then sent via a NPN transistor to the gate of the P channel MOSFET as can be seen in the figure above it is the node where the collector of the NPN transistor, pull up resistor, 10V Zener diode and the gate of the MOSFET is connected.

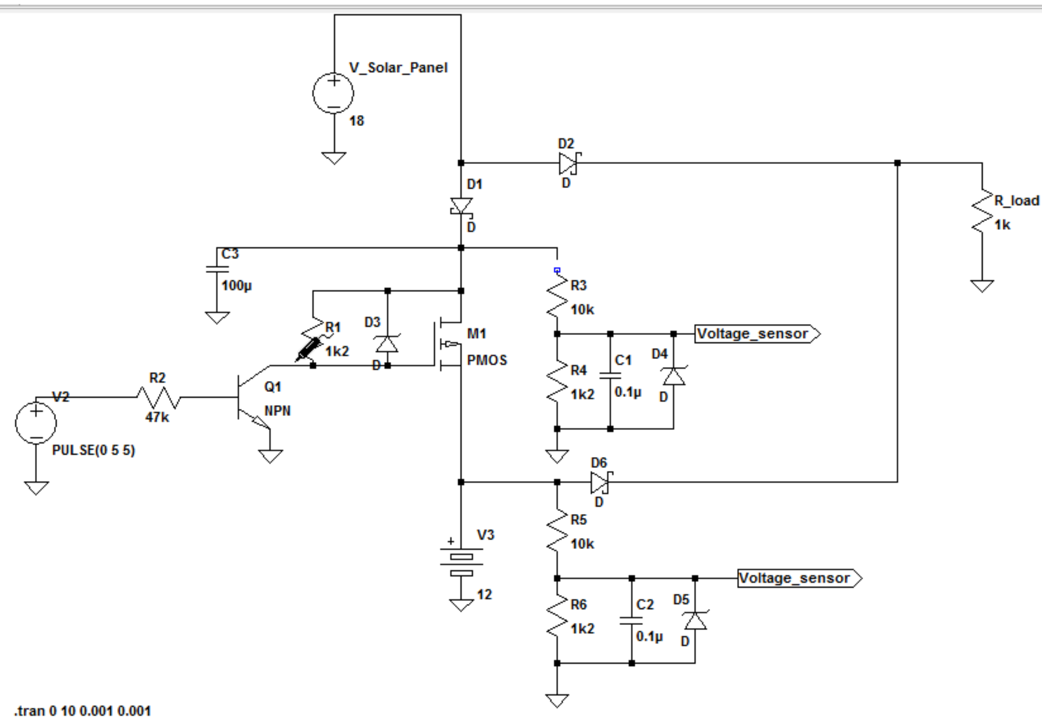

Figure 13: Voltage after the pulse at reference 1

Reference on the Figure 13 above simulation with pulse after 5 seconds.

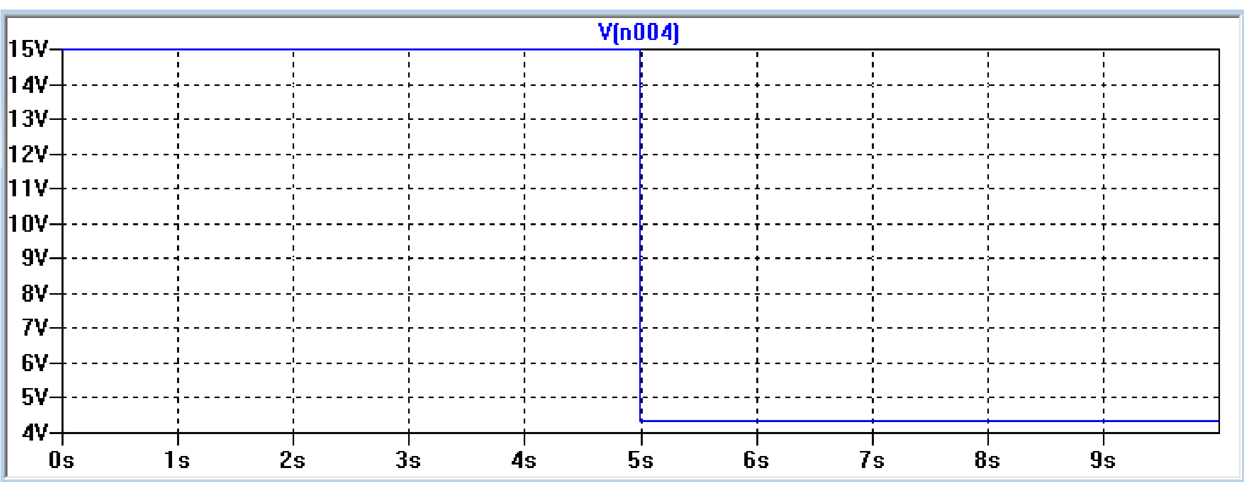

Figure 14: simulation of pulse at reference as shown on the figure above

The voltage sensor simulation measurements are as follow in the figure below. Where there was a 5V pulse from the PWM Arduino at 5s lasting 5s. In the Figure 15 below the voltage sensor Voltage and currents are shown with the pulse.

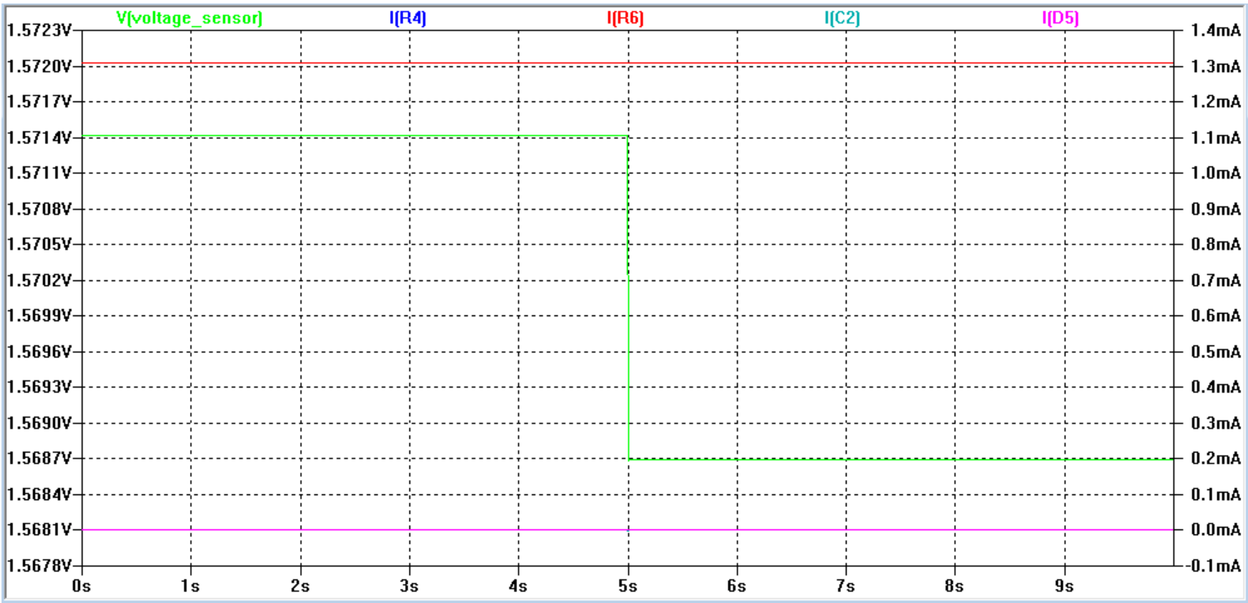

Figure 15: Voltage sensor measurements

In the Figure 15 above the green line represents the Voltage sensors output voltage to the input output pin of the Arduino. The dark blue line I(R4) is the second resistor in the voltage divider as can be seen in the Figure 13 above. The red line in the graph I(R6) represents the first resistor in the voltage divider as can be seen in Figure 13 above. The capacitor current is represented by the light blue line in the graph I(C2). And finally the diode current in the voltage divider is represented by the pink line I(D5).

Soldering circuit

By using the Fritzing software the following soldering circuit in Figure 16 below, for the charge controller, that is the P channel- MOSFET (in the circuit it only has a P channel FET but that is because the software does not make allowance for that form of MOSFET it only has e 8 pin SOIC MOSFET's which we will not be using therefore it is represented as below), NPN transistor and the voltage and current sensing the Arduino is not included on the circuit however nor the Schottky diode switching between power supplies.

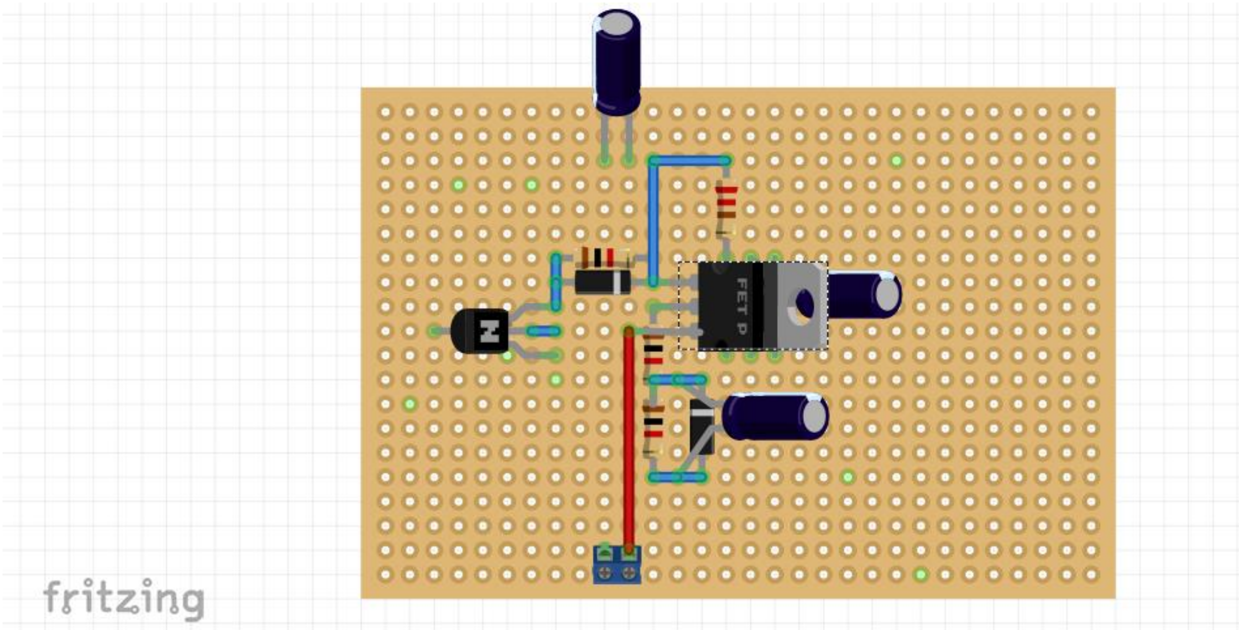

Figure 16: Charge controller Soldering circuit in Fritzing

However the circuit had to be redesign to connect the units to a common ground. This redesign circuit can be seen in Figure 17 below.

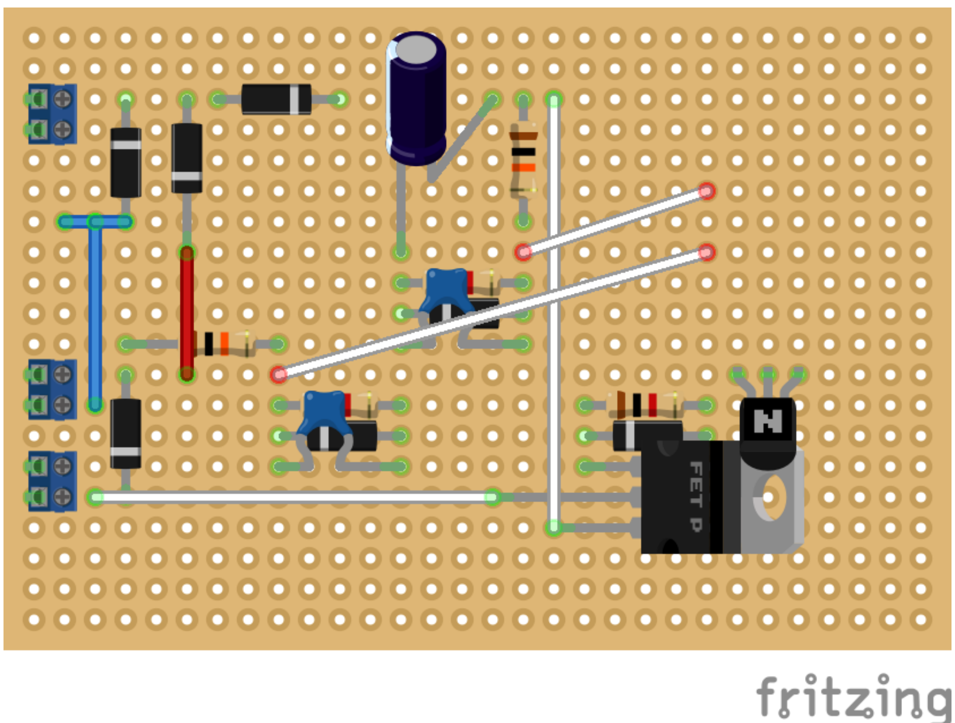

Figure 17: Fritzing layout 2

3.3.6 Physical Tests / Measurements

For the subsystem I am responsible for, the following tests and measurements where done.

3.3.6.1 Battery

For the battery the following measurements were taken to test the capability and efficiency of the 12V 9Ah battery.

Table 2: Battery measurements

Measurement	Value [V]	Value [A]
Reference	12	9
Loaded measurement	12.77	-

The rest of the battery measurements can be seen under the other section of test and measurements as it was connected to the circuit.

3.3.6.2 Solar panel

Voltage testing:

The voltage output of the PV panel can simply be measured using multi meter and placing the solar panel under different circumstances.

Table 3: Solar Panel Test

Test	Voltage measured [V]	Current measured [A]	Power [W]
Short circuit	22.05	3.05	67.25
Open circuit	22	0	0
Midday light	17.3	2.15	37.195

From the Table 3 above it is clear that though the solar panel did not yield exactly the same results as the specifications set in the datasheet of the solar panel, the solar panel still operates as desired, the deviation in the results may simply be from the fact that the measurements could not be taken under ideal conditions.

3.3.6.3 Charge controller test

The following aspects of the charge controller must be tested to ensure that the charge controller works, namely the P channel MOSFET operation, Voltage sensor to Arduino and the Current sensor to the Arduino. In the event that any of these circuit do not operate as expected, test must be done to identify the cause for the incorrect operation of the subsystem. The first test that must be done is a visual check of the circuit to inspect whether there are any loose connection, short-circuits or incorrect circuit connections. Before testing these individual aspects of the charge controller the circuit as a whole must be tested to determine if it works basically.

Circuit 1:

The fist charge controller circuit built is shown in the Figure 18 below, to determine if it worked in broad terms the battery, voltage source and a load was connected to the circuit. By measuring the results in m

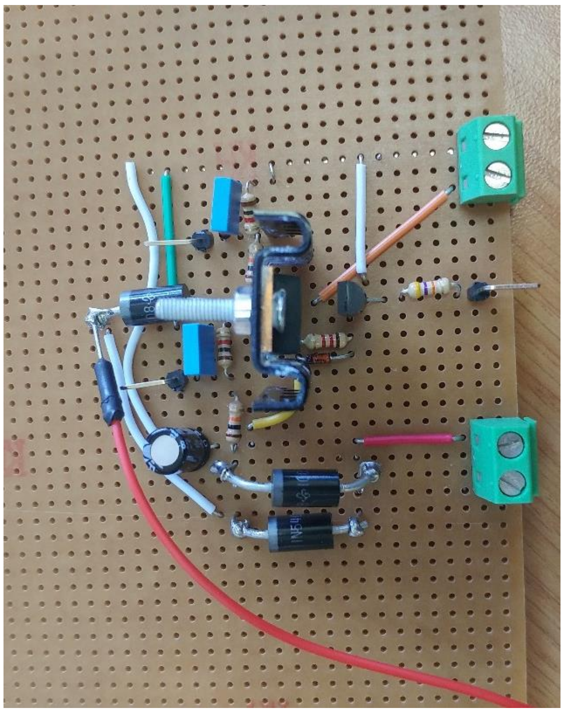

Figure 18: Charge controller circuit rev 1

Basic over all circuit test and trouble shoot:

Continue testing and troubleshooting until mistake is found in the circuit.

Table 4: Test and trouble shoot, charge controller circuit 1

Test and trouble shoot	Result
Visual test for loose connections	Checked all soldered points. No loose connections
Visual test for short circuit from double connection	Checked circuit for short circuit connections. No short circuit connections found

Visual test correct connections made on circuit	Checked whether the circuit built is the exact circuit designed. Discovered an incorrect connection made from the circuit designed to the circuit built.

From the trouble shooting described in the Table 4: Test and trouble shoot, charge controller circuit 1 above the following analysis and mitigation can be done as follow in

Table 5: Test charge controller circuit 1, fault and mitigation

Fault	Mitigation
Transorb incorrectly connected to the positive and negative terminals of the circuit	Unsolder the transorb and diode components from the circuit.
Common ground not made between all the components	Re-solder the circuit to make a common ground between all the components.
Not enough space for the optocoupler to connect to the charge controller conveniently and to the common ground conveniently.	Unsolder the circuit and rearrange the circuit to allow for better connection of the optocoupler to the charge controller circuit

From the mitigation in Table 5 it is clear that the best option would be to unsolder the entire circuit rearrange it and solder the new circuit. From this the following circuit 2 in Figure 19 below, is created.

Circuit 2:

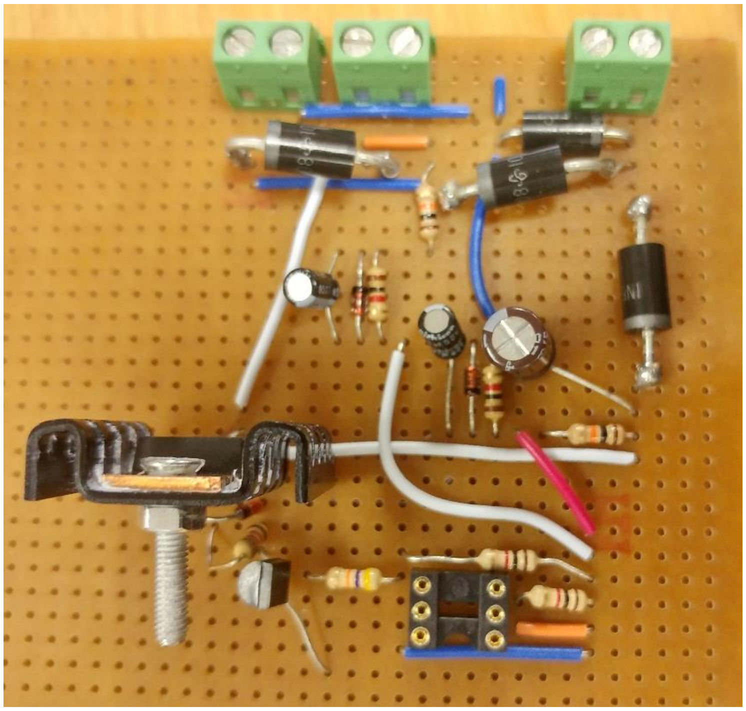

Figure 19: Charge control circuit rev 2

After applying power to the circuit in Figure 19 and measuring the nodes it was clear that the switching of the circuit was still not functional.

Test and trouble shoot	Result
Visual test for loose connections	Checked all soldered points. No loose connections
Visual test for short circuit from double connection	Checked circuit for short circuit connections. No short circuit connections found
Visual test correct connections made on circuit	Checked whether the circuit built is the exact circuit designed. Discovered an incorrect connection made to the optocoupler
Visual test correct connections made on circuit	Check correct design, not common ground not connected with Arduino.

Therefore the following trouble shooting as described in the Table 6 below, was done to determine the fault.

Table 6: trouble shoot and mitigation of circuit rev2

Fault	Mitigation
Common ground not made between the system and the Arduino	Ground wire to connect common ground of the system to the common negative of the Arduino.

Miscommunication between CF Greyling and SJ du Plessis as to which wire is the ground of the optocoupler	Unsolder the connection between the emitter of the NPN transistor and the supposed ground to connect to the actual ground with the optocoupler.

From these mitigation the following circuit was built circuit 3.

Circuit 3:

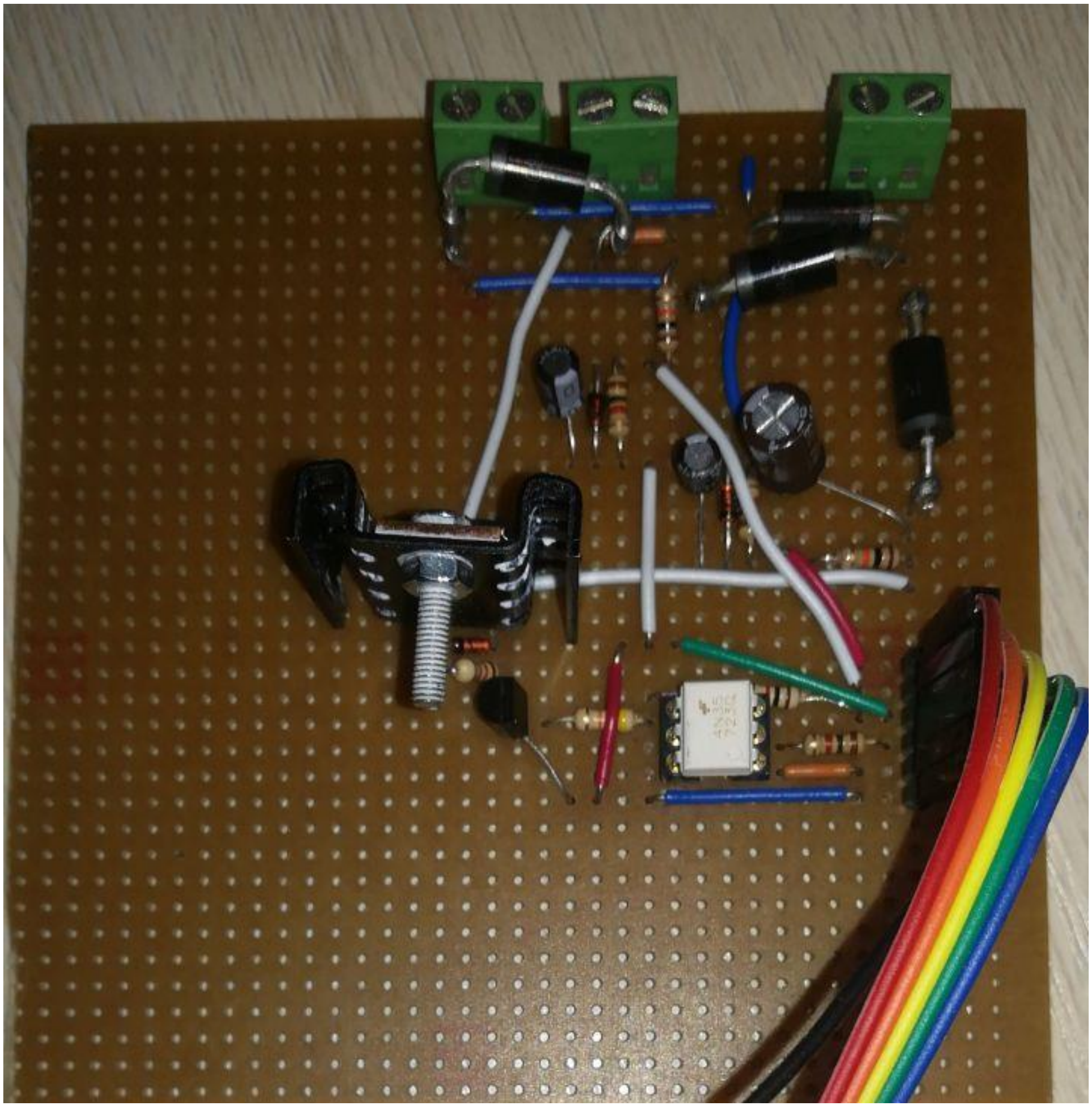

Figure 20: Circuit 3 of the charge controller

Once the mitigation in Table 6 was made on the circuit, the following measurements were taken. With the load and the battery both represented as 1k ohm resistors each. The test was conducted with the

Arduino providing a pulse at 100% duty cycle and the PV panel was represented by a power source set at 15.78V and about 0.2A.

Table 7: Measurements of Charge controller circuit rev3

Measured	Value [V]
V_P	15.78
$V_{Battery}$	15.10
V_{load}	15.14
V_P to V_2	0.765
V_P to V_4	0.642
V_3 to V_4	0.038
V_{GS}	9.88
V_{DS}	15.11
V_{GD}	9.89

3.3.6.4 Power switching of diodes

To test the switching abilities of the diodes a load is connected at the system with an 18V power source connected to represent the PV panel of the system as can be seen in the Figure 21 below. As the circuit changed from the removal of the mains power from the system there will only be the switch between the PV panel and the battery charger as power supplies for the system. Therefore only 3 Schottky diodes will be necessary for the switching. The diode between the voltage source and the load is to stop the current from flowing back to the voltage source if the voltage source's voltage is lower than the voltage from the battery supply. Similar the diode between the voltage source and the MOSFET charge controller prevents current from flowing back to the voltage source from the MOSFET. When the supply from the solar panel is higher than that of the battery the Schottky diode between the battery and the load stops the battery from draining power from the load.

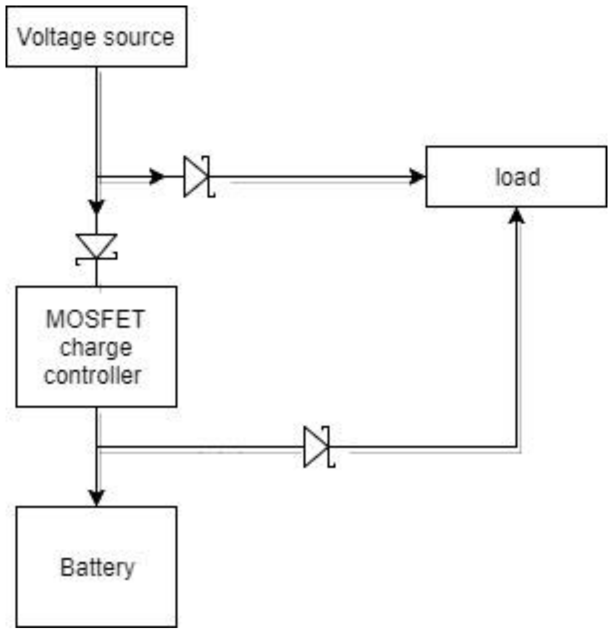

Figure 21: Schottky diode switch circuit

By numbering the circuit as follow in Figure 22 below, we can more easily reference the circuit for the test below.

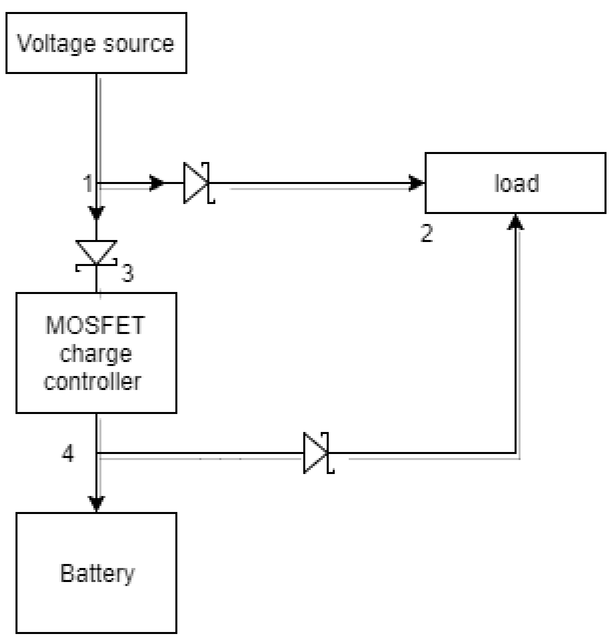

Figure 22: Numbered diode circuit

Test 1:

In the following test tabulated below the measured sections are referenced to the numbering in Figure 22 above, where for example V1-2 is the voltage measured from point 1 to 2 in the block diagram above. This measurement was done at 50% duty cycle of the Arduino and the voltage source provides 0.2 A current to the system.

Table 8: diode circuit Test 1

Measured	Value [V]
Voltage source	16.28
Battery	12.77
V1-2	0.651
V1-3	0.54
V4-2	12.77
V3-4	15.74
Battery to Vs (Of the MOSFET)	15.7
Battery to Drain (Of the MOSFET)	12.77

Test 2:

In the following test tabulated below the measured sections are referenced to the numbering in Figure 22 above, where for example V1-2 is the voltage measured from point 1 to 2 in the block diagram above. This measurement was done at 30% duty cycle of the Arduino.

Table 9: Test 2 diode voltage measurements

Measured	Value [V]
Voltage source	16.28
Battery	12.77
Load	15.64
Vcb	1.463
Vbe	3.585
Vds	2.971
Vgd	0
Vgs	0

The measurements in test 2 was still not what we would like therefore after changing the circuit as in charge controller rev3. Results of test 3 were as follow.

Test 3:

The measurements done in the following Table 10 below.

Table 10: measurements of the diode circuit test 3

State	**Measured**	**Value [V]**
State 1:	V_P	20.3
	$V_{Battery}$	0
	V_{1-2}	-12.21
	V_{4-2}	-0.730
	V_{1-3}	-12.17
State 2:	V_P	0
	$V_{supplied\ by\ Battery}$	13
	V_{1-2}	-12.21
	V_{4-2}	-0.730
	V_{1-3}	-12.17
State 3:	V_P	0
	$V_{supplied\ by\ Battery}$	0
	V_{1-2}	0
	V_{4-2}	0
	V_{1-3}	0
Stage 4:	V_P	18.93
	$V_{supplied\ by\ Battery}$	14.68
	V_{1-2}	0.467
	V_{4-2}	3.87
	V_{1-3}	0.659

From the Table 10 above the test was completed with integrated Arduino to pulse the MOSFET. However the Arduino picks up the 0.678 V of the diodes and this makes the Arduino switch and run current through the battery to the load from the solar panel.

However after test of the diode circuit on its own the diode circuit worked as desired. When there is no power supply from the PV panel power comes from the Battery moving through the diode between point 4 and 2 in the figure. When the PV panel is on and the battery is low or presents no voltage the current moves to the battery to charge it and to the load to provide it with power.

Table 11: Diode circuit management

Option	Set of battery	Set solar	V1-2	V4-2	V1-3
Option A	Battery =high	Solar = Low	No voltage	Voltage	No voltage
Option B	Battery=low	Solar = High	Voltage	No Voltage	Voltage

In the **Error! Reference source not found.** above the diode circuit management as tested is described for when the voltage output of the solar panel is high and the voltage output of the battery is low, which diode will switch. As well as when the solar panel voltage output is low and the battery voltage output is high.

From the testing it is conclusive that the diode switching functions as required and stated in the **Error! Reference source not found.** above. While the charge controller, which is the p channel MOSFET switches to a open state when a 5V pulse is given to the gate of the MOSFET and the switch is closed when the pulse is low. Therefore adhering to the requirements of the system and therefore allowing for battery charging through the Arduino.

3.3.7 Health and Safety Considerations

For the project health and safety forms an important role. Therefore the bylaw 25 (included in the Appendix A of the design portfolio) is followed during design. To ensure that people do not accidently touch live wires the wires and circuits of both the charge controller and the whole battery will be enclosed within a box. Thither more this box will be high enough to be out of reach of children and not be placed in such away such as to pose a risk for the users. Connecting wires between the solar panel and the charge controller will be well insulated with no open connections and will be connected to the wall there will be no wires for children to pull at or fall over and pull out of the circuit. Test points will be set in the circuit for the maintenance and therefore the circuit will not become dangerous through neglect. All capacitors and other possible issues are included to ensure that people do not get accidently shocked by touching then and acting as aground for the unloading. The solar panel will be secured to the roof to ensure that it is not tampered with. Other considerations are as stated in the safety requirements at the start of the document.

3.3.7.1 HIRA

To ensure that the project does not hold danger to any parties involved with either, manufacturing, installation, use, maintenance or the repurposing of the system HIRA (hazard identification and risk assessment) is used in the design and management of this project. HIRA is determined using a RAG (red amber green) status for possible hazards and risk throughout the project.

3.3.7.2 Life cycle

When considering the possible safety hazards during the project we look systematically at the project's life cycle and then at each interface of the project and how there might be hazards or risks during that part of the life cycle and how it may pertain to each interface. The life cycle can be divided into the following components namely, manufacture, testing, installation, use, upkeep and refurbishment. We can now look more closely at these aspects.

3.3.7.2.1 Manufacturing

a. Function: Charge controller construction
    a. Resources
        i. Technique
            1. Soldering of components onto strip board
                a. Capable of soldering
                b. Have the appropriate equipment to solder correctly

2. Drill holes for components that are to large
    a. Capable of drilling safely
    b. Correct drilling bit
3. Tools and equipment
    a. Soldering iron
    b. Drill
4. Materials
    a. Drill bit
    b. Soldering wire
    c. Ferro board
5. Facilities
    a. University laboratories

3.3.7.2.2 Testing

a. Function: Test circuit with voltage source, battery and charge controller, Arduino
    a. Resources
        i. People involved
            1. Members CF Greyling, SJ du Plessis
                a. Use correct measuring equipment
                b. Use correct safety equipment
        ii. Tools and equipment
            1. Power source
            2. Battery
            3. Oscilloscope
        iii. Materials
            1. Connection wires
            2. probes
        iv. Facilities
            1. Thevenin labs of NWU
    b. Risk
        i. Risk of injury from voltage supply
        ii. Risk of injury from loose wiring connection
    c. Impact

        i. Injury to person testing
        ii. Damage to circuit
    d. Priority
        i. Amber priority
    e. Mitigation
        i. Do not make contact with power supply acting as a ground
        ii. Check for loose or open wires

3.3.7.2.3 Installation

a. Function: Solar Panel instalment
    a. Resources
        i. Installation technique
            1. People
                a. Qualified for instalment
                b. Use correct safety equipment
        ii. Tools and equipment
            1. Ladder
            2. Socket wrench
        iii. Materials
            1. Brackets
            2. Fittings
        iv. Facilities
            1. Roof
    b. Risk
        i. Risk of injury to person installing the Solar panel on the roof
        ii. Risk of falling from the ladder during installation
    c. Impact
        i. Injury to person who installs the solar panel
        ii. Damage to the solar panel
        iii. Damage to the house
        iv. Damage to the system
    d. Priority
        i. Amber priority

    e. Mitigation
        i. Ensure more than one person is present at installation
        ii. Ensure correct safety gear is used
        iii. Ensure ladder is held secure
        iv. Ensure fastening is not done at awkward angles that may cause the installer to fall over
b. Function: Control Panel installation
    a. Resources
        i. Installation technique
            1. People
                a. Qualified for instalment
                b. Use correct safety equipment
                c. Knows where wiring is in the walls
        ii. Tools and equipment
            1. Drill
            2. screwdriver
        iii. Materials
            1. Brackets
            2. Drill bits
            3. Fittings
        iv. Facilities
            1. wall
    b. Risk
        i. Risk of injury to person if drilling not done correctly for the charge controller enclosure.
        ii. Risk of drilling into water pipes
        iii. Risk of drilling into wiring concealed in the wall
    c. Impact
        i. Injury to person who installs the control panel
        ii. Damage to the control panel
        iii. Damage to the house
            1. Water pipes damaged

2. Electrical wiring

iv. Damage to the system

d. Priority

i. Amber priority

e. Mitigation

i. Ensure more than one person is present at installation

ii. Ensure knowledge of components behind the wall

iii. Ensure capable person does the instalment

iv. Do not drill into walls that do not know what is behind it

3.3.7.2.4 Use

a. Function: Battery use

a. Risk

i. Over use with not enough charge

ii. Heat over exposure

b. Impact

i. Battery will become drained

ii. Heat damage to the battery

iii. Potentially dangerous lead acid could leak from battery

c. Priority

i. Amber priority

d. Mitigation

i. Disconnect non-essential components when battery running low

ii. Do not place battery where it will be exposed to excessive heat.

3.3.7.2.5 Upkeep

a. Function: charge controller connections

a. Risk

i. Over time heat from running the circuit could melt the wire insulation

b. Impact

i. Damage to insulation

ii. Open wire created

iii. Could shock user or technician

c. Priority
   i. Amber priority
d. Mitigation
   i. Use heatsinks to relay the heat from the components to the heat sink
   ii. Think insulation on wiring

b. Function: battery
   a. Risk
      i. Faulty or over heated battery could leak acid
   b. Impact
      i. Acid spilled over system
      ii. Damage to components
      iii. Health risk to user
   c. Priority
      i. Amber
   d. Mitigation
      i. Check battery state regularly

3.3.7.2.6 Refurbishment

a. Function: Add transformer for mains 220V AC power.
   a. Risk
      i. Incorrect connection of the transformer to the system
   b. Impact
      i. Refurbished could get shocked
      ii. Could blow the other components causing electrical fire
   c. Priority
      i. Amber
   d. Mitigation
      i. Present the circuit diagram for the connection of transformer to the circuit

3.3.8 Risk of Failure

3.3.8.1 Charge controller

1) MOSFET
   a) Risk

    i) Overheat
    ii) Voltage spike
  b) Impact
    i) Irreparable damage to the circuit
  c) Priority
    i) Amber
  d) Mitigation
    i) Replace MOSFET
2) Function: NPN BJT
  a) Overheat
    i) Replace if blown from heat damage
  b) Voltage spike
    i) Replace if damage from voltage spike
  c) Current spike
    i) Replace if damaged from current spike
3) Circuit connection
  a) Loose connection
    i) Ensure

3.3.8.2 PV panel

1) Function: dust on PV panel
  a) Risk
    i) Dust settle on the PV cells
  b) Impact
    i) Efficiency decrease
    ii) Damage to PV panel
  c) Priority
    i) Amber
  d) Mitigation
    i) Clear solar panel regularly
2) Function: Wind effect on PV panel
  a) Risk
    i) Wind blow away the solar panel

b) Impact
    i) Damage to panel
    ii) Damage to system from force of ripping the panel out
a) Priority
    i) Red
b) Mitigation
    i) Secure to roof tightly
3) Function: PV panel stolen
    a) Risk
        i) PV panel getting stolen from the roof
    b) Impact
        i) Cost of replacement
        ii) System not working
    c) Priority
        i) Amber
    d) mitigation
        i) Secure PV panel to the roof
4) Function: Transport PV panel
    a) Risk
        i) Damage during transportation of the PV panel
            (1) Getting dropped
            (2) Bumps during transportation
    b) Impact
        i) Damage to PV panel
        ii) System cannot work without panel
    c) Priority
        i) Red
    d) Mitigation
        i) Ensure to wrap the PV panel for transportation
5) function: PV cells functionality
    a) Risk
        i) PV panel cells not functioning correctly

b) Impact
   i) System working inefficiently
   ii) Over use of battery
c) Priority
   i) Amber
d) Mitigation
   i) Remove obstacle
   ii) Replace faulty cells

3.3.8.3 Battery

1) Function: Battery charging
   a) Risk
      i) Overcharge
   b) Impact
      i) Damage to battery
      ii) Potentially dangerous
   c) Priority
      i) Amber
   d) Mitigation
      i) Replace battery if damage occurred
2) Function: Battery life
   a) Risk
      i) Battery life expire (general lifespan of 2 years)
   b) Impact
      i) Battery not working correctly or providing enough power to system
   c) Priority
      i) Amber
   d) Mitigation
      i) Test battery every 6 months
      ii) Replace battery that is at the end of its life span
3) Function: Battery not charging
   a) Risk
      i) Over use of battery

- ii) Drain battery completely
- b) Impact
  - i) Can no longer charge fully
- c) Priority
  - i) Amber
- d) Mitigation
  - i) Remove load from battery when it is depleted to a d
- b) Drained
  - i) Battery completely drained:
    - (1) Damage repairable:
      - (a) Charge battery to full without a load
    - (2) Damage irreparable
      - (a) New battery
  - ii) Drained below 12V
    - (1) Charge without load

3.3.9 Discussion of Tools Used to Enhance Productivity

For the basic project management and documentations combination of word and pdf documentation is used to document project management. Calculations and other tabular documentation of the project is done in Excel where a cleaner and more simplistic output of the project management is documented. Other tools used to enhance productivity is the use of group conversations on WhatsApp instead of meetings in person where parties would have very far to drive and therefore take up a lot of time where time is now saved in this manner. Another communication tool used to enhance productivity is emails. Emails make communication with for example the MPS Supplier easier than phone calls and much more practical than a physical visit to his office as it is far away and to get an appointment would be difficult.

Other tools such as human resources is used in the form of Prof Holm who with class provides a great source of knowledge on the subject matter and the process of the project. Prof Holm also provides the added tool of efundi that provides resources on the project management and therefore we have tools of documentation. Another tool is Google drive which enhances productivity as it allows for file sharing where the emails cannot send such big files it also provides a singular digital base for the groups entire documentation.

By using tools such as LTspice circuits can be simulated before they are built therefore giving a clear picture as to what outputs the components ought to give. With RF flow the functional analysis and architecture can be drawn of the system to improve the efficiency of the project. Functional analysis of the project allows for a systematic approach which is more efficient and makes it easier to spot mistakes.

During the project hazard identification and risk assessment is analysed by the use of RAG status (Red amber green), where the hazards and risks are therefore mitigated and inspected according to how critical there status is. These RAG compiled in excel that allows for quick and easy assessment of the different possibilities.