ELEC2217 - D5 Smart Meter

Final Review - Group H

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1. Introduction

The review outlines the development of the smart meter design, and includes details of the construction of the housing, circuitry and software. It also summarises the performance of the smart meter, the management of the project, and the contributions of each team member.

2. Power Supply

Since the second review, the power supply has been modified to reduce the power consumption of the meter and improve the output voltage levels of the power supply; whilst still using the same design philosophy and topology **(**Fig. 1). In the final stages of refinement, the use of simulation was reduced, as it was found that the simulated power supply was not indicative of real world response, therefore a method of trial and error was used to improve the supply.

To improve the design, some of the components were modified, starting with the dropping capacitor. Several capacitor sizes were tried, including 1.5 μF and 0.85 μF, but the final decided value was 0.99 μF by utilising three 0.33 μF X2 safety capacitors in parallel. This value was chosen because it allowed more current to flow which increased the output voltages, whilst also improving the input power consumption of the smart meter. The bleed resistance of 500 kΩ was unchanged to ensure the voltage stored inside the capacitors drops to suitable levels within two seconds.

The bridge rectifier and the voltage smoothing capacitors were unchanged in the power supply design since the second review, however the Zener diodes used to generate the output voltage were modified. The 12 V Zener diode previously used to generate the 12 V output was replaced with two 5.1 V 1N5338BRLG Zener diodes in series to produce a 15 V output. This change was implemented to counter the voltage drop generated by the current limit from the dropping capacitor, to produce enough voltage to drive the rails for the Op-Amps in the interface circuitry.

In the final design, the power supply worked well, however the output voltage dip was not entirely fixed, with both voltage rails dropping below their optimum value to 4.2 V and 14 V respectively. On the other hand, the total power measured in the final review was 1.6 W, which is below the maximum requirement of 2 W for the smart meter, and a considerable improvement on the previous designs. Overall, as the voltage dip from the power supply was compensated in software, it can be judged to be a success.

3. Housing

The meter housing was largely unchanged since the second review. The design consists of a 120 mm x 120 mm cube, with troughs corresponding to the protruding ridges in the lid. The interior contains a section for the power supply (which had its own casing); grooves for slotting the circuit board; holes for the RJ45 ports, LED, LCD, and mains cable; and mounting holes for the Il Matto. Changes include a different mounting lug with a larger base, allowing for more contact area for gluing.

After construction, the housing was water tested before the real IP65 testing using a showerhead, and passed. During the real test (Fig. 2), no water leaked into the housing, which was a success.

Overall, the design worked well. Designing the housing to the maximum size made inserting the components easier (Fig. 3), and reduced the chance of knocking the other components and introducing loose connections.

4. Interface Circuitry

The design of the interface circuitry changed over the course of the project. The final circuit is shown in (Fig. 4). The design consists of three sections; analogue input, analogue output and digital input in reference to the Il Matto. The circuitry for the digital outputs from the Il Matto that were described in previous reviews, consisting of n-channel MOSFETs and pull up resistors, has been removed from the final design (Fig. 4). This was due to numerous failures in the MOSFET components ordered. Furthermore, it was found that the higher voltage level was not needed, as the testbed operates at TTL logic with a minimum voltage high level of 2.4 V. After testing the smart meter with the testbed, it could be seen that this worked well. The digital inputs to the Il Matto are potentially divided so the high level is 3.3 V (Fig. 5).

For the analogue input to the testbed to control the mains capacity, the PWM on board the Il Matto was used (Fig. 6). In the programme, the timer was set up to produce a signal of 47 kHz, which was within the low pass filter break frequency used on the interface design. The output of this low pass filter was amplified by a non-inverting amplifier with gain of 3. However, for the final tests some problems were encountered as the power supply only produced 3.16 V over the Il Matto. This meant that the maximum demandable current from the mains was about 2.85 A, and not the full 3 A. This caused problems when the requests for all three loads was on with no renewable capacity, however other problems of mismatched mains capacity were fixed by the software.

For the analogue outputs from the testbed, the circuits outlined in the second review were kept, however with slightly modified resistor values to match available components. Again, problems occurred with the 3.16 V supply to the Il Matto, as this affected the centre point of the AC signal and the scaling of the ADC readings (Fig. 7). After testing the AC signals to make sure that the signals would not clip the bottom (ground) rail of the op-amps, which they did not for the maximum possible inputs, it was decided to fix the centre point a scaling issues within the programme, as none of the analogue inputs exceeded 3.16 V. The AC circuits have been redesigned to work off 3.3 V and not 5 V, this is because the 5 V rail line from the power supply is currently about 4.2 V. This redesign was simple and involved changing only two resistor values on the board. These circuits work by using a summing amplifier with gain of less than one to add the AC and offset voltage. The DC analogue signals were simply potentially divided (Fig. 8); and voltage buffers were added to reduce the signal strength into the Il Matto's ADCs, improving the accuracy.

The final design has decreased in complexity significantly since the first design, with the DC-DC converter deemed to be too inefficient to operate, as it had a very large current draw of 30 mA. Initial designs for the AC inputs to the Il Matto were also more complex with the use of a capacitor to decouple the AC signal to allow shifting. This was ruled out however because it contained a phase shift component, and the capacitor had to be large to prevent attenuation of the relatively low 50 Hz frequency, which wasted space.

Connecting to the RJ45 sockets was done using the inner twisted pair cable removed from the ethernet cable, this allowed easy debugging of any errors when constructing the interface circuitry, with the ends soldered directly onto the interface board. To connect the interface with the Il Matto, ribbon cable was used with matching headers for the Il Matto, the wires were then split and soldered directly into the interface board. An improvement to this would be to use headers soldered onto the interface circuitry, as this would make debugging easier and the circuit less susceptible to breaking when being put in the box. Measuring the current draw of the interface showed it to be less than 2 mA. The interface board was cut to fit within the box, being 100 mm wide and 80 mm tall, and slotted into a groove built into the housing.

There were some problems found with the interface in the latter stages of testing, these were all poor connections on the board, or where connections had been damaged, as well as an incorrect setup of the header cable, these were all debugged and fixed for a fully functioning interface.

5. Software and Display

The code is made using nine files with the main code being split between two files (helloWorld.c and helloWorld.h). The main code is structured into three parts: the condition checking while loop, the decision-making condition block, and a controller function.

Firstly, the checking while loop is made to check the condition of the system quickly without any decision or control. So long as there is no change to the system condition, such as the load call changes, renewable energy changes and mains condition, it would stay inside this loop. This allows for a fast response to a change whilst keeping the controlled condition unchanged. Theoretically, for most of the time, the code should run within this loop.

Secondly, there is a decision-making condition block. This is where the current decision calculations are made, and was based on the flowchart included in the ZIP file.

For the last section of the code, a controller was implemented to check whether the mains is working (mains detection) as well as a feedback controller to compensate the mains current request based on the busbar voltage. (e.g. increase the current from the mains when busbar voltage is below 240 V.)

The other files include the modified LCD library, which included a new function to display data in rows and columns of a table. The existing functions were also edited to increase the size of the text.

During the development, the screen was used to debug the program by displaying different strings indicating the different sections of the code that are executed in real time. It made it easier to debug the code and diagnose where the problems were. In the final product, the load calls and responses, battery status, battery level, busbar current and voltage, mains condition and level, and renewable currents are displayed (Fig. 9).

All of the changes to the code are stored in Github and developed under different branches for each team member. It allowed versions of code to be managed, and tasks that needed to be done within the code could be commented in each code commit. By working in parallel and merging code branches together into a master branch, it allowed for the code to be completed in a shorter time. None of the members had used Github before, so it was an additional skill to develop besides the C programming for this project.

6. Meter Operation and Performance

The operation of the smart meter was made simple to ensure user compatibility, therefore once the test bed is plugged in, the smart meter turns on automatically and immediately starts controlling the loads.

The meter performed with well, with a few drawbacks. The controlling of load requests was good, and the decision making of charging the battery when given spare capacity worked well. In most cases the current supply matched demand. The areas of improvement included the accuracy of the ADC inputs, and the mains control function that checks the status of the mains power.

Due to complications in the power supply not producing the expected 3.3 V to the Il Matto, the ADC readings of the wind and solar capacities were skewed. This was adjusted for in software. A similar problem was encountered in the mains current control. As 3.3 V could not be produced by the Il Matto when 100 % of the mains is requested, the full 3 A could not be requested by the smart meter. Again, this was partially adjusted for in software, by multiplying the mains current by a factor of 1.2, the overestimate cancelled out the underestimate caused by the reduced output voltage. When all three loads were requested in the test, the smart meter struggled to provide the 3 A required from the mains, but performed well when only two loads were requested.

The meter also falsely detected a failed mains supply during tests, in which the battery was discharged to account for the supposed lack of current. This was due to the ADC reading of the busbar voltage being skewed. False readings of a failed mains supply were reduced by using incremental control when the mains is requested. This increased the requested mains current by small amounts until the busbar voltage reached 240V.

Overall, these drawbacks were mostly accounted for in software, and the meter performed well for the majority of the test.

7. Project Management

Regular weekly meetings were scheduled throughout the project to ensure progress was tracked and further actions were assigned (Appendix B). There was an extensive use of the Gantt chart to monitor developments and plan timescales (Fig. 10-13).

Matthew had the role of project leader, and had the role of designing and building the interface circuitry, including testing with the power supply and Il Matto. During the final week joined the rest of the team on debugging and optimizing the whole system when running with the testbed, this included improving both the interface and program.

Enyang focused on the power supply, which included generating simulations, connecting the physical circuit, debugging the circuit design, testing and modifying the design, along with Lawrence.

Ricki was the team’s secretary, and recorded the minutes during meetings. He was in charge of the housing and worked alongside Fransiskus. Once the housing was completed, he joined Fransiskus on the software, and helped code the main program.

Lawrence took the role of the budget manager, which included ordering components and managing the total finances of the group. For the smart meter, most of his work was focused on the power supply, which included generating simulations, construction and testing of the supply, along with Enyang Zou. In the latter stages of the project, Lawrence helped with debugging and refining both the software and the interface circuitry in preparation for the final test.

Fransiskus was in charge of designing the housing along with Ricki. He was also in charge for the software development including the user interface, input and output and control. He was joined by Ricki and Lawrence for the control and interface finalisation part of the software.

8. Conclusion

Overall, the meter has performed well and the team is happy with the results. The meter produced a good result in both reviews, with the software having good control of all loads and the mains supply, and being able to make the optimum decisions in the test scenarios. Improvements that could be made are a more thorough test of the power supply, compression of the interface board, an improved mains failure detection code, and the aesthetics of the housing. The team worked well together, with no disagreements and all members cooperating well, to evenly distribute workload and work in tandem on separate parts of the design.

9. Appendix A – Report figures

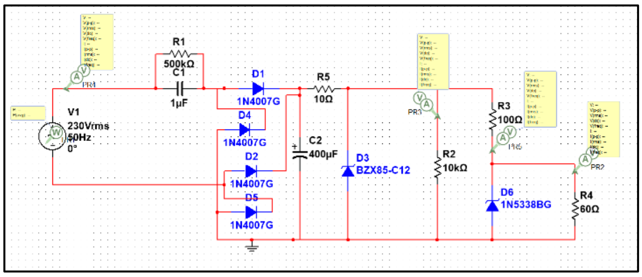

Fig. 1. The circuit diagram of the power supply,

Fig. 2. IP65 testing of the housing.

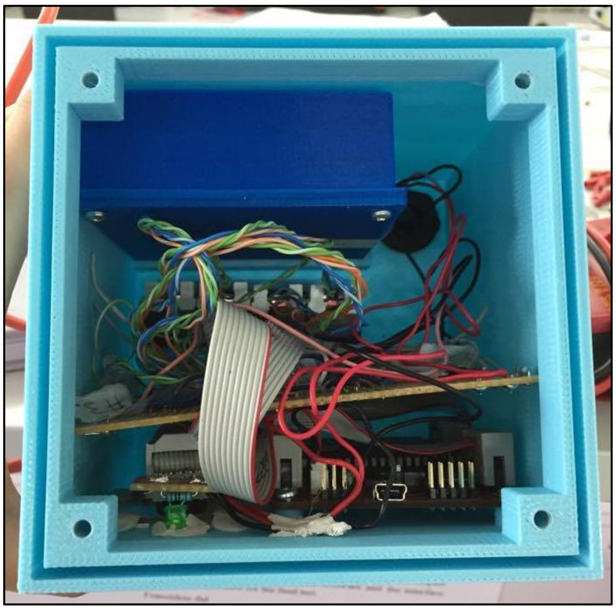

Fig. 3. The interior of the meter, with all the components inside.

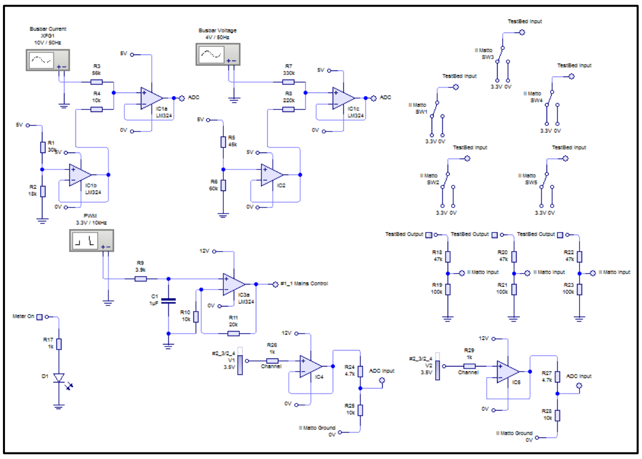

Fig. 4. The final design of interface circuitry.

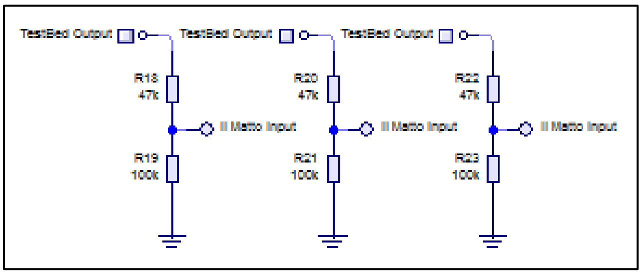

Fig. 5. Potential dividers for inputs to Il Matto.

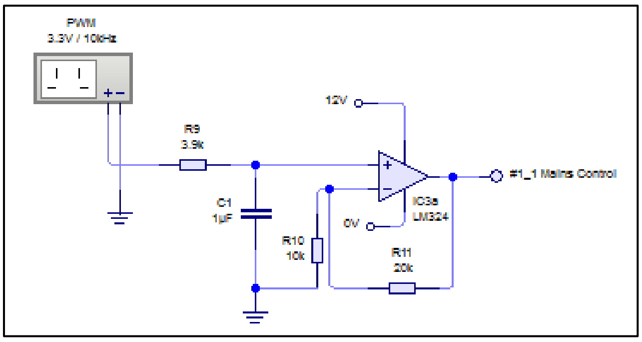

Fig. 6. Design of the mains capacity control circuitry.

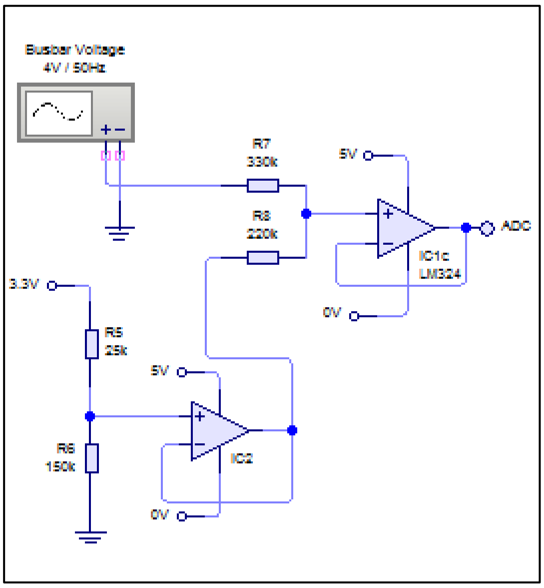

Fig. 7. Design of the AC input circuitry.

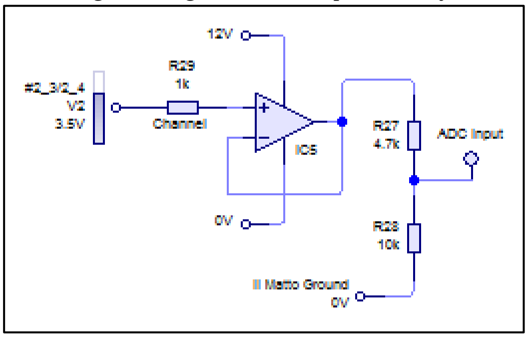

Fig. 8. Design of the DC input circuitry.

Fig. 9. The meter display, showing various information.

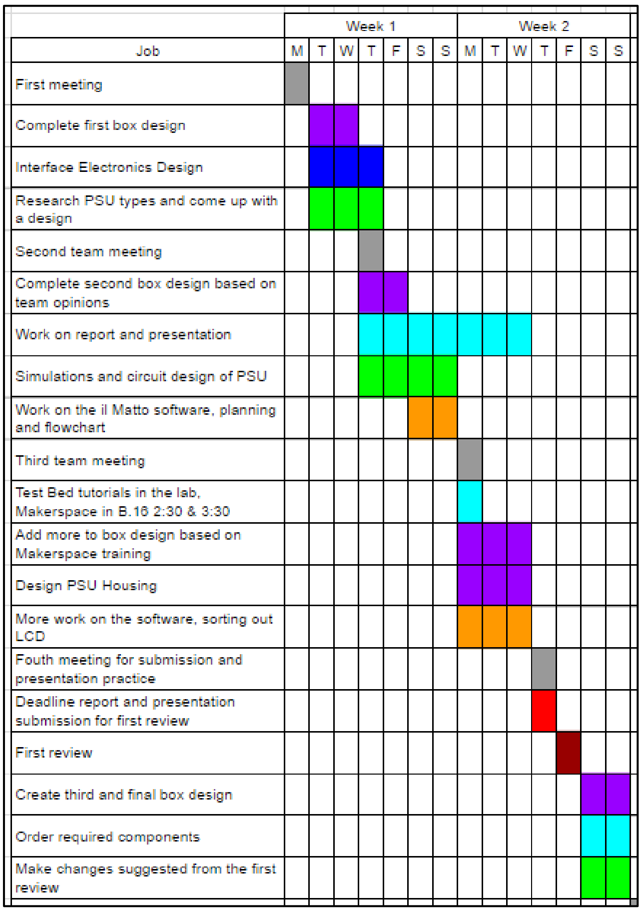

Fig. 10. Gantt chart weeks 1 and 2.

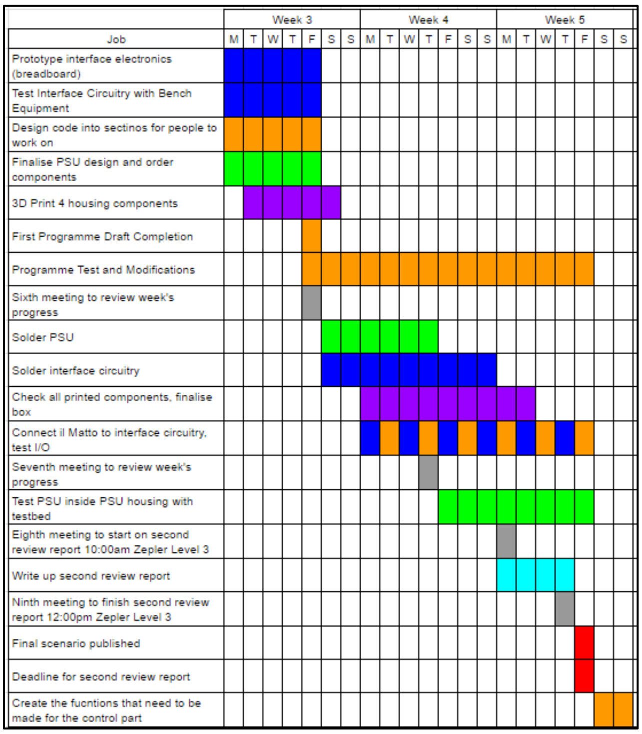

Fig 11. Gantt chart weeks 3 to 5.

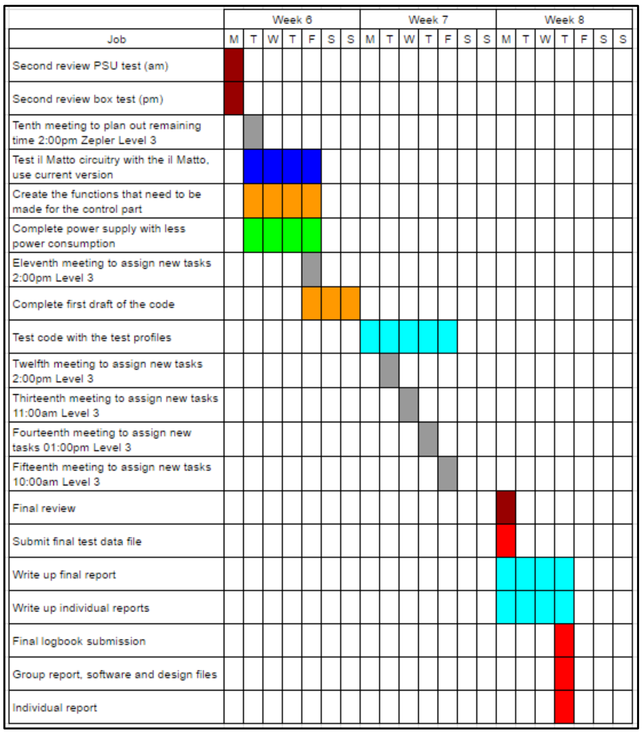

Fig. 12. Gantt chart weeks 6 to 8.

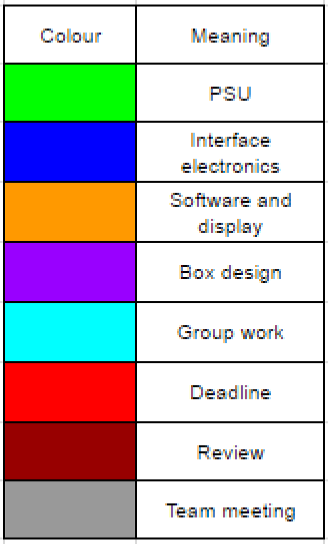

Fig. 13. Gantt chart key.

10. Appendix B – Meeting minutes

Monday 30th January 2017 - Meeting 1
11:00am - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Fransiskus, Eric

Topic	Notes	Actions
Group roles	• Leader - Matthew • Secretary - Ricki • Budget Manager - Lawrence	• Ricki to make Gantt chart with deadlines. • Lawrence to make budgeting spreadsheet.
Meeting	• Regular meetings each week. • Need to work on the 4 page report and presentation in the next meeting.	• Ricki to arrange a room for meeting on Thursday, look for 12/1/2pm, and make an event on the Facebook group.
Power Supply	• Lawrence and Eric. • Need to decide on power supply design. • Simulations.	• Lawrence and Eric to justify power supply choice with evidence ready for review (see the handbook for an idea). • Write up some text explaining this ready for writing up the report.
Housing	• Design needs to be exported in STL format. • Can design like a “house”, with a sloped overhanging top to remove water, port connections on the underside and recessed into the housing to prevent water from entering. • Also need a hole for the power LED. • Can make lots of grooves in the interior of the housing so that we can place partitions in different places, as the design changes. • Cut some acrylic for the top section, and for making partitions to separate the power supply from the Il Matto. Also a window for the Il Matto display. • Grooves to make the top removeable for easy access.	• Ricki and Fransiskus to design on Solidworks. • Write up some text explaining this ready for writing up the report.
Interface electronics	• Matthew to lead. • Design the stripboard circuit to separate out the wires in the RJ45 cables and create the connections to the Il Matto.	• Matthew to put a flowchart together. • Matthew to look at the specs of the Il Matto, check the output voltages, 3.3V or 5V? • Write up some text explaining this ready for writing up the report.
Software and display	• Need to plan out what things the code should contain, what functions, and what should be displayed on the screen?	• Matthew to get the Il Matto set up ready for programming (use the Pong code and strip it out).

Thursday 2nd February 2017 - Meeting 2
12:00pm - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Fransiskus, Eric

Topic	Notes	Actions
Box	• Design almost finished apart from the holes for the wires and the power LED. • Things to consider to save space include reducing overhang, putting the acrylic window pane on the outside of the box or resize it so it is flush and glue it into the frame, moving the locations of the screw holes so that we can slide the il Matto in flush to the wall. • We can also change the inner walls, depending on the size of the PSU and the interface circuitry.	• Ricki and Fransiskus to continue tweaking the design. • Find out the dimensions of the glands/grommet for the PSU cable from the lab technicians.
Power supply	• We've gone for a full bridge wave rectifier supply. It makes a smoother voltage output than a half wave, as there is less ripple. • The drawback is that it is less efficient, we're losing energy in the diodes. • The thing that needs tweaking is the efficiency, this can be done by changing the values of the components in the system. • We know that the il Matto runs on 5V and draws 5mA.	• Lawrence and Eric to continue working with the design, by changing the parameters and checking the simulation results. • Also need to look at what bleed resistors to use, the capacitors need to go below 30V after 2 seconds from power off. • Need to get the transient response timing graph of the power supply on power up. • Need to review the different power supply types and give reasoning for your answer.
Interface electronics	• Simulated the AC input that has been converted into a suitable DC signal for the il Matto. • Simulated and designed the 10V DC output controlling the mains from the il Matto, by using PWM on the output pin and an Op Amp as the gain. • The varying DC 0-5V input for the wind turbine and PV panel can be read using the ADC pins. • The TTL logic signals can be read by general pins.	• Matthew to look at the effect of the input impedance for the signals coming into the il Matto.
Software and display	• No progress made as of yet. However we know what pins and processes we need to sort out the input signals from Matthew's interfacing work. • Ricki and Fransiskus could move onto this once the box is done.	• Ricki and Fransiskus to create a rough flowchart highlighting what the program will do.
General comments	• Lawrence to get the required component lists from Matthew, will need to check what components the lab has. • Team to start putting together the report and presentation. • Ricki to create meeting for Monday morning and Thursday afternoon (book a room for presentation practice). • Team to continue to add to the Gantt chart.	

Monday 6th February 2017 - Meeting 3
10:00am - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• Redesigned inner layout to compensate with the LCD being separate from the il Matto. • This allows us to use any of the pins for the LCD, but has the downside of taking up more space within the box.	• Ricki and Fransiskus to complete new design, and include these changes in the report and presentation. • Find out the dimensions of the glands/grommet for the PSU cable from the lab technicians.
Power supply	• Efficiency of ~49%. • Capacitors go below 30V in 1.9s. • Takes about 100ms to reach a steady 5V. • Ripple is less than 0.01V.	• Lawrence and Eric to review the different power supply types and give reasoning for your answer. • Complete your section of the report and presentation. • Calculate power factor.
Interface electronics	• Putting a voltage follower and op-amp in front of everything.	
Software and display	• Rough flowchart has been made.	• Ricki, Fransiskus , and Matthew to create a rough flowchart highlighting what the program will do. • Look into getting the LCD to run off whatever 16 pins we want. • Create pin layout of what we're using.
General comments	• Team to complete the report and presentation. • Ricki to book a room on Thursday for 1pm (multiple hours) for first review submission and presentation practice. • Team to continue to add to the Gantt chart.	

Thursday 9th February 2017 - Meeting 4
01:00pm - 54 / 8033 and 04 / 4055
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
First review	• Time was spent making changes to the report before submission, ensuring it reads in a single voice. • Last minute changes to the presentation, and roles were assigned to who will present what part. • In the final hour we practised the presentations, aiming to get the duration in between 8 and 10 minutes. No tasks were assigned.	• None

Monday 13th February 2017 - Meeting 5
10:00am - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• STL file submitted. • Could print the smaller parts on Tuesday afternoon, and the big box on Wednesday morning. • STL files for the other three components need to be made, zip it and resubmit.	• Ricki and Fransiskus to hear from Mark/Tony on Tuesday, and start printing the 4 components of the housing. • Lawrence to print on Tuesday afternoon.
Power supply	• Looks pretty good at the moment, however we need to improve the power factor before components are ordered. • One alternative is making the circuit to drop to 12V, and then linear regulate to 5V. • Need to ensure capacitor height is less than 20mm when on its side, could use insulating tape on the legs.	• Lawrence and Eric to test with different Zener diodes to try and improve power factor. • – Lawrence and Eric to check if that is better than our current method.
Interface electronics	• In a position to order components and build prototypes. • MOSFETs need to be ordered.	• Build on a breadboard, test, then create on stripboard.
Software and display	• Can split up into sections. For now, Matthew can do I/O once interface electronics is done, and Ricki and Fransiskus to do the control part.	• Continue working on it.
General comments	• Gantt chart updates	

Friday 17th February 2017 - Meeting 6
02:30pm - Zepler Level 2
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• All parts except the main box are printed. Test piece for holes and grooves was made and tapping the holes was successful. Rubber gasket may not be necessary.	• Lawrence to print box on Saturday.
Power supply	• Components have been ordered. • Changing the Zener diodes makes little change.	• Lawrence and Eric to solder together the power supply components that we have, and make the etches in the tracks ready for when the X2 rated capacitors arrive.
Interface electronics	• Everything works on the breadboard prototype, the analog inputs and outputs, the digital inputs (had to divide down from 5 V to 3.3 V for the Il Matto input). • Just need to wait for the MOSFETs to arrive.	• Matthew to solder it all together. Board size of 115 x 90 mm (length x height), leave bottom 10 mm of height blank as this part fits in the groove.
Software and display	• Fransiskus has added the global timer, used for monitoring the battery capacity and the power usage. PWM is in progress.	• Fransiskus and Ricki to continue working on it.
General comments	• Gantt chart updated and next week (week 4) is planned.	

Thursday 23rd February 2017 - Meeting 7
02:30pm - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• All printed. Rubber gasket may not be necessary.	• Ricki to glue on the mounting lug and the acrylic window. Check port sizes. • Do a water test to see if a rubber gasket is necessary.
Power supply	• Components have arrived and are soldered to the board. Ready to test!	• Lawrence and Eric to test the power supply using the testbed. See Richard in the Level 2 labs.
Interface electronics	• Soldering is half done. • MOSFETs have arrived.	• Matthew to check the DC-DC converter to see if it works. • Matthew to solder it all together. Board size of 115 x 90 mm (length x height), leave bottom 10 mm of height blank as this part fits in the groove.
Software and display	• Fransiskus has added PWM, and the IO. • A third timer is to be used for the ADC sampling over time.	• Fransiskus and Ricki to continue working on it. • Ricki to learn the code that has been currently made.
General comments	• Gantt chart updated and next week (week 5) is planned.	

Monday 27th February 2017 - Meeting 8
10:00am - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• New mounting lug printed and glued onto the lid. • Only the window is left to fixed, after that the box is done!	• Need to glue window onto front of box. Laser cut a gasket out of rubber and have that in between? • Do a water test to see if a rubber gasket is necessary.
Power supply	• PSU soldered and tested. We have a problem that the power draw alternated between 1.5W and 2.4W. The test bed fuse has a current limiting resistor of 100mA, which makes things difficult as our interface circuitry draws 45mA, and our il Matto with the display draws 50mA. • The results aren't in line with the simulations.	• Replace capacitors and resistors, get the optimum solution by this Friday.
Interface electronics	• Had to choose a method to manipulate the analogue inputs before they're sent to the il Matto. One method was to DC offset the signal between 0 and 3.3 V. The other method was to make a peak detector. We've decided to go for the first option.	• Continue soldering onto the board. • When completed, test it with the il Matto.
Software and display	• Fransiskus has added the ADC sampling.	• Continue coding, test with interface circuitry when it has been soldered.
General comments	• Gantt chart updated and next week (week 5) is planned.	

Thrusday 2nd March 2017 - Meeting 9
12:00pm - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• Box is completed, and the water test was successful. • Rubber gasket for the lid was not necessary.	• None required, box is complete!
Power supply	• Tried new zener diodes, found a problem with the Il Matto and display drawing 100mA, which is too high! The current limiting resistor in the test bed limits the current draw to 100mA. • The problem may be with the Il Matto. • Apart from that, power supply is very close to being completed.	• Try the testbed again with a new Il Matto. • Replace capacitors and resistors, get the optimum solution by this Friday.
Interface electronics	• Everything is completed. Resistors may be swapped to limit current draw, but apart from that it is finished. • Tested the AC 0V - 10V input circuit with the Il Matto, worked.	• Test completed interface circuitry with the various Il Matto inputs/outputs.
Software and display	• Average power and energy consumption coded, requires testing.	• Look a remaining code that needs to be written, and break up the problem into smaller functions that team members can work on independently.
General comments	• Gantt chart updated.	

Tuesday 7th March 2017 - Meeting 10
2:00pm - Zepler Level 3
Present: Ricki, Lawrence, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• Box passed IP65 testing, no water inside which is great!	• None required, box is complete!
Power supply	• It needs to be slightly improved, the power is 2.1W, need to change the capacitor value so that the power consumption is ~1.8W. We can do this by having capacitors in series and parallel to get the capacitance we want.	• Eric to solder new power supply and test.
Interface electronics	• MOSFETs have been replaced, so it should now work.	• Matthew to test completed interface circuitry with the various Il Matto inputs/outputs.
Software and display	• Contacted Alex about the various questions we had. We now know that the current draw of the loads is known (they are the same as the test profiles), we also know that the maximum mains current is 4A, and the battery charge and discharge current is 1A. • We also know that not supplying enough current to the loads will drop the busbar voltage, and supplying too much current will increase the busbar voltage. • This makes designing our code easier. We can work in terms of currents instead of constantly checking the busbar.	• Ricki and Fransiskus to use this information to design the control functions. • Ricki to email Alex about losing power to the ward. • Modify the code for finding the peak of the busbar voltage and current, then RMS to find the actual values.
General comments	• Gantt chart updated.	

Friday 10th March 2017 - Meeting 11
2:00pm - Zepler Level 2
Present: Ricki, Matthew, Eric, Fransiskus

Topic	Notes	Actions
Box	• None required, box is done.	• None required.
Power supply	• 0.66uF capacitor gives a power consumption of ~1.5W, which is good. • Finished, only testing left to do.	• Eric to connect PSU to the interface circuitry and il Matto and check the voltage across the il Matto and 15V Zener diode.
Interface electronics	• Done.	• Matthew to use ribbon cables for the wires linking the interface circuitry and il Matto.
Software and display	• Code skeleton has been made for the decision making, ADC timer has been removed in favour of using the ADC read functions within the while loop, reverting back to a global timer, with the timer variable incrementing every millisecond.	• Get first draft of code done by next week ready to test on the profiles.
General comments	• Gantt chart updated.	

Friday 10th March 2017 - Meeting 12
2:00pm - Zepler Level 3
Present: Ricki, Eric, Fransiskus, Lawrence

Topic	Notes	Actions
Box	• None required, box is done.	• None required.
Power supply	• Tested on Monday, total power consumption with interface and il Matto connected is 1.6W.	• None required.
Interface electronics	• Ribbon cables done.	• Carry out necessary testing, get it complete by the end of today.
Software and display	• First draft has been made, and tested on the first profile. • Lots of bugs, will need to fix.	• Explain to team how code works. • Get team to try and make custom profiles. • Test individual branches of the flowchart.
General comments	• Gantt chart updated.	

Wednesday 15th March 2017 - Meeting 13
11:00am - Zepler Level 2
Present: Ricki, Eric, Fransiskus, Lawrence, Matthew

Topic	Notes	Actions
Box	• None required, box is done.	• None required.
Power supply	• None required, power supply is done.	• None required.
Interface electronics	• None required, interface circuitry is done.	• None required.
Software and display	• First draft has been made, and tested on the first profile. • Lots of bugs, will need to fix. • The Il Matto isn't getting 3.3V, will need to change the input resistor going into the Il Matto to a lower value in order to increase the voltage. We get 3.01V after the resistor, and 4.1V before the resistor. Doing so won't change the power consumption. This needs to be fixed so that the ADCs work correctly. We should aim for a voltage of 3.6V going into the il Matto.	• Change resistor to 10Ohm for the current limiting to the il Matto. • Test and calibrate the 4 ADCs, check to see if the LCD readings match that of the profiles. • Test the PWM out to see if it's varying well, compare with what the LCD is saying. • Get team to try and make custom profiles. • Test individual branches of the flowchart. • Check code for errors, adjust the control so that the battery isn't rapidly charging and discharging.
General comments	• Gantt chart updated.	

Thursday 16th March 2017 - Meeting 14
01:00pm - Zepler Level 3
Present: Ricki, Eric, Fransiskus, Lawrence, Matthew

Topic	Notes	Actions
Box	• None required, box is done.	• None required.
Power supply	• None required, power supply is done.	• None required.
Interface electronics	• None required, interface circuitry is done.	• None required.
Software and display	• Good progress made so far, still need to find all the bugs, and continue to refine our code. • Power supply is delivering 2.92 V to the Il Matto, this should be fine.	• "While" loop at around line 850 hangs, will need to improve/increase the incremental control so it is quicker, or reduce V_threshold. • Optimise the 3 and 8 minute battery charging parameters, so it works better. • Get the interface circuitry checked for loose connections (LED wire is loose). • Get everything inside the box, so the hardware is finalised. • Fix non-updating battery level, could put an extra screen debug print in the code to see what is happening. • ADC calibration if required, to match the new Il Matto supply. • Create own test profiles (see Dave Batt). • Optimise wait time between the two samples when checking if the mains works, may also be in the control. • Check to see if we can produce a higher supply to the Il Matto using 0.99uF capacitor.
General comments	• Gantt chart updated.	

Friday 17th March 2017 - Meeting 15
11:00am - Zepler Level 2
Present: Ricki, Eric, Fransiskus, Lawrence, Matthew

Topic	Notes	Actions
Box	• None required, box is done.	• None required.
Power supply	• None required, power supply is done.	• None required.
Interface electronics	• None required, interface circuitry is done.	• None required.
Software and display	• Power supply is now delivering 3.16 V to the Il Matto, this should be fine. Replaced 0.66uF with 0.99u, this makes the ADC more accurate, but it reduces power efficiency. • Completed a lot of the tasks yesterday, not much left to complete.	• Get everything inside the box, so the hardware is finalised. • Optimise the 3 and 8 minute battery charging parameters, so it works better. • Fix non-updating battery level, could put an extra screen debug print in the code to see what is happening. • ADC calibration if required, to match the new Il Matto supply. • Optimise wait time between the two samples when checking if the mains works, may also be in the control. • Run a full 24 minute test, and fix any bugs.
General comments	• Gantt chart updated.	

11. Appendix C – Budgeting details

ELEC2217 EEE Smart Meter Design Exercise 2017 - Requisition Form

Note: *We can only order items through RS or Onecall. If you choose to order from a different supplier, you must place the order yourself and claim the cost back. Only order in-stock items. If an item is out of stock, you should order an alternative item, or use a different supplier. ONE group member should be designated as responsible for ordering items and keeping track of spend against the budget.*

Once the form is completed, email to both Mark Temple and David Kemmish
mst1a11@ecs.soton.ac.uk and dk@ecs.soton.ac.uk

Form completed by: Group: H

Contact name: Lawrence Coles

Contact email: lcc2g15@soton.ac.uk

Supplier (please use RS/Onecall only): RS

Total spend before this requisition (£): £ -

Line	Quantity	Supplier Stock Code	Description	Unit Price £ (ex VAT)	Total Price £ (ex VAT)	In Stock? [Y/N]
1	1	874-1481	EPCOS 1µF Polyester Capacitor	£ 1.43	£ 1.43	Y
2	5	625-6451	ON Semiconductor 1N5338BRL	£ 0.33	£ 1.67	Y
3	1	544-2538	Murata Power Solutions Throug	£ 3.68	£ 3.68	Y
4	10	671-4736	Fairchild BS170 N-channel MOS	£ 0.12	£ 1.20	Y
5	1	874-1490	EPCOS 1.5µF Polyester Capacitor (PET) 305 V		£ 1.97	Y
6						
7					£ -	

Total requisition value (ex VAT): £ 9.95
Total requisition value (inc VAT): £ 11.94

Total spend after this requisition: £ 11.94

ELEC2217 EEE Smart Meter Design Exercise 2017 - Requisition Form

Note: *We can only order items through RS or Onecall. If you choose to order from a different supplier, you must place the order yourself and claim the cost back. Only order in-stock items. If an item is out of stock, you should order an alternative item, or use a different supplier. ONE group member should be designated as responsible for ordering items and keeping track of spend against the budget.*

Once the form is completed, email to both Mark Temple and David Kemmish
mst1a11@ecs.soton.ac.uk and dk@ecs.soton.ac.uk

Form completed by: Group: H

Contact name: Lawrence Coles

Contact email: lcc2g15@soton.ac.uk

Supplier (please use RS/Onecall only): RS

Total spend before this requisition (£): £ 11.94

Line	Quantity	Supplier Stock Code	Description	Unit Price £ (ex VAT)	Total Price £ (ex VAT)	In Stock? [Y/N]
1	5	812-487	Magnatec BZX85C12V Zener Di	£ 0.14	£ 0.68	Y
2	10	214-1490	TE Connectivity ROX1S Series A	£ 0.08	£ 0.77	Y
3	5	874-1428	EPCOS 330nF Polyester Capacit	£ 0.34	£ 1.68	Y
4					£ -	Y
5						Y
6						
7					£ -	

Total requisition value (ex VAT): £ 3.13
Total requisition value (inc VAT): £ 3.76

Total spend after this requisition: £ 15.70

12. Appendix D – First review report

ELEC2217 - D5 Smart Meter

First Review - Group H

Matthew Parsons, Enyang Zou, Ricki Tura, Lawrence Coles, Fransiskus Chandra

1. Introduction

In the first two weeks of the project, progress has been made on all aspects. Group roles have been allocated, meetings have been recorded, and the use of a shared cloud drive has made it very easy to work collaboratively. The power supply, interface circuitry, and housing have been designed, and the software has been planned.

2. Power Supply

The power supply was designed and simulated in MultiSim by Enayang Zou and Lawrence Coles. It is aiming to convert the 230 V_{rms} 50 Hz AC power to 5V DC which is used to power up the Il Matto and the interface circuitry. The power supply topology being used is a bridge rectifier, capacitor-coupled charge pump circuit, which was chosen after comparing the different topologies available (Table. 1) as it had a low voltage ripple and low cost. The current power supply design consists of four parts (Fig. 1): a voltage dropping capacitor with accompanying bleed resistor, bridge rectifier, voltage smoothing capacitor, and a Zener diode.

The voltage dropping capacitor is a capacitor series with AC source to reduce the AC from 230 V_{rms} to approximately 8 V_{pp}. It also has a 400 kΩ bleed resistor in parallel so that it discharges to less than 30 V (discharge 91 %) within two seconds. The value of the resistor was chosen in order to balance the efficiency and the discharge time of the capacitor, as a larger resistance generates a more efficient system, but reduces the amount of current to the rest of the power supply.

The bridge rectifier transfers the AC voltage to DC, and produces a lower voltage ripple in the output voltage when paired with the 470 µF smoothing capacitor. This electrolytic capacitor will smooth the DC voltage from the rectifier, a larger the value filter makes the voltage ripple on the load smaller, and a 470 µF capacitor makes ripple less than 0.01 V (Fig. 2).

As the Il Matto input voltage should be within 4.5 V - 5.5 V, the Zener diode 1N5338BRLG is used to limit voltage across the load at 5.1 V using its Zener voltage characteristics. The load is simulated parallel with the Zener diode and the voltage across the load is shown as (Fig. 3). The diode should be in series with a resistor to limit the current going through it and the 1N5338BRLG allows 240 mA, so it needs a 25 Ω resistor in series. The load of the circuit is simulated using resistors to produce a current draw equal to the average current draw of the interface circuitry and the Il Matto microcontroller.

For the current design, the efficiency of the system is 39.7% with a power factor of 0.1. Whilst the efficiency is good for this type of power supply, the power factor is below the minimum of 0.3, therefore going forward, the power supply design will be modified in order to increase the power factor without sacrificing efficiency.

3. Housing

The housing was modelled on Solidworks by Fransiskus Chandra and Ricki Tura. It is a four piece design that features the main 3D printed body and top, with a separate power supply housing and corresponding lid (Fig. 4).

The main body has 2.5 mm walls and a 3 mm base, with cut outs on the front side for the power LED and the Il Matto's LCD. A transparent acrylic panel will be glued onto the front to seal the holes. On the interior, there will be mounting "dowels" for the Il Matto board to keep it secure. To allow access to the Il Matto's pins, the LCD will be separated from the Il Matto, and will be connected using female to male jumper wires. The interface boards will be slid into grooves and held in a vertical orientation to save space (Fig. 5). A raised enclosure has been designed to keep the power supply box from moving within the main housing. The underside of the body has a recessed portion for the RJ45 sockets, so that the port faces are flush with the body (Fig. 6).

The main body lid has grooves and drilling holes for fixing on to the main body. A laser cut rubber gasket can be placed inside the groove to make the box more water tight. The mounting lug is flush to the back of

the lid, and is made according to the specifications. A tap wrench will be used to create the threads necessary to secure the lid to the main housing. 12 mm M4 screws will be used to secure the lid to the body.

The power supply box is a simpler design with two holes on the side for input and output cables, and four screw holes on the top for mounting the lid (Fig. 7). The lid for the power supply box will use self-tapping screws. The lip around the edge of the lid only goes around two of the edges, to allow for the box to become flush to the corner of the main body interior, whilst still allowing for easy alignment of the lid and body when mounting.

4. Interface Circuitry

For the DC analogue output a scheme of Pulse Width Modulation (PWM) was decided upon, using the Il Matto's inbuilt PWM driver. A Low Pass Filter (LPF) smooths the PWM signal to a DC signal. A non-inverting amplifier of Gain 3 is then used to amplify the signal from max 3.3 V to max 10 V (Fig. 8).

For the analogue inputs, it was decided to divide the signal amplitude and then shift it, so the full signal fits within the Il Matto's ADC input range of 0 to 3.3 V. To do this, the signal was divided down to an amplitude of 3.3 V, decoupled using a capacitor and then shifted using another potential divider connected to the 5 V supply rail (Fig. 9). A voltage follower at the start of this circuit neglects the effects of the channel impedance, so the signal received is more accurate (Fig. 9). This requires a negative power supply, and a DC-DC converter (See Budget Details) to supply this. The decoupling capacitors in Fig. 9 also allows the separation of Testbed Ground to Il Matto Ground.

A simple potential divider will be used to converter the 0 to 5 V DC analogue inputs to in the 3.3 V range (Fig. 10), however if space is limited, then the voltage followers can be removed and large values of resistance will be used negate the effect of the channel impedance. As the difference in ground voltage is small, this will be ignored, but a difference amplifier could be used if the ground potential difference is not small. For digital inputs, no circuitry is needed, as the Il Matto can take a 5 V high input to a General I/O. For digital outputs, a N-Channel MOSFET is used as a switch controlled by the Il Matto output (Fig. 11).

5. Control Software and Display

The pin layout (Fig. 12) shows the allocation of the test bed signals to the Il Matto. Four ADC pins are used to convert the analog voltage signals from the busbar, wind turbine, and solar panel, into discrete digital values. Eight pins are used as GPIO for receiving and transmitting the logic levels to and from the three loads and the battery. One pin is used for generating the PWM signal which can produce a varying voltage from 0 to 3.3 V, which is then amplified in the interface circuitry to a range of 0 to 10 V, which is used to define the mains current. Lastly, the 16 pins in ports B and C are used to interface between the LCD and the Il Matto.

One of the Il Matto's three timers will be used to keep track of all the time dependant parameters such as energy usage and battery charging duration. Another timer will be used for the PWM mains current signal. The LCD will be in the portrait orientation, which allows for more lines of information to be displayed. Code has been created to set up the main image (Fig. 13), ready for the information to be coded at a later stage. A future task includes editing the LCD library so that the LCD runs from ports B and C of the Il Matto.

A rough layout of the code was made into a flowchart (Fig. 14). It needs to be adapted to the provided profiles, and use of the global timer to monitor the battery capacity also needs to be considered. The initialisation steps, which happen within 20ms of start up, include setting all the outputs to zero, and setting the PWM signal to the mains to zero. This ensures that no unwanted current flows through the busbar.

6. Time plans

Four team meetings have been planned and carried out. The project tasks have been organised into categories with the expected durations displayed in a Gantt chart (Fig. 15).

7. Budget details

Most of the components for both the interface circuitry and the power supply are available from the labs, only a few components have to be

purchased against the budget allocated to the group. The current order list is shown in a spreadsheet (Fig. 16) using approximately 50% of the budget, however this might decrease as the designs develop and alternative components sourced.

8. Appendix

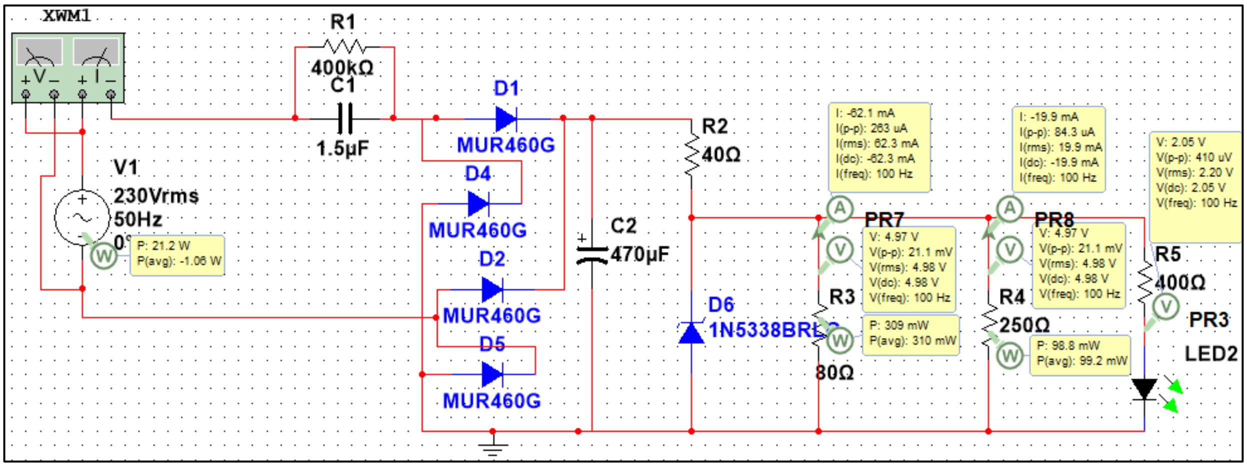

Figure 1.

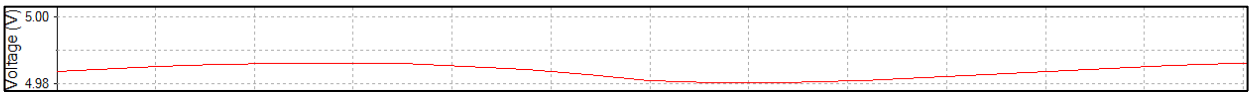

Figure 2.

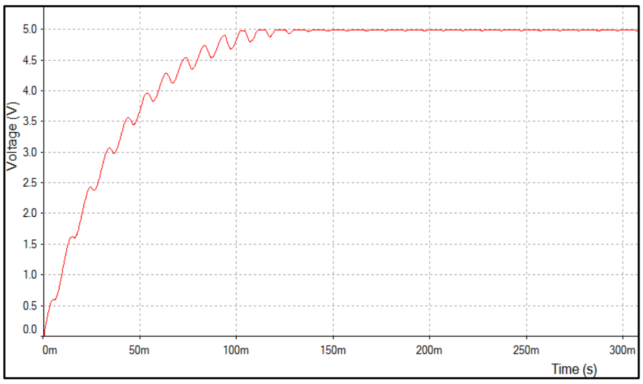

Figure 3.

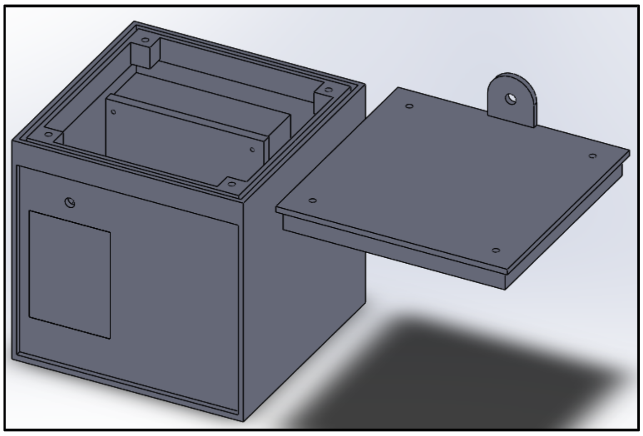

Figure 4.

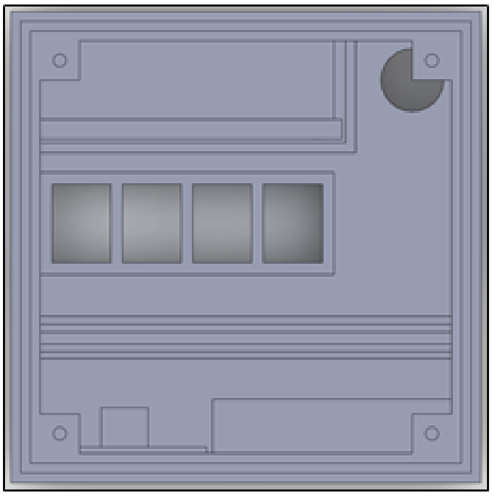

Figure 5.

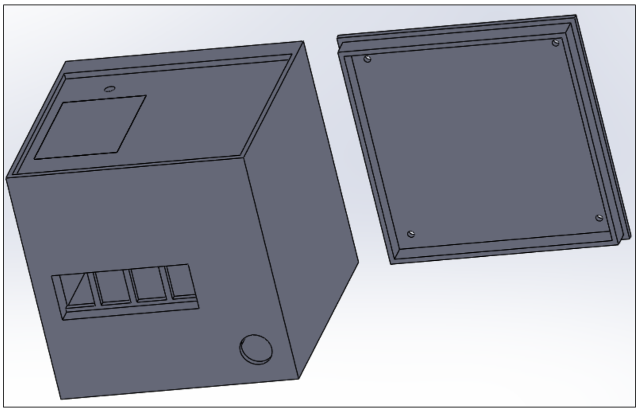

Figure 6.

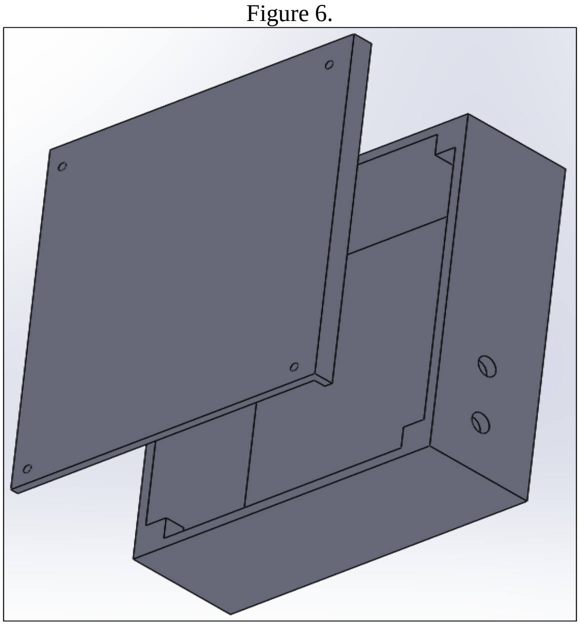

Figure 7.

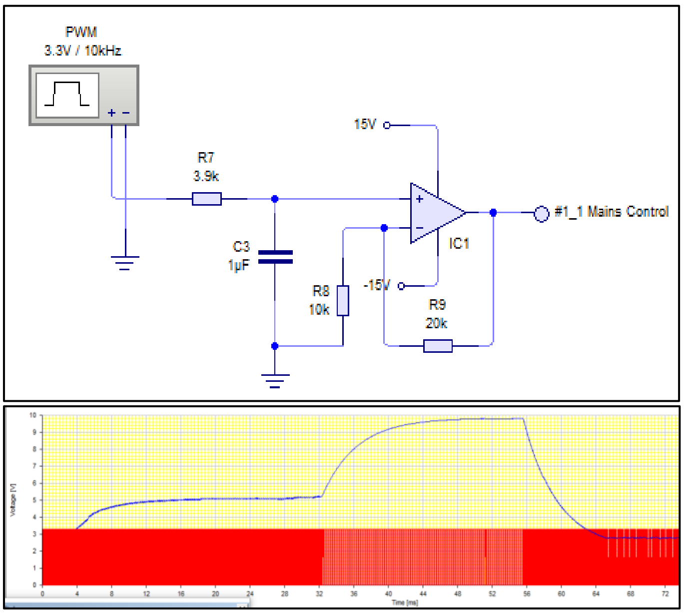

Figure 8.

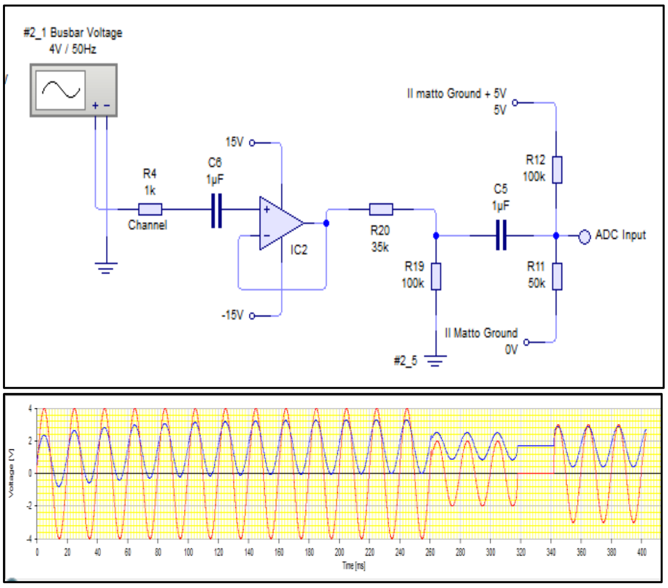

Figure 9.

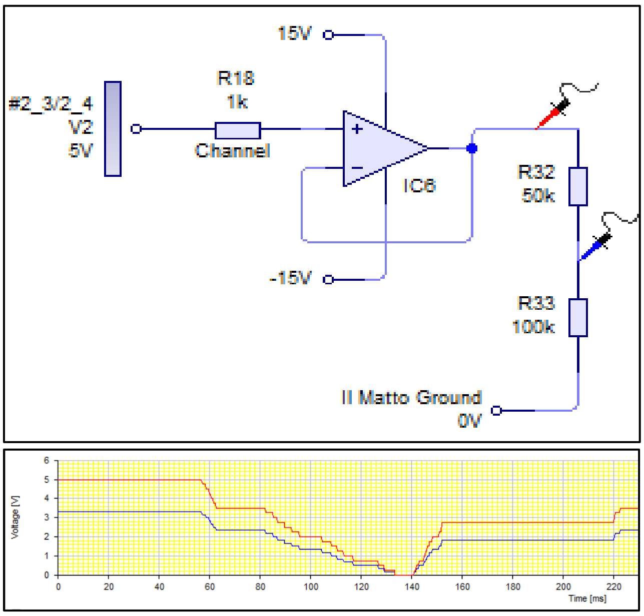

Figure 10.

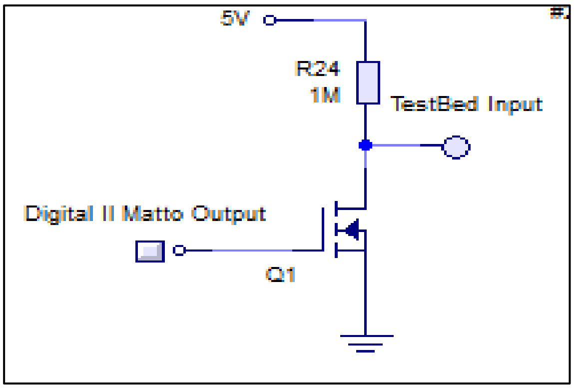

Figure 11.

Port	Pin	Function	Port	Pin	Function
A	0	ADC Busbar voltage	D	0	Charge battery
	1	ADC Busbar current		1	Discharge battery
	2	ADC Wind turbine current		2	Load 1 switch
	3	ADC Solar panel current		3	Load 2 switch
	4	Call for load 1		4	Load 3 switch
	5	Call for load 2		5	PWM Mains current control
	6	Call for load 3		6	-
	7	-		7	-

B&C	LCD interface

Figure 12.

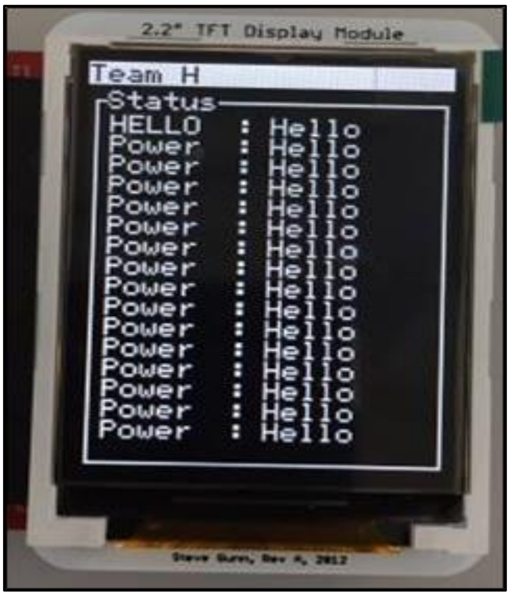

Figure 13.

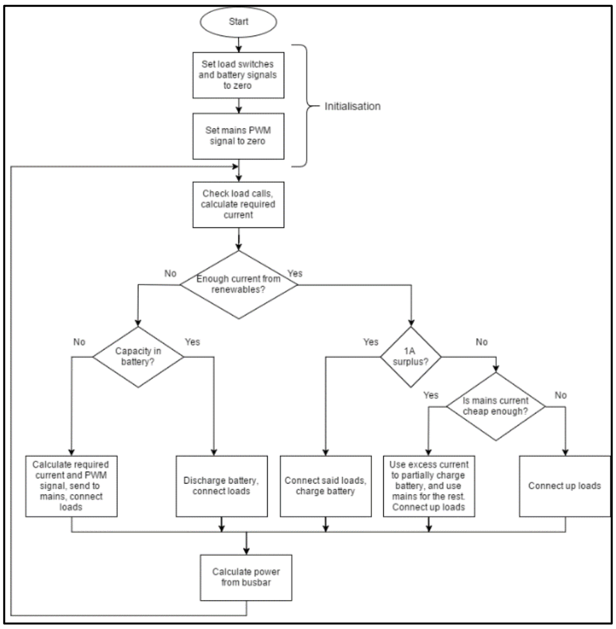

Figure 14.

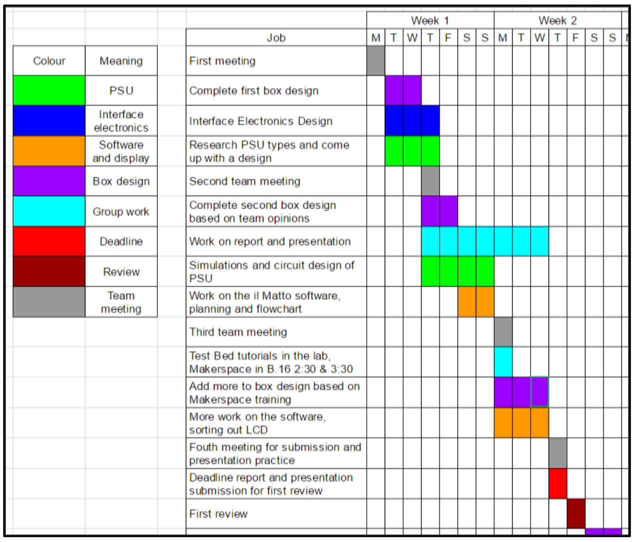

Figure 16.

Line	Quantity	Supplier Stock Code	Description	Unit Price £ (ex VAT)	Total Price £ (ex VAT)	In Stock? [Y/N]
1	1	874-1481	EPCOS 1μF Polyester Capacitor	£ 1.43	£ 1.43	
2	5	625-6451	ON Semiconductor 1N5338BRL(	£ 0.33	£ 1.67	
3	1	544-2538	Murata Power Solutions Throug	£ 3.68	£ 3.68	
4	10	671-4736	Fairchild BS170 N-channel MOS	£ 0.12	£ 1.15	
5	10	661-0530	Texas Instruments LM324N, Qu:	£ 0.23	£ 2.27	
6						
7					£ -	
			Total requisition value (ex VAT):		£ 10.20	
			Total requisition value (inc VAT):		£ 12.24	
			Total spend after this requisition:		£ 12.24	

Figure 17.

	Half wave Capacitor-coupled charge pump	Full Bridge Capacitor-coupled charge pump	Transformer power supply	Switch mode power supply
Description	Uses a dropping capacitor and a Zener diode in order to limit the voltage with a half wave rectifier to generate DC.	Uses a dropping capacitor and a Zener diode in order to limit the voltage with a full bridge rectifier to generate DC.	Uses a transformer to drop the voltage and a rectifier to generate DC voltage.	Uses a IC in order to switch the current through an inductor to generate DC and reduce the voltage.
Reliability	High reliability due to the use of entirely analogue components, which have a large Failure in time values	High reliability due to the use of entirely analogue components, which have a large Failure in time values	Lower reliability due to the transformer, which can suffer breakdown due to shock, thermal cycling or electrical breakdown.	Lowest reliability due to the IC , which has a risk of breaking down due to its silicon transistors. It is more susceptible to voltage spikes due to its semiconductor nature.
Cost	Low cost due to the analogue components being relatively cheap	Low cost due to the analogue components being relatively cheap	Higher cost due to the transformer	High cost due to lots of components in order to implement this design with the IC
Efficiency	Medium efficiency, can be around 20-50%.	Medium efficiency, can be around 20-50% but slightly higher than the half wave design, due to more power being transferred to DC	Low efficiency, due to losses on the transformer being excess of 1W.	Highest efficiency due to the switching IC design.
Other factors	Has a greater voltage ripple on the output due to the half wave design. Can have a low power factor if not designed correctly.	Can have a low power factor if not designed correctly.		There can be switching noise due to the method of voltage regulation

Table 1.

13. Appendix E – Second review report

ELEC2217 - D5 Smart Meter

Second Review - Group H

Matthew Parsons, Enyang Zou, Ricki Tura, Lawrence Coles, Fransiskus Chandra

1. Power Supply

During the continued development of the power supply, the design has been adapted and modified throughout the development cycle. The initial design produced for the first review was not able to supply the 5 V output for the load circuitry, whilst drawing over 2 W of power from the test bed. In order to solve this problem, the chosen method of improvement is to modify the value of the voltage dropping capacitor, increasing the value allowed more current to flow to the load, whilst carefully making sure the fuses in the test bed were not triggered by making the capacitor value too high. It was found during testing that the current load circuitry drew too much current from the power supply, therefore the design was not providing the voltage required to drive the op amps in the interface circuitry.

In order to solve the problem of the power draw and power delivery, multiple parts of the entire circuitry design were changed. To replace the DC-DC convertor, a 12 V Zener diode was placed in parallel with the 5 V Zener diode to directly output the 12 V DC voltage to the op-amps as well as 5 V to the Il Matto and MOSFETs. The new power supply circuit is shown in Fig 1. In simulation, a 10 kΩ resistor was used to simulate the op-amp load and a 60 Ω resistor was used to simulate the load across the 5 V Zener diode.

It was found when testing the constructed power supply that the voltage on the output dropped from 12 V and 5 V to 9.43 V and 2.9 V respectively, when tested with the actual load of the Il Matto and the interface circuitry. This effect is due to the Zener current through the diodes not being high enough to supply a full Zener voltage across the output. As a result, the load circuitry was changed in order to reduce the load current so that the correct output voltage is supplied. As testing is progressing, refinements are being made in order to reduce the power used by the system.

2. Housing

Several changes were made to the housing design since the first review. The acrylic panel at the front has been reduced in size to cover just the LCD, and the mounting lug has a wider base to allow for more contact area when gluing. A combination of laser cut rubber strips and silicone sealant was used to secure the acrylic window whilst keeping the housing waterproof (Fig. 3). It was found that a rubber gasket between the lid and the main body of the housing wasn’t necessary, the box is watertight regardless.

The waterproof testing consisted of holding the housing under a running tap, with the ports for the power cable and RJ45 sockets taped up. No water got inside the housing, which means it is ready for the real testing.

The box for the power supply has also been made, and fits nicely in the space we allocated (Fig. 4). Completing the housing took longer than anticipated. This was due to problems encountered when 3D printing such as failed prints and uncalibrated beds.

3. Interface Circuitry

The interface circuit design is completed, and shown in Fig 5. Modifications have been made from the previous review, these are mostly on the AC analogue inputs to the Il Matto. The previous scheme was discarded because the circuits had a phase shift element on both circuits which was not the same. This caused the two signals to be out of phase, which would complicate the programming, and so an alternative was designed. This uses a non-inverting summing amplifier with a weighted gain to produce the correct signal between 0 V and 3.3 V. Another solution was to use a half wave precision rectifier and potential dividing this signal, which allows the input to be buffered without the need to for a negative rail. Another possible change to the design revolves around the testbed using TTL logic, where the high level is >2 V. Because of this, there might not be a need for MOSFETs giving digital voltage level of 5 V, when a voltage above 2 V would suffice.

The circuit has been constructed on Veriboard shown in Fig 6, where the blue wires are showing inputs, and green lines outputs (not all of these wires have been completed). Note that the DC-DC converter has been removed due to its large current draw, with the power supply being modified to produce a positive 12 V and 5 V level. Other small modifications are required, notably increasing digital input and pull up resistor resistances. Progress against the time plan has been good, with the circuit tested well within time, however modifications have meant that more time needs to be spent on it than expected. Tests have been run with the Il Matto connected to verify that the analogue inputs and outputs work.

4. Software and Display

The basic input/output has been coded which includes ADC, digital input reading, digital output, as well as PWM output to control the 10 V output through the op-amp (Fig 7). The ADC needs to be scaled based on the input from the interface. Furthermore, the testing with the interface circuit has to be done. The debugging interface has also been coded for the display.

The code towards the first profile is in progress, the total energy consumed and average power programmed. This leaves the load call respond and battery charging energy function to be coded.

The next steps include using the flowchart made during the first review to break up the control part of the program into manageable sections with functions. This allows multiple team members to work on the code by working individually on a function, then combining the code into a single program. Once this is planned and executed, the software can be tested against the preset profiles.

5. Time Plans

Due to set backs, tasks have taken longer than expected. This is reflected in the updated Gantt chart (Fig. 9). However, progress overall has been good, and the project is in line with the time limits.

6. Appendix

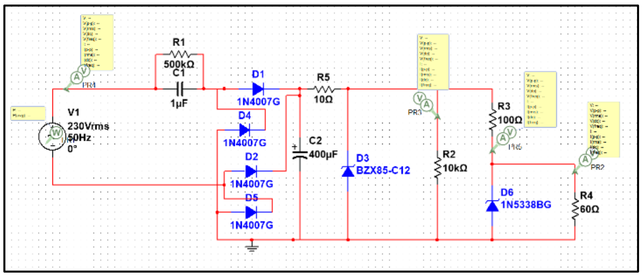

Fig 1: The circuit diagram of the power supply.

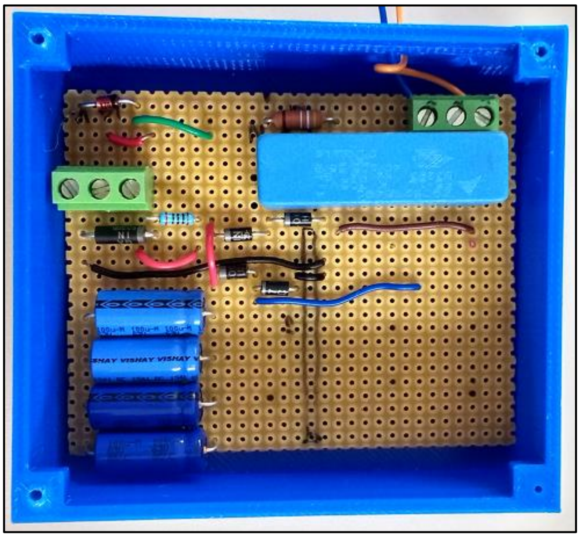

Fig 2: The power supply inside its box.

Figure 3: The completed housing with the lid.

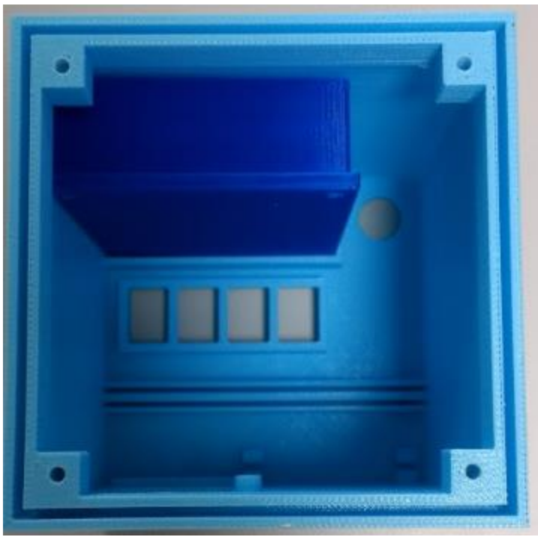

Figure 4: The interior of the housing, with the power supply box inside (top left). The holes for the power cable and RJ45 sockets are visible, as well as the grooves for inserting the interface circuitry boards.

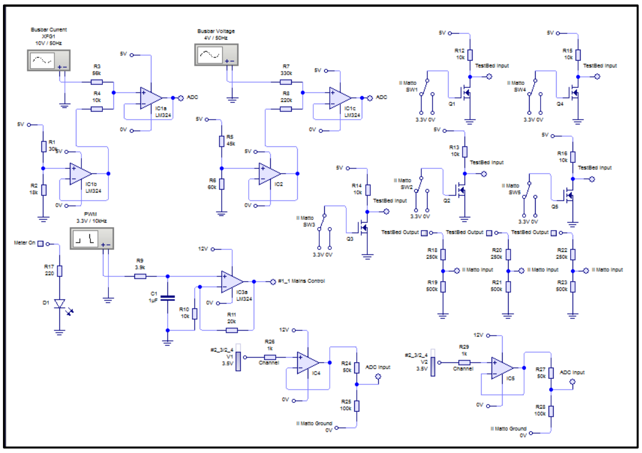

Fig 5: The circuit diagram for the interface circuitry.

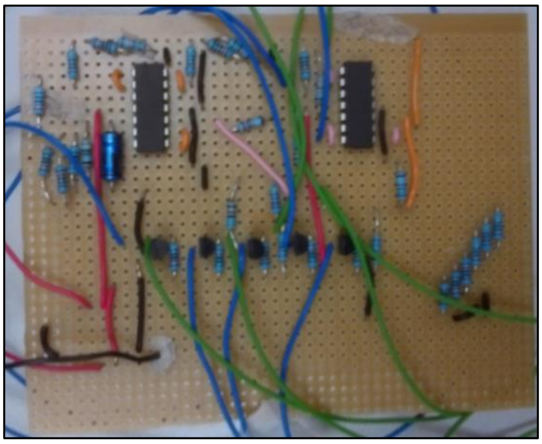

Fig 6: The interface circuit board.

```
//FUNCTION LIST
void init_usr_intfc();          //Created function, draws the main theme, sets up table
void init_adc();                //Created function, enables ADC pins
void init_adc_timer();
void init_global_timer();       //Sets up timer 1 for the global time count, and the relevant interrupt
void init_pwm();                //Sets up the registers, for the voltage output pin
void init_digital();            //Sets up the digital inputs on port A, outputs on port D
void set_pwm_vout(double vin);
uint8_t get_digital(uint8_t pin);
void set_digital(uint8_t pin, uint8_t val);
double get_time();
uint16_t read_adc(uint8_t channelNum);
void update_avg(const uint16_t* voltage_read, const uint16_t* current_read, uint64_t* sample,
                double* instan_power, double* avg_power);
void printNumber(double* value, char* dataToStrBuff, char*sprintfBuff, uint8_t row, uint8_t col);
```

Fig 7: An extract of the main header file, showing the functions we have coded so far.

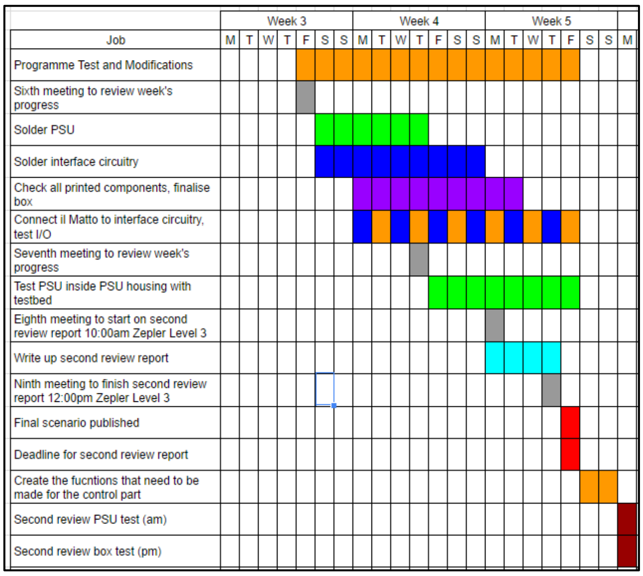

Fig 9: An extract of the Gantt chart, showing progress up to the second review.