2022

D5 Smart Meter Design Exercise: Handbook

MALAYSIA CAMPUS V1.15 2022

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1 Introduction

The aim of this team exercise is to gain an insight into design principles, together with prototype manufacture and testing. At the completion of the project, participants will be familiar with the constraints of working to budget, interpreting and meeting specifications, project management, and the demands of a development programme.

The teams are tasked to develop a reliable smart electricity meter to manage a micro grid. The meter needs to be low-cost, require minimal technical support to operate, and be highly energy-efficient. The final design must be based around the "Il Matto" low-power 8-bit microcontroller board. Teams also work with a 265V supply.

A micro grid is a self-contained power network that can operate either on its own or connected to the national power network. It may operate independently due to unreliability of the network, or to reduce operating costs. It must have its own power generation and/or energy storage facilities and loads, and its own control capability. Micro grids may be found in facilities such as schools, hospitals or military bases, but with the rapid growth of renewable energy and microgeneration there is a demand for houses to be equipped with their own independent operating capability.

This design exercise aims to expose you to the above concepts and give you the opportunity to use your knowledge, innovative thinking and creativity to design and develop components and systems that could be used to manage energy intelligently: for example, by making best use of renewables and/or storing energy in a battery. Please note that the final scenario will not be released until later in the project, so you should ensure your meter is designed flexibly and in particular that the software is modularised and well documented so that it can be adapted later.

The objective is to design, develop and manufacture a smart electricity meter for use in a micro grid (e.g. commercial or residential property), having the following features:

- The ability to determine the amount of energy consumed over a time interval (e.g. kWh).
- To be able to intelligently and dynamically select sources of energy to supply the metered property, dependent on factors including availability, demand and cost, and making best use of energy storage where it is available.
- To intelligently control the power demand within the property (e.g. by disconnecting or time-shifting loads) taking into account factors including consumer requirements and the cost of available power from different sources.

This project can be split coarsely into four main tasks:

1. **Power Supply.** In simple terms, the power supply has to efficiently convert the AC line input (~265 Vrms) to a nominal DC voltage needed for the functionality of the rest of the smart meter system – e.g. measurement, control and communication.
2. **Smart Meter Housing.** The smart-meter should be self-contained, water-resistant, and attractively designed. It must also be suitable for mounting on our test equipment. You will manufacture it using our 3D printers and laser cutter.
3. **Interface Circuitry.** The smart meter must interface with our D5 Test Bed, which emulates the behaviour of a micro-grid, with renewable energy resources, storage, and a mains supply. This is emulated via various analogue and digital signals. You must interface between these and the Il Matto microcontroller board.
4. **Control Software and Display.** Your Il Matto must contain software to intelligently control the micro grid: making decisions about what sources and loads to turn on and off, and perhaps including other functionality e.g. billing and communications. It should display its status via a TFT/LCD screen and LED.

2 Specifications and Requirements

You should take note of the following specifications/requirements:

- The design must be based around an "Il Matto" microcontroller board and LCD display that you have previously been supplied.
- Teams will be expected to build additional electronic circuits including a power supply and test bed interface with this existing controller. Circuit diagrams and layout diagrams are required with clear labelling and consistent wiring colours.
- The PSU must have correct wiring: brown for Live, blue for Neutral and green for Earth and be labelled. If it does not, it will automatically fail the test.
- A 'hardware-in-the-loop' test bench, with a LabView interface, will be available to support the development of the meter and performance assessment at the end of the project
- A software emulator of this system has been produced so you can run pre-trials remotely via LabView (Download Student edition for "Fall 2019" form National Instruments if you can't download from isolutions – 2019 edition has less compatibility problems; if they only have 2020 then please save as v2019 if you modify the labview part of the algorithm file).
- No external communication is allowed with the meter once it is connected to the test bench to run the test profile, but you may wish to demonstrate other features separately during the review.
- The meter must meet basic design requirements, in particular meter power consumption (as specified in IEC Standard 62053-22) should not exceed 2 W with load.
- To simulate an Il Matto, display and interface circuitry connected, the load resistance should be set to an appropriate value (depending on your designed output voltage) to result in ~1W load power consumption. For example, if your power supply DC output is 12V, then the single resistor load should be set to 144 Ohm. If there are multiple DC voltage outputs or multiple resistive loads, one should make sure that the total resistive load corresponds to 1W power consumption.
- The meter must include an internal sealed power supply, enabling it to be powered from a 265 Vrms input.
- The power supply must include bleed resistors where appropriate (to discharge down to <30 V within 2 seconds). The input and output sides of the circuit should be clearly separated, and it should be contained in a segregated area of the housing as described later.
- The meter must be in a suitable housing so that it can be installed outside. It should satisfy tests for IP55 classification, have maximum dimensions 120 x 120 x 120mm, and be fitted with a mounting lug as described later.
- The housing should consist of **at least 3 separate sections**, each can be a maximum of 120 x 120 x 45 mm to minimise 3D printing waste; these should be assembled using up to 4 bolts/screws between each section where appropriate.
- More screws may be used if needed, but access to the main inside area of the smart meter should be possible by removing no more than 4 at once; the principle is quick access.
- You may not use blutak, glue or any other liquid as a sealant, laser cut gaskets can be used to seal the housing. Rubber sheet for gaskets is ~2 mm thick and should be discussed with the workshop.
- A **green** continuous LED will clearly indicate when the meter is operational. The meter will be expected to display data including the amount of consumed energy for the system (not the smart meter electronics) on a TFT/LCD screen and should be visible in outside lighting conditions.

- Apart from 3D printing and laser cutting, the meter and its housing must be constructed using hand/workshop tools available for use by students in the laboratory.
- All meters **must** be clearly identified with their Group Letter.
- The cost for all components that are not available within the Teaching Laboratory should not exceed **RM125**.
- Any students who have access to their own equipment may use these to enhance their design but they will be judged accordingly and must still provide clear documentation on how the items were produced.
- You are not allowed to use boxed (canned) solutions or design kits – you need to build your own electronic circuit/device to solve the problem at hand.
- A list of components to use will be made available on the Teams page, containing:
    - Anything available from the lab component drawers
    - Connectors or cables that you might need (ask via Teams for what is available)
    - Soldering irons, solder, solder suckers and solderwick
    - Protoboard and stripboard
    - The special mains plug and cable (to connect to the test bed); this will only be issued once your parasitic power supply has passed testing.
    - Cable gland size
    - RJ45 socket specification
    - 3-way mains connector to the PSU board (pin spacing and diameter)
    - Il-Matto and 2.2'' TFT displays, though you must assemble these yourself **Note:** you may use your own, prototypes.

We reserve the right to vary this specification during the exercise; so daily monitoring of the Teams page and regular communication with the course Team is essential – this is part of the project management aspect of the work.

This document has been modified back and forth with lockdowns and therefore we may have missed an inconsistency, if anything is unclear then please raise a question on Teams.

3 Conduct of the Project

3.1 Group Management

- The Group is responsible for resource management. Each Group is free to manage the project as they wish, but a Chairman and a Secretary are to be appointed for administrative purposes. Minutes should be kept of all formal meetings; these should be concise and detail any action required by group members and be included as an appendix to the Final Report and be seen within your logbooks.
- Groups are responsible for ensuring that a consensus is reached on any design decisions. Individual disagreement is a normal aspect of group work, but it can normally be managed by effective communication.
- Individuals are free to describe any significant issues within the group as part of their 200-word individual reflective account.
- Working effectively as a team is a core principle of this course, failing to do so will adversely affect your marks.

3.2 Laboratory Work

- All practical work is to be carried out in the EEE teaching laboratories at UoSM. No practical work in the laboratory may be undertaken outside normal opening hours.

- It is the responsibility of the groups to familiarise themselves with the current regulations for working in the laboratory, and the safe operation of any equipment.
- It is the responsibility of the team to ensure that the design complies with current Health and Safety at Work requirements, and the Risk Assessment and Operating Procedure for this exercise and each laboratory.

3.3 Budgets and Ordering Components

The overall budget for each group is a maximum of RM125. This will be allocated after the first review.

This sum is to cover all purchased components and consumables (i.e. components available from the lab drawers, and any materials used for 3D printing[1]/laser cutting, will not be charged). We will stop all orders if a team's budget is exceeded. An overspend will have a significant detrimental effect on the group's overall assessment. No form of private sponsorship or funding is permitted.

You may only order items from an approved university supplier, e.g. RS (prefer) or Element14 (prefer) or Digikey. If you can only get the items you need from other suppliers then you will need to discuss with the Lab Manager to see if it's possible to purchase it through other means, and do not buy it with your own money as you may not be refunded. This is at your own risk.

Components can be ordered from approved suppliers by:

- Completing the Requisition Form (Excel spreadsheet).
- The lab manager may recommend items from our existing stock as alternatives.
- A final order form should be submitted at the end of the project to enable construction of your circuits.
- You will be informed through emails or other means when the goods have arrived and are available for collection

It normally takes a few days for orders to arrive, so don't leave it until the last minute!

Note: it is the responsibility or the group to ensure the GST at the current rate has been included in the budget when components are ordered.

Note: The final circuits will be made on strip board and therefore any components you want to purchase need to be compatible with this (e.g. through hole not surface mount).

[1] A limit of 1 reel of 3D print material per team to reduce waste; usage estimates for the lab UP3D printers should be included with the design submission.

4 Assessment and Feedback

4.1 Assessment Breakdown

This exercise contributes 70% of the marks for the ELEC2217 “Electrical and Electronic Engineering Design” module. The other 30% comes from the D2 Integrated Circuit Design Exercise.

Approximately 40% of your marks for this exercise are for your individual contribution, with the remaining 60% from group assessment. The weightings associated with these assessments may change at the discretion of the exercise leaders, but the principle will be to assess performance with respect to your peers.

This is an indication of the weighting of the assessments:

First Review (Week 3)	Group: 10%	Individual: 10%
Group presentation: 15 minutes - Each person identifies their role, show box design in detail, and early circuitry, and software design/progress. 2 page technical drawing submission of box design with brief justifications and CAD drawing + circuit diagram + load resistance Each person submits 5 example pages of their logbook. ***Feedback:*** *oral feedback immediately after presentation, cohort feedback within one week*		
Second Review (Week 7)	Group: 15%	Individual: 10%
4-page short report; Guideline: 1 on project plans, progress and team roles, 1 on box and power supply with images, 1 on interface circuitry and 1 on software. Full circuit diagram when presenting PSU for testing. ***Note:*** *The box and PSU design ends at this review.* Individual logbook check and sign. Individual contributions breakdown, signed by all team members ***Feedback:*** *PSU and box scores, cohort feedback email within one week*		
Final Review (Week 10)	Group: 15%	Individual: 15%
Competitive test bench assessment with new and unseen test profile Measurement of power supply efficiency and power factor Observation of system features (e.g. user interface) Sign-off (but not assessment) of **logbooks** ***Feedback:*** *Integration and specification feedback; test scores before end of the week.*		
Group Final Submission	Group: 20%	Individual: 0%
3,000-word group report Individual contributions breakdown form, signed by all group members Submission of software and design files Specifications/user guide sheet ***Feedback:*** *by email within three weeks*		
Individual Final Submission	Group: 0%	Individual: 5%
200-word individual reflective account Submission of individual logbook. ***Feedback:*** *by email within three weeks*		

4.2 Academic Consultations

Each group is allowed a maximum of *three* short consultations with members of the academic staff. The consultation is an opportunity for project teams to demonstrate (at their own discretion) progress, understanding and their approach to problem solving. These are in addition to the formal reviews and must be arranged on an as-required basis. This can be done via Teams. These are most commonly used to resolve any disputes within your team if you cannot come to a consensus amongst yourselves; depending on the circumstances this may be viewed as bad project management.

4.3 Logbooks and Individual Contributions

Please note that **individual contributions are assessed primarily through logbooks**, and they are considered to be of considerable importance to the examiners. In the industrial environment it can constitute a primary document in any legal action. It should form an action-by-action record of your involvement in your team's activity. We expect to see crossings-out, mistakes, lines of approach eventually discarded, etc.! Logbooks are living documents and not written with hindsight.

You should always work on the project with your logbook, making contemporaneous notes as you go. **A dedicated logbook only for use in D5** will be issued to you at the start of the project, which you must use only for this course. Logbooks are your proof of development, solutions to challenges, and planning.

Logbooks should be used each time you work on the project, they should be chronological and not be post-edited in any way; if a mistake is made just cross it out and move on. If a dead end in the work is reached then state in the book your decision to change plan and start the new plan. If you later identify a flaw in previous thinking, just refer back to that page, DO NOT EDIT the original. This is how all professional engineers work; a logbook is never perfect and is not expected to be as clear as a technical report, but you should be able to refer back to it to find the information you need to complete the report or to help a colleague who is building upon your work. Make it very clear where key decisions were made or important results. Any pictures or items stuck into the logbook should be labelled so that it is clear what it is and why it's there.

Pages must not be removed from your logbook under any circumstances. Any additional loose material should be glued or stapled into the logbook otherwise it will be disregarded. It must be presented at each review for validation. Failure to comply will result in a poor individual performance mark. Depending on the Review, you may be required to show the logbook live or give some best example pages of your work. <u>**If you do not have your logbook with you for the reviews, then you will receive an individual mark of 0 for that.**</u>

4.4 Timeline

The following activities are planned. Note that timings may need to be refined as the project progresses. You will be kept informed of any changes via email and the course Teams page.

Week 2		
Lecture 1: Kick-off presentation	Online	Mon 14th Feb 10-11 am
Lecture 2: CAD drawing workshop		TBD
Lecture 3: Introduction to LabView Test Bed		TBD
Week 3		
Submit first box design file, technical report and logbook examples.	Teams	Wed 23rd Feb 5 pm
First review (plan, progress and box design)	Online	Fri 25th Feb 3pm – 6pm
Week 4		
Submit revised house design (if required)	Teams	Mon 28th Feb
Submit initial component order	Teams	Mon 28th Feb
Week 5		

No deliverables		
Week 6		
Final scenario published	Online	Fri 11th March
Submit 4-page technical report (pdf) and contribution form. (For pre-Review2 reading by D5 academics)	Teams	Thur 17th March 2022 5pm
Week 7		
Second review (PSU trial and box environmental trials + logbooks)	EEE Lab am, outdoor pm	Fri 25th March AM/PM
Week 8-9 (Week 8 is Mid-Sem break)		
No deliverables		
Week 10		
Final review	EEE Lab	Fri 15th April 9am – 5pm
Submit final test data file and proof of specification.	Teams	Fri 15th April 5pm
Week 11		
Final logbook submission	Teams	Mon 18th April 5pm
Group report, individual contributions form, software and design files		
Individual reflective account		

4.5 Reviews and Deliverables

4.5.1 First Review

This is an important milestone: you **must pass** this step to be able to continue with the project and access your project budget. We expect to see significant progress with the housing design, hardware (particularly design/simulation of the power supply), and embedded software.

You are required to give up to **15-minute** team presentation (**strictly timed**- **you will be cut off when the alarm goes so practice**) on your design studies, plans, team and progress, we expect to see a Gantt chart on the final slide and an example of your meeting minutes. This will be followed by some questions from us. **You are required to submit your presentation beforehand**, (pptx format) via Teams. All team members **must speak** during the presentation.

You must also submit, before the review, a **2-page technical drawing** document (PDF format) on your box design including a brief justification and your first draft of the PSU circuit. A CAD file (STL format) for the box assembly must also be submitted.

In addition, a pdf containing **5 Logbook page examples** should be submitted beforehand by each team member.

Oral feedback on the day and general feedback provided to the cohort via email.

At the review, you will be given oral feedback about your housing design. If rejected, you will need to revise your design and resubmit (STL format) by the advised deadline. This will be reviewed by

Workshop staff before you are given clearance to print your design. If accepted, you are free to begin printing. **Designs must not be printed without prior approval!**

Any further revisions to the housing design must be approved by the Workshop staff before printing is attempted. **Any box designs that have been printed without approval will not be awarded credit.**

4.5.2 Second Review

At this review, your general progress will be assessed, and two specific aspects will be tested.

You must submit a **4 page progress update** report (PDF format), which must include a photo of your box and describe your progress against the plan and contributions (page 1) include figures of your final box design (page 2), Your final PSU design and simulation results including power consumption (page 3) and any progress on software algorithm and interface circuitry (page 4). The format can be anything you like but should look professional with font no smaller than 11pt**. Include Team name and members in the title.**

You are not required to give a presentation.

You must also submit an individual contributions breakdown, signed by all group members.

Firstly, your power supply circuit will be safety-tested on its own. The power consumption will be recorded at this review, **you should only change the PSU after this point if something fails**. It must operate without tripping the safety devices on the Test Bed! You will then fit the power supply into its segregated area in the housing, and we will verify that your smart meter will power up from the mains (you should **ensure that the LED illuminates and the TFT/LCD screen is functional**).

Figure 1 Testing the water-resistance of a Smart Meter in the specially engineered water retaining device (kids paddling pool!).

Secondly, as shown in Figure 1, we will test the water-resistance of your 3D-printed box. You will then be asked to disassemble your box (**please bring your own tools, you will have 1 minutes to open it**) and we will look at how much water has been let in. **Note:** you are welcome to cover the RJ45 ports with tape for this test. You are not required or permitted to do any further work on the housing after this review.

Logbooks will be inspected to assess your individual contribution and signed off. Oral feedback will be given on the day and general feedback given for each team via email.

4.5.3 Final Review

This is the functional test of your smart meter. We will have released the final scenario some time before this review, but the testing will be performed with a new and unseen test profile. You are required to give a short presentation at this review to explain how the program is done.

In this test, it is expected that your meter will be powered from the 230V/240V output from the testbed. If it is not working then you can use the benchtop supply but your mark will be modified accordingly.

We will test the overall power consumption of your meter and compare this with the result from Review 2.

We will also observe the operation of any additional features (e.g. the user interface). These are expected to be documented in the final report.

Logbooks will be signed off, but will not be inspected at this review.

Note: You should leave your hardware prototypes, along with any unused components (clearly identified) in the lab after the review.

4.5.4 Group Final Submission

You are required to submit a group report. The main body of the report must not exceed 3,000 words, however any previously submitted material can be used in this report or be in the appendices. You must also submit a ZIP file of design files and software.

The **report** should include:

- Title, date, course number, team number and page numbering
- Section numbering and figure captions
- Introduction
- Description of the design, development and testing of each component
- Description of the algorithm and flow chart
- Information on management of the project and contributions of each member
- Overall Conclusions
- Appendices: meeting minutes, budget details, Gantt chart

The **specifications sheet/user guide** should be <u>2 pages maximum</u> and include:

- This should be like a product specification sheet to ‘sell’ your smart meter.
- It should contain a picture(s) of your final design.
- User guide on any functions and display description
- Any technical details such as dimensions and power consumption.

You must also submit an individual contributions breakdown, signed by all group members.

The final design file should contain final versions of any: CAD drawings, strip board layout, circuit diagrams, component lists, emulator algorithm and il Matto programs developed during the project.

4.5.5 Individual Final Submission

You should hand in your logbook details will be provided on how nearer the time.

You are also required to submit an individual reflective account (up to 200 words), describing your **personal reflections and conclusions** on your contribution to the project. It should be supported by evidence from your logbook. It should **not just be a list of what you did**.

5 Practical Guidance and Requirements

5.1 Part 1: Power Supply

Your smart meter shall be mains-powered and capable of operating at a nominal voltage of 265V AC, consuming as little power as possible and an absolute maximum of 2W under normal operating conditions. Bear in mind that the whole smart meter (not just the power supply) should not consume more than 2W. In order to simulate an Il Matto, display and interface circuitry connected, the load resistance should be set to an appropriate value (depending on your designed output voltage) to result in 1W load power consumption. For example, if you power supply DC output is 12V, then the single resistor load should be set to 144 Ohm. If there are multiple DC voltage outputs or multiple resistive loads, one should make sure that the total resistive loads sum to 1W.

The following notes are not exhaustive or complete; you will need to research into this subject. Many component manufacturers provide application notes that include power supply designs. You should consider issues that are specific to electronic metering, some of which are briefly detailed:

1. **Meter supplies do not contain fuses, unlike other mains-powered equipment.** As a general rule, a commercial meter cannot be fused as it is expected to operate without interruption over its useful lifetime (around 20 years), during which it may experience voltage surges due to events within the power network or from lightning strikes. For this design exercise, there is a requirement to design and build a power supply to provide power for the controller, any additional I/O boards, display etc. In this case the power requirements are limited as the meter does not have to directly measure phase currents but working at mains voltages and currents requires care and attention. The designed smart meter is only required to work with the associated test benches in the teaching laboratory and these provide a 230V/240V Vrms AC supply with additional protection. **Under no circumstances should other mains supplies be used in the development, test or subsequent operation of the developed smart meter**.

2. **Meters automatically operate when connected to the mains.** It is not sufficient to just provide a low voltage DC supply as the meter also cannot contain an additional reset button. Therefore, additional circuits may be required to ensure that the control and measurement software always operates correctly on power-up. Another issue is that for commercial meters, on loss of mains, the meter must ensure that no information is lost. This can be achieved by using an EEPROM which saves data when the meter detects that it is powering down. **For this design exercise, meters must automatically operate on power-up; however, the need to save data on power-down is not a specific requirement.** Documentation for the first review could include a timing diagram indicating the series of events that will occur during the first 20ms of power-up along with the PSU circuit diagram.

3. **All power supply components must be correctly rated for use at mains voltages.** Care must be taken when specifying components for use in the mains power supply. Generally, within reason, derating is encouraged (e.g. use capacitors rated for use at 305 Vac, use higher power ratings of resistors, etc.). **However, if the design requires Capacitors to be placed directly between Live and Neutral (e.g. for EMI suppression) or in series with the AC supply, X1 or**

X2 safety capacitors must be used. X Capacitors are designed to fail-safe and do not fail short circuit; they are used in applications where a short circuit of a capacitor could cause a fire. If it is necessary to place a capacitor between Earth and either Live or Neutral, then Y safety capacitors are used. **To avoid risk of shock after testing is complete, all capacitors storing >30V must have bleed resistors, suitably sized to reduce their voltage to <30V within 2 seconds of the AC supply being removed.**

There are four principal types of circuits that could be chosen for the low-voltage power supply:

1. A capacitor-coupled "charge pump" supply
2. A mains-frequency transformer-coupled supply
3. A high-frequency (switch-mode) transformer coupled supply

When designing meter supply circuits, there are several key considerations: reliability, efficiency, and cost.

- Reliability of the power supply may be the most important consideration, as the meters are expected to work for a considerable time without maintenance.
- Efficiency should be as high as possible to obviate power consumption by the meter itself.
- The meter cost needs to be low so that utilities can justify the cost of replacing old meters.

Based on the simplest analysis of these requirements, it is clear that the use of a battery is not a good design solution in this case. A matrix to select the appropriate supply might therefore look like Table 1. It is important that you consider these issues.

	Capacitor-coupled Charge Pump	**50 Hz transformer coupled supply**	**Switch mode power supply**
	A well-proven circuit with low component count.	A well-proven circuit with low component count.	A commonly-used supply configuration in meters requiring significant levels of supply current. A high component count
Reliability	Most reliable Requires use of a X1 or X2 capacitor as the 'Charge Pump'.	Medium reliability Transformers can suffer electrical breakdown. For 50 Hz operation, they are relatively large and heavy and if mounted directly on a PCB, transformer may pull away from the circuit board under mechanical shock or thermal cycling.	Least reliable There are well documented common failure mechanisms in the scientific literature; transformer and semiconductor switches are particularly prone to breakdown. Increased IC count reduces theoretical mean time to failure.
Cost	Lowest	Highest	Medium
Efficiency	Medium/High Typical efficiencies for meters are in the range of 20-80% where single phase meter power supplies have efficiencies less than 50% but three phase	Low 50Hz transformers are very inefficient (or large and expensive). The efficiency of this supply is unlikely to be greater than approximately 10%. The dissipation would be approximately 3W leading	High This has the highest theoretical efficiency for high loads. SMPS are useful where higher powers are drawn periodically, for example in a meter with an integrated communications module.

	meters are considerably higher:	to an efficiency in the range 5% to 25%.	

Table 1: Initial Analysis of potential meter power supplies

When considering theoretical reliability, it is necessary to find the 'Failure in Time' number (FIT) for each component (this is the number of times the component will fail per billion hours). The theoretical mean time to failure (MTTF) of a circuit with N components can be calculated as:

$$FIT_{Circuit} = \sum_{i}^{N} FIT_{Component_i}$$

$$MTTF = \frac{114155}{FIT_{Circuit}}, \qquad years$$

Obtained results can only be used for comparison purposes. Consideration should be given to the reasons why the obtained theoretical values do not represent practical experience in the field.

To estimate efficiency, it is usually necessary to use a simulation package (e.g. Multisim). A quoted value from a manufacturer's application note is likely to be idealistic and should not be accepted without verification as part of the design process.

Figure 2 shows a simulation of a **capacitor-coupled charge-pump**. The main losses are in the series resistor R1 and the Zener diode D3. The overall efficiency is about 12% (20 mW/170 mW).

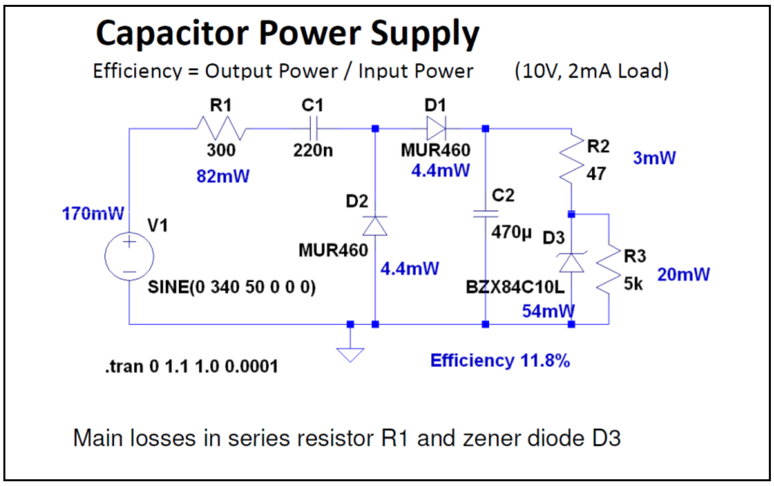


Figure 2: A typical capacitor-coupled charge-pump circuit

Figure 3 shows a 50 Hz **transformer** specification in which the core losses are quoted as 1.3W.

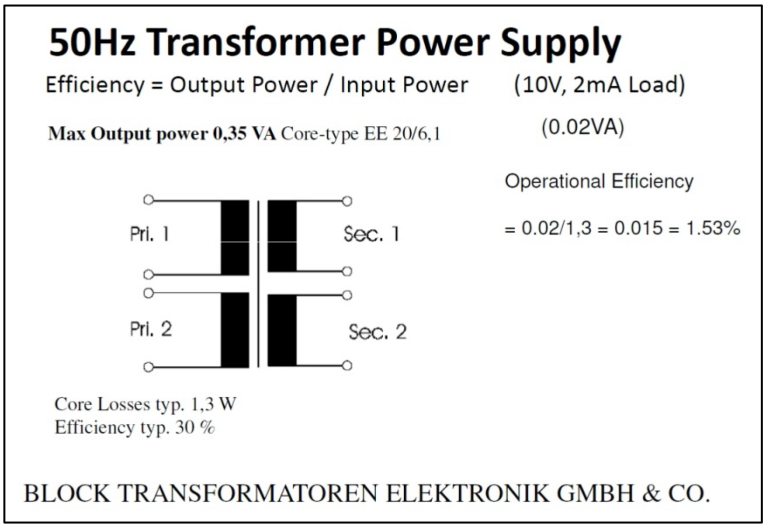


Figure 3: A typical transformer-coupled 50 Hz circuit

Figure 4, has the highest theoretical efficiency. Even for the LNK562-564 family of devices manufactured by Power Integrations, which are described as “Energy Efficient Off-Line Switcher ICs for Linear Transformer Replacement”, the typical minimum power consumption is around 150mW[i] which would lead to efficiencies of 35% to 50%.

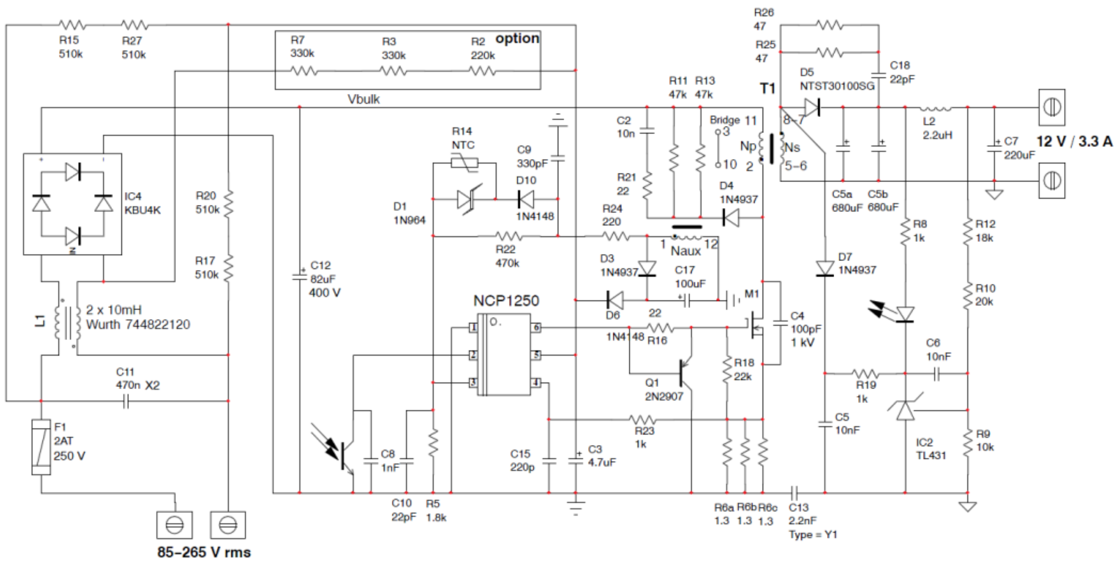


Figure 4: A generic switched-mode transformer-coupled power supply.
Taken from an “ON Semiconductor” application note.

A separate Standard Operating Procedure relating to power supply design should be referred to. Particular attention should be paid to the requirement for safety capacitors, and for circuitry to be mounted on stripboard rather than breadboard.

5.2 Part 2: Smart Meter Housing

The smart meter should be mounted in a suitable container, in order to protect the circuitry from environmental conditions (e.g. dust, water) and to protect users against the possibility of electric shock. For this exercise, you have access to 3D printers and laser cutters. The container must be marked with the Group letter and incorporate a mounting lug as shown in Figure 5.

The maximum outside dimensions of the housing shall be **120 mm x 120 mm x 120mm**. This excludes the mounting lug, which may be attached separately.

As part of the housing design, you must incorporate a segregated area for your power supply. This is to ensure your safety when working on the equipment, to protect against contact between the 240 Vrms A.C supply and low-voltage wires/components in your system. It is suggested that you integrate removable laser-cut acrylic components into your box design for this.

The segregated area must be fabricated from either plastic or earthed metal. Alternatively, a separate box can be constructed for this purpose (though it must still fit inside the housing). Your design must also include mains cable retention, to prevent the cable from being accidentally pulled out. The cable gland used for the mains wiring does not count towards the box dimensions (details for this part are included on the Teams page). **The gap around any part of the segregated area/box must be <5 mm**. This gap may be used to connect the PSU to the rest of the smart meter circuit.

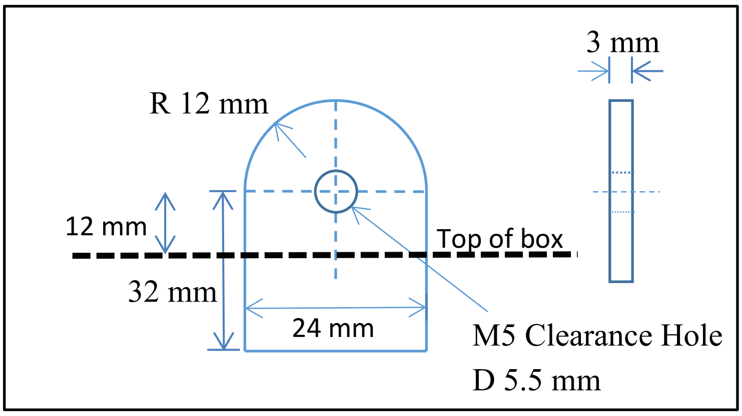


Figure 5: Dimensions of the mounting lug which must be located at the top of the Smart Meter box flush with its back face thus allowing mounting on a vertical wall.

5.3 Part 3: Interface Circuitry

Your smart meter must interface with the Test Bed. Note the connections, and voltage levels, of these interfaces. Also note that outputs from the Test Bed have an impedance of at least 1kΩ. You may need to translate between voltages, and this may require you to have more than one DC voltage available (or even positive and negative supplies). You should consider this as part of your system design.

You may wish to design your power supply to output more than one DC voltage, but it is likely to be more straightforward to convert the DC voltage afterwards. You may purchase ICs to assist with this (i.e. you do not have to build this part from discrete components, you could use a level shifter or regulator).

You are encouraged to design your interface circuitry early in the project, in particular so that you can account for the space required to accommodate it.

You will need to incorporate the 4 signal input/output RJ45 ports in required to connect to the test bed, the details of these can be found in the lab components document on Teams.

5.4 Part 4: Control Software and Display

You must write software to run on the Il Matto microcontroller and run the display. You should consider how to implement the required functionality, and how to maximise the accuracy and reliability of the system. It is easy to throw software together, but you should demonstrate how the software has been designed, implemented, and tested (**with plenty of comments**). You will need to submit your code as a ZIP file with the final report.

You may also write an algorithm to be contained within the LabVIEW program (described later) to enable simulation of your il Matto program. There are differences between the two because the LabVIEW version is pure software whereas the il Matto version must also interact with the hardware – but the principle of the algorithm is the same, the decision is made using the same inputs and the control is produced via the same outputs. It will be necessary for you to understand the relationship between the input and output signals that the LabVIEW program is expecting to see; this will be the same for both simulation and real hardware configurations.

5.5 Circuit construction

For the electronics, you should always have a circuit diagram and possibly a layout diagram with you at all times when working with the circuit. Asking questions about your circuit with no diagram or layout will be a waste of time.

You should build and test your circuits on breadboard first before moving to PCB/strip board. Do not leave the integration until the last minute – circuits will always respond differently when under load, just because it worked fine on its own does not mean it will work when connected to the next piece of circuitry.

6 Test Bed and Smart Meter Operation

6.1 Test Bed Interface

Due to the economic, practical, and safety implications with operating and controlling a “real” micro grid, the teams’ smart meter design will be required to interface with a model system via a Test Bed. The model system consists of a number of time-variant electrical power sources, controllable loads, and an ideal battery (100% efficient voltage conversion). The battery can be switched between inactive, charging and discharging modes as required. It can be assumed that this battery begins each test empty. For the purposes of this exercise, the smart meter must ensure that unidirectional power flow is maintained at all times. The battery can be charged if there is 1A excess current available, storing 1A per ‘hour’ of simulation time, with no limit on the battery capacity. The battery can be discharged at 1A per ‘hour’ of simulation time, until it is empty.

The Test Bed provides a 230V/240V mains supply via an IEC socket to power the Smart Meter. The Test Bed also has four RJ45 sockets (Ports 1-4) that provide access to analogue and digital voltage input and output channels for the Smart Meter to both monitor and control the simulated micro grid. A schematic diagram of the model circuit and analogue input and outputs is shown in Figure 6.

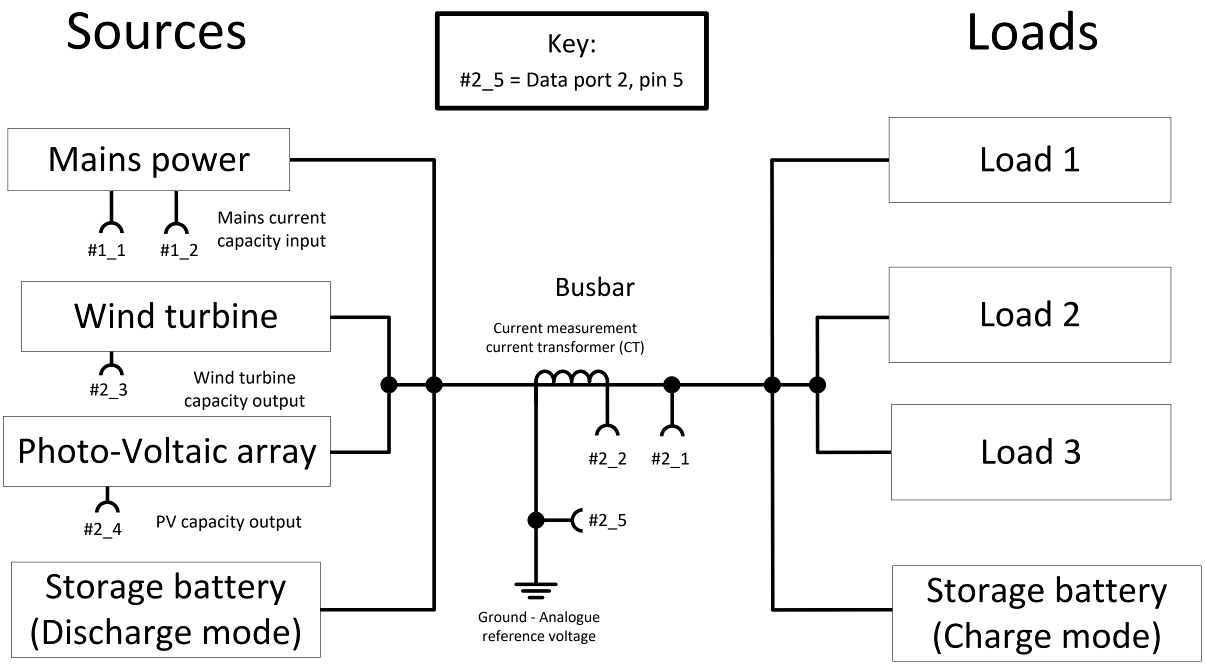


Figure 6 Domestic network schematic with analogue channels labelled

The analogue input voltage channels provide control for the mains current capacity, the output voltages consist of measurement voltages from the Busbar voltage and current sensors, as well as the available capacity from the non-dispatchable power sources. The digital input channels act as switches for the energy storage operation and load connections to the network. The digital output channels communicate the real-time demand for each load. A detailed explanation of the data inputs and output functionality of the test bench unit is provided towards the end of this document.

For the purposes of this project, the digital and analogue input/outputs all use a common ground connection internally in the Test bed.

6.2 Possible Scenarios and Profiles

For the purposes of developing and testing the smart meter, a number of pre-determined generation and load demand profiles will be available to you, of increasing complexity. These will provide a predictable environment in which to develop the functionality and performance of the smart meter designs – accurate recording of the meter's development progress will be required in the final report. Ultimately your Smart Meter will look to balance supply and demand to ensure stability of supply, but may also optimise for certain parameters.

During the final review, the smart meters will be exposed to a unique and unknown profile of supply and demand for a period of 24 minutes (representing 24 hours of 'real time') when their performance will be recorded. The final scenario (but not the final data) will be published in advance of the final review, which will describe the required operation of the meter and how it will be evaluated. Groups will be expected to tailor their algorithms to meet the specific requirements of the task.

Possible scenarios include optimisation of the use of energy to reduce costs (e.g. certain forms of energy have different associated costs), or perhaps to maximise the profitability of a factory production line (where certain parts can be shut down) in response to changes in the supply and demand of energy, or maximise customer satisfaction for a domestic customer running their own domestic micro grid.

The relative performance of each smart meter will be evaluated with respect to the stated criteria and will then be competitively ranked and an operational grade generated.

You are encouraged to explore different scenarios as described above and initially design your system as flexibly as possible to accommodate changes in the required optimisation algorithm. You should implement and test such situations using your knowledge, skills and available hardware.

7 Equipment and Laboratories

7.1 Training and Access to 3D Printers and Laser Cutters

Please contact Ms. W. Peh Yee (W.Peh-Yee@soton.ac.uk) with any queries about access to the 3D printer or their operating procedure, or use of the Teaching laboratories for this project.

Laser cutter available in UoSM is located in the Mechanical Engineering's workshop. The technician in charge of this equipment is Mr. Amin. Please contact in advance Dr. Ivan Ling (ivan.ling@soton.ac.uk) or Mr. Amin from the Mechanical Engineering department if you wish to have access to this equipment. This equipment require specific type of autoCAD drawing files (e.g. .dxf). AutoCAD, Microsoft Visio or Solidwork can be used to generate this file. The use of this the equipment must be under staff supervision at all time.

7.2 Access to Test Beds and Workshop Tools

Before attending, please read through the Risk Assessment and Standard Operating Procedure (included in this Handbook). You will need to sign off the Standard Operating Procedure at the end of the session (we will have printed copies for you).

The Test Beds are located in the Teaching Labs at EEE Lab 2. There are **two** Test Beds so the **5** teams at UoSM are expected to arrange their own schedule for the use of the test beds. These devices should only be operated during the standard lab opening hours. Please get in touch with Dr. Vun Jack (c.vun-jack@soton.ac.uk) or Dr. Lenin (l.gopal@soton.ac.uk) if you have doubts operating the test bed.

In normal operation, the 230V/240V output from the Test Bed is turned off and you can power your Smart Meter from a separate power supply. However, you may test your power supply (or complete Smart Meter) during development/testing by arranging for the test sessions with Dr. Vun Jack or Dr. Lenin.

8 D5 Test Equipment – Standard Operating Procedure

This is defined in compliance with the "General ECS Teaching Labs" risk assessment, which is extended by the "D5 EEE Smart Meter Design Exercise" risk assessment.

8.1 General Testing of Circuit Operation without Mains Power Supply

The work in this section only can be carried out without dedicated staff supervision, as it is covered by the standard risk assessment for the ECS Teaching Labs. During general testing, the mains output from the Test Bed must remain isolated via a key switch. If you notice the mains supply is active (red neon light is on) or the key is in the switch, please inform a lab technician straightaway.

8.2 Testing of Power Supply Circuit with Mains Power Supply

To be carried out by students **and** supervisory staff together:

- Visual inspection
    - ➢ Thoroughly check the circuit for soldering quality: dry joints, poor connections, inadvertent connections between neighbouring rails and excess solder.
    - ➢ Ensure physical separation between AC and DC sides of circuit.
    - ➢ Use a DVM to ensure live and neutral rails remain independent through the circuit.
    - ➢ Ensure that any capacitors are sufficiently rated (X2 design) and that bleed resistors are in place so that any charged capacitors are discharged to <30Vdc within 2 seconds after turning off the mains supply.
    - ➢ Ensure that the ground, live and neutral connections are clearly labelled and agreed between students and supervisory staff.

After visual inspection passed, Test Bed key will be supplied and under supervision from staff:

- Initial test equipment set-up
    - ➢ With mains supply lead disconnected from Test Bed, connect a CAT II rated DVM to mains connections in interlock box, with probes inside interlock box and with no exposed connections. Close lid on interlock box.
    - ➢ Ensure mains key switch is turned off.
    - ➢ Connect interlock box to Test Bed via mains output, ensure that the voltage measured by DMM is ≈0Vac.
    - ➢ Turn on mains output from Test Bed via key switch. Ensure that the voltage measured by DMM is ≈240Vac.
    - ➢ Open lid on interlock box. Ensure that the voltage measured in DMM is ≈0Vac. If not, isolate supply via key switch, remove the key, and inform a technician immediately.

- Mains application
    - ➢ Position the test circuit board in interlock box, connect an additional CAT II DMM to the 'output' side of the circuit, with no exposed terminals. Close lid.
    - ➢ Turn on key switch (if applicable).
    - ➢ Ensure that the mains voltage is at 230Vac and there's no voltage sag.
    - ➢ Ensure that the output DC voltage is consistent and at the correct value, and that the output AC voltage is below 1Vac.
    - ➢ Switch off the key switch, and measure the mains terminal DC voltage. Ensure that any stored charge dissipates to <30Vdc within 2s.
    - ➢ Open lid on box once charge has dissipated.

8.3 General Testing of Complete System with Mains Power Supply

This must be carried out under staff supervision.

In order for the required plug to be provided to the group, the successfully tested power supply circuit must be enclosed in a plastic or earthed metal box, with mains cable retention. The gap around any part of the box must be <5mm.

- A supervisor will inspect the box and ensure that gap size is <5mm. Provided circuit has previously passed testing (as above), a special plug and lead will be provided.
- Teams must wire the cable into their power supply, and this connection must be inspected before the plastic/earthed metal box housing their power supply is closed.
- When the supervisor is satisfied that plug is wired correctly, a seal will be applied to the box housing the power supply.

Only teams with sealed power supplies will be permitted to connect their power supply directly to the Test Bed with the mains output active.

If any changes are required to the power supply circuit, the seal must be removed first (to enable access to the power supply housing). The circuit must then be tested as per the "Testing of Power Supply Circuit" procedure, before following the above procedure for general testing.

Team: ______________________

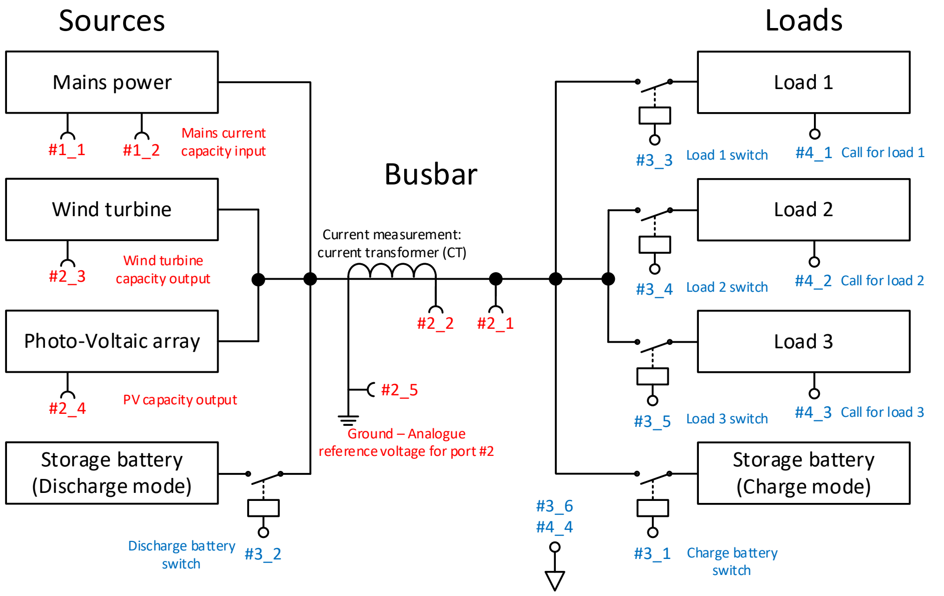
We have read and understand the above procedure, the associated Risk Assessment, and have been trained on the safe use of the equipment:

Member 1	Name:	______________________	Signature:	________________	Date:	__________
Member 2	Name:	______________________	Signature:	________________	Date:	__________
Member 3	Name:	______________________	Signature:	________________	Date:	__________
Member 4	Name:	______________________	Signature:	________________	Date:	__________
Member 5	Name:	______________________	Signature:	________________	Date:	__________
Member 6	Name:	______________________	Signature:	________________	Date:	__________
Member 7	Name:	______________________	Signature:	________________	Date:	__________

Trained by:

Name: ______________________ Signature: ______________________

9 Test Bed Schematic



Channel name	Data type	Signal type & Voltage range	Plug and pin identifier	Ethernet port RJ45 Pin # (B)	Ethernet port RJ45 Colour	Description
Mains capacity	Analogue input (From Smart Meter to Test Bed)	DC 0 to 10V	#1_1	3		The difference in voltage (0-10V) between these pins controls the current capacity from the mains $I_{mains,rms} = \frac{V_{\#1\_1-\#1\_2}}{10} I_{mains,rms\_max}$
Analogue ground reference for mains capacity			#1_2	6		
Busbar voltage	Analogue output (From TB to SM)	50Hz AC -4 to 4V	#2_1	3		$V_{bus} \sim 100 V_{\#2\_1-\#2\_5}$
Busbar current		50Hz AC -10 to 10V	#2_2	6		$I_{bus} \sim V_{\#2\_2-\#2\_5}$ (1V~1A)
Wind turbine capacity		DC 0 to 5V	#2_3	1		$I_{wind,rms} \sim V_{\#2\_3-\#2\_5}$ (1V~1A,rms)
PV capacity		DC 0 to 5V	#2_4	4		$I_{pv,rms} \sim V_{\#2\_4-\#2\_5}$ (1V~1A,rms)
Analogue ground reference			#2_5	5		Each of the other analogue output channels (#2_1 - 4) reference this channel
Charge battery	Digital input (from SM to TB)	TTL Logic HIGH = 5V LOW = 0V	#3_1	3		Logic HIGH: turn on Logic LOW: turn off
Discharge battery			#3_2	6		
Switch for load 1			#3_3	1		
Switch for load 2			#3_4	4		
Switch for load 3			#3_5	5		
Digital ground reference			#3_6	2		Each of the other digital input channels (#3_1 - 5) reference this channel
Call for load 1	Digital output (From TB to SM)	TTL Logic HIGH = 5V LOW = 0V	#4_1	3		Logic HIGH: call for 'turn on' Logic LOW: call for 'turn off'
Call for load 2			#4_2	6		
Call for load 3			#4_3	1		
Digital ground reference			#4_4	4		Each of the other digital output Channels (#4_1 - 3) reference this channel

*for the purposes of this exercise, all Test Bed Ground connections are common.

10 Test Bed Software User Guide

10.1 LabVIEW software setup

Start the NI LabVIEW 2019 (32-Bit) software (or newer if installed).

There are 4 different versions of the labview code depending on what you are trying to do (these were the latest versions at time of writing, but the Notes/Teams page will contain the latest versions if they are updated):

1. Smart Grid Test Bed with algorithm emulator for testing (06_Smart Grid Testbed_v2021emulator testing v4.vi)
2. Smart Grid Test Bed with algorithm emulator for reviewing (06_Smart Grid Testbed_v2021emulator review v4.vi)
3. Smart Grid Test Bed with smart meter plugged in for testing (06_Smart Grid Testbed_v2021 testing v4.vi)
4. Smart Grid Test Bed with smart meter plugged in for reviewing (06_Smart Grid Testbed_v2021 review v4.vi)

During lockdown you will only need to access number 1 and 2, but you may like to check 3 and 4 to see how your smart meter will be tested by the Technicians once it is constructed; although 3 would only be used if lockdown is lifted and you're able to return to test your own smart meters.

The following instructions are focussed on program number 2 above, but the principle applies to them all the same. Program 1 can be used for testing but instead of loading in the profiles, as described below, you can manually select when the different options are available so you can test your algorithm in real time before running a profile.

Open the file in LabView. You will see the GUI front panel of the program, Figure 7, which has an array of inductors for you to monitor the different outputs and inputs for the smart meter whilst the test program is running.

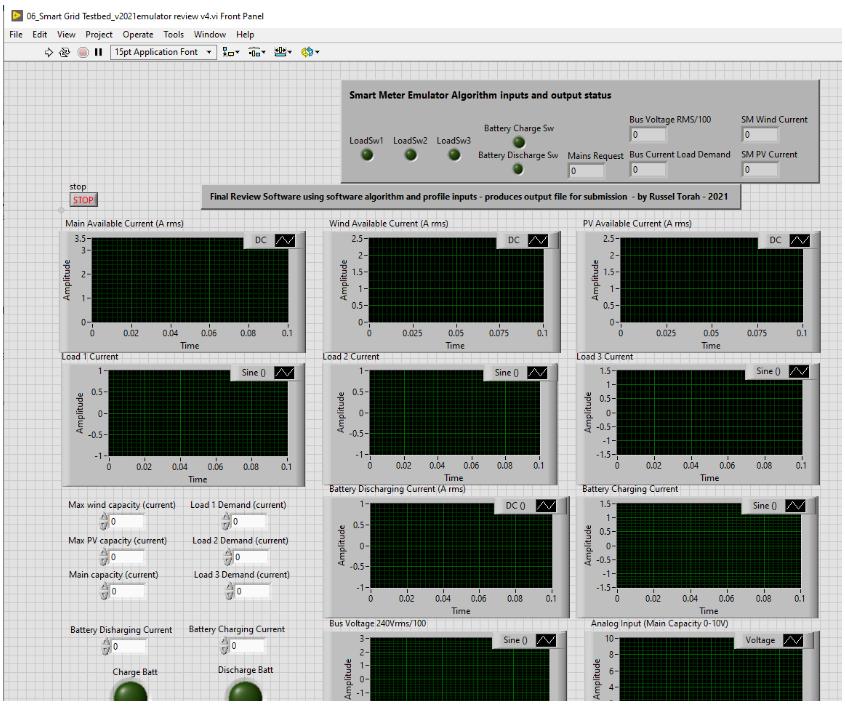


Figure 7: Front panel GUI of the LabVIEW program.

Select the, "Window" option from the drop down menu and select, "Show Block Diagram." This will load the actual LabVIEW program in another window.

In the Block Diagram window, double click on the box labelled, "Read From Measurement File – load 1."

Set the file name directory to match the load1 file "load1.tdms" – example profiles can be found on the notes/Teams page containing all 5 files you need (load1, load2, load3, pv and wind). These files represent an example scenario for different loads being called over time and rise and fall of available PV and Wind harvester outputs to supplement or replace the mains supply.

Repeat for the following boxes: load 2, load 3, wind and pv (each of the required boxes are highlighted in Figure 8).

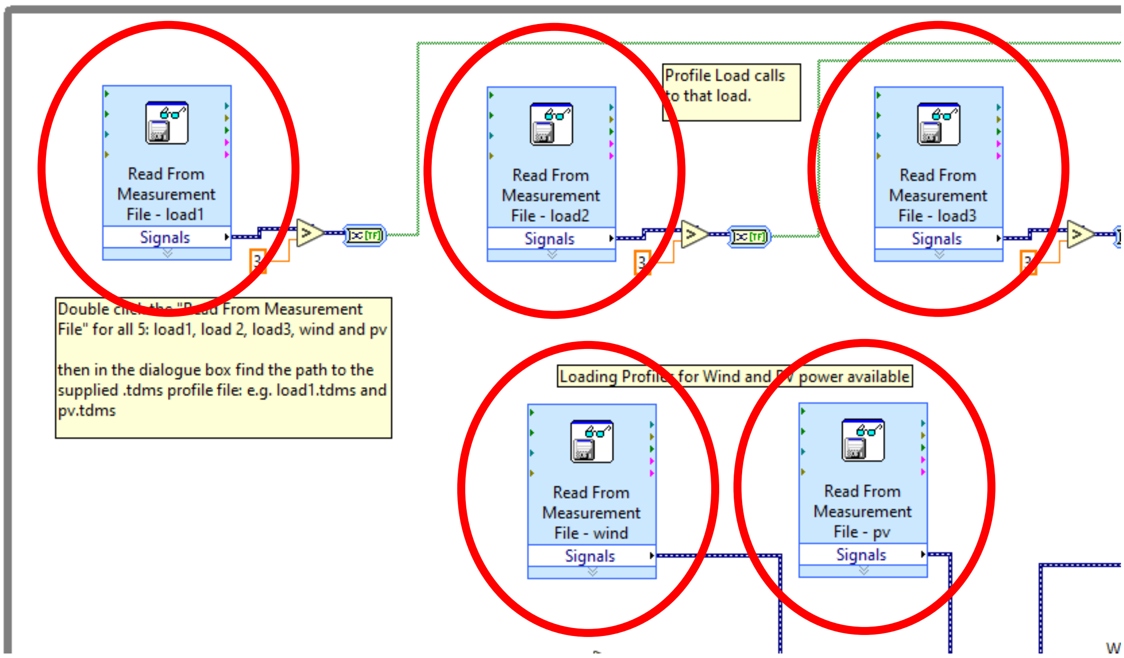


Figure 8: Read Profile file allocation process with units highlighted in red

You can edit these profiles to try different scenarios but they must all of be the same data length or the program will not function correctly.

The alternative is to run program number 2 which has manual switches on the front panel instead of requiring measurement profiles, therefore you can test how your algorithm responds in real time. The rest of the instructions apply to all versions.

Finally, do not click run yet until you have set all the front panel values covered in the next section.

10.1.1 Front panel parameter setup

Return to the Front Panel Window and set the maximum current values for the model to the desired values by typing in the boxes shown in Figure 9

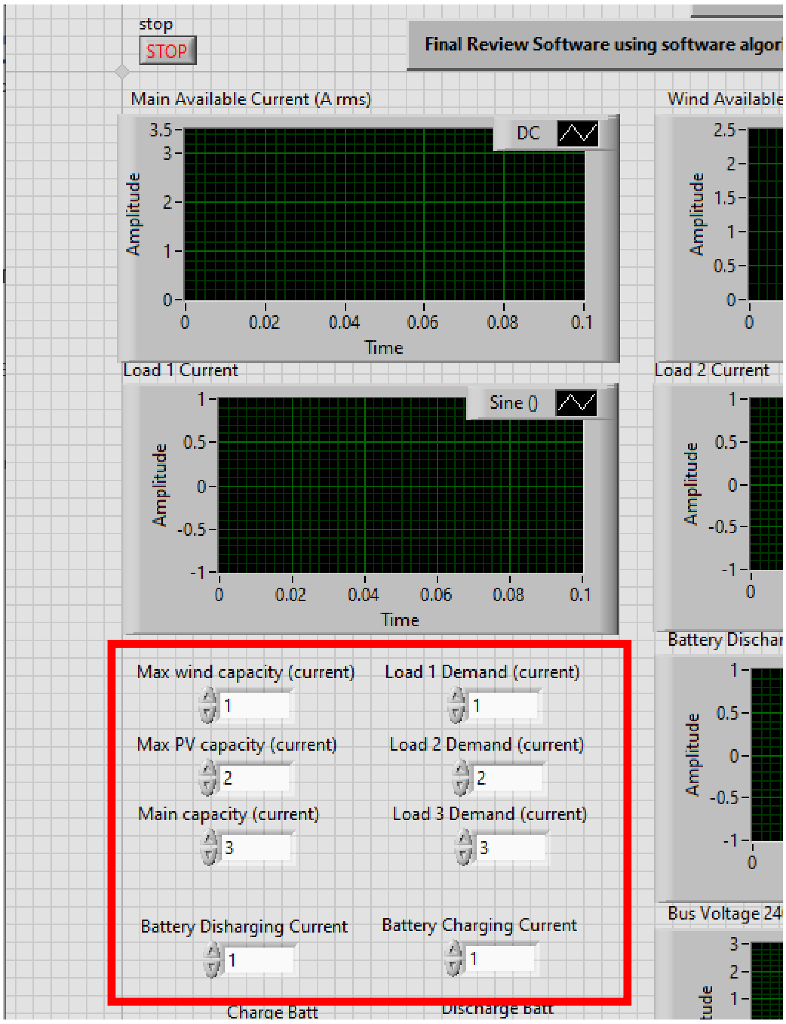


Figure 9: Maximum supply and demand current value inputs.

The following values are good starting points for testing but may vary in the final review so your algorithm (and therefore circuit) should respond to the actual value not the desired value.

Max wind = 1 A

Max PV capacity = 2 A

Main capacity = 4 A

Battery charging current = Battery discharge current = 1 A.

Load 1 Demand = 0.8 A

Load 2 Demand = 1.8 A

Load 3 Demand = 1.4 A

10.2 Loading your Smart Meter Algorithm

The test bed program uses another LabVIEW program embedded within it to act as an emulator for the il Matto controller on your Smart Meter. Therefore, to run the test bed program you need to have loaded in your algorithm first.

The file to use is “smart meter algorithm emulator.vi” – then you edit it for your specific requirements.

This file takes the outputs from the Test Bed and sends back the inputs to the Test Bed, as described shown above in Section 8 showing the Test Bed schematic.

After loading the file, look again at the Block diagram (Window > Show Block Diagram or Ctrl+E) and you will see there the area to add your algorithm, shown in Figure 10.

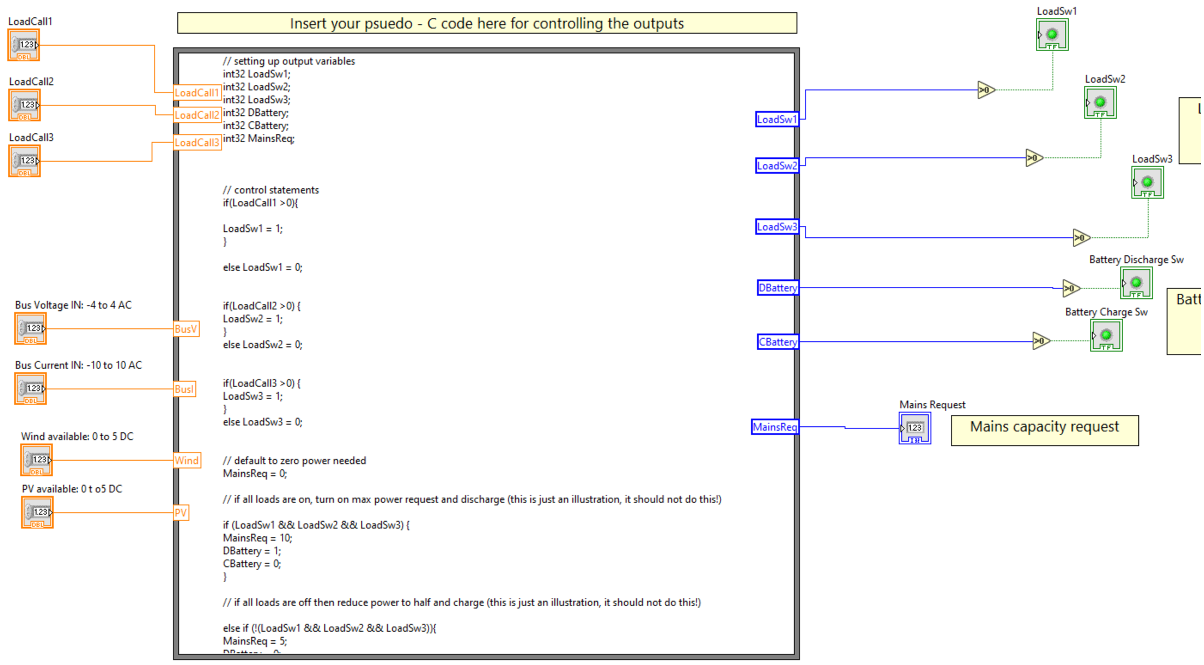


Figure 10: Algorithm emulator for Smart Meter control

Your algorithm/program can be copy and pasted in the middle (Node), take care not to add any extra unseen characters. If the code is invalid, the “run” button will be broken; you can press it to get some information on what the error is for debugging. All debugging should be recorded in your logbook for future reference.

You will see that there are inputs to the left which are coming from the main LabVIEW program, and represent the inputs to your smart meter; their value ranges are stated. On the right are the output signals to send back to the Test Bed; digital switch values to turn on the loads and battery calls, and an Analog output for the Mains Request which has a value of 0-10 as described before.

A very basic example of the code is shown to help you understand the process, the code should be written in C++ just like the il Matto but without the additional settings for the microcontroller.

More help on this can be found in the LabVIEW help files and raised on the Teams channel.

This file can be edited for your specific Team, but must be kept in the same folder and with the same filename as the original otherwise it will not load it from the main program. **You can modify this program as you wish (adding in variable counters or storing data as you would on the Il Matto) so long as the final inputs and outputs have the same name and datatype to be compatible with the main program.**

10.3 Running the Test Bed program

Once all the parameters are set and you have updated your algorithm file then you are ready to run the program. For the testing version you can just click on the run button and watch all the outputs change as you press the switches. For the review version, when you click run it will ask you to name a file to save, this will be the output file which is used to generate your score so it is essential for the final submissions. The file name can be anything but it should be a ".tdms" file output. An example is shown in Figure 11, to help prevent accidental overwrites it is set to increment the file name if you accidently call it the same as a previous test.

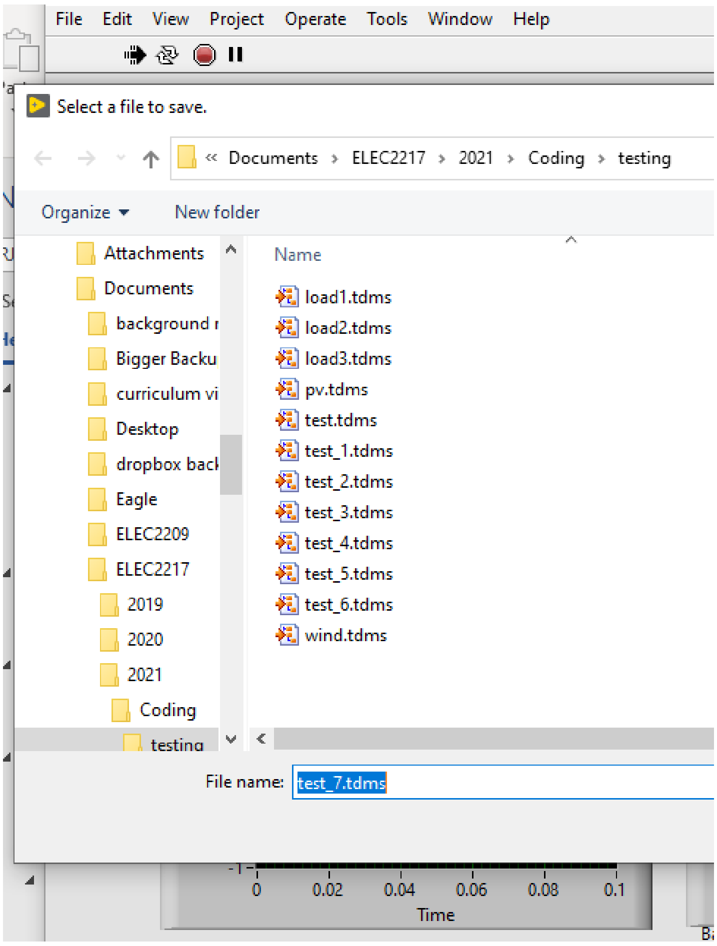


Figure 11: Saving the output file for the review.

The program will then start running through the profile you have entered, it should take a couple of minutes and then an error message ("Error 4 occurred at Read from Measurement File…") will be generated, as shown in Figure 12. When this appears, click STOP and the program will end and your profile is complete. Do not click 'continue' because this will create additional lines in your output file which will make it invalid.

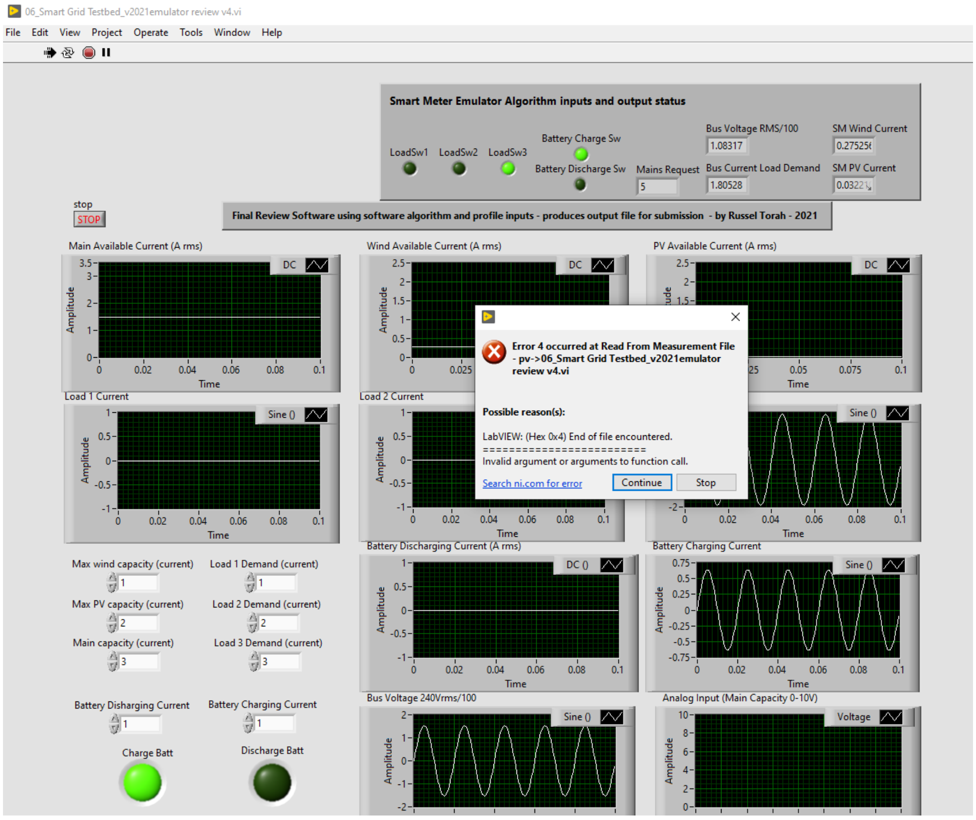


Figure 12: Error warning at the end of the program run – just click STOP, do not click continue.

The final step is to find your output file and check that it has the correct number of data output lines, it should load in Excel and have 729600 lines, as shown in Figure 13.

	A	B	C	D	E	
1	**Root Name**	**Title**	**Author**	**Date/Time**	**Groups**	**Description**
2	test_3.tdms		rnt		1	1. Wind Capacity (A rms); 2. PV Ca
3						
4	**Group**	**Channels**	**Description**	*wf_xcolumns*		
5	Untitled	10		One		
6						
7	**Untitled**					
8	**Channel**	**Datatype**	**Unit**	**Length**	**Minimum**	**Maximum**
9	**Time**	DT_DOUBLE	s	729600		
10	**DC**	DT_DOUBLE		729600		
11	**DC 1**	DT_DOUBLE		729600		
12	**DC 2**	DT_DOUBLE		729600		
13	**DC ()**	DT_DOUBLE		729600		
14	**DC () 1**	DT_DOUBLE		729600		
15	**DC () 2**	DT_DOUBLE		729600		
16	**DC () 3**	DT_DOUBLE		729600		
17	**DC () 4**	DT_DOUBLE		729600		
18	**DC () 5**	DT_DOUBLE		729600		
19	**Implicit**	**Start**	**Interval**	**Length**		
20	DC_Time	0	0.0005	729600		
21	DC 1_Time	0	0.0005	729600		
22	DC 2_Time	0	0.0005	729600		
23	DC ()_Time	0	0.0005	729600		
24	DC () 1_Time	0	0.0005	729600		
25	DC () 2_Time	0	0.0005	729600		
26	DC () 3_Time	0	0.0005	729600		
27	DC () 4_Time	0	0.0005	729600		
28	DC () 5_Time	0	0.0005	729600		
29						
30						

Figure 13: Output profile file sizes, loaded in Excel and showing the length is 729600 for each input.

The output file can be checked to see the different waveforms produced and see if they match what you were expecting to see for the load calls, this will help you to improve the algorithm and final output.

For the actual review, this output file is what is required for submission and it will then be processed automatically to give your scores based on the scenario requirements.