

Test on Inverters

Aim:

To facilitate the evaluation of inverters, Solar Inverters, charge controllers, SPCUs and other power handling devices a test-rig was built with two AC and two DC meters along with Online Data monitoring. This document lists the specifications and details of this test-rig.

Primary Objectives

1. **No load losses/No load current**
2. **Efficiency:**
 - a. DC-AC conversion efficiency at various loading conditions
 - b. Charge controller efficiency (MPPT or PWM depending on the type of inverter)
 - c. Grid charger efficiency.
3. **Increase in energy yield because of MPPT:** This could be a comparative study between inverter with and without MPPT of same capacity under similar conditions.
4. **Logic of the inverter:** Logic of the inverter is to be tested to confirm whether the change over happens at right voltages and state of charge as claimed by Powerone.
5. **Inverter loading capacity at 0.8 p.f and 0.5 p.f**
6. **Crest factor of the inverter**
7. **Battery charger suitability:** Suitability of the battery charger for various battery bank capacities has to be tested as Powerone claim charging is controlled using a voltage feedback mechanism. Battery charging current has to be monitored under 3 stages of charging. This has to be monitored using real battery bank.

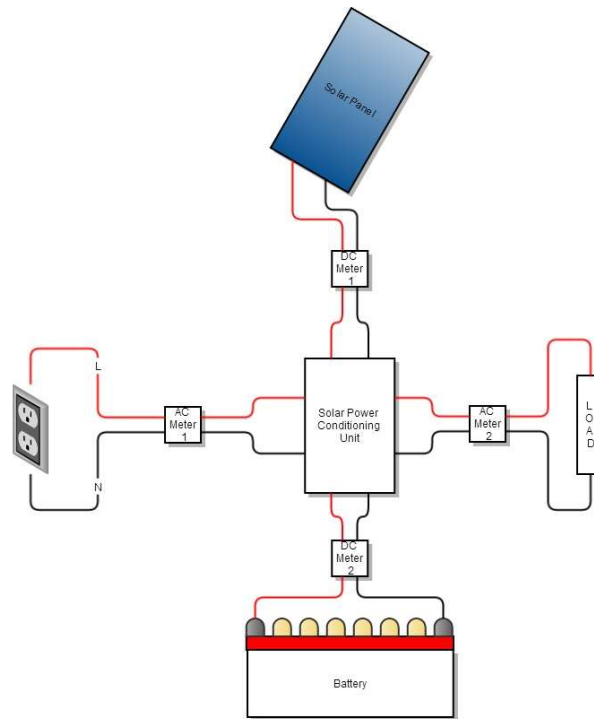
Secondary Objectives

1. **Accuracy of parameters displayed in the inverter display.**
2. **Harmonics in AC output:** This could be measured using Yokogawa clamp meter.
3. **Protections:** Over voltage, over load, battery deep discharge, short circuit, battery reverse polarity, solar array reverse polarity protections have to be tested for their effectiveness and response time.
4. **Output voltage regulation**

Apparatus Available

1. Inverter Test Bed
2. Single Unit Inverter + Charge Controller
3. Data Logger (Raspberry Pi)
4. Digital Storage Oscilloscope.
5. Clamp Meter

Test Setup:



Procedure with Tabular Columns:

No load losses/current:

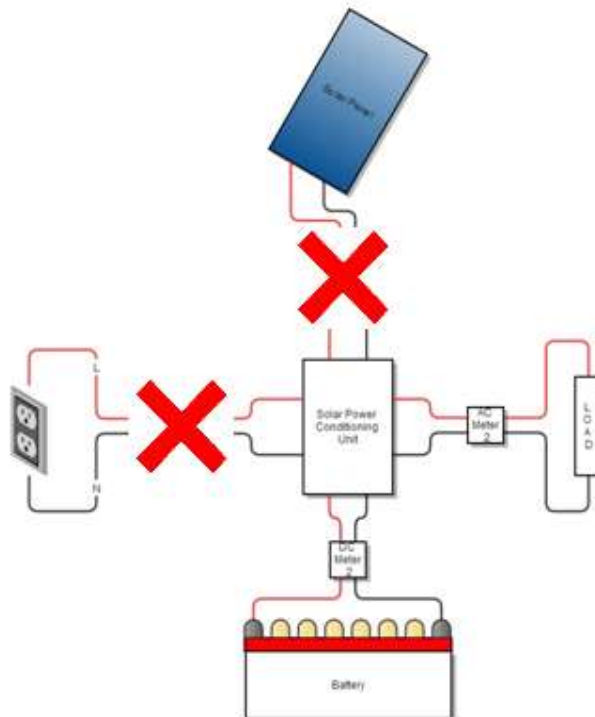
1. Disconnect the grid from the system so that inverter takes power from the DC source.
2. Also disconnect the Solar Panel so that the inverter takes power only from the Battery.
3. Disconnect the load so that the inverter runs on No Load Conditions.
4. Turn on the inverter.
5. Take the Current and Watt reading from the DC Meter 2 to determine no load current and no load loss power drawn from the battery.
6. Conduct Efficiency Test to determine the Efficiency of DC-AC conversion.
7. To determine the actual no load loss and no load current of the inverter before the output transformer, multiply the efficiency of conversion to the no load loss supplied from the battery. The readings of DC meter 2 is the exact measure of the no load loss and no load current supplied.

Sl. No	Battery Voltage (V)	Battery Current (A)	Power Delivered(W)	No load Loss (W)
	[Only Battery Supplies for No load loss]	[Battery Current drawn by output transformer]	[Denotes the no load loss + DC-AC conversion loss]	[Denotes only the magnetizing current drawn by the output transformer]

Efficiency:

1. DC-AC conversion Efficiency:

- Disconnect the panel and the grid from the system so that the inverter is supplying the load from the battery.
- Apply the lamp load in steps to maximum load.
- Take the DC2 meter readings and the AC2 Meter Readings.
- Calculate the efficiency and tabulate.
- Repeat it for different loads. And with different power factors.



Sl. No.	Battery Power (W)	Power Factor	AC Power (W)	Loss (W)	Efficiency (%)

2. Charge Controller Efficiency:

- Connect the Power supply to the inverter's solar Input Terminals and disconnect the grid and the load.
- Change the switch position at the back of the inverter to solar charging.
- Take the DC1 and DC2 readings till the battery is charged.
- Alternately, use Battery sim, to measure the efficiency.
- The difference in the power readings of the two meters gives the losses in the charge controller.

- f. Calculate the efficiency.
3. **Grid Charger Efficiency:**
 - a. Disconnect the Panel and the load.
 - b. Connect the Grid and the battery.
 - c. Take the real power reading from AC1 Meter and the Watt reading of the DC2 meter.
 - d. The difference in these readings gives the loss in the system.
 - e. The efficiency is calculated.

Increase in Energy Yield using MPPT

1. Connect Panel to the MPPT.
2. Connect the MPPT to the battery through DC1.
3. Now do the same connections with a Non-MPPT charge controller to the same battery and same panel such that the MPPT and the non-MPPT charge controllers are in parallel. Make sure that the DC2 meter is connected between the non-MPPT charge controller and the battery. As shown in the circuit diagram.
4. Put this system to charge the battery. Run the data logger so that it can record the data of the battery charging.
5. From the data that logged, the energy output is calculated. This gives the energy supplied to the battery of each charge controller. The MPPT controller should give a higher energy reading. The difference in the energy yield of both the charge controller, gives the increase in the energy yield by MPPT.

Logic of the inverter

Determination of logic of inverter deals with the actual working of the inverter. We need to test logic in which the inverter system has been designed. That is, conduct a study on whether the system has been designed to draw power from the both the solar panel and the battery, the load sharing between the battery and the panel. Test whether there is a power drawn only from the battery and the inverter system uses solar panels only to charge the battery. To conduct the tests to determine the logic of the inverter, we do the following:

1. Connect all the components- that is connect the solar panel to the inverter system through DC1, connect the grid to the inverter system through AC1, connect the battery through DC2 and connect the load through AC2.
2. Now disconnect the grid from the system.
3. Take the readings from the remaining meters for a particular load.
4. Now disconnect the battery and check if the system is drawing power from the panels (for models with cold start on solar). If yes, connect the battery and take the readings to see if the real power of the load is the sum of the power from the panel and the battery times the efficiency of the Inverter.
5. Take continuous reading for some time to understand the dynamic load sharing between the panel and the battery. Use the data logger to store the above readings for a comparison.

Maximum loading capacity of the inverters for a PF of 0.8 and 0.5

The inverters usually have overload protection and a warning for overload on the inverter. We use this for detecting the maximum loading capacity. To vary the power factor, we use a

saturable inductor. The saturable inductor can be obtained using a transformer and energising the one of the coils by a DC source and the other coil carries the AC load current. The amount of DC current that flows through the coil determines the saturation of the inductor. The higher the saturation, higher the PF and lower the saturation lower the PF of the load. We use a lamp load as it's a purely resistive load and the variation of the saturation of inductor, we can achieve the different PF.

1. The connections are made such that the grid is removed and the solar panel and the battery are connected to the system. The load is a lamp load with a series Saturable Reactor.
2. The saturation of the reactor is adjusted by varying the DC control current so that the required PF is set.
3. Now we slowly increase load by turning on more Lamps. And check for the overload warning.
4. Once we get the overload warning, we take the AC2 meter reading to get to know the maximum load that the inverter can handle.
5. We repeat the procedure for 0.5pf.

Measurement of Crest Factor

Crest Factor is the ratio of the Peak-peak value of the AC to the RMS value of the AC. To measure that, we use an oscilloscope to determine the Peak Voltage and the RMS value. Se we just take the ratio of the two to determine the crest factor.

Accuracy of the parameters displayed on the inverters

All the necessary connections are made and the values of the inverter displays and the readings of the meters are compared to measure the accuracy of the displays of the inverters.

Harmonics in AC output

Use Clampmeter which is capable of displaying the harmonic content. Or use oscilloscope which has the capability of Fourier analysis. Obtain the peak values at different frequencies. The Total Harmonic Distortion of the power should be about 3% (according to Indian Standards). To measure the total harmonic distortion, The amplitude of the different order harmonics are measured from the oscilloscope and THD is calculated using the formula:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} v_h^2}}{v_1}$$

Where v_h is the amplitude of the h^{th} order harmonic
 v_1 is the amplitude of the 1st Order Harmonic

Note: Connect oscilloscope probes through a transformer (230/9-0-9 Transformer with 500mA rating)

Current Harmonics can also be measured using an oscilloscope. Except that a current transformer needs to be used.

Output Voltage Regulation

Output voltage regulation is the measure of the ability of the inverter to maintain the output voltage of the inverter constant when there is a sudden change in load from no load to full load. Mathematically it is defined as,

$$V_{reg} \% = \frac{V_{NL} - V_{FL}}{V_{NL}} \times 100\%$$

This is a straight forward measurement. Procedure is as follows:

1. Connect the battery and the panel to the inverter system.
2. And disconnect the grid.
3. Increase the load to full load of the inverter in steps and switch off the load main switch.
4. Now measure the Output Voltage of the Inverter when load main switch is in OFF position (no load).
5. Now switch on the load main switch.
6. Measure the Output Voltage at the instant the load is turned on.
7. Calculate the Output voltage regulation.

Appendix A- Data Logger

The Test-Rig has 4 panel meters (2 AC meters and 2 DC meters) which are of industrial standards and communicates over RS-485 line using MODBUS protocol. There is a RS-485 to RS-232 protocol and communicates to the Raspberry Pi data logger through an RS-232 to USB converter.

A simple GUI is written on the Raspberry Pi for data logging. The program basically, communicates with the meters through a serial port. The software reads the data from the serial port and loads the values read into a database file. The software also asks the user to specify the location and name of the database file and also asks the user to specify the name of the table for the recording the data for the data logging.

The columns in the database tables are classified into 4 types:

1. Timestamp columns:

- | | | |
|------------|---|--------|
| a. time_y | : | year |
| b. time_mo | : | month |
| c. time_d | : | day |
| d. time_h | : | hour |
| e. time_mi | : | minute |
| f. time_s | : | second |

2. DC meter columns:

- | | | |
|-------------|---|---|
| a. <name>_v | : | voltage reading of meter name (eg. solar_v, batt_v) |
| b. <name>_i | : | current reading of meter name(eg. solar_i, batt_i) |
| c. <name>_p | : | power reading of meter name (eg. solar_p, batt_p) |
| d. <name>_e | : | energy reading of meter name (eg. solar_e, batt_e) |

3. AC meter columns:

- | | | |
|-------------|---|---|
| a. <name>_v | : | voltage reading of meter name (eg. grid_v,load_v) |
| b. <name>_i | : | current reading of meter name(eg. grid_i,load_i) |
| c. <name>_p | : | power reading of meter name (eg. grid_p,load_p) |
| d. <name>_e | : | energy reading of meter name (eg. grid_e, load_e) |

A typical data logging table:

[illegible]

Test rig Document

Specification

The test-rig has the following limits and capabilities:

Metering

There are two DC meters and two AC meters, purchased from ElMeasure, the range of measurement for each is outlined below

DC meters

- Model : ElMeasure EDC1100
- Voltage : **0 – 150V**
- Current : **0 – 50A**
- Accuracy : Class I

- Display : 1 line 6 figure LCD
- Input: two push buttons to scroll through display, and for setup
- Parameters measured: Voltage, Current, Power, Watt Hours

AC meters

- Model : ElMeasure LG+5310
- Voltage : **0 – 415V**
- Current : **0 – 20A**
- Accuracy : Class I
- Display : 3 x 1 line 6 figure LCD
- Input: two push buttons to scroll through display, and for setup
- Parameters measured: Voltage, Current, Frequency, Real Power, Reactive Power, Volt Amps, Power Factor, Watt Hours, Load Hours.

Connections

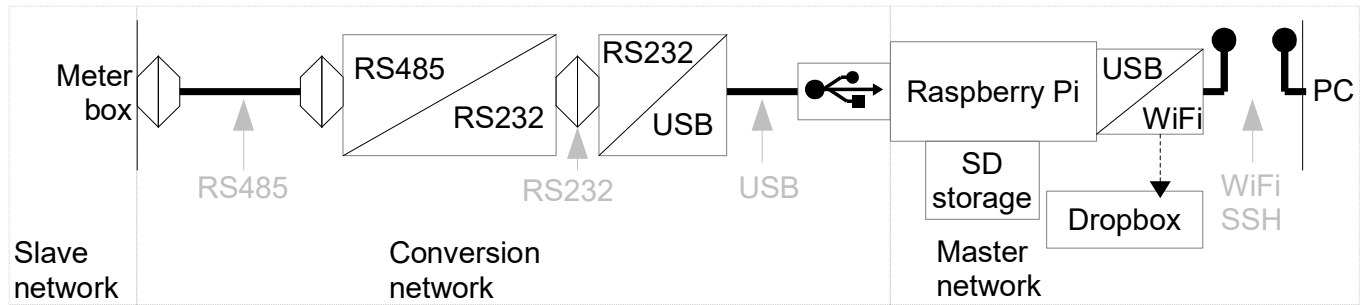
There are four lug terminals to connect the inputs and outputs. These are rated at **50A**.

Power

The meters require an auxiliary power supply, provided via a three pin AC PC type socket. Burden is nominally around 4VA for each meter.

Communication

The diagram below shows the flow of information for the test-rig.

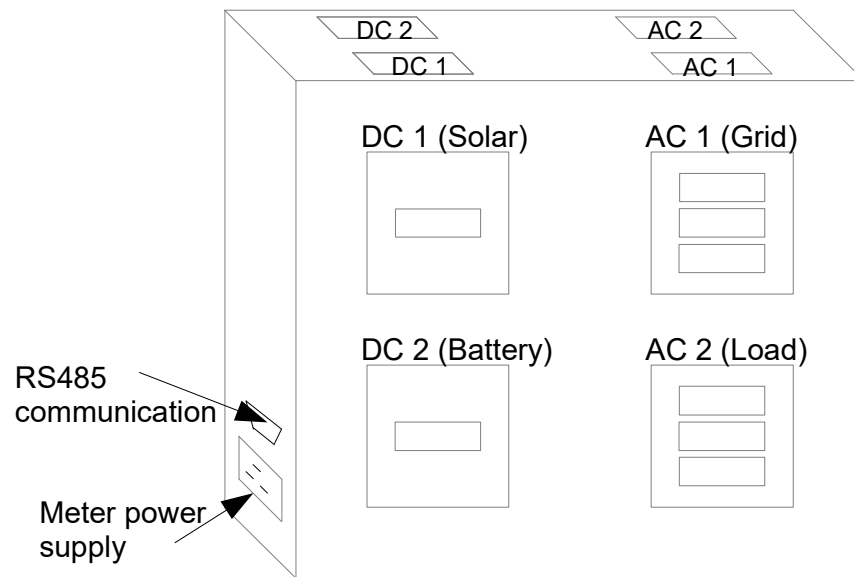


Drawing 1: System communication flow

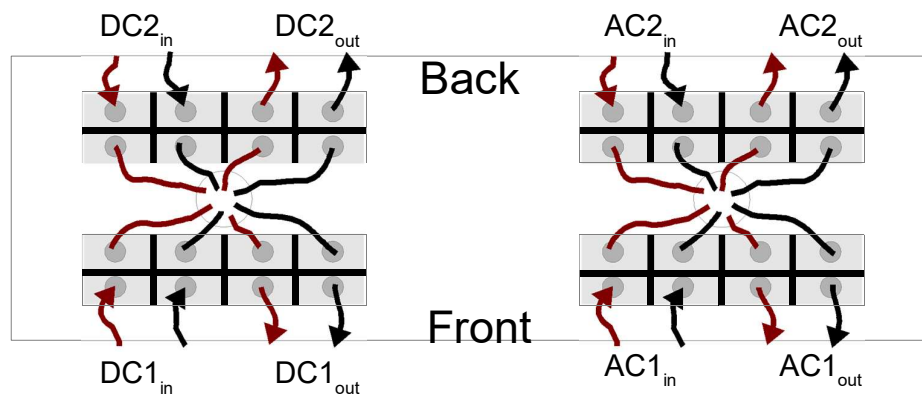
- Slave network: 4 meters communicating over RS485*
- Conversion network: RS485 to USB
 - RS485 to RS232* – Hexin 2108B, requiring a 9V DC supply
 - RS232 to USB* – Prolific Technology PL2303, power from USB, requires installation of a driver
- Master network: logging control and storage
 - The Raspberry Pi (RPi) reads and logs data
 - The setup of the log is done on a PC, communicating over SSH* with the RPi
 - Storage is on the RPi and there is an option of uploading data to dropbox, for easier access and monitoring.

- For an explanation of the communication protocols used please refer to the appendix

Physical Design

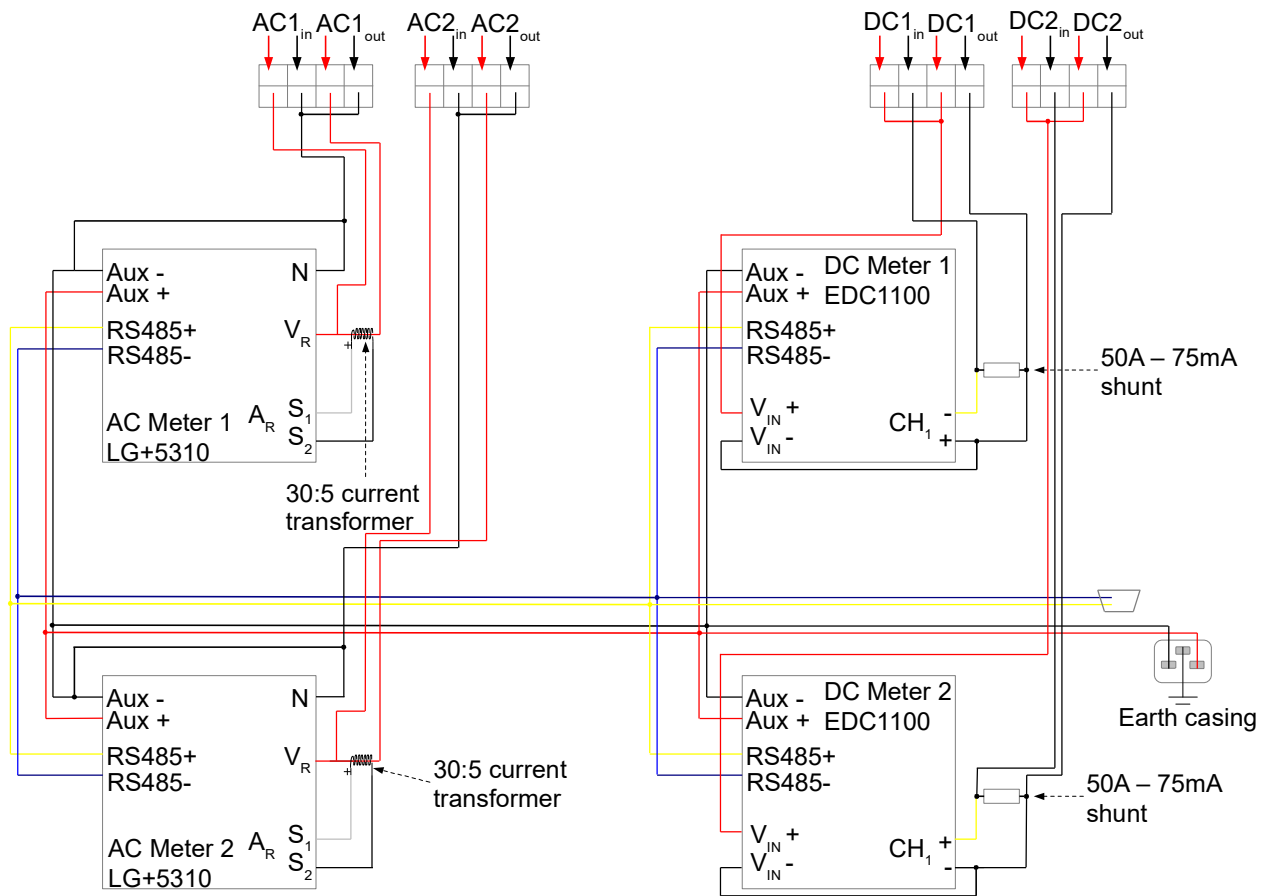


Drawing 2: Physical layout



Drawing 3: Top panel connection layout

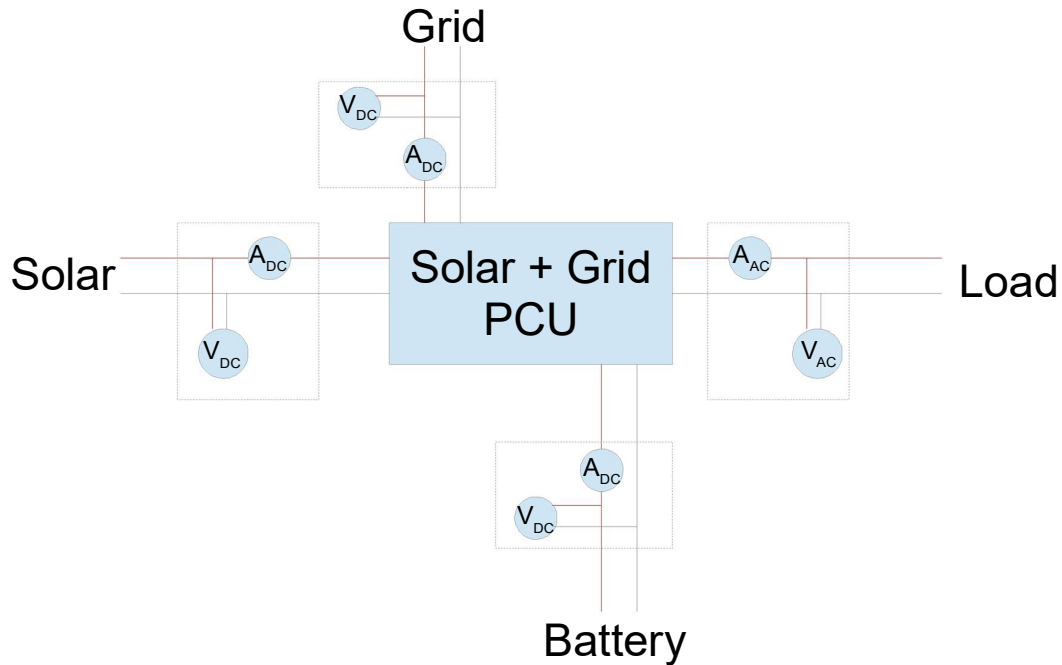
Electrical connection



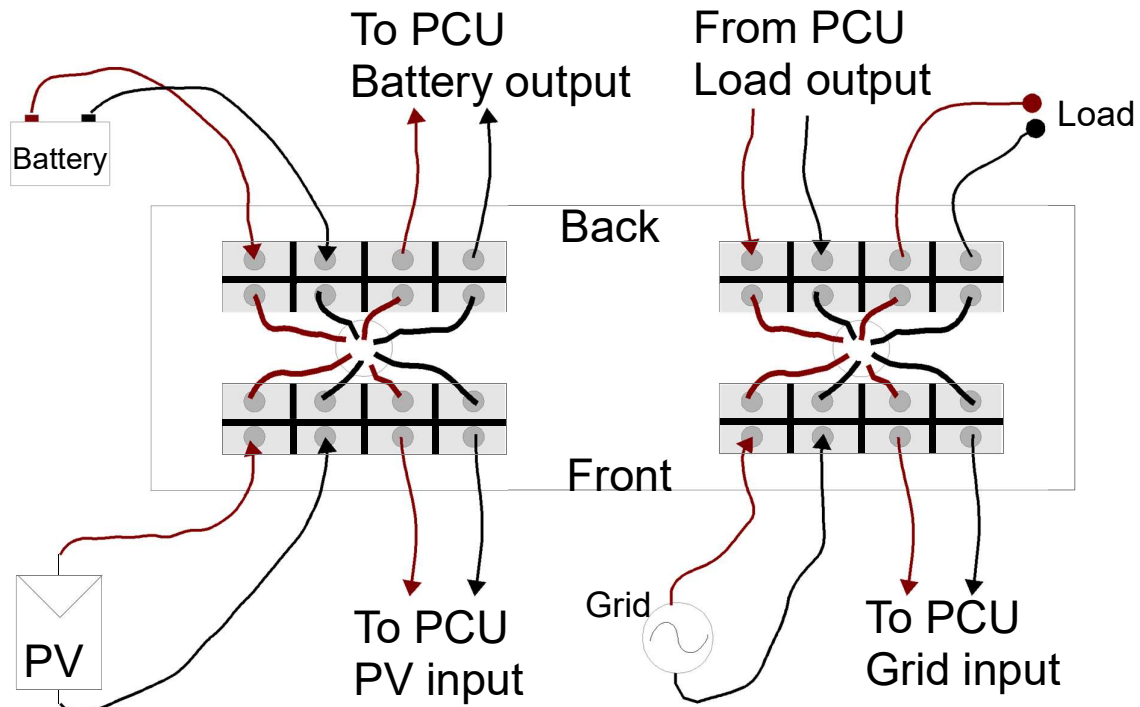
Drawing 4: Electrical connection diagram for meter box

Operation

The test-rig can be used to measure any AC or DC devices within the limits listed above. For example, a connection diagram and sketch of the physical connections for testing a Solar-PCU are shown below. Please refer to the software guide for setting up the data logging and communication.



Drawing 5: Connection diagram for Solar-PCU testing



Drawing 6: Physical connection sketch for Solar-PCU testing

Appendix

Communication protocols and transmission specifications used

RS485

This refers to TIA-485-A transmission specification. In particular the ElMeasure meters use half- duplex transmission on a twisted pair. The advantage of RS485 over RS232 is that it uses a differential pair to communicate. As noise often affects the common mode of a signal a differential pair has a better noise rejection. Hence RS485 is suitable for use over long distances (around 1.2km), so is commonly used for industrial metering and control equipment.

RS232

A common specification. This is used as an intermediary between RS485 and USB, simply because an RS485 to USB converter could not be found

USB

A common specification.

Modbus RTU

The Modbus RTU protocol is used by the ElMeasure meters for communication. A Modbus guide is included with the communication which was found a help in understanding how to use modbus.

SSH

Secure SHell (SSH) is used to remotely log into the RPi and control the data logging/ download data.