# Justifications for design choices

Any figures that do not have sources have been created by the authors.

**Characterising components:**

When designing a system it is necessary to know the behaviour and limitations of its constituent components. There are three main components that make up the energy subsystem: the battery cells, the PV panels and the SMPS.

**Battery cells:**

WHAT IS THE BATTERY CELL NUMBER (ID) AND SUCH?

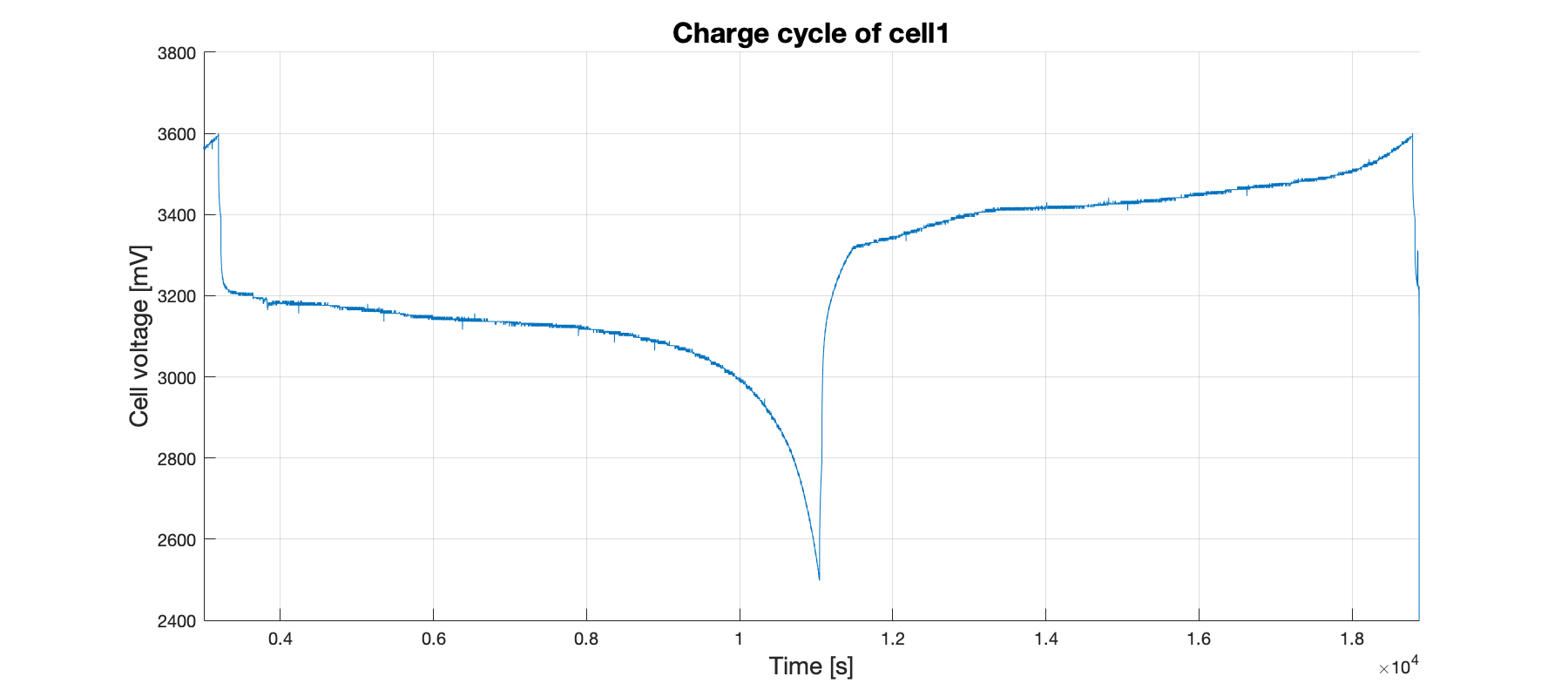
To determine the behaviour of the battery cells they were all tracked through a full charge cycle using the provided “Battery\_Charge\_Cycle\_Logged\_V1.1.ino” code. Every cell behaved similarly in terms of the cell voltage compared to time. The cell voltage of cell1 over a full charge cycle is shown below:

Figure 1: One full charge cycle of battery cell1. Note that the time axis starts at 3000 seconds.

Note the following important points on the graph. At 3190 s the cell is done charging and enters an idle state for 30 s after which it starts discharging. At 11000 s the cell is done discharging and enters an idle state for 30 s after which it starts charging. Finally, at 18800 s the cell is once again fully charged and the charge cycle is completed. The specific behaviour in each region of the graph will be discussed in later sections.

The provided charging algorithm also logs the current into the cell. By integrating said current for a full charge or discharge section it is then possible to determine the cell capacity in terms of mAh. The results of this analysis is presented in the table below:

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Cell number | 1 | 2 | 3 | 4 | 5 |
| Capacity (mAh) | 542.7 | 526.1 | 519.5 | 530.1 | 543.7 |

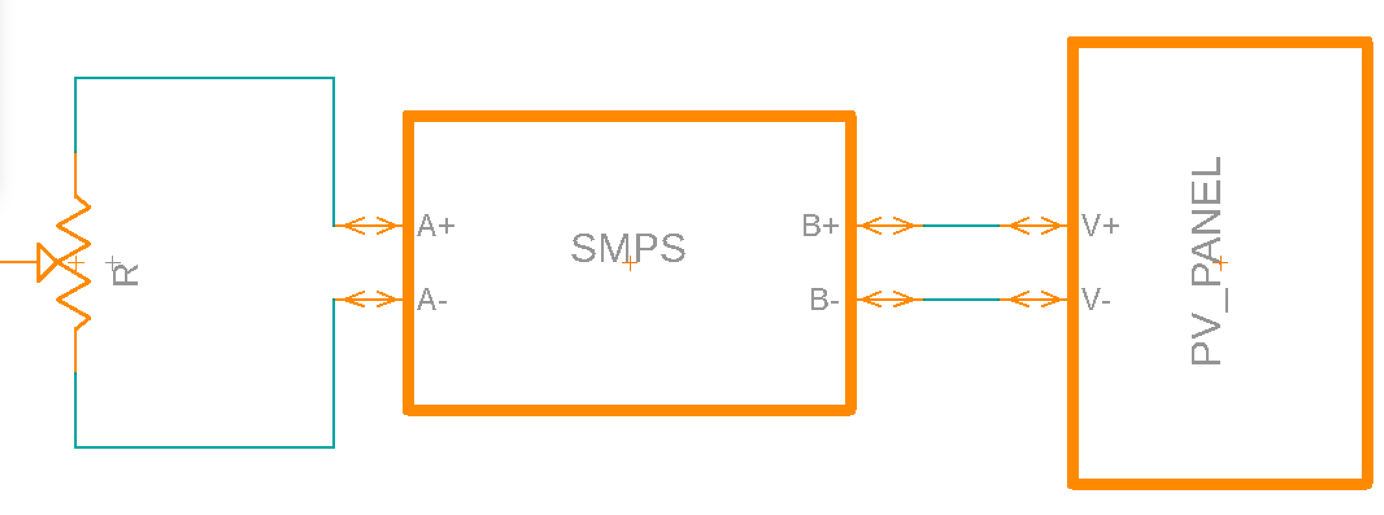
What is important to notice is that the cells all have different capacities.

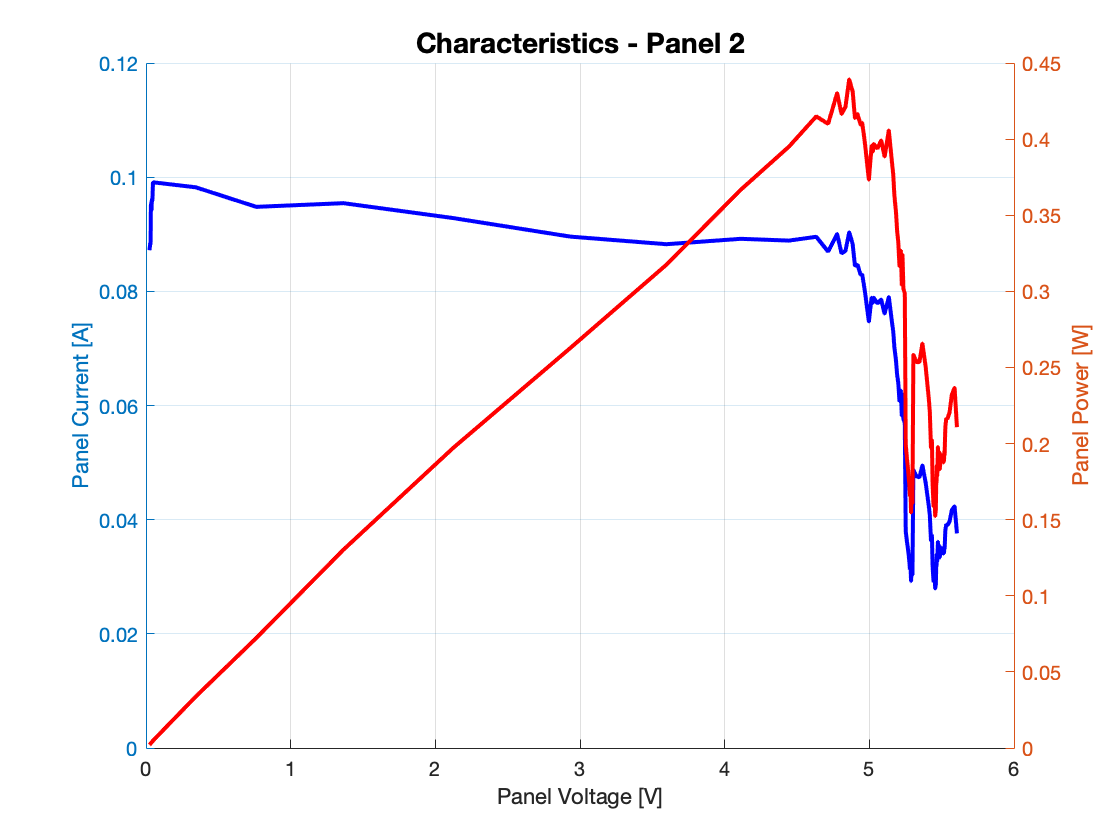
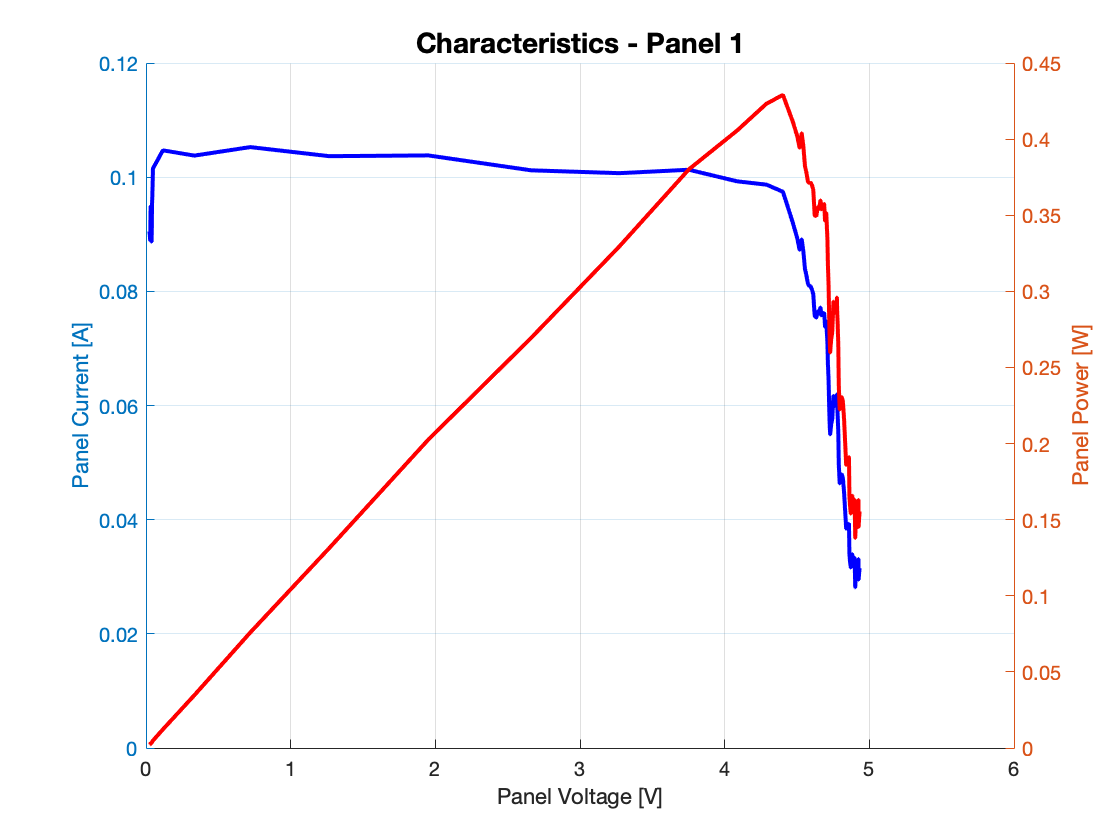
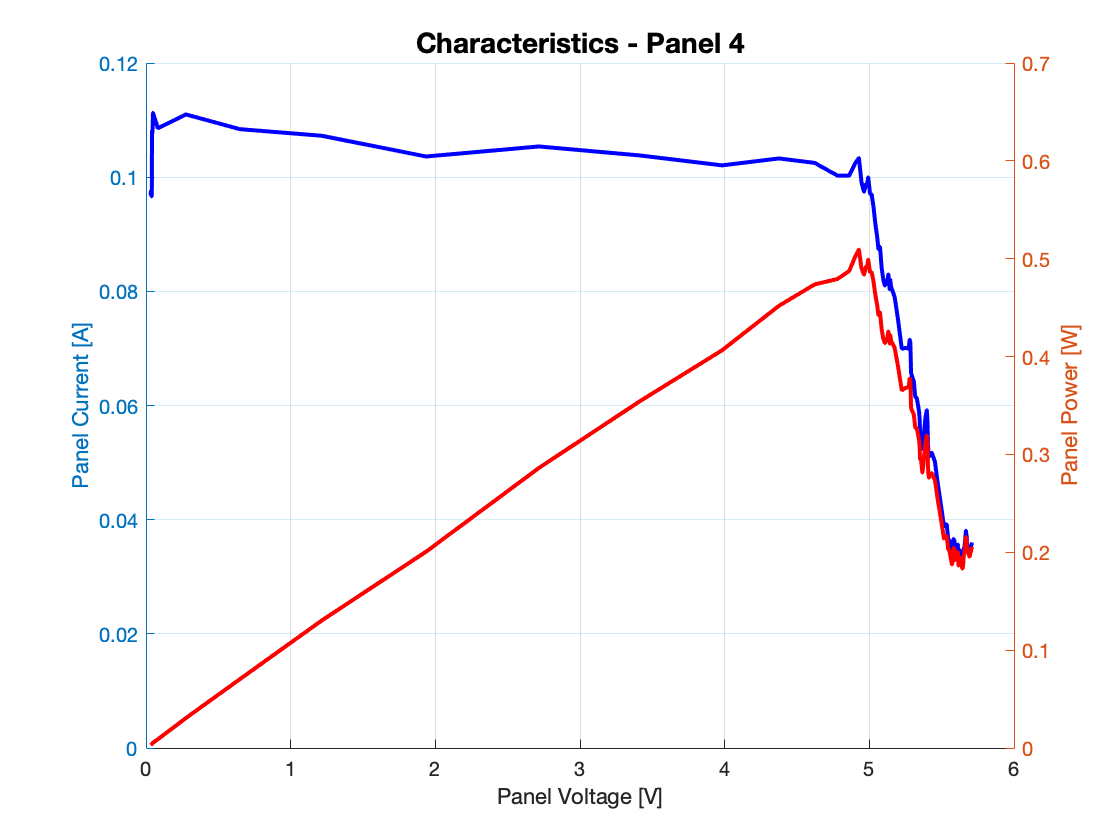
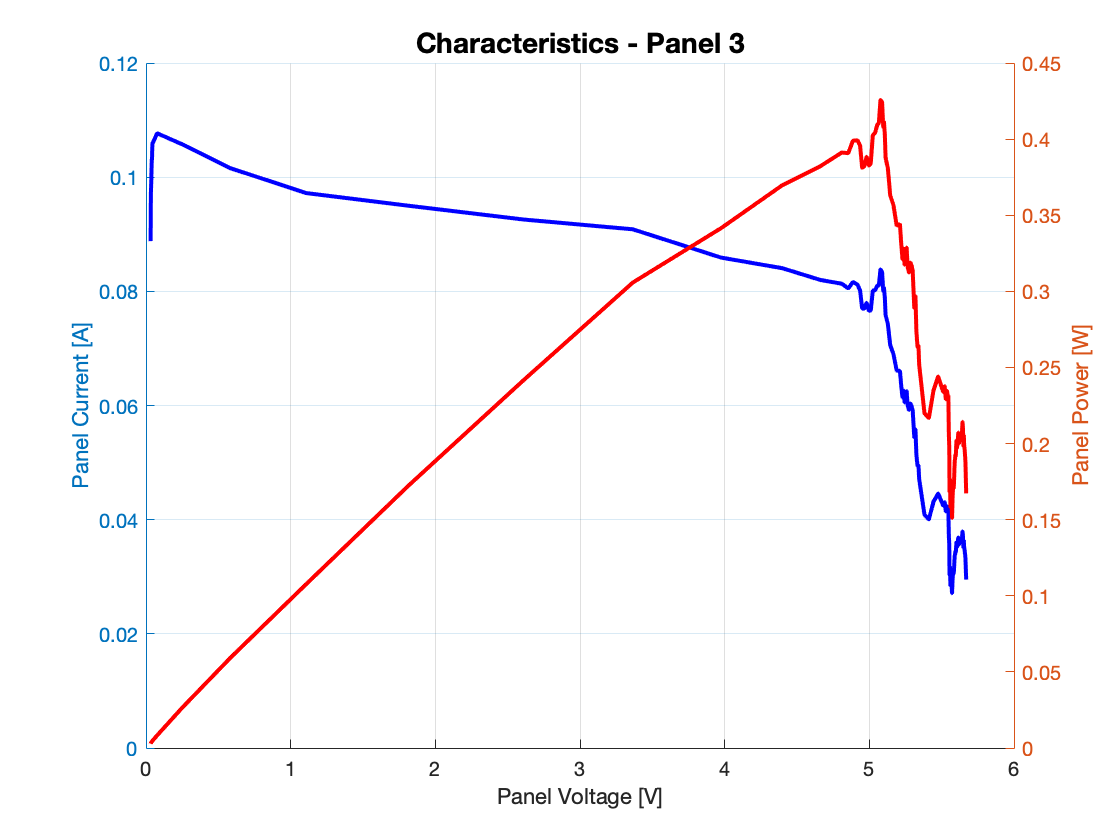
**PV panels**

To charge the batteries

What is rated power etc?

The PV panels are characterised by their I-V curves. To determine the I-V curves each panel was connected to the SMPS in the manner shown below. To get consistency between panels, each panel was activated using the provided lamp and not direct sunlight.



The SMPS was used in a boost configuration such that the voltage and current of the panels could be measured directly. Using the “PV\_characterisation.ino” code (1), the input current was swept and the corresponding input voltage logged. The resistance on the output was changed at set currents such as to not exceed the maximum output voltage of the SMPS. The produced I-V curves and power output graphs are shown below:

Though the data is a noisy, it is clear that all panels exhibit the standard I-V characteristics of a PV cell. That is, they behave as non-ideal current sources with a nearly constant current at low voltages and a rapid current reduction at high voltages (2).

**SMPS**

The SMPS has been thoroughly characterised in 2nd year labs. Its characteristics vary with mode of operation, input power, output voltage and many other factors. However, as will be discussed in later sections, for the energy submodule the SMPS will be operating in buck mode with an output voltage in the range 2.4 - 3.6 V.

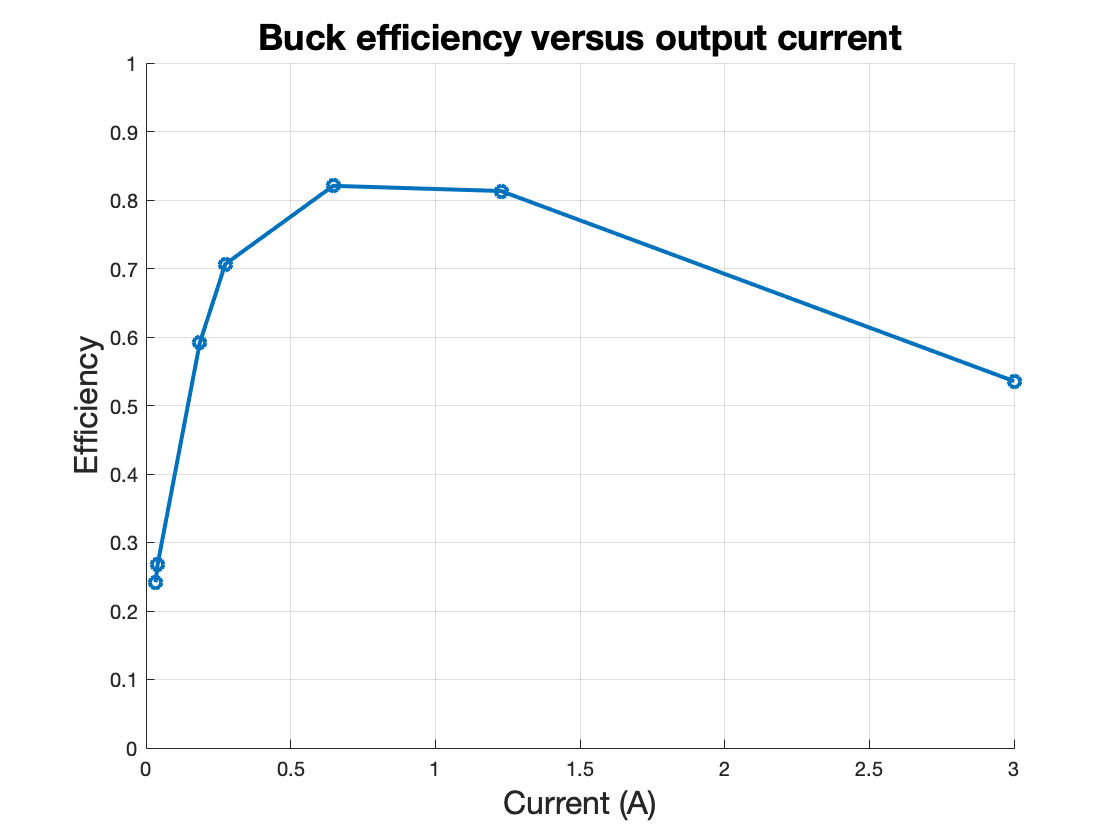


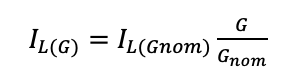
Figure 2 details the efficiency of the SMPS in closed loop, synchronous, buck mode with a target output voltage of ~2.7 V (3). The efficiency of the buck SMPS varies greatly with the output current, with very low efficiency at low output currents.

The SMPS has a power rating of 10 W and maximum input/output voltage of 20 V. When run of the USB power supply the input current is limited to 2.5 A. (4). However, when power is being provided directly at the SMPS ports the current limit is far higher at in our out, and as such is unlikely to impact the operation of the circuit.

Figure 2: Buck SMPS efficiency at V\_out = 2.685 V

**Configuration of solar panels:**

PV cells should not be connected directly in series. In a series connection partial shading can have a huge impact. From lectures we have:



Meaning that if a single PV cell has an incoming irradiance of half the others then the current will be halved and the power of the array will drop to almost half of peak power. On Mars partial shading is expected to occur as dust covers parts of the solar array.

This leaves two configuration total-cross tied connection (TCT) and full parallel. Both configurations are shown below:

Et bilde som inneholder tekst, klokke

Automatisk generert beskrivelse

TCT has the advantage over series connection that the drop off in the current of one cell has a far smaller impact on total output power.

Could also have done two parallel connections of two PV panels in series, but this has the disadvantages of series connection without the advantages of TCT. See linked article to see comparison.

Disadvantage of pure parallel connection is that voltage is lower. To charge the batteries we use the SMPS in a buck configuration, and the voltage is therefore stepped down. Thus, if the voltage of the PV array is not higher than the charging voltage of the battery then we won’t be able to charge at all. The advantage of parallel connections is that a change in the current of one cell will not impact the current of other cells. However, at the maximum power point of the array as a whole, each individual cell might not be operating at its own maximum power point. Disadvantage, SMPS losses might be high at low voltages.

Remember that capacitor on SMPS input will be able to hold some energy. At 62.5 kHz it holds enough power that input power is constant no matter the duty cycle.

What is the maximum power drawn by the batteries? There are 5 batteries and we charge at 250 mA:

In addition to this there will be losses in the circuit. However, the rated power of the PV cells together is:

So we need to draw as much power as possible out of the solar panels. Might not be able to use the full 5 battery cells.

<https://www.sciencedirect.com/science/article/pii/S0360544211001484?casa_token=aN6AlhJsx9IAAAAA:yUMOdvzscbw5ltokpvOcWVfY8IOHd0nr_6eLwivW_ZHVWAsjFMjRJ7ihyQtg2kn25_U9QIG5yg> , configuration of solar panels

<https://www.sciencedirect.com/science/article/pii/S0038092X16300111>

Testing both configurations and comparing them. Test each multiple times.

**Configuration of battery cells:**

Check if charging at a lower current has any effect on capacity, if not, then we can charge more cells, just at a lower rate. Then we can use the full battery-pack.

Can also provide less power if in series, as maximum current is far lower.

**SMPS configuration**

**Safety mechanisms:**

Needs to shut itself down when too much power has been drawn, if not we might damage batteries.

**MPPT:**

<https://www.sciencedirect.com/science/article/pii/S1364032117305750>

**Sources:**

(2) <https://bb.imperial.ac.uk/bbcswebdav/pid-2060823-dt-content-rid-8486224_1/courses/10435.202020/2%20Notes%20-%20Photovoltaic%20Energy%20-%20ELEC50012%2020-21%281%29.pdf>

(3) Edvard’s power logbook

(4) Power lab instructions v0.99

(5) <https://static.rapidonline.com/pdf/502676_v1.pdf>

**Appendix:**