Shading of photovoltaics, impacts and recommendations

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Abstract

The goal of this document is to provide an overview regarding shading of photovoltaic cells, modules and arrays. It also discusses the impact of shading on electrical output, and recommendations for how to mitigate the negative effects of shading.

1. Basic photovoltaic (PV) operation

To understand how and why shading affects PV cells it is first useful to have a basic understanding of how these cells operate. PV cells generate electricity when exposed to direct sunlight. For crystalline silicon PV cells, this occurs when photons (light waves/particles) are absorbed in the silicon giving up their energy to increase the energy of electrons (excited carriers). A P-N junction (which is essential in the operation of a PV device) then captures and directs these excited carriers to build up in specific regions inside the cell before being extracted through metal contacts and used to power electrical devices.

2. Effects of low light, shade and temperature on the operation of a single PV cell

The current generated by a PV cell is mostly proportional to the total amount of direct light being absorbed. It is important to note the term 'direct light'. This means only light which shines unobstructed, directly from the sun to the cell is absorbed and can hence generate current.

Similarly as the intensity of light changes throughout the day, so to will the current generated by a PV cell. This will mean that in the morning and evening when the PV cell is absorbing less light, it will generate less current.

The effect of reducing light intensity and shading a single cell have very similar effects. This is depicted in Figure 1.

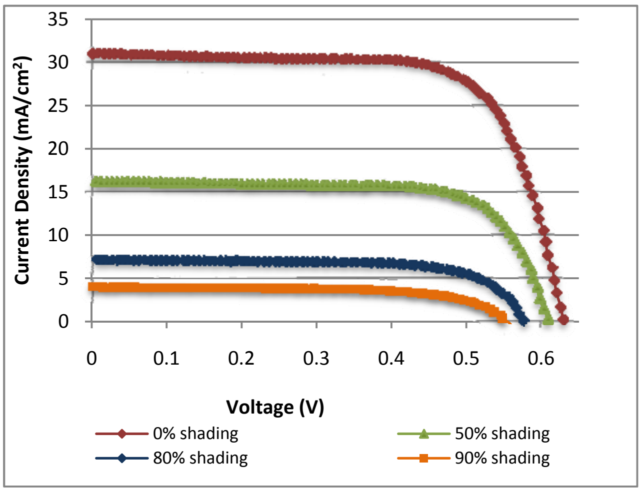

Figure 1 - shading or reducing light to the cell has similar effects on performance.

It shows how reducing the light to the cell (by either shading or intensity), the current generated by that cell is similarly reduced.

Another factor which can affect the output performance of a PV cell is temperature. As the temperature of the cell increases it causes some of the properties of the P-N junction to change. These changes mean the excited carriers no longer need as much energy before being captured and directed by the P-N junction. This causes a reduction in the voltage of the cell as seen in Figure 2.

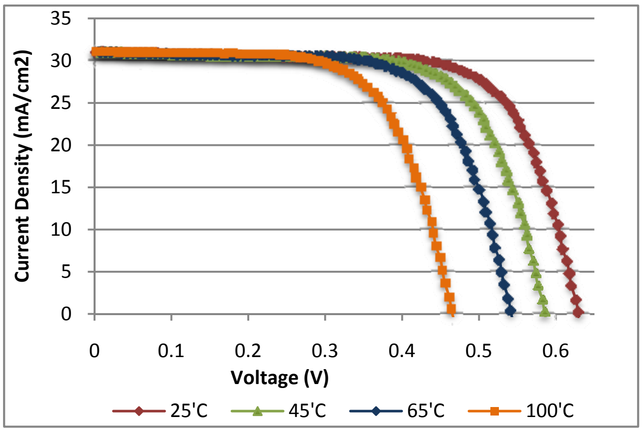

Figure 2 – shows how increasing cell temperature reduces the cell voltage for the same amount of incident light.

3. Effects of shading on the operation of a multiple PV cells

While the effects of shading on a single cell are simple to understand, those effects are much more complex in a situation where multiple PV cells are connected together in strings. This is what occurs in a PV module.

When cells are electrically connected in series (a series string), the combined voltage is the sum of all the cell's voltages. In general however, the current of the combined cells will be equal to the lowest current of any of the cells at that operating point. This means that some cells will not be able to operate at their preferred maximum power. This is what is referred to by mismatch.

The effect of mismatch on a module operating normally is very small. However when a cell (or cells) within a series string become shaded, their current output is reduced (recall Figure 1). This shaded cell (cells) will then reduce the current of all the other cells. Importantly, the difference in module power between normal operation and partial cell shading will be dissipated into the shaded cell. This would be enough to destroy a module. The difference in operation of a 72 cell monocrystalline module when it is operating normally compared to when one cell is 50% shaded is shown in Figure 3.

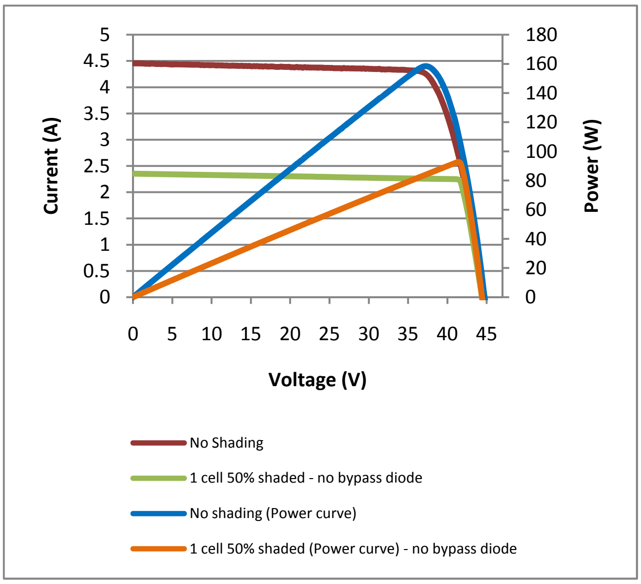

Figure 3 - operation of a 72 cell monocrystalline module when it is operating normally, and with a cell 50% shaded (no by-pass diode).

Obviously the situation shown in Figure 3 would be unacceptable for energy production, and module durability. To limit the effect of shading of a cell on a module, bypass diodes are used. A bypass diode allows a proportion of the cells not affected by shading to continue operating normally, while only a sub-set of cells all connected to the same bypass diode operate at a reduced power. Figure 4 shows the affect on a module's current-voltage performance for different levels of shading of a single cell, while Figure 5 shows the power-voltage performance for the same shading conditions.

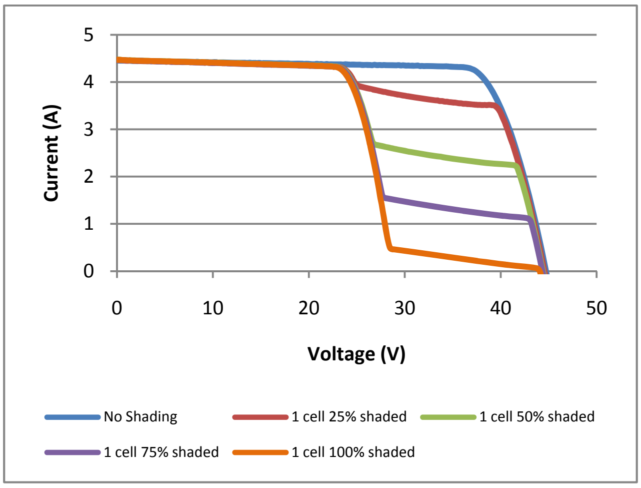

Figure 4 – current-voltage performance of a 72 cell monocrystalline module with 3 bypass diodes installed, for different levels of shading for a single cell.

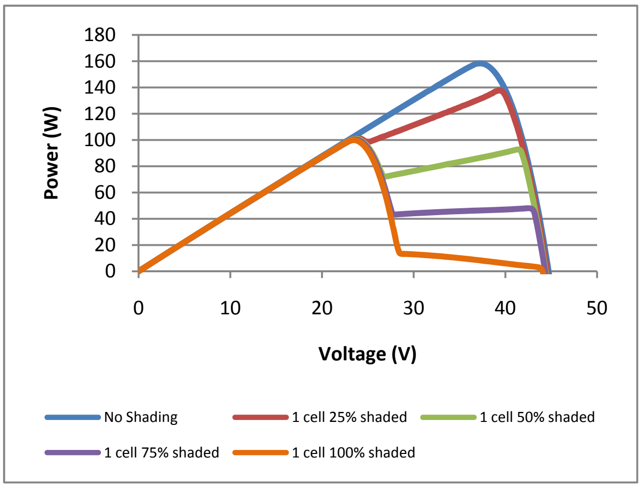

Figure 5 - power-voltage performance of a 72 cell monocrystalline module with 3 bypass diodes installed, for different levels of shading for a single cell.

4. Effects of shading on the operation of a PV array

If a PV array experiences some shading of a module (or modules), the effect on array power will be similar to the effect on module power when a cell experiences a similar shading event. The only difference is total power will be affected by a lesser amount, and that affect will decrease as the number of modules per string increases.

Figure 6 is an example of what the effect on array performance can be if a single module experiences some shading. It shows an array with 15 modules connected in series. One of those modules has experienced some shading and covered approximately 20% of the module. The blue curve shows the current-voltage performance of the array, while the red curve shows the power-voltage relationship. The two peaks in the power-voltage curve represent two local maximum power points. The greater being 2.606 kW and the lesser 2.523 kW.

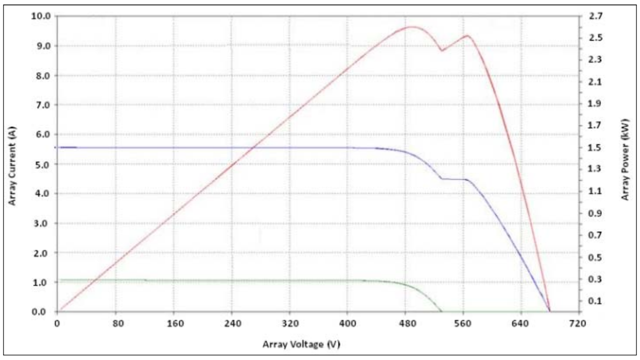

Figure 6 - I-V and P-V curves for an array of 15 modules with one module experiencing shading of approximately 20% of the module area.

While this shows that a shading event on a single module in an array string can have a relatively small impact on total array power, it shows there is a negative effect and this effect can be variable. It also illustrates how regular shading events can make energy prediction for an array more complex.

5. Calculating the effect on PV array performance of shading

By understanding how shading affects:

- a single cell;
- a group of cells within a module;
- a group of modules in an array;

it is possible to draw some simplified conclusions about how array power is then affected.

1. As the number of modules in an array string increases, the effect on total array power, for shading of a single module, will decrease.

2. Within a module if **one cell** is shaded by more than 50%, ALL the cells protected by the same bypass diode will no longer contribute to the power of the module.

3. Even small periods of shading of single cells can affect an entire array's performance output.

6. Recommendations regarding shading

Throughout the entire life of a PV array, it is fair to assume that every cell in every module will be shaded at least once due to naturally occurring, unavoidable environmental factors (eg. dirt, cloud, bird droppings, etc.). It is therefore important when designing a PV array that care is taken to avoid regular shading events. Failure to do so will void future warranty claims. It is especially important in maximising the overall array power that, when the array is operating near maximum power, regular shading events are avoided. This can also lead to higher energy production long term through improved durability of modules, where the modules are likely to maintain performance further above their warranted power.

7. Glossary

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