Low Shunt Resistance Cells and their effect on Solar Car Performance.

Now that the solar panels are being tested at 50% Sun and the maximum power doubled for the purposes of calculating the ballast weight, an interesting phenomenon has become evident in some panels. When calculated in this fashion the power output derived from some panels, rather than being slightly greater as expected, can actually be much less than the power obtained by simply measuring the panel at 100% Sun! How can this be? What cruel twist of fate is at work here? Well, fear not, this is not some demonic scheme dreamt up by the scrutineers to intentionally advantage certain teams. As ever it can be explained by simple science.

The losses in a solar cell, as shown by having a Fill factor less than unity, are created by several inherent characteristics. The equivalent circuit of a solar cell is a current source in parallel with a diode and a shunt resistance and this all then in series with a further resistance. The series resistance Rs is caused by the bulk resistance of the semiconductor material, the bulk resistance of the metallic contacts and the interconnections and the contact resistance between the metallic contacts and the semiconductor. The shunt resistance Rsh is caused by the leakage across the junctions around the edge of the cell and in the non-peripheral regions near crystal defects and the precipitates of foreign bodies in the junction region. A high series resistance reduces the output voltage under load so the FF is lowered. A low shunt resistance leaks off some current and so also lowers the FF.

The characteristic resistance of a solar cell is given by: Rch = Voc/Isc. If Rs is a lot less than Rch or Rsh is a lot greater than Rch then they will have little effect on the fill factor.

In other words, if the cells are poorly made they could have a fairly high series resistance and a low FF. However, cells that were originally well made can still have a low FF when made into modules. One way this can happen is if the original cells are badly cut to size. This can create leakage around the cut edges, say by badly executed laser cutting creating tiny short circuits across the junction, or perhaps by contamination when being sealed onto the backing material.

So, what happens if we have a panel made from high quality cells that have been 'damaged' while being assembled? They would have a lower than expected shunt resistance but could we detect this easily? The open circuit voltage will be the same unless the shunt resistance was extremely low, low enough to bleed off a significant amount of the generated current, rendering the cells useless anyway. The short circuit current will be the same because at zero volts the shunt resistance will not bleed off any current. It's in between (which is where the cells are most likely to be operating) that things get interesting. The FF would most likely appear to be in the normal range as well and unless you were able to plot voltage against current you probably wouldn't be aware that anything was different, and even then you still might not.

Whereas a 'normal' cell will deliver a constant current almost equal to the short circuit current from just below the maximum power voltage down to a short circuit, our low Rsh cell delivers an increasing current all the way. The rate of increase depends on the value of Rsh. A lower Rsh giving a greater rise in Isc. And then there's what happens if you reduce the light level.

The short circuit current of a cell is directly proportional to the available sunlight, but the open circuit voltage increases logarithmically with increased sunlight. This mean Voc initially rises very rapidly to around 0.6V per cell then only rises very little after that. This means that the power lost in Rsh is reasonably constant down to fairly low light levels. Put another way, the proportion of power lost due to Rsh increases as the light level reduces.

Imagine a solar panel made from our otherwise very high quality silicon cells with a very low Rs that have been perhaps contaminated so that they now have low Rsh. Now, let's go a step further and assume that (almost) all of the losses in our panel are caused by Rsh and none are caused by Rs.

At 100% Sun,
Power generated = $I_{100\%}$ x Vout
And,
Power lost in Rsh = $(Vout)^2$/Rsh
Then,
Power out = Power generated – Power lost
Or
$I_{100\%}$ x Vout – $(Vout)^2$/Rsh

At 50% Sun, similarly,
Power generated = $I_{50\%}$ x Vout
and
Power lost in Rsh = $(Vout)^2$/Rsh
Again,
Power out = Power generated – Power lost
But notice that if we double this we get
Derived Power out = 2 x [$I_{50\%}$ x Vout – $(Vout)^2$/Rsh]
Or, since $I_{100\%}$ = 2 x $I_{50\%}$,
Power out = $I_{100\%}$ - 2 x $Vout^2$/Rsh

In other words, 2 x (Power at 50% Sun) is less than Power at 100% Sun, so when it is used to derive the ballast weight it returns a smaller than expected figure. This is despite the panel appearing quite 'normal' in all other respects. I will admit that I have taken a few liberties with the calculations above and I will now take a few more, but I think that you will get the point.

To get an idea of the numbers we are talking about, Ian Gardner has had his Victorian Master Panel tested by Murdoch Uni in WA. They came up with the values (which appear a little strange because they tested at 20^oC rather than 25^oC):

Rs = 3.26 ohms
Rsh = 854 ohms
Voc = 21.22 V
Isc = 0.657 A
Pmax = 10.54 watts
Vpmax = 17.35 V
Ipmax = 0.607 A
FF = 0.756

To make the numbers easier lets assume cell voltage = 20 V, I = 0.6 A, Rs = 3.3 and Rsh = 850.

Then, at 100% sun, the power lost in Rs = 0.6 x 0.6 x 3.3 = 1.188 watts while the power lost in Rsh = 20 x 20 / 850 = 0.47 watts, so total power lost = 1.67 watts.

At 50% sun, power lost in Rs = 0.3 x 0.3 x 3.3 = 0.297 watts, and power lost in Rsh = 0.47 watts so now total power lost = 0.767 watts. If we double the power as required by the rules, we get the apparent total power lost = 1.534 watts. In other words, as we expected, the total power derived according to the rules = (1.67 – 1.534) = 0.136 watts more.

Now, bear in mind that this is a reasonable quality commercial panel with a FF of 0.756 and our previous discussions were for low FF panels. Is there anything that we can do to this panel to “take advantage” of the double 50% sun readings? What would happen if we simply reduced the value of the shunt resistance to 400 ohms?

At 100% sun the power loss in Rsh = 20 x 20 / 400 = 1 watt so now the total loss = 2.188 watts.

At 50% sun the total power loss now = 1.297 watts and the derived power has lost 2.594 watts.

This means that our derived power is now (2.594 – 2.188) = 0.406 watts less. That works out to 80 gm less ballast without even trying!

How could this effect be created for an existing panel, I hear you ask? Here’s one way. You could buy an 820 ohm 0.6 watt metal film resistor from Jaycar for a few cents and somehow connect it across your panel. This would drop Rsh to around 410 ohms. The resistor is only around 2.5 mm diameter and about 7 mm long so you could hide it in a connector, for instance. Of course you would need to do the numbers for your particular panel so I’m sure that you can do much better with a bit of trying.

Bear in mind that this will only work for you in bright sun, as opposed to the extra series resistance ploy which works in reduced sunlight. But, since panels are measured at AM1.5, in places like Hobart, Alice Springs or Perth you can expect greater than 100% sun for much of the time so you will be laughing.

And now, a word of warning. This effect has been observed independently by several of the scrutineers which has lead to this analysis of a possible scenario. A number of different solar panels tested have produced results that tend to indicate the presence of this condition in varying degrees. What, if anything, the scrutineers intend to do about it has yet to be decided, but, bear in mind that they do know about it and will consider any misuse of this knowledge to be most definitely “not in the spirit of the event”.

Again, you have been warned.