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Are you extracting the most work and lifespan from your solar cell?

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Abstract: The electrical operation of a solar cell is described highlighting the origins of the I-V and P-V curves. The work reveals that an illuminated solar cell should always be kept loaded at the maximum power point, so that: (i) maximum power is extracted from the cell; and (ii) to minimise internal power dissipation, otherwise an increased heating of the cell and faster degradation. A Utilisation Factor (UF) metric is introduced to determine how much available power is converted to work. It is shown with no power loss through ohmic elements, 95% of the available power is utilised for external work while the remaining 5% required to bias the diode. The UF decreases with increasing values of R_s. The power dissipated by the cell is calculated for various values of R_s and found that the cell dissipates a constant minimum power for voltages less than the maximum voltage. A method to estimate the maximum ambient temperature is proposed so that the panel does not overheat during open circuit operation as overheating leads to degradation.

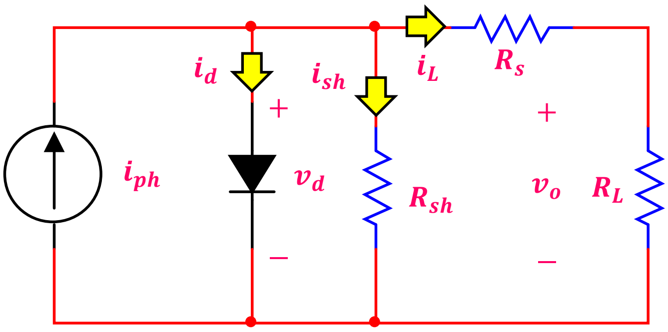

Figure 1: Solar Cell Model

Review of the Electrical Model of a Cell

A commonly utilised electrical model of a solar cell is shown in Figure 1 [1]. It consists of a current source in parallel with a p-n diode, a shunt and series resistance. The current source (photon current) i_{ph} is due to sunlight illumination of the cell. The well published I-V and P-V curves (refers to i_L , v_o and p_o) for varying values of R_s are shown in Figure 2. In all cases R_{sh} is set to 1MΩ.

Consider Figure 2A, the I-V and P-V curves when R_s is set to zero (red solid and dashed traces). In the I-V curve, initially the output current is constant with voltage but starts to decrease when the diode is turning on (forward-biased) and characterised by a knee point in the vicinity of 0.5V. The diode continues to shunt more current as the voltage rises and reduces the available current for external work. In the P-V curve, initially the available output power increases linearly with voltage due to a constant output current but reaches a maximum level in the vicinity where the output current starts to drop, and continues to drop with increasing voltage. Figures 2B-2E show that the maximum power extracted from the cell decreases with increasing values of R_s and also occurs at a lower output voltage.

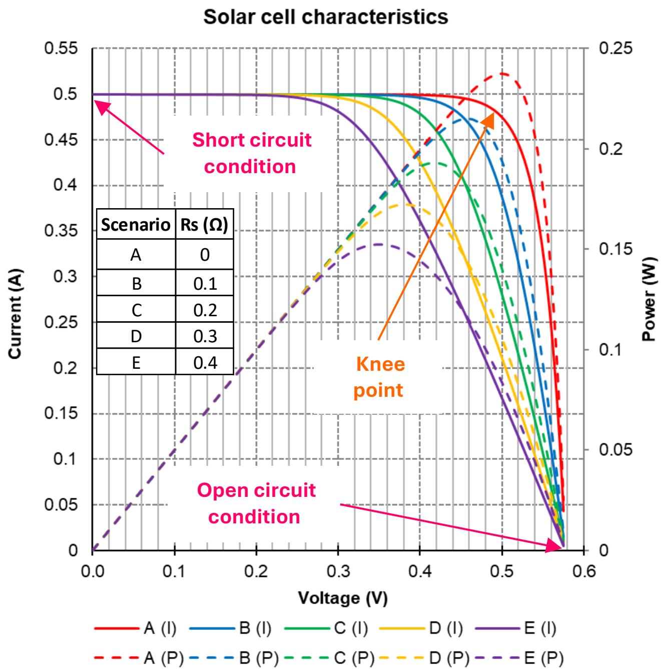

Figure 2: I-V and P-V curves

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Power Extraction & Dissipation by the Cell

Consider a cell with I-V and P-V curves shown in Figure 2A. In the case where the cell terminals are shorted (short circuit condition) no voltage is developed across the diode and therefore all the available current flows through the short and no power is dissipated by the diode. In the case where the cell terminals are disconnected from the load (open circuit condition) all the available current must flow through the diode resulting in a maximum open circuit voltage; the diode dissipates all the available power and heats the cell. This phenomenon highlights that an illuminated cell should always be loaded to minimise power dissipation within the cell. It is reported [2] that PV modules of a mono crystal silicon type left open circuit in a desert environment are visibly degraded compared to those connected to a charge in identical weather conditions throughout three years of exposure to the sun. Moreover, amorphous silicon solar cells operating under open circuit conditions were found to degrade faster compared to similar cells operating under maximum power conditions [3].

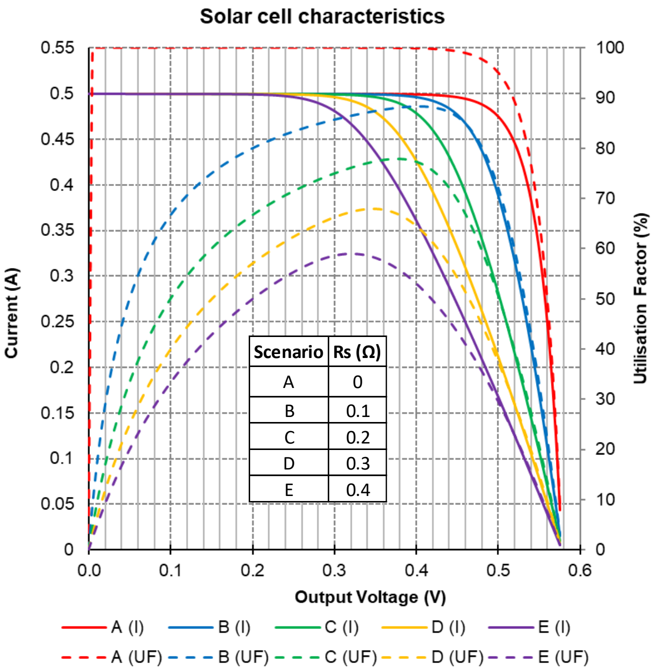

Figure 3: I-V and Utilisation Factor Curves

Utilisation Factor

A solar cell's Fill Factor (FF) is a performance metric, commonly referred to in many solar cell books, and is defined as the ratio of the maximum power point to the theoretical maximum power (product of open-circuit voltage and short-circuit current) and provides a baseline indication of the cell's efficiency at the maximum power point. However, the theoretical power does not represent the available power. This article introduces the UF metric defined in equation (1) as the ratio of the output power to the available power and provides an alternate measure of efficiency.

$$UF(\%) = \frac{v_o i_L}{v_d i_{ph}} \times 100 \ldots (1)$$

Note, for the case where R_s is zero, $v_d = v_o$ and UF reduces to the ratio of load current to photon current. The UF curve representing the scenario in Figure 2A is shown in Figure 3A. In this example the UF measured at the maximum power point is 94.98% and indicates that approximately 5% of the available power is required to bias the diode. The analysis is extended to include scenarios where R_s is varied, the results are shown in Figures 3B-3E. The UF measured at the maximum power point at other scenarios are 85.63% (B), 76.06% (C), 66.77% (D), and 58.18% (E). As expected,

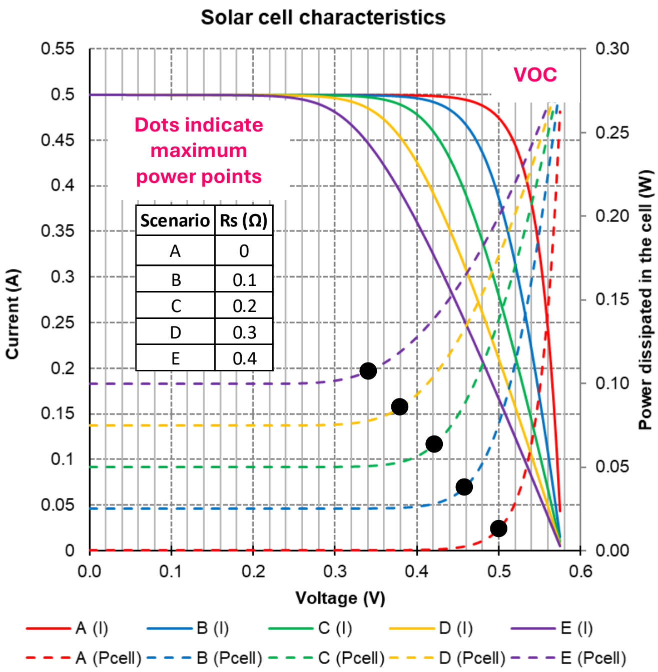

Figure 4: I-V and Power Dissipation Curves

power extraction from the cell reduces with increasing values of R_s as more available power is lost in heating R_s. All UF curves exhibit a zero when the output voltage is zero as no power is extracted.

The internal power dissipated by the cell is the sum of the power dissipated by the diode, R_{sh} (which is insignificant in this work), and R_s. Figure 4 shows the I-V curves together with the power dissipated by the cell for each scenario. With respect to the dissipated power the flat portion of the curves is dominated by R_s whilst at the knee point and beyond the dissipated power starts to rise quickly and is dominated by the power dissipated by the diode. As all scenarios tend towards their respective open circuit voltage (VOC), which are similar but not the same, all the available power is dissipated by the diode regardless of R_s. At the maximum power point the ratio of power dissipated by R_s and the diode is approximately 60%:40% for R_s equal to 0.1Ω and approximately 70%:30% for R_s values greater than 0.1Ω.

The dots in Figure 4 show the location of the maximum power point for each scenario and that the cell dissipates a constant minimum power for voltages less than the maximum voltage (voltage at the maximum power point). Operation above the maximum voltage will lead to higher power dissipation by the cell. The results highlight that a solar inverter with Maximum Power Point Tracking (MPPT) is crucial not only for extracting the most power from your PV panel but it also ensures the panel does not unnecessarily heat due to internal power dissipation.

Half Cut Solar Cells

Panels with half-cut solar cells contain twice as many cells but where each cell generates half the current of that of a full cell, and dissipates only 25% of the power of a full cell for the same values of R_s. This effect would be characterised with a downward shift of the power curves in Figure 4, tending towards zero.

Nominal Operating Cell Temperature

The Nominal Operating Cell Temperature (NOCT) is defined as the temperature reached by open circuited cells in a module with a sunlight irradiance of 800W/m^2, 20°C air temperature, 1m/s wind velocity, and is mounted with an open back side. The associated cell temperature is characterised by equation (2) [4]. The NOCT is a commonly adopted performance parameter and stated in many solar panel datasheets with a typical value of 45°C. Typical maximum operating temperature of a module is 85°C. These two datasheet values can be utilised together with equation (2) to estimate the maximum ambient temperature T_{air} for a given irradiance S, to ensure the panel does not overheat during open circuit condition.

$$T_{cell} = T_{air} + \frac{NOCT - 20°C}{800W/m^2} \times S \ldots (2)$$

References

[1] A. Parisi et al, "Thin Film CIGS Solar Cells, PV Modules, and the Problems of Modeling", International Journal of Photoenergy, Volume 2013.

[2] M. Boussaid, A. Belghachi, K. Agroui, M. Abdelaoui, M. Otmani, "Solar cell degradation under open circuit condition in out-doors-in desert region", Results in Physics, Vol. 6, September 2016, pp. 837-842.

[3] C. Lund, M. Sinclair, T. Pryor, P. Jennings, J. Cornish, "Degradation studies of A: SI: H solar cell modules under different loads in the field", Division of Science and Engineering, Murdoch University, South Street, Perth, Western Australia, 6150. Vol. 6, September 2016, pp. 837-842.

[4] J. W. Stultz, "Thermal and other tests of photovoltaic modules performed in natural sunlight", JPL document 5101-76, DOE/JPL1012-78/9, Jet Propulsion Laboratory, California Institute of Technology, Pasadena California, 31 July, 1978.