PhD Open Days

Discrete Model for Solar Photovoltaic Technology Analysis

Doctoral Program in Electrical and Computer Engineering (PDEEC)

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Introduction

Since the Industrial Revolution, energy needs have increased considerably. However, the use of energy from non-renewable sources, such as fossil fuels, is not only polluting, but is also a limited resource on Earth. Thus, there was a need for an energy transition to a cleaner and more renewable model, such as solar energy. In the XIX century, the photovoltaic effect was discovered and, since then, the development of solar cells has evolved into different photovoltaic generations. Electrical models are used to characterise the operation of electrical devices, such as solar cells. The main objective of these models is to characterise the devices as accurately as possible, such as the 1M3P/1M5P models, which use 3/5 parameters for this purpose. However, when the cell(s) are exposed to extreme conditions, such as high temperatures, these models fail to correctly represent the functioning of solar cells.

Methodology

The proposed model is called d1MxP because it is a discretisation of other more complex models (1MxP), such as the 1M5P shown in figure 1.
By analysing the figure and taking into account the working principle of the p-n junction, equation (1) defines the I-V characteristic curve of the solar cell.

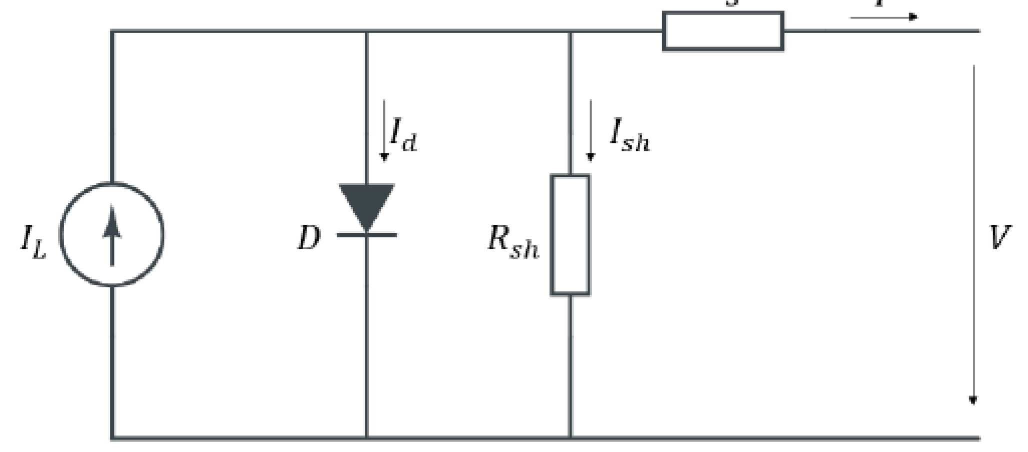

Figure 1: The 1M5P equivalent circuit model of a photovoltaic solar cell.

$$I = I_L - I_d - I_{sh} = I_L - I_o\left(e^{\frac{V+R_s I}{nV_T}} - 1\right) - \frac{V + R_s I}{R_{sh}} \qquad (1)$$

The variables R_s, R_{sh} , I_o, I_L and n in the equation above correspond to the parameters of the 1M5P model, which are obtained from (2) and (3).

$$\begin{cases} R_s = -\dfrac{1}{\frac{dI}{dV}|_{V=V_{OC}}} \\ R_{sh} = -\dfrac{1}{\frac{dI}{dV}|_{I=I_{SC}}} \\ I_o = \dfrac{I_{SC}\left(1+\frac{R_s}{R_{sh}}\right) - \frac{V_{OC}}{R_{sh}}}{e^{\frac{V_{OC}}{nV_T}}} \\ I_L = I_o\left(e^{\frac{V_{OC}}{nV_T}} - 1\right) + \dfrac{V_{OC}}{R_{sh}} \end{cases} \qquad (2)$$

$$n \rightarrow ln\left(I_{SC}\left(1+\frac{R_s}{R_{sh}}\right) - \frac{V_{mp}}{R_{sh}} - I_{mp}\left(1+\frac{R_s}{R_{sh}}\right)\right) = ln\left(I_{SC}\left(1+\frac{R_s}{R_{sh}}\right) - \frac{V_{OC}}{R_{sh}}\right) - \frac{V_{OC}}{nV_T} + \frac{V_{mp}+R_s I_{mp}}{nV_T}. \qquad (3)$$

The use of this classic model has several disadvantages, such as:

(i) the model's dependent variable (the output current) is dependent on itself, resulting in greater complexity in the analysis, which in many cases becomes limiting. The use of an iterative method, such as the Newton-Raphson method, is one of the alternatives;

(ii) the entire voltage range is characterised by a single equation and only a small number of points are used to adjust the entire voltage range.

The model presented proposes a solution to the disadvantages of the classic models by considering the performance of the solar cell between every two adjacent experimental points. Thus, the solar cell diode is decomposed into a set of adjustable parallel diodes in order to obtain greater precision in the range of voltages of the solar cell considered. The solar cell diode is broken down into an ideal diode in series with a resistor and an independent voltage source. The diode is switched on whenever its voltage is higher than the threshold voltage (V > V_γ). Whenever switched on, the branch collects current from the model's current source, and the slope of the I-V curve is proportional to -1/ R_γ . It is therefore possible to apply this analysis to the connection of every two adjacent experimental points, as illustrated in figure 2.

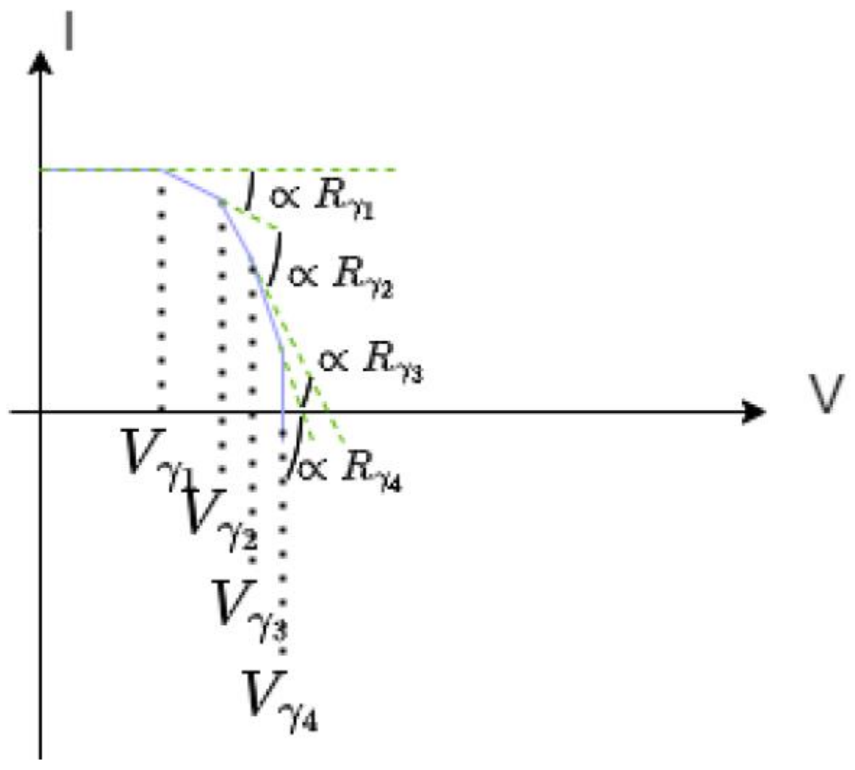

Figure 2: I-V curve for N branches in parallel.

The slope between each two experimental points depends on the resistance of the branch. On the other hand, the diode of the N branch can become responsible for activating the respective branch, considering the effect of all N-1 parallel branches previously activated. The resistance of the N branch is based on the previous slope and the desired slope m. Analytically, the system of equations (4) allows the characteristic parameters of the proposed discrete model to be obtained.

$$\begin{cases} V_\gamma = V_i \\ R_\gamma = -\dfrac{1 + m_i m_{i-1}}{m_i - m_{i-1}} \end{cases} \qquad (4)$$

Thus, the equivalent circuit is equivalent to adding weighted resistors in parallel in order to obtain a curve that fits the experimental data, as shown in figure 3.

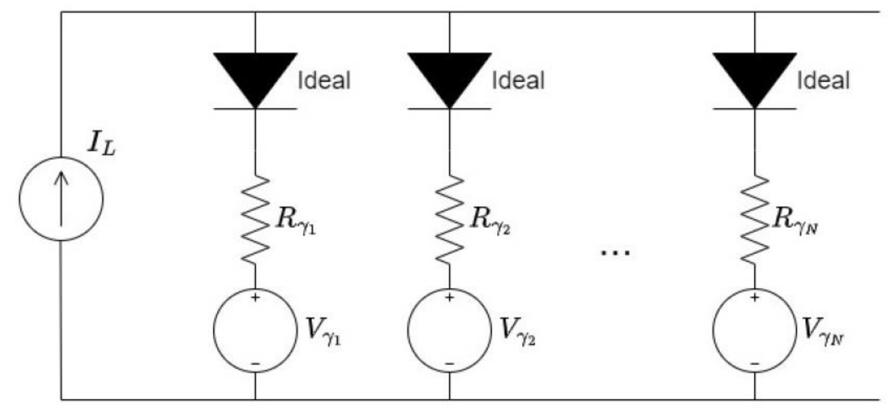

Figure 3: Proposed equivalent circuit d1MxP model.

The model, based on 1MxP models, assumes that the slope decreases as the load increases. Experimentally, this is not always the case, so the d1MxP model discards these points.

Model d1MxP

The d1MxP model was developed in MATLAB. The experimental I-V points were obtained using a monocrystalline silicon cell at an irradiance of 550 W/m2 and at different temperatures. Figure 4 shows that for all temperatures the d1MxP model curve fits the experimental data better.

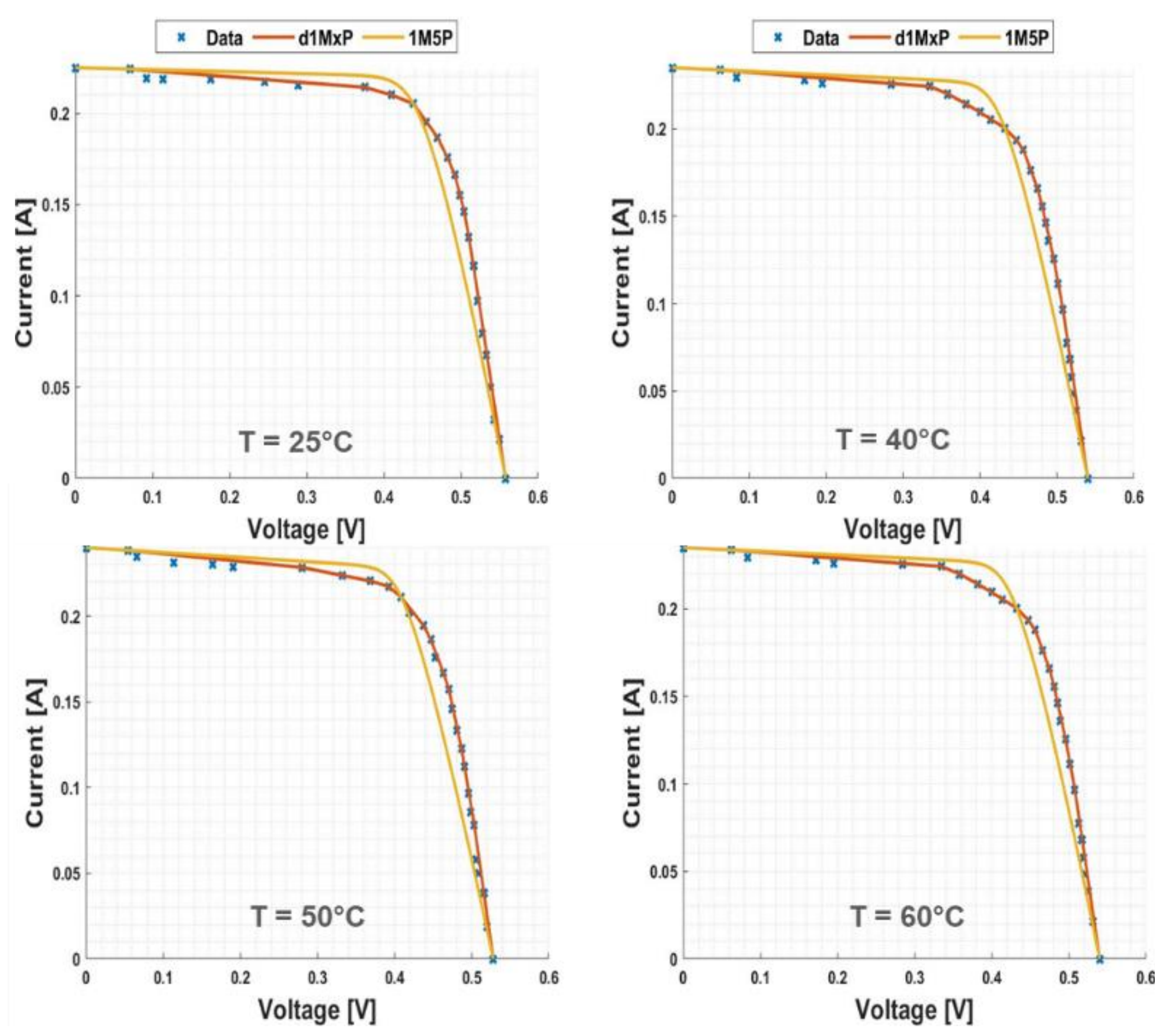

Figure 4: Comparison of the results of the different models.

- The d1MxP model is based on discretising the electrical functioning of diodes;
- The discrete model allows for excellent characterisation of solar cells.

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