Matlab-Simulink of Photovoltaic System Based on a Two-Diode Model

M. Azzouzi, *Member, IAENG, L. Mazzouz and D. Popescu*

***Abstract*—Our aims in this work are the modelling and the simulation of photovoltaic cell with two diodes. The study is based on the comparison between several models that characterize the photovoltaic cell. The electric characteristics will be determined, the impact of internal factor as the series and the shunt resistances and then the external factors such as the temperature and the radiation.**

***Index Terms*—Solar cell, modeling, solar energy, photovoltaic, I-V, P-V, two diodes**

I. Introduction

THE versions performance of a PV system depends heavily on weather conditions, such as solar radiation, temperature, wind speed and radiation. To provide energy continuously throughout the year, a PV system must be properly sized. However the information provided by the manufacturers of photovoltaic devices allows only sizing approximately the system [1].

Mathematical modeling of solar cells is essential for any operation of optimization of performances or diagnosis of PV generator. The photovoltaic module is generally represented by an equivalent circuit in which the parameters are calculated using the experimental current-voltage characteristic. These parameters are generally not measurable or included in the data production quantities. Consequently , they must be determined from the equations I-V systems at various operating points given by the manufacturer or from direct measurement on the module [2].

II. Modeling of two diodes solar cell

Modeling of the photovoltaic cell is considered as a crucial step and has led to a diversification in the proposed models by different researchers. Several models were encountered in the literature, whose the precision remain dependent on the mathematical modeling of various intrinsic physical phenomena involved in the process of electricity generation.

The two diodes model is widespread for interpreting dark and illuminated current-voltage characteristics of solar cell [3].

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A. Ideal model

The equivalent circuit of the ideal model of a two diodes PV cell is shown in Fig. 1, it is the simplest model which has five parameters: the saturation current of the first diode I_{s1}, the saturation current of the second diode I_{s2}, the ideality factor of the first diode m1, the ideality factor of the second diode m_2 and the photovoltaic current I_{pv} [4].

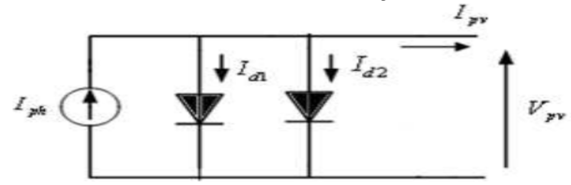

Fig. 1. Equivalent scheme of the 2M5P model

The characteristics equation is derived directly from Kirchhoff's law:

$$I_{pv} = I_{ph} - I_{d1} - I_{d2} \tag{1}$$

The first diode current is $I_{d1} = I_{s1}\left(e^{\frac{qV_{pv}}{m_1kT}} - 1\right)$ and the second diode current is $I_{d2} = I_{s2}\left(e^{\frac{qV_{pv}}{m_2kT}} - 1\right)$ so the output current is presented by the following non linear I-V equation:

$$I_{pv} = I_{ph} - I_{s1}\left(e^{\frac{qV_{pv}}{m_1kT}} - 1\right) - I_{s2}\left(e^{\frac{qV_{pv}}{m_2kT}} - 1\right) \tag{2}$$

For the same radiation and PN junction temperature conditions, the short circuit current Isc is the greatest value of the current generated by the cell and the open circuit voltage Voc is the greatest value of the voltage at the cell terminals [4][5]. They are given by:

$$I_{sc} = I_{pv} = I_{ph} \ for\ V_{pv} = 0 \tag{3}$$

B. Model with series resistance

The photovoltaic cell in this case is represented by the electrical circuit in Fig. 2. The number of parameters to be determined is 6 and the model can be called also 2M6P (Lumped, 2 mechanism model with six parameters) [6]. This circuit is achieved by parallel connection of two diodes with the two saturation currents I_{s1} and I_{s2}, two ideality factors n_1 and n_2 of the two diodes, a current source generating a photo-current I_{ph} which depends on the solar radiation and the series resistance Rs

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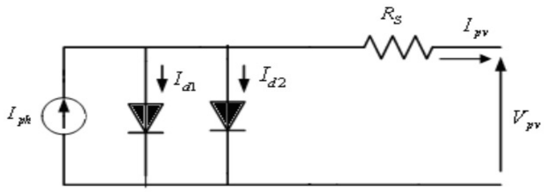

Fig. 2. Equivalent scheme of the 2M6P model

The Newton-Raphson method has been used and the output current is given by the equation:

$$I_{pv} = I_{ph} - I_{d1} - I_{d2} \quad (4)$$

The first diode current is $I_{d1} = I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right)$, and the second diode current is $I_{d2} = I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right)$ so the I-V characteristics of the solar cell with double diodes and series resistance are given by:

$$I_{pv} = I_{ph} - I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right) - I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right) \quad (5)$$

The output power is:

$$P = V_{pv}\left(I_{sc} - I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right) - I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right)\right) \quad (6)$$

C. Model with series and shunt resistances

It is also known by the name 2M7P (Lumped, 2 Mechanism model with 7 Parameters). The operation of a solar cell can be modeled by considering the equivalent circuit in Fig. 3. This circuit is realized by the parallel connection of two diodes having the saturation currents I_{s1} and I_{s2}, the diode factors n_1 and n_2, a current source generating a photocurrent I_{ph} which depends on the solar radiation [4], the series resistance R_s, and the parallel resistance R_{sh}.

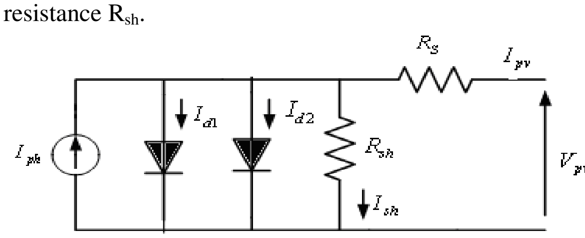

Fig. 3. Equivalent scheme of the 2M7P model

The Newton-Raphson method has been used and the output current is given by the equation:

$$I_{pv} = I_{ph} - I_{d1} - I_{d2} - I_{sh} \quad (7)$$

The first diode current is $I_{d1} = I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right)$, and the second diode current is $I_{d2} = I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right)$ and the shunt current is $I_{sh} = \frac{V_{pv} + R_s I_{pv}}{R_{sh}}$, so the I-V characteristics of the solar cell with double diodes and series resistance are given by:

$$I_{pv} = I_{ph} - I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right) - I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right) - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \quad (8)$$

The output power is:

$$I_{pv} = V_{pv}\left(I_{sc} - I_{s1}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_1 kT}} - 1\right) - I_{s2}\left(e^{\frac{q(V_{pv}+R_s I_{pv})}{m_2 kT}} - 1\right) - \frac{V_{pv} + R_s I_{pv}}{R_{sh}}\right) \quad (9)$$

III. Influence of Temperature and Radiation

The radiation is maintained constant at 1000W/m^2 and the temperature is variable (25°C, 50°C, 75°C, 100°C). Fig. 4 shows the simulation results of I-V and P-V characteristics respectively under the same conditions. For all the three models, the current generated by the incident light is going to stay constant although it increases slightly while the voltage decreases. The power increases when the voltage increases [7].

Fig. 5 shows the electrical characteristic for several values of solar radiation which varies between 250 W/m² and 1000 W/m² and for a constant temperature that equals to 25 °C, where we can remark that the current and the power are increased when the radiation is high, but the short circuit current is variable as well as the open circuit voltage [7] [9].

The influence of the ambient radiation and the cell temperature on the cell characteristics is presented in Fig. 6. This figure shows in which sense the increase of the radiation and the cell temperature, respectively, increase the current and then the power [8] [11].

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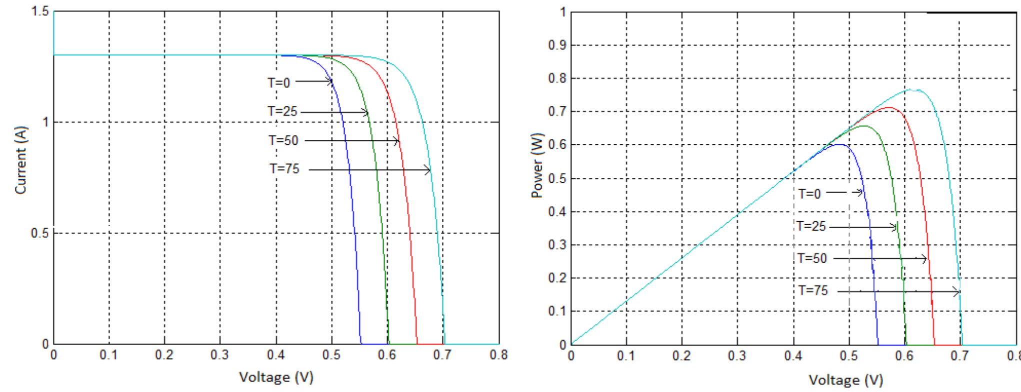

Fig.4. Influence of temperature

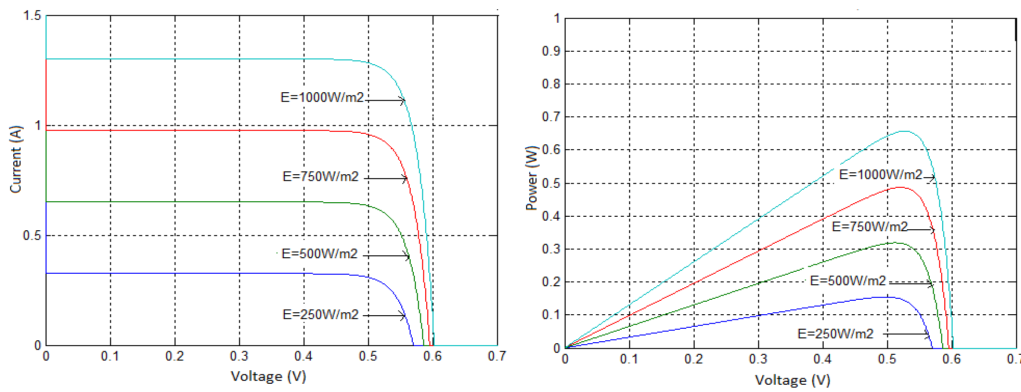

Fig. 5. Influence of radiation

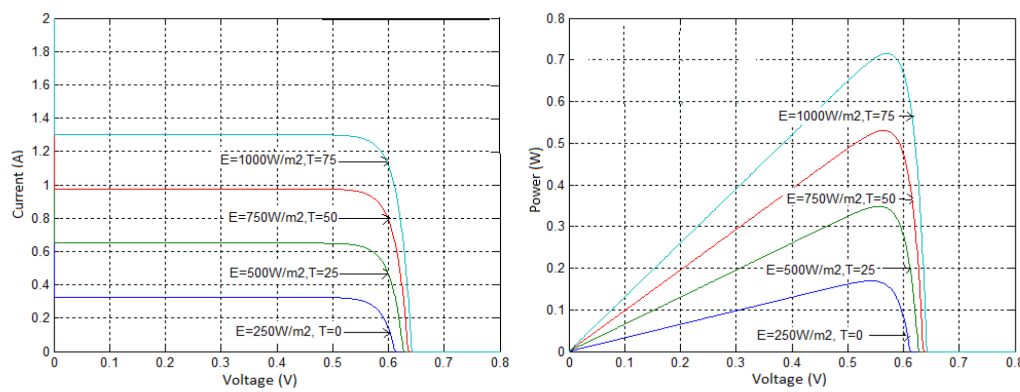

Fig.6. Influence of temperature and radiation

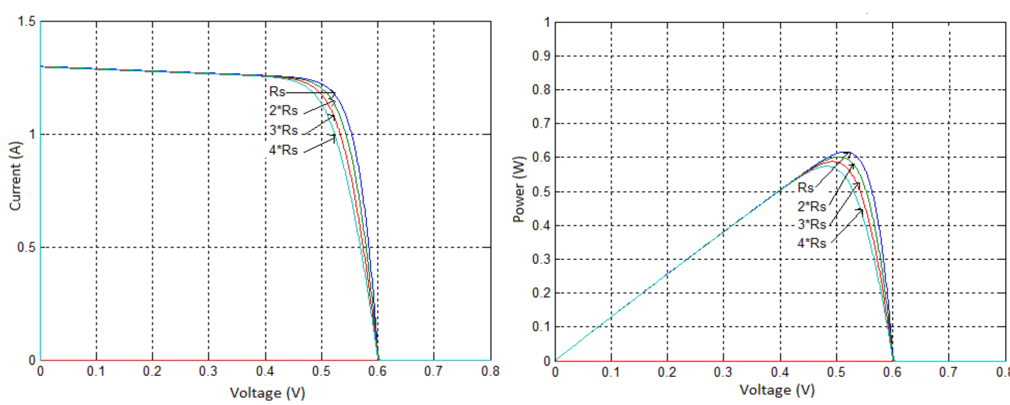

Fig. 7. Influence of series resistance

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IV. Influence of the Radiation and Series Resistance

The series resistance of the PV cell is low, and in some cases, it can be neglected. However, to render the model suitable for any given PV cell, it is possible to vary this resistance and predict the influence of its variation on the PV cell outputs. As seen in Fig. 7, the variation of *Rs* affects the slope angle of the *I-V* curves resulting in a deviation of the maximum power point [10].

The simultaneous influence of radiation and series resistance is shown in Fig. 8. Both the current and the power are increased in function of the radiation and the series resistance. The short circuit current and the open circuit voltage are also increased.

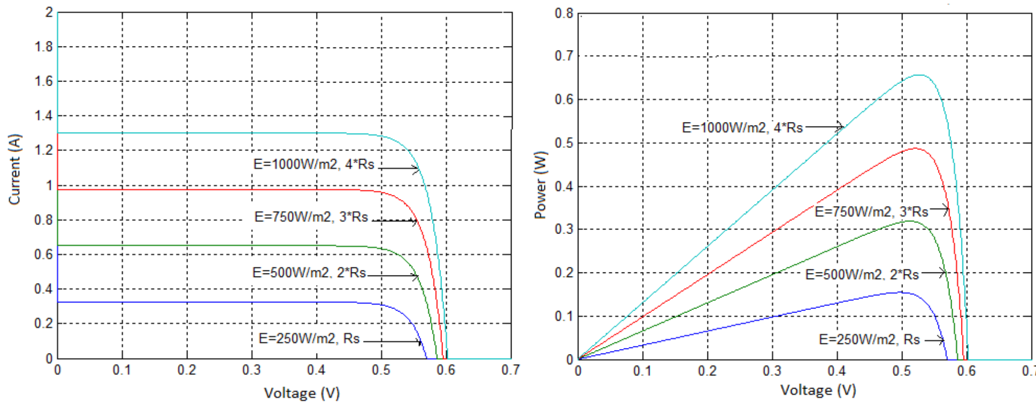

Fig. 8. Influence of the radiation and series resistance

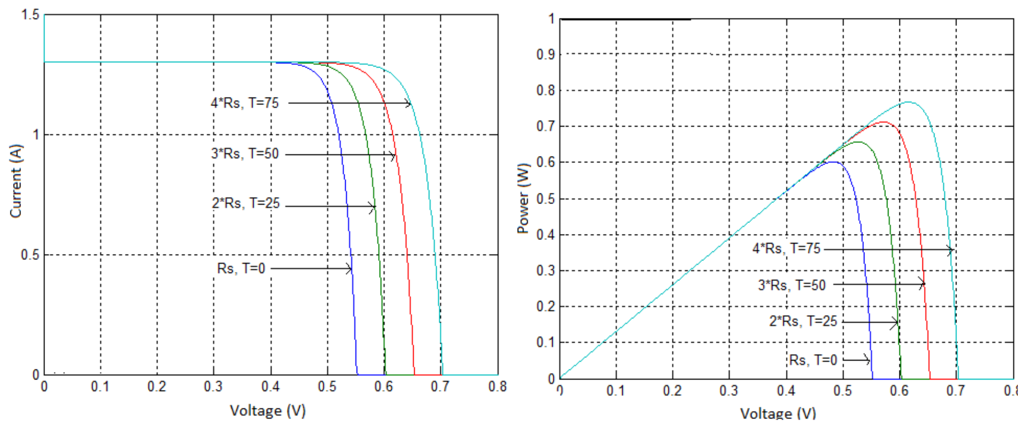

Fig. 9. Influence of the temperature and series resistance

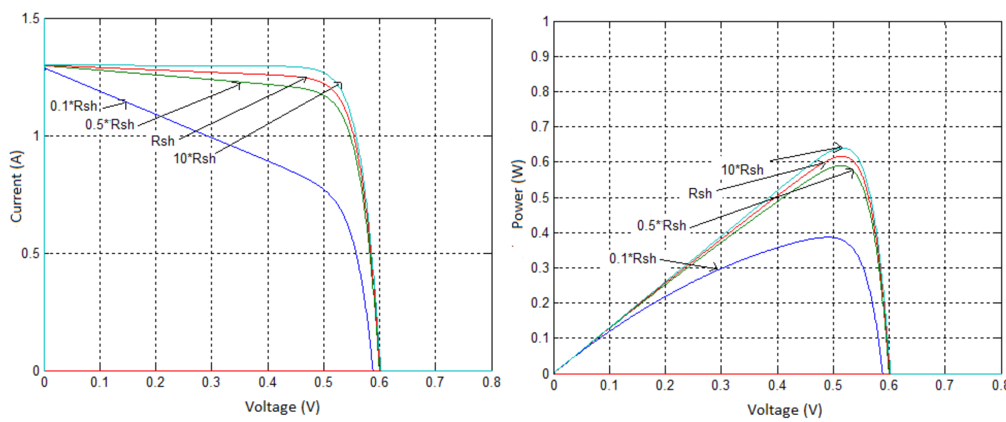

Fig. 10. Influence of shunt resistance

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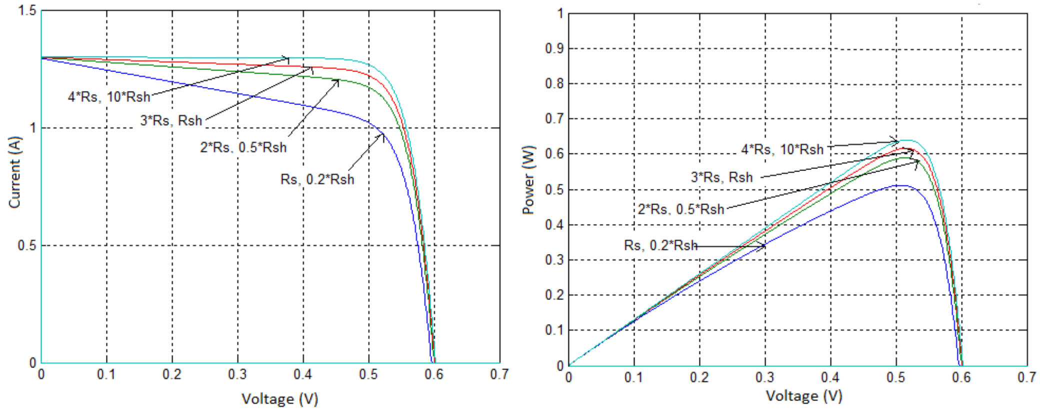

Fig. 11. Influence of series and shunt resistances

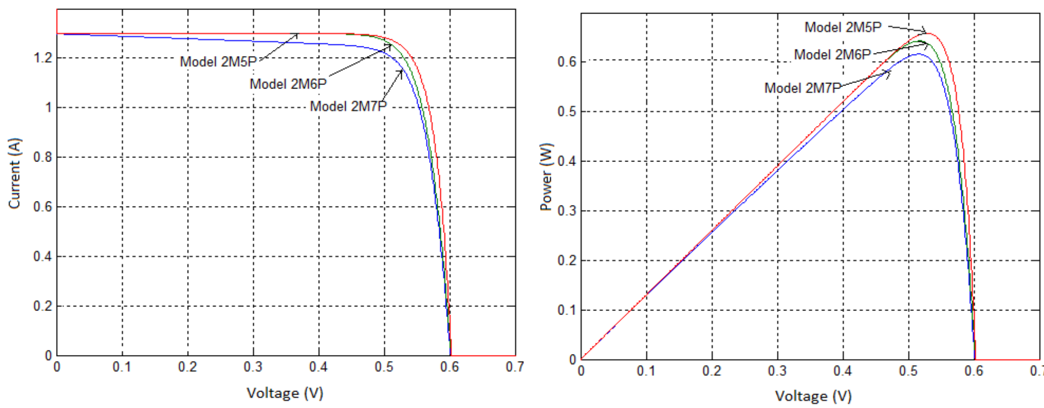

Fig. 12. Comparison between the I-V and P-V characteristics of the three models

V. Influence of the Temperature and Series Resistance

Fig. 9 shows that the open circuit voltage increase logarithmically with the ambient irradiation while the short circuit current is a linear function of the ambient irradiation

VI. Influence of Series and Shunt Resistances

The shunt resistance of any PV cell should be large enough for higher output power and fill factor. In fact, for a low shunt resistor, the PV cell current collapses more steeply which means higher power loss and lower fill factor. These results can be seen in Fig.10 [10].

Fig. 11 shows the influence of the two resistors series and parallel at the same time, where it can be concluded that the effect of the series resistance is negligible, relative to the shunt resistance. A minimization of the value of the shunt resistance induces an estrangement from the real operation of the cell.

VII. Comparison Between the Three Models

To make a comparison between the models of a double diodes PV cell, the same reference conditions were selected for each model, the performance of the solar cell is normally measured in standard test conditions (STC), the illumination is normalized to 1000W/m², and the temperature is equal to 25 °C. The results are illustrated in Fig. 12 and shows that the model 2M5P has maximum power, has maximum power, but the short circuit current and the open circuit voltage are the same for the three models.

VIII. Conclusion

Three models of two diodes PV cell were presented in this paper. The parameters are chosen the same for all these models of PV cell. A Matlab program were developed to presents each model with different effects on the voltage-current and power-voltage characteristics such that the influence of radiation, temperature, series resistance and resistance shunt. In order to compare the obtained results we obtained that the model is the performed one because it is closed to the real operation of the two diode PV cell.

Appendix

PV : photovoltaic
I-V: current-voltage
P-V: power-voltage
2M5P : two mechanisms, five parameters
2M6P : two mechanisms, six parameters
2M7P : two mechanisms, seven parameters
I_{ph}[A] : the current generated by the incident light
I_{s1} [A] : the first diode reverse bias saturation current
I_{s2} [A] : the second diode reverse bias saturation current
I_{sh} [A] : the shunt resistance current
I_{sc}[A] :short circuit current
I_{pv}[A] : the output current
V_{pv}[V] : the terminal voltage

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V_{ph}[V] :the photovoltaic voltage
I_{d1}[A] : the first diode current
I_{d2}[A] : the second diode current
V_{oc} [V] : open circuit voltage
q : the electron charge [1.60217646 $*10^{-19}$C]
k : the Boltzmann constant [1.3806503$*10^{-23}$J/K]
T [K] : the temperature of the PN junction
E[W/m^2] : the radiation
R_s[Ω]: series resistance
R_{sh}[Ω]: shunt resistance
m1: the ideality factor of the first diode
m2: the ideality factor of the second diode

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