PV Cell simulation with QUCS

A generic model of PV Cell

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***Abstract*— This paper shows a circuit to emulate the operation of a photovoltaic (PV) cell. The values of equation is based on data sheet in the Standard Condition Measurement (SCM), this model allows emulate PV cell, including effects due to variations of irradiance receiver and temperature of cell. The generic model is the same for all types of PV cells, only can used the same equations including variable depends of Data sheet information and external conditions. Finally, it shows a simulation using free software Quite Universal Circuit Simulation (QUCS).**

***Keywords*— *simulation, cell, photovoltaic, modeling, QUCS, software, training*.**

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1.- INTRODUCTION

In this paper show results of the study to selection a models of photovoltaic cell, only based of information included on data sheet in *SCM* for a commercial PV cell. The equivalent circuits that show on section II include the relation between electronic component and curve IV of PV cell. After on section III is shown the idea of a generic model and on section IV is included a simulation using an electronic simulator.

On a previous work is used mathematical applications (for example: MATLAB/Simulink on [1] [2]), other study used circuit simulator with a proprietary licence (for example: ORCAD on [3]). In this work, is used for checks model a software with a General Public Licence (GPL), the application selected is QUCS [4] (http://qucs.sourceforge.net/)), which lets select a generic diode to adjust parameters to current conditions of PV cell, and include equations and graphics to study the characteristic curves of PV cell. QUCS is a multiplatform application that runs on Windows and Linux, and can be used for specific distributions on the field of electronics, which have all pre-installed applications.

The PV model can be used to build a model for PV module, because a PV module is a set of cells connected in series and parallel.

The equivalent circuits used to simulate a PV cell are: single diode, dual diode, single diode without parallel resistor and single diode without resistor. The most popular are single diode, although dual diode has more accuracy, the dual diode is more complex than single diode, and result of work show that the single diode has a good accuracy. Therefore model of PV Cell selected is a single diode show in Fig. 1.

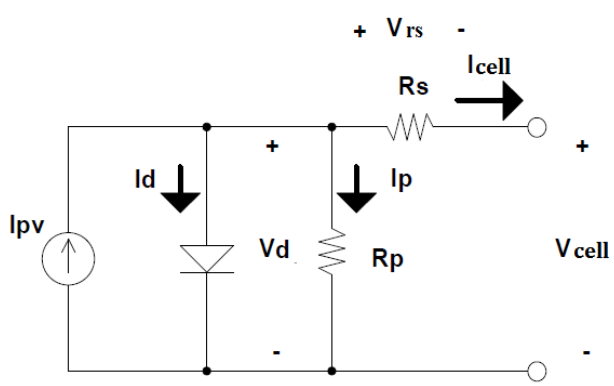


Fig. 1.- Photovoltaic solar cell model with parallel and serie resistance.

2.- EQUIVALENT CIRCUIT AND EQUATIONS FOR ELECTRONIC APPLICATION

The equivalent circuit shows in Fig. 1 is formed by a current source in parallel with a diode and includes two resistors for real effects of a photovoltaic cell. The configuration of electronic components is used to adjust the curve *IV* (Fig. 2) of *PV* cell: *Ipv* change current short circuit (*Isc*), *Id* change voltage open circuit (*Voc*) and *Rs* change maxim power point (*Pm*). Also *Id* affect to fill factor (*FF*) and include exponential effects. The equivalent circuit needs a high parallel resistor (*Rp*) to avoid convergence problem in simulation.

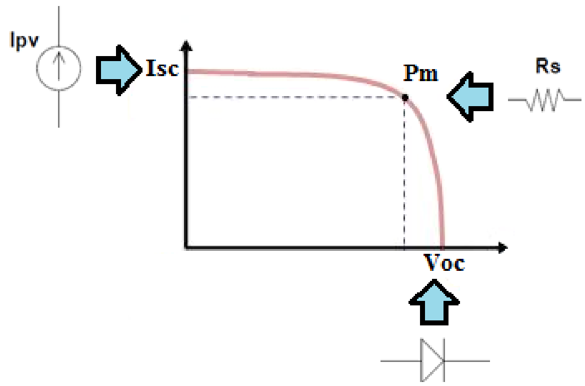


Figure 2.- Efect value circuit and curve I-V.

The parameters that define model in circuit of Fig. 1, must use data sheet information with values in standard conditions of measurement (*SCM*): *Voc*, *Isc*, *Pm*, temperature coefficient variation to *Voc* (β) and temperature coefficient variation to *Isc* (α). In Eq. 1 shows the intensity value generated by the photovoltaic cell, [6]: *I* is output current of photovoltaic cell, *V* is output voltage of photovoltaic cell, *Ipv* is the photogenerated current, *Is* is the saturation current of diode, *Rs* is series resistance due to the junction between the semiconductor and the metal contacts (interconnects), *Rp* is parallel resistance due to no linearity of union *PN*, *m* is ideal factor of diode and *Vt* is thermovoltage.

$$i_D = I_S\left(e^{v_D/nV_T} - 1\right)$$

$$C_D = \frac{\tau_T}{V_T} I_S e^{v_D/nV_T} + \frac{C_{jo}}{\left(1 - \frac{v_D}{V_o}\right)^m}$$

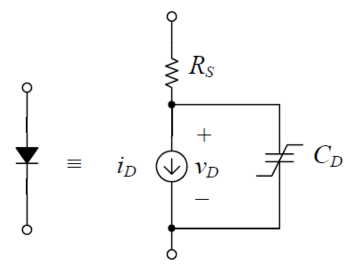


Fig. 3.- Pspice model of the diode

$$\mathrm{Icell} = \mathrm{Ipv} - \mathrm{Is}\left[e^{\left(\frac{(V+I\cdot Rs)}{m\,Vt}\right)} - 1\right] - \left[\frac{V + I\cdot Rs}{Rp}\right] \quad (1)$$

$$\mathrm{Icell} = \mathrm{Ipv} - \mathrm{Id} \quad (2)$$

$$\mathrm{Vcell} = \mathrm{Vd} - \mathrm{Vrs} \quad (3)$$

Comparing the second term of Eq. 1 and diode model [7] show in Fig. 3, and considering high value of *Rp* (for example 100kΩ) can simplified Eq. 1 delete third term, the results show in Eq. 2 to current generate by PV Cell. Output voltage of PV Cell is diode voltage less voltage drop on *Rs* (*Vrs*), which show in Eq. 3.

The value of *Id* in Eq. 2, is obtain using equation of pspice model in diode for variable i_D (fig.3), and is simplify adjust parameter diode *Rs* and *Cjo* to 0Ω and 0F, respectively (fig. 3).

Furthermore, PV Cells are a nonlinear device, because current and voltage output are depends of irradiations and temperature. Therefore around the day the output of PV Cell changes. The irradiations affect principally to *Isc*, show as in Eq. 4, where: *G* is irradiation in W/m² (external condition), *Isc_smc* is short current in *SCM* (value on data sheet) and *Tc* is temperature in ºC of cell (external condition. The temperature affects the values of *Isc*, *Voc* and *Pm*, show as in Eq. 5 to obtain Is for diode parameter, where: *Voc_smc* is voltage open circuit in *SMC* (value on data sheet) and *Tc* is temperature in ºC of cell (external condition). Then, Eq. 4 is obtained using approximation of Luque-Sala and Duffie & Beckman, besides empirical tests simulation to study the effects of temperature on Is to get Eq. 5 based on the approximation Duffie&Beckman. Value for *Rs* show in Eq. 6 and is base on empirical relationship between the value of *Voc_smc* and *Isc_smc* with *Rs*, [10]. This approach only use when *Rp* is high, therefore maximum power point depends of R_S value, and then is included variable for maximum power in *SMC* (*Pm_smc*). It shows all references in [5].

$$Ipv = \frac{Isc\_smc \cdot G \cdot \left(1 + \alpha \cdot (Tc - 25)\right)}{1000} \quad (4)$$

$$Is = \frac{Ipv}{\left(e^{\left(\left(Voc\_cem + \beta \cdot (Tc-25)\right) / 0.0257\right)} - 1\right)} \quad (5)$$

$$Rs = \left(\frac{Voc\_smc}{Isc\_smc} - \frac{Pm\_smc \cdot \left(\frac{Voc\_smc}{0.0257} + 1\right)}{(Isc\_smc)^2 \cdot \left(\frac{Voc\_smc}{0.0257} - \ln\left(\frac{Voc\_smc + 0,0185}{0.0257}\right)\right)}\right) \quad (6)$$

3.- BLOCK DIAGRAM OF GENERIC MODEL

Using equations and circuit describe in section II, the inputs parameter are: irradiation and temperature, and the output are: value of voltage and current depends circuit connect (curve *I-V*). Other parameters values obtains from data sheet in *SMC*: *Voc_smc*, *Isc_smc*, *Pm_smc*, α and β. Therefore, these parameter is used to modeled the PV cell.

You can be use a generic model or a particular model for PV Cell, if have a generic model should include all parameter as input variable but use a particular model should include data sheet parameter once and only include as input the irradiance and the temperature. Blocks diagram of the system is showed in Fig. 4.

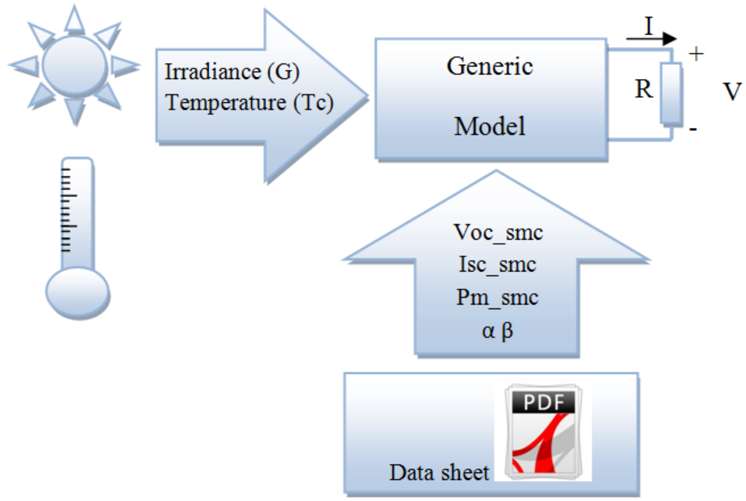


Fig. 4.- Block diagram for design model.

An example for use a generic model is create a library in a electronic application that included a generic model and a particular model, this model can be used in a design for regulator circuits or study photovoltaic characteristics of a standalone system.

4.- EXAMPLE MODEL USING QUCS

The schematic circuit used at QUCS, it shows in Fig. 5, with parameter needs for calculate based on equation used in section 2. For simulation needs parameter for data sheet for PV Cell, in Table 1 show electrical parameter to PV cell for module of Isofoton I-106, for more information you can see [6].

Parameters	Value
Maximum Power module (Pm)	106 W
Short current circuit module (Isc)	6,54 A
Voltage open circuit module (Voc)	21,6 V
Temperature coefficient of Isc (α)	0,042 %/^{o}C
Temperature coefficient of Voc (β)	-0,328 %/^{o}C
Series cell	36
Parallel cell	2
Short current circuit cell	3,27 A
Voltage open circuit cell	0,6 V

Table 1.-Electrical parameter of cell Isofoton I-106/12

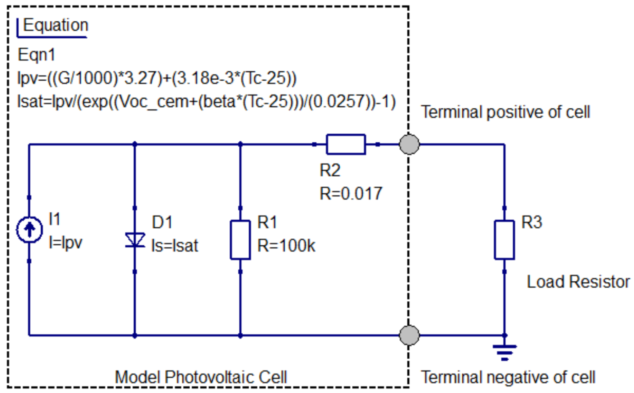


Fig. 5.- Model PV Cell for commercial cell in Qucs.

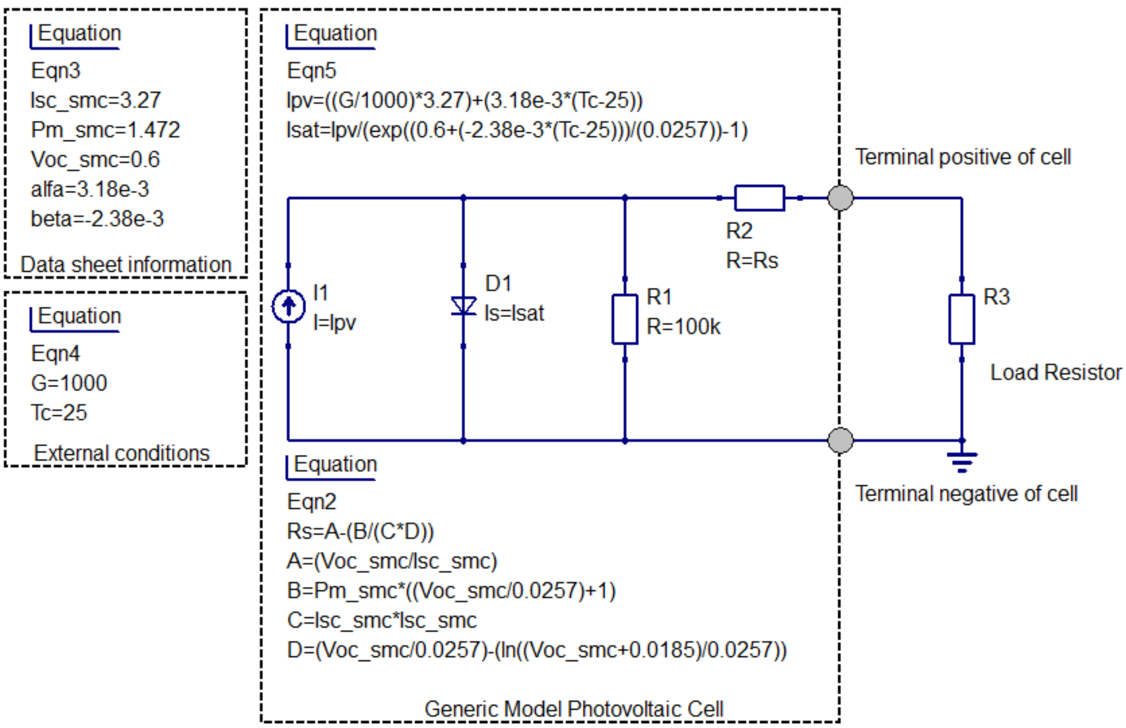
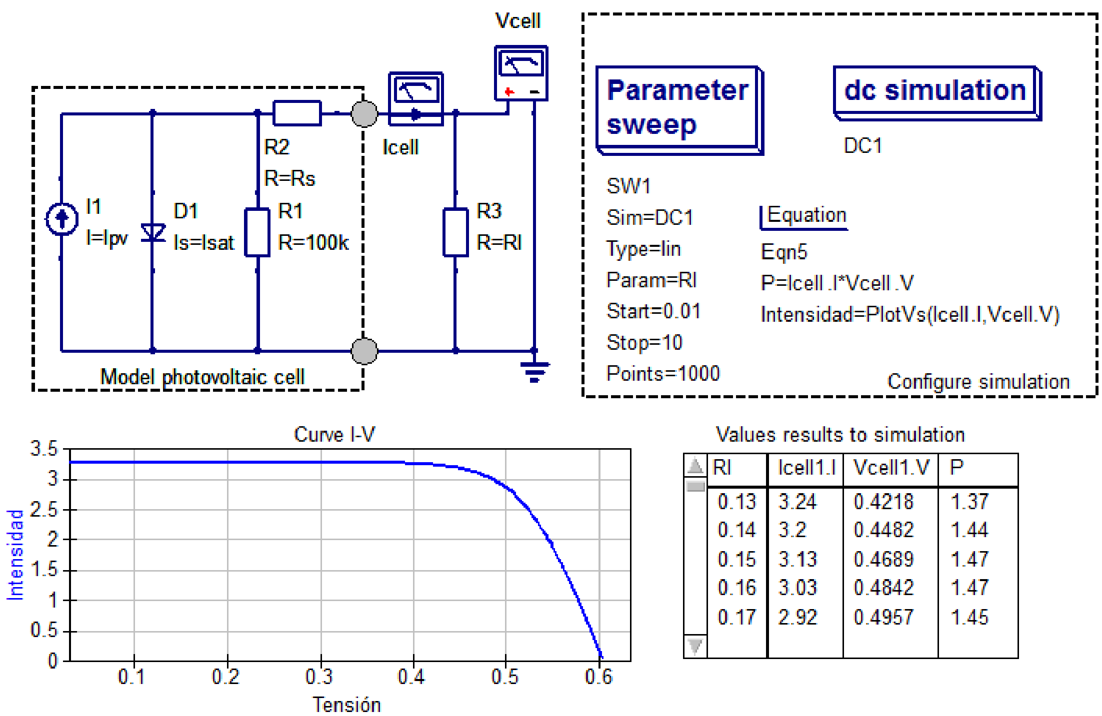


Fig. 6.- Generic Model PV Cell in Qucs.

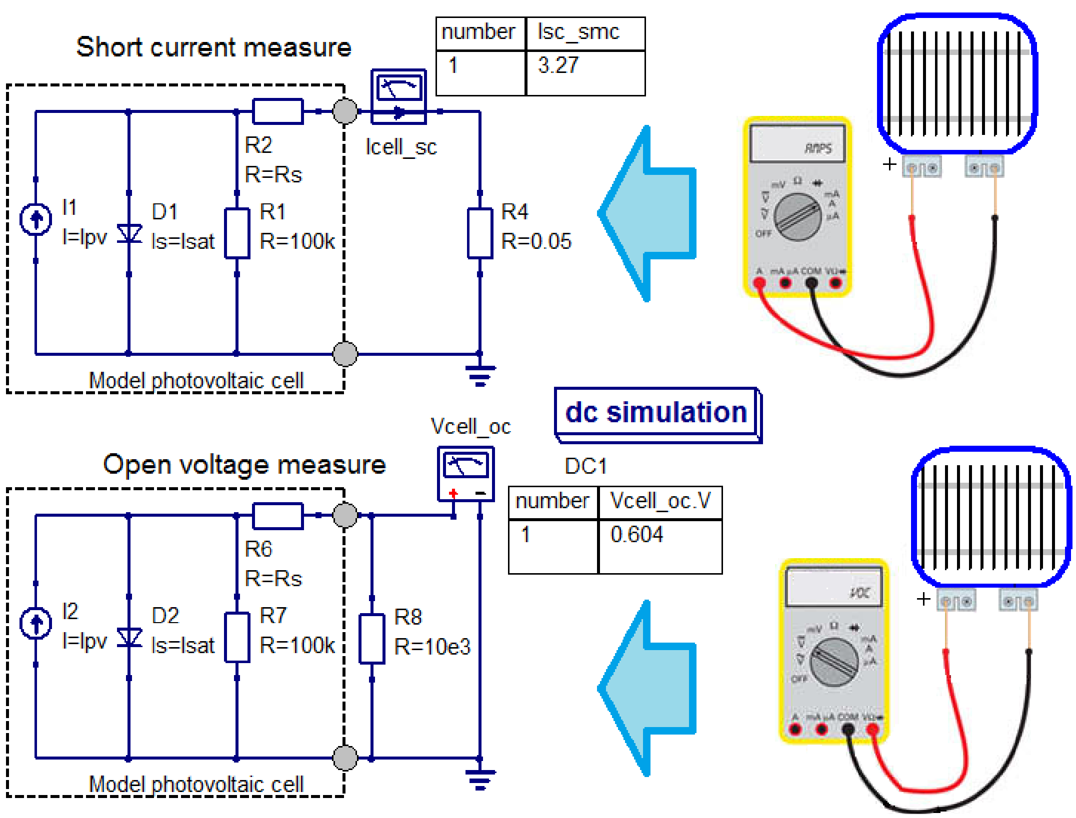
QUCS advantages are use equations to define value, for examples in Fig. 5 include variable *Ipv* and *Is* (*Isat*) used in Eq. 5.

The generic model that shows in Fig. 6, where it is modeled various PV cells changing parameters on Data sheet information Block, using Equation Eqn3. Also, for external condition of Irradiance and temperature are change on External condition Block, using Equation Eqn4. The advantage, it include on the same page the schematic circuit and the simulation results, you can see [7].



Rl	Icell1.I	Vcell1.V	P
0.13	3.24	0.4218	1.37
0.14	3.2	0.4482	1.44
0.15	3.13	0.4689	1.47
0.16	3.03	0.4842	1.47
0.17	2.92	0.4957	1.45

Fig. 7.- Schematic circuit to measurement to obtain curve I-V.



number	Isc_smc
1	3.27

number	Vcell_oc.V
1	0.604

Fig. 8.- Schematic circuit to measurement voltage open circuit an short circuit current.

In Fig. 7 shows a circuit used to measurement characteristic of PV Cell and parameter for simulation with results in table and graph, the table used to obtain maximum point because include all values calculation to simulation and graph to represent curve IV, also include configuration of simulation using components: dc simulation and parameter sweep, last used to modify value to load resistor R3 from 0.01Ω to 10Ω.

In figure 8 show circuit to measure short current and open voltage, the results show in a table, last measure are similar to reality using a multimeter instrument.

5.- MODEL COMPARISON

The result of simulation for model propose in *QUCS* (*Isc_qucs*, *Voc_qucs* y *Pm_qucs*) is compare with a value calculated (*Isc_cal*, *Voc_cal* y *Pm_cal*) in Table 2. For calculates values used information on data sheet on *SMC* and variation of temperature coefficient, does not included effects on temperature of *Isc* because are less significative. First column on Table 2 indicate values of external condition, changing values of irradiance (*G*) and cell temperature (*Tc*). After to compare results of Table 2, indicates that model of *PV* Cell is good accurate.

Condition	Isc_cal	Isc_qucs	Voc_cal	Voc_qucs	Pm_cal	Pm_qucs
1000 W/m^2 y 25^OC	3,27 A	3.27 A	600 mV	604 mV	1,470 W	1,468 W
1000 W/m^2 y 74^OC	3,27 A	3,43 A	488 mV	486 mV	1,219 W	1,156 W
750 W/m^2 y 35^OC	2,45 A	2,48 A	576 mV	580 mV	1,063 W	1,091 W
750 W/m^2 y 65^OC	2,45 A	2,58 A	507 mV	508 mV	0,947 W	0,954 W

Table 2.- Measurement and comparison

In figure 9 include graph of curve I-V for 3 values of irradiation (1000, 800 and 400 W/m^2) at the same value of cell temperature (25ºC).

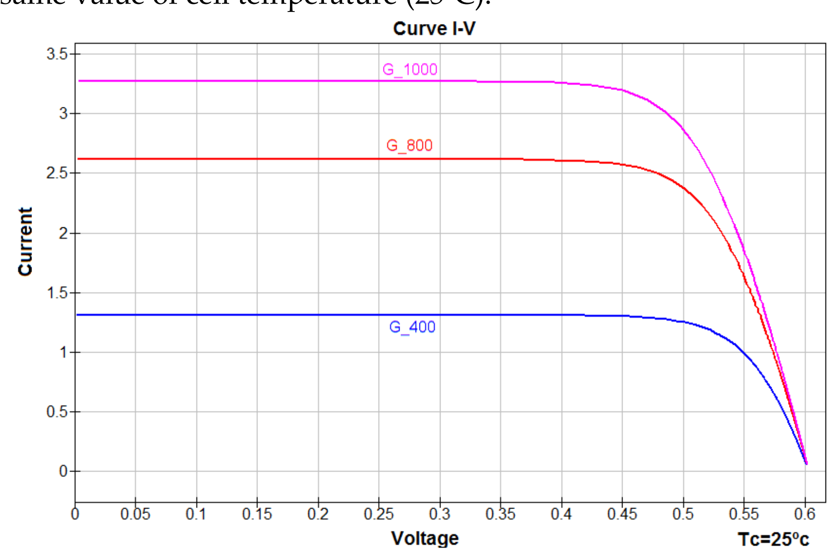


Fig. 9.- Result simulation in QUCS in curve I-V to the variation irradiance

In figure 10 include graph of curve I-V for 3 values of cell temperature (75, 25 and 5ºC) at the same value of irradiance (1000W/m^2).

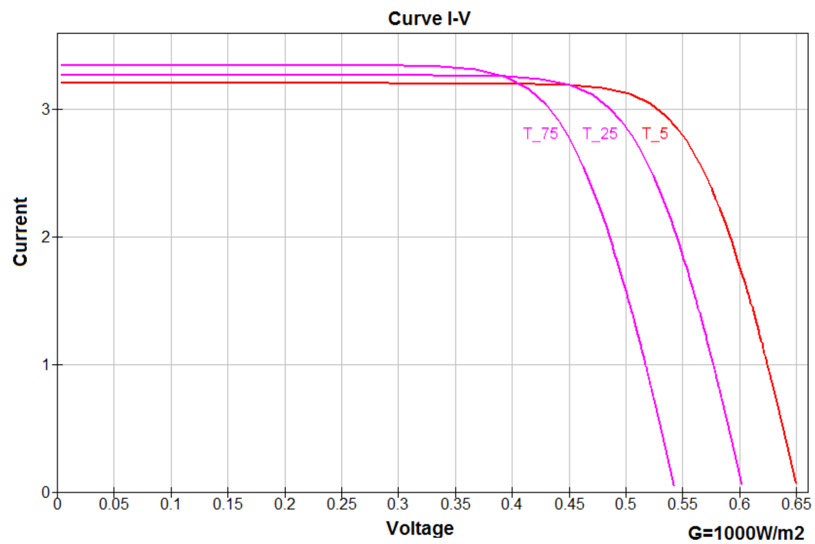


Fig. 10.- Result simulation in QUCS in curve I-V to the variation cell temperature

6.- SUBCIRCUIT FOR A GENERIC MODEL

Other advantage to use QUCS, it create a subcircuit for a best presentation. And it is used input parameters to model the PV cell. An example it shows on figure 11.

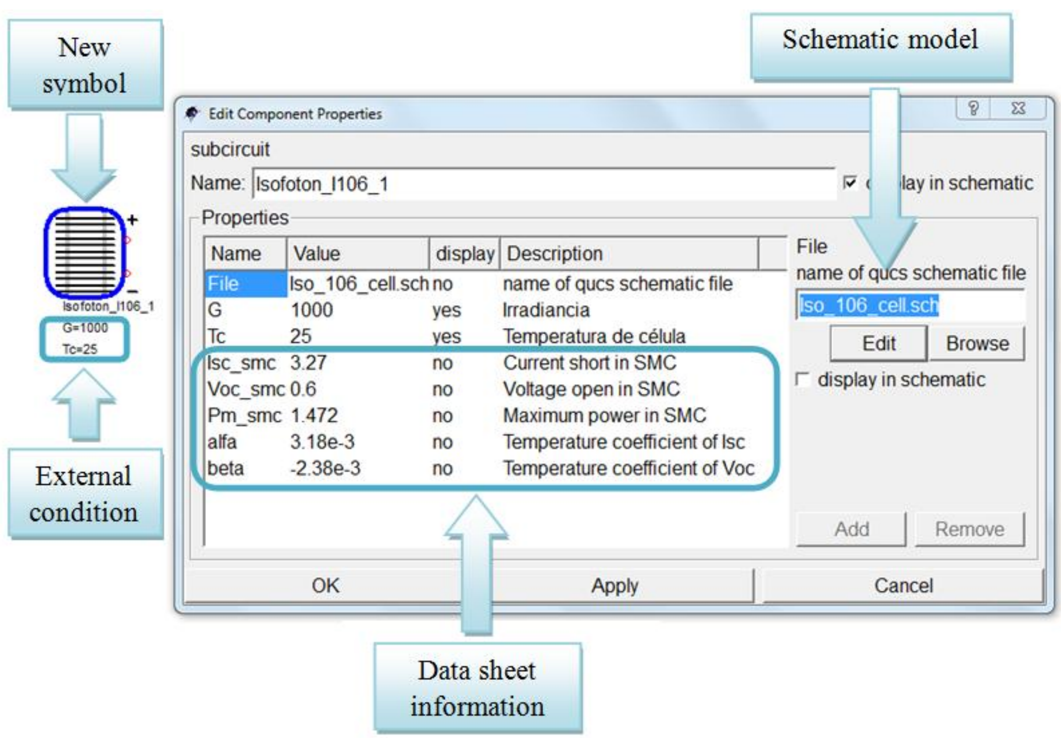
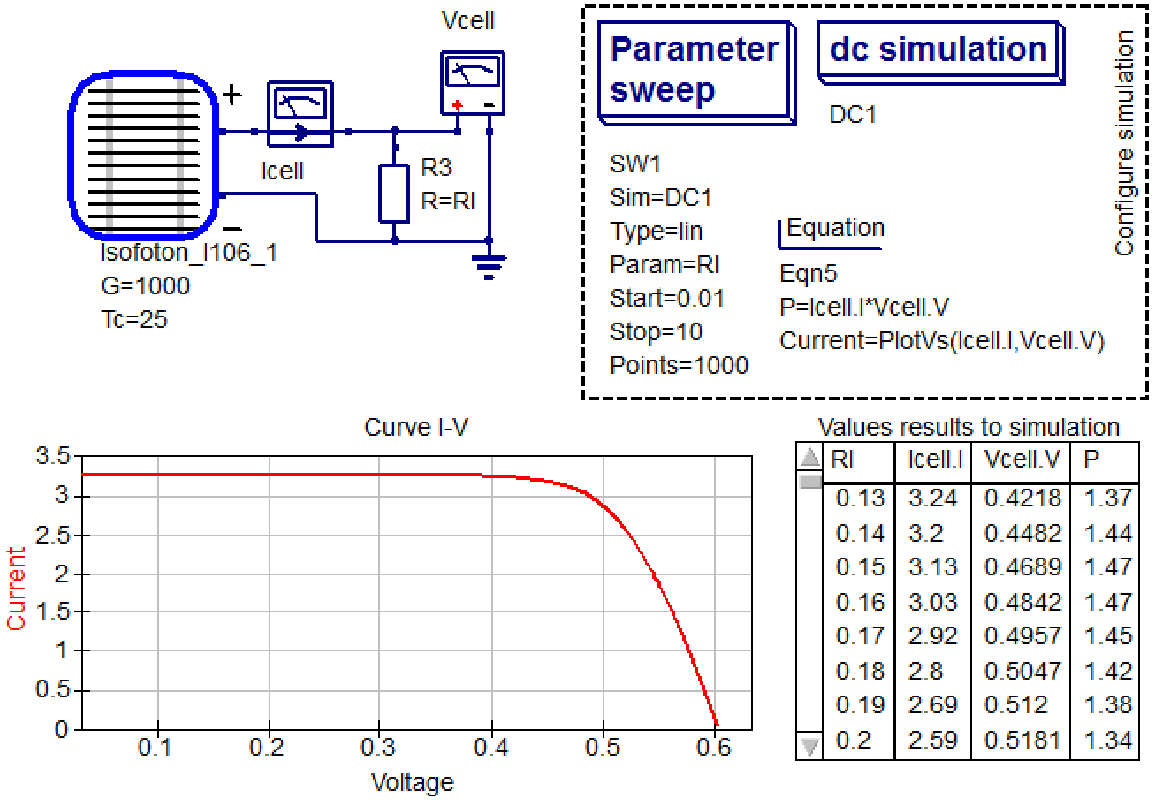


Fig. 11.- Subcircuit for a generic model

In figure 12 are shows the circuit used to check the model.



RI	Icell.I	Vcell.V	P
0.13	3.24	0.4218	1.37
0.14	3.2	0.4482	1.44
0.15	3.13	0.4689	1.47
0.16	3.03	0.4842	1.47
0.17	2.92	0.4957	1.45
0.18	2.8	0.5047	1.42
0.19	2.69	0.512	1.38
0.2	2.59	0.5181	1.34

Fig. 12.- *Schematic circuit with subcircuit model to measurement to obtain curve I-V.*

7.- FILES DESCRIPTION OF PROJECT

All files that you need, you can found it on: PVCELL_IN_QUCS_prj.

The files description is:

- "Equivalent_Circuit.sch": it includes an electronic circuit to model a PV cell, this circuit shown in figure 5.
- "Equivalent_Circuit_Generic.sch": it is added equations for a generic model, this circuit shown in figure 6.
- "Tester_Generic_Model.sch": it includes simulation components to obtain curve I-V, this circuit shown in figure 7.
- "Tester2_Generic_Model.sch": it includes simulation components to obtain voltage open and short current, this circuit shown in figure 8.

- "Tester3_Generic_Model.sch": it includes simulation components to obtain various curves I-V with different values of: irradiation or cell temperature, the results is shown in figure 9 and 10.
- "Iso_106_cell.sch": this schematic is used to create a subcircuit and a new symbol, this subcircuit is shown in figure 11.
- "Iso_106_cell_Tester.sch": this schematic used a subcircuit with a new symbol, it made for check the subcircuit of photovoltaic cell. It is shown in figure 11 and 12, first the form to include characteristics and second the circuit to check model.

8.- CONCLUSION

In this paper show a circuit used for modeling photovoltaic cells and as extract all parameter to electronic circuit. Shows all equations needs to obtain values to data sheet of manufacture to particular photovoltaic cell or used equation to build a generic model. After is reviewed model using free software QUCS and compare results of other simulation to check model.

One advantage using *QUCS* application is that by changing variable of photovoltaic cell using equation component (block data sheet information in Fig. 6) to modeled other cells. Other advantage is show results in graphs and tables on the same page of circuit for used to educational applications or in design circuits.

Also, change values of irradiance and temperature of PV cell model to obtain output PV Cell (voltage and current based on curve I-V), as a result you can study dependence on climatic variations using electronic circuit simulation application.

9.- REFERENCES

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