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A STUDY OF SILICON SOLAR CELLS AND MODULES USING PSPICE

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ABSTRACT: A study of $0.1m^2$ silicon solar cells and modules constructed from such series connected cell-strings was carried out using PSPICE. The study showed that this widely available simulation tool can reveal useful properties of solar cells, and modulus, which are relevant to module design as well as the design of power supply regulators and inverters utilized with PV systems.

INTRODUCTION

Photovoltaic solar energy plays a crescent role in the energetic system production (Luque, 2001 and Castro, et al, 2005). Several public programmes aim to promote this type of energy production by means of subsidies, financing and mainly with feed-in tariff.

The importance of photovoltaic cells in the direct conversion of solar energy into electrical energy is well known and established. As silicon is among one of the most abundant materials available, the interest of producing PV cells from silicon material has dominated the industry. Recently, it has been reported that experimental crystalline silicon solar cells have reached ac confirmed efficiency are now available (Green, et al, 2001). Experimenting with actual PV cells in the laboratory is often an expensive and time consuming task. For this reason it is wise to resort to simulation techniques to overcome this problem. Many commercial simulation software already exist, (David, et al, 1996)

In this work $0.1m^2$ silicon cell have been simulated and modules constructed by connecting up to 26 of these cells. In cells in series, using the MicroSim® evaluation PSPICE (MicroSim®, 1997). The simple study carried out leads to valuable information that would be useful in the design of PV modules and power supply systems utilizing such PV modules as their basic energy source

METHOD AND MATERIALS

THE PSPICE SIMULATION PROGRAM

The lumped parameter model of a silicon solar cell used in this work is the equivalent circuit shown in Fig. 1 (Wenham et al, 2001 and Krein, 2001). The solar cell represented by this equivalent circuit may be may be of the single or polycrystalline type. In this model I_L represents the bipolar current due to light generated carriers that reach the electrical terminals, and D_I represents the p-n junction of the solar cell. R_s is the series resistance that accounts for the overall voltage drop that the carriers encounter in moving from where they are generated to the points of metal contacts of the cell. R_{sh} is the shunt leakage resistance which accounts for the formation of the so called ‘’ hot spot’’ due to the shadowing of a cell in a module.

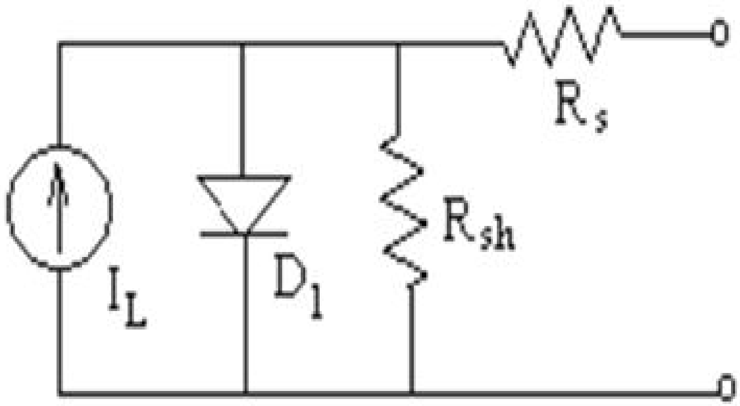

Fig. 1 Equivalent circuit of a silicon cell

The I – V relation for a single cell related to the above circuit model is given by the equation.

$$I = I_L - L_o\left\{\exp\left[q\left(\frac{V+IRs}{nKT}\right)\right] - 1\right\} - \frac{V+IRs}{Rsh} \qquad 1$$

Where I_L is the current due to illumination of the solar cell, I_o is the dark saturation current, q is the electron charge, n is the so called " ideality factor" or the diode emission factor (Ikegami, et al , 2001), K is Boltzmann's constant and T is the cell absolute temperature in degrees Kelvin. For a group of N-series-connected identical cells that would constitute a basic module, the current through each cell in the group is the same as the current through the single cell (I_{wt} = I). The module voltage V_{wt} is N times the voltage V of a single cell (V_{wt} - NV). In order to develop the I – V relation for the above variables for I and V in equation (1) can be replaced by I_{wt} and V_{wt} respectively as shown in equation (2).

$$I_{wt} = I = I_L - I_o\left\{\exp\left[q\left(\frac{Vwt + INRs}{NnKT}\right)\right] - 1\right\} - \frac{Vwt + INRs}{NRsh} \qquad 2$$

The same topology is usually used for the equivalent circuit of the module as for the cell as is suggested by equation (1) and (2), Wenhen et al, (2001). The ideality factor is modified in the manner shown, the series current assumption for identical cells is reasonable. However, the diode currents, R_{sh} , R_s and the output voltage of the cells combine in no simple way to form the corresponding values of the module parameters since the equivalent current of the cells is not linear.

The PSPICE program used in the simulation of the equivalent circuit of Fig.1 is given in Fig. 1b.

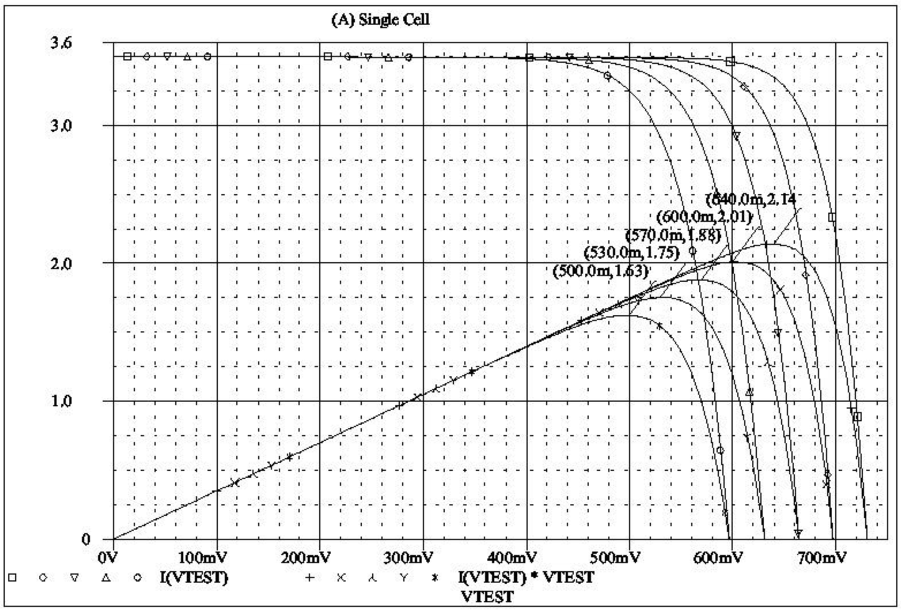

Fig. 1b: I –V Curves and output power curves under parametric variations (cell temperature)

This program is modified to simulate modules of 2, 5, 10, and 31 series connected cells (Markvart, 1994), (Keown, 1993). An example of a module obtained by connecting 2-cells in series is shown in Fig.2. The other series connected cell-strngs are obtained similarly. The PSPICE input file was modified accordingly to investigate parametric changes in the equivalent circuit, and to show the effect of such changes on the maximum power output and operating voltage V_m at the maximum power point. The I – V characteristics and the output power curves were obtained using PROBE. The effects of ambient temperature changes were studied using the same input file by taking T as a parameter. In each investigations carried out, set of curves for the I –V characteristics and a set of curve for the output power were obtained as shown in Fig. 1b. From these curves the variation of the open circuit voltage V_{oc} and the variation of the operating output voltage V_m were tabulated in Tables 1 - 6.

RESULTS AND DISCUSSION

Solar cell study

We simulated the solar cell circuit shown in Fig. 1 assuming that it represented 0,1m^2 silicon cell using typical parameter values under standard test conditions as suggested in (Wenhen et al, 2001). The main interest in the simulation was to observe and determine the variations of V_m at maximum power point as the cell parameter are varied.

First, to make sure that the temperature variation was the main factor in determining the output operating voltage (Markvart, 1994). We investigated the variation of the maximum output power of the cell for R_s values of 0.001, 0.01, 0.02, 0.03, and 0.04Ω with R_{sh} held constant at 100Ω and the cell temperature constant at 25^{o}C. The ideality factor was taken as n = 1.1, and I_o = 1.0 x 10^{-10}A. The results of this simulation are shown in Table 1.

Secondly, we investigated the effect of varying R_{sh} on V_m and V_{oc} for R_{sh} values of 300, 100, 30, and 10Ω, at R_s = 0.001Ω and 25^{o}C. Finally, holding R_s at 0.001Ω, R_{sh} at 100Ω, I_o = 1.0 x 10^{-10}A, the I-V curves and the output power curves for values of T = 5^{o}C to 85^{o}C in step of 20^{o}C were plotted for two different cells, first with n = 1.1 and next with n = 1.5. The value I_L in all of the above tests was taken as 3.5A. The results of these simulations are given in Table

II, III respectively. As can be seen from the tables the test confirmed that increasing the cell temperature was the main factor which determines the fall of the V_m. These tests also showed that increasing the value of n resulted in unrealistic values of V_{oc}.

As can be seen from the tables, for n = 1.1, V_{oc} falls by 1.67mV/^{o}C, V_m falls by 1.75mV/^{o}C, and for n = 1.5, V_{oc} falls by 0.8mV/^{o}C, V_m falls by 1mV/^{o}C. From these results we observed that the fall of the operating voltage Vm/^{o}C is a more critical parameter in design considerations for both values of n. The results show that n =1.1 is a more realistic value of the ideality factor for the silicon solar cell as it yields voltage fall rate values closer to known practical values for such cells.

SOLAR MODULE STUDY

The module study was based on identical cell strings with no shading on any of the cells. The modules were simulated up to 31 series connected cell-strings.

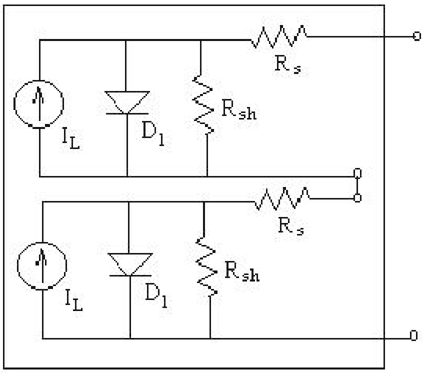

Fig. 2 A 2-cell series cell-string module

In practice 36 series cell-strings are usually considered for 12V power supply system, this limitation was not of major significance in our study. To see the effect of decreasing the number of series connected cells on the output voltage fall rate (mV/^{o}C for V_{oc} and V_m) the tests were carried out for 2, 5, 10 and 31 cell-strings. Each module was tested for n = 1.1 and n = 1.5. The 2-cell module was simulated using the equivalent circuit shown in Fig.2. The equivalent circuits for the other modules were similarly extended. All cells in the module were assumed to be identical and to produce a short current of 3.5A under standard test conditions. The parametric variation tests carried out for the module were similar to those carried out for the single cell. The I – V curves and the variation of output power versus temperature rise were obtained from curves and the results are as tabulated in Tables 4 - 6.

The simulation results for n = 1.5 did not reflect realistic values for V_{oc} since they yield higher output voltage levels than is possible for the type of the silicon cells used. As is observed from the Tables the fall in both V_{oc} and V_m is reasonably linear for the indicated increasing temperature values. It is also observed that the value of n is important in the modeling of the cell and modules and that the closer n is to unity the closer is the voltage fall rate to the known practical values. Finally, the fall rates to be considered in power system design should be those of the operating voltage V_m

Table I: R_s variation

R_s	0.001	0.01	0.02	0.03	0.04
V_{oc}(mV)	697.210	697.230	697.250	697.265	697.280
V_m(mV)	610	600	600	600	600
P_m(W)	2.0224	2.0178	2.0140	2.010	2.0058

Table 2: R_{sh} variation

R_{sh}	300	100	30	10
V_{oc}(mV)	697.40	697.40	697.40	697.40
V_m(mV)	600	600	600	600
P_m(W)	2.0156	2.0156	2.0156	2.0156

Table 3: V_{oc} variation for n = 1.1

Cell No.	1	2	5	10	31
5°C	0.73V	1.46V	3.65V	7.305V	22.65V
25°C	0.697V	1.395V	3.49V	6.975V	21.62V
45°C	0,662V	1.328V	3.32V	6.64V	20.6V
65°C	0.631V	1.261V	3.15V	6.31V	19.55V
85°C	0.597V	1.194V	2.984V	5.97V	18.5V
V_{oc} Fall (mV/°C)	1.67	3.325	8.325	16.69	51.875

Table 4: V_m variation for n = 1.1

Cell No.	1	2	5	10	31
5°C	0.64V	1.28V	3.19V	6.39V	19.80V
25°C	0.60V	1.21V	3.02V	6.03V	18.70V
45°C	0,57V	1.14V	2.84V	5.68V	17.60V
65°C	0.53V	1.06V	2.66V	5.32V	16.51V
85°C	0.50V	0.99V	2.49V	4.97V	15.42V
V_m Fall (mV/°C)	1.75	3.62	8.75	17.75	54.75

Table 5: V_{oc} variation for n = 1.5

Cell No.	1	2	5	10	31
5°C	0.963V	1.926V	4.820V	9,720V	30.15V
25°C	0.947V	1.894V	4.734V	9.560V	29.65V
45°C	0,930V	1.861V	4.651V	9.400V	29.17V
65°C	0.913V	1.827V	4.568V	9.240V	28.67V
85°C	0896V	1.793V	4.482V	9.073V	28.15V
V_{oc} Fall (mV/°C)	0.834	1.660	4.230	8.0875	25.00

Table 6: V_m variation for n = 1.5

Cell No.	1	2	5	10	31
5^{o}C	0.84V	1.68V	4.21V	8.420V	26.09V
25^{o}C	0.82V	1.64V	4.10V	8.210V	25.45V
45^{o}C	0,80V	1.60V	4.00V	8.000V	24.80V
65^{o}C	0.78V	1.56V	3.89V	7.970V	24.15V
85^{o}C	0.76V	1.52V	3.79V	7.580V	23.50V
V_m Fall (mV/^{o}C)	1.00	2.00	5.25	10.5	32.375

CONCLUSION

Although PSPICE has its limitation in the study of more complicated modules and arrays of PV modules, it is sufficient to investigate the effects of parametric variations of PV cells and of modules constructed from such cells. It has been that such study can reveal and quantify the operating voltage drop V_m at the module output at high temperatures. We can thus supply regulators and inverters of power supply systems that utilize PV sources as their primary source of energy. This widely available simulation tool can also be used in the teaching of photovoltaic subjects and can substitute for expensive and time consuming experiments.

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