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Research Article

ANALYSIS OF EXTERNAL LOAD RESISTANCE INFLUENCE ON THE SINGLE-CRYSTALLINE SILICON PHOTOVOLTAIC MODULE (PV)

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ABSTRACT

The solar photovoltaic is the important energy for many countries in Africa nowadays. But the quality of the commercial photovoltaic (PV) module is a real obstruction of progress of this energy despite the large availability of solar radiation. The main purpose of this work is to contribute to the understanding of external load resitance (R_L) influence on a comercial PV module. Hence, an experimental study is leaded to evaluate the effects of the R_L on the output current, the output voltage, the output electric power, the serie resistance (Rs) and the shunt resistance (Rsh) of a comercial PV module. This study has allowed to observe that the behavior of theses five electrical parameters under real condition. Then, the optimum electric power is obtained for the weak R_L.

Keywords: Serie resistance; Shunt resistance; Load resistance; Single-crystalline silicon photovoltaic module; Current; Voltage and Electric power.

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1. INTRODUCTION

The extraction of the electric parameters of the solar photovoltaic module is a good way for its characterization. The measurements of the current and the voltage (I, Icc, V and Vco) allows to find Rs and Rsh. The evolution of these parameters with external load resistance R_L can allow to understand the mecanism which gouvernes the flow of the density carrier at the p-n junction. The ideal solar PV module is defined by Rs = 0 and Rsh = ∞ [1]. Many authors have shown that the external influences such as irradiation level, temperature, dust, external load resistance etc. can affect the evolution of the Rs and Rsh. The behavior of the Rs and Rsh are studied in presence of the magnetic field. The shunt and serie resistances increase with the increase of the magnetic field strength. This increase of Rsh is able to stock the shunt at junction, but the increase of Rs can fall down the good quality of the PV module [2]. G. Sissoko et al. [3] have observed an increase of the serie and shunt resistance with the increase of the illumination wavelength. The high value of the serie resistance causes the reduction of the efficiency of the solar cell same at high solar illumination [4]. The increase of the temperature causes evenly the increase of the serie resistance stocking the carriers charge at the junction [5]. Usually, the studies are curried out only to find the optimum external load resistance under external parameters. [6] combines the effects of the temperature and external load resistance on the solar cell. It appears evenly that electric power decreases with the increase of the temperature. It decreases fastly when R_L is great. This paper presents a study of the influence of R_L to allow the ability to optimize the performance of a PV system. The serie and shunt resistances of PV module are evaluated by assimilating they into an equivalent electrical circuit that includes some single diode. In order to understand how the series and shunt resistances are affected by the external load resistance, a PV module is installed with a rheostat. The electric power (Pel), Rs and Rsh values and the rest of the parameters can be extracted using the Isc, Voc, I and V values under the real temperature and solar illumination conditions. This work is organized as follows: in section I, it will be presented the theory on the influence of the Rs and Rsh on the solar cell. It will be also question in this section of the theory of the R_L. This section will do evenly a presentation about the experimental protocol. The last section will be concerned the results and discussions.

2. THEORIES AND METHODS

2.1. Evaluation of the serie resistance (R_S) and shunt resistance (R_{sh})

The serie and shunt resistances have not physical existence [7]. The Rs is the diffusion layer (n) resistance and Rsh is shunt resistance being in parallel with the p-n junction [4]. Taking back the representation of Rs and Rsh for the conventional solar cell given by Smith, H. K et al., we can model them for the Back Surface Field (BSF) solar cell as follow.

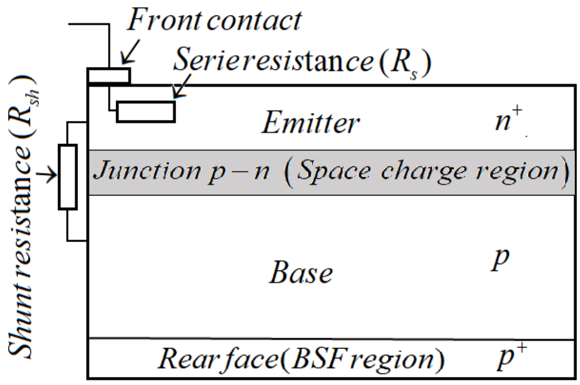

Fig.1. Representation of the shunt and serie resistances in BSF solar cell

According to this PV model, the serie resistance allows for the resistivity about the diffusion layer. The shunt resistance simulates the resistivity of the p-n junction face up to the possible shunt. Consequently, the study of the influence of the load resistance on these resistances will allow to evaluate the behavior of the diffusion layer and the p-n junction. A photovoltaic system converts directly the sunlight into direct current electricity. The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form panels or modules [8] Then, our theory description will concern the unit solar cell and the experimental work will concern the PV module. To calculate the Rs and Rsh the electric equivalent circuit of the solar cell will be used. The main importance of the electric equivalent circuit is to present the electrical circuit of the solar cell with its different components. The figure 2 gives the electric representation of single-diode solar cell.

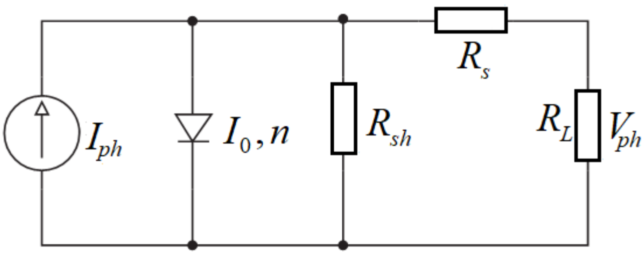

Fig.2. Equivalent electrical circuit of the solar cell

This model provides a good compromise between simplicity and accuracy [9]: Following the figure 2, the generate photocurrent by the solar cell under illumination has been proposed [6, 8-9]:

$$I = I_{ph} - I_0\left[\exp\left(\frac{V_{ph}+IR_s}{nV_T}\right)-1\right]-\frac{V_{ph}+IR_s}{R_{sh}} \quad \textbf{(1)}$$

Where I_0 is the saturation current of the diode, n is the ideality factor that considers the deviation of the diode from the Shockley diffusion theory, V_T is the thermal voltage of the diode, a constant that depends of the temperature, I_{ph} presents the generate current and V_{ph} gives the photovoltage under the load resistance. For the next, it is assumed that the contribution of the diode can be neglected. Then, the last equation **(1)** becomes as follow

$$I = I_{ph} - \frac{V_{ph}+IR_s}{R_{sh}} \quad \textbf{(2)}$$

The practical solar cell presents a hybrid behavior, which may be of current or voltage source depending on the operating point [9]. The practical solar cell has a series resistance Rs whose effect is stronger when the solar cell operates in the voltage source region (open circuit), and a parallel resistance Rsh with stronger influence in the current source region (short circuit) [9]. The expressions of the Rs and Rsh can be determinated using the differents states of the solar cell [2-3].

$$R_{sh} = \frac{V_{ph}}{Icc - I_{ph}} \quad \textbf{(3)}$$

$$R_s = \frac{V_{CO} - V_{ph}}{I_{ph}} \quad \textbf{(4)}$$

The main purpose of this work is to evaluate the influence of the R_L on electric parameters on single-crystalline silicon solar module in real operation condition. That can provide to the reader more necessary informations for the installations of the photovoltaic panels. R_L represents others external equipments which will use the provided electric power by the solar cell. The optimum value has been evaluated by many studies at maximum power operation point [6, 10, 11]. The electric power outputs from the cell is depending of load resistance [12]. the expression of the optimum load resistance is presented by equation **(5)** [6, 10-11].

$$R_{Lmp} = \frac{V_{\max}}{I_{\max}} \quad \textbf{(5)}$$

This paper is carried out to evaluate the influence of the R_L on electric parameters on single-crystalline silicon solar module in the real operation conditions. Then it will be realised an experimentation dispositive to study this influence.

2.2. Experimental dispositive

The experimental dispositive picture is given in the following photo

Fig.3. Presentation of the experimentation dispositive

This experimental dispositive includes:

- A single-crystalline photovoltaic module (PV) whose its manufacturing electrical specifications (at AM1.5, 100mW/m^2, 25°C) are :
-

Table 1. Manufacturing electrical specifications of PV module H245

Maximum power (P_{max})	20Wp
Short circuit current (I_{cc})	1.36 A
Open circuit voltage (V_{co})	20.5 V
Voltage at P_{max} (V_{MP})	16.5V
Current at P_{max} (I_{MP})	1.21A

- A pyranometer SRO3
- A rheostat maximum resistance 230 Ω
- Two digital multimeters ref. 940 SI

For every value of the external load given by the rheostat, the values of the photocurrent (I_{ph}), the photovoltage (V_{ph}) are measured out. Every electrical quantity is obtained by a statistic measurement which allows to find the average of I_{ph} and V_{ph}. It is the same thing for the measurement of the V_{co} (at high value of the external resistance) and I_{cc} (at the absence of the rheostat in the circuit). The front face temperature of the PV module is found using MIDI logger with a thermocouple J and the global solar irradiance is obtained using this MIDI datalogger by thermocouple J connected to a pyranometer. The different measurements precisions are presented in the next table.

Table 2. The precisions of the different equipments

Digital multimeter	For the calibre in Direct Current (DC) of 40V	±1.2%
	For the calibre in Direct Current (DC) of 10A	±2.5%
	For the calibre of 400Ω	±1.2%
Pyranometer SRO3	Second class	±7.8%
Thermocouple J	-100°C to 1300°C	±0.1%
MIDI logger	GL200-UM-251	±0.08%

The next section will give the results and discussion.

3. RESULTS AND DISCUSSION

The real operation conditions are evaluated by the measurements of the solar global irradiance and the operation temperature in front face of the PV module. Theses quantities are given in the following table.

Table 2. Results of measurements of operation condition parameters

Times (h)	Solar global irradiance ($W.m^{-2}$)	Front face temperature (°C)
12.00am	471.50313	34.6
12.05am	506.88935	34.6
12.10am	530.06263	34.9
12.15am	555.84551	34.8
12.20am	539.97912	35.2
12.25am	603.65344	35
12.30am	602.71399	35.4
12.35am	601.56576	35.9
12.40am	506.47182	36.2
12.45am	620.04175	36.2
12.50am	734.55115	36.1
12.55am	652.19207	35.5
1.00pm	733.08977	35.6
1.05pm	829.43633	36.1
1.10pm	662.00418	35.7
1.15pm	708.03758	36.6
1.20pm	806.15866	37.1
1.25pm	508.76827	37
1.30pm	489.56159	37.9
1.35pm	467.53653	36.9
1.40pm	433.29854	37.1
1.45pm	464.09186	37.3
1.50pm	627.87056	36.3
1.55pm	414.09186	36.4
2.00pm	398.85177	36

To get good appreciation the time range of 12am to 2pm is chosen because of the high solar global irradiance and the high temperature can be obtained generally between 11am to 3pm in October at Ouagadougou. The Figure 4 presents the evolution of the solar global irradiance and the front face temperature using the Origin 8 software.

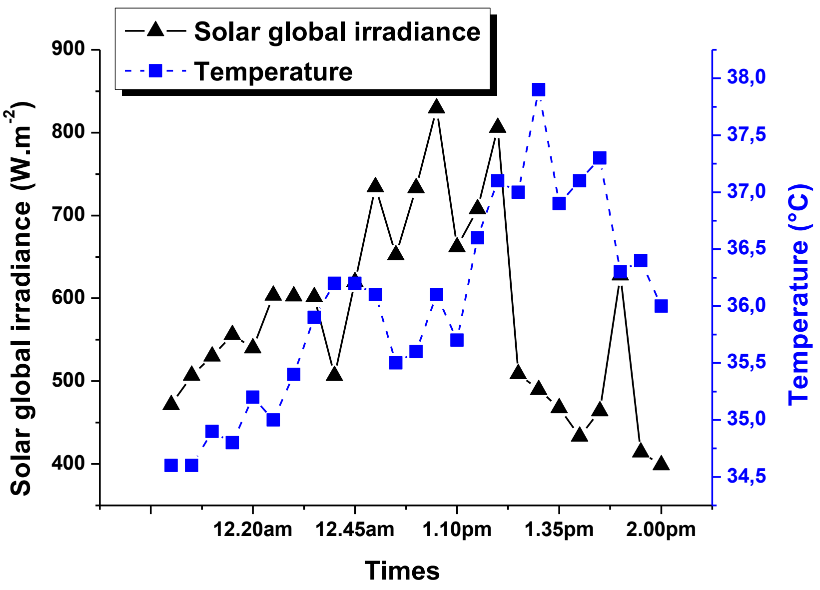

Fig.4. Evolution of the temperature and the solar global irradiance between 12.00am to 2.00pm the 29/09/2018

The operation solar global irradiance is weak compared to the standard test condition (STC) value which is 1000W.m^{-2}. But the operation temperature is higher than STC temperature which is 25°C. Then, these quantities will influence negatively the output electrical parameters of the PV module. The measurements of the output electrical parameters are directly the current and the voltage. The electric power, the shunt and serie resistances are found using the measured values. The following table shows the different electrical parameters in function of the external load resistance.

Table3. The output parameters of PV module

R_L (Ω)	V(V)	I(A)	Pel (W)	R_S (Ω)	R_{Sh} (Ω)
230	18.17361	0.08034	1.46007	4.324	20.54304
201.47	18.22213	0.08852	1.61302	3.3763	20.79013
162.33	17.49349	0.10915	1.90941	9.41374	20.4399
133.175	18.00107	0.13453	2.42168	3.86479	21.67576

85.1	17.41231	0.20272	3.52982	5.46907	22.84241
54.323	16.69426	0.29922	4.99526	6.10501	25.07474
23.538	13.2597	0.47636	6.31639	11.0448	27.13593
5	6.43852	0.5876	3.78327	20.56242	17.0602
0.03	0.09772	0.59138	0.05779	31.15303	0.26155

The mesurements and the calculations of these quantities according to the external load resistance allows to find the evolution curves. The first evolution curve is shown in the figure 5 giving the I and V in function of R_L.

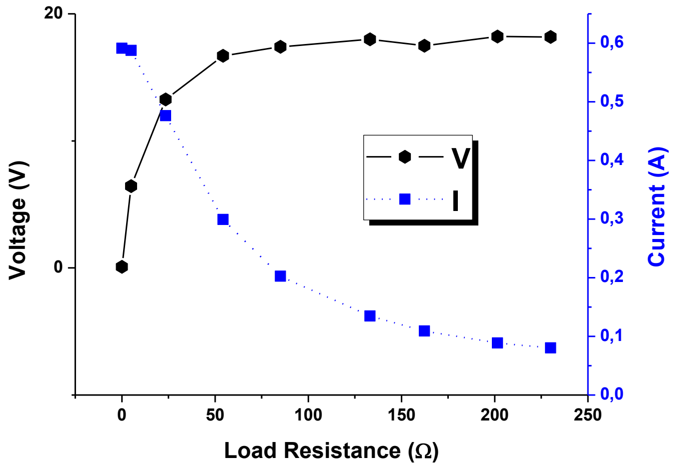

Fig.5. Evolution of I and V according to the R_L

The increase of the load resistance causes the increase of the output voltage of the PV module. But the output current decreases with this increase of the R_L. In fact, the external load resistance represents an opposition to the carriers charge photogenerate flow at p-n junction under illumination. Then, when its value increases, there is a storage of these carriers charge at the p-n junction causing the increase of the voltage and the decrease of the current. The meeting point of the both current and voltage curves give the optimum power point. The following figure 6 shows the evolution of the electric power in function of the load resistance.

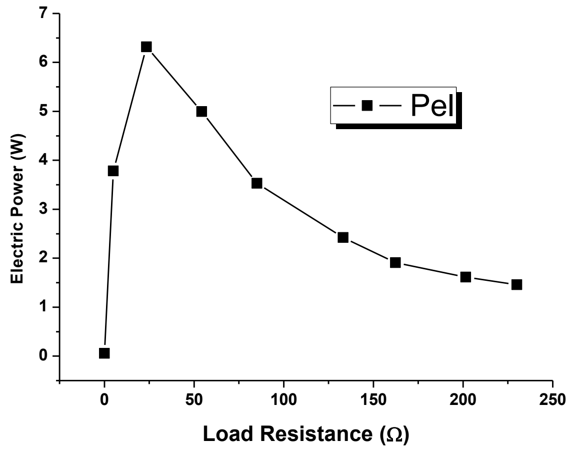

Fig.6. Electric power varying in function of the load resistance

Before the value of 23.538Ω of the external load resistance, the output electric power increases fastly and getting the optimum point at this value. It decreases exponentially after this value of R_L. This point correspnds to the meeting point of the curent and voltage curves. The increase of the load resistance causes a speed ageing of PV module asking its more production of the carrier charge. Hence, in this operation condition of the PV module, it is better to use weak external load to find optimum output electric power. In the next figure **7** it is presented the serie and shunt resistance evolution according to the load resistance.

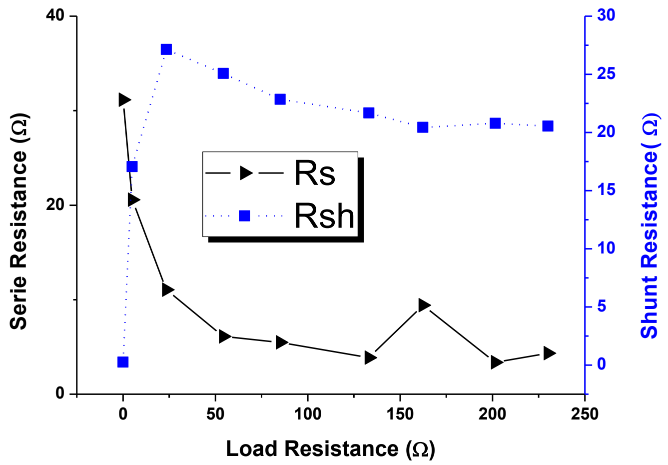

Fig.7. Evolution of R_{Sh} and R_S in function of the load resistance

The serie resistance decreses with external load resistance while the shunt resistance increases. The meeting point of the both curves gives the maximum power point. For the very weak value of the load resistance, the output voltage is very weak corresponding to a great value of the output current. That situation can explain the high serie and low shunt resistance. Moreover, the obtained values of the shunt and serie resistances are sensibly higher than their values in STC situation. In fact, these electrical quantities are influenced by the solar irradiance as shown by V. L. Brano et al. [7].

$$R_S = \frac{R_{S_0}}{\alpha_G} \quad \textbf{(6)}$$

And

$$R_{Sh} = \frac{R_{Sh_0}}{\alpha_G} \quad \textbf{(7)}$$

Where R_{sh0} and R_{S0} are the STC shunt and serie resistances and $\alpha_G = \frac{\phi}{\phi_0}$ with $\phi_0 = 1000 W.m^{-2}$, the STC solar irradiance and $\phi(W.m^{-2})$ the solar irradiance obtained by the measurements. The solar irradiance at Ouagadougou in October can be affected by the dust and the clouds. So, obviously, the decrease of the solar irrandiance causes a simultaneous increase of the shunt and serie resistances. That can explian the high values of the serie and shunt resistance observed on the Figure 7. The Rs resistance is the sum of many structural resistances of the device [9.]. The Rsh resistance exists mainly due to the leakage current of the p-n junction and depends on the manifacturing method of the photovoltaic cell [9]. Then the performances of the PV module can be reduced with the increase of the load resistance.

4. CONCLUSION

The influence of the load resistance has been studied in real operation condition of the PV module in this paper. The I, V, Vco, Icc are measured out and the electrical power, the serie and shunt resistances has been calculated. The increase of the load resistance causes the increase of the voltage while the current decreases. The serie resistance decreases with the increase of the load resistance while the shunt resistance has presented two levels of the evolution. In the first level, the shunt reistance increases until the optimum power point with the increase of the load resistance. After the optimum power point, the shunt resistance decreases during the increase of the load resistance. The serie and shunt resistances can be also affected by the solar irradiance. Hence, it is better in the real operation condition for the domestical PV installation to use the external load resistance smaller than the real supported capability of the PV module. That can contribute to extend the life time of the PV module.

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