Functioning of the Half-Cells Photovoltaic Module in hybrid EV under Partial Shading

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***Abstract*— Photovoltaic (PV) is a clean energy source that is capable of powering a vehicle's electrical energy requirement whilst providing zero operating emissions. This paper focuses on the effect of partial shading in solar roof of hybrid electric vehicle in changing output power with different scenario of shading. A simulation model has been developed in Matlab / Simulink to investigate the performance of the solar panels under shading conditions. An analyse study based on I-V and P-V measurements values has been done to deduce the advantage of the half-cell solar panel compared to full cell under partial shading. It has been demonstrated that half-cell solar panel can reduce the power losses more than a full cell solar panel. Our study suggests that half-cell module design could minimise the shading effect for hybrid electric vehicle.**

***Keywords*— photovoltaic, Half cell, Shading, Electric Vehicle, current–voltage characteristics**

I. INTRODUCTION

Hybrid electric vehicles present an alternative for reducing emissions of carbon dioxide CO2 and nitrogen derivatives NOx in the atmosphere. These transport means have to consume clean energies as fuel cells, solar energy, wind energy and others microsystems sources.

Tunisia has an excellent geographical conditions and it provide of a multiple renewable energies such as solar, wind and geothermal field. The objective is to profit of these energies kinds in order to minimize CO2 concentration in atmosphere and to freshen air [1].

Like other countries, Tunisia aims to develop a new generation vehicles such as electric vehicle (EV) and hybrid vehicle (HV). These projects have captured the attention of researchers in the purpose of environmental results [2].

Many works [3] are interested by the economic efficiency of the integration of electric vehicles. They present an overview of the impact of the increasing number of the EV into vehicle market.

To improve vehicle performance, various researches deal with the energy management optimization for the new generation of vehicle. MAHMUD and al. works on the development of architecture for the distributed energy management of electrical vehicle (EV) based in the internet of energy (IOE) [4]. Chowdhury, Muhammad Sifatul Alam and al [5], use Fuel Cell, Battery and PV panel to provide power for a Hybrid Electric vehicle. In different researches [6-8], renewable energy are used to power the hybrid electrical vehicle in order to replace the internal combustion engine of a plug-in hybrid electric vehicle (PHEV).

Most of the time, renewable energies are easily dismantled and there don't generate waste, as in nuclear energy for example [9]. Solar energy is inexhaustible on a human scale. In the same way, it respects the environment and does not cause pollution.

The Photovoltaic system performance operates under constantly changing environment influenced by solar radiation level, shading, temperature, etc. The main problem associated with the use of PV cells is its non-linear characteristics, which vary with operating temperature and solar irradiance [10]. This problem gets more complicated under shading condition and these affect the output plot of the P-V system.

In this context, Pallavi Bharadwaj and Vinod John [11] present a study to explain the phenomenon of partial shading and propose a detailed model giving the PV panels output under different scenario of shading. These problems can affect EV because the vehicles are moving and there is a possibility of solar panels being under complete or partial shading.

The half-cells are connected in two parallel strings to reduce the cell-to-module losses during assembly process. Therefore, when cutting a solar cell in half, the power losses are reduced by a factor of four. Other advantage of this technology residing on the small size and resistance to cracking of half-cut cells resulting a more physically durability compared to traditional solar cells [12].

In this work, a MATLAB simulation study is developed to show the benefits of the use of half-cell technologies in solar panels instead of solar full cell technologies. A description of the two cells technologies is established based on Mathematical Modelling of PV Panel. Different shading cases are treated using MATLAB SIMULINK Model and the curves results V-I and P-V are presented and discussed.

II. MATHEMATICAL MODELLING OF PV PANEL

A. *Equivalent Circuit Model*

In presence of sun radiation, the equivalent circuit of a photovoltaic cell includes a current source, diode (single or double), a shunt resistor and a serial resistor. Under no irradiation, solar cell behaves as a normal diode with no output. Thus, the cell has just a p-n junction diode attitude and will drive a diode current or dark current Id from a source. This diode impose his I-V characteristic curve.

B. *Single diode model*

The most electric model, used in the energy sector (fig.1), represent a cell or a PV module called in the literature “one diode model». It allows to show the irradiation effect and the PV conversion using a perfect current source (Iph), one diode to reproduce the behaviour of the PV cell, a parallel resistor (Rsh) presenting the various leakage currents and a serial resistance (Rs) modeling the losses.

The one diode model requires three parameters to completely characterize the I–V curve, namely short-circuit current (Isc), open circuit voltage (Voc) and diode ideality factor “a” [21]. The equation (1) describes the output current of the cell.

$$\boldsymbol{I = I_{pv} - I_0 \left[exp\left(\frac{V+IR_S}{aV_T}\right) - 1\right] - \left(\frac{V+IR_S}{R_P}\right)} \quad (1)\ [13]$$

$$\boldsymbol{I_0 = I_{0,STC} \left(\frac{T_{STC}}{T}\right)^3 exp\left[\frac{q\,E_g}{ak}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right]} \quad (2)$$

With :

I_{pv} : Current generated by the light incidence
I_0 : Reverse saturation current
V_T : Thermal voltage of the PV Module
R_S : Equivalent serial resistance
R_P : Equivalent parallel resistance
E_g : Band gap energy of the semiconductor
$I_{0,STC}$: The nominal current at STC (Standard Test Conditions).
k: Boltzmann constant
q: Electron charge
V, I: Outputs voltage and current

A developed equation to define the saturation current which considers the temperature variation as given in (3) :

$$\boldsymbol{I_0 = \frac{(I_{sc,STC} + K_I \Delta T)}{exp\left[(V_{oc,STC} + K_I \Delta T)/\ aV_T\right] - 1}} \quad (3)\ [14]$$

Where K_I is the short circuit current coefficient, (ΔT = T - T_{STC}) , G is the surface irradiance of the cell (W/m^2) , G_{STC}(1000 W/m^2) is the irradiance at STC.

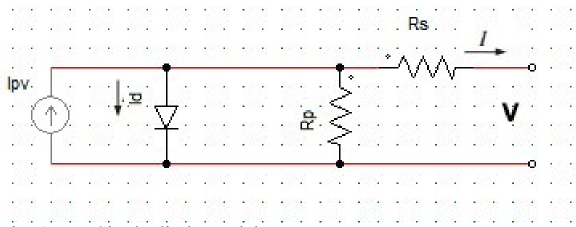

Fig. 1. Single diode model

C. *Two diode model*

The two diode model can explain more the real behaviour of the solar cell, because it’s taken into account the charge transfer mechanism inside the cell. Adding a diode in parallel with the first to consider the ideality factor “a” only done by a fixed value.

This model requires the computation of seven parameters, namely IPV, Io1, Io2, Rp, Rs, a1 and a2 instead of five unknown parameters in the one diode model. The output current equation of the two-diode model shown in Fig. 2 is described in Eq. (4).

$$\boldsymbol{I = I_{pv} - I_{o1} \left[exp\left(\frac{V + IR_S}{a_l V_{T1}}\right) - 1\right] - I_{o2} \left[exp\left(\frac{V+IR_S}{a_2 V_{T1}}\right) - 1\right] - \left(\frac{V+IR_S}{R_p}\right)} \quad (4)\ [15]$$

Where I_{o1} and I_{o2} are the reverse saturation currents respectively of diode 1 and diode 2, V_{T1} and V_{T2} are the thermal voltages of respective diodes, a_1 and a_2 represent the diode ideality constants.

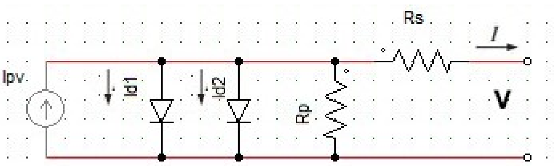

Fig. 2. Two diode model

D. Half-Cell Two-diode model

To analyse the effect of half-cell technologies (fig.3), we have adopted the two diodes model by adding the connection in parallel of two half-cells as shown in Fig. 4. In this case, each half-PV cells create a current equal to half of total current (fig.3). The expression of current I_h is shown in (eq.5) .

$I_h = I1 + I2$ or all cells are similar in solar panel $I_{pv} = I_{pv1} = I_{pv2}$, $R_{s1} = R_{s2} = R_s$ and $R_{p1} = R_{p2} = R_p$

$$I_h = 2 * (I_{pv} - I_{o1}\left[exp\left(\frac{V+IR_S}{a_l V_{T1}}\right) - 1\right] - I_{o2}\left[exp\left(\frac{V+IR_S}{a_2 V_{T1}}\right) - 1\right] - \left(\frac{V+IR_S}{R_p}\right)) \quad (5)$$

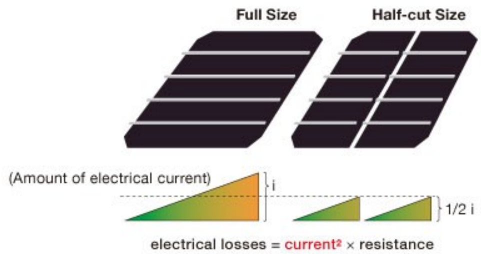

Fig. 3. Two-diodes model for Half-Cells

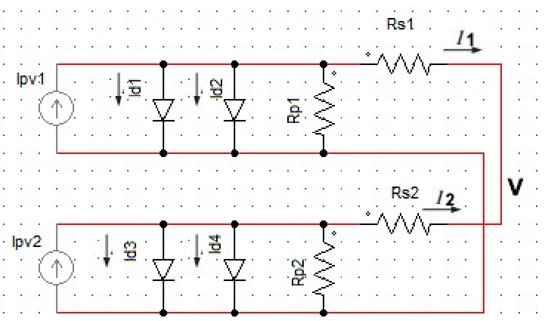

Fig. 4. Comparison between solar half-cell and full-cell power loss

Usually the solar panel can be simulated as 3 parts separated with bypass diodes and each part is constructed of number n of cells. Compared to full cell solar panel, the half-cell solar panel can be simulated as 6 parts separated with bypass diodes and each part as constructed of number 2*n of cells. The configurations are shown in fig. 5.

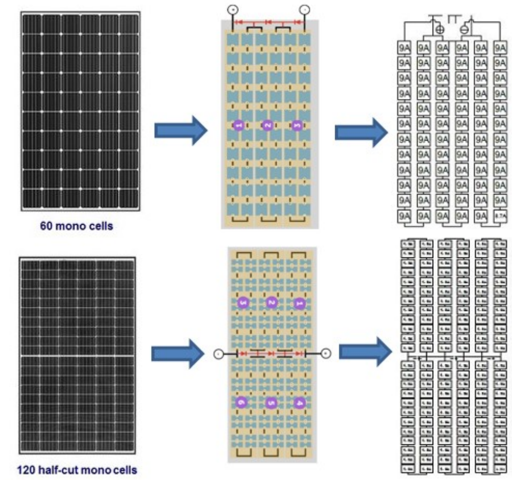

Fig. 5. Configurations of full cells and half cells solar panels

III. SHADING PATTERNS

Shading in photovoltaic panels can be caused by various factors and can disregard cells row function during exploitation. This happens quite often, but even these negative results can be effectively limited.

In the case of installations on roofs, the structural elements of the buildings such as exits, neighbour building, trees, satellite dish, etc., can influence the behaviour of the installation due to shading. Therefore, it is necessary to find solutions able to "eliminate the possibility of shading" [16]. Even in situations where the installations are on the ground, at certain times of the day, certain rows of panels produced a shadow on others. However, it is also necessary to have well studied separation distances between the panel's rows from the beginning, modify the connection configurations of the panels in chains and the adjustment of the horizontal / vertical position (depends on the availability of bypass diodes). It's important to avoid mounting panels in shaded areas or use the appropriate control of MPPT (Maximum Power Point Tracking) modules to solve the problem. In our case, the vehicles are mobile and it is very difficult to have sizes in advance like in other cases. The most common reasons for shading photovoltaic cells in the case of integrating solar energy into vehicles are landscape elements, horizon, trees or poles that already exist or may appear during the vehicle shifting.

The shading can be caused due to many reasons and configured in many ways. To diversify the study of shading effect, many scenarios presented in table1 can be simulated based on MATLAB simulation. The two cases of a full and half-cells are considered. The panels produced by Jinko solar [17] containing 78 full cells or 154 half-cells are the subject of the model simulation.

The specification of the solar panel is described in table (2).

TABLE I. SCENARIOS OF PARTIAL SHADING SOLAR PANEL

Case	Number of shading half cell	Number of shading full cell
C0	0	0
C1	6	3
C2	12 (6 per part)	6
C3	18 (6 per part)	9

As described in figures 5 and 6, the half-cells solar panel can be simulated as 6 parts separated with bypass diodes and each part as constructed of 26 half cells. Therefore, the simulation is based on changing the number of shading cells in each case to obtain and observe the variation of I-V curves. In all cases, the shading was introduced by changing the irradiance to the panels.

TABLE II. SPECIFICATIONS OF JINKO SOLAR PANEL 78 CELL

Specifications	
Module Type	JKM445M-78H-V
Maximum Power (Pmax)	445Wp
Maximum Power Voltage (Imp)	43.72V
Maximum Power Current (Imp)	10.18A
Open-circuit Voltage (Voc)	52.04V
Short-circuit Current (Isc)	10.84A
Module Efficiency STC (%)	20.50%

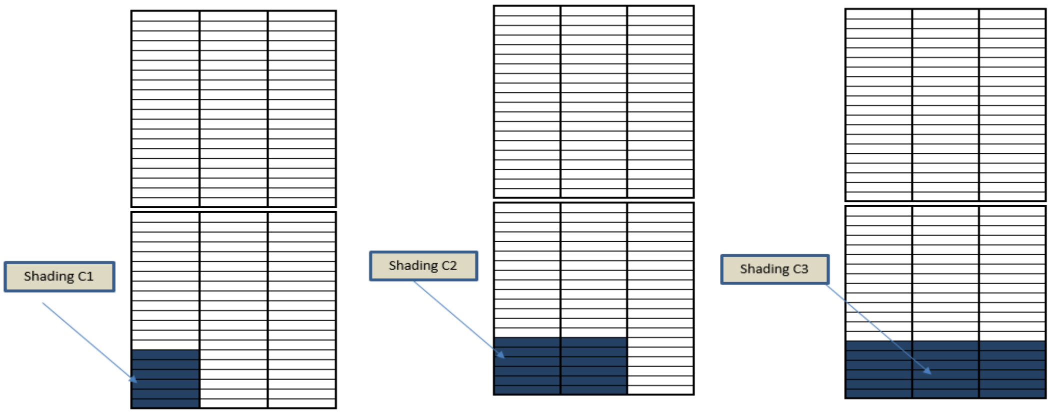

Fig. 6. Three cases considering various shading zone in the PV module formed of half cells: (a) shading of six halves cells; (b) shading of twelve halves cells; (c) shading of eighteen halves cell

IV. MATLAB SIMULINK MODEL FOR THE SYSTEM

In order to study the shading effect, a model of the solar cell is available in software library MATLAB / SIMULINK. The fig.7 provides a model of PV panels with the possibility allowed to modify the cell characteristics. The model block has the following ports: Ir Incident irradiance, (+) Positive electrical voltage and (-) Negative electrical voltage.

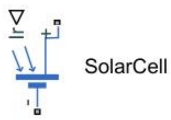

Fig. 7. Solar Cell model in SIMULINK MATLAB software

A simulation model of a PV module built from full-cells in the MATLAB/SIMULINK package is shown in fig.8. The simulation permit to establish the current I and power P curves fluctuations depending on voltage V.

In the same way, fig.9 reproduce the Simulation model of a PV module built from Half-cells in the MATLAB/SIMULINK package in the purpose to visualize the current and power attitude VS voltage considering the cases of shading configurations.

V. SIMULATION RESULTS FOR PV STRING SHADING

The obtained curves show that the shading affect the performance of PV panel. Its P-V plot indicates that the output power drastically decreases with its efficiency MATLAB/SIMULINK package in the purpose to visualize the current and power attitude VS voltage considering the cases of shading configurations.

There I-V and P-V plots of panel differ to a considerable extent from those without diode configuration. Because of bypass diode, the non-shaded cells in serial configuration generate its maximum current for the given irradiances.

In the presence of bypass diode, the additional peak is introduced in the PV panel characteristics. The panel has more power in comparison to the condition when diodes are not taken into consideration. Peak power of PV panel under shaded condition depends on the configuration in the panel.

The comparison between half-cells technologies and full cells technologies show that the first one is more suitable for shading problem effects.

In case C0, the result of I-V and P-V measurements are the same for full cells and half cells solar panel. When partial shading effect study is starting in case C1 by shading 6 half cells or 3 full cells, the I-V and P-V measurements were changed by comparison of the two solar panels technologies.

The simulation results show that the output of half-cells solar panel are high compared to full solar cell (figure 10). Also the current decrease by 17% in half cells solar panel and by 44% in full cells solar panel. The Relative Decrease in Voltage **ΔU** is 31%. In case C2 by shading 12 half cells or 6 full cells, the simulation results show that the output of the half-cells solar panel is high compared to full solar cells (figure 11). The Relative Decrease in Voltage **ΔU** is 72 %.

VI. DISCUSSION AND CONCLUSIONS

Shading effect is one of the influential factors results in a power output reduction of PV modules and arrays. The proposed model in this article was made on the basis of an assumed cases of partial shading. The model varied the degree of the partial shading and compare between half-cells solar panel and full cells solar panel. The half-cells solar panel are less susceptible to power losses resulting from the full cells solar panel due to the low current and generate low heating of this type of module.

During partial shading , the simulation results show that half-cells are more suitable for PV installation and especially for shifting objects like a vehicle when shading can't be estimated due to keep of moving in the road. Also shading lead to the formation of local peak and global peak in the I-V and P-V curve and the MPPT algorithm, as it will not be able to find the maximum power point.

In future studies, consideration should be given to dimension of vehicle and use the more possible area (roof, windows...) based in thin film solar panels in place of actual solar panel and the effect of partial shading on the MPPT to extract the maximum power

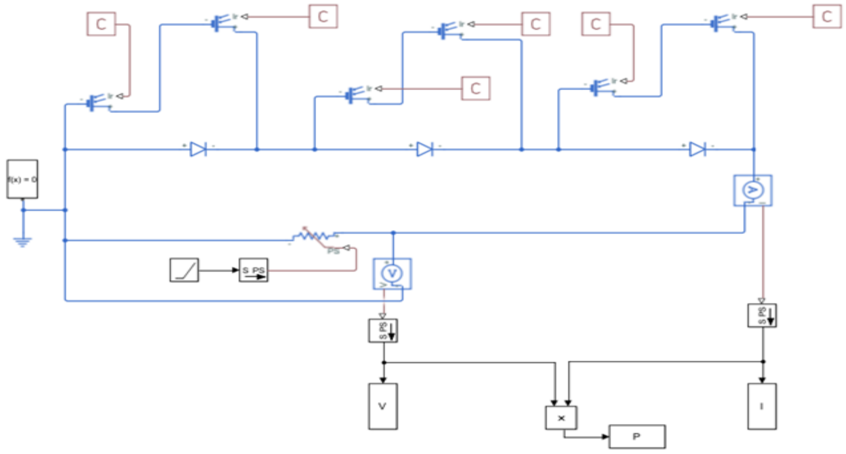

Fig. 8. SIMULINK model of full cell solar panel cases considering various shading zone in the PV module formed of half cells: (a) shading of six halves cells; (b) shading of twelve halves cells; (c) shading of eighteen halves cell

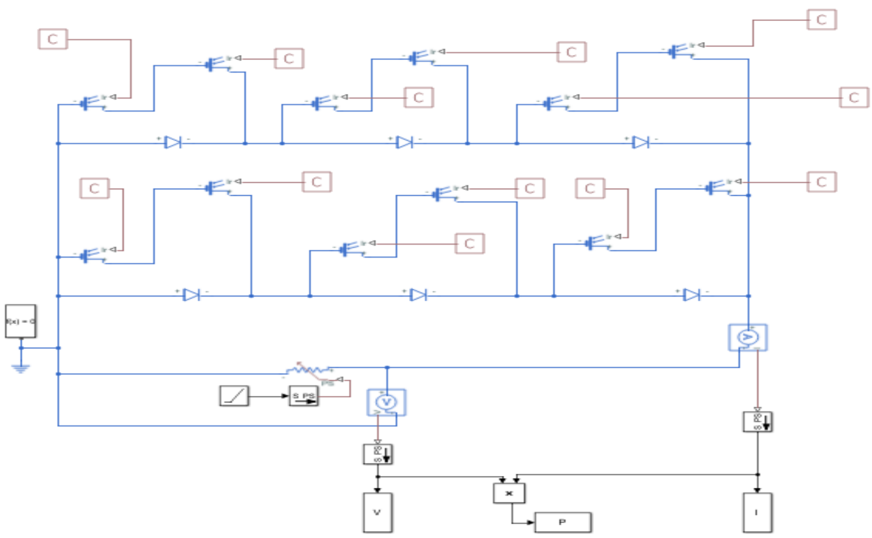

Fig. 9. Simulink model of half-cells solar panel

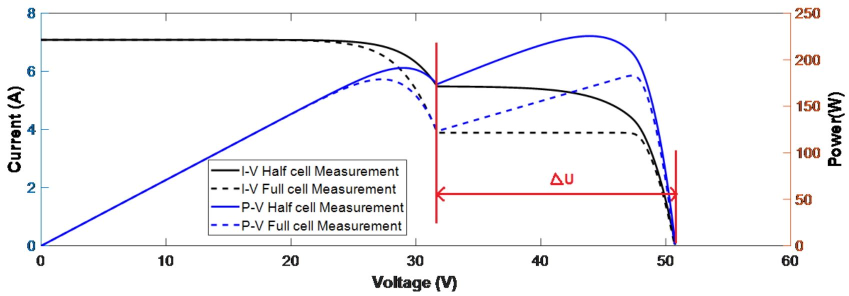

Fig. 10. I-V and P-V plots simulation results of scenario C1 for half-cells solar panel and full solar cells

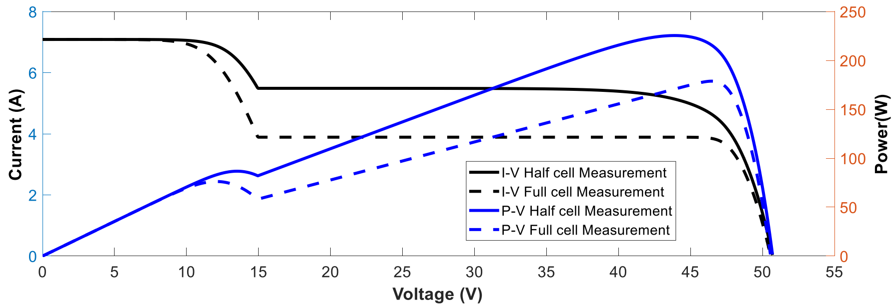

Fig. 11. I-V and P-V plots simulation results of scenario C2 for half-cells solar panel and full solar cells

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