

Experimental results of a photovoltaic simulator

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Abstract-- The development of PV power generation is faced to some economic difficulties when using real PV cells. First of all, PV cells are expensive. Also, in the case of high capacity PV power generators, the installation needs big ground and a large investment in terms of solar panels.

Moreover, these installations don't allow experimentations within different conditions of light and temperature.

For all these reasons, the PV array simulator becomes very useful and the development of PV power generator may be more rapid and easier.

The work presented in this paper deals about an experimental platform of a PV simulator which is realized in the laboratory of Automatic at the University of Setif1, Algeria. This platform is based on a DC/DC converter associated to a PI Controller with a DSPACE 1104 for the implementation of the algorithm. The main objective of this platform is to emulate the current-voltage output characteristics of actual PV arrays under different temperatures and solar irradiations. The modeling of PV cells is based on the electric model "One diode" and the parameters are extracted by using the commercial PV panel SM110-24.

The experimental results indicate that, using the proposed method, the PV module I-V Characteristics are reproduced with an average accuracy of 0.03%. Therefore, the developed platform can be used in laboratories for experimentation without worrying about unnecessary investments.

Keywords: Photovoltaic simulator, dc/dc converter, DSPACE1104, photovoltaiques panel, solar energy.

I. INTRODUCTION

A solar panel is a device that converts light into electricity. Solar electric energy is being used on a larger scale because of environmental concerns and to some extent falling price of solar cells. Manufacturers of solar electric equipment need solar panels for testing their product such as characteristics of the solar cells and maximum power tracker circuit. Photovoltaic (PV) simulators are indispensable for the operational evaluation of PV energy production system components (e.g. battery chargers, DC/AC inverters, etc.), in order to avoid the time-consuming and expensive field-testing process.[1]

Several methods of PV simulators have been suggested such as Microcontroller-based PV simulator implementations are presented in [2]-[3]. The PV module mathematical model included in the microcontroller program is used to control a power converter, which is usually of switched-mode type in order to achieve high energy conversion efficiency.

Some simulators are implemented using experimental PV equivalent circuit with diodes [4], this simulator using experimental PV equivalent circuit with diodes uses the short circuit current to be its input, not the real inputs of the solar cell: solar irradiance (s) and cell's temperature (T).

Or by using a switched - module power converter controlled by digital chips or analog circuit to fill the current-voltage output characteristics of PV arrays [1]-[5]-[6].

In this paper PV array simulator based in DC/DC Converter which controlling by DSPACE 1104 using PI Controller with reference from PV model, and resistance is used as the load. Through changing the value of resistance, a series of data on work points of load.

II. PV CHARACTERISTIC

PV array is a p-n junction semiconductor, which converts light into electricity. When the incoming solar energy exceeds the band-gap energy of the module, photons are absorbed by materials to generate electricity. The equivalent- circuit model of PV is shown in Fig. 1. In this model, it consists of a light-generated source, diode, series and parallel resistances. The mathematical expression of the equivalent model can be written as (1)–(3). Where R_s is relatively small and R_{sh} is relatively large, which are neglected in the equation in order to simplify the simulation.[8]

$$I = I_{ph} - I_d \left[\exp \left(\frac{q}{k_B T_A} V \right) - 1 \right] \quad (1)$$

$$I_{ph} = S [I_{scT} + K_1 (T - T_r)] \quad (2)$$

$$I_d = I_{rr} \left[\frac{T}{T_r} \right]^3 \exp \left(\frac{q V_g}{k_B T} \left[\frac{1}{T_r} - \frac{1}{T} \right] \right) \quad (3)$$

where

I, V output current, voltage (A, V).

T cell temperature (K).

S solar irradiance (W/m²).

I_{ph} light-generated current.

I_d PV saturation current.

I_{rr} saturation current at Tr.

I_{scr} short-circuit current at reference condition.

T_r reference temperature.

K_i short-circuit temperature coefficient.

q charge of an electron. = 1.6*10⁻¹⁹ C

k_b Boltzmann's constant. =1.38*10⁻²³ J/k

E_g band-gap energy of the material.

Q total electron charge.

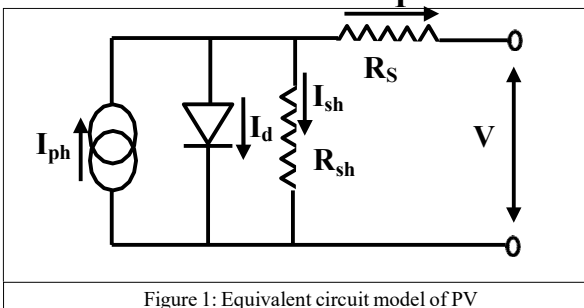


Figure 1: Equivalent circuit model of PV

The PV characteristic is plotted in Fig. 2

The other parameters those have not been defined in above equations, are adopted from parameters of SM110-24 solar cell and listed in Table 1. The value of series and shunt resistances ($R_s = 0.691$ ohm and $R_{sh} = 10850$ ohm) are adopted from [8]. Cell's temperature and solar irradiance will be the inputs for this system, so their value can be varied and analyzed then.

TABLE 1 SOLAR CELL SM 110-24 PARAMETERS'

nominal Power	P _n	110W
maximum Power	P _{mpp}	110W
Maximum power voltage.	V _{mpp}	35V
Open circuit Voltage	V _{oc}	43.5
Short circuit current	I _{sc}	3.45A
Tolerance on Peak Power		±5%
Temperature	NOCT	45°C
number of series solar cells	N _s	72

A. (I- V)(I-P) Characteristic Curve

Theoretical P-I-V characteristic curve can be calculated through PV characteristic equations. Fig 2a,b shows the i(v), p(v) characteristic curve of the PV cell using MATLAB/Simulink.

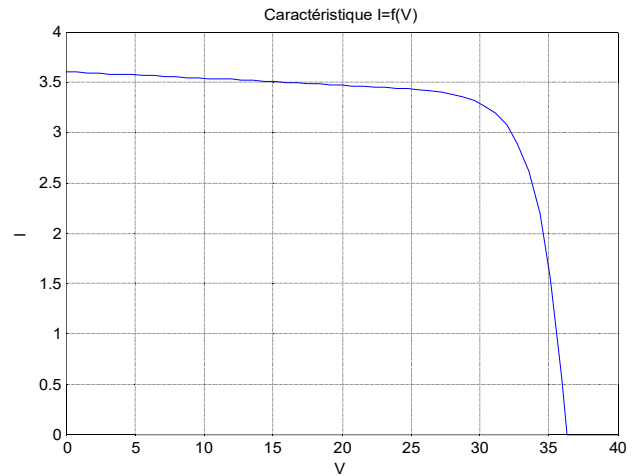


Figure 2.a I-V characteristics of a solar panel

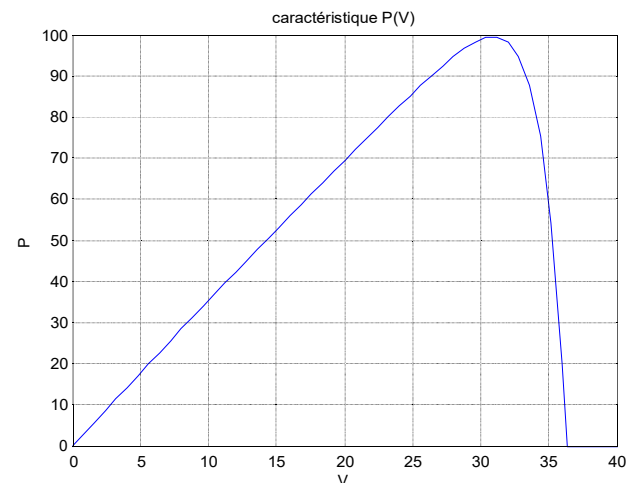


Figure 2.b P-V characteristics curve of a solar panel

II. THE BLOCK DIAGRAM OF THE PROPOSED PV SIMULATOR

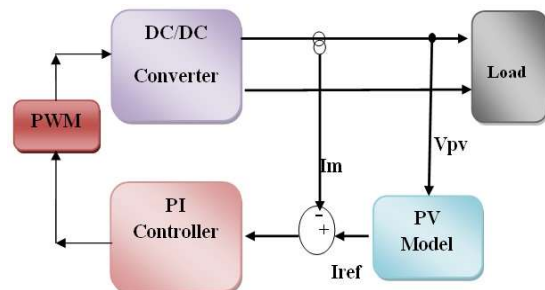


Figure 3. PV simulator block diagram.

As illustrated in Fig. 3, the proposed PV simulator is composed of five subsystems:

The designed circuit is buck converter which outputs a voltage source with the output current is controlled to create current as its reference determined by the PV model. Figure 1 shows the PV simulator block diagram. As shown in the figure, the PV static model require voltage to calculate the current reference I_{ref}

Voltage that'll be referenced to the PV Static Model is the output voltage measured at load R.

the one that will be controlled is the current and it will be controlled by PI controller and generate PWM pulse on the next block.

A constant frequency PWM control signal, VPWM, is produced by the DSPACE unit and it is used to control the power switch in order to modulate the DC input voltage into a high-frequency wave, The DC output voltage is regulated to the desired value by adjusting the PWM signal duty cycle value. The simulator DC output voltage is measured using a voltage divider, while the DC output current is measured using a current shunt sensor. Both sensors are connected

A. Simulation results in different operation point

The proposed simulator works at the intersection of its own output curve and the load's I-V characteristic curve. Taking resistive load as example, when the load changes from R1 to R2 or from R2 to R3, the operation point will transfer from point A to B, and then to point C correspondingly as show in Fig 4.a,b.

Fig4.c show the Result of output current in different operation point

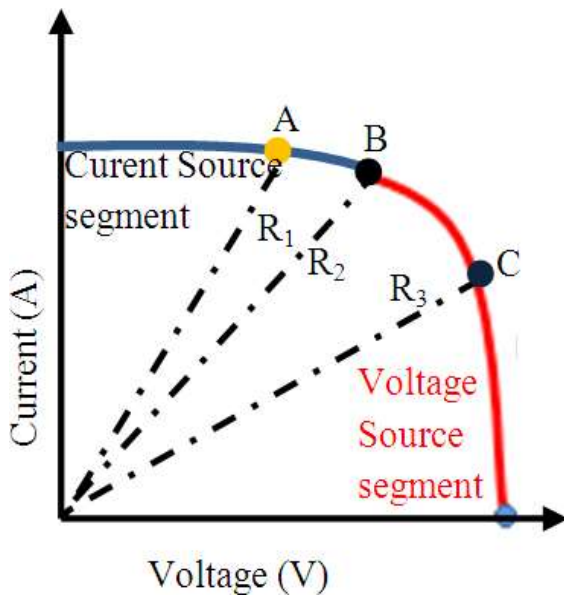


Figure 4.a operation point of PV

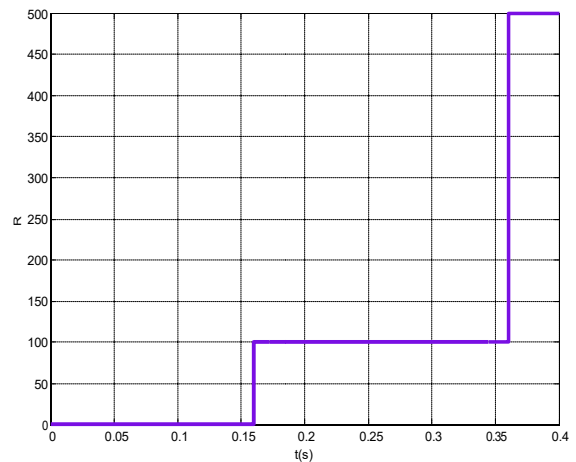


Figure 4.b variation of load

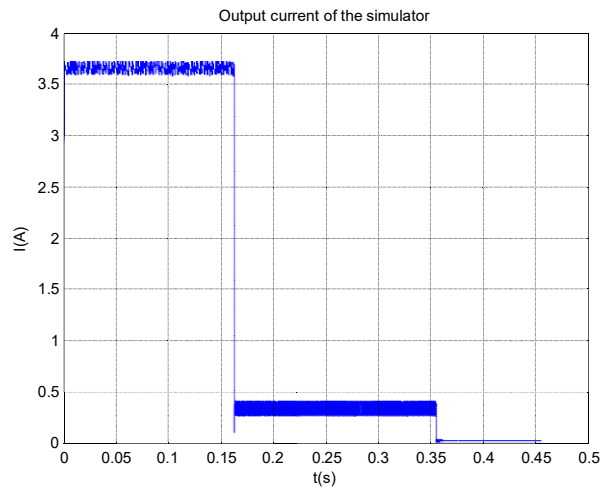


Figure 4.c output current in different point

B. Control strategy

the basic principle of pv array simulator based on the descriptions of the pv array mathematical model and the PI control method

the basic control principle of PV array simulator can be designed, as shown in Fig .5. For the most PV power generators, a DC-DC converter or a voltage source PWM inverter is adopted, and a DC resistor is used in the input. So the voltage of the load can be used as output voltage of PV array simulator. The output current is the control object of PV array simulator. Therefore, the reference current can be obtained from the V-I characteristic curve of PV array based on voltage value of load. Then output current is controlled to be corresponded to the reference current. Therefore, the outputs of PWM rectifier are the same to the real PV array.

The Transfer Function Block Diagram of Buck Converter PV-Simulator is in Fig 5[9]-[10]

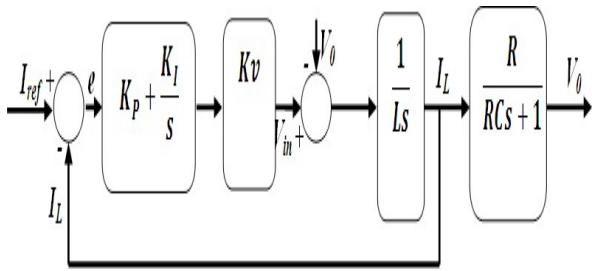


Figure 5 Transfer Function Block Diagram

III. PHOTOGRAPH OF THE PROPOSED PV SIMULATOR & EXPERIMENTAL RESULTS

As to verify the simulation, A prototype PV simulator has been developed using the above described methodology, tested and evaluated in the laboratory. its photograph is shown in Fig. 6. A resistor bank was used as the load. The voltage sensor and the current sensor

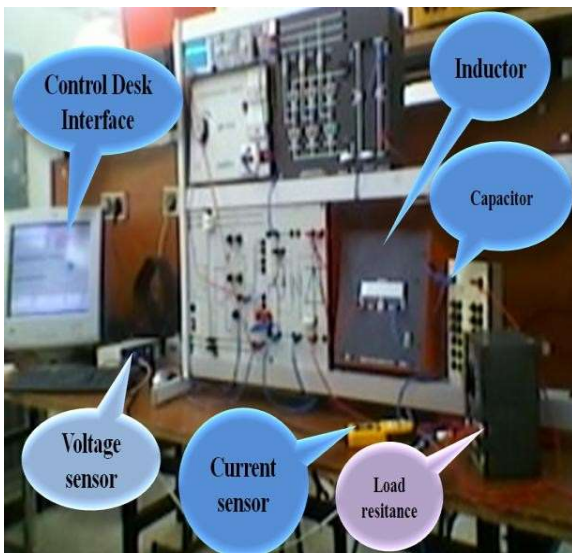


Figure 6. Photograph of the proposed PV Simulator

For the in-laboratory evaluation, the dc input voltage is set to 40V. The currents are measured by using ac current clamps Fluke i400S.

A. Experimental results

A hardware circuit that emulates PV characteristic is built Fig.6 and tested. Fig. 7a,b shows the experimental results of the current–voltage reference curves and P(V) characteristic curve using the PV equivalent circuit shown in Fig. 1 at T= 25°C and G= 350 W/m²

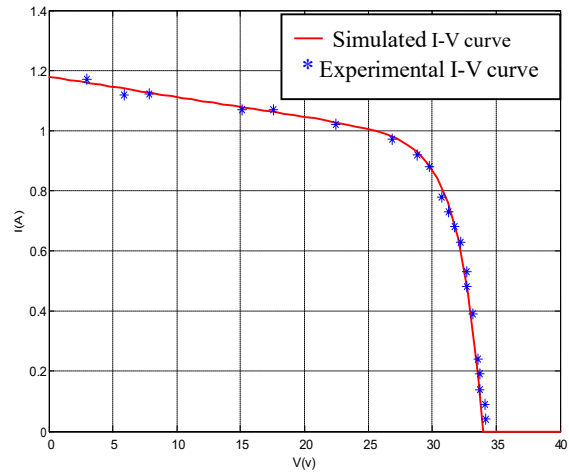


Figure 7.a Experimental & simulated I-V curve

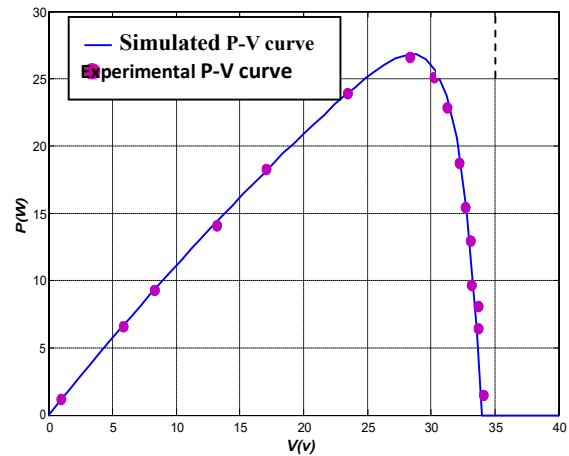


Figure 7.b Experimental & simulated P-V curve

In Fig.7, we present corresponding experimental and simulated real power traces for both generated and consumed power.

The error between measured and simulated data is under 0.03%.

For the experimental result, the currents and phase voltages are measured and shown in Fig.8 respectively

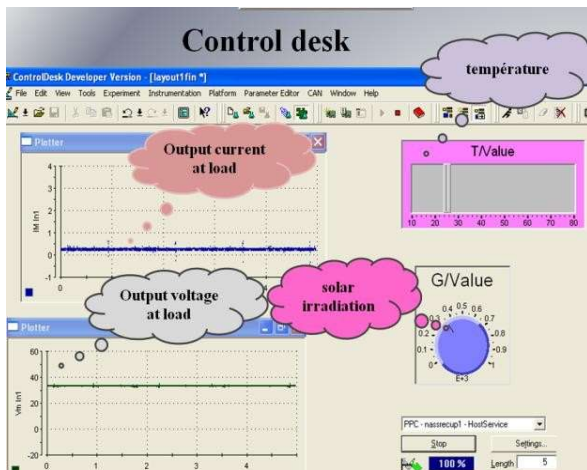
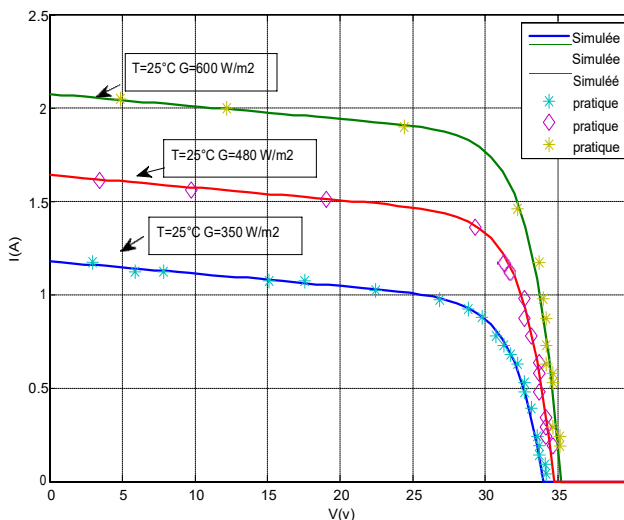


Figure.8 Experimental output current and voltage

B. Experimental results at different irradiances

PV characteristic under different irradiance levels (temperature= 25°C Fig. 9 shows The PV curves were generated by the power stage at different irradiance reference levels.



IV. CONCLUSION

An innovative PV field simulator has been proposed and its power architecture and control design has been presented in this paper.

The proposed simulator makes it possible to reproduce the I-V characteristic of an actual PV field, as a function of modules and climate characteristic parameters.

PV simulator consists of a step-down dc-dc converter and controlled by a DSPACE DS1104 controller board. According to the mathematical modeling of the I-V characteristics of PV

arrays and the analysis of the current control process;

The experimental results indicate that, using the proposed method, the PV module I-V characteristics examined are reproduced with an average accuracy of 0.03%.

The simulator may be used to design laboratory experiments or as a teaching aid apart from being used for testing and development purposes.

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