Design and development of an IV tracer for photovoltaic panels characterization

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***Abstract*— Our project consists in designing of an autonomous and portable instrument which allows the on field measurement of IV feature as well as of the main parameters of a single panel and of the whole photovoltaic (PV) in order to compare them with the data provided by the PV panels manufacturer. The comparison between the measured and the provided data allows immediately whether the current panel features coincide with those reported by the manufacturer.**

The instrument in question is essentially an electronic load controlled by a microcontroller PIC18FXXX who will trace the IV curve and display principals characteristics of the photovoltaic panel on a GLCD (Graphic LCD), in particular its current of short-circuit, open circuit voltage and maximum power. All this tests are carried out under temperature and solar irradiation conditions.

Keywords- Photovoltaic panels, current-voltage characteristics, electronic load.

I. INTRODUCTION

Photovoltaic (PV) panels are highly reliable, but performance problems always arise, and the industry needs fast and accurate tools to detect them. The producers in actually PV power plants want to ensure that all the PV panels and strings are of a consistent quality, that they were not damaged during expedition or installation, and that the array produces the contractual power. These producers would a permanent record of the as-built system performance, a benchmark for comparison since the arrays age and degrade especially in cases where warranty negotiations are required. Later in the system's life cycle, companies O & M (Operations and Maintenance) want to evaluate the state of older arrays and have the ability to efficiently locate a faulty panel.
I-V curve tracers can provide a visual representation and a quantitative measure of PV panel performances. Initially, curve-tracers instrument was developed for testing transistors and diodes. Now it is a priority in PV R&D (Research and Development) and manufacturing, for using with individual cells and panels. [1]

II. Solar Module Electrical Test Basics

I-V curves or traces are measured by sweeping the load on a PV source over a range of currents and voltages. Curve tracers accomplish this by loading a PV module or string at different points across its operating range between 0V and Voc.

At each point, the output current and voltage are measured simultaneously. The load presented by the curve tracer may be resistive, reactive (typically capacitive) or electronic. Field test gear uses resistive or capacitive loading, whereas reference I-V test systems at research facilities tend to use electronic loads.
In field test equipment, the actual I-V measurement sweep typically requires less than a second. However, there is a sweep speed limit for certain cell types. High-efficiency cell technologies from Sanyo, Sun Power and other manufacturers cannot be swept arbitrarily fast. Because these cells store considerably more charge, more time is required for the cells to reach steady-state operating conditions at each point in the curve. [1]
There are a number of key parameters that are typically measured in any testing environment: [2]

- Open-circuit voltage (Voc): The module voltage at which point there is zero current flow.
- Short-circuit current (Isc): The current flowing out of the module when the load resistance is zero.
- Maximum power output of the cell (Pmax): The voltage and current point where the module is generating its maximum power. The Pmax point on an I-V curve is often referred to as the maximum power point (MPP).
- Voltage at Pmax (Vmax): The module's voltage level at Pmax.
- Current at Pmax (Imax): The module's current level at Pmax.
- Conversion efficiency of the device (η): The percentage of power converted (from absorbed light to electrical energy) and collected when a solar cell is connected to an electrical circuit. This term is calculated using the ratio of the maximum power point, Pmax, divided by the input light *irradiance* (E, in W/m²) under standard test conditions (STC) and the *surface area* of the solar cell (Ac in m²).

- Fill factor (FF): The ratio of the *maximum power point,* Pmax, divided by the *open circuit voltage* (Voc) and the *short circuit current* (Isc)

- Cell diode properties
- Cell shunt resistance

- Cell series resistance

FIG1 show the principals characteristics of the photovoltaic module. [1]

III. Electronic load

The electronic load is an instrument, which permits to simulate a static or dynamic load. It can be used to test PV modules and strings. It allows an electronic control of the current or voltage load . The electronic load developed in this work is based on linear metal oxide semi conductor field effect transistors (MOSFET) as shown in FIG2. VGS is the gate-source voltage, VDS the drain-source voltage and ID the drain current of the MOSFET. VPV is the output voltage of the PV module, IPV the output current, ISC the short circuit current and VOC the open circuit voltage. **[4]** and **[5]**

The operating point of the MOSFET is determined by: (a) the characteristics of the PV panel, (b) the characteristics of the MOSFET, and (c) the circuit

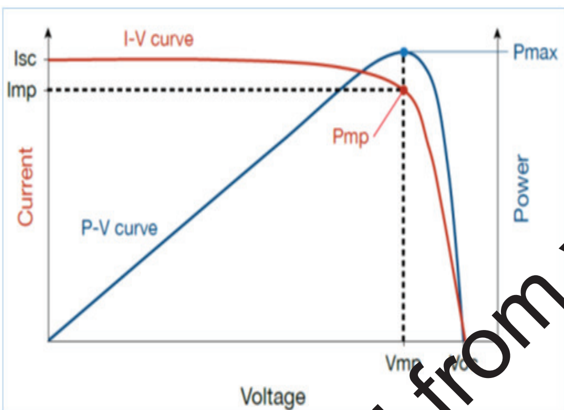

FIG1: Principals characteristics of the photovoltaic panel.

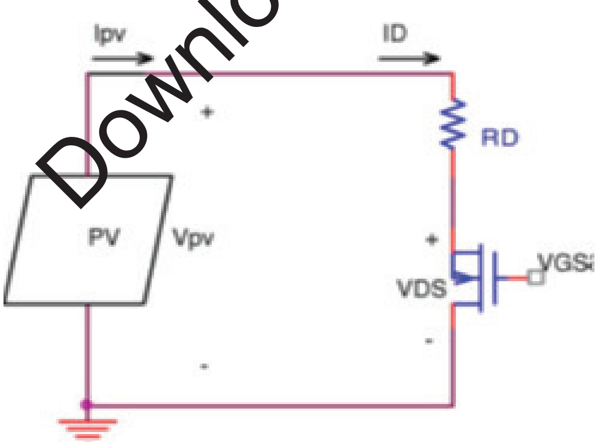

FIG2: Basic circuit test

connection. All the voltages and current in the circuit can be determined by solving the equations representing the three groups. First the characteristics of a MOSFET :

$$\mathbf{I_D = K_N(V_{GS} - V_t)^2}$$
$$\textbf{for constant current region} \qquad (1)$$
$$\mathbf{I_D = K_N\left(2(V_{GS} - V_t)V_{DS} - V_{DS}{}^2\right)}$$
$$\textbf{for ohmic region} \qquad (2)$$

Where $\mathbf{K_N}$ is the device constant, $\mathbf{V_t}$ the threshold (gate) voltage, $\mathbf{V_{GS}}$ the gate-source voltage, $\mathbf{V_{DS}}$, the drain-source.

Voltage, and $\mathbf{I_D}$ the drain current of the MOSFET. The approximate equation for a PV panel can be written as:

$$\mathbf{I_D = I_{PV} = I_{sc} - I_s e^{KV_{pv}}} \qquad (3)$$

Where $\mathbf{V_{PV}}$ is the voltage across the PV panel, $\mathbf{I_{PV}}$ the panel output.

Current of the PV panel which is equal to $\mathbf{I_D}$, $\mathbf{I_{sc}}$ the short circuit current, $\mathbf{I_s}$ the dark-saturation current of the PV panel and $\mathbf{K}$ is a constant which depends on the temperature and cell arrangement in the panel . The series resistance of the panel RS is neglected in Eq. (3)

The following equation can be written for the circuit:

$$\mathbf{V_{PV} = V_{DS} + R_D I_D} \qquad (4)$$

When the MOSFET is working in the constant current region

($(V_{GS} - V_t) < V_{DS}$), Eqs. (1), (3) and (4) hold. When the MOSFET is working in the ohmic region **($(V_{GS} - V_t) > V_{DS}$)**, Eqs. (2) and (4) hold. If the PV characteristic, the MOSFET characteristics and $\mathbf{R_D}$ are all given, the operating point of the MOSFET is determined by the value of $\mathbf{V_{GS}}$. By sweeping $\mathbf{V_{GS}}$ in the appropriate range, the operating point of the MOSFET can be changed, which also drives the operating point of the PV panel to move along its *I–V* characteristic curve.

This process is illustrated in **FIG3**, which shows the load curves (nonlinear) for the MOSFET drawn for different values of $\mathbf{R_D}$ and the characteristics of the MOSFET. **[3]**

IV. DESIGN AND SIMULATION

The aim of our work is to design a microcontroller –based instrumentation system for testing photovoltaic panels performances by the way of tracing the IV characteristic and extracting the principals electric parameters of this curve such us the maximum power (**Pmp**), voltage at Pmp (**Vmp**) current at Pmp (**Imp**), short-circuit current (**Isc**) and open circuit voltage (**Voc**). All that under real meteorological test conditions like temperature and solar irradiation, which have a direct influence on the photovoltaic panel operation.

All results will be presented later on a Graphic LCD displaying 128 X 64 pixels. The principle of this circuit is to connect a variable electronic load with the PV panel or group of PV panels; create at each step a new operating system point i.e. a new pair (Current – voltage) until the sweep of the entire curve.

This system is designed around a PIC microcontroller 18F4XX which manages the electronic load control, the different data acquisitions and displaying on GLCD.

The circuit therefore includes several blocks as shown in **FIG4**:

- Current and voltage measurement.
- Temperature and irradiance measurement.
- The electronic load based on MOSFET.
- A converter PWM/DC to attack the gates of the MOSFETs.
- A microcontroller.

A. ***Command stage:*** PWM/DC converter: this circuit is used to convert a PWM signal derived from a microcontroller into DC voltage whose value is proportional to the duty cycle of the PWM signal.

B. ***Temperature sensor:*** this block supports the measurement of temperature, for this, we will use a CZ LM35 type available on the market.

C. ***Solar irradiation sensor:*** The measurement is done using a reference cell. The short circuit current is proportional to the light flux, it is sufficient to measure the difference of voltage at the terminals of the shunt and then amplifying it adequately to deduce the value of the luminous flux (W/m²).

D. ***Current sensor:*** A shunt resistance of 0.1 Ω is used for generating a voltage image Vc to be injected in a ADC pin of a µC after amplification and adaptation.

E. ***Voltage sensor:*** we use a simple voltage divider for this task.

F. ***Microcontroller:*** the microcontroller used is the 18F458 manufactured by Microchip; a component meets the requirement of our system.

FIG4 shows the block diagram of the whole system.

The simulation is done using PROTEUS software as shown in **FIG5:**

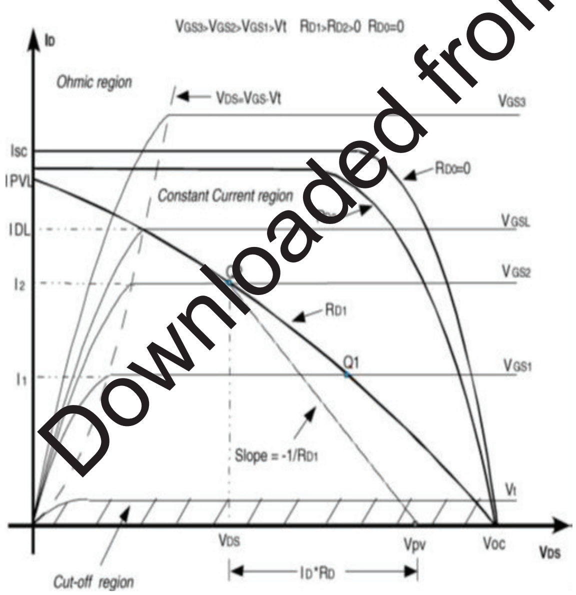

FIG3: MOSFET characteristics and load

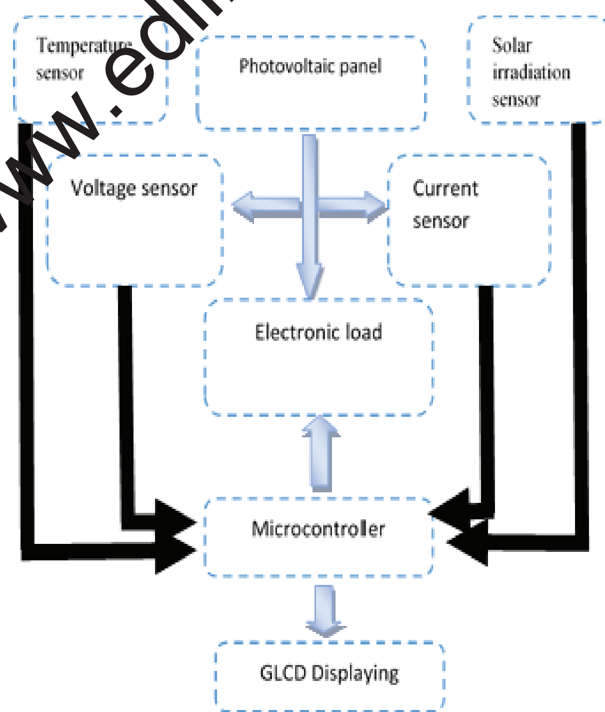

FIG4: Block diagram of the whole system of PV panel characterization

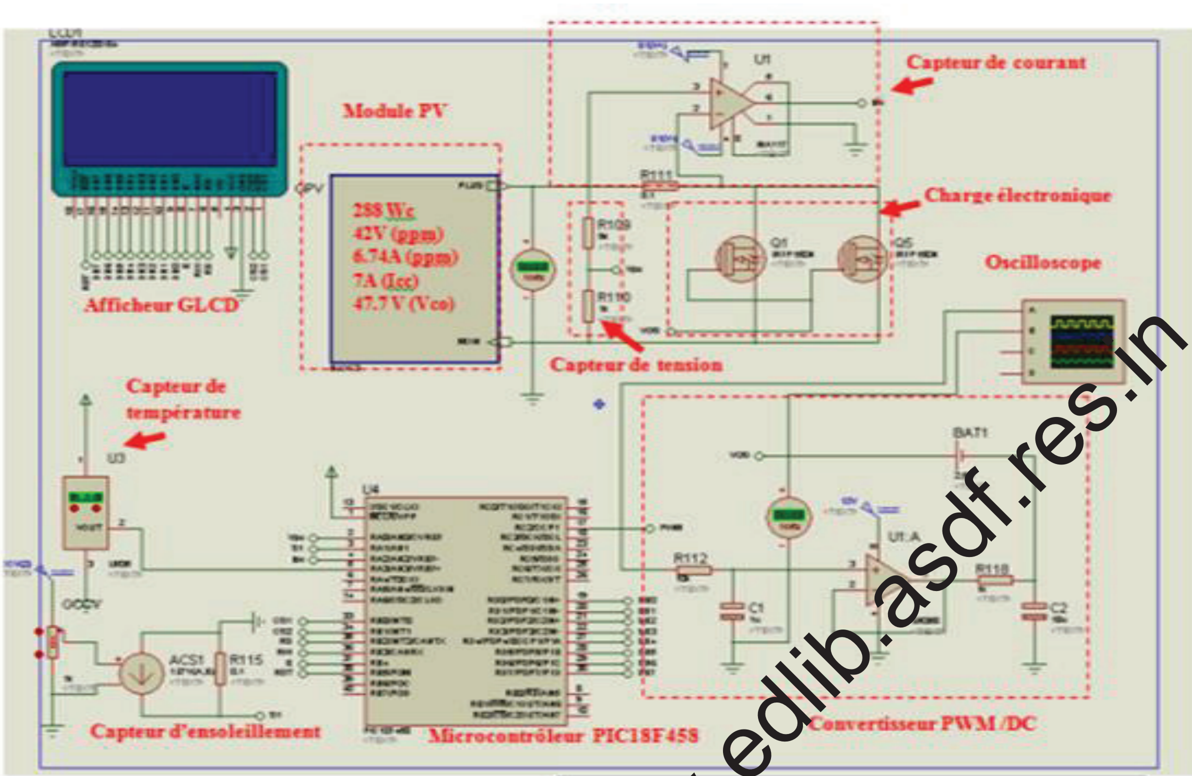

FIG5: Global circuit of the IV tracer in PROTEUS.

V. SIMULATION RESULTS:

The input and output signals of the PWM/DC block, the IV cure tracing of the PV panel with 288 W_p and the displaying of all important electrical and meteorological parameters are shows respectively in FIG6,7,8 and 9.

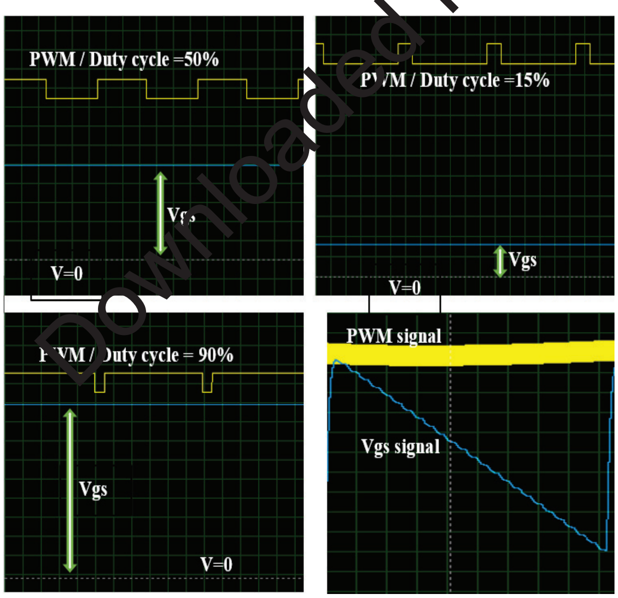

FIG6: Shape of the voltage Vgs

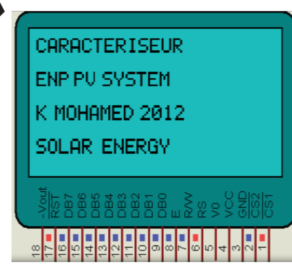

FIG7: Home page

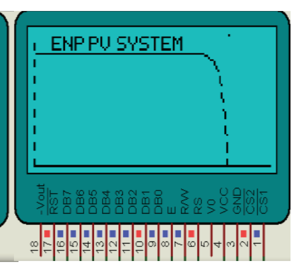

FIG8: IV curve tracing

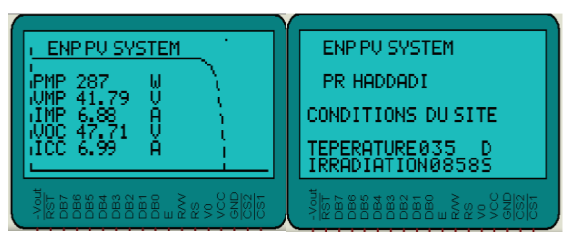

FIG9: Displaying of the electrical and meteorological parameters

ISBN : 978-81-925233-8-5

VI. CONCLUSION

IV curve tracing is the most informative measurement that can be performed on a PV panel. The visual shape of the curve provides immediate diagnostic for a PV specialist.

When coupled with the associated solar irradiance and temperature data, it provides a quantified comparison to expected performance.

The basic element in our work is the electronic load; it allows an electronic control of current of the PV panel. It is based on the MOSFET which present a simplicity to the command contrary to the bipolar transistor.

The portability and the autonomy of the IV tracer ensured by the use of the microcontroller and a graphic LCD displaying is essential for a diagnosis on field and gives the possibility of making immediate decisions for possible operations of repair and maintenance.

The IV tracer presented in this work is basic and it is an initial step towards a more efficient and complete product; several ameliorations can be envisaged:

- Integrate new, more reliable and more accurate sensors.
- Embed a memory for saving different measures and curves.
- Development of a communication interface with the server or the PV plant control system using a cable connection or wireless connection (WIFI) for a deeper and more advanced statistical studies diagnosis.
- Improvement of the calculation algorithm in order to be able to extract all the other parameters characterizing a module or a photovoltaic generator and can be to implement it on more powerful calculator like DSP or FPGA.
- Dimension the stage of power to be able to support voltage until 1000V and of the current up to 10 A which are the two ordinary values of a photovoltaic string in a large scale PV power plant.

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