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Modelling and simulation of an automatic solar module characteristics data acquisition system

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Abstract: This paper is devoted to the design and simulation of an automatic data acquisition system of solar module characteristics. The system is essentially composed of three parts. The first part is devoted to the acquisition of the electrical parameters of the solar module (Current, Voltage and Power) in automatic ways using an automatic variable load. The second part is focused on devices which measure the ambient temperature and solar irradiation. In the last part, we study the design of an acquisition interface and a database for data saving. The results of simulations validate the correct operation of the measuring bench.

Keywords: PV MODULE, AUTOMATICALLY VARIABLE LOAD, ACQUISITION INTERFACE, DATABASE

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Introduction

The performance of photovoltaic modules is based on a number of significant parameters extracted from the characteristic I-V such as the short-circuit current I_{sc} , the open-circuit voltage V_{oc} , the current I_{mpp} , and the voltage V_{mpp} at the point of maximum power, the form factor FF, the series resistance R_s and the shunt resistance R_{sh} [1]. On the other hand, the atmospheric parameters in which the solar module must operate are generally not taken into account by the manufacturers. These climatic parameters often change abruptly, which can affect the efficiency of photovoltaic

systems [2]. Thus, to study their influence on the operation of the solar module, it would be interesting to have a database in which various data (PV Current, voltage and Power, Temperature and irradiance) will be permanently recorded for their exploitation.

This work consists in designing a device for automatic acquisition of the characteristics of solar modules and climatic parameters.

To have the characteristic of the current (I) as a function of the voltage (V), we opted for an automatic variation of the load at the terminals of the PV module which is an 8-bit R / 2R digital-to-analog converter (DAC). The climatic parameters taken into

account are the temperature and solar irradiation. The acquisition of all these parameters is done in automatic ways controlled by a microcontroller which name is PIC16f877. The overall scheme of the simulated electronic card is design under the ISIS PROTEUS software.

Synoptic diagram of the system

As we pointed out in the introduction, the purpose of this work is to have a database in which data will be permanently recorded. This is the result of an automatic device set to acquire all these data. To realize this automatic system of acquisition, it is necessary to involve a certain number of elements:

The solar module: which is a technological device intended to convert solar radiation into electrical energy.

Automatically Variable load: current and voltage values measurement requires a variable load that will vary the voltage and the current at the terminals of the solar module, which will be used for plots of different characteristic curves.

Sensors: to measure the climatic parameters.

Acquisition card: responsible for collecting all these parameters that we want to record in the database.

Computer: After acquisition and appropriate conversions of data by the acquisition card, it is necessary to route them to a computer (Computer) via a RS232 serial link for operation and possibly storage.

The figure below illustrates the synoptic diagram of the system

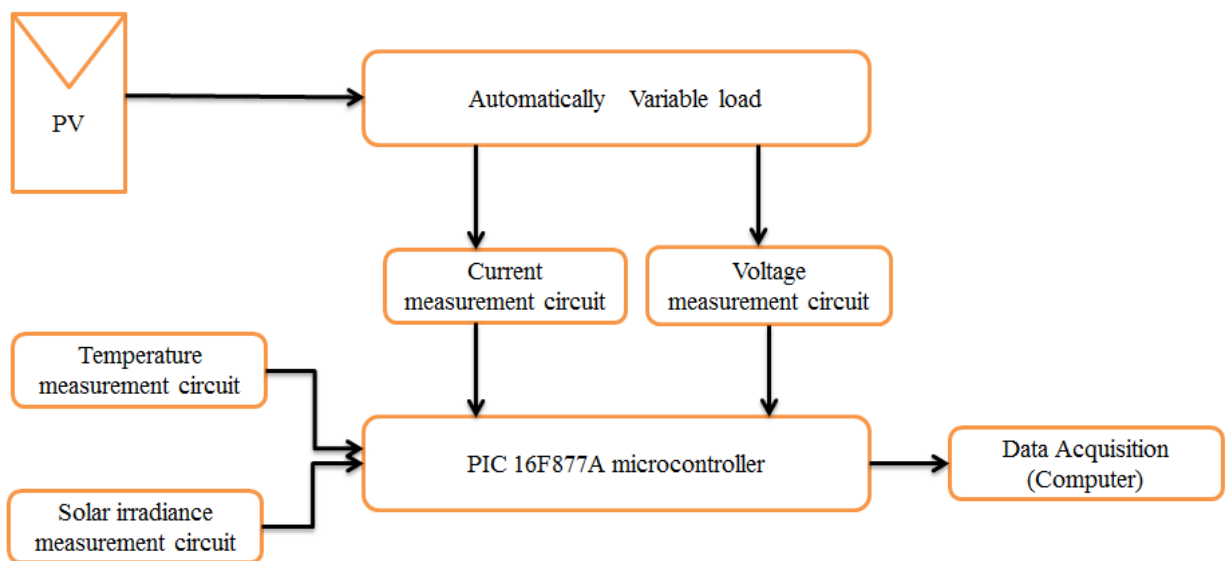


Figure 1: Synoptic diagram of the automatic acquisition system

Effects of Climatic parameters on solar cells

Climatic parameters such as temperature and irradiation have a considerable influence on the characteristics of a solar module. Increasing the temperature with fixed irradiation results in a net decrease of the open circuit voltage (V_{oc}) and an increase of the short circuit current (I_{cc}), as well as a decrease in the maximum power (P_{max}). Similarly, when the irradiation varies for a temperature kept constant at 25 ° C, the short-circuit current (I_{cc}) varies due to the irradiation, whereas the open-circuit voltage (V_{co}) varies very little [3].

Measurement of electrical parameters

Equivalent Circuit of Solar Module

In the absence of a solar module model under the ISIS software that we used, we designed a simpler diode module model by paralleling a current and voltage generator. Using a voltmeter and an ammeter, we made sure to obtain the critical values of our photovoltaic generator, namely, the maximum short-circuit current I_{cc} and the maximum open-circuit voltage V_{oc} .

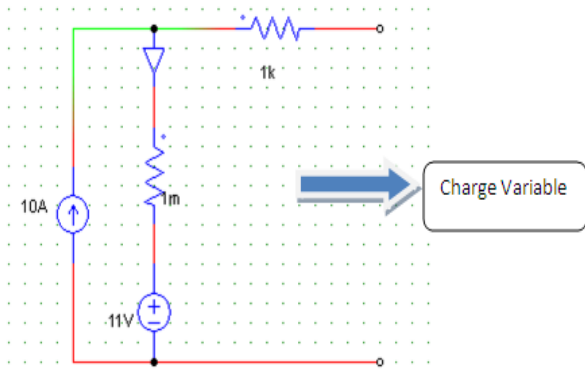


Figure 2: one-diode module model

Our study will focus on the monocrystalline SP75 with the following features:

| | |
|------------------------------|--------|
| Maximum power Pmax | 150 W |
| Optimum maximum tension Vopt | 17.6 V |
| Optimum maximum current Iopt | 9.19 A |
| Open circuit voltage Vco | 21.6 V |
| Short circuit current Icc | 10.2A |

Table 1: Characteristics of the single-crystal SP75 panel

Automatically variable load

For the automatically variable load, we use an 8-bit R / 2R (Figure 3) digital-to-analog converter (DAC) developed in [4]. It is a resistance network composed of only two values, R and 2R. The role of this load is to automatically vary the impedance at the terminals of the photovoltaic generator (GPV) to allow measurement of the current and voltage of the module. With this load R / 2R network, we can obtain 256 measurements of current-voltage torque (I-V).

To control this digital resistor, we will need a sequencer, an automaton that is responsible for generating the control signals needed to operate and control the units involved in the execution of a given instruction. We use PIC microprocessor as a sequencer, very popular specialized and accessible on the local market. The binary signals generated by a sequencer and applied to the transistors set the value of the resistor.

The bipolar transistor is chosen as an electronic switch due to the low power loss compared to others types of transistors.

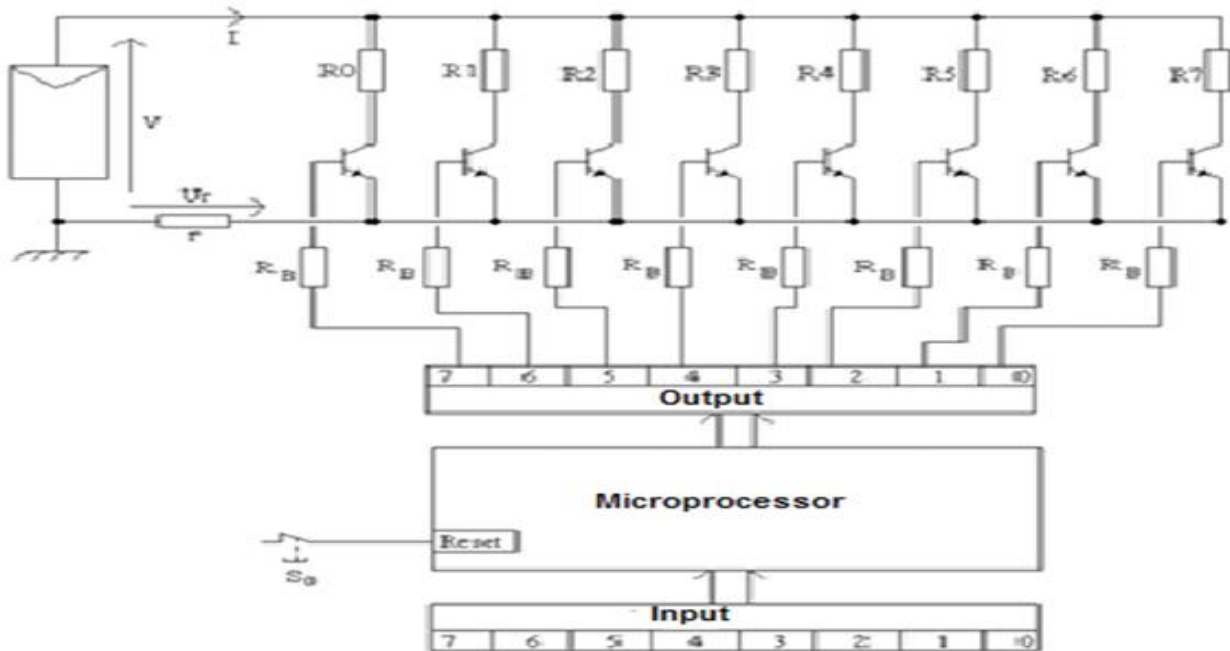


Figure 3: Programmable control of the automatically variable load.

Voltage measure

We use a voltage divider bridge to measure the voltage. It is made by two resistors placed between the output of the solar panels and the ground. Figure 4 allows to go from the voltage V_{pv} at the outputs of the photovoltaic module to the voltage V_{pm} range in 0 and 5 volts, to be then measured by the microcontroller.

The relation expressing the voltage V_{pv} as a function V_{pm} is:

$$V_{pm} = \frac{V_{pv} \cdot R_{12}}{R_{11} + R_{12}} \quad (1)$$

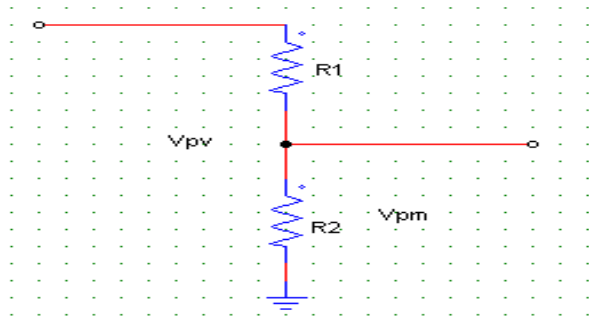


Figure 4: Diagram of voltage measurement

Current measurement

For current measurement (Figure 5) the simplest method is to measure the voltage across a resistor to derive the current flowing through it. This method is not expensive compared to other techniques and provides good accuracy in low frequency. The measuring resistor and the circuit associated with it must have good temperature stability and good accuracy [5].

As for the voltage measurement circuit, this voltage obtained at the output of this amplifier must be between 0 and 5 volts and thus be measurable by the microcontroller. The I_{pv} current of the photovoltaic generator is:

$$I_{pv} = \frac{V_{shunt}}{R_{shunt}} \quad (2)$$

The relationship between the measured voltage (V_m) and the shunt voltage (V_{shunt}) is:

$$V_m = -\frac{R_2}{R_1} \cdot V_{shunt} \quad (3)$$

R_1 and R_2 must be chosen so that V_m is between 0 and 5 v.

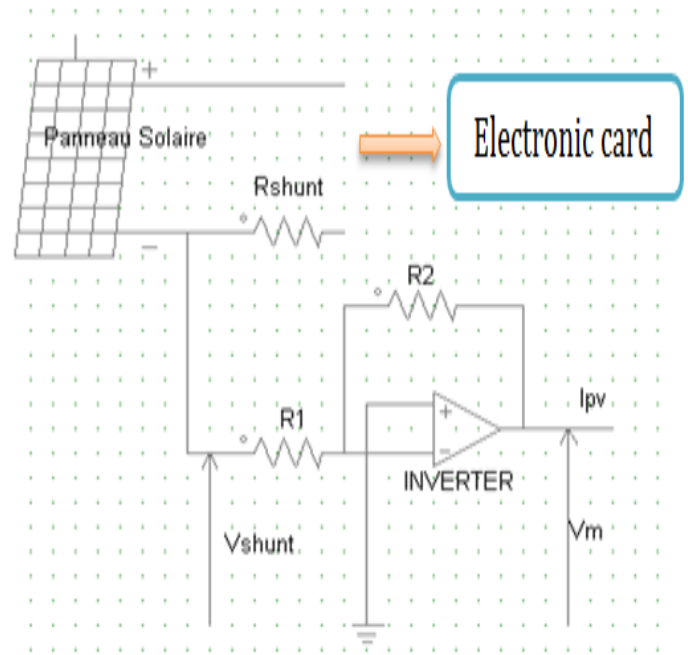


Figure 5: Current measurement circuit

Measurement of climatic parameters

As described above the characteristics of a photovoltaic panel are influenced by several climatic parameters that must be controlled, namely the temperature of the panel and the solar irradiance. If one or the other of these quantities varies too much during the successive measurements corresponding to a curve, then the results will not be relevant, hence the need to characterize these different parameters.

Temperature measurement

We use the RTD Pt100 temperature sensor described in [6] to measure the temperature. It is a resistance which value changes as a function of the evolution of the temperature (At 0 ° C the value of the resistor is 100 ohm).

The theoretical value of the resistance for a Pt100 probe is:

$$R_T = 100 (1 + 0,004\theta) \quad (4)$$

With θ the temperature. To adapt the signal from the platinum resistance to the microcontroller input, it is necessary to use a conditioner.

The temperature measurement circuit is as follows:

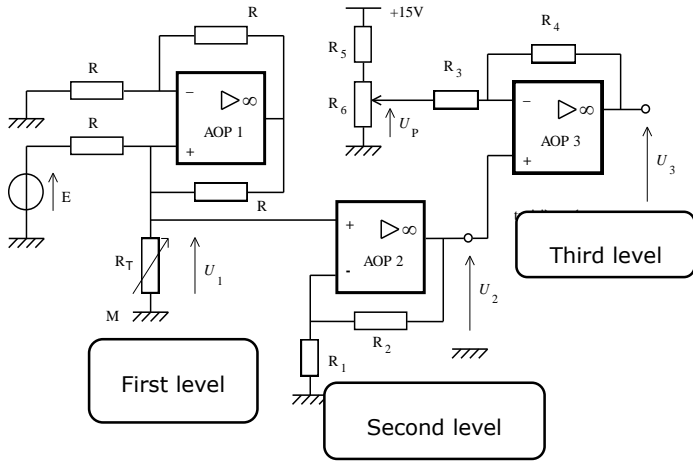


Figure 6: Conditioning circuit for the Pt100 sensor

The whole consists of a first current generator level is followed by a second amplifier level. The third level allows to obtain a linear response $U_3 = k\theta$.

- ✓ The current generating circuit enables the platinum resistance to be fed with a current of constant intensity

$$I = \frac{E}{R} = 1 \text{ mA} \quad (5)$$

The voltage across the platinum resistance is, therefore, an affine function of the temperature:

$$U_1 = a\theta + b \quad (6)$$

- ✓ The second level amplifier allows to amplify the U_2 voltage

$$U_2 = \left(1 + \frac{R_2}{R_1}\right) U_1 \quad (7)$$

- ✓ The last level eliminates the constant term from the voltage divider (U_P) and adjusts the yield with resistor R_4 to have a direct reading of the temperature:

$$U_3 = \left(1 + \frac{R_4}{R_3}\right) U_2 - \frac{R_4}{R_3} U_P \quad (8)$$

By choosing:

$E = 10 \text{ V}$; $R = 10 \text{ k}\Omega$; $R_1 = 1 \text{ k}\Omega$; $R_2 = 10 \text{ k}\Omega$; $R_3 = 10 \text{ k}\Omega$; $R_5 = 3.3 \text{ k}\Omega$ and playing on the result to be obtained which should be $U_3 = 0.05\theta$ so as to have $0^\circ\text{C } U_3 = 0\text{V}$ and at $100^\circ\text{C } U_3 = 5\text{V}$, we get by calculation $R_4 = 103.636\text{k}\Omega$ and $R_6 = 286.96\Omega$.

Operational amplifiers (TL081) are supplied with $+15\text{V} / -15\text{V}$.

The simulation of this conditional circuit gives the following results:

| T (°C) | RT(Ω) | U3(V) |
|--------|-------|-------|
| 0 | 100 | 0,09 |
| 10 | 104 | 0,58 |
| 50 | 120 | 2,53 |
| 100 | 140 | 4,97 |

Table 2: Simulation Results of the Conditioning Circuit for the Pt100 Sensor

Solar irradiance measurement

To measure the global solar radiation at the surface of the photovoltaic modules, we use the Kipp & Zonen CMP11 pyranometer, with a sensitivity of $8.44 \mu\text{V/W.m}$.

As the temperature, to adapt the output signal of the pyrometer to the input of the microcontroller, it is necessary to use a conditioner described in [7].

The irradiance measuring circuit is as follows:

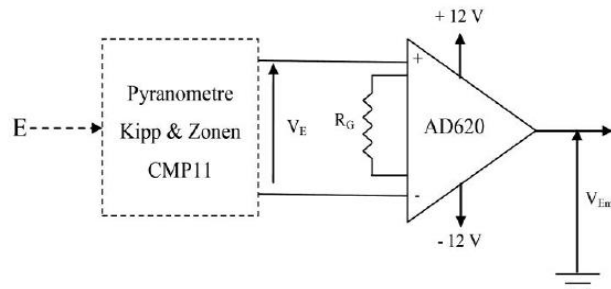


Figure 7: Conditioning circuit for the Kipp & Zonen CMP11 sensor

The relations leading the operation of this circuit are given in the following:

$$V_{Em} = G \times V_E \quad (9)$$

$$G = 1 + \frac{49,4K}{R_G} \quad (10)$$

$$V_E = S \times E \quad (11)$$

Thus, the irradiance E is defined as a function of the output voltage of the amplifier by the following relation:

$$E = \frac{V_{Em}}{8,44.10^{-6}(1+\frac{49,4K}{R_G})} \quad (12)$$

To test the operation of the conditioning circuit, the latter has been simulated with Isis Proteus.

| | | | | | | | |
|-----------------------|---|------|-----|------|------|------|------|
| E (W/m ²) | 0 | 100 | 400 | 600 | 900 | 1000 | 1200 |
| VEM(V) | 0 | 0.45 | 1.7 | 2.53 | 3.79 | 4.21 | 4.7 |

Table 3: Results of simulation of the conditioning circuit for Kipp & Zonen CMP11

Design of the electronic card

The electronic card which control the acquisition of the various parameters is captured and simulated under the Isis proteus software.

In addition to the sensors and the automatic variable load, the electronic card contains the following elements: Microcontroller PIC 16F877A, Quartz oscillator delivering a periodic signal which runs the steps of the microcontroller program, the RS232 link used to transmit information from the microcontroller to the acquisition interface without using the synchronization clock.

The figure below shows the simulated electronic card under ISIS:

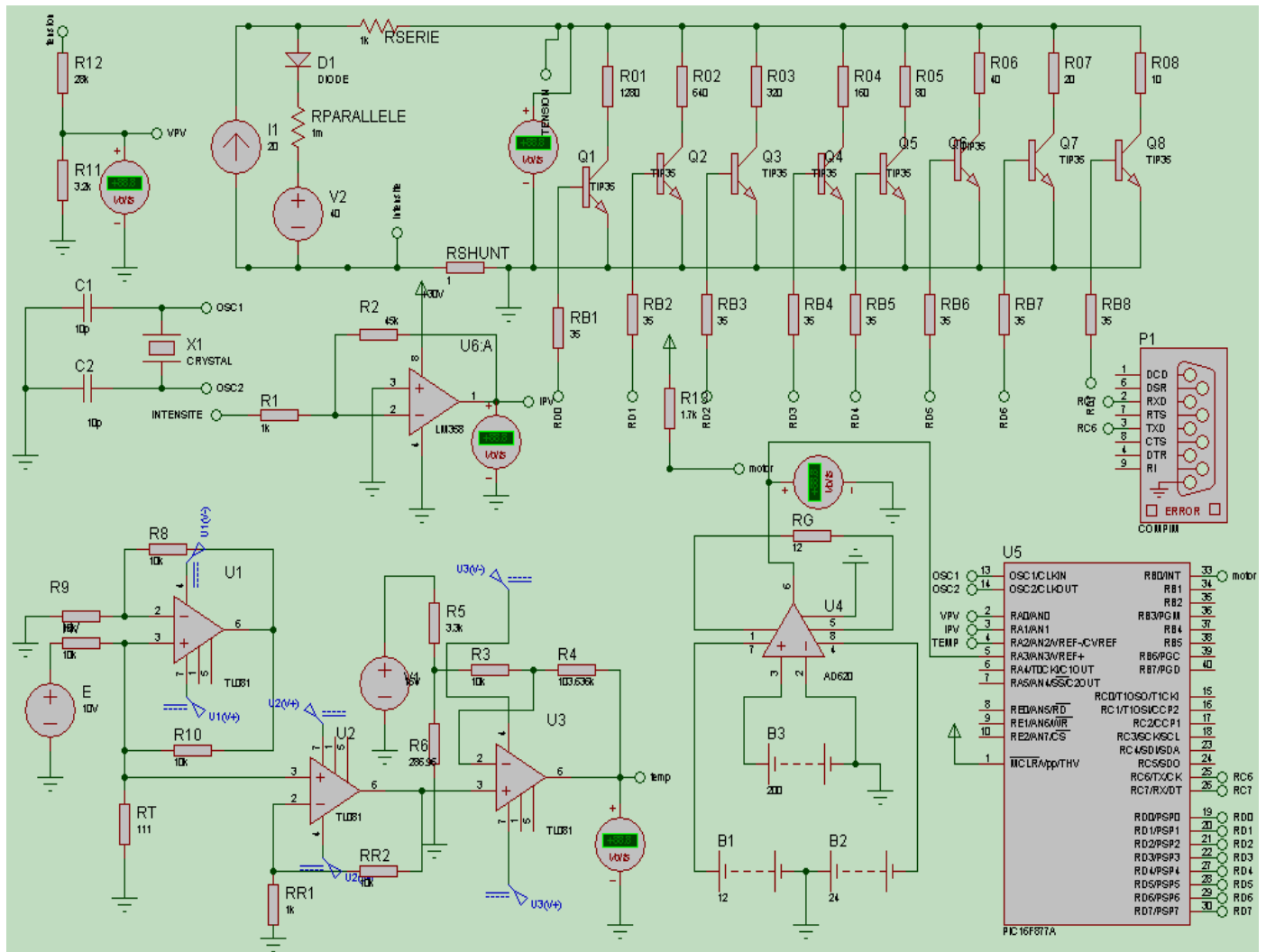


Figure 8: simulation diagram of the electronic card

Acquisition interface and Recording of data

The interface we designed is used to read the data received from the RS232 serial link. We used the Visual Studio Express 2012 software developed by Microsoft Corporation.

The read data are: Temperature (°C), solar irradiance (W/m²), current (A), voltage (V) and power (W) of the photovoltaic module.

When the electronic card is powered, just choose port 2, click the Start button to start playback. After 256 read values the loop resumes. The end of the acquisition will be decided by the managers of the laboratory.

The figure below shows the acquisition interface in operation:

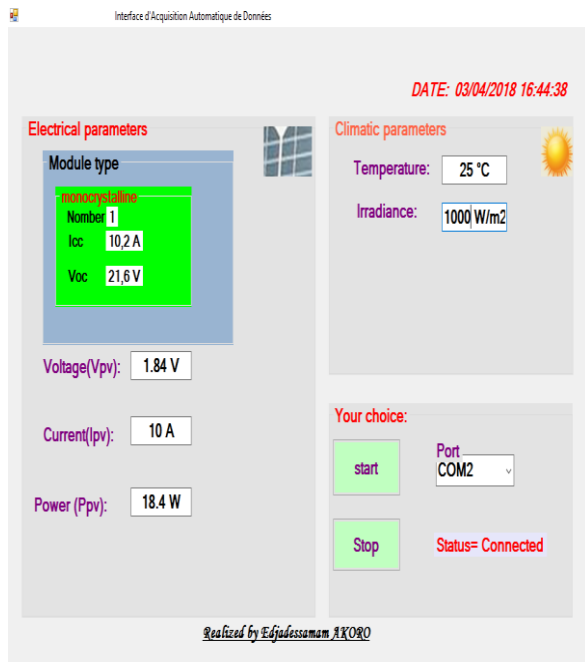


Figure 9: The system of acquisition in full operation

In order to better analyze the data read on the interface, a database is created for the recording. This database is nothing more than a file in which a line of data is written every second and recorded automatically. Each line is associated with a date, the year, the month, the day, the hour, the minute and the second.

The following figure shows the file containing the recorded data for a temperature of about 31 ° C and a solar irradiation of 1000 W / m².

| DATE | VOLTAGE(V) | CURRENT(A) | POWER(W) |
|------------------|------------|------------|----------|
| 29/01/2016 14:12 | 21,63 | 0,67 | 14,49 |
| 29/01/2016 14:12 | 12,32 | 4,7 | 57,9 |
| 29/01/2016 14:12 | 8,6 | 4,7 | 40,42 |
| 29/01/2016 14:12 | 8,6 | 6,31 | 54,26 |
| 29/01/2016 14:12 | 6,63 | 7,17 | 47,53 |
| 29/01/2016 14:12 | 6,63 | 7,17 | 47,53 |
| 29/01/2016 14:12 | 5,38 | 7,72 | 41,53 |
| 29/01/2016 14:12 | 5,38 | 7,72 | 41,53 |
| 29/01/2016 14:12 | 4,52 | 8,11 | 36,65 |
| 29/01/2016 14:12 | 3,92 | 8,11 | 31,79 |
| 29/01/2016 14:12 | 3,92 | 8,37 | 32,81 |
| 29/01/2016 14:12 | 3,45 | 8,58 | 29,6 |
| 29/01/2016 14:12 | 3,45 | 8,58 | 29,6 |
| 29/01/2016 14:12 | 3,09 | 8,73 | 26,97 |
| 29/01/2016 14:12 | 3,09 | 8,73 | 26,97 |
| 29/01/2016 14:12 | 2,78 | 8,86 | 24,63 |
| 29/01/2016 14:12 | 2,78 | 8,86 | 24,63 |
| 29/01/2016 14:12 | 2,54 | 8,97 | 22,78 |
| 29/01/2016 14:12 | 2,54 | 8,97 | 22,78 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |
| 29/01/2016 14:12 | 2,34 | 9,07 | 21,22 |

Figure 10: Data record file (temperature = 31 ° and Irradiance=1000 W/m²)

Conclusion

The work presented in this article deals with the automatic acquisition of the characteristics of solar modules. As part of the optimization of photovoltaic installations, our main objective was to set up a system that would facilitate the acquisition of the different characteristics of solar modules and then to save them in a database.

The results obtained are acceptable for the automatic acquisition of the characteristics of the solar modules. Data acquisition can be performed for all variables in a time range as small as one second which allows controlling the operation of the photovoltaic generator in real time.

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