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A High Efficient Micro-controlled Buck Converter with Maximum Power Point Tracking for Photovoltaic Systems

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Abstract. In recent years, the use of solar energy has become an alternative source of energy of great importance. Several researches and efforts have been concentrated on the improvement of the efficiency of photovoltaic systems and in the accessibility to this technology. In this sense, this work presents a buck converter controlled by P&O technique for the maximum power point tracking of the photovoltaic panel. The system is simulated and implemented experimentally using a microcontroller device. The analysis by simulations and practical results show a good performance of the control technique and the improvement of the efficiency of the system.

Key words

DC/DC Converter, Maximum Power Tracking, Photovoltaic Systems.

1. Introduction

In recent decades, researches on the use of solar energy as an alternative source of energy have become a role of prominence in the field of electrical engineering.

In parallel, new materials for the manufacture of photovoltaic panels and new methods of control are being developed to reduce costs and increase the efficiency of power converters. Among these techniques, a great effort has been spent with the algorithms for the maximum power tracking (MPPT) considering the variations of parameters such as temperature, solar irradiation or the load of the system. Several techniques for maximum power point tracking are based on the comparison between the measurements current and previous of the power delivered by photovoltaic panel [1]. From these, other algorithms of control have been developed as the short circuit current or open circuit voltage techniques and perturbations methods [2-5]. In general, the first class of papers assumes slow variations of parameters while the second works with rapidly changing environmental conditions. Most commonly, the climatic conditions do not change with great severity, becoming appropriate to use the methods based on the comparison of output power. Usually, these methods are easier to the digital implementation and they offer a good stability of operation.

This paper presents a buck converter controlled by Perturb and Observer (P&O) technique for the maximum power point tracking of the photovoltaic panel. Firstly, a complete analysis of the photovoltaic devices and converter is developed in the MatLab environment. Secondly, the MPPT Buck converter was implemented experimentally using microcontroller Freescale HC08-QT4. The results show the good performance of the control technique and the improving of the efficiency of the system.

2. Modeling of the cell and solar panels

A. Principle of Operation and Equivalent Circuit

The operation of solar cells may be described from a PN junction where there are diffusion currents and drift currents for the direct and reverse polarization, respectively. Usually, the cells operate in reverse direction so that the current drift is desirable. When the PN junction is exposed to light, photons with energy greater than the gap of energy are absorbed, causing the emergence of pairs electron-hole. These carriers are separated under the influence of electric fields within the junction, creating a current that is proportional to the incidence of solar irradiation [6].

Fig. 1 shows the equivalent circuit of the solar cell, formed by a current source I_{ph} in anti-parallel with diode driven by a current I_d. The diode determines the current-voltage output characteristic (*IxV*) and includes the voltage and current dependence of the cell in relation to the temperature.

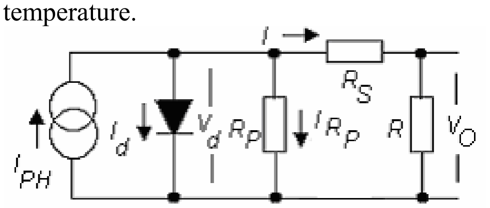

Fig. 1: Circuit equivalent of complete solar cell, considered the internal losses.

Based on this complete equivalent circuit, the output current of the solar cell can be calculated as,

$$I = I_{ph} - I_d - I_{Rp} \tag{1}$$

where I_{ph} is the current generated by irradiation also called short-circuit current, I_d and I_{Rp} represent the diffusion current of the internal diode and the loss of current in R_p.

Considering the characteristic *IxV* the PN junction, the output current of the cell can be rewritten of the way:

$$I = I_{ph} - I_o(e^{\frac{q(V_o+IR_s)}{AKT}} - 1) - \frac{V_O + IR_s}{R_p} \tag{2}$$

where I and V_O are, respectively, the output current and voltage of the solar cell. I_o is the reverse saturation current of the diode, q is the charge of the electron, A is the diode ideality factor, K is the Boltzmann constant, T is the temperature in ºK, R_s and R_p represent the internal series and parallel resistances, respectively.

According [7], the parallel resistance has greater influence in the region of low voltages where the current through of the equivalent circuit is very small. This resistance is mainly due to the leakage of current in the cell surface, acting significantly only when the cells are in low brightness. The series resistance has origin in the metallic contacts and it offers significant influence on the performance of the solar cell.

Other approximate models can be built in accordance with the type of application. A simplified model is shown in Fig. 2 and its equations are given by (3) and (4).

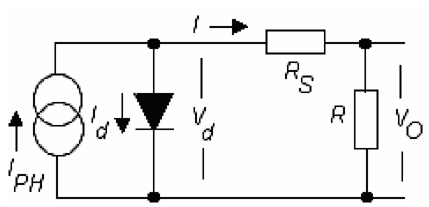

Fig. 2: Simplified equivalent circuit of the solar cell.

$$I = I_{ph} - I_o[(e^{\frac{Vo+R_sI}{AV_T}} - 1)] \tag{3}$$

Replacing the term $V_T = KT/q$ (thermal voltage), the equation of the output voltage of the cell will be given by:

$$V_o = -IR_s + \frac{AKT}{q}\ln(\frac{I_{ph} - I + I_o}{I_o}) \tag{4}$$

The output power of the solar cell is calculated as:

$$P_o = IV_o \tag{5}$$

B. Dependency with temperature and solar irradiation.

Looking up the equations (1) to (4), it can be observed a high dependence of the output current of the cell in relation to the temperature and solar irradiation. In function of this, the output power of the cell is strongly dependent of the climate conditions in which it is placed. Experimental observations show that between the dawn and the dusk or on cloudy days and/or rainy, the yield of the photovoltaic generator sets appreciable variations in terms of generated power [8] [9].

The solar cells can be connected so as to form blocks with values pre-defined of output voltage, named module or solar panel. The most common way to connect the cell is series connection where each unit contributes with a voltage of around 0.5 V [9].

3. The model using MatLab – Simulink

Fig. 3 shows the model of the photovoltaic panel implemented in Simulink-MatLab environment. This model allows the choice of the physical parameters of the cell and to verify the behavior of panel in relation to the external variables (temperature and irradiation). The variables considered in the model include the current, voltage and power generated by solar cell (Io_{cel}, V_{cel} and P_{cel}, respectively). Multiplying these variables by the number of cells (n_{cel}), it can be calculated the variables relative to the solar panel.

The diagram includes a solar cell block that was implemented by equation (4), a source controlled by voltage connected to the output of the cell and a controlled resistive load, responsible by the changes of the operation point under fixed values of temperature and irradiation.

Fig. 4 and 5 show the output current versus voltage and output power versus voltage characteristic curves of the solar panel, respectively. In both, were used 5 levels of irradiation within of a range 200 to 1000 W/m^2.

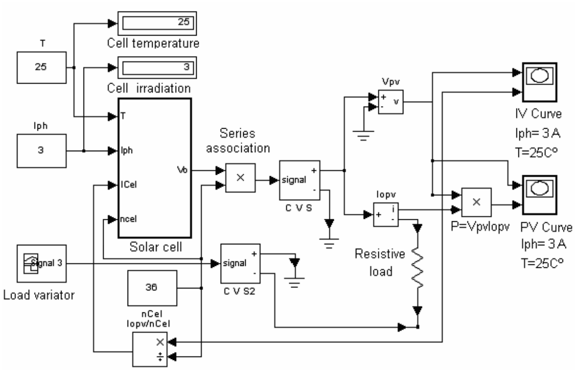

Fig. 3: Diagram for the simulation of the solar panel.

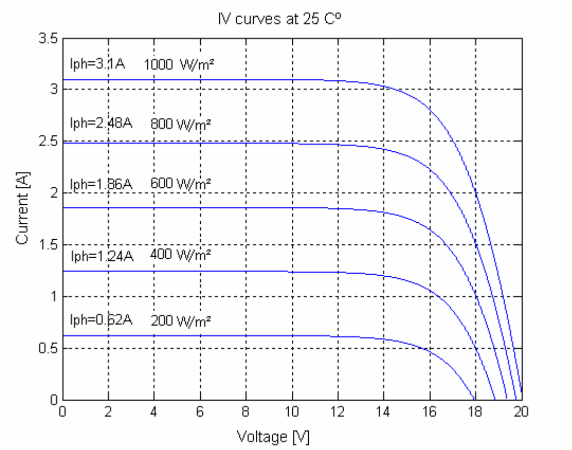

Fig. 4: IxV characteristic of solar panel with 36 cells.

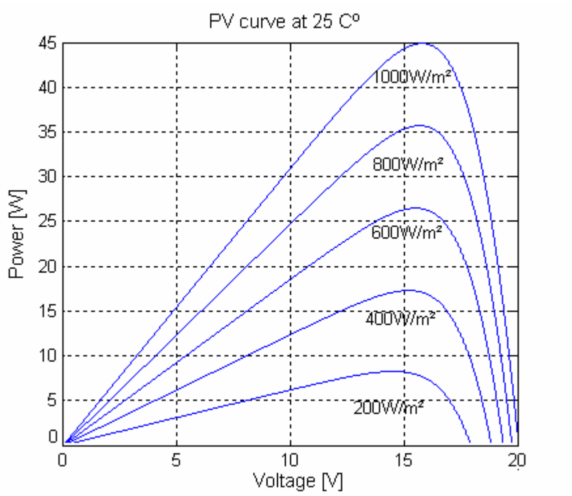

Fig. 5: PxV curves of solar panel with 36 cells.

4. The Buck Converter and the MPPT Algorithm

Due to the variations of the temperature and solar irradiation, the voltage generated by the solar panel must be applied to power converters that provide the conditioning required by the type of load. To increase the efficiency of the photovoltaic system, it is fundamental that the control of the converter guarantees its operation near to the maximum power point, independent of the conditions of solar irradiation and/or temperature.

In this section, it will be presented the design and simulation of a buck converter controlled by the maximum power point tracking algorithm. The algorithm used is the Perturb and Observer (P&O) that offers good conditions to its digital implementation [10]. The basic structure of a DC-DC converter, called step-down or Buck, is presented in Fig. 6.

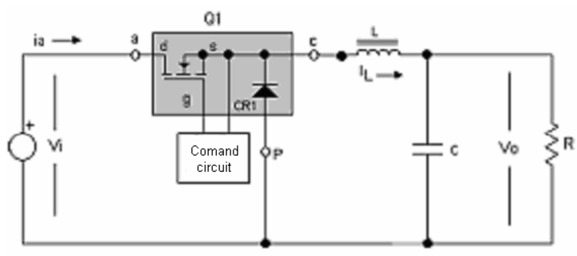

Fig. 6: Simplified diagram of a converter buck.

The conditions used in the design of the buck converter are input voltage equal (18 VDC$\pm$ 10%), output voltage (12 VDC), switching frequency ($f = 40kHz$), inductor current ripple ($\Delta i_L = 75mA$), capacitor voltage ripple ($\Delta V_C = 500\mu V$) and an output current equal to $I_o = 1.2A$ for a resistive load of 10Ω.

A. The maximum power point tracking algorithm

Due to the low efficiency of solar panels, one of the major challenges in relation to the design of photovoltaic generators refers to the maximum utilization of energy generated. In general, the pulse width modulation (PWM) techniques are used to provide the control of the power converter, responsible for the transfer of energy from the solar panel to the load. Every variation of temperature or solar irradiation causes changes on the electric characteristics of the solar panel and it is needed a new point of operation. To guarantee an operation under better delivery power conditions, a common type of control used is the Maximum Power Point Tracking Algorithm (MPPT).

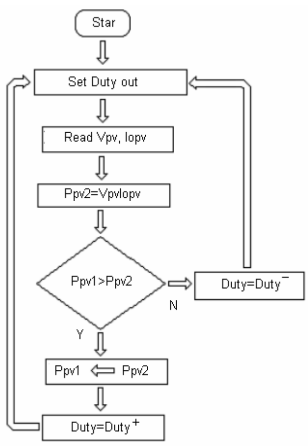

Fig. 7: Flow chart of the P&O control algorithm.

Several algorithms have been proposed, among these, the algorithm Perturb and Observer (P&O) is used in this work [1]. Fig 7 and 8 show the flow chart and the block diagram with the necessary steps for the implementation of the P & O algorithm.

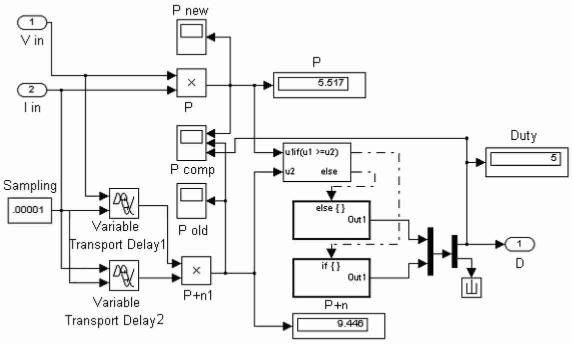

Fig. 8: Block diagram of the P&O algorithm in the Matlab - Simulink.

Samples of current and voltage of the system are acquired and used in the calculation of the current and previous power. A delay time was introduced after the sampling to calculate the previous power and to provide the comparison between the power signals according the strategy of the algorithm P&O.

5. The high-efficient converter photovoltaic

The complete diagram of the converter with control MPPT is shown in Fig. 9, including all elements described previously.

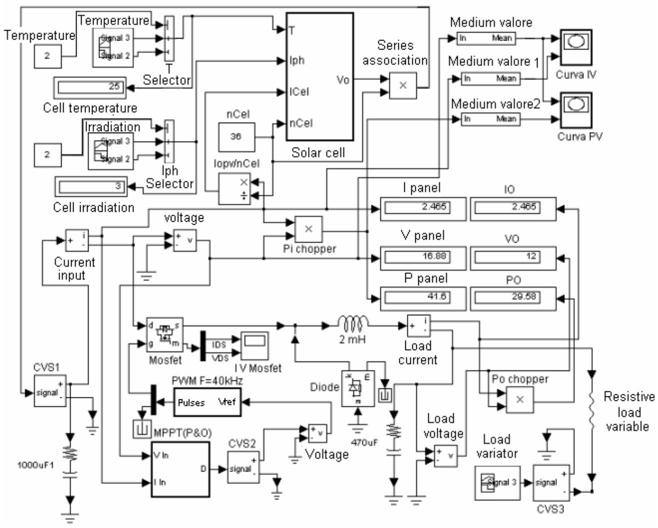

Fig. 9: Complete diagram of the photovoltaic converter with MPPT algorithm.

Fig. 10 shows the waveforms of voltage, current and average power of the solar panel, obtained at output of the system. The load used is variable and the irradiation and temperature are considered constant. The average output power of the panel is over 40 W, indicating values in the region of maximum power, according to the curves shown in Fig. 5.

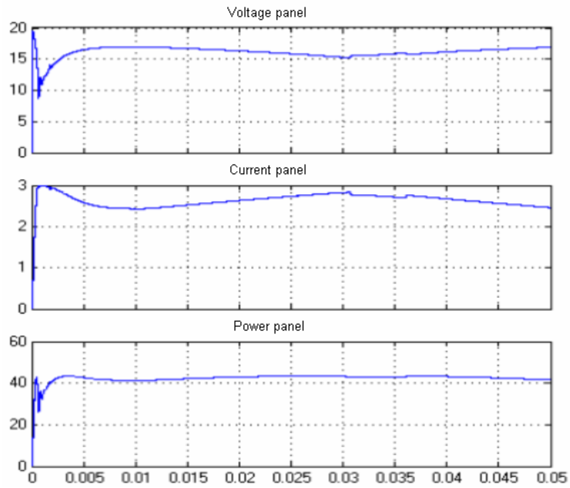

Fig. 10: Output signals of the solar panel with resistive load variable.

Fig. 11 shows the waveforms of the input and output voltage and current load of the power converter. The action of the P&O control algorithm can be observed by the presence of oscillations in the input voltage.

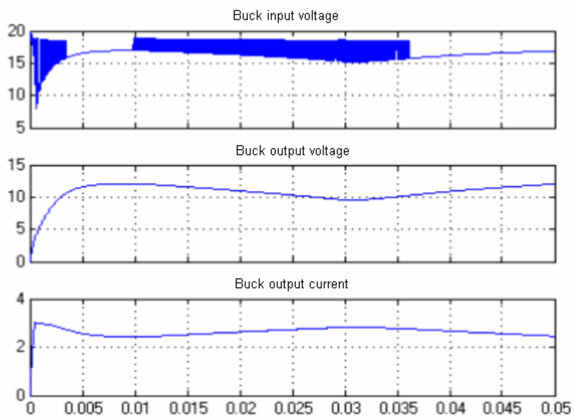

Fig. 11: Output waveforms obtained by simulation of the chopper with resistive load.

Fig. 12 and 13 show the simulation of the photovoltaic panel operating close to the maximum power point.

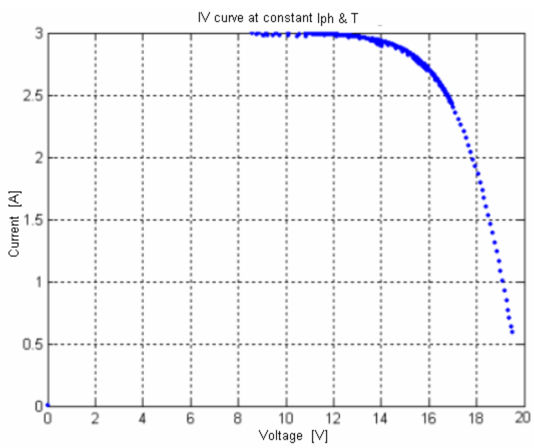

Fig. 12: *IxV* characteristic curve of the solar panel.

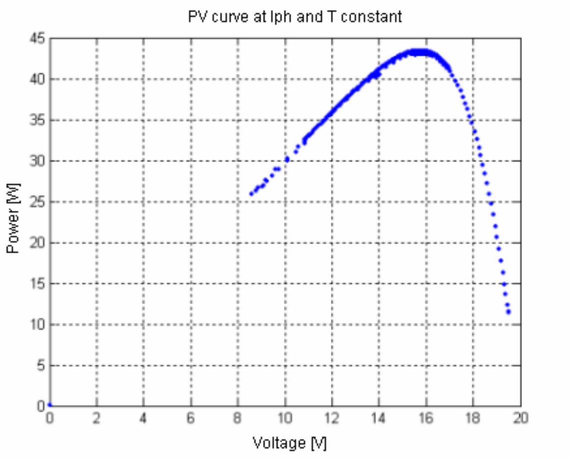

Fig. 13: $P\,xV$ characteristic curve of the solar panel

Fig. 14 shows, in detail, the PxV characteristic of the solar panel. It can be noted that the output power of the solar panel is around the 43 W which, according to Fig. 5, indicates proximity of the point of maximum power.

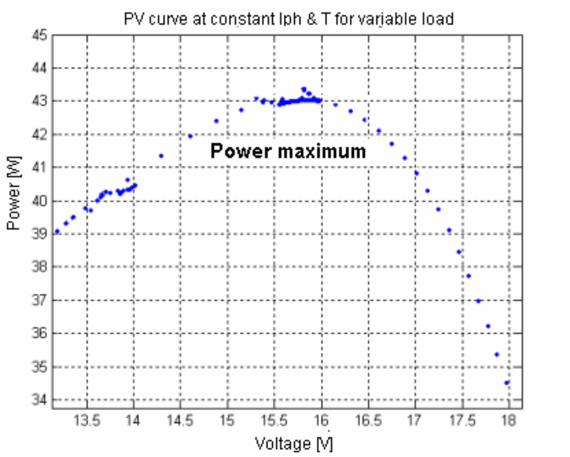

Fig. 14: Details of the operation of the system at maximum power point.

6. Experimental results

Essentially, the prototype developed is composed of one photovoltaic panel associated with a Buck converter controlled by P&O algorithm. Initially, the output of the system was connected to a resistive load equal to 5Ω and, after this, to a 12 VDC battery. Fig. 15 shows the electrical diagram of the experimental set.

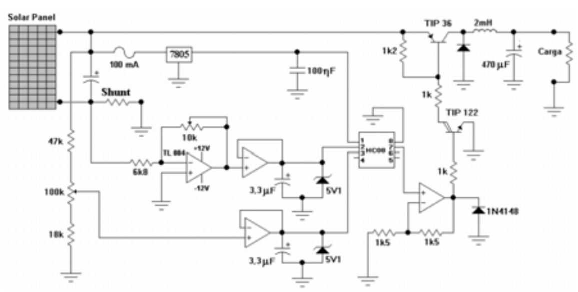

Fig. 15: Electric diagram of prototype to the photovoltaic generator.

The MPPT algorithm has been programmed into micro-controller HC08QT4 - Freescale, which is responsible for sampling of the output voltage and current of the solar panel. In following, the micro-controller runs the P&O algorithm and it provides the signals to the control of switching devices of the Buck converter.

The switching device of the converter is composed by two transistors, one of high gain of current of the type Darlington (TIP 122) and another of fast switching and medium power (TIP 36). The converter also has an inductor of $2mH$, an electrolytic capacitor of $470\mu F/100V$ and a fast diode power with the functions of filtering and limitation of induced voltage, respectively.
The composition of the experimental set can be described, basically, as:
- A KYOCERA Solar Panel, model KC-50, comprising 36 rectangular cells of polycrystalline silicon with maximum power of 50 W; open circuit voltage of 21.5 V, short-circuit current of 3.1 A; maximum voltage of power 16.7 V and current of maximum power of 3 A;
- A Buck converter as previously described;
- An acquisition and measurement system of solar irradiation consisting of a Data Acquisition System National Field Point 200 and a piranometer Eppley 8-48, respectively;
- An acquisition system and measuring for the input voltage and current of the converter Buck, of type Scope Meter Fluke model 199;
- Resistive load of 5Ω or battery 12VDC.

Fig. 16 shows the results of measurements of solar irradiation, current and voltage available at the output of photovoltaic panel, during an exposition of approximately 04:50hrs, in the range of 10:42hrs to 15:32hrs. The range of sampling was set to 10s. During approximately the first 200 samples was used as a resistive load of 5Ω, and then was done connecting the battery to 12VDC output of the converter.

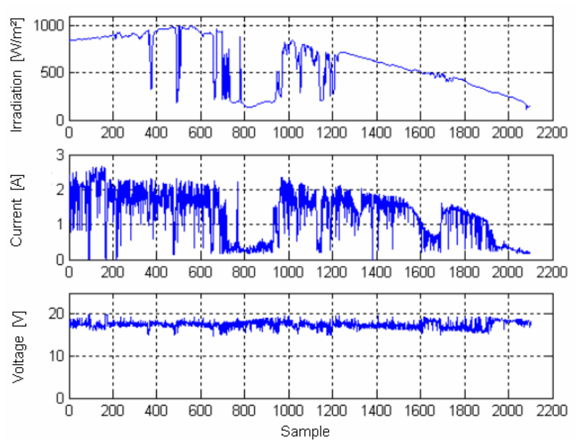

Fig. 16: Measurements of solar irradiation, current and voltage of input power converter.

Note the correlation between solar irradiation and output current of the panel, already discounted the loss in relation to the internal photocurrent generated. The voltage output of the solar panel remains virtually constant.

Fig. 17 and 18 show the curves *IxV* of the panel used for the levels of irradiation equal to 1000, 800, 600, 400 and 200 W/m^2.

In all cases, the operation points of the solar panel were located to the right of graphics, always near to the point of maximum power. With the battery as load, showed by Fig. 18, the system offered better performance, even for lower levels of solar irradiation.

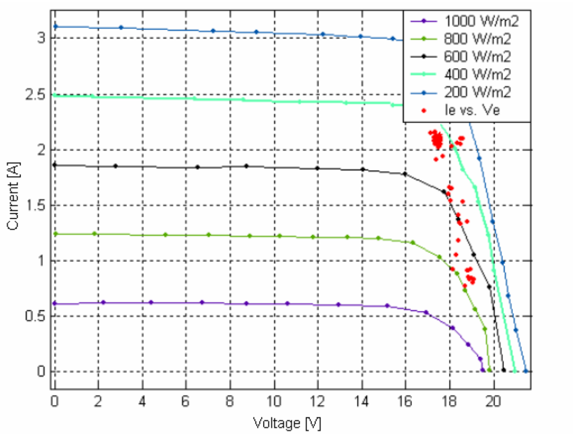

Fig. 17: Operation points of the solar panel with MPPT control, considering a resistive load equal to 5Ω.

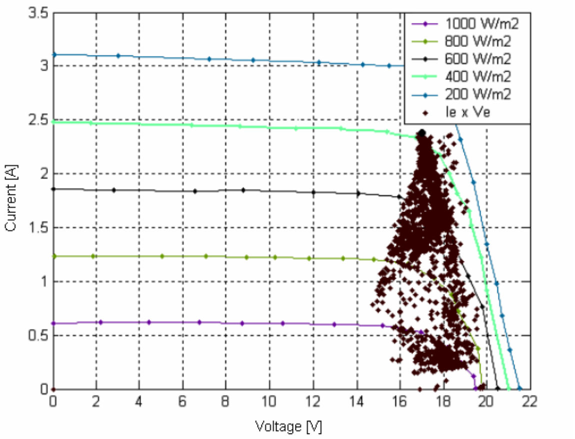

Fig. 18: Operation points of the solar panel with MPPT control, considering as a 12VDC battery charge.

7. Conclusion

The location of the operation points near the region of maximum power point indicates the good performance of the prototype developed. The work allowed to detailed analysis of a photovoltaic generator composed by the association of a solar panel, Buck converter with MPPT control and loads type resistive or battery by means of resources of simulation and experimentally. From mathematical modeling of the solar panel, it was developed a flexible structure to the simulation accounting the effects of changes in solar irradiation, temperature and load. A Buck converter was designed for the desired operating conditions. The system was implemented experimentally with a micro-controlled Buck converter. The experimental results confirm the good performance of the P&O technique for the maximum power point tracking of the solar panel. Although the P&O algorithm presents some technical limitations facing sudden changes in weather conditions, the simplicity and facility of its implementation using programmable digital devices make it a great potential for applications of low cost and high efficiency of photoelectric conversion.

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