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MPPT algorithm based on Multiple Linear Regression model for Solar PV systems

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Abstract. Currently, there are numerous maximum power point tracking (mppt) algorithms implemented in systems powered by photovoltaic (PV) panels. These systems are indirectly affected by sudden changes in weather conditions, making them unstable and inefficient. This work presents a model to establish the optimal working point of photovoltaic panels to be used in installations sensitive to changes in environmental conditions, such as solar pumping, to obtain maximum power in any temperature and irradiance condition of the panels. The model reduces the response time of the system because it also has a control system implemented whose setpoint value is the one provided by the algorithm itself. This is possible with the help of external temperature and solar radiation sensors that provide these values in real time. The setpoint is the working voltage target for the panels (Vmpp), for which the system does not become unstable despite the oscillations allowed by the control system. The algorithm is based on a model that consists of a Multiple Linear Regression through which the entire P-V curve of any photovoltaic panel can be represented for any temperature and radiation. The characteristics of the model allow a control system design that makes the system more efficient.

Key words. Maximum power point tracking, PID control, Photovoltaic panel, Solar pumping.

1. Introduction

In recent years, the need to increase agricultural production [1] has become more and more evident, due to the progressive increase in the population. On the other hand, the environmental policies of most countries are in line with reducing the consumption of fossil fuels, making increasingly extensive use of renewable energy sources. For this reason, photovoltaic pump irrigation installations meet the dual objective of using a renewable energy source to power the pumps, while obtaining water resources from wells for areas where water is scarce or difficult access [2]-[3].

There are numerous algorithms for maximum power point tracking (mppt) of photovoltaic modules. Heuristic algorithms [4] can be used, such as "perturbation and observation" (P&O) [5]-[6] and "incremental conductance" (INC) [7], which, although they are easy to apply, require a large number of iterations and a long time to reach the point of maximum power on the IV curve

In this work, a model is proposed that uses a multiple linear regression to obtain the curve of the photovoltaic panel for any temperature and irradiance. To obtain the model, the change in the curves of photovoltaic panels from different manufacturers with temperature and irradiance has been studied. The area of the curve in which it is interesting for the mppt to work (area very close to the mpp) has been extracted, discarding the entire part of the curve that goes from the Voc to the first change in slope. Thanks to this model, the reference voltage is generated immediately and provided to the control system (ON/OFF, PID, etc) to generate the corresponding duty ratio. In short, with external sensors that measure temperature and irradiance in real time, the control system can control the transfer function of the DC-DC converter in the most efficient way possible, finding the Vmpp very quickly.

2. Solar PV system description

A typical photovoltaic (PV) system consists of PV modules, an MPPT system, a DC-AC inverter, and the corresponding electrical load. The MPPT system will be made up of two elements, the MPPT controller where the algorithm is implemented and a DC-DC converter. This converter will increase or reduce the voltage it receives, providing the inverter with an optimal voltage (Vmpp), the one that maximizes the power capable of feeding the photovoltaic panels.

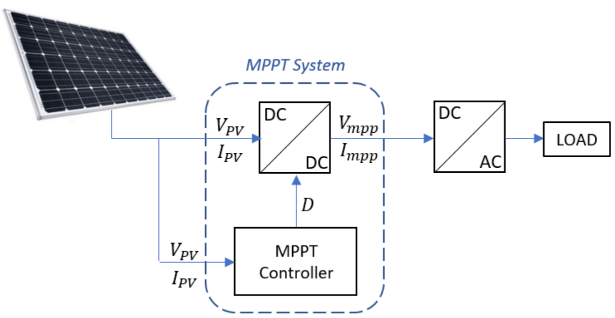

Fig. 1. Block diagram of a solar PV system that represents the elements above described.

The type of DC-DC converter to consider would be the buck-boost converter (Figure 2), which provides an output voltage magnitude greater or less than the input voltage magnitude depending on setpoint. The input voltage would be the magnitude provided by the terminals for each string of panels (V_{PV}) and the output voltage is Vmmp, corresponding to the Maximum Power Point. The output voltage is adjustable by varying the duty cycle of switching MOSFET transistor.

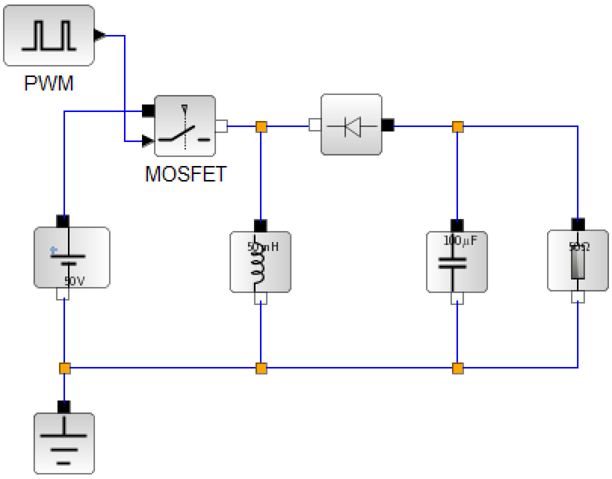

Fig. 2. Buck-Boost DC-DC converter model developed in SCILAB/Xcos.

3. Multiple lineal regression model

The model developed in this article will help provide the optimal parameters to the MPPT system to control the buck-boost DC-DC converter where an electrical load would be connected, based on the ambient temperature and irradiation data at the location of the panel photovoltaic panels. A change in irradiance or temperature will mean updating in real time (immediate) the voltage target of the photovoltaic panels. Based on this idea, the parameters of any control system integrated in the MPPT controller (ON/OFF, PID, etc) will be the most optimal for all working conditions.

For the realization of the model, the P-V curves of the photovoltaic panels have been parameterized, for all the values of irradiance and temperature provided by the manufacturer of the panels. We have worked with the curves provided for irradiance values of 1000, 800 and 600 W/m², and for cell temperature values of: 25, 40, 55, 70 ºC. An example of these curves can be seen in Figure 1 where we explicitly see the dependence of the P-V curves on temperature and irradiance.

For each P-V curve we identify the point of maximum power and its corresponding voltage (Vmpp). As seen in Figure 3, the maximum power points of all the curves would be represented by the red dashed line.

It is evident that, independently analyzing the effect of cell temperature and radiation on the P-V curves, the dependence between the maximum power value with respect to cell temperature is stronger than its dependence with respect to solar radiation, so that the voltage Vmpp is extremely more sensitive to changes in temperature than to changes in radiation, as will be reflected later in the model, however it is also true that a change in the radiation implies a direct effect on temperature.

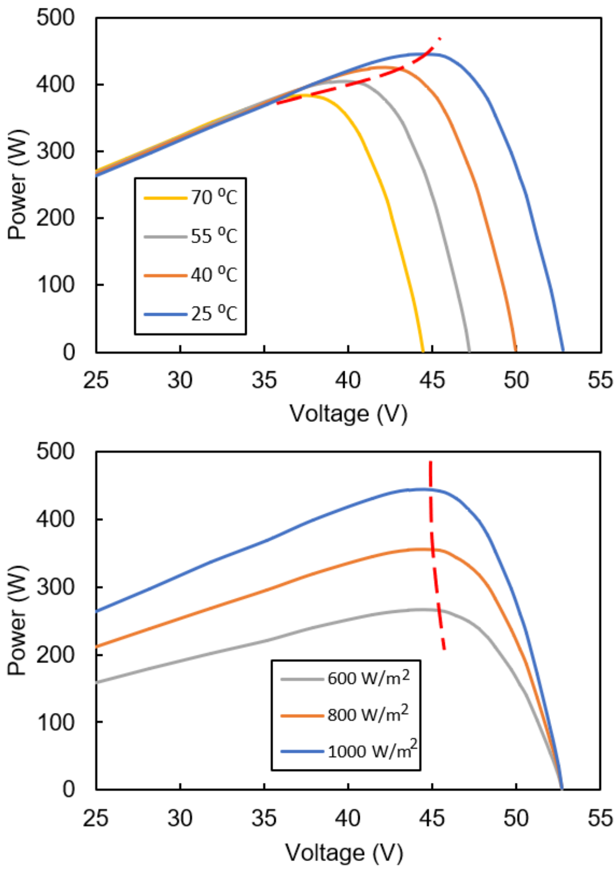

Fig. 3. P-V characteristics of the module at different temperature (up) and irradiance levels (down). The red dashed line represents the place of the maximum powers of all PV curves.

In this way, for each P-V curve, we are going to extract the vectors [$Vmpp_k$, G_k, T_k] for each curve and through specific data processing software (e.g., SPSS), we will obtain the multiple linear regression that calculates Vmpp as a function of irradiance and temperature. The general equation that allows us to obtain the work curve for any value of temperature and irradiance is shown to follow

$$Vmpp = \alpha \cdot G + \beta \cdot T_{amb} + \gamma \tag{1}$$

where V_{mpp} is the working or reference voltage and α, β and γ are parameters dependent on irradiance and ambient temperature. Thanks to the help of a temperature and irradiance sensor at the location of the photovoltaic panels, we can establish the operating curve, using Equation 1.

Because not all solar panels have exactly identical behaviors due to the number of different manufacturers, the parameters α, β and γ are characteristic parameters of each solar panel, therefore they can be provided by each manufacturer in order to be implemented in the mppt algorithm.

Figure 4 shows the flowchart of the new proposed algorithm. The algorithm continuously increases or decreases the voltage based on the value of the previous voltage sample and the reference voltage Vmpp.

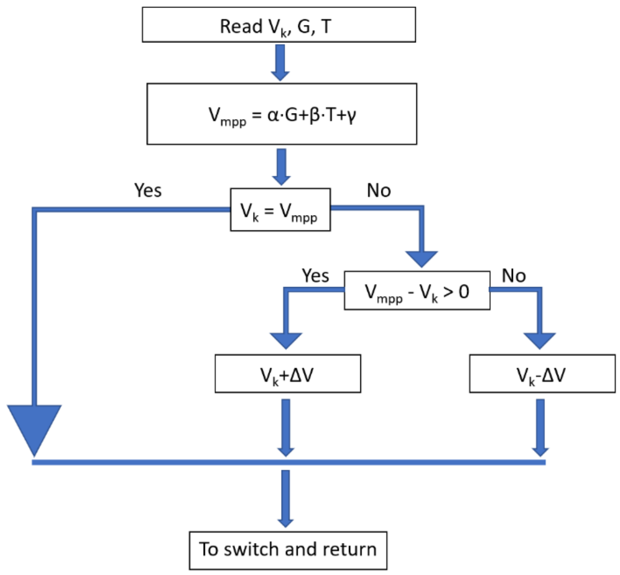

Fig. 4. Flowchart of the MPPT algorithm proposed.

Bearing in mind that the DC-DC converter to be considered in this work is a boost-buck converter, the equation that allows us obtaining the duty cycle ratio D can be deduced from [8]:

$$V_{out} = \frac{D}{1-D} \cdot V_{in} \tag{2}$$

Where V_{in} is the input voltage, V_{out} is the output voltage and D is the duty cycle ratio, it being calculated as:

$$D = \frac{V_{in} \pm \Delta V}{2V_{in} \pm \Delta V} \tag{3}$$

If the input voltage has to be increased, the plus sign is used and in case the voltage has to be reduced the minus sign would be used.

In order to provide the duty cycle ratio to the converter, the proposed algorithm can be executed in two ways, providing a step size ΔV or controlling the reference voltage Vmpp, which would imply the use of a PID controller [9] being in this case very useful to know the transfer function of DC-DC converter.

A transfer function for a buck-boost converter was obtained in [8] whose expression that relates the output voltage to the input voltage is as follows:

$$\frac{V_{out}}{V_{in}} = \frac{D(D-1)}{LCs^2 + \frac{L}{C}s + (1-D)^2} \tag{4}$$

Where L and C are the inductance and capacitance of the converter. In this case the step size ΔV is not a fixed value, and it is calculated as Vmpp – Vin. After that duty cycle is calculated applying Equation 3.

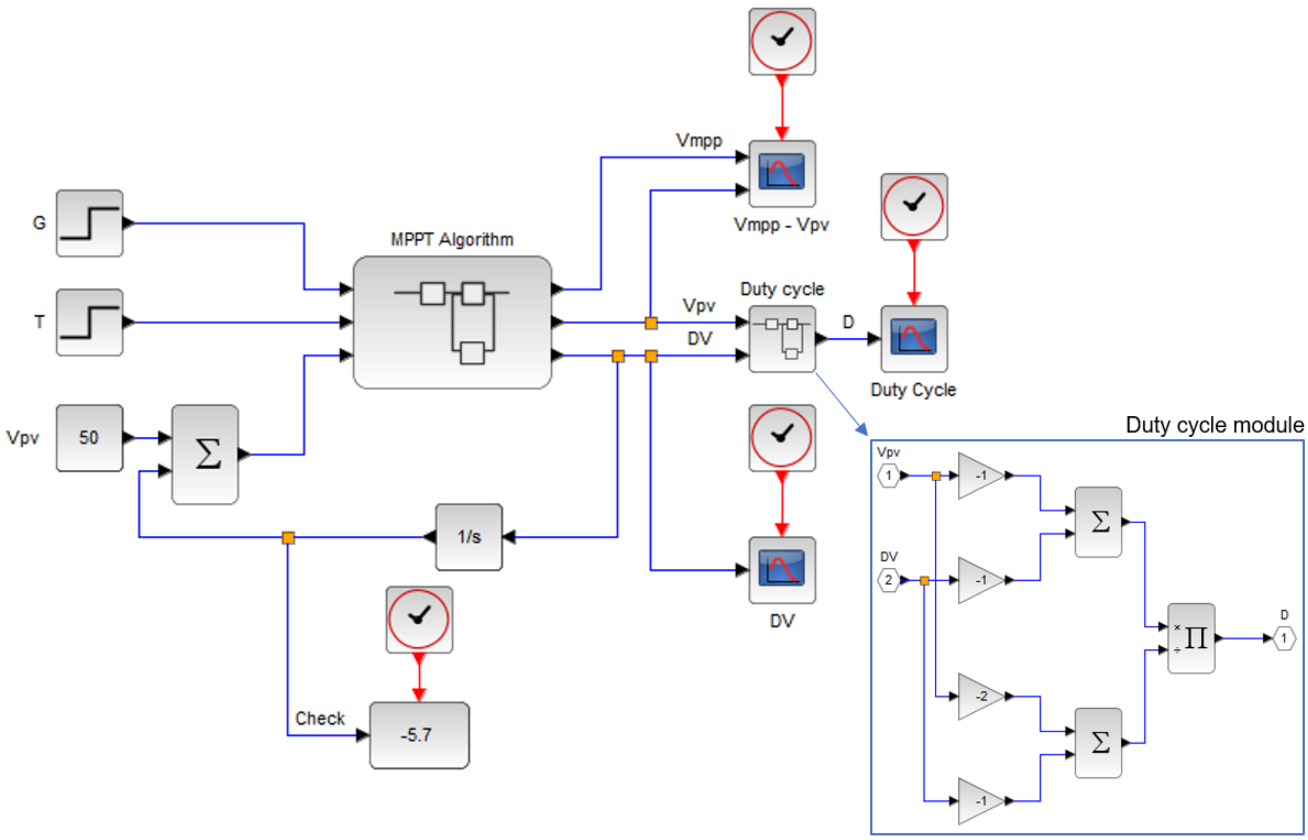

Fig. 5. SCILAB/Xcos scheme for simulating of the MPPT controller.

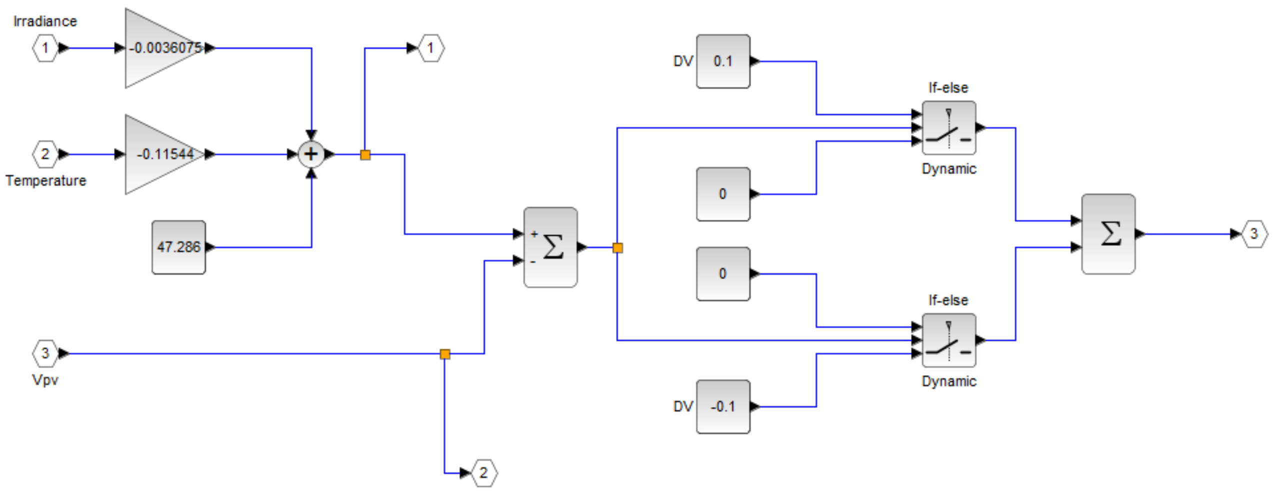

Fig. 6. SCILAB/Xcos scheme for simulating of the MPPT algorithm proposed.

4. Simulation and results

The MPPT algorithm has been implemented by using SCILAB/Xcos. A block diagram of the MPPT controller is shown in Figure 5, including a view of the duty cycle module. Also, the block diagram of MPPT algorithm proposed developed in SCILAB is shown in Figure 6.

Regarding to the buck-boost DC-DC converter the parameters that define each of the elements are an inductance L=50 mH and a capacitor of C=100 μF. The switching frequency is 1.5 kHz.

The photovoltaic panel model used for this work is the SERAPHIM SII Series 425-440 W from whose I-V curves we obtained the parameters α, β and γ of the equation of our model (Eq. 1). These parameters were obtained as a result of a multiple linear regression whose variables were the voltage Vmpp, temperature and the solar radiation.

The results of the regression were $\alpha = -0.0036\ m^2/A$, $\beta = -0.1154\ V/^{o}C$ and $\gamma = 47.286$ V, with a multiple correlation coefficient $R \approx 1$ and standard error of $2.696 \cdot 10^{-15}$, which it demonstrates the quality of the fit.

The algorithm has been evaluated by means of the results obtained from simulations. The simulations show the behaviour of the MPPT controller by changing the voltage setpoint (Vmpp) when the environmental conditions (temperature and radiation) change. The environmental conditions under which the simulations are carried out are detailed in Table 1.

Solar radiation and temperature were programmed to change in two ways, one slowly and the other rapidly. The rapid change in radiation (Figure 7) would be related to situations in which clouds appear randomly and quickly. In the case in which we program a slower and more gradual radiation change (Figure 9), it would be related to the radiation levels that occur throughout a cloudless day.

Table I. – Simulations Conditions

MAGNITUDE	RANGE
Ambient Temperature	25ºC-50ºC
Irradiation	600 – 1000 W/m^2

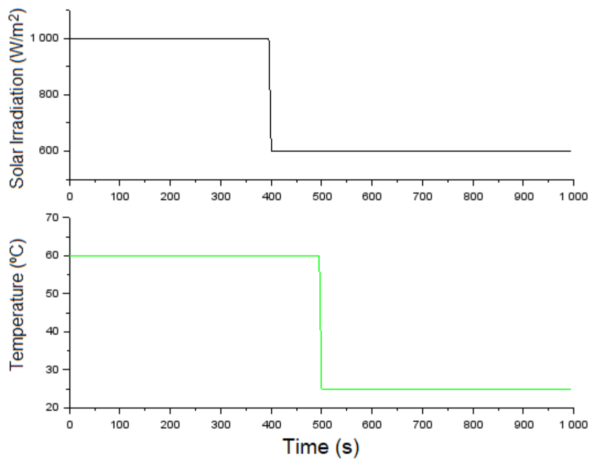

Fig. 7. Simulated signal waveform of a rapid drop in solar radiation and temperature.

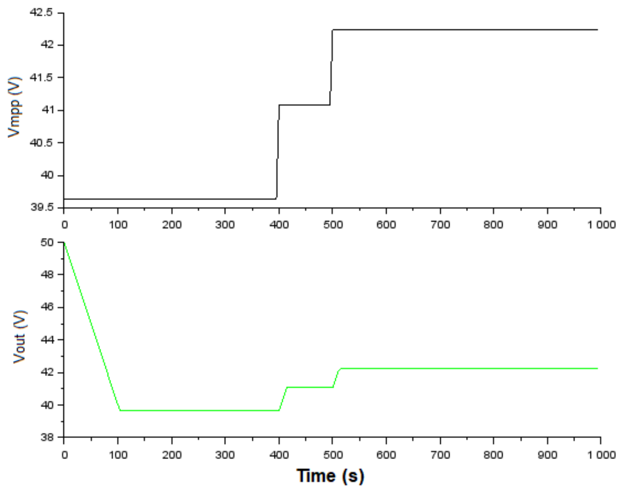

Fig. 8. Response of the DC-DC converter (Vout) against the target voltage provided by the algorithm (Vmpp) for a rapid drop in solar radiation and temperature.

The result obtained by applying the algorithm to sudden changes in radiation and temperature is represented in figure 8 where the reference voltage Vmpp and the time evolution of the voltage at the output of the converter (Vout) can be seen. To obtain this response, a sudden change in radiation from 1000 W/m^2 to 600 W/m^2 and, consequently, a sudden drop in temperature from 50ºC to 25ºC was programmed.

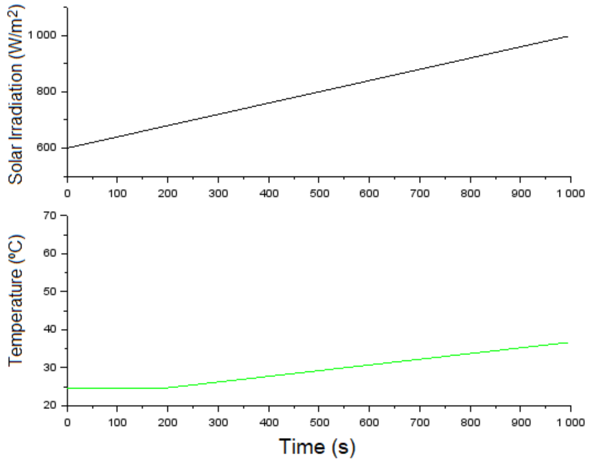

Fig. 9. Simulated signal waveform of a slow rise in solar radiation and temperature.

On the other hand, we were also interested in the response that occurred in the system when solar radiation and temperature changed smoothly. In this case we cause an increase in solar radiation from 600 W/m^2 to 1000 W/m^2 and an increase in temperature (as a consequence of the increase in solar radiation) from 25ºC to 40 ºC.

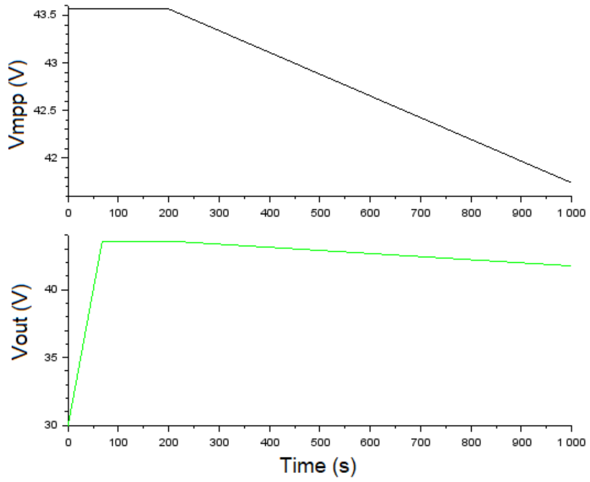

Fig. 10. Response of the DC-DC converter (Vout) against the target voltage provided by the algorithm (Vmpp) for a slow rise in solar radiation and temperature.

As a result of the smooth change in environmental conditions, figure 10 shows the constant change in the reference voltage Vmpp and the time evolution of the voltage at the converter output (Vout).

These simulations were carried out under the condition that the algorithm provides a small ΔV = 0.2V in a constant and uninterrupted way until reaching the reference voltage Vmpp.

Another way the system can work is by providing a single ΔV whose value is |Vmpp-Vin|. This method is very fast to reach the reference voltage but as a consequence a transient effect is produced and therefore a PID controller would be necessary to minimize the transient effect. The PID can be obtained through the transfer function described in equation 4, where Vout is the target voltage (Vmmp).

Figure 11 shows the result of performing a direct (and not gradual) control of the input voltage by the DC-DC converter to reach the reference voltage Vmmp where the transitory effect is evident.

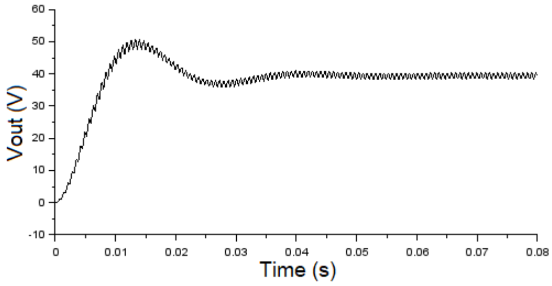

Fig. 11. Waveforms of PV voltage regulation through the buck-boost DC-DC converter.

In this case, the boundary conditions are a voltage at the terminals of the photovoltaic panels of 50 V and a sudden change in solar radiation and temperature. The reference voltage Vmpp, according to the Multiple Linear Regression model, is 40 V.

5. Conclusion

In this paper, an algorithm for maximum power point tracking controller is presented and the model has been developed in a simulation setup using SCILAB/Xcos. The MPPT model has been studied considering systems that are affected by significant changes in environmental conditions (temperature and irradiance), such as solar pumping systems.

As a result, the proposed model instantaneously provides the voltage values at the point of maximum power once the instantaneous values of solar radiation and temperature of the photovoltaic panels are known by means sensors, so this new algorithm can be applied, as an alternative to conventional techniques, for whatever the environmental conditions, being very useful for designers and manufacturers of photovoltaic systems that require MPPT controllers.

This procedure causes the DC-DC converter to operate the photovoltaic system in an area close to the mpp, which means that the photovoltaic panels are providing the maximum possible power at all times. The control would be faster when the algorithm directly provides the step size ΔV to reach the reference voltage Vmpp, but the transient effect would require the use of a PID controller to minimize the transient effect.

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