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A Study of a Photovoltaic Production Line Controlled with a PI Corrector

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Abstract
This article presents a study and simulation of a photovoltaic production line. It consists of PV panels sized to recover the maximum power output. These photovoltaic panels power a DC-DC boost converter that produces a DC output voltage greater than the input voltage. The output of the DC-DC boost converter is influenced by the variation of temperature and solar irradiance. Thus, a PI control is used to stabilize its value. The boost converter supplies a DC-AC converter that converts the DC input voltage to AC voltage. The control of the inverter applied is a sinusoidal pulse width modulation. An LC filter is connected to the output of the inverter to eliminate some unwanted frequency components. This system is simulated under the Simulink matlab software.
Keywords: Photovoltaic, PI corrector, DC-DC boost converter, Inverter, LC filter.

1. Introduction

Photovoltaic energy reaches nowadays an important interest as one of the next generation sources (Islam, Mekhilef, and Hasan 2015). The photovoltaic panels contain solar cells that convert sunlight into electricity. They produce a continuous electrical energy that is influenced by irradiation and temperature change. In order to harness this energy, a power conditioning system is required to adjust the output power appropriately to the load (Boumaaraf, Talha, and Bouhali 2015; Selvaraj, Rahim, and Krismadinata 2008; Kouro, Samir, et al. 2007). It consists of two power processing stages, DC- DC converter and DC-AC converter. DC-DC converter place the system at the favourable functioning point (Akhter 2007; Mitulkumar Dave and Dave 2012). This provides a maximum output voltage of a fixed value basing on its control system. DC-AC converter is introduced between the boost converter and the load (Villanueva, Elena, et al. 2009; Islam, Mekhilef, and Albatsh 2011). It converts the DC input voltage into an AC output voltage. Its control specifies the frequency and the value of the output voltage. The output signal of the inverter comprises several sinusoidal components. Thus a filter is inserted in the inverter output to eliminate undesirable frequency components (Kim, Hyo-Sung, and Seung-Ki Sul 2011; Pasterczyk, Robert, and al. 2009). In this manner a sinusoidal signal is recovered in the output of the production line. In this paper, we study the full photovoltaic system production chain. The first part studies the photovoltaic panels functioning and presents the characteristics of those used. The second part presents the composition of the DC-DC boost converter, its operation and its dimensioning in continuous conduction operating mode (Naim, Weiss, Ben-Yaakov, 1997). This power processing stage provides a continuous value of the output voltage greater than the input voltage. It is controlled by a PI regulator in order to maintain its output voltage constant independently of climatic variations. Sizing the PI controller parameters is based on the desired closed-loop model thus ensuring good behavior. The third part analyzes the H bridge inverter functioning. This stage is controlled by the sinusoidal pulse width modulation. It compares a sinusoidal signal to a triangular one. The triangular signal frequency is chosen considering the switching frequency of the inverter. The output signal of the inverter presents several sinusoidal components and voltage ripple. So, the last part of this work analyzes an LC filter to recover a sinusoidal signal at the output of the system. The system is simulated under Matlab Simulink software. The output signals illustrate the smooth running of the system.

2. PV Panels characteristics

PV cell is a semiconductor which converts sunlight to electricity if radiated. It contains positive and negative electrical charges. Radiation is a set of photons with distinct energy values. A photon with energy greater than semi-conductor band-gap energy provokes the electrons and holes to move toward the PN junction. Then a voltage is generated. External connection collects electrical charges which produce an electrical current. The PV module is made by wiring solar cells in series to increase voltage and parallel to increase current. The PV module characteristics change with climatic condition change. In this paper the PV generator is sized to generate the required power. Its characteristics are given by figure 1, figure 2, figure 3 and figure 4.

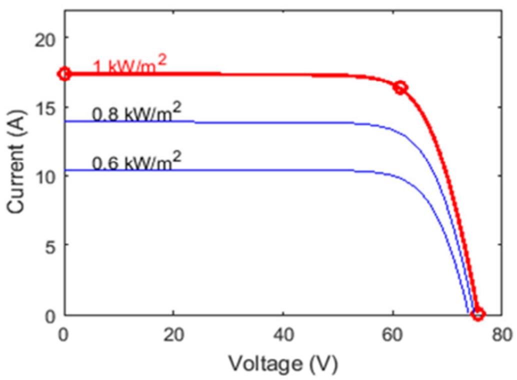

Figure 1: Current – voltage curves according to values change of the radiation

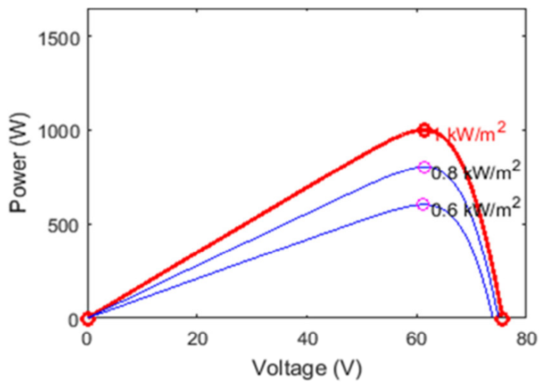

Figure 2: Power – voltage curves according to values change of the radiation

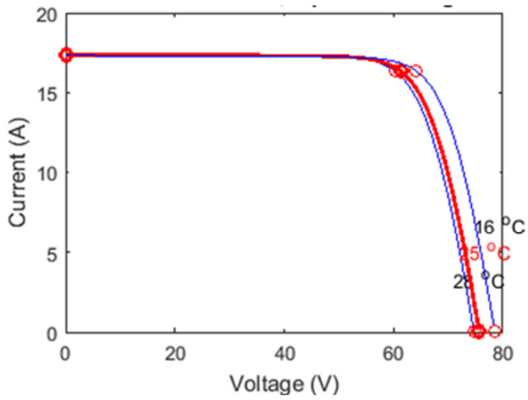

Figure 3: Current – voltage curves according to values change of the temperature

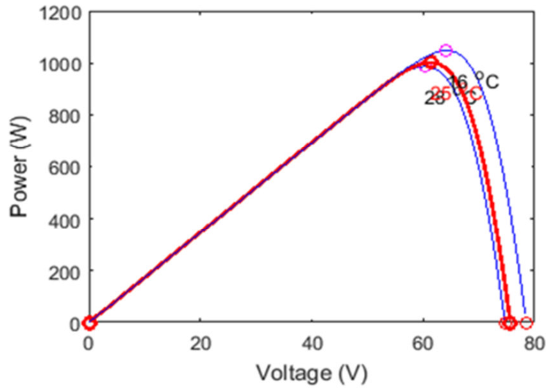

Figure 4: Power – voltage curves according to values change of the temperature

The photovoltaic panel used can produce a maximum power of 1.1 KW. The corresponding current is equal to 17.38A and the voltage is equal to 61.28V. The radiation fall decreases the current value. The temperature descent decreases the voltage value. Then the maximum power that can be delivered by the photovoltaic panel is affected by radiation and temperature change.

3. Boost converter

This application requires a voltage value of 220V that cannot be provided by photovoltaic panels selected. Then a DC-DC boost converter which generates an output voltage larger than the input voltage is used. It contains input inductor, output capacitor, and two interrupters. The schematic diagram is given by figure 5.

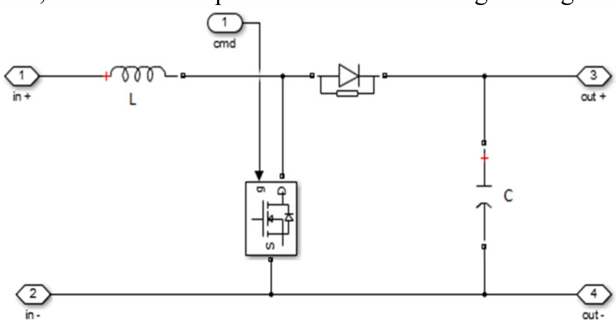

Figure 5: Schematic of boost converter

The step up converter presents two phases of operation (Akhter 2007; Mitulkumar Dave and Dave 2012). Energy accumulation phase: the current goes through the Mosfet and the inductor is loading by energy. The diode blocks the current so the capacitor feed the load. The freewheeling phase: the Mosfet blocks the current witch goes through the diode. The energy stored in the inductance is added to the energy of generator and transmitted to the capacitor and the load.

In the continuous conduction mode the voltage expression is:

$$V_s = \frac{V_e}{1-D} \qquad (1)$$

To choose the inductance and capacitor values expressions below are considered:

$$L = \frac{V_e*(V_s-V_e)}{\Delta I_L*f_d*V_s} \qquad (2)$$

$$C = \frac{I_s*D}{f_d*\Delta V_s} \qquad (3)$$

The boost converter in this work is controlled by a PI regulator. It is used to maintain the desired value of boost output voltage regardless radiation and temperature variation. Its transfer function is given by:

$$C(p) = A*(1+\frac{1}{T_i p}) \qquad (4)$$

The PI regulator controls the time of energy accumulation phase for a fixed value of frequency. This value affects the size of the component and commutation loses. This application uses a frequency of 20 KHz. Sizing the PI regulator parameters depend on a program developed in Matlab software. It consists of calculating the closed loop transfer function made by the boost mathematical model and the PI regulator transfer function in figure 6. Then identify the resulted equation to the desired one which is established by the desired response time and pulsation.

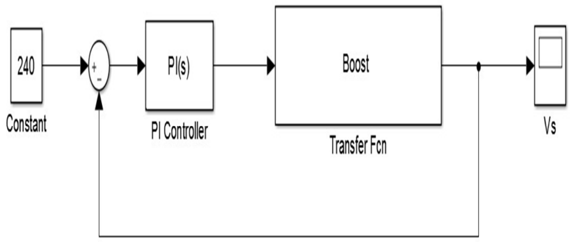

Figure 6: Closed loop PI control

The transfer function of the DC-DC boost converter that links the output voltage to the duty cycle in continuous conduction mode is given by (Naim, Weiss, Ben-Yaakov, 1997):

$$\frac{V_s}{D} = \frac{{V_s}^2(1-D)^2}{V_e LC} * \frac{\left(1-\frac{L{V_s}^2}{R{V_e}^2}p\right)(1+R_c C_s)}{p^2+\frac{(1-D)^2}{RC}p+\frac{(1-D)^2}{LC}} \qquad (5)$$

The resulted output signal of the boost converter is given in figure 7 and the control signal is given by figure 8.

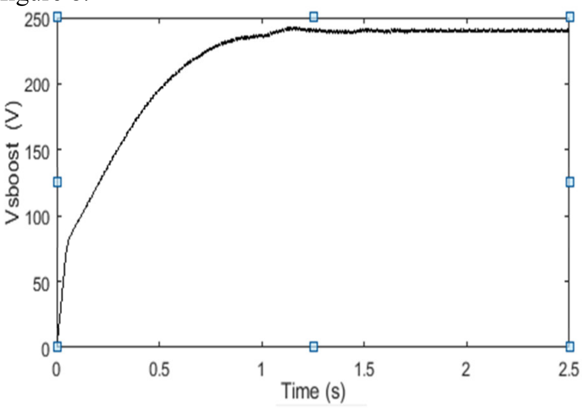

Figure 7: DC to DC boost converter output voltage

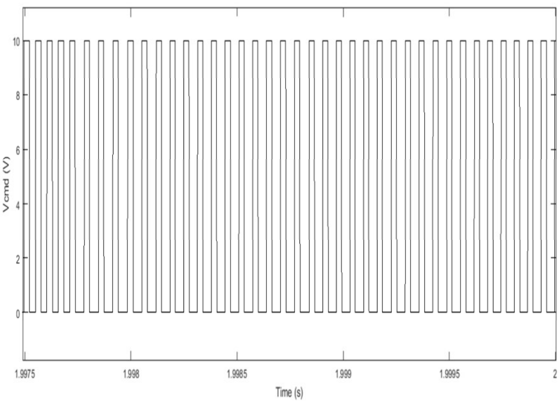

Figure 8: DC to DC boost converter control signal

The boost converter control signal changes its state with a frequency of 20 KHz. The changes of the irradiation and the temperature started at 0.5s and persisted along the simulation. The PI regulator fixes the boost output voltage at the desired value as quickly as possible and forces the voltage to maintain it for the rest of simulation time.

4. Inverter:

The H bridge inverter converts the DC input voltage to an AC output voltage of a desired value and frequency. This inverter is formed by four switches, two series switches per leg. Two legs are coupled in order to link a load to the DC rail and ground. This structure is given in figure 9.

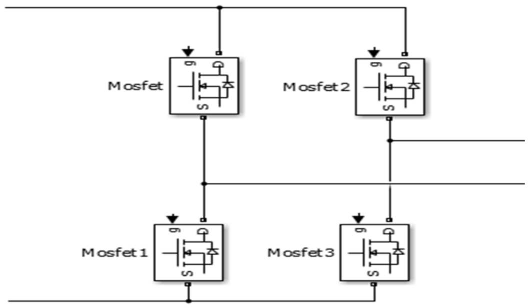

Figure 9: H bridge structure

The two switches on the high side control the accessibility of the DC voltage across the load while the two switches on the low side control the connection of the load to the ground. Switches commutation refers to reversing the output voltage of the inverter between the positive and the negative DC rail. This results an alternating voltage signal (Kim, Hyo-Sung, and Seung-Ki Sul 2011; Pasterczyk, Robert, and al. 2009).The inverter operates in the SPWM control. It consists of comparing a sinusoidal wave to a high frequency triangular wave. This refers to comparing the instantaneous magnitude of the sinusoidal signal with that of the triangular signal at a point of time. If the triangular signal is less than the sinusoidal signal, the load will be connected to the positive side of DC rail else the load will be connected to the negative side of the DC rail. This results multiple output pulse of different width per half cycle. The switching frequency of the resulted signal is that of the triangular signal. The comparison scheme is given by figure 10.

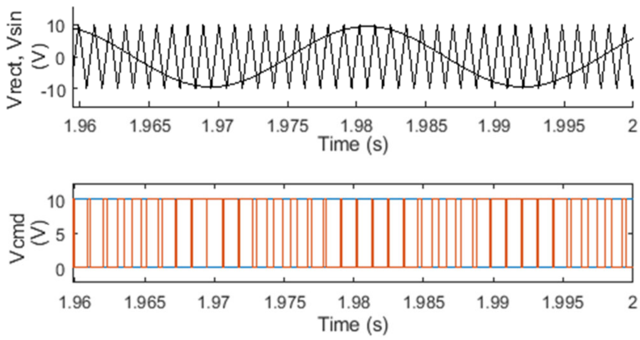

Figure 10: SPWM control principle

The output voltage of the inverter before filtering is given in figure 11.

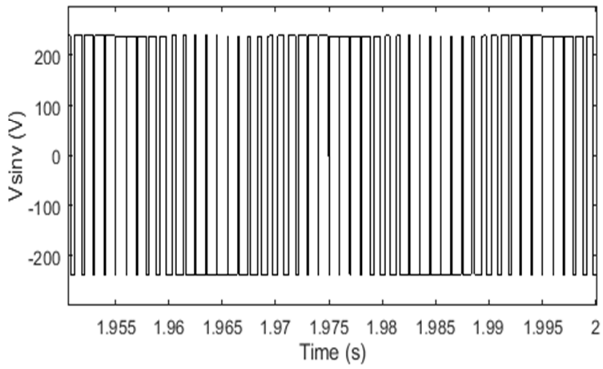

Figure 11: Inverter output voltage

The inverter output signal alternates between 240 V and -240 V with a frequency of 1 KHz.

5. Filter

The output signal of the inverter includes several sinusoidal components. The switching acts cause voltage ripple. The purpose of this work is to generate a sinusoidal signal at the output of the system with attenuated ripple. So a filter which eliminates undesirable frequency components and decrease voltage ripple is required. Second order passive LC filter were being largely chosen to get this target (Kim, Hyo-Sung, and Seung-Ki Sul 2011; Pasterczyk, Robert, and al. 2009). It is given by figure 12.

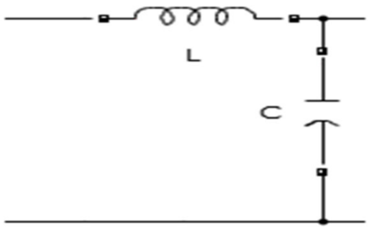

Figure 12: LC filter

To calculate the inductor and capacitor values the equation (6) was used:

$$LC = \frac{1}{4*\pi^2*F_C{}^2} \quad (6)$$

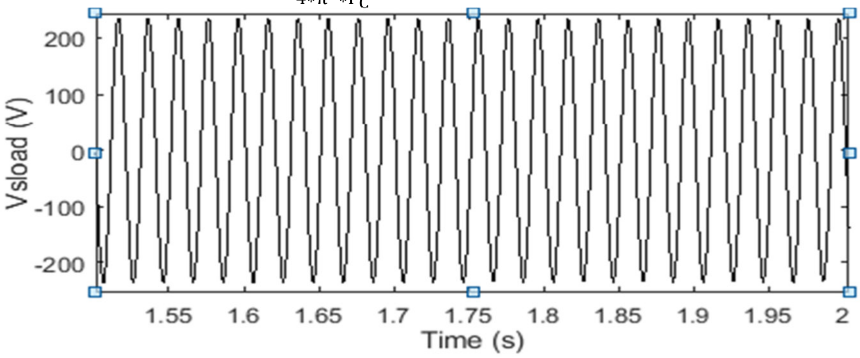

Figure 12: LC filter

The resulted signals are given in figure 13. The filter output signal is sinusoidal of frequency 50 Hz.

6. Conclusion

A photovoltaic production chain composed of pv cells, DC to DC boost converter, DC to AC converter; LC filter and a resistive load have been studied theoretically and simulated under Matlab Simulink software. The PI control has been dimensioned and used to stabilize the output voltage of the boost converter. The sinusoidal pulse width modulation controls the output voltage of the inverter. The output voltage of photovoltaic chain possesses the required characteristics.

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