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Simulation Results of a 1 kW Photovoltaic System with MPPT Function in the Inverter

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***Abstract*— Photovoltaic pumping systems are commonly used in remote regions, where the access to electrical energy is difficult or very expensive. This paper presents simulation results of a 1 kW photovoltaic system proposed in a cascade topology, consisting of a DC-DC boost converter followed by a single-phase inverter. The Maximum Power Point Tracking (MPPT) function is performed by the inverter, instead of by the DC-DC converter, as usually is done. The MPPT function uses an Incremental Conductance algorithm. This paper presents simulation results, in steady state and transient conditions, for the proposed photovoltaic system operating in different circumstances, which in real facilities can be caused by solar radiation variations.**

Keywords - Photovoltaic Pumping Systems; Maximum Power Point Tracking - MPPT; Inverter; DC-DC Converter; Simulation.

I. INTRODUCTION

The access to clean water is not an easy task in many regions of the world. Many times the problem is not the availability of the water but the difficulty on accessing it, because the only available is the groundwater. The use of pumping systems is very common. Older systems are purely mechanical powered by wind. These systems have many disadvantages and were rapidly substituted by electrical pumps. In urban areas this is a common solution but for those regions where the electricity is not accessible it is still a problem. The solutions that first were used take fuel generators to produce electricity. With the development of the renewable generation systems new and more efficient solutions are being developed.

In this paper it is presented the power electronic circuit of a 1 kW photovoltaic (PV) system for pumping water. The power electronic circuit is necessary to interface the solar photovoltaic panels and the pump. The photovoltaic panels are a DC voltage source and the pump can be either a DC voltage pump or an AC voltage pump. The most common ones are the AC voltage pumps. In the case of being used an AC voltage pump the power electronic circuit should be responsible for converting the DC voltage of the panels to the proper AC voltage for the pump. Also, in order to extract the maximum power from the panels, exploiting their maximum efficiency, they should be operated in their maximum power point. This point changes according to the variation of irradiance and temperature. Hence, Maximum Power Point Tracking (MPPT) units are introduced to track the maximum power point, under varying atmospheric conditions.

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In literature it can be found different converter topologies [1] and MPPT algorithms [2-3]. However, the various methods that have been proposed in literature can be roughly classified into the Perturbation and Observation method (P&O) and the Incremental Conductance method (ICond). The P&O periodically increase or decrease the solar panels array voltage at each sampling period and tests the power change afterwards, approaching the maximum power point. The ICond calculates the derivative of the power at each sampling period to get the correct direction for perturbing the solar panels array reference voltage to locate the maximum power point quickly.

As it is presented in [1] the main application topologies are constituted by:

- A single DC-AC converter that handles the MPPT, voltage amplification, and output current control;
- A dual converter where the DC-DC converter is responsible for the MPPT and the DC-AC inverter controls the output current;
- A dual-stage converter, where each PV module or string is connected to a dedicated DC-DC converter that is connected to a common DC-AC inverter.

When it is intended to connect the solar panels to the grid it can be explored even more topologies, like for example the new topologies based in multilevel inverters. The single DC-AC converter based in multilevel inverters normally neutral point clamped (NPC) avoids transformers, although, in PV applications, the transformerless systems have problems related to leakage currents [4]. Also, it can be exploited existing equipments to connect the solar panels to the grid and with that reduce costs. This is the case of using Active Power Filters as interface like is shown in [5-7].

In this paper it is presented a topology for being used in a pumping system. It is based in a dual converter where the DC-DC converter is responsible for elevating the solar array voltage and the DC-AC inverter controls the panel's current according to a MPPT control algorithm. Commonly the MPPT is implemented in the control of the DC-DC converter but it was intended to have some simulation results that could help designer of these systems to compare the presented results with other configurations to analyze the advantages and disadvantages of having the MPPT control in the inverter.

One advantage that is readily visible is that, if the solar array has a level of voltage high enough for the inverter to produce the desired voltage in the output, the DC-DC converter can be waived.

This paper presents the simulation results of a 1 kW single-phase photovoltaic system to feed a water pump. It presents simulation results in steady state and in transient conditions during solar radiation fluctuations. All the simulations were made with the software PSIM 9.0 from Powersimtech.

II. TOPOLOGY

A. Hardware

The proposed topology is presented in Fig. 1. It is constituted by the cascade of two power converters: a DC-DC converter that boosts the solar panels array voltage to a level that is adequate for the inverter to produce a maximum output voltage of 230 V AC in the output of the system; and a DC-AC converter that synthetizes the 50Hz output sinusoidal voltage, variable in amplitude according to the available power in the panels.

Since this is a small power application (1 kW) it is viable to use MOSFET power semiconductors commutating at high frequency. With high commutation frequencies the current and voltage ripple in the output of the DC-DC converter is smaller and this way the size of the inductance and capacitor can be reduced. This is important to reduce the size and weight of the power converter, which is relevant for this type of application. So, it was considered a commutation frequency of 50 kHz, for both the DC-DC and the DC-AC power semiconductors switches.

The solar panels array was modeled using the PSIM model with the parameters of real panels, taken from manufacturer datasheet. Table I presents the values of the parameters of the solar panels, DC-DC converter and load (representing a single-phase induction motor). In the simulations it was defined a configuration for the connections of the panels where all the panels were connected in series to obtain a higher output voltage.

It is not a purpose of this paper to analyze the water pump control. It intends only to analyze the converter behavior. So it is assumed that the voltage in the pump will change according with the power available in the solar panels array. The simple change of the voltage amplitude will change the speed of the pump. This is one of the classic methods to control the speed of induction motors that suits to loads with a torque curve like water pumps. The water pump is modeled by a simple RL circuit, which represents the equivalent circuit of the stator.

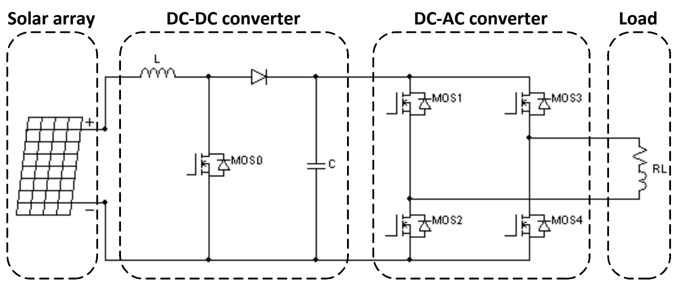

Figure 1. Power electronics topology of the studied photovoltaic system.

TABLE I. CIRCUIT PARAMETERS

Solar panels array	
Number of panels	5
Series Resistence	5.5 mΩ
Shunt Resistence	1 kΩ
Short Circuit Current	8.21 A
Open Circuit Voltage	164.48 V
DC-DC converter	
Indutance	5 mH
Capacitor	330 µF
Load	
Resistence	52.9 Ω
Indutance	1.39 m

B. Control

The typical control strategy used for this kind of topology is to implement a MPPT algorithm in the DC-DC converter. In this paper it is purposed to study a system with the MPPT control in the DC-AC converter. So, the DC-DC converter is only responsible to boost the voltage at the output of the solar panels array to the fixed value of 400V in its output. This way the control of the DC-DC boost converter is simplified and can be implemented by a simple PI algorithm responsible to maintain the voltage in the DC link constant, and with the desired value. In Fig. 2 is represented a scheme that graphically illustrates the control structure implemented for the DC-DC converter.

The control of the DC-AC converter is responsible to make the converter generate a single-phase AC voltage with fixed frequency (50 Hz) and variable amplitude, which is changed in accordance with the MPPT algorithm reference, so that at each instant the maximum power available at the solar panels array can be extracted and delivered to the load. The implemented MPPT algorithm is an Incremental Conductance algorithm like the one described in [4-5]. To reduce the output voltage fluctuations and the ripple in the DC link, the implemented MPPT algorithm uses the average value of the solar panels voltage and current instead of using the instantaneous value.

Both the control algorithms, of the DC-DC and DC-AC converters, were implemented using the programing language C, by means of the C Block component of PSIM. This approach gives to the simulations a behavior that is closer to practical implementation since this control algorithm is quite similar to the one that would be implemented in practice. It can be nearly directly exported to a microcontroller.

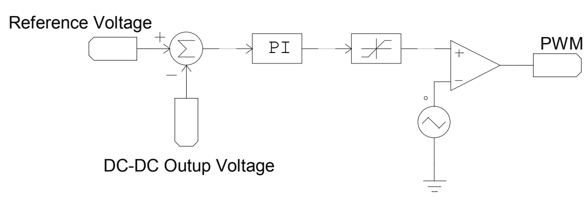

Figure 2. Graphical scheme of the DC-DC converter control.

A characteristic of great importance for the design of the control, in any system, is the dynamics of the system. The dynamic behavior of a PV system depends substantially upon the atmospheric conditions to which the system is subjected, namely solar irradiation and temperature fluctuations. In order to predict its dynamic behavior it is necessary to account for variations in solar irradiance that occur as a result of random cloud passage over all, or part, of the array. This variation may differ considerably from day to day depending on weather. On clear days, for example, the solar radiation may not change substantially from minute to minute, whereas, on cloudy days, the solar radiation may change rapidly, in some cases, causing the PV system to go from full load near no load or vice versa in a few seconds [10]. The proposed control is able to follow a change of solar radiation from a maximum of 1000 W/m^2 to a fourth of that power in 4 seconds.

III. SIMULATION RESULTS

In order to obtain a good characterization of the proposed topology it was defined a set of simulations. So the system was simulated under different operating conditions, in steady state and during transients caused by solar radiation variations.

In Fig. 3 is presented the output voltage of the DC-DC converter, and the current and voltage in the solar panels array during the startup of the system with a maximum solar radiation of 1000 W/m^2. It can be seen that the DC link voltage grows stable without a significant voltage ripple. The current from the panels also grows in a controlled way. In 3 s the system goes from zero to the maximum power. The voltage in the solar panels array decreases until it reaches the point of maximum power.

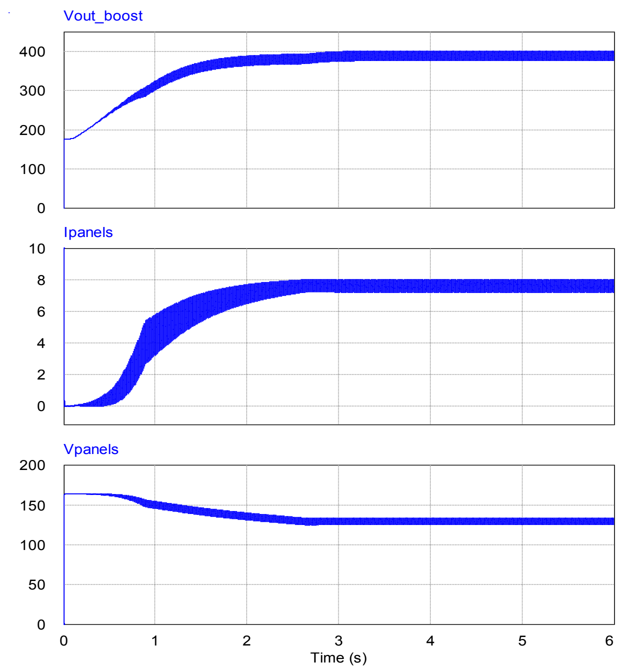

Figure 3. Output voltage of the DC-DC converter (Vout_boost), current (Ipanels) and voltage (Vpanels) in the solar panels array during the startup of the system with maximum solar radiation.

Fig. 4 presents the system behavior in steady state for the maximum power. It shows the DC-DC converter output voltage, the current from the panels, the instantaneous extracted power and the maximum theoretical power that can be extracted from the solar panels array in steady state. It can be seen that the ripple in the DC-DC converter is not too high, only 6%.

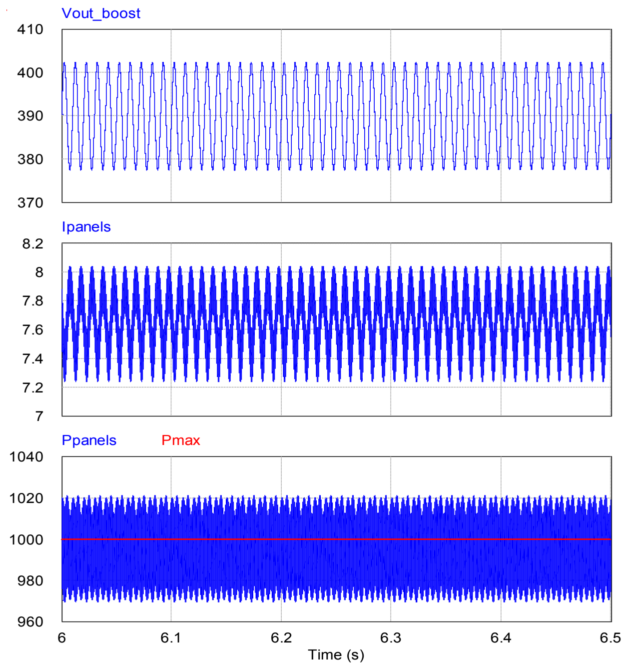

Figure 4. Output voltage of the DC-DC converter (Vout_boost), solar panels current (Ipanels), instantaneous power extrated from the panels (Ppanels) and maximum theoretical power (Pmax) in steady state.

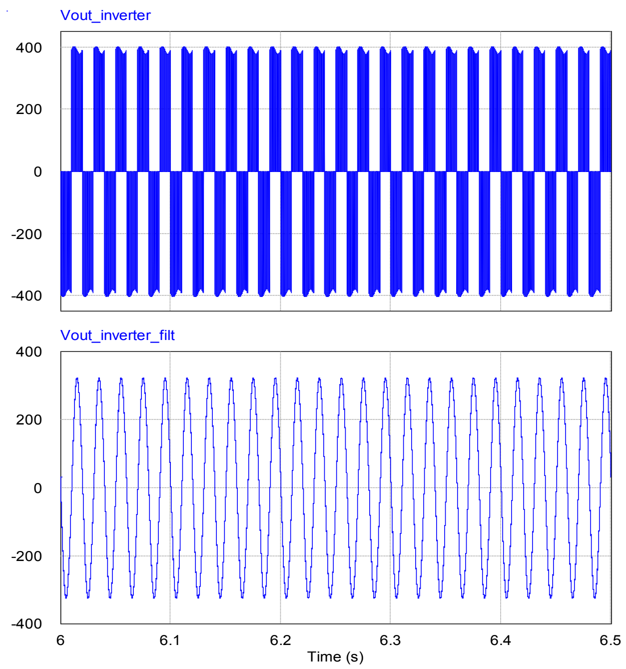

Figure 5. Output voltage (Vout_inverter), and its 50Hz fundamental (Vout_inverter_filt) in steady state.

Also the current extracted from the panels is stable with a ripple of 10%. The power follows the maximum theoretical power of the system. It has an average value of 996 W and its ripple is 5%, the expected in a system with an ICond control method.

The AC output voltage and its 50 Hz fundamental voltage are presented in Fig. 5. It is visible that the amplitude and frequency of the output AC voltage are constant. The rms value of this voltage is 229 V.

It was intended to test the behavior of the system when a fluctuation in the solar radiation occurs. For that it was made a simulation in which it was imposed a fluctuation on the solar radiation from the maximum power 1000 W/m^2 to 800 W/m^2, and then again to the maximum power. In Fig. 6 is sown the power extracted from the panels, the current in the panels and the fundamental of the output voltage, during the fluctuation in the solar radiation. As expected, the system follows the maximum available power. The AC output voltage amplitude was reduced by the control in accordance with the reduction of the available power.

It was also tested the behavior of the system when the solar radiation changes from the maximum power of 1000 W/m^2 to half that power in just 2.5 s. Fig. 7 shows the power change and the variations of the panels current and AC output voltage in that conditions. It is seen that the power extracted from the panels follows the maximum available power. Also the AC output voltage amplitude is reduced to follow the change in power.

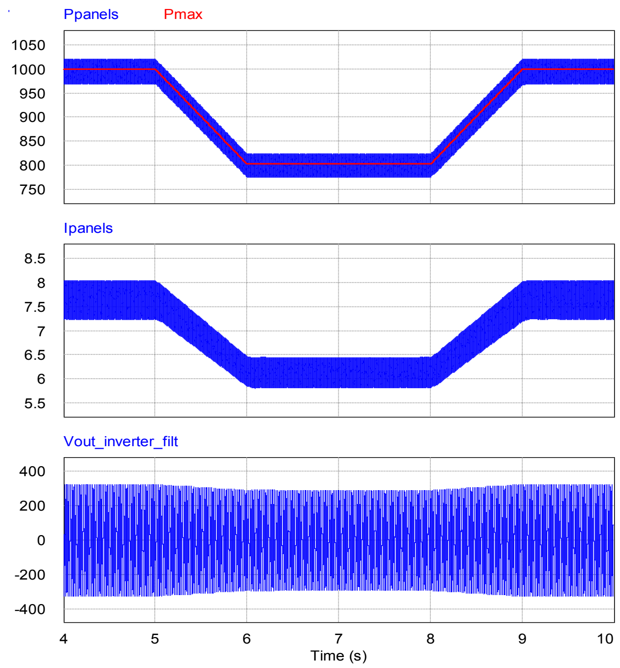

Figure 6. Extracted power (Ppanel), maximum theoretical power (Pmax), current in the panels (Ipanels) and the fundamental output voltage (Vout_inverter_filt) during a fluctuation in the solar radiation from 1000 W/m^2 to 800 W/m^2.

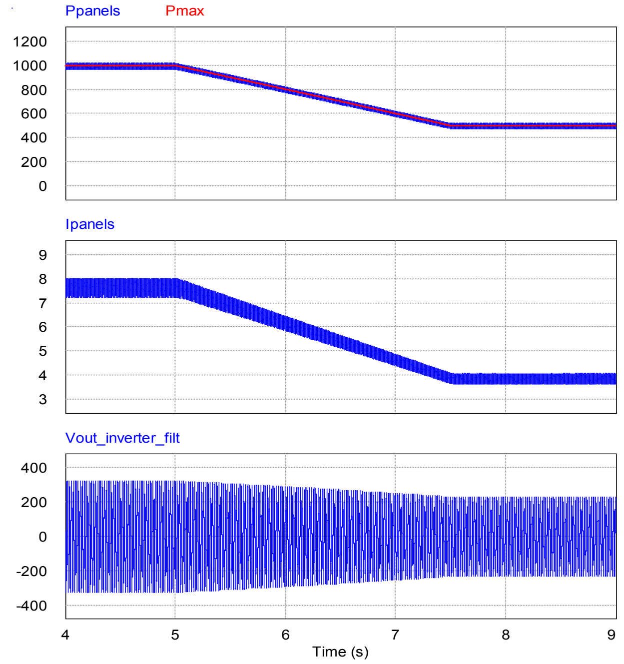

Figure 7. Extracted power (Ppanels), maximum theoretical power (Pmax), current in the panels (Ipanels) and the fundamental output voltage (Vout_inverter_filt) during a fluctuation in the solar radiation from the maximum power to half of that power.

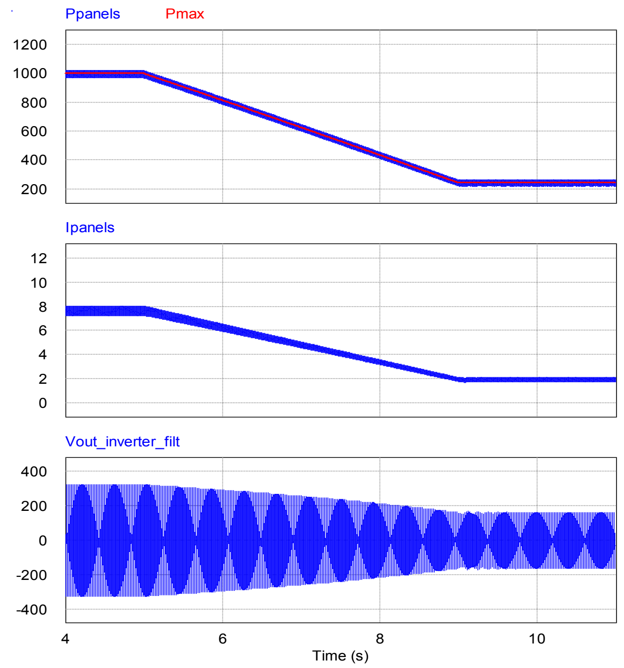

Figure 8. Extracted power (Ppanels), maximum theoretical power (Pmax), current in the panels (Ipanels) and the fundamental output voltage (Vout_inverter_filt) during a fluctuation in the solar radiation from the maximum power to a fourth of that power.

In Fig. 8 shows is presented the power change and the variations of the panels current and AC output voltage when the solar radiation changes from the maximum power of 1000 W/m2 to a fourth of that power in 4 s. It is seen that the power extracted from the solar panels array follows the maximum available power. Also the AC output voltage amplitude is reduced to follow the change in power. A variation from the maximum radiation to a fourth of that power in only 4s is perfectly compatible with the expected dynamic behavior of a solar system.

Finally it was tested if the system was able to startup with a minimum power of 250 W/m2. In Fig. 9 it is shown the output voltage of the DC-DC converter, and the current and voltage in the solar panels array in that condition of operation. It can be seen that the system was able to perfectly startup. Like for the condition of maximum power, the DC link voltage grows stable without a significant voltage ripple, less than with maximum solar radiation. The current from the solar panels array also grows in a controlled way. In 1 s the system goes from zero to the maximum available power. The voltage in the solar panels array decreases until it reaches the point of maximum power.

IV. CONCLUSIONS

This paper presents the design and simulation results of a 1 kW photovoltaic (PV) system for water pumping systems. The PV system consists in a cascade topology, which uses a DC-DC boost converter followed by a single-phase inverter. Contrary to the traditional approach commonly adopted for this topology, in which the Maximum Power Point Tracking (MPPT) task is performed by the DC-DC converter, in this paper the MPPT function is integrated in the control system of the inverter. It is used an Incremental Conductance algorithm for the MPPT. It is shown that the proposed system is able to always extract the maximum power available from the solar panels array, even when there are solar radiation fluctuations. The AC output voltage amplitude remains constant and is not affect by the MPPT algorithm fluctuations, and it only changes when there is a change on the solar radiation.

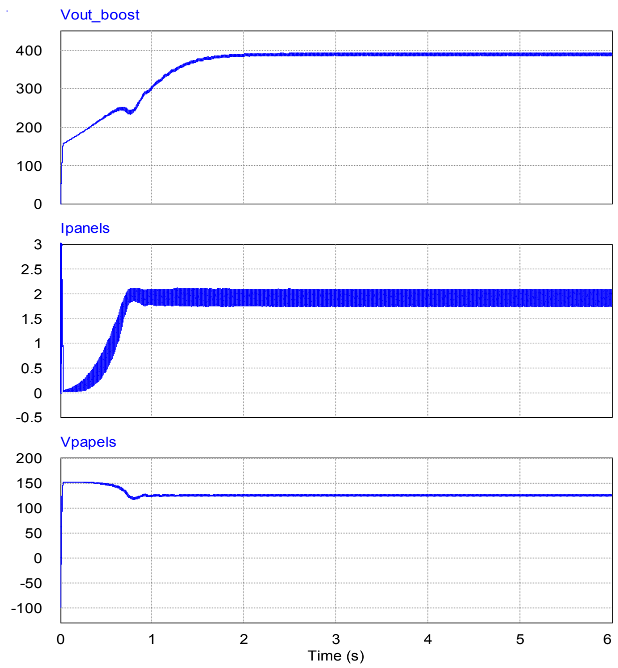

Figure 9. Output voltage of the DC-DC converter (Vout_boost), current (Ipanels) and voltage (Vpanels) in the panels during the startup of the system with a solar radiation of only 250 W/m^2.

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