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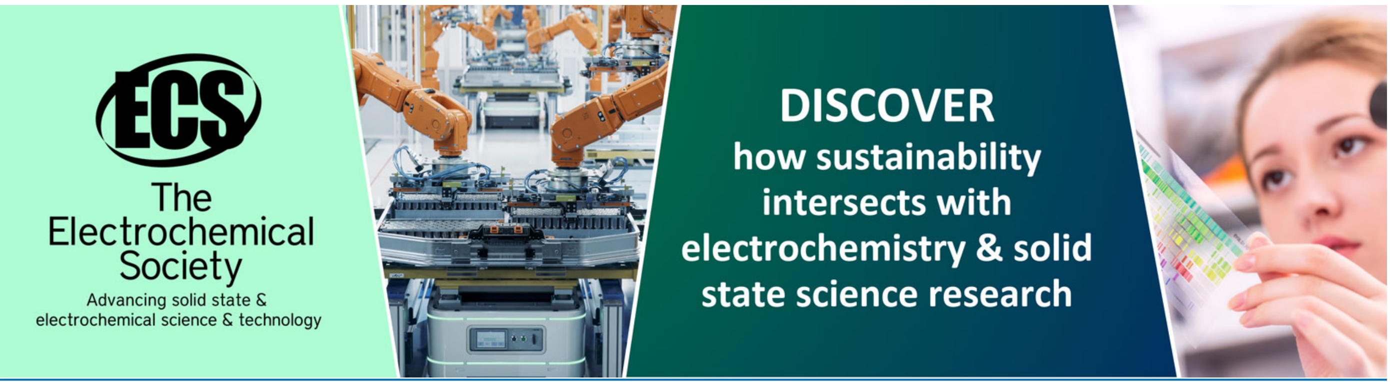

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A control strategy for PV stand-alone applications

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Abstract. This paper proposes a stand-alone photovoltaic (PV) system study in domestic applications. Because of the decrease in power of photovoltaic module as a consequence of changes in solar radiation and temperature which affect the photovoltaic module performance, the design and control of DC-DC buck converter was proposed for providing power to the load from a photovoltaic source.In fact, the control of this converter is carried out with integrated MPPT (Maximum Power Point Tracking) algorithm which ensures a maximum energy generated by the PV arrays. Moreover, the output stage is composed by a battery energy storage system, dc-ac inverter, LCL filter which enables higher efficiency, low distortion ac waveforms and low leakage currents. The control strategy adopted is cascade control composed by two regulation loops.Simulations performed with PSIM software were able to validate the control system.The realization and testing of the photovoltaic system were achieved in the Photovoltaic laboratory of the Centre for Research and Energy Technologies at the Technopark Borj Cedria. Experimental results verify the effeciency of the proposed system.

1. Introduction

A photovoltaic system (PVs) converts light energy into electricity. The basic device of a PVs is the PV cell. PV Cells are grouped to form modules or Panels. Modules may be grouped to form large PV arrays. A PV cell is basically a p-n semiconductor junction; the use of monocrystalline solar cell is recommended in many PV applications on account of its efficiency photovoltaic solar cells. In fact, Monocrystalline solar panels have the highest efficiency rates since they are made out of the highest-grade silicon. The efficiency rates of monocrystalline solar panels are typically 15-20% live the longest. The performance of a PV system depends also on the atmospheric conditions. The PV power, output voltage and current vary as functions of temperature and solar radiation. Hence, the I–V and the P–V characteristics of the PV system are nonlinear, and there is an optimum operating point (MPP) on the characteristics that can supply maximum power to the load. Therefore, Perturbation and Observation control algorithm (P&O) is proposed to extract the Maximum Power Point (MPP) at all times, irrespective of the type of PV panel or weather conditions [1, 2].
An inverter is inevitable at the output of the first stage, in order to generate a single-phase-level. In this stage, a LCL filter is necessary to reduce the total output signal harmonic distortion.
Because of the intermittent PV production, this system needs to be secured by storage system such as battery bank at the output of the first stage. Another reason for battery is the system applications context which is specific to isolated locations or countryside.

2. Proposed Stand-Alone PV System

The proposed System depicted in Figure 1 is composed by dc-dc converter connected to PV system, tracking the maximum power point of the panels. Connected at the output of the first stage, the inverter generates an output sinusoidal waveform. In this stage, a LCL filter was performed to reduce the total output signal harmonic distortion. Furthermore, a battery bank is connected at the output of the first stage.

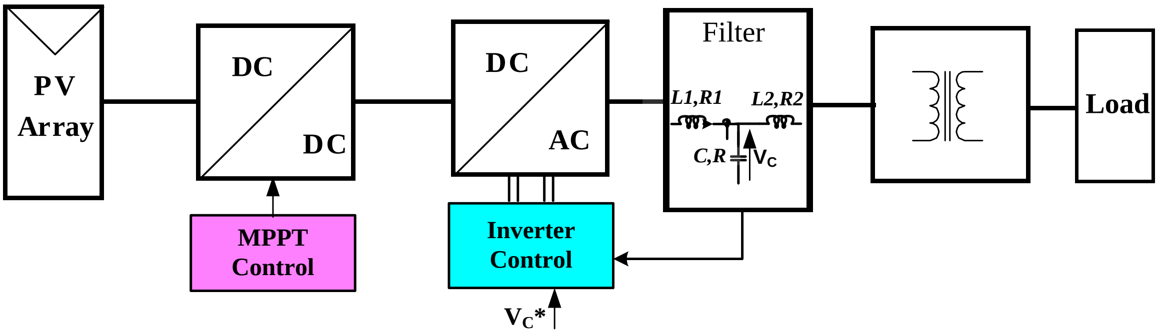

Figure 1. Stand-Alone PV System.

3. Experimental Setup

3.1. System Overview

The test bench presented in Figure 2 is installed in the Centre for Research and Energy Technologies at the Technopark Borj Cedria. It allows to determine the electrical characteristics of the solar panel.
The experimental system is divided of PV array connected to an acquisition chain and computer. The PV is Eurosolar M 510 A, whose electrical specifications are presented in Table 1. The radiation is measured using a pyranometer sensor. Also, the array surface temperature is measured using a thermocouple. Then, the experimental data was recorded for different atmospheric conditions and the result graphs were plotted.

PV panel simulated is Eurosolar M 510 A. The PV parameters are summarizing in Table 1. PV system is composed by 8 PV panels of 50 W, as shown in Figure 3, resulting in 400 W of total installed power. PV system is further interconnected in a 4 PV parallel-series configuration. Initially, each PV panel is producing 50 W at a1000 W/m² radiation

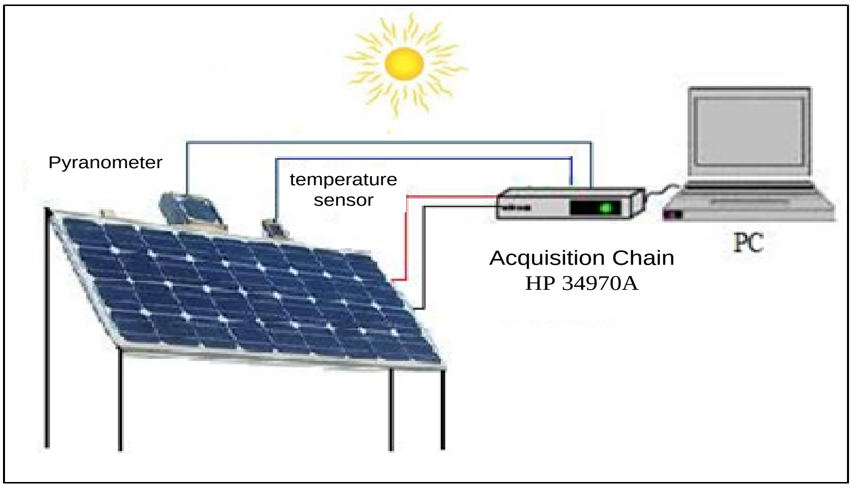

Figure 2. Test bench Photovoltaic system.

Figure 3. Photo-voltaic system.

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Table1. PV panel Electrical STC specifications.

Panel Type	Eurosolar M 510 A
Maximum Power	50 W
Optimal Current	2.95 A
Optimal Voltage	17 V
Short circuit current	3.25 A
Open circuit Voltage	21.4 V

3.2. Experimental results

Figures 4 and 5 prove that The PV current and power output vary with atmospheric parameters such as temperature and radiation. By increasing temperature, PV voltage will be drop. The PV Array current and Power decrease with decreasing radiation.

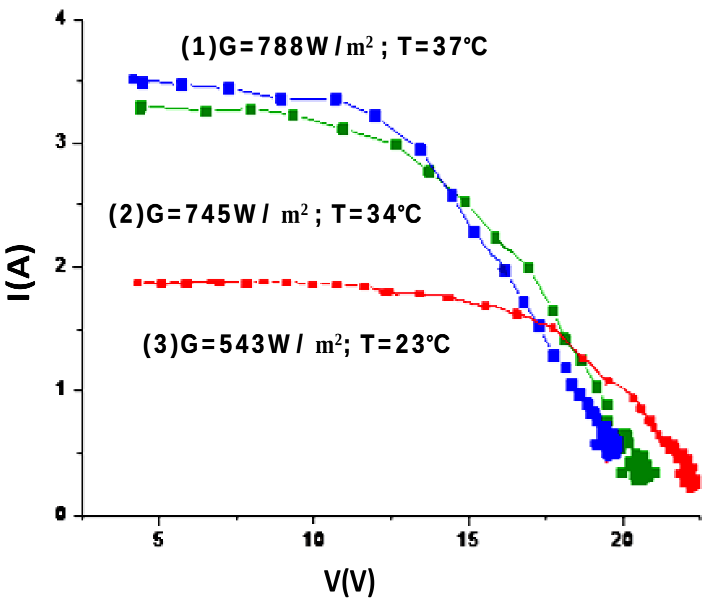

Figure 4. Characteristics I (V) curves of different temperatures and radiation.

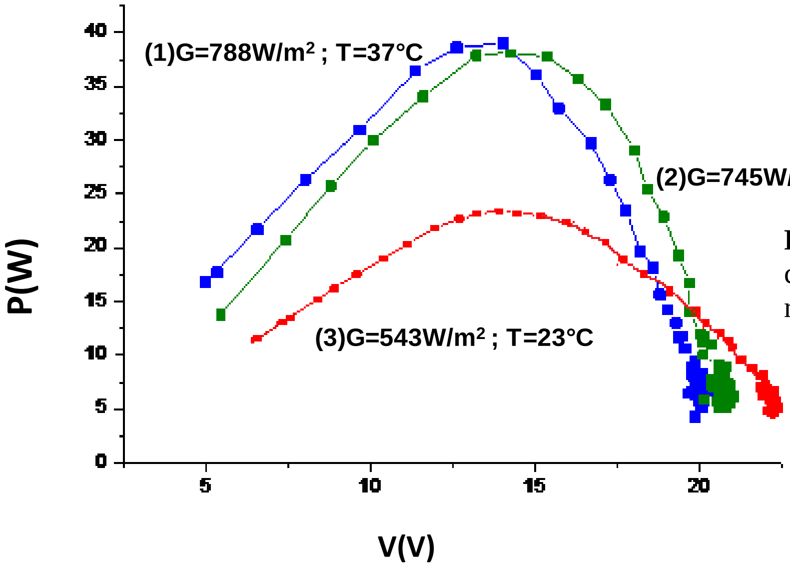

Figure 5. Characteristics P (V) curves of different temperatures and radiation.

The performance of the experimental system can be evaluated by comparing the measured array powers obtained from the experimental system with the theoretical one. In fact, theoretical results of the PV system are obtained from the PSIM-simulation software.

Figure 6 and 7 exposes the effect of radiation variations on the V-I and V-P PV characteristics. It is further seen that the PV current increases with increasing radiation (Figure 6). It is further observed that the PV power output increases with raising radiation (Figure 7). So theoretical and experimental results are consistent.

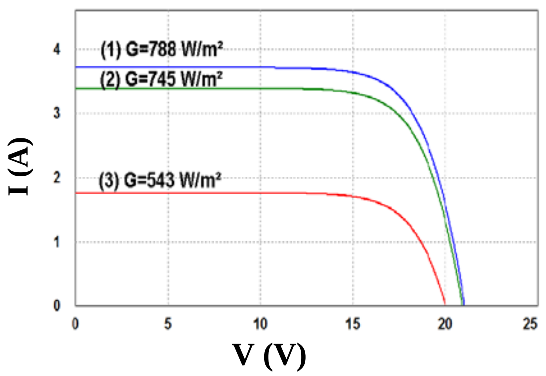

Figure 6. Characteristics I (V) curves of different radiations

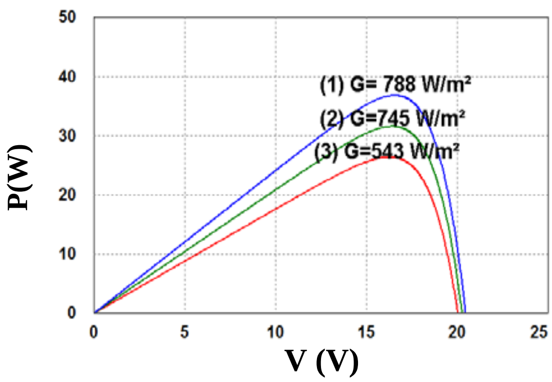

Figure 7. Characteristics P (V) curves of different radiations

4. Stand-Alone PV Control System

4.1. Control of single-phase PV-DC/DC-Inverter

4.1.1. Control of the DC-DC converter. Figure 6 and 7 show the V-I and V-P curves of a PV array, which each curve presents a maximum point at the MPP.
In order to guarantee that the maximum power will be extracted from the PV panels, a maximum power point tracker (MPPT) algorithm is required. Several algorithms are proposed in literature. Therefore, the Perturb & Observe (P&O) algorithm is widely used for its facility of implementation . Figure 8 belows the flow chart of the operation of the P&O MPPT algorithm.

After one perturb operation the current power is calculated and compared with previous value to determine the change of power ΔP. If ΔP>0, then the operation continues in the same direction of perturbation. Otherwise it reverses the perturbation direction. Figure 9 illustrates the MPPT simulation results where the PV power (PMPPT) follows its reference (Pref) at a1000 W/m² radiation [1], [2].

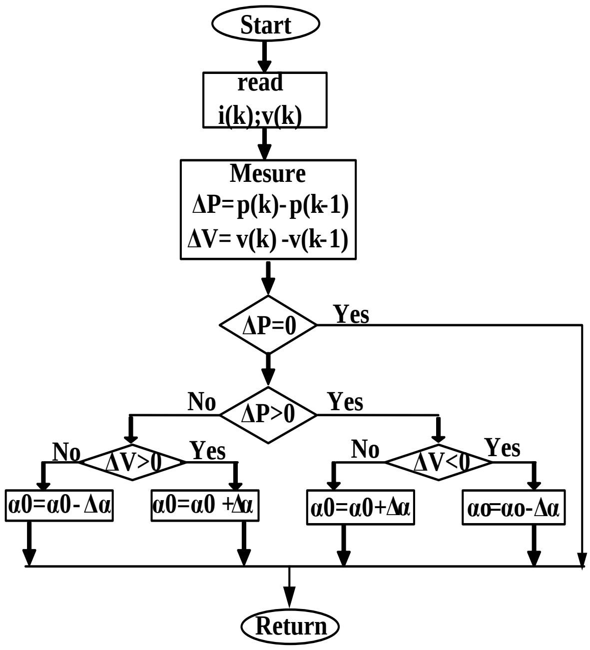

Figure 8. P&O MPPT flow chart.

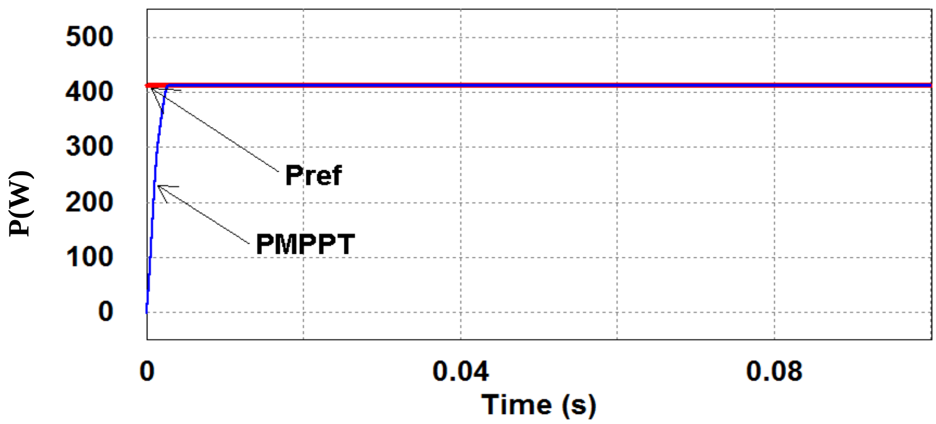

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Figure 9. MPPT PV Power.

4.1.2. Control of the DC-AC inverter

4.1.2.1. Modeling filter. For the PV inverter in stand-alone system, the most common control structure for the dc-ac inverter is using a P+Resonant (PR) controller with a low-pass output filter. In fact, LCL filter is used that being a higher order filter (3rd) leads to more compact design.
The drawback is that due to its own resonance frequency which can produce stability problems. So a special control design is required.
The resonant frequency of the LCL filter is shown in:

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{L_{o1}+L_{o2}}{L_{o1}.L_{o2}.C_o}} = 1130 \text{ Hz} \quad (1)$$

A method for designing both the controller and LCL filter ensuring stability is shown in Figure 10.
4.1.2.2. Synthesis of the closed loop control

The DC-AC Control inverter is performed where P+Resonant (PR) is introduced and applied to single phase PWM inverter control. In this approach the PI dc-compensator is transformed into an equivalent ac-compensator. The control strategy adopts a cascade control loop which is composed of two internal and external regulation loops. The cascade control loop of the PV inverter with PR controller is depicted in the Figure 10.

The P+Resonant (PR) controller is defined as: $C(s) = K_P + \frac{K_I}{s^2+\omega_0^2}$ (2)

The PI controller H(s) is defined as: $H\left(s\right) = \frac{1}{L_{o1}s + R_{o1}}$ (3)

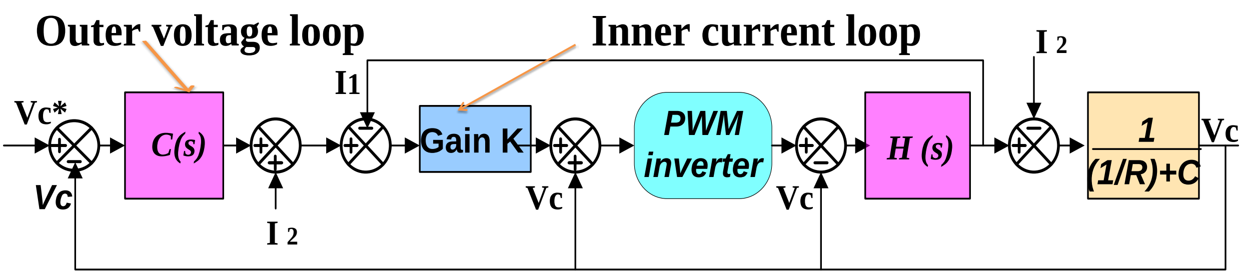

Figure 10. Closed control loop Synthesis.

Figure 11 and 12 expose the effect of LCL filter use. Indeed, in Figure 12 the total output signal harmonic distortion is reduced compared with the signal in figure 11.The issue of stability is becoming more important when LCL filter is used.

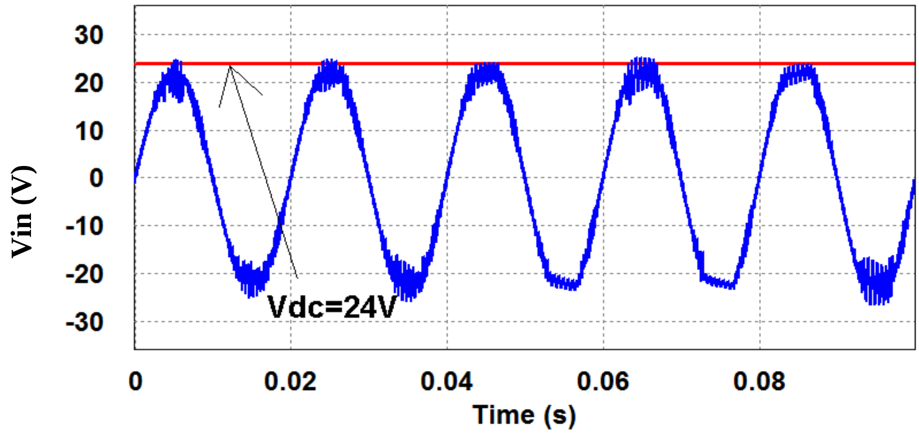

Figure 11. Voltage before Filter and Transformer.

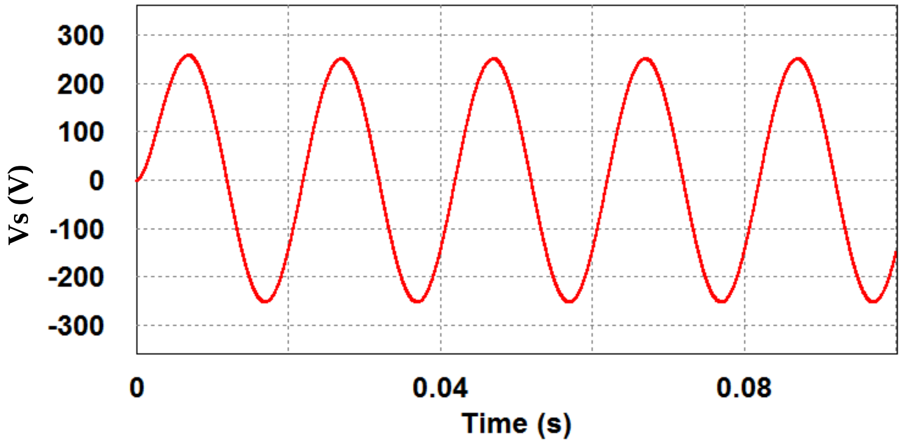

Figure 12. Voltage after Filter and Transformer.

5. CONCLUSIONS

This paper proposed a stand-alone PV system. The experimental results confirm the theoretical ones discussed above.

By means of simulation results, the efficiency of the proposed structure, as well as its control system, were verified. A method for designing both the controller and LCL filter ensuring stability is developed.

ACKNOWLEDGEMENTS

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