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Reference voltage optimizer for maximum power point tracking in triphase grid-connected photovoltaic systems

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ABSTRACT

The problem of maximum power point tracking (MPPT) in photovoltaic (PV) arrays is addressed considering a PV system including a PV panel, a PWM DC/AC inverter connected to triphase grid. Interestingly, the proposed PV system features higher reliability and reduced cost as it involves no chopper and no radiation/temperature sensors, unlike standard systems. We seek the achievement of three control objectives: (i) the voltage reference must be designed so as to achieve maximum power point tracking (MPPT), (ii) the DC link voltage must be tightly regulated over a wide range voltage-reference variation, (iii) and the power factor correction (PFC) requirement must be satisfactorily realized. To meet these objectives, a multiloop controller is designed, using nonlinear design techniques, based on the nonlinear system model. Then, it is formally demonstrated that the proposed controller actually meets the desired control objectives.

1. Introduction

Due to dramatic increase in energy consumption over the last decades, most countries have decided to strongly promote the use of renewable energies. In this respect, photovoltaic (PV) based renewable energy presents several features e.g. simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. In addition to these benefits, the recent progress made in the PV technology has resulted in quite lower cost and more efficient PV cells. This evolution is expected to continue in the future due to economies scale [1,2].

Photovoltaic devices generate electricity from sunlight due to the photovoltaic effect of some semiconductor materials [3]. In large plants, PV modules (typical commercial units) are associated in series and in parallel to obtain high power PV generators. PV electricity is released as a DC current between the terminals of the PV generator.

Several PV- grid connection structures have been proposed in the literature and for larger plants 3-phase grid are typically used. In [4–12], the PV generator is connected to the grid through a chopper and a 3-phase inverter (Fig. 1). There, the chopper is controlled so as to maximize the power extracted from the photovoltaic panel and regulate the input voltage across the terminals of inverter which supplies the incoming energy to the utility grid. In [1,13–15], the inverter is the only power converter interfacing the PV generator and three-phase grid, (see Fig. 2). This simpler structure prevents the disadvantages of using chopper (additional losses, investment and maintenance). In this case, the input voltage at the inverter terminals is no longer constant but it varies depending on the maximum power extracted from the photovoltaic panel. Through this structure, the inverter is controlled to meet two objectives, (i) MPPT requirement and (ii) adaptation of DC and AC voltage sources.

The dependence of the power generated by a PV array and its MPP on atmospheric conditions is illustrated in the power–voltage (P–V) characteristics of PV arrays of Figs. 3 and 4. These particularly show that the array power depends nonlinearly on the array terminal operating voltage. Moreover, the MPP varies with the radiation and temperature, necessitating continuous tuning of the array terminal voltage if maximum power is to be transferred. Different techniques to maximize PV power transfer to various loads have been reported in the literature, including the constant voltage method, the open circuit voltage method, the short circuit method, perturb and observe method (P&O), the incremental conductance method (IncCond) and the Ripple Correlation Control (RCC) method. The constant voltage method is the simplest one but it has been commented that the method could only collect about 80% of the available maximum power under varying irradiance. An improve-

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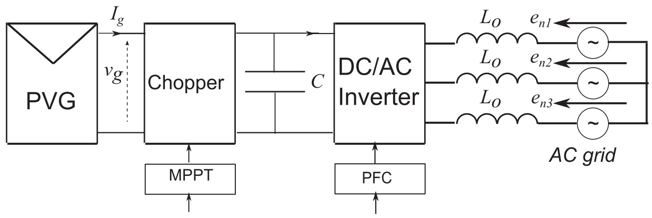

Fig. 1. PV-grid connection structure with chopper.

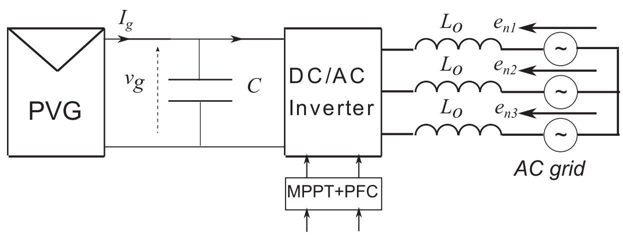

Fig. 2. PV-grid connection structure without chopper.

ment on the constant voltage method uses the open circuit voltage to estimate the maximum power output voltage while the short circuit current method uses the short circuit current to estimate the maximum power output current. In [7], a faster searching technique for the PV array has been realized using an improved version of extreme seeking control. Its principle is based on the adjustment of the current reference of DC/DC converter, depending on the variations of power and current coming from the PV generator. This technique requires the chopper between the PV generator and the inverter. The maximum power point tracking (MPPT) strategy proposed in [1] is based on directly adjusting the shoot-through duty ratio of the cascaded Z-source inverter and consequently the PV array voltage, according to the result of the comparison of successive output power measurements. The control algorithm used is a Perturb and Observe (P&O) iterative method. Also perturb and observe (P&O) method is used in [4,11]. This method makes a perturbation in the operating voltage of the PV array. The system then oscillates about the maximum power point (MPP) which can be minimized by reducing the perturbation step size. However, a small perturbation size slows down the MPPT. moreover Perturb and observe (P&O) method can fail under rapidly changing atmospheric conditions [16]. The incremental conductance (IncCond) method, used in [10,13,17] is based on the fact that the slope of the PV array power curve is zero at the MPP, positive on the left of the MPP, and negative on the right (see Fig. 3). In [18], the Ripple correlation control (RCC) is used to seek the MPPT. Ripple correlation control (RCC) makes use of ripple to perform MPPT. This method correlates the time derivative of the time-varying PV array power $\dot{P}$ with the time derivative of the time-varying PV array current $\dot{I}_g$ or voltage $\dot{V}_g$ to drive the power gradient to zero, thus reaching the MPP. (RCC) and (IncCond) methods require the power, current and voltage derivatives which can be a cause of divide-by-zero singularity problems. However, in all these works, the converter dynamics were neglected which was only modeled by its steady state gain.

In this paper, we are addressing the problem of controlling PV systems consisting of PV panels, PWM DC/AC inverter connected to triphase grid. The aim is to ensure maximum power point tracking whatever the position of the PV panel. Furthermore, to reduce the PV system (development and maintenance) cost, we are seeking a solution not necessitating solar radiation sensor when the temperature is supposed constant.

In the present paper, a new faster searching technique of maximum power point for the PV array has been realized using an optimal voltage reference generator. The PV is connected to 3-phase grid through DC/AC inverter without DC/DC chopper. The voltage reference optimality, involves the PV delivered power, is to be understood in the sense to extract the maximum power from photovoltaic generator regardless of solar radiation. If the voltage v_g is made equal to $v_{g_{ref}}$ then, maximal power is captured, and transmitted to the grid through the DC/AC inverter.

This new technique, remedy to the disadvantages of (RCC), (IncCond) and (P&O) methods, and offers an MPPT without oscillates about the maximum power point and without using the power, current and voltage derivatives.

In the present work, a new control strategy involving an optimal voltage reference generator and a voltage and power factor correction (PFC) controller is developed. The control strategy, designed by the backstepping technique, is based on nonlinear model taking into consideration the DC/AC inverter dynamics and the 3-phase grid self inductor. The new controller enforce the voltage to perfectly track its varying reference trajectory, despite the solar radiation, and the output grid current remains (almost) always in phase with the supply net voltage complying with the PFC requirement.

The paper is organized as follows: in Section 2, the system modeling is presented; Section 3 is devoted to the controller design; the controller tracking performances are illustrated through numerical simulations in Section 4. A conclusion and a reference list end the paper.

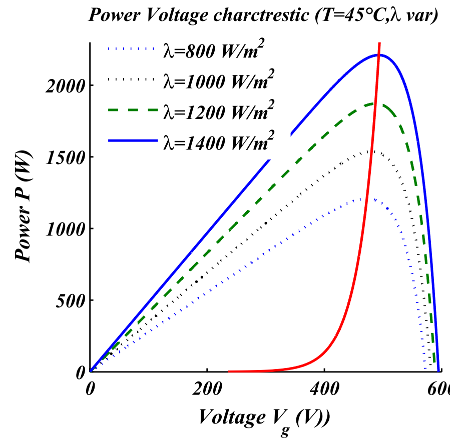

Fig. 3. (*P–V*) characteristics of the PVG, with constant temperature and varying radiation.

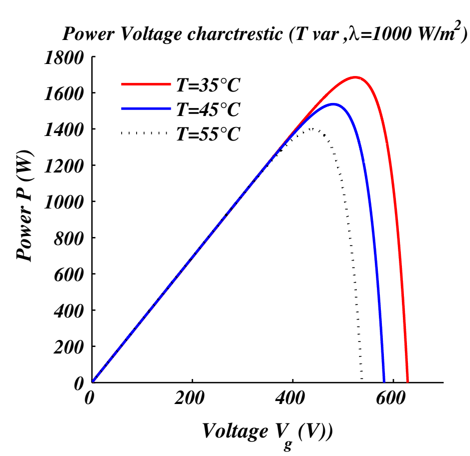

Fig. 4. (*P–V*) characteristics of the PVG, with constant radiation and varying temperature.