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Technical Note

# Digital power factor control and reactive power regulation for grid-connected photovoltaic inverter

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ABSTRACT

The overall efficiency of photovoltaic (PV) systems connected to the grid depends on the efficiency of direct current (DC) of the solar modules to alternate current (AC) inverter conversion. The requirements for inverter connection include: maximum power point, high efficiency, control power injected into the grid, high power factor and low total harmonic distortion of the currents injected into the grid. An approach to power factor control and reactive power regulation for PV systems connected to the grid using field programmable gate array (FPGA) is proposed. According to the grid demands; both the injected active and reactive powers are controlled.

In this paper, a new digital control strategy for a single-phase inverter is carried out. This control strategy is based on the phase shift between the inverter output voltage and the grid voltage, and the digital sinusoidal pulse width modulation (DSPWM) patterns, in order to control the power factor for a wide range of the inverter output current and consequently the control and the regulation of the reactive power will be achieved. The advantage of the proposed control strategy is its implementation around simple digital circuits.

In this work, a simulation study of this strategy has been realized using Matlab/Simulink and PSIM. In order to validate its performance, this control has been implemented in a FPGA. Experimental tests have been carried out demonstrating the viability of this control in order to control the power factor and the injected power into the grid.



## 1. Introduction

With the increasing concern about global environmental protection, the need to produce pollution-free natural energy such as solar energy has received great interest as an alternative source of energy for the future since solar energy is clean, pollution-free and inexhaustible. In an effort to use the solar energy effectively, a great deal of research has been done on the grid-connected photovoltaic generation systems. In PV systems connected to the grid, the inverter that converts the output direct current (DC) of the solar modules to the alternate current (AC) is receiving increased interest in order to generate power to utility. Generally, the grid-connected PV systems extract maximum power from the PV arrays. The maximum power point tracking (MPPT) technique is usually associated with a DC–DC converter. The DC–AC converter injects sinusoidal current into the grid, controlling the power factor [1–4]. Some key points have been identified in which significant improvements can be carried out in the design and implementation of the inverters connected to the grid, as: low total harmonic distortion, elimination of the DC component injected into the connected grid, control both the active and reactive power and the digital implementation of the control.

- The generated pulse width modulation (PWM) patterns [7], is able to reduce the magnitude of the low order of harmonic components present in the input AC supply.
- Digital implementation provides improvements over their analog counterparts. They are immune to noise and are less susceptible to voltage and temperature changes. Hence, an interest to digital implementation has been noted. Using FPGA's will provide flexibility and simplicity in modifying the designed circuit without altering the hardware and rapid prototyping [10–12].

Another very important aspect of the systems connected to the grid is to select a proper power factor according to the grid

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demands: active or reactive power. The most efficient systems are those, which allow variation in the active and reactive power injected into the grid, depending on the power grid requirements [8–10]. The proposed control strategy is capable of controlling, not only the current injected into the grid, but also the power factor (PF). Varying the PF, within a certain range, the injected reactive power can be dynamically changed and controlled. The basic idea of the control is to use a DSPWM patterns previously calculated and tabulated applied to a constant DC bus voltage. Acting on the phase shift of the inverter output voltage as control parameter, the output current amplitude and the power factor can be controlled, therefore the magnitude of the power injected into the grid, both active and reactive power. This control has been digitally implemented in a FPGA and it has been validated with the simulation and experimental results.

## 2. Inverter topology

In Fig. 1a, is shown the power stage of the single-phase inverter connected to the grid in order to explain the key of the output current control of the inverter. In addition, an active and reactive power can be controlled.

The main specification of the inverter connected to the grid is that the current must be injected from a PV panel with a power factor within a certain range [10]. The analysis is based on the inductive coupling between the inverter and the grid.

In order to explain the circuit characteristics, in Fig. 1b, is represented the phase diagram for the fundamental component of the inverter output voltage, $V_{inv}$, the fundamental component of the inverter output current, $I_{out}$, through the coupling inductance $L$, the fundamental component of inductance voltage, $V_L$, and the fundamental component of the grid voltage, $V_{grid}$ [6].

The phase difference between the grid voltage and the fundamental current component of inverter output current is represented by angle ($\varphi$), the difference phase (phase shift) between the grid voltage and the inverter output voltage is represented by angle ($\delta$).

From the phase diagram, Fig. 1b, the active power ($P$) and reactive power ($Q$) provided by the converter to the grid may be calculated respectively as Eqs. (1) and (2) [3].

$$P = \frac{V_{grid}}{\omega \bullet L}\left(V_{inv} \bullet (\delta)\right) \tag{1}$$

$$Q = \frac{V_{grid}}{\omega \bullet L}\left(V_{inv} \bullet \cos(\delta) - V_{grid}\right) \tag{2}$$

From Eqs. (1) and (2), it can be deduced that the value and sense of both the active power ($P$) and reactive power ($Q$), for the fundamental component of the output current, depend on the following parameters:

- the amplitude of $V_{inv}$;
- the phase shift between the inverter output voltage and the grid voltage, $\delta$.

As a result, the power flow (generation and absorption) of both the active and reactive power can be controlled, selecting an adequate amplitude $V_{inv}$ of inverter output voltage and the phase shift ($\delta$) between the inverter output and grid voltage.

From the phase diagram, Fig. 1b, one can obtain another important relationship for the output inverter current injected into the grid and its phase in Eq. (3):

$$I_{out} \bullet \cos\varphi = \frac{V_{inv} \bullet \sin\ \delta}{\omega \bullet L} \tag{3}$$

Where:

$$|V_L| = \omega \bullet L \bullet I_{out} \tag{4}$$

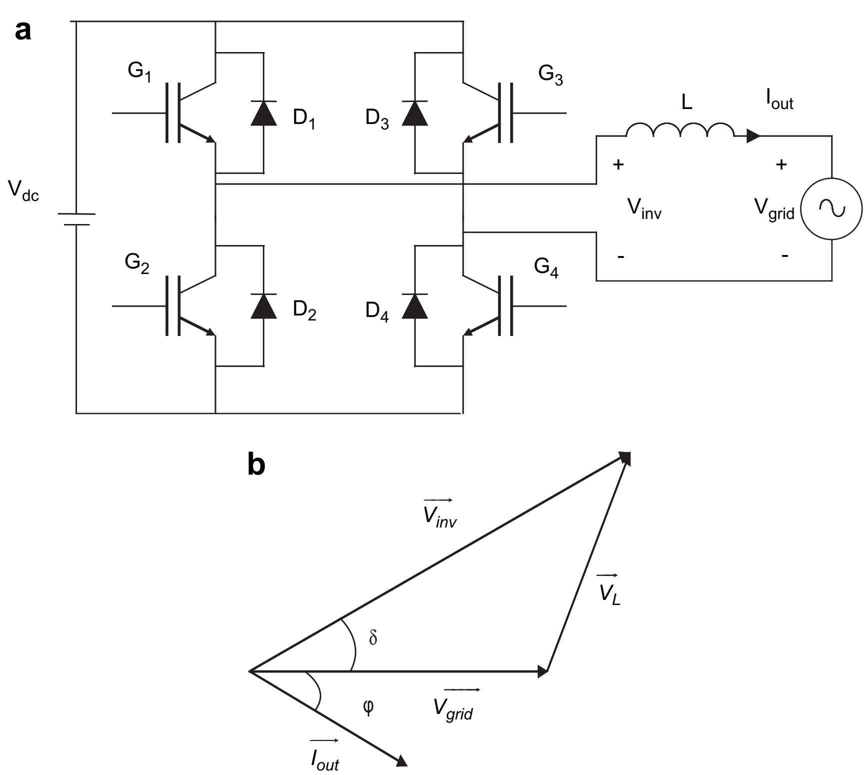


**Fig. 1.** Single-phase inverter connected to the grid. (a) Inverter model. (b) Phase diagram with $V_{inv}$, $V_L$, $V_{grid}$ and $I_{out}$.