E-ISSN: 2583-2131

Erudite Journal of Engineering Technology and Management Sciences

Vol. 4, No. 1, March 2024, pp. 13-16

Journal homepage: http://www.ejetms.com

ACTIVE AND REACTIVE POWER CONTROL OF SINGLE-PHASE GRID-CONNECTED PHOTOVOLTAIC SYSTEMS

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Received: 10 February 2024
Accepted: 01 March 2024

Keywords:
Power control,
Grid,
Solar PV.

ABSTRACT

In this study, a simple digital power control technique for single-phase grid-tie converters is proposed. The suggested technique is based on the application of dead-beat control theory to the instantaneous powers in the virtual two-axis reference frame. A voltage estimation scheme is added to the proposed direct power control algorithm that allows grid voltage sensorless operation. The simulation and experimental results confirm that the proposed control strategy provides fast, accurate and decoupled power control with a lower alternating current distortion.

1 INTRODUCTION

In recent years, with ever increasing energy demand, and environmental pollution caused by fossil fuels, distributed generation and renewable energy sources (RES) are attracting special attention. Usually, a power electronic converter is required to transfer the electricity generated from these energy sources to the power grid. A single-phase voltage source converter (VSC) is the most widely used solution for connecting a low power RES to the singlephase grid [1].

To regulate the power exchange with the grid, and at the same time, reduce the harmonic components in the alternating current (AC) side current, various control strategies have been proposed, such as current hysteresis control (CHC) [2–5], voltage-oriented control (VOC) [6–10] and proportional-resonant (PR)-based control [11]. In VOC, the errors between the active and reactive components of the line current and the reference values are fed to proportional-integral (PI) controllers in the synchronous reference frame, which generate the reference voltage for the converter. This voltage is then applied to the converter using a voltage modulator. [1, 6–10].

To generate the orthogonal component from a single-phase quantity, different techniques can be used, such as applying a 908 phase shift [12], Hilbert transformation [13], using an all-pass filter [14] and using a second-order generalised integrator (SOGI) [15]. PR-based control is another technique to control singlephase converters and the CHC method is implemented in the stationary reference frame. Unlike the PI controller, the PR controller provides a very high gain at the fundamental frequency of the AC system (resonant frequency) [11].

This paper presents a digital control strategy for singlephase grid-connected converters based on the dead-beat control theory and direct control of fictitious instantaneous powers. It is easy to implement, does not need any PI controllers and has excellent dynamic response. Besides, a voltage estimation scheme is added to the proposed direct power control (DPC) algorithm which allows grid voltage sensorless operation.

2 SINGLE-PHASE ACTIVE AND REACTIVE POWERS IN VIRTUAL TWO-AXIS REFERENCE FRAME

It is a common practice to transform the multiphase electrical machine and power electronic converter systems into the two-axis stationary (ab) or rotary (dq) reference frames. These transformations bring significant simplicity and ease of analysis, especially when determining the instantaneous active and reactive powers in three-phase systems. Hence, the essence of this paper is to create a virtual two-phase system from an ordinary single-phase signal.

2.1 Fictitious phase

In this work, the fictitious phase is obtained using the SOGI [15]. Fig. 2 illustrates the basic scheme of the SOGI structure, in which k is the damping factor, and v is the fundamental angular frequency. An outstanding feature of SOGI is that, depending on the selected damping factor k, it provides some kind of filtering and can improve the performance under distorted grid voltages.

2.2 Active and reactive powers

In fact, a pulse width modulation (PWM) scheme transfers the current ripples to the switching frequency that can be easily eliminated from the instantaneous powers defined by an LPF with a cut-off frequency lower than the switching frequency. Hence, the filtered fictitious powers are in direct relation with the actual powers and can be used in order to control the actual active and reactive powers.

3 PROPOSED DPC

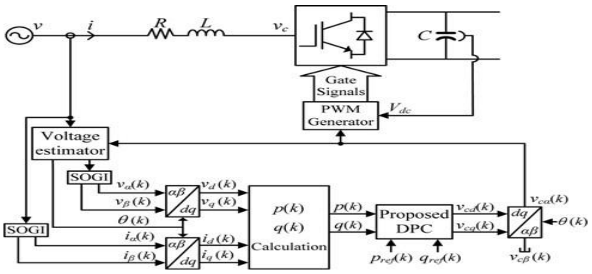

Figure 1 Block diagram of the proposed DPC

The proposed DPC is based on dead-beat control. In discrete time control theory, dead-beat control is considered because of its high dynamics. The main idea of this method is to find the input signal, which when applied to the system, will make the output error zero (or minimum) in the least possible time.

In the proposed DPC, at each sampling period, the reference voltage for the converter is determined, such that by applying it, the power errors at the next sampling period will be driven to zero. For this purpose, the active and reactive powers at the next sampling period are predicted, and used as the reference values for the current sampling period. The active and reactive powers at the next sampling instant (k + 1) are predicted from the virtual two-phase converter model. The fictitious signal is discarded and v_a will provide the reference value for the PWM generator. Fig.1 shows the block diagram of the proposed DPC for the single-phase converter.

4 CONTROL DELAY COMPENSATION

Owing to computational time delay, there always exists one sample time delay between the reference voltages calculated by the controller and the converter output voltages. Indeed, the converter reference voltages that are calculated at the kth sampling instant are applied to the converter at the beginning of the (k + 1)th sampling instant.

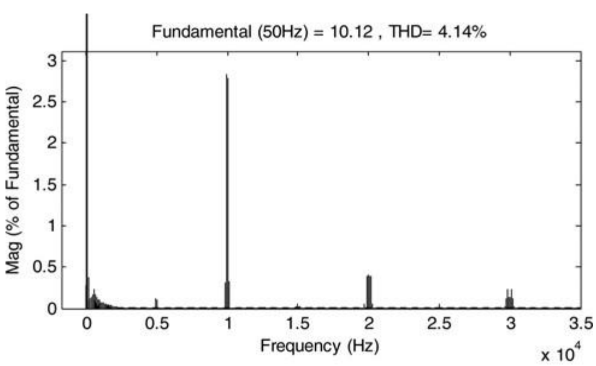

Figure. 2 Simulated waveforms with various step changes of reference powers

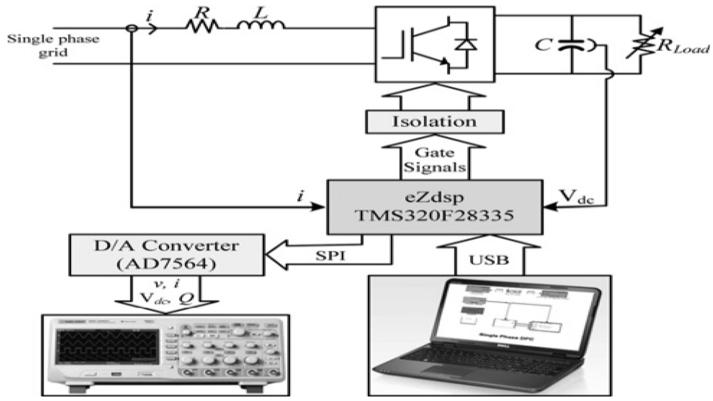

Figure. 3 Simulated grid current harmonic spectrum (P_{ref} ¼500 W, Q_{ref} ¼0 VAr) VOC

5 GRID VOLTAGE ESTIMATION

The concept of DPC for three-phase converters permits voltage sensorless implementation. This means that the grid voltages are estimated using the measured currents and converter parameters, and the voltage sensors are eliminated. Hence, in accordance with the idea of voltage sensorless implementation of three-phase DPC, in this paper, a voltage estimation scheme is added to the proposed DPC algorithm which allows getting rid of the grid voltage measurement. The relations of the grid voltage estimator are presented in (19) [16].

6 SIMULATION RESULTS

In order to verify the validity of the proposed DPC, a digital computer simulation model has been developed in MATLAB/ SIMULINK. The steady-state, the transient response and the current harmonic spectrum of the proposed DPC are compared with the VOC. The decoupling feedforward control for the active and reactive powers is also added to the VOC [1, 6–10]. The PI controllers of the VOC are tuned according to the optimal approach suggested in [6], leading to a 200 Hz bandwidth. The parameters of the converter and control system are given in Table 1.

Fig. 4 shows the responses of the VOC and the proposed DPC to various step changes in the active and reactive reference powers. It can be seen from Fig. 4 that the dynamic response of the proposed DPC is incredibly faster than the VOC. Besides its fast response, a decoupled control of the active and reactive powers is also achieved in the proposed DPC.

The harmonic spectrum of the grid current with 500 W active power at unity power factor is shown in Fig. 5. The total harmonic distortion (THD) of the proposed DPC is slightly better than the VOC.

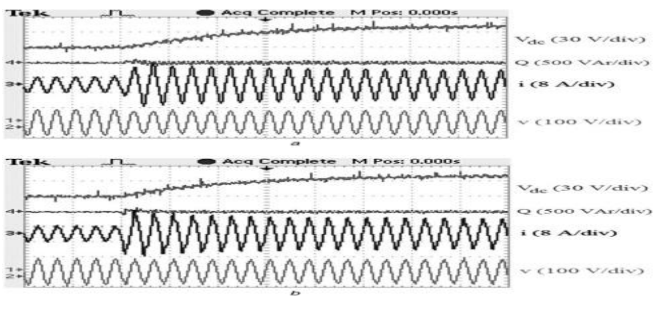

Figure 4 Experimental steady-state waveforms

Fig. 4 shows the responses of the VOC and the proposed DPC to various step changes in the active and reactive reference powers. It can be seen from Fig. 4 that the dynamic response of the proposed DPC is incredibly faster than the VOC. Besides its fast response, a decoupled control of the active and reactive powers is also achieved in the proposed DPC.

7 EXPERIMENTAL RESULTS

An experimental test bench, shown in Fig. 5, is implemented to confirm the performance of the proposed scheme. The DC side of the converter is connected to a resistive load. In all experiments, the reference active power is generated from a DC-link voltage regulator and the reference reactive power is set arbitrarily. The TMS320F28335 digital signal processor (DSP) is used to implement the control algorithm. An digital-to-analogue (D/A) converter, AD7564, is used to display the measured waveforms. The DSP sends waveforms on the serial peripheral interface and AD7564 serial D/A converts these digital data to analogue signals to be displayed on the oscilloscope.

The experimental parameters are chosen, the same as simulations as in Table 1. The experimental results of the VOC and the proposed DPC techniques are compared .The steady-state waveforms, where the DC-link voltage is set to 200 V, which translates to 400 W, and the power factor is regulated at unity. The sinusoidal current waveform approves proper operation of the proposed DPC. Compared with the VOC, the proposed technique provides more precise current control with minimum distortions, even when the grid voltage is distorted. The THD for the proposed DPC and VOC is 3.9 and 4.5%, respectively, which meets the IEEE Std 519 recommendation.

The dynamic performance of the converter with the VOC and the proposed scheme. These results show the decoupled power control of the proposed DPC as well as the VOC scheme. From Fig. 5, the performance of the converter controlled by the proposed technique is better than the VOC regarding reactive power tracking speed. When comparing the transient behaviour with the DC-link voltage change, only a slight improvement is obtained with the proposed technique. The general conclusion drawn from the experiments is that the proposed approach is an interesting alternative to the VOC technique for grid integration of single-phase VSCs.

8 CONCLUSIONS

In this paper, a DPC technique for the single-phase grid-tie converter has been proposed which is based on the deadbeat strategy. The PI controllers of the VOC are replaced with simple algebraic equations. A fictitious phase is obtained using the SOGI scheme to improve the performance of the converter under distorted grid voltages. The grid voltage sensor is replaced with a voltage estimator. The simulation and experimental results confirm the superiority of the proposed technique in providing more precise control, better regulation performance and at the same time faster dynamic response.

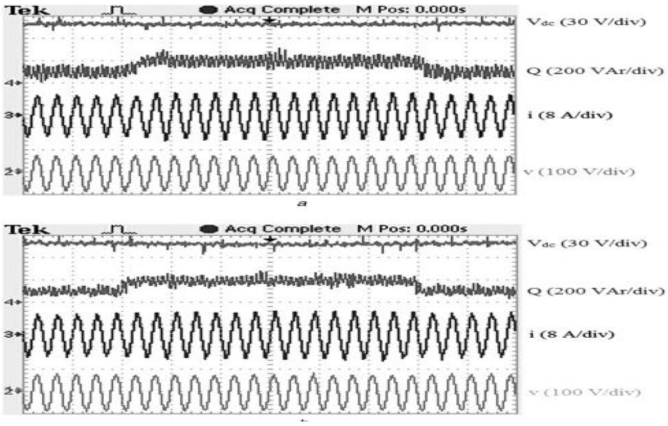

Figure 5 Experimental waveforms with step change of reactive power reference from 100 to 200 VAr (Vdc ¼ 200 V)

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