

**ARTICLE**

# Vector Control of Three-Phase Solar Farm Converters Based on Fictive-Axis Emulation

**Kai Kang<sup>1\*</sup> Qiaoyu Wang<sup>1</sup> Jiayi Meng<sup>2</sup>**

1. Electrical and Computer Systems Engineering Department, Monash University, Melbourne, Victoria, Australia

2. Faculty of Arts, Melbourne University, Melbourne, Victoria, Australia

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**ABSTRACT**

In this paper, a new method for adjusting the current of three-phase voltage source DC-AC converter in orthogonal (DQ) reference frame is presented. In the DQ reference system, AC variable appears in the constant form of DC, making the controller design the same as the DC-DC converter [1]. It provides controllable gain benefits at the steady-state operating point, and finally realizes zero steady-state error [2]. In addition, the creative analytical model is dedicated to building up a series of virtual quantities orthogonal to the actual single-phase system. In general, orthogonal imaginary numbers get the reference signal by delaying the real quantity by a quarter period. However, the introduction of such time delay makes the dynamic response of the system worse. In this paper, orthogonal quantities are generated from a virtual axis system parallel to the real axis, which can effectively improve the dynamic performance of traditional methods without increasing the complexity of controller structure. Through PSCAD simulation, the ideal experimental results are obtained.

**1. Introduction**

In the past few years, many researches have been done on VSC control regulation and various methods have been proposed, such as hysteresis, no difference frequency, prediction, proportional integral (PI) and proportional resonance (PR) based control strategies. In general, these methods can be divided into two categories: fixed frame controllers and synchronous frame controllers. Among static frame controllers, the linear PI controller is used intensively in numerous industries. However, since well-known shortcomings such as non-zero steady-state error, other methods have been proposed, such as

a PR controller, to track the AC reference signal in the static coordinate system with zero steady-state error<sup>[3]</sup>. In addition, the PR control is one of the most popular classical control theories that is to implement for single and three-phase applications while providing satisfactory and controllable performance. This part we analyze the controller strategies based on the solar farm system<sup>[4]</sup>.

Secondly, DQ transformation projects the three-phase current of stator a, b and c into the direct axis (D axis), the quadrature axis (Q axis) and the zero axis (0 axis) perpendicular to the DQ plane as the rotor rotates. Thus, it realizes the diagonalization of the stator inductance matrix and simplifying the operation analysis of synchronous

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*\*Corresponding Author:*

Kai Kang,

Electrical and Computer Systems Engineering Department, Monash University, Melbourne, Victoria, Australia;

Email: 1643360071@qq.com

motor [5]. The transformation from ABC coordinates to DQ coordinates. For the convenience of research, this paper adopts the method of combining DQ transformation and PI control to analyze [6].

The next part gives the control strategy based on virtual axis simulation (FAE). Finally, we evaluate the sensitivity of the proposed method to changes in system parameters and summarizes the paper.

## 2. Designed System Description

### 2.1 Three-Phase VSC

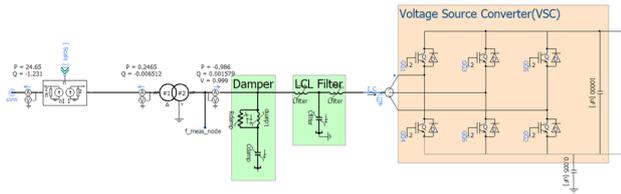


Figure 1. The topology of three-phase VSC

The integrated circuit design of Figure 1 illustrates a three-line diagram of the solar plant application system where the VSC is connected to the utility grid through the combination of line reactor filter that is made of by Damper and LCL filter and a coupling model transformer.

Mainly using steady and high-efficiency control strategy for three-phase VSCs that could be realised according to the innovation of vector control of three-phase electrical systems. Previous vector control methods are pretty popular, where a series of flexible strategies are used to define and change the control system parameters in order to assure predefined dynamic performance and decoupled axes. One of the most convenient methods is simple PI controllers. In the next section, the control structure is briefly introduced [7].

### 2.2 Current Control Loop

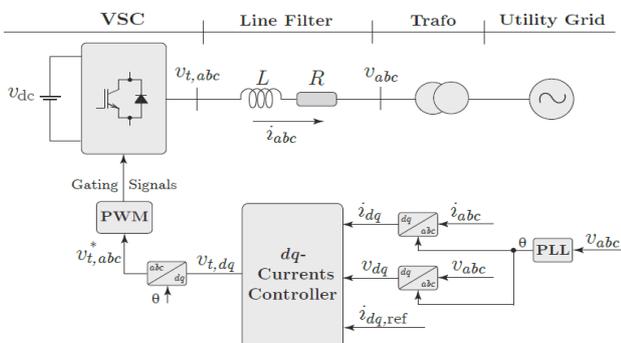


Figure 2. The technological process of dq current controller

Firstly, assuming the variables of single-phase systems are replaced by those of three-phase systems. In this way the dynamics process of the ac-side of solar plant system can be described as

$$V_{i,abc} = R_{i,abc} + L \frac{di_{i,abc}}{dt} + u_{i,abc} \quad (1)$$

In the  $\alpha\beta$  coordinate system, it can become

$$V_{i,\alpha\beta} = R_{i,\alpha\beta} + L \frac{di_{i,\alpha\beta}}{dt} + u_{i,\alpha\beta} \quad (2)$$

Transforming this equation into the new Laplace domain, a flow diagram of the control strategy in the stationary logical structure is drawn (Figure 3).

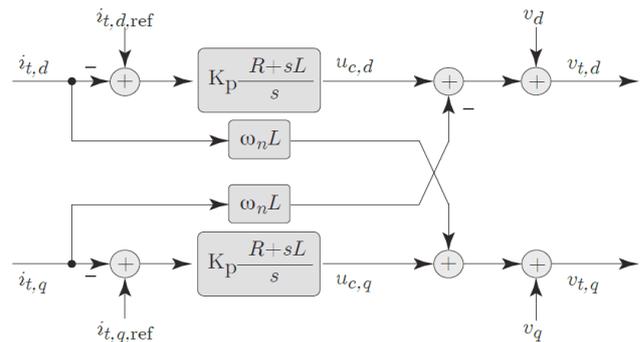


Figure 3. Reference parameter setting frame

The detailed changes of the ac-side variables in the logical frame ( $dq$  frame) is derived as

$$\begin{aligned} U_{ad} &= U_{cd} - L\omega_i q + U_{id}; \\ U_{aq} &= U_{cd} + L\omega_i q + U_{iq}; \end{aligned} \quad (3)$$

$id$  and  $iq$  are respond to  $ucd$  and  $ucq$  through the first-order integration function, the control strategy is realized through redefining the parameters of closed-loops and using basic first-order PI controllers [8].

Therefore, the integration function of the control strategy is derived as follows, where the time variable  $T_s$  is equal to  $L/R$ , and  $K_s$  is equal to  $1/R$ :

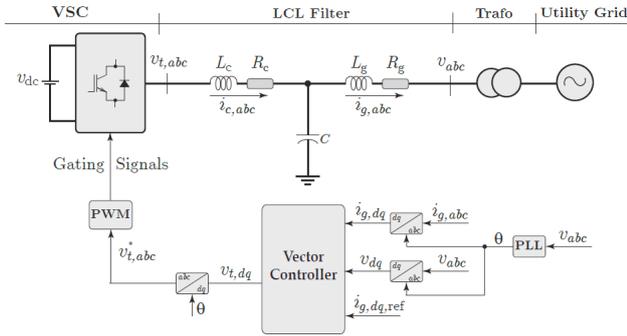
$$H_s = \frac{K_c}{1+sT_s}; \quad (4)$$

And then the transfer function  $H_o$  can be defined according to the open-loop structure:

$$H_o(s) = H_R(s) * H_{pe}(s) * H_s(s); \quad (5)$$

$$\text{Where } HR(s) = \frac{1+sTn}{sTi}, \text{ and } Hpe(s) = \frac{Kcm}{1+sTpe}; \quad (6)$$

### 2.3 Changing the Basic Current Controller into PQ Controller

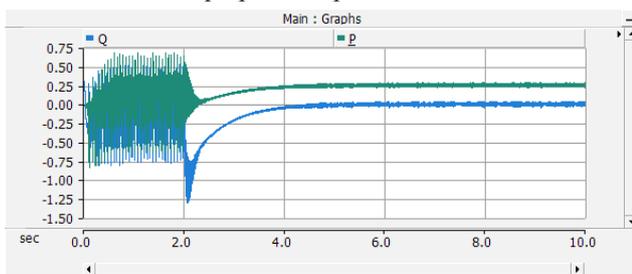


**Figure 4.** Vector controller with active and reactive power

This section, changing the method of defining reference parameters by using active and reactive power values. It is pretty convenient to control the output power through applying the property of active power whose final power in the DC and AC side is always equal [9].

### 2.4 Performance Evaluation

The original method of current controlling will produce some inevitable errors. In the climbing process of the preparation stage, the oscillating harmonic generated by the secondary current will have a great influence on the power, which will continue to affect the steady-state output, resulting in a large steady-state error. And from the graphic results, it is obvious that there are large oscillations in the preparation phase.



**Figure 5.** Conventional result of PQ control

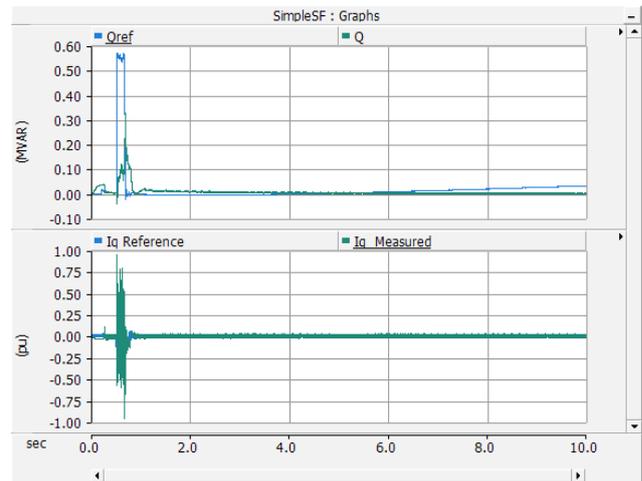
In this test, compared with the conventional method, the advanced vector current controller has better performance. The results of testing application demonstrate the innovation strategy of controller has the following advanced properties [10]:

- (1) It is realizable to track all reference signals with zero steady-state error within few milliseconds.
- (2) It would not impose excessive disruption and

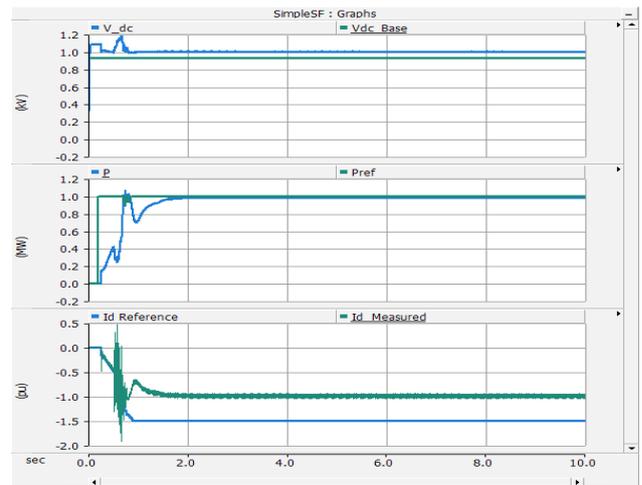
strange oscillation to the solar plant application.

- (3) It contraries to the traditional method, and it would not be impacted by unregular oscillatory dynamics.

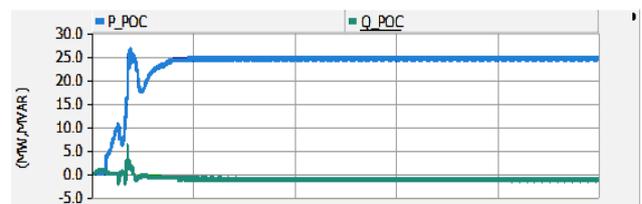
During the steady process, the controller can monitor and correct the current with zero steady-state error by reading continues feedback from loops. And total harmonic distortion (THD) value of the current during this state is 4.5%, which is beneficial for the solar plant to store and deliver current.



**Figure 6.** Simulation Results of reference signals (a)



**Figure 7.** Simulation Results of DC voltage and dq reference values (b)



**Figure 8.** Simulation Results of active and reactive power on the middle position (c)

Figure 6 Simulation results of the advanced dq current controller: (a) changing values of Q and iq. (b) changing values of P and id. (c) the grid active and reactive power corresponding to the converter current.

### 3. Conclusion

This paper introduces a new design of vector controller for the current and voltage regulation of three-phase VSCs. Compared with the traditional method, the orthogonal components of voltage and current are generated to meet the needs of a stationary and synchronous controlling frame by the SOGI based on phase locked loop. In addition, conventional methods use phase shifting to generate orthogonal current, which results in poor transient response. However, the controller can produce the expected orthogonal current and physical system and has a higher kinetic advantage. Finally, the performance of the proposed control strategy is evaluated by simulation and experiment compared with the traditional control strategy<sup>[11]</sup>.

The research shows that the proposed method has the following characteristics:

- (1) Maintain system stability, track reference value, stability error is zero.
- (2) It is much faster than the traditional method.
- (3) Compared with traditional methods, it has better dynamic response.
- (4) It is robust to inconsistencies between physical axis and virtual axis parameters.

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