A GRID-CONNECTION CONTROL SCHEME OF PV SYSTEM WITH FLUCTUANT REACTIVE LOAD

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ABSTRACT

The fluctuations of reactive load in micro-grid will have a great impact on the supply voltage. In this paper, a novel grid-connection control is proposed in view of this problem, based on a model of a PV system with load paralleled in large system. It can not only make full use of photovoltaic power, but also maintain a stable voltage with a fluctuant reactive load. It used double-loop control. The grid-connected current of the PV system and the current of large system are both decoupled into active and reactive component by abc/dq0 transformer. On the one hand, the active component of the PV grid-connected current is adjusted to the reference value given by the Maximum Power Point Tracking (MPPT) in order to maintain maximum active power output of PV. On the other hand, the reactive component of the large system current is adjusted, in order to maintain a constant reactive power output. Thus a stable supply voltage can be maintained with a fluctuant reactive load, as the supply voltage of the grid-connected PV system is mainly sustained by the large system. Its advantages are shown compared with the common unity-power-factor control with a fluctuant reactive load by simulation with Matlab/Simulink.

INTRODUCTION

Distributed generation technology is a new, promising way of energy utilization. Where solar power is competitive to stand out from a variety of distributed power and become more developed relatively.

The control of grid-connected photovoltaic power generation system is a comprehensive process, which involves not only the technology about solar cell and grid-connected inverter, but also to the control and optimization problems of the system. [1]

In the end of the distribution network, the impact on power quality caused by the reactive load in the end of distribution network is more serious than which in centre grids. The fluctuations of reactive load will have a great impact on the supply voltage of power system, there by affecting other loads on this node. [2] The regulation of the PCC (Point of Common Coupling) voltage achieved by the PV system control scheme， has a positive impact and important significance for the application of PV.

The main circuit topology of three-phase active reactive power compensation device and three-phase grid-connected inverter is exactly the same. Thus, in support of a reasonable control strategy it can be integrated together with both function of grid connection and reactive power compensation control. When it output from photovoltaic cells, the inverter transforms DC into AC current delivered to the power grid, while selectively supply a certain reactive current compensation. [3]

When the reactive load fluctuates, the reactive component of the output current can be adjusted to achieve reactive power compensation by the control of PV grid-connected inverter, thus reduce the reactive power provided by large power grids through the transmission line. By reducing the reactive power flow in the grid, it can reduce the energy loss in transmission lines and transformers caused by reactive power transmission. Since the voltage of grid-connected PV system mainly depends on the support of large power grid, when the reactive load fluctuates, a stable system voltage can be achieved by maintaining a constant reactive power output of large power grids.

SYSTEM STRUCTURE

Three-phase grid-connected PV system structure is shown in Figure 1. The solar energy is transformed to DC electricity by PV arrays, and converted to AC electricity by inverter after a voltage regulation capacitor, then supplied to the load through the filter circuit, and paralleled in grid through the isolation transformer.

The reference value of DC voltage is given by the Maximum Power Point Tracking (MPPT) with the input of voltage and current in DC side of inverter. The AC voltage and current output from inverter as well as in the large power grid are measured to be the input of control module. The ultimate output is a set of PWM pulse signal for the IGBT inverter to achieve PV power generation capabilities.

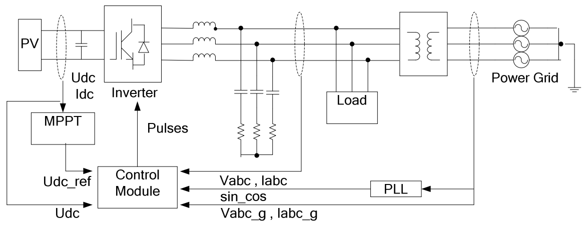

Figure 1. The structure of the grid-connected PV generation system

ACTIVE AND REACTIVE COMPONENT OF CURRENT

dq0 transformation

In the view of electrical engineering, Park transformation is actually replacing three-phase stator windings by the other equivalent windings - d winding, q and 0 winding with the same structure [4]. The dq coordinate system is synchronized with rotor, and its rotation speed is the same as the angular frequency of grid voltage. It is assumed that the power of three-phase wings abc of synchronous motor stator is supplied by balanced three phase sinusoidal AC voltage, transformed to the dq coordinate system, the positive sequence active current of the abc three phase is equivalent to the DC component in d-axis winding. That means, in terms of synchronous motor rotor, the stator windings supplied by a balanced three-phase sinusoidal AC current can achieve the same action as the rotor d-axis winding supplied by DC current. So we can transform the three-phase sinusoidal quantities to DC quantities by dq0 transformation for control.
dq0 transformation is shown in Figure 2:

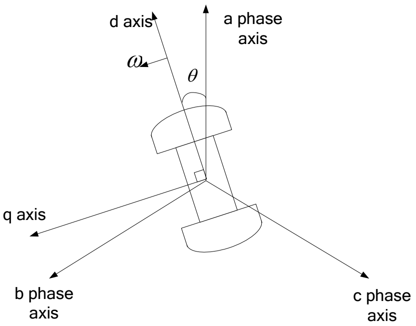

Figure 2. dq0 transformation

The currents in three phase windings of stator are i_a 、 i_b 、 i_c . The angle between d axis of rotor and axis of a phase winding is $\theta = \omega t + \theta_0$ ， in which ω is the rotor angular velocity， θ_0 is the angle when t is 0. dq0 components of stator current are respectively i_d 、 i_q 、 i_0 . i_a 、 i_b and i_c can be obtained by projecting i_d 、 i_q on to the a、b、c axes of the three phase, plus zero sequence current i_0 .

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = C_{dq0}^{-1} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix}, \quad \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = C_{dq0} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

In which

$$C_{dq0}^{-1} = \begin{bmatrix} \cos\theta & -\sin\theta & 1 \\ \cos(\theta - 2\pi/3) & -\sin(\theta - 2\pi/3) & 1 \\ \cos(\theta + 2\pi/3) & -\sin(\theta + 2\pi/3) & 1 \end{bmatrix}$$

$$C_{dq0} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta + 2\pi/3) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

Instantaneous active and reactive power

In the d-q plane as shown in Figure 4, $\boldsymbol{e}$ 、 $\boldsymbol{i}$ refer to the voltage vector and current vector, with amplitude of e 、 i respectively. Their projections on d、q axes are e_d 、 e_q and i_d 、 i_q . φ_e 、 φ_i are respectively the phase angle of $\boldsymbol{e}$ 、 $\boldsymbol{i}$ （with reference of a axis）. θ refers to the angle between d axis and a axis.

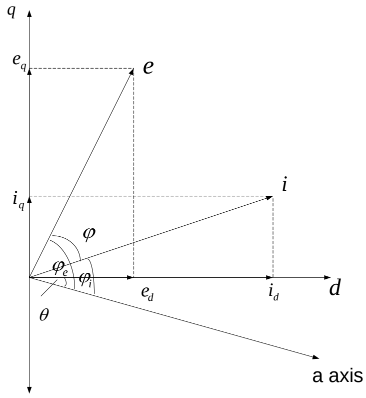

Figure 3. Voltage vector and current vector in dq coordinate

Instantaneous active and reactive power in dq coordinate system is as follows [6]:

$$\begin{cases} p = \frac{3}{2} ei\cos[(\varphi_e - \theta) - (\varphi_i - \theta)] = \frac{3}{2}(e_d i_d + e_q i_q) \\ q = \frac{3}{2} ei\sin[(\varphi_e - \theta) - (\varphi_i - \theta)] = \frac{3}{2}(-e_d i_q + e_q i_d) \end{cases}$$

Set the d-axis coincides with electromotive force (EMF) vector of the grids, the q axis component of EMF is 0, and the d axis component is the amplitude of voltage vector of grids.
Then active and reactive power can be calculated as:

$$\begin{cases} p = \frac{3}{2} e_d i_d \\ q = -\frac{3}{2} e_d i_q \end{cases} \qquad (1-1)$$

The active power is determined by i_d only while reactive power is determined by i_q only. So i_d can be seen as the active component of current while i_q can be seen as the reactive component. In symmetrical three phase AC system, if we consider the fundamental component only, the d、q components are DC variables. That means i_d 、 i_q are DC variables, so that can be adjusted by PI regulator respectively, to achieve the independent control of active and reactive power.

CONTROL SCHEME FOR INVERTER

Three-phase voltage source inverter model in the dq coordinate system can be described as

$$\begin{pmatrix} e_d \\ e_q \end{pmatrix} = \begin{pmatrix} L_s p + R_s & -\omega L_s \\ \omega L_s & L_s p + R_s \end{pmatrix}\begin{pmatrix} i_d \\ i_q \end{pmatrix} + \begin{pmatrix} u_d \\ u_q \end{pmatrix} \quad (1\text{-}2)$$

$$\frac{3}{2}\left(u_d i_d + u_q i_q\right) = v_{dc} i_{dc} \quad (1\text{-}3)$$

e_d 、 e_q refers to the d、q components of EMF respectively; u_d 、 u_q refers to the d、q component of the grid side voltage vector of inverter; i_d 、 i_q refers to the d、q component of the grid side current vector; p is the differential operator. ω is the synchronous angular frequency of the grid. L_s refers to the grid side inductance.

It can be seen in equation （1-2）, that the d、q component of the inverter variables couples to each other. Feedforward control strategy can be adopted. When the current is regulated with PI regulator, the control equation for u_d 、 u_q is as follows:

$$u_d = -\left(K_{iP} + \frac{K_{iI}}{s}\right)\left(i_{d\_ref} - i_d\right) + \omega L_s i_q + e_d \quad (1\text{-}4)$$

$$u_q = -\left(K_{iP} + \frac{K_{iI}}{s}\right)\left(i_{q\_ref} - i_q\right) - \omega L_s i_d + e_q \quad (1\text{-}5)$$

Where K_{iP} 、 K_{iI} refers to the proportional gain and integral gain of current loop control; i_{dref} 、 i_{qref} refers to the reference value of i_d 、 i_q .

Substitute equation1-2 for equation 1-4、1-5:

$$L_s p\begin{pmatrix} i_d \\ i_q \end{pmatrix} = \begin{pmatrix} -R_s + K_{iP} + \frac{K_{iI}}{s} & 0 \\ 0 & -R_s + K_{iP} + \frac{K_{iI}}{s} \end{pmatrix}\begin{pmatrix} i_d \\ i_q \end{pmatrix} - \left(K_{iP} + \frac{K_{iI}}{s}\right)\begin{pmatrix} i_{d\_ref} \\ i_{q\_ref} \end{pmatrix}$$

The equation above shows that the feedforward control algorithm achieved the decoupling control of inverter current i_d 、 i_q .

In the grid-connected PV power generation system, load voltage is mainly depends on the support of large power grid. So we can ensure the stability of load voltage, as long as the output reactive power of large power grid is controlled constant. Since reactive power output of the PV depends on the inverter control within its capacity, reactive load can be supplied by the PV system only.

The q-axis component of current output from inverter is free variable, regulated by the reactive power demands, while the d-axis component is regulated by the maximum power tracking control, and provides the reference value of d-axis component of system voltage through PI control; the q-axis component of current in large power grid is regulated with the reference value of 0, and provides the reference for q-axis component of the system voltage through PI control. They are decoupled to be the d、q component of the command voltage for grid-connected inverter, and then converted to be the three-phase command voltage through Parker inverse transformation to generate the PWM pulse for inverter control.

The sine and cosine of fundamental angular frequency of power grid is obtained by the Phase Locked Loop (PLL). V_d , V_q and I_d , I_q are the Park transformation results of the output variables from inverter; V_{d-g} , V_{q-g} and I_{d-g} , I_{q-g} are the Park transformation results of the variables in power grid.

The control scheme is shown in Figure 4.

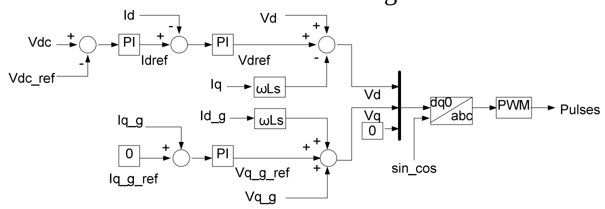

Figure 4. The control scheme of grid-connected inverter in this article

SYSTEM SIMULATION AND ANALYSIS

Based on the description above, a simulation model is built on the platform of MATLAB / SIMULINK. In this example, the light intensity of PV power generation system is 1000kw/m2, the temperature is 298K. The maximum power output of PV arrays is 10000w. Its simulation duration is 3. The voltage amplitude of large power grid is 150V, and its rated frequency is 60 hz. The active load is 10000w, while reactive load is 1000var. At the time of 1.5, reactive load increase in 3000var.

The simulation results are shown in the following figures, compared with the results of general unity power factor PQ control under the same situation.

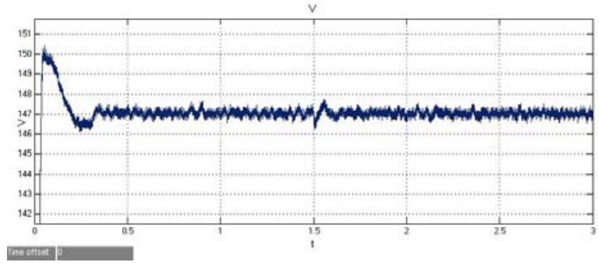

Figure 5. The amplitude of system voltage under novel control scheme

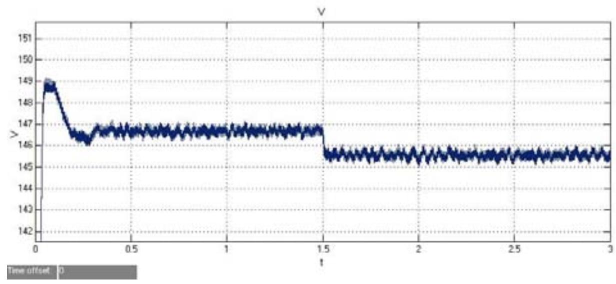

Figure 6. The amplitude of system voltage under

traditional PQ control scheme

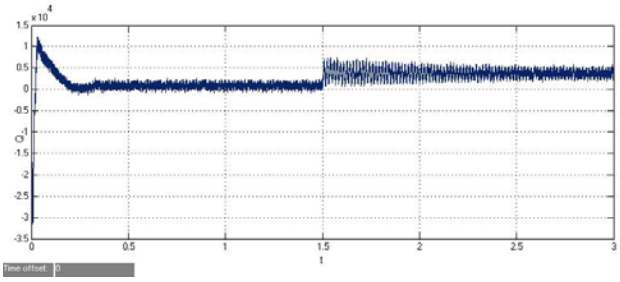

Figure 7. The reactive power output from the inverter under novel control scheme

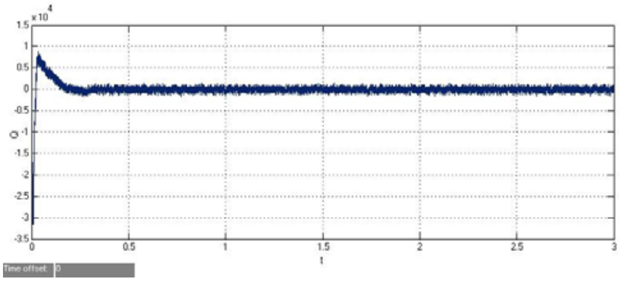

Figure 8. The reactive power output from the inverter under traditional PQ control scheme

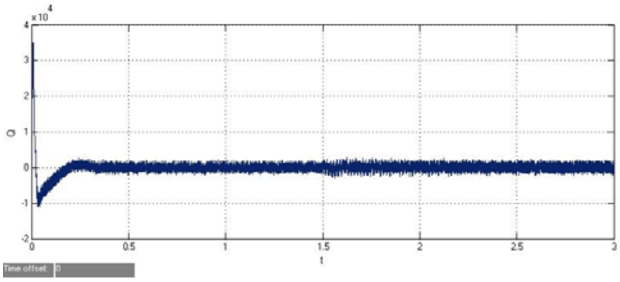

Figure 9. The reactive power output of the large grid under novel control scheme

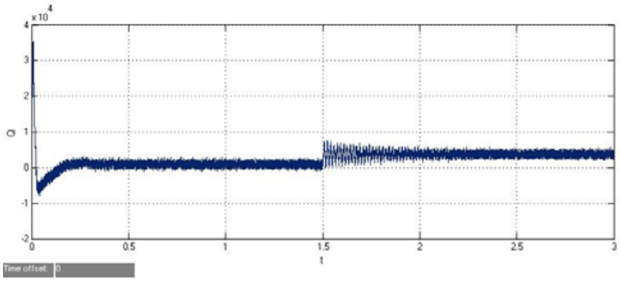

Figure 10. The reactive power output of the large grid under traditional PQ control scheme

SUMMARY

The control scheme in this article achieved the independent control of active and reactive power by Park transformation, and decoupling of active and reactive current. It takes the active current output from inverter and reactive current of the large grid to form the command voltage by PI regulation, thus achieve not only the maximum active power output but also the stability of system voltage in the situation of fluctuant reactive load. The scheme has obvious advantages compared to the traditional unity power factor PQ control for grid-connected PV system.

Acknowledgments

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