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Analysis of Decoupling Method in DQ Transform-based for Grid Connected Inverter

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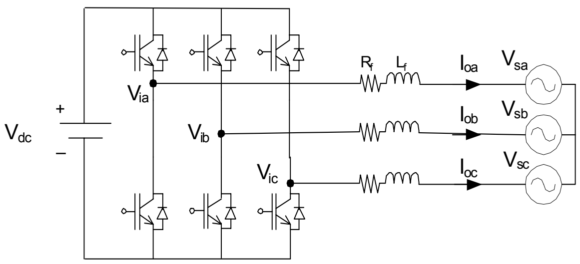
Abstract- There are many types of grid-connected inverter controllers, PI controller based is the most popular methods. But, a common PI control is produced zero-steady state error and phase delay in sinusoidal reference. Synchronous reference frame or DQ transform based controller is capable for reducing both of zero-steady state error and phase delay is. But DQ transform based controller has cross-coupling component which difficult to analyze the system in single phase model.

In this paper, to obtained single phase model of the system, DQ transform based controller is analyzed in two techniques. The first is by neglecting cross-coupling. The second is eliminated cross-coupling component by decoupling method. By these two techniques, single phase model is obtained. Then, the single phase model is analyzed to evaluate its performance in stability and frequency response, through Root Locus and Bode diagram, respectively. MATLAB and PSIM simulation is used to verify the analysis. Simulation result is shown; cross-coupling component has no significant influent to the controller.

1. Introduction

Fossil fuel based energy is become more and more expensive. In the other hand, energy consumption is increased by the time. Both of this reason is boosted the research attention on Renewable Energysuch as Wind power, PV power, Fuel Cell and so on.



<Fig. 1> Grid-Connected Three phase Inverter

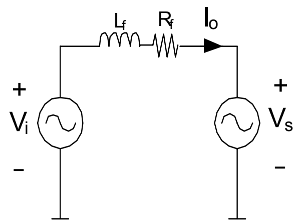
Renewable Energy is also well known as Distributed Generation (DG). This term is used by its characteristic, small rating but distributed in a wide area. Most of the DG power is generated in DC. But recently, mostly low/medium voltage electric power is delivered in AC. Inverter is needed to connect DG into Grid. To produce current waveform in sinusoidal form, the inverter is needed a closed loop control.

There are many types of inverter controller to produce sinusoidal current waveform,such as deadbeat [1], repetitive control, fuzzy [2] etc. Those types are very complex and difficult to analyze. PI controller based is the most popular method. But, in inverter application the reference is sinusoidal. And common PI control is produced zero-steady state error and phase delay in sinusoidal reference. Resonant controller is suitable for sinusoidal reference, but this controller is produced higher order of transfer function compared to common PI controller [3]. DQ transform based controller is also suitable for sinusoidal reference. DQ transform based controller is reduced both of zero-steady state error and phase delay. However, to evaluate its performance, it needed the single phase model of system.

In this paper, to obtained single phase model of the system, DQ transform based controller, is analyzed in two techniques. The first is by neglecting cross-coupling. And the second is eliminating cross-coupling component by decoupling method. By these two techniques, single phase model is obtained. Then,the single phase model is analyzed to evaluate its performance in stability and frequency response, through Root Locus and Bode diagram, respectively. MATLAB and PSIM simulation is used to verify the gain parameter obtained from the method.

2. Grid-connected Inverter System and Modeling

2.1 Grid-connected Inverter System



<Fig. 2> Grid-Connected Three phase Inverter in single phase equivalent circuit

Grid-Connected Three phase inverter is connected to the grid via any type of filter. To simplify the system, inductor filter is used in this system, as shown in Fig. 1. Generated power, it can be from fuel cell, solar or any type of renewable energy is represented as V_{dc} and grid voltage is represented as V_s. $i_o$is injected current from inverter to the grid. L filter is used to filter V_i, output voltage of PWM inverter which contains high switching frequency component.

L_f is inductance of filter and R_f is resistance of filter. In this application to reduce the losses in inverter, switching frequency is lower than mostly used in inverter application, at 5 kHz. It is shown in Fig. 2, single phase equivalent circuit for the system. Inverter is modeled as a voltage source. The system parameters are shown in Table 1.

<Table 1> Values of the system parameter

Parameters	Value
V_{dc}	200V
Inductor Filter	L_f=6.5mh, R_f=0.01Ohm
Grid Voltage (Vs)	110 V, 50 Hz
Inverter Switching Freq	5 kHz

2.2 Modeling of the System

As shown in Fig. 2, the inverter is connected to the grid via L filter. Voltage equation loopfor this circuit can be expressed as follow:

$$L_f \frac{di_{od}}{dt} = V_{id} - R_f . i_{od} + \omega L_f i_{oq} - V_{sd}$$

$$L_f \frac{di_{oq}}{dt} = V_{iq} - R_f . i_{oq} - \omega L_f i_{od} - V_{qd} \qquad (1)$$

In (1) is shown, ωLi_{oq} and ωLi_{od} are cross-coupling components. There are two techniques to do this, the first is neglected the cross-coupling component. The second is eliminates the cross-coupling component by decoupling method. By neglecting the cross coupling component in (1) and apply PI controller for i_o, it will result:

$$L\frac{di_{od}}{dt} = \left(K_p + \frac{K_i}{s}\right)(i_{od}* - i_{od}) - R.i_{od} - V_{sd}$$

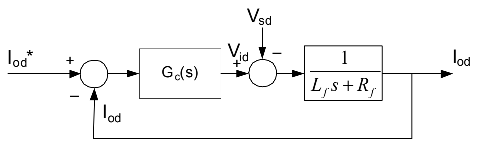
$$L\frac{di_{oq}}{dt} = \left(K_p + \frac{K_i}{s}\right)(i_{oq}* - i_{oq}) - R.i_{oq} - V_{qd} \qquad (2)$$

The decoupling method is determined by following controller:

$$V_{id} = \left(K_p + \frac{K_i}{s}\right)(i_{od}* - i_{od}) - \omega Li_{oq}$$

$$V_{iq} = \left(K_p + \frac{K_i}{s}\right)(i_{oq}* - i_{oq}) + \omega Li_{od} \qquad (3)$$

Where K_p and K_i are proportional and integral gains for i_o, output current controller. Substituting (3) into (1) is yields (2). In this case, two techniques are yields same result. Equation (2) can be drawn into model as shown in Fig.3. Both of d and q axis has same model as shown in Fig. 3.



<Fig. 3> Model of the system in s-Laplace domain

Which Gc(s) is current controller in (3). From Fig. 3, the closed loop transfer function of the system can be derived as:

$$i_{od} = \frac{(K_p s + K_i)}{L_f s^2 + (R_f + K_p)s + K_i} i_{od} *$$

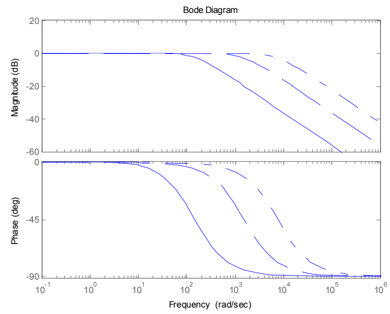
$$- \frac{s}{L_f s^2 + (R_f + K_p)s + K_i} V_{sd} \qquad (4)$$

Which i_o* is reference of output current.

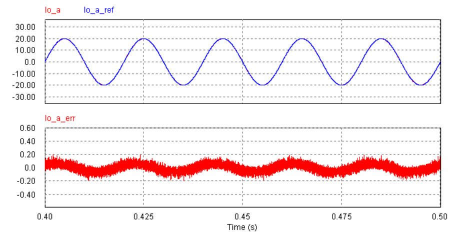
3. Simulation Results and Discussion

To verify the performance of the designed gain parameter, Root Locus and Bode plot are provided. It is guaranteed that the system is stabil for any value K_i and K_p.

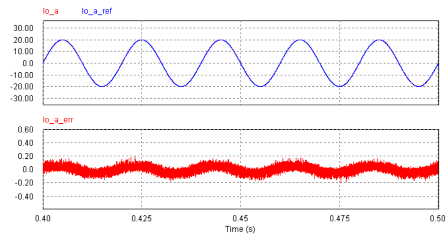
In Fig. 4, is shown frequency response of the system by increased K_p. It should be note that i_o in dq form is dc formor the operating frequency is at 0 rad/s. In Fig. 4, it is shown that at 0 rad/s, K_p=1 is provided 0 dB attenuation. Increasing K_p will be increased cut off freq of Low Pass Filtering characteristic of the system. This Low Pass Filtering characteristic is shown the damping out capability to high frequency disturbance. Increasing K_i is not influenced to the freq response. In Fig 5 and Fig 6, it is shown that between with or without decoupled control, the result is similar. It is explained that cross-coupling component has no significant influent to the system.



<Fig. 4> Bode plot of Ki=10 and Kp=1(solid line), Kp=10(dash line) and Kp=50(dash dot)



<Fig. 5> PSIM simulation result for Kp= 50 and Ki=30 with controller based on eliminating cross-coupling



<Fig. 6> PSIM simulation result for Kp= 50 and Ki=30 with controller based on neglecting cross-coupling

4. Conclusion

To obtained single phase model of the system, DQ transform based controller is analyzed in two techniques. The first is by neglecting cross-coupling component. The second is eliminated cross-coupling component by decoupling method. Simulation result is shown; cross-coupling component has no significant influent to the controller. For future work, proportional and integral gain is design by CRA method.

5. Acknowledgement

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