International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Current Control of a Three-Phase Grid Connected Voltage Source Converter Using Vector Control Strategy under Unbalanced Grid Conditions

Nageswara Rao Muddam

PG Scholar, Department of Electrical and Electronics Engineering, SRKR Engineering College, Bhimavaram, Andhra Pradesh, India-534204

Abstract: ***This paper presents the current control of a three-phase grid connected voltage source converter with LCL filter using vector control strategy under unbalanced grid conditions. The conventional voltage source converters are effective when an asymmetric fault occurs. When three-phase unbalanced grid fault occurs, the unbalanced currents and grid voltages give rise to uncontrolled oscillations in the active and reactive powers which are delivered to the network. To avoid this problem, the new control strategy proposed in this paper. This strategy controls the unbalanced currents and voltages in the converter which are injected to the grid and avoid the uncontrolled oscillations in the network effectively. Using simulation results, the proposed control strategy for a three-phase grid connected converter is proven to be reliable and more effective.***

Keywords: LCL filter, grid connected voltage source converter, vector control strategy, asymmetric faults

1. Introduction

In power systems the asymmetric faults such as single phase to ground faults, phase to phase faults, two phase to ground faults, three-phase faults occurs frequently power systems. These faults affect the transmission system and interrupt the supply [1]. Occurrences of grid faults usually give rise to the appearance of unbalanced grid voltages at the point of connection of the voltage source converter (fig1). Under unbalanced conditions, the currents injected into the grid lose their sinusoidal and balanced appearance [2].The interaction between such currents and the unbalanced grid voltages may give rise to uncontrolled oscillations in the active reactive power delivered to the network. The proper operation of the voltage source converter under such conditions is a challenging control issue. However, the injection of such unbalanced currents may also give rise to other useful effects. For instance, the injection of a proper set of unbalanced currents under unbalanced grid voltage conditions allows attenuating power oscillations, maximizing the instantaneous power delivery, or balancing the grid voltage at the point of connection. However, the injection of unbalanced currents into the grid cannot be accurately achieved by using most of the conventional current controllers currently implemented in the industry [3]. Therefore, the improved control strategy specifically designed to inject unbalanced currents into the grid will be presented in this paper.

Current controlled voltage source converters (VSCs) are mostly used converters in power conversion applications because of decoupled power flow control, high power quality injection and fast dynamic response [4]. The schematic circuit diagram of three-phase voltage source inverter with LCL filter as shown in fig1. To control this converter effectively, it is very important to extract the positive and negative sequence components from an unbalanced system and develop a suitable control strategy, here neglecting the zero sequence components. Several strategies on how to control the positive and negative sequences of the grid connected converter under unsymmetrical grid faults have been developed in order to give a perfect exchange of active and reactive powers [5]. There are some methods to extract the positive sequence component and after that developed a voltage current dual loop control method for a grid connected inverter, which attempts to reduce the frequency doubled effects of active power. But these methods do not consider the negative sequence component in grid connected current [6]. The goal is to keep maintain the grid voltage and frequency under control, to oppose the active and reactive power ripples and the total harmonic distortion of grid currents. Anyway to control negative sequence component in grid connected current, the other literature applies the positive negative sequence separation method and the double loop control method to control grid connected current [7].

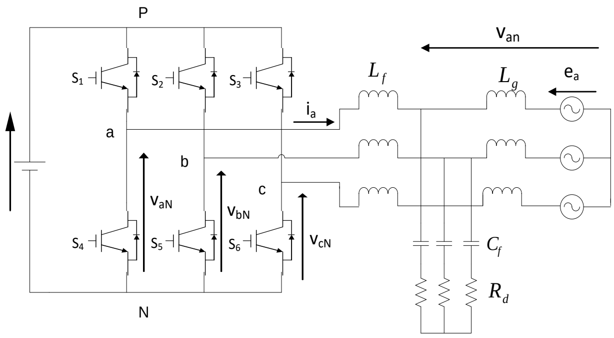


Figure 1: Three-phase voltage source inverter with LCL filter

Vector control strategy is one of the methods that control the voltage source converter. This strategy applied to the grid side connected converter is typically in charge of controlling reactive power exchange with the grid (Q_g).

2. Analysis of LCL filter

The output current of grid side inverter has the ripples caused by the switching. In order to have lower harmonic distortion (LHD), it is necessary to eliminate that ripples. Therefore to eliminate the ripples in the output currents it is necessary to use filters.

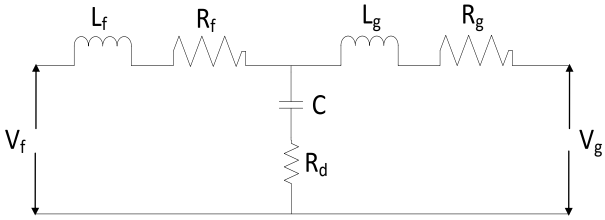


Figure 2: Circuit diagram of LCL filter with damping resistor

There are different types of filters, L, LC and LCL filters. In order to have pure outputs LCL filter is the best filter to utilize. This type of filter often allows the current ripple or current harmonics exchanged with the grid to be reduced more effectively and efficiently than does the simpler L filter configuration. Increasing damping resistance helps to attenuate the gain at the resonance frequency, basically mitigating instabilities and amplified resonances when the nonlinearities of the converters or even of the control creates harmonics at the specific frequency[8]. A minimum damping resistance in general is always necessary to avoid a dangerous resonance with a very large amplification ratio. Therefore, an effective balance must be carefully achieved.
Hence, first of all it is useful to mathematically derive the input/output and voltage/current relations of the LCL filter, the dq expressions are obtained for both the positive and negative sequences.
Using the space vector notation

$$\vec{v}_f^s = R_f \cdot \vec{\iota}_f^s + L_f \cdot \frac{d\vec{\iota}_f^s}{dt} + R_g \cdot \vec{\iota}_g^s + L_g \cdot \frac{d\vec{\iota}_g^s}{dt} + \vec{v}_g^s \qquad (1)$$

Multiplying the above equation by $e^{-j\theta}$, the dq components of the positive sequence can be obtained:

$$\vec{v}_f^{s+} \cdot e^{-j\theta} = R_f \cdot \vec{\iota}_f^{s+} \cdot e^{-j\theta} + L_f \cdot \frac{d\vec{\iota}_f^{s+}}{dt} \cdot e^{-j\theta} + R_g \cdot \vec{\iota}_g^{s+} \cdot e^{-j\theta} + L_g \cdot \frac{d\vec{\iota}_g^{s+}}{dt} \cdot e^{-j\theta} + \vec{v}_g^{s+} \cdot e^{-j\theta} \qquad (2)$$

Resulting in:

$$\vec{v}_f^{a+} = R_f \cdot \vec{\iota}_f^{a+} + L_f \cdot \frac{d\vec{\iota}_f^{a+}}{dt} + R_g \cdot \vec{\iota}_g^{a+} + L_g \cdot \frac{d\vec{\iota}_g^{a+}}{dt} + \vec{v}_g^{a+} + j \cdot \omega_a \cdot L_f \cdot \vec{\iota}_f^{a+} + j \cdot \omega_a \cdot L_g \cdot \vec{\iota}_g^{a+} \qquad (3)$$

Note that, being $\theta = \omega_a . t$ the angular position of the rotatory reference frame:

$$\frac{d\vec{\iota}_g^{s+}}{dt} \cdot e^{-j\theta} = \frac{d\left(\vec{\iota}_g^{s+} \cdot e^{-j\theta}\right)}{dt} + j \cdot \omega_a \cdot \vec{\iota}_g^{s+} \cdot e^{-j\theta} \qquad (4)$$

$$\frac{d\vec{\iota}_f^{s+}}{dt} \cdot e^{-j\theta} = \frac{d\left(\vec{\iota}_f^{s+} \cdot e^{-j\theta}\right)}{dt} + j \cdot \omega_a \cdot \vec{\iota}_f^{s+} \cdot e^{-j\theta} \qquad (5)$$

With dq components:

$$\vec{v}_f^{a+} = v_{df}^{\ +} + j \cdot v_{qf}^{\ +} \qquad (6)$$

$$\vec{v}_g^{a+} = v_{dg}^{\ +} + j \cdot v_{qg}^{\ +} \qquad (7)$$

$$\vec{\iota}_f^{a+} = i_{df}^{\ +} + j \cdot i_{qf}^{\ +} \qquad (8)$$

$$\vec{\iota}_g^{a+} = i_{dg}^{\ +} + j \cdot i_{qg}^{\ +} \qquad (9)$$

Therefore, by decomposing into dq components, the basic equations for vector orientation are obtained:

$$v_{df}^{\ +} = R_f \cdot i_{df}^{\ +} + L_f \cdot \frac{di_{df}^{\ +}}{dt} + R_g \cdot i_{dg}^{\ +} + L_g \cdot \frac{di_{dg}^{\ +}}{dt} + v_{dg}^{\ +} - \omega_a \cdot L_f \cdot i_{qf}^{\ +} - \omega_a \cdot L_g \cdot i_{qg}^{\ +} \qquad (10)$$

$$v_{qf}^{\ +} = R_f \cdot i_{qf}^{\ +} + L_f \cdot \frac{di_{qf}^{\ +}}{dt} + R_g \cdot i_{qg}^{\ +} + L_g \cdot \frac{di_{qg}^{\ +}}{dt} + v_{qg}^{\ +} + \omega_a \cdot L_f \cdot i_{df}^{\ +} + \omega_a \cdot L_g \cdot i_{dg}^{\ +} \qquad (11)$$

Similarly the same procedure can be fallowed to obtain the mathematical expressions for the dq components of the negative sequence:

$$v_{df}^{\ -} = R_f \cdot i_{df}^{\ -} + L_f \cdot \frac{di_{df}^{\ -}}{dt} + R_g \cdot i_{dg}^{\ -} + L_g \cdot \frac{di_{dg}^{\ -}}{dt} + v_{dg}^{\ -} + \omega_a \cdot L_f \cdot i_{qf}^{\ -} + \omega_a \cdot L_g \cdot i_{qg}^{\ -} \qquad (12)$$

$$v_{qf}^{\ -} = R_f \cdot i_{qf}^{\ -} + L_f \cdot \frac{di_{qf}^{\ -}}{dt} + R_g \cdot i_{qg}^{\ -} + L_g \cdot \frac{di_{qg}^{\ -}}{dt} + v_{qg}^{\ -} - \omega_a \cdot L_f \cdot i_{df}^{\ -} - \omega_a \cdot L_g \cdot i_{dg}^{\ -} \qquad (13)$$

From the above positive and negative sequence values (10-13) of dq reference we can find the open loop transfer functions: positive sequence transfer functions

$$\frac{i_{dg}^{\ +}(s)}{v_{df}^{\ +}(s)} = \frac{1}{(L_f+L_g)s+(R_f+R_g)} \qquad (14)$$

$$\frac{i_{qg}^{\ +}(s)}{v_{qf}^{\ +}(s)} = \frac{1}{(L_f+L_g)s+(R_f+R_g)} \qquad (15)$$

Similarly, negative sequence transfer functions

$$\frac{i_{dg}^{\ -}(s)}{v_{df}^{\ -}(s)} = \frac{1}{(L_f+L_g)s+(R_f+R_g)} \qquad (16)$$

$$\frac{i_{qg}^{\ -}(s)}{v_{qf}^{\ -}(s)} = \frac{1}{(L_f+L_g)s+(R_f+R_g)} \qquad (17)$$

To find the closed loop transfer functions of the above expressions (14-17) we can include closed loop PI controller gain $\left(k_p + \frac{k_i}{s}\right)$ and then:

The closed loop transfer function of the system: for positive sequence

$$\frac{i_{ds}^{\ +}(s)}{i_{ds}^{\ +*}(s)} = \frac{sk_p+k_i}{s^2(L_f+L_g)+s(R_f+R_g+k_p)+k_i} \qquad (18)$$

$$\frac{i_{qs}^{\ +}(s)}{i_{qs}^{\ +*}(s)} = \frac{sk_p+k_i}{s^2(L_f+L_g)+s(R_f+R_g+k_p)+k_i} \qquad (19)$$

Similarly for negative sequence

$$\frac{i_{ds}^{\ -}(s)}{i_{ds}^{\ -*}(s)} = \frac{sk_p+k_i}{s^2(L_f+L_g)+s(R_f+R_g+k_p)+k_i} \qquad (20)$$

$$\frac{i_{qs}^{\ -}(s)}{i_{qs}^{\ -*}(s)} = \frac{sk_p+k_i}{s^2(L_f+L_g)+s(R_f+R_g+k_p)+k_i} \qquad (21)$$

By equating the denominators of the above equations with the standard second-order denominator of classic control theories, we can get the values of k_p and k_i.

$$s^2(L_f) + s(R_f + R_g + k_p) + k_i \equiv s^2 + 2\xi\omega_n s + {\omega_n}^2 \qquad (22)$$

From the above equation, the required k_p and k_i values:

$$k_i = L_f {\omega_n}^2 \qquad (23)$$
$$k_p = L_f 2\xi\omega_n - R_f - R_g \qquad (24)$$

2.1 Power expressions

The original apparent power expression for three phase unbalanced system is equal to the power original expression of a three phase balanced system:

$$S = \frac{3}{2} \cdot \vec{v}_g \cdot \vec{i}_g^{\,*} \qquad (25)$$

From the above equation, after simplifying separating the real and imaginary terms we can get the general active and reactive power expressions as:

$$P_g = \frac{3}{2} \cdot [P_0 + P_{C2} \cdot \cos(2\omega t) + P_{S2} \cdot \sin(2\omega t)] \qquad (26)$$
$$Q_g = \frac{3}{2} \cdot [Q_0 + Q_{C2} \cdot \cos(2\omega t) + Q_{S2} \cdot \sin(2\omega t)] \qquad (27)$$

Being each P_0, P_{C2}, P_{S2}, Q_0, Q_{C2} and Q_{S2} constant power terms in matrix form are:

$$\begin{bmatrix} P_0 \\ P_{C2} \\ P_{S2} \\ Q_0 \\ Q_{C2} \\ Q_{S2} \end{bmatrix} = \frac{3}{2} \begin{bmatrix} v_{dg}^+ & v_{qg}^+ & v_{dg}^- & v_{qg}^- \\ v_{dg}^- & v_{qg}^- & v_{dg}^+ & v_{qg}^+ \\ v_{qg}^- & -v_{dg}^- & -v_{qg}^+ & v_{dg}^+ \\ v_{qg}^+ & -v_{dg}^+ & v_{qg}^- & -v_{dg}^- \\ v_{qg}^- & -v_{dg}^- & v_{qg}^+ & -v_{dg}^+ \\ -v_{dg}^- & -v_{qg}^- & v_{dg}^+ & v_{qg}^+ \end{bmatrix} \cdot \begin{bmatrix} i_{dg}^+ \\ i_{qg}^+ \\ i_{dg}^- \\ i_{qg}^- \end{bmatrix} \qquad (28)$$

Thus, the above equation shows how the P_g and Q_g expressions of a three phase unbalanced system are oscillatory, in contrast to the powers of the three phase balanced systems, which are constant.

Table 1: System parameters for LCL filter

f_g	Grid frequency	50Hz
f_{sw}	PWM carrier frequency	15KHz
P_n	Nominal Power	20KW
V_g	Phase grid voltage	380V
V_{DC}	DC link Voltage	700V
L_f	Inverter side inductor	1 mH
L_g	Grid side inductor	0.11 mH
C_f	Capacitor filter	0.614 uF
R_D	Damping Resistor	0.14 ohms

3. Vector Control under Unbalanced Condition

The control strategy for the control of voltage source inverter followed under an unbalanced grid conditions are based on the basic principles of the vector control strategy. The schematic block diagram is shown in the fig 3. The control technique uses two current loops per sequence (i.e., two dq controllers for the positive sequence and another two dq controllers for the negative sequence). Therefore, this control strategy is known in the specialized literature as dual vector control method.

In this vector control strategy, for unbalanced conditions, the coupling terms are cancelled at the output of the current PI regulators. The cancelation terms for the LCL filter from

$$e_{df}{}^{+} = -\omega_a \cdot L_f \cdot i_{qf}{}^{+} - \omega_a \cdot L_g \cdot i_{qg}{}^{+} + v_{dg}{}^{+} \qquad (29)$$
$$e_{qf}{}^{+} = \omega_a \cdot L_f \cdot i_{df}{}^{+} + \omega_a \cdot L_g \cdot i_{dg}{}^{+} + v_{qg}{}^{+} \qquad (30)$$
$$e_{df}{}^{-} = \omega_a \cdot L_f \cdot i_{qf}{}^{-} + \omega_a \cdot L_g \cdot i_{qg}{}^{-} + v_{dg}{}^{-} \qquad (31)$$
$$e_{qf}{}^{-} = -\omega_a \cdot L_f \cdot i_{df}{}^{-} - \omega_a \cdot L_g \cdot i_{dg}{}^{-} + v_{qg}{}^{-} \qquad (32)$$

In an ideal case, the proper cancelation of the coupling terms using the LCL filter would be achieved measuring both the converter side and grid side currents, because both the currents are involved in these coupling terms. Assuming that both currents (i_f and i_g) have similar fundamental values, an approximation can be implemented minimizing the coupling terms for both cases where only the grid side current or the converter side current is measured. Then

$$\begin{aligned} e_{df}{}^{+} &\approx -(L_f + L_g) \cdot \omega_a \cdot i_{qf}{}^{+} + v_{dg}{}^{+} \\ &\approx -(L_f + L_g) \cdot \omega_a \cdot i_{qg}{}^{+} + v_{dg}{}^{+} \end{aligned} \qquad (33)$$
$$\begin{aligned} e_{qf}{}^{+} &\approx (L_f + L_g)\omega_a \cdot i_{df}{}^{+} + v_{qg}{}^{+} \\ &\approx (L_f + L_g)\omega_a \cdot i_{dg}{}^{+} + v_{qg}{}^{+} \end{aligned} \qquad (34)$$
$$\begin{aligned} e_{df}{}^{-} &\approx (L_f + L_g)\omega_a \cdot i_{qf}{}^{-} + v_{dg}{}^{-} \\ &\approx (L_f + L_g)\omega_a \cdot i_{qg}{}^{-} + v_{dg}{}^{-} \end{aligned} \qquad (35)$$
$$\begin{aligned} e_{qf}{}^{-} &\approx -(L_f + L_g) \cdot \omega_a \cdot i_{df}{}^{-} + v_{qg}{}^{-} \\ &\approx -(L_f + L_g) \cdot \omega_a \cdot i_{dg}{}^{-} + v_{qg}{}^{-} \end{aligned} \qquad (36)$$

The output of the current controllers creates the voltage reference values that, after cancelling the coupling terms, that reference values are transformed into $\alpha\beta$ coordinates, by using the θ angle. Once transformed into positive and negative $\alpha\beta$ sequences, the positive and negative sequences are added which generating a total $\alpha\beta$ reference. After that these reference values are transformed into abc coordinates for the subsequent creation of the order commands for the IGBTs of the converter, by means of the PWM.

On the other hand, for the current loop controllers and for the current reference generation, the positive and negative sequences of the voltages and currents must be calculated. This sequence calculation is performed in two different blocks, as displayed in fig 3. First of all the vector control is oriented to the grid voltage by means of the selected grid synchronization method. Although there are several grid synchronization techniques in the specialized literature for unbalanced three phase systems, the one utilized in this paper [9]. This grid synchronization block calculates the dq components of the positive and negative sequences of the grid voltage and the angle (θ) for the different transformation blocks of the control algorithm. Note that in the presence of unbalance currents the corresponding dq components include oscillatory terms at double the fundamental frequency (100Hz in a grid of 50Hz). To eliminate these components, various described in the specialized literature, such as low pass filters, notch filters tuned at the oscillatory frequency, and also DSC methods were used [10].

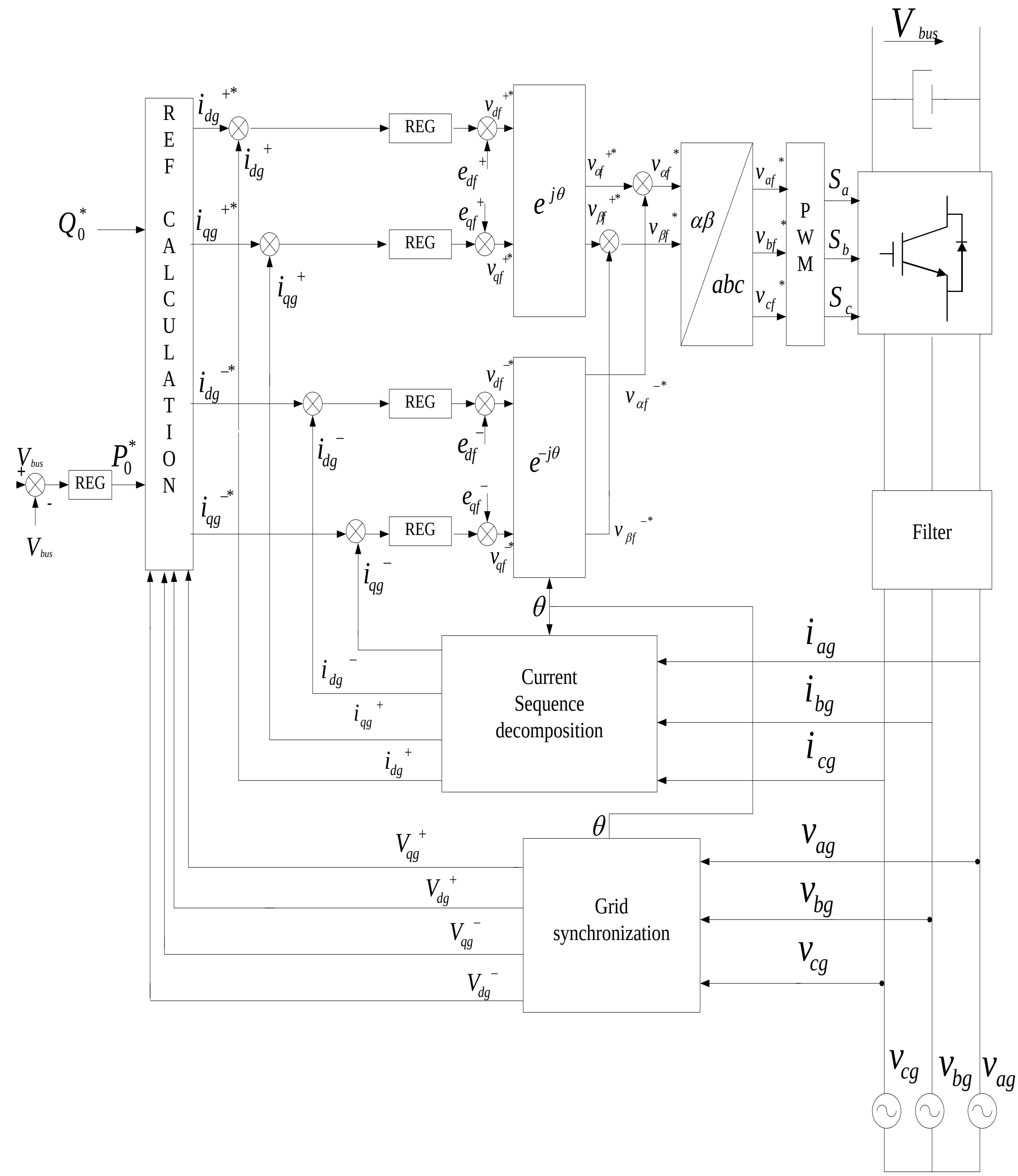


Figure 3: vector control strategy for an unbalanced three-phase system

It is to be pointed that the low pass filter applied to the currents would significantly affect the bandwidth of the current loops, so maybe it is not the best option. Note also that for the cancelation of the coupling terms at the output of the voltage regulators it is also necessary to filter the oscillations.

In general it is necessary to control the DC bus voltage with an extra voltage loop, as presented in the fig. The output of The DC bus voltage regulator is the reference for the active power exchanged with the grid ($P_0{}^*$).On the other hand, the other reference for the given system is the mean value of the grid reactive power ($Q_0{}^*$). Thus, from these power reference values, the current positive and negative dq references are generated. For that purpose, the matrix equation (28) needs to be inverted:

$$\begin{bmatrix} i_{dg}{}^{+*} \\ i_{qg}{}^{+*} \\ i_{dg}{}^{-*} \\ i_{qg}{}^{-*} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} v_{dg}^{+} & v_{qg}^{+} & v_{dg}^{-} & v_{qg}^{-} \\ v_{dg}^{-} & v_{qg}^{-} & v_{dg}^{+} & v_{qg}^{+} \\ v_{qg}^{-} & -v_{dg}^{-} & -v_{qg}^{+} & v_{dg}^{+} \\ v_{qg}^{+} & -v_{dg}^{+} & v_{qg}^{-} & -v_{dg}^{-} \\ v_{qg}^{-} & -v_{dg}^{-} & v_{qg}^{+} & -v_{dg}^{+} \\ -v_{dg}^{-} & -v_{qg}^{-} & v_{dg}^{+} & v_{qg}^{+} \end{bmatrix}^{-1} \begin{bmatrix} P_0{}^* \\ P_{C2}{}^* \\ P_{S2}{}^* \\ Q_0{}^* \\ Q_{C2}{}^* \\ Q_{S2}{}^* \end{bmatrix} \quad (37)$$

For the calculation of the current reference values the dq positive and negative sequences of the voltages are necessary. However, for the inversion of matrix, a squad matrix is preferable. For that purpose, the last two rows of the above matrix equation are omitted for the current reference values calculation. It is possible to make zero the oscillatory terms of the active power $P_{c2} = 0$ and $P_{s2} = 0$. Therefore:

$$\begin{bmatrix} i_{dg}{}^{+*} \\ i_{qg}{}^{+*} \\ i_{dg}{}^{-*} \\ i_{qg}{}^{-*} \end{bmatrix} = \frac{2}{3}\begin{bmatrix} v_{dg}^{+} & v_{qg}^{+} & v_{dg}^{-} & v_{qg}^{-} \\ v_{dg}^{-} & v_{qg}^{-} & v_{dg}^{+} & v_{qg}^{+} \\ v_{qg}^{-} & -v_{dg}^{-} & -v_{qg}^{+} & v_{dg}^{+} \\ v_{qg}^{+} & -v_{dg}^{+} & v_{qg}^{-} & -v_{dg}^{-} \end{bmatrix}^{-1} \begin{bmatrix} P_0{}^{*} \\ 0 \\ 0 \\ Q_0{}^{*} \end{bmatrix} \tag{38}$$

From the above, the calculations are eased and the active power oscillations are eliminated, which is very useful in order to minimize the oscillations of the DC bus voltage. (Otherwise, if there are any oscillations in the active power reference value then there will be oscillations in the DC bus) Thus, from above equation the current references results in:

$$i_{dg}{}^{+*} = \frac{2}{3}\left\{\frac{v_{dg}^{+}}{|v_g^{+}|^2-|v_g^{-}|^2}P_0{}^{*} + \frac{v_{qg}^{+}}{|v_g^{+}|^2-|v_g^{-}|^2}Q_0{}^{*}\right\} \tag{39}$$

$$i_{dg}{}^{+*} = \frac{2}{3}\left\{\frac{v_{dg}^{+}}{|v_g^{+}|^2-|v_g^{-}|^2}P_0{}^{*} + \frac{v_{qg}^{+}}{|v_g^{+}|^2-|v_g^{-}|^2}Q_0{}^{*}\right\} \tag{40}$$

$$i_{dg}{}^{-*} = \frac{2}{3}\left\{-\frac{v_{dg}^{-}}{|v_g^{+}|^2-|v_g^{-}|^2}P_0{}^{*} + \frac{v_{qg}^{-}}{|v_g^{+}|^2-|v_g^{-}|^2}Q_0{}^{*}\right\} \tag{41}$$

$$i_{qg}{}^{-*} = \frac{2}{3}\left\{-\frac{v_{qg}^{-}}{|v_g^{+}|^2-|v_g^{-}|^2}P_0{}^{*} - \frac{v_{dg}^{-}}{|v_g^{+}|^2-|v_g^{-}|^2}Q_0{}^{*}\right\} \tag{42}$$

Where:

$$|v_g^{+}|^2 = (v_{dg}^{+})^2 + (v_{qg}^{+})^2 \tag{43}$$

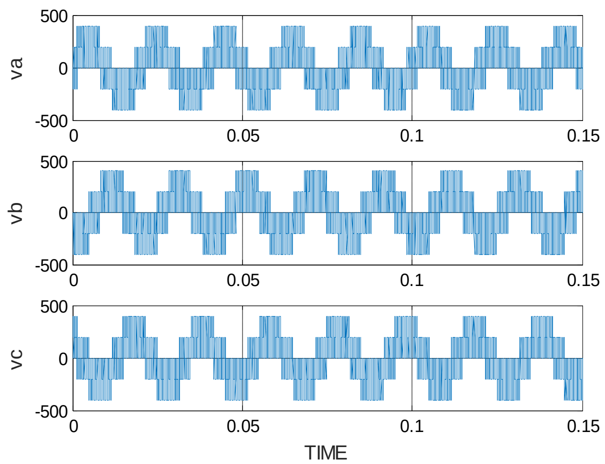
$$|v_g^{-}|^2 = (v_{dg}^{-})^2 + (v_{qg}^{-})^2 \tag{44}$$

Therefore, these current reference values are in function of the average active and reactive power references and the positive and negative sequence dq voltages. Note that the reactive power value will present oscillations, since terms Q_{c2} and Q_{s2} are not made zero.

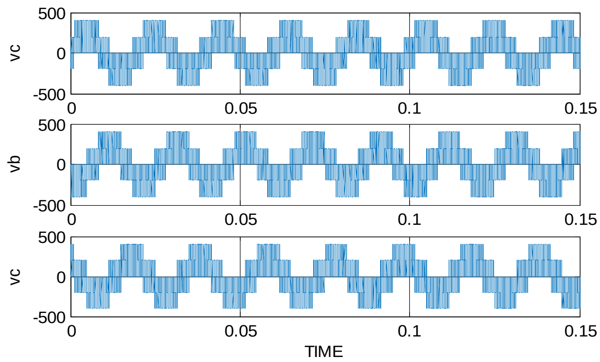
4. Simulation Results

The single-phase to ground fault applied on the given grid connected system, then the unbalanced currents and voltages effects the system and fluctuations in the active and reactive powers. The proposed control strategy effectively controls the unbalanced voltages and currents and eliminates the fluctuations in active and reactive power components.

(a)



(b)



(c)

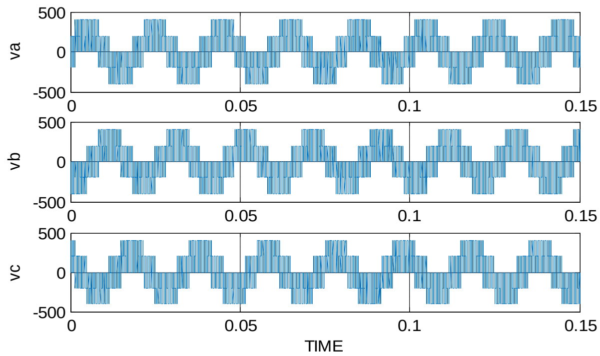
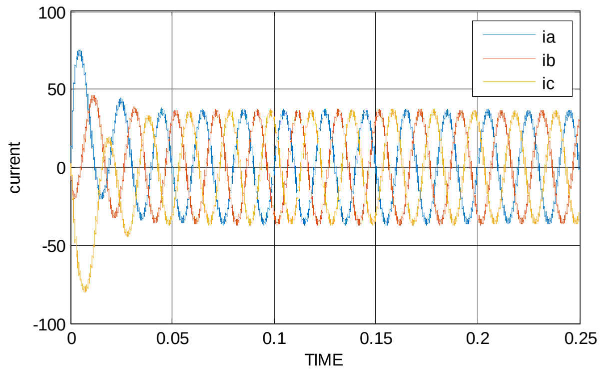


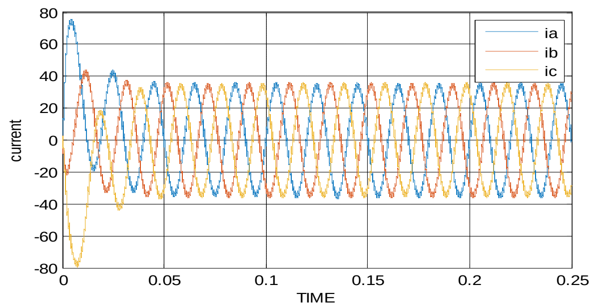
Figure 4: voltage magnitudes of grid connected converter (a) dip at 0.1 power angle jump, (b) dip at 0.5 power angle jump, (c) dip at 0.9 power angle jump.

From the above figure4, it is shown that by using proposed vector control strategy the unbalanced voltages under the unbalanced single phase to ground fault are controlled effectively.

(a)



(b)



(c)

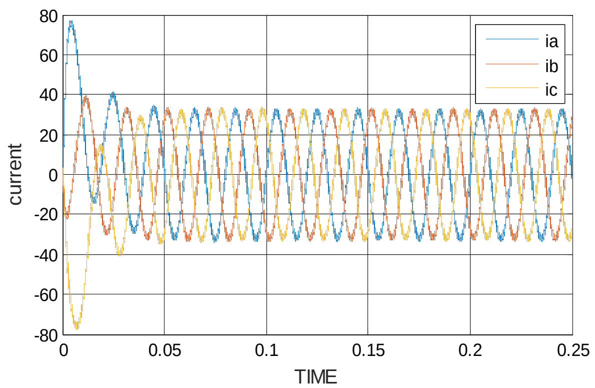
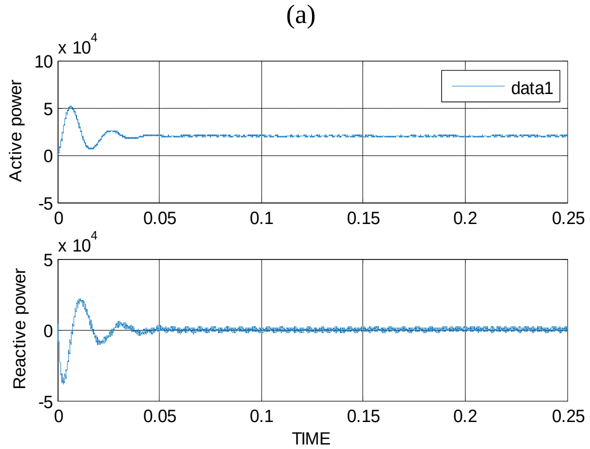


Figure 5: currents of the grid connected system (a) dip at 0.1 power angle jump, (b) dip at 0.5 power angle jump, (c) dip at 0.9 power angle jump.

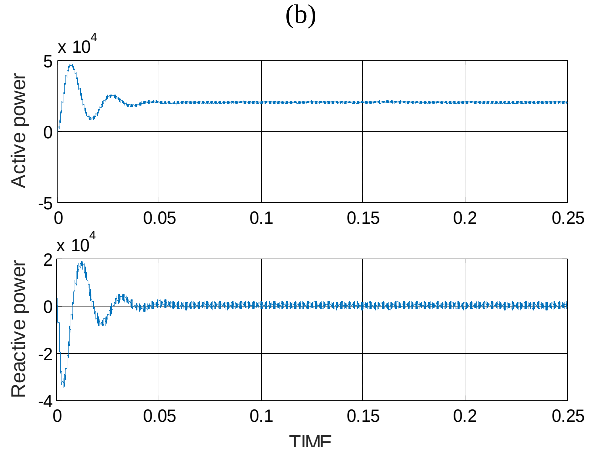
From the figure5, it is shown that the unbalanced currents under fault conditions at different power angle jumps are controlled by proposed control strategy accurately.

From the figure6, when a single phase to ground fault occurred at the point of grid connected converter the proposed control strategy eliminates the unwanted oscillations in the active and reactive powers by controlling unbalanced currents and voltages at grid connected converter.

(a)



(b)



(c)

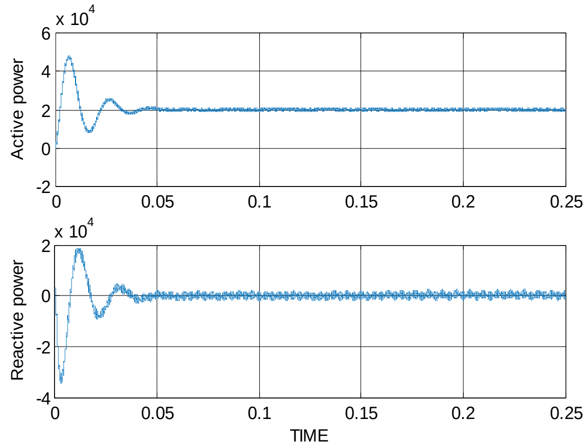


Figure 6: active and reactive power control (a) dip at 0.1 power angle jump, (b) dip at 0.5 power angle jump, (c) dip at 0.9 power angle jump.

5. Conclusion

This paper employs the vector control strategy to control the grid connected system efficiently. By using proposed control technique, the control of unbalanced voltages and currents during the grid fault conditions at different dip positions (power angle jumps) are achieved accurately and efficiently. We validate the proposed vector control strategy by simulation and control the voltage source converter with LCL filter under unbalanced grid conditions.

References

[1] Jiang, W., Wu, Z., Li, W., et al.: 'Control strategy of suppressing active power secondary fluctuations of grid-connected inverter base on unbalanced grid', Autom. Electr. Power Syst., 2014, 38, (15), pp. 106–111

[2] Rodriguez, J., Pontt, J., Silva, C.A., et al.: 'Predictive current control of a voltage source inverter', IEEE Trans. Ind. Electron., 2007, 50, (1), pp. 495–503

[3] Tongguang Yang, Weihua Gui, "Research on Multi-objective coordinated control strategies of grid-connected inverter under unbalanced voltage conditions," *Transactions of China Electrotechnical Society*, vol. 30, no. 11, pp. 148-157, Jun. 2015.

[4] Weidong Jiang, Zhiqing Wu, Yangyang She, et al., "Control Strategy of Suppressing Active Power Secondary Fluctuations of Grid connected Inverter Based on Unbalanced Grid." *Automation of Electric Power Systems*, vol. 15, no. 15, pp. 106-111, Aug. 2014.

[5] Wei Zhang, Hongsheng Wang, Yuan Ren, et al., "Investigation on control of three-phase grid-connected inverters under unbalanced grid voltage conditions," *Transactions of China Electrotechnical Society*, vol. 25, no. 12, pp. 103-110, Dec. 2010.

[6] Fainan A. Magueed, Jan Svensson, "Control of VSC connected to the grid through LCL filter to achieve balanced currents,"in Proc. IEEE Industry Applications Society Annual Meeting 2005, vol. 2, pp. 572-578.

[7] Jiabing Hu, Yikang He, "Modelling and control of grid-connected voltage-sourced converters under generalized unbalanced operation conditions," IEEE Trans. Energy Conversion.vol. 23(3):903-913, may. 2008.

[8] C. Lascu, L. Asiminoaei, I. Boldea, and F. Blaabjerg, "High performance current controller for selective harmonic compensation in active power filters," IEEE Transactions on Power Electronics, vol. 22, no. 5, pp. 1826–1835, Sep. 2007.

[9] F. Liu, Y. Zhou, S. Duan, J. Yin, B. Liu, and F. Liu, "Parameter design of a two-current-loop controller used in a grid-connected inverter system with LCL filter," IEEE Transactions on Industrial Electronics, vol. 56, no. 11, pp. 4483–4491, Nov. 2009.

[10] Yang Yong, Zhao Chunjiang, "Proportional resonance controller of grid-connected inverter for distributed generation system," Electric Power Automation Equipment, Vol. 32, No. 11, Nov. 2011.

.