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Power Quality Improvement By Four Leg Voltage Source Inverter

[1]Prof. S.R.Malluramath, , [2]Prof.M.G.Ganachari

[1]Assistant professor in Department of E&C HSIT,Nidasoshi.
(shwetarm.ece@hsit.ac.in)

[2] Assistant professor in Department of CSE HSIT,Nidasoshi.
(mgganachari.cse@hsit.ac.in)

Abstract— **This paper presents a hysteresis band current control scheme for Three-phase four leg voltage Source Inverter that compensates power quality problems. The inverter is capable of compensating power factor, current unbalance and current harmonics. Today most inverter are designed for balanced three phase loads and consequently the associated control strategies are quite effective for three phase three wire system but are not able to manage load that require neutral current compensation. If four leg four wire topology is used the controller can be simplified because there is no need to split DC capacitor. A simulation is carried out using MATLAB/Simulink simulation to verify the proposed system.**

Keywords-- ***power quality (PQ), Point of Common Coupling (PCC), Voltage Source Inverter (VSI).***

I. INTRODUCTION

The widespread use of non-linear loads is leading to a variety of undesirable phenomena in the operation of power systems. The harmonic components in current and voltage waveforms are the most important among these.a Conventionally, passive filters have been used to eliminate line current harmonics. However, they introduce resonance in the power system and tend to be bulky. Current controlled voltage source inverters can be utilized with appropriate control strategy to perform active filter functionality. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may detoriate the quality power [1], [2].Recently various control strategies for grid connected inverters incorporating PQ solution have been proposed. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4].

But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. Generally current controlled voltage source inverters are used because of their faster response compared to voltage controlled voltage source inverters as its power is controlled by switching instant. And also in current controlled voltage source inverter active and reactive power is controlled independently.

This paper suggests a new method that consists four leg current controlled Voltage Source Inverter that is capable of simultaneously compensating problems like power factor, current unbalance and current harmonics. In three phase three leg topology the zero sequence currents in the load cannot be compensated and hence the zero sequence currents flow in the neutral wire (between the system and load).The zero sequence currents thus return to the ac distribution system. If the load is non linear and contain harmonics then these harmonics also enter the ac system thus degrading the power quality. In three phase application with three leg inverter, if the load requires a neutral point connection a simple approach is to use two capacitor to split the dc link and tie the neutral point to the midpoint of two capacitors. In this case the unbalanced loads will cause the neutral currents that flow through the fourth wire distorting the output voltage. Another drawback is the need for excessively large dc link capacitors. The important parameters of VSIs are the level of dc link voltage, value of interface inductor and hysteresis band. These parameters must be carefully selected to provide satisfactory performance while tracking reference currents [5], [6]. In [7] a control strategy based on p-q theory is proposed where load current and inverter current sensing are required to compensate load harmonics.

II. SYSTEM TOPOLOGY AND OPERATING PRINCIPLE

The proposed system consists of a four leg voltage source inverter with a capacitor on dc side as shown in Fig. 1. It is assumed that a non-linear unbalanced load is connected to three-phase balanced source voltages. Generally, an active power filter generates a harmonic spectrum that is opposite in phase to the distorted harmonic current it measures. Harmonics are thus cancelled and the result is a non-distorted sinusoidal current. Similarly in this proposed scheme the Compensation currents are injected using hysteresis current controller. Hysteresis controller is a non linear current controller in which actual currents are compared to reference currents instantaneously. The current error is either exceeding the upper limit or lower limit of the hysteresis band, according to the band limit, the upper or lower switch becomes ON or OFF. Conventionally two level hysteresis controllers are used, because of its simplicity. In [8] three level hysteresis controller is proposed with superior performance on harmonics.

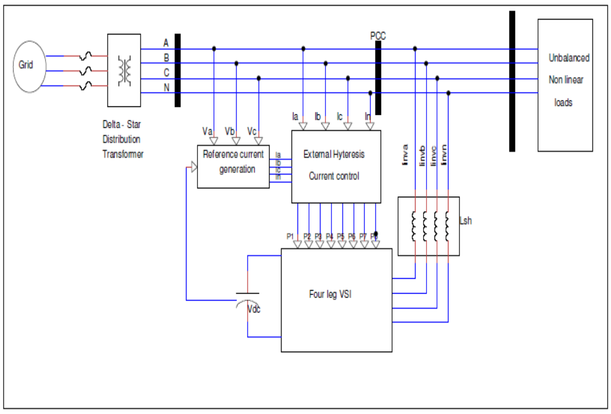


Fig.1 Schematic of Proposed System

The single phase equivalent circuit of the system is shown Fig.2

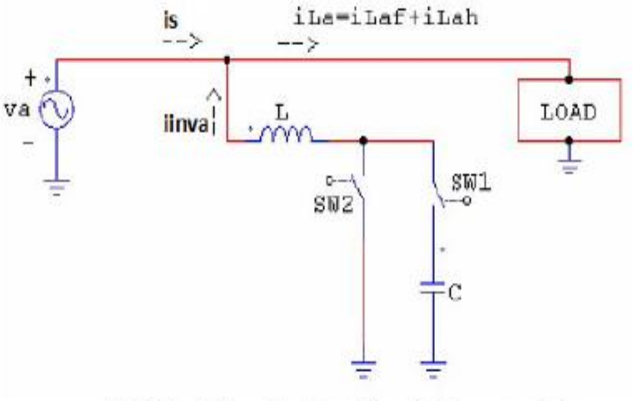


Fig.2 Single Phase Equivalent Circuit of the system VSI

Load current can be written as

$i_{La} = i_{Laf} + i_{Lah}$ (1)

$i_L = i_{Inva} + i_S$ (2)

In equation (1), iLaf is the fundamental component and iLah harmonic component of load current. Since the harmonic component of load current should not be transferred to the supply side, the inverter has to inject a current whose magnitude should be equal to harmonic component.

We should have,

iLah = iInva (3)

From equation (2) and (3), we get

iS = iLaf (4)

If iLah > iInva switch2 should be off and switch 1 should be on so the current generated by dc capacitor iInva is equal to iLh..

If iLah < iInva switch2 should be on and switch 1 should be off so the current iInva should be transferred to the ground in order to have iInva= iLah..

III. CONTROL STRATEGY

The main aim of the proposed approach is to compensate for the zero sequence neutral current and also to make the voltage source inverter to function as an active filter. There are many control approaches available for the generation of reference source currents for the control of VSI system in the literature [9], [10]. The block diagram of the control scheme is shown in Fig. 3

A. Voltage control of DC capacitor

The Dc link voltage regulates balanced power flow in the grid system so the DC link voltage is maintained constant across the capacitor. A PI controller is used to maintain the DC link voltage at specified value. The DC link voltage is sensed and compared with reference value and the error is passed through a PI controller.

$$V_{dcerr} = V_{dc}^{*} - V_{dc} \qquad (5)$$

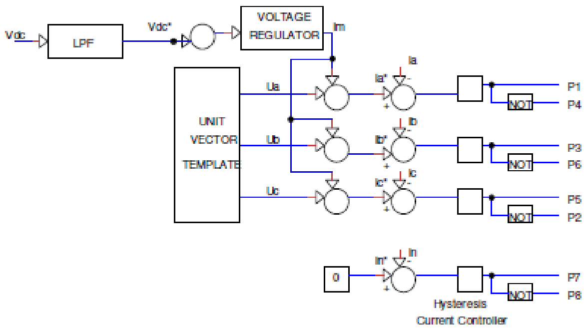


Fig.3 Block diagram representation of control scheme

B. Current Control of VSI

Unit vector templates are generated as

$$U_a = \text{Sin}(\Theta) \qquad (6)$$

$$U_b = \text{Sin}(\Theta - 2\Pi/3) \qquad (7)$$

$$U_c = \text{Sin}(\Theta + 2\Pi/3) \qquad (8)$$

The multiplication of current Im with unit vector template (Ua ,Ub ,Uc) generates reference grid currents (Ia*, Ib*, Ic*).

The instantaneous values of reference grid currents are computed as

$$I_a^{*} = I_m \cdot U_a \qquad (9)$$

$$I_b^{*} = I_m \cdot U_b \qquad (10)$$

$$I_c^{*} = I_m \cdot U_c \qquad (11)$$

The neutral currents present if any due to the loads connected to the neutral conductor should not be drawn from the grid. Thus reference grid neutral current is considered as zero and can be expressed as

$$I_n^{*} = 0 \qquad (11)$$

Current errors are obtained by comparing reference grid currents (Ia*, Ib*, Ic*) with actual grid currents (Ia, ,Ib ,Ic). These current errors are given to the hysteresis current controller.

$$I_{aerr} = I_a^{*} - I_a \qquad (12)$$

$$I_{berr} = I_b^{*} - I_b \qquad (13)$$

$$I_{cerr} = I_c^{*} - I_c \qquad (14)$$

$$I_{nerr} = I_n^{*} - I_n \qquad (15)$$

C. Switching Control of IGBTs

Switching pulses are generated using hysteresis current controller. The basic principle is based on deriving switching signals from the comparison of current error with a fixed tolerance band. Thus the actual currents track the reference currents generated by current control loop. The switching pattern of each IGBT is formulated as,

If (Ia* - Ia) = +hb then the upper switch S1 will be ON in the phase a leg of inverter.

If (Ia* - Ia) = -hb then the lower switch S4 will be ON in the phase a leg of inverter.

Where hb width of hysteresis band. Similarly switching pulses are derived for other three legs.

IV. SIMULATION RESULTS

To verify the proposed control approach simulation study is carried out using MATLAB/Simulink. The block diagram of the designed system is shown in Fig.4. A Four leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents with unity power factor despite of unbalanced non linear loads at PCC. The supply voltages are assumed to be a balanced three-phase voltage sources with the magnitude of 440V. The L, C values of the inverter are selected 2mH and 1000uF respectively. The inverter is effectively controlled to inject compensation current that cancel out source current harmonics. This utilizes the control circuit shown in Fig.5 In this control circuit the Proportional and Integral gains of PI controller are KPVdc =0.189 and KIVdc = 0.27.

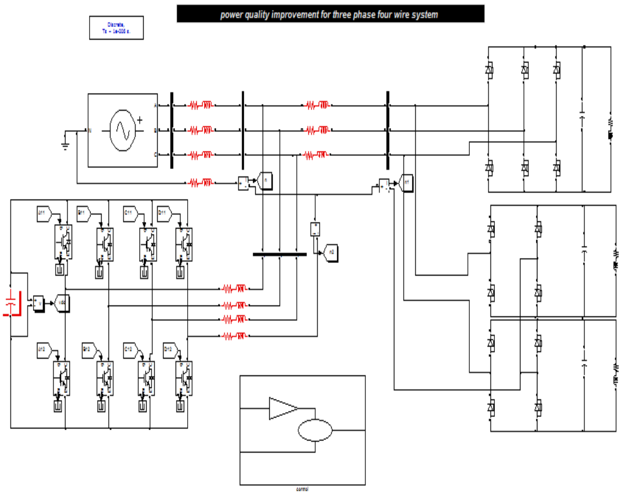


Fig.4 Designed system with Four leg VSI

The System Parameter is given in Table I shown below

TABLE 1
SYSTEM PARAMETER

3-phase supply	: 430V, 50Hz
3-phase Non-linear Load	: R=26.6 Ω L=10mH
1-phase Non-linear Load(A-N)	: R=36.6Ω L=10mH
1-phase Non-linear Load(C-N)	: R=26.6Ω L=10mH
DC-link capacitance and Voltage	: C=3300µF , 1500V
Coupling Inductance	: 2 mH

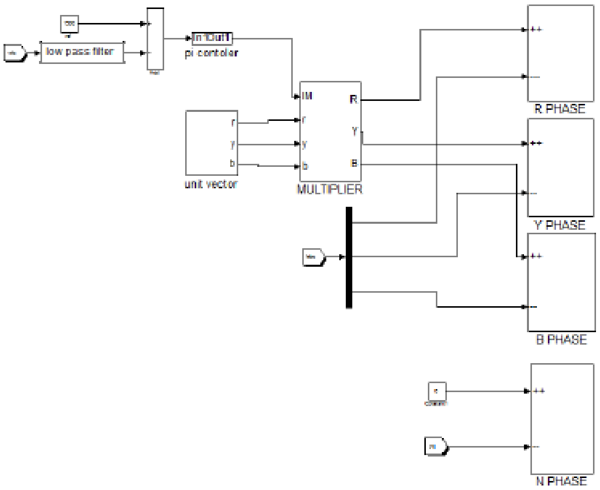


Fig.5 Control circuit

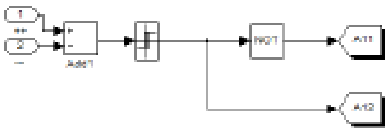


Fig.6 shows the DC capacitor voltage maintained at 1500V reference. The waveforms of grid voltage (Va,Vb,Vc), grid currents (Ia, Ib, Ic), load currents (Ila, Ilb, Ilc) and inverter currents (Iinva, Iinvb, Iinvc) with and without the inverter is shown in Fig.7a and 7b. In Fig.7a the inverter is not connected to the network; therefore the grid current is identical to the load current profile. In Fig.7b the inverter is made to inject compensating current as a result the source side harmonics are reduced. Thus once the inverter is in operation the grid only supplies fundamental current.

From Fig.7b it can be noticed that the highly unbalanced load currents after compensation appear as pure sinusoidal balanced set of currents on grid side. It can also be observed that the supply voltage and current are in phase which shows that the unity power factor is maintained.

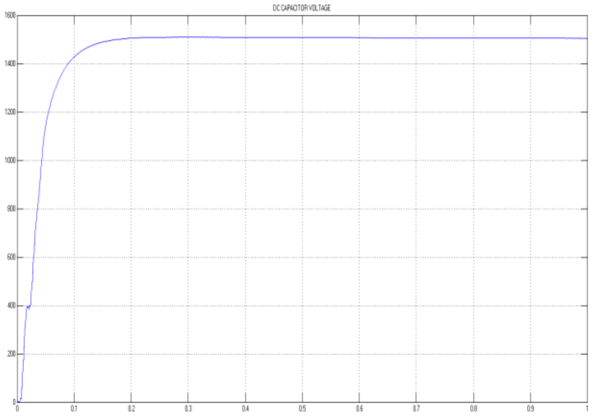


Fig.6 DC capacitor voltage

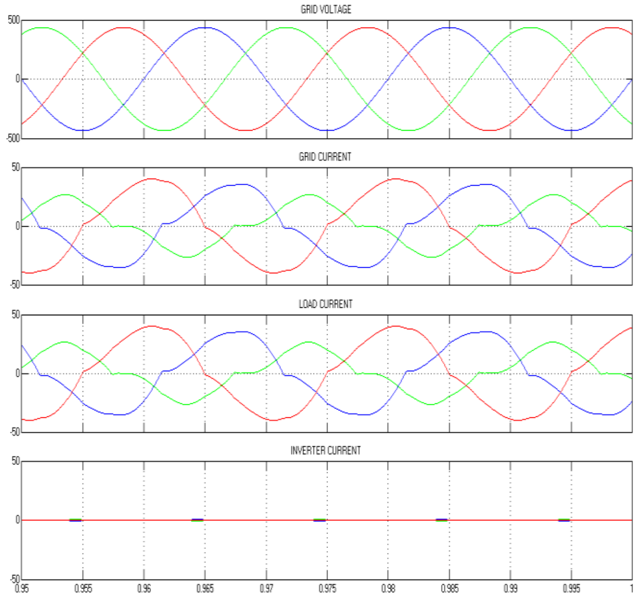


Fig.7a) Grid Voltage, Grid Current, Load Current and Inverter Current without VSI

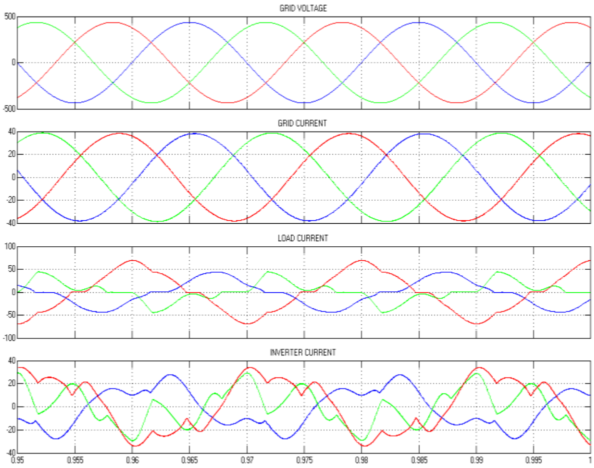


Fig.7b) Grid Voltage, Grid Current, Load Current and Inverter Current

with Four leg VSI Fig.8 shows the simulation results of neutral currents for grid, load and inverter. The load neutral current due to single

phase loads is effectively compensated by the fourth leg of the inverter such that the current in grid side neutral conductor is\ reduced to zero.

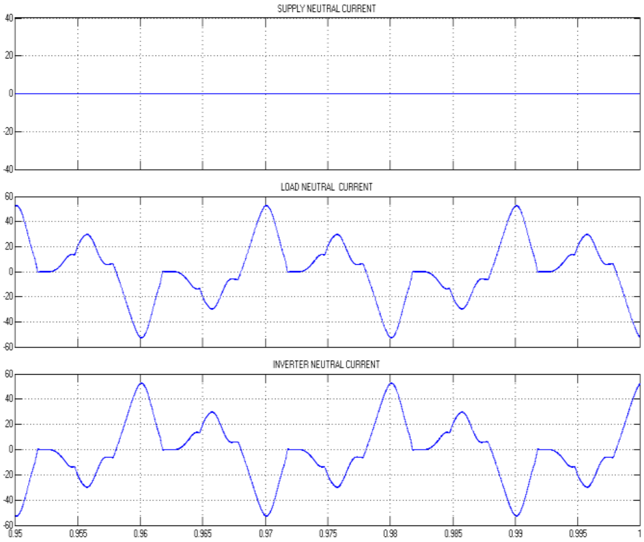


Fig.8 Grid, Load and Inverter neutral currents

The total harmonic distortions (THDs) of phase a, b and load currents are noticed as 12.49%, 23.68% and 8.45% respectively. After compensation the grid current THDs are reduced to 0.54%, 0.47% and 0.43% for a, b and c phases respectively which is shown in Fig.9. Thus from the simulation results it is evident that the three phase four leg current controlled voltage source inverter can be effectively utilized to compensate current harmonics and also enables the grid to supply sinusoidal power at UPF.

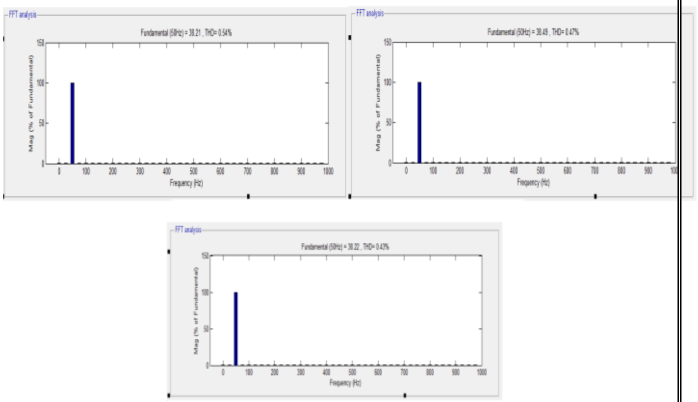
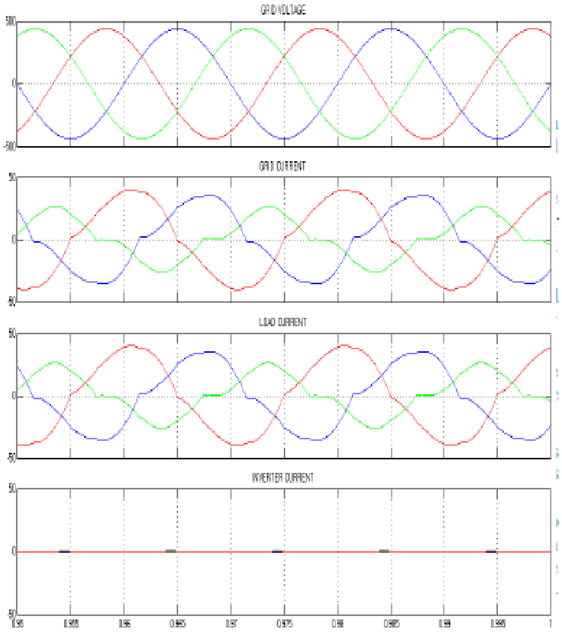


Fig.9 Grid Current Harmonic Spectrum

V. CONCLUSION

This paper has presented a control of a three phase four leg voltage source inverter to control the quality of power at PCC. It has been shown the inverter can be effectively utilized for power conditioning. The current harmonics and current unbalance caused by unbalanced non linear load connected at PCC are compensated effectively such that the grid currents are always maintained sinusoidal at unity power factor. And the load neutral current is prevented from flowing into the grid by compensating it locally by the forth leg of the inverter. The simulation results confirm the improvement of quality of power by maintaining the THD of the source current after compensation well below 3%



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