Modelling and Control of Four Leg Inverter with Utilization in Power Quality Improvement in Grid Connected System

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Abstract: ***In standalone power supply system, three phase inverter with an additional neutral leg is used to deal with load unbalance. The goal of the three phase four leg inverter is to maintain the desired sinusoidal output voltage waveform over all loading conditions and transients. It is ideal for applications like data communication, industrial automation, military equipment, which require high performance uninterruptible power supply. The three phase four leg inverter can be utilized in grid connected system as power converter to inject power generated from photovoltaic cell to the grid and also as shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All these functions may be achieved either individually or simultaneously. In this paper the topology of three phase four leg inverter is shown along with its control. The MATLAB/Simulink based simulations are provided which support the functionality of the four leg inverter.***

Keywords: Active Power Filter (APF), Distributed Grid (DG), Power Quality (PQ), Point of common coupling (PCC), Renewable Energy Sources (RES), Combined Heat Power (CHP)

1. Introduction

Over the last few years, an increase of DG units connected to the low voltage distributed network is observed. The RES connected to DG units are PV (micro), CHP & Wind Power [1, 2]. This leads to the development of relatively small generation units geographically distribution & connected to the distribution network. In order to reduce voltage unbalance in 3-phase connections various inverter topologies are considered among which 3-phas 4-wire inverter topology is seen most effective. It can be used as APF, a review of different APF is given in [3] & its control tech is discussed in [4]. The basic idea is the maximum utilization of inverter rating which is most of the time underutilised due to intermittent nature of RES. The actual control technique of APF is shown in [5].Its utilization when used with RES is explained in [6] while actual explanation of grid connected distribution system inverter is in [7].

2. Four Leg Inverter Topology

In case of Four Leg Inverter the neutral point to the mid-point of the 4th neutral leg [5] & 4-leg inverter topology is shown in figure. 1

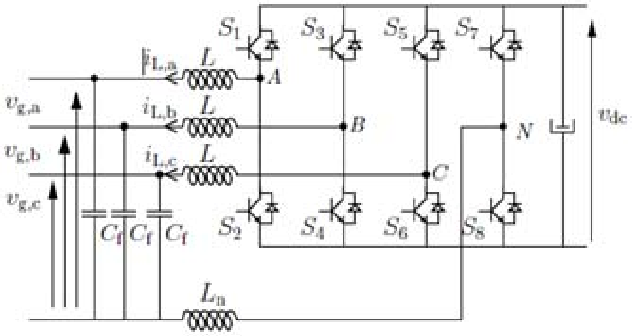

Figure 1: Topology of the 3-phase 4-leg inverter

3. Control of Grid Interfacing Inverter

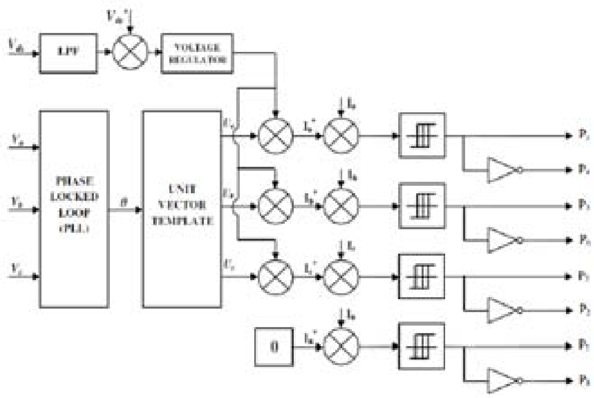

Figure 2: Block diagram representation of grid-interfacing inverter control.

The control diagram of grid connected inverter is shown in the figure 2. The fourth leg of the inverter is used to compensate the load neutral current. This allows it to maintain balanced output voltage in case of unbalanced and non-linear loads. The main aim is to regulate the power at the point of common coupling during 1) PRES= 0, 2) PRES< Total load power (PL), 3) PRES > PL.

The inverter switches duty ratio varies in cycle such as the injected power of load and inverter combination appears as balanced resistive load to the grid. The Dc link voltage regulation carries the information regarding the exchange of active power in between photovoltaic source of (RES source) and grid. Thus, the output of DC link voltage regulator results in an active current (I_m).The multiplication of active current component with unity grid voltage vector templates (U_a, U_b and U_c) generates the reference grid currents (I_a*, I_b* and I_c*). The reference grid neutral current set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angles (ϴ) obtained from phase lock loop (PLL) is used to generate unit vector template:

$U_a = \sin\Theta$ ---------- (1)
$U_b = \sin(\Theta - 2\pi/3)$ ---------- (2)
$U_c = \sin(\Theta + 2\pi/3)$ ---------- (3)

The actual DC link voltage (Vdc) is sensed and passed through first order low pass filter to eliminate switching ripples present in DC link voltage and generated reference current signals. The difference of this filtered DC link voltage and reference DC link voltage (V_{dc}^*) is given to discrete PI regulator. The dc link voltage error of nth sampling instant is given as:

$V_{dcerr\,(n)} = V_{dc}^* - V_{dc\,(n)}$ ---------- (4)

The output of discrete PI regulator at nth sampling instant is expressed as*:*

$I_{m\,(n)} = I_{m\,(n-1)} + K_{pVdc}\,(V_{dcerr\,(n)} - V_{dcerr\,(n-1)}) + K_{IVdc} V_{dcerr\,(n)}$ -- (5)

Reference 3-phase grid currents-

$I_a^* = I_m \cdot U_a$ ---------- (6)
$I_b^* = I_m \cdot U_b$ ---------- (7)
$I_n^* = 0$ ---------- (8)
$I_c^* = I_m \cdot U_c$ ---------- (9)

Current errors given to hysteresis current controller:

$I_{aerr} = I_a^* - I_a$ ---------- (10)
$I_{berr} = I_b^* - I_b$ ---------- (11)
$I_{cerr} = I_c^* - I_c$ ---------- (12)
$I_{nerr} = I_n^* - I_n$ ---------- (13)

This hysteresis controller then generates the switching pulses (P_1 to P_8) for gate drives of grid interfacing inverter.

The average model of 4-leg inverter can be obtained by the following state space equation:-

$dI_{Inva} / dt = (V_{Inva} - V_a) / L_{sh}$ ---------- (14)
$dI_{Invb} / dt = (V_{Invb} - V_b) / L_{sh}$ ---------- (15)
$dI_{Invc} / dt = (V_{Invc} - V_c) / L_{sh}$ ---------- (16)
$dI_{Invn} / dt = (V_{Invn} - V_n) / L_{sh}$ ---------- (17)
$dV_{dc}/dt = V_{Invad} - I_{Invbd} - I_{Invcd} - I_{Invnd} / C_{dc}$ ---------- (18)

Hence, to produce the desired sinusoidal output voltage, the steady state duty cycles are time varying sinusoidal. But, to apply classical control techniques we need a DC operating point.

$V_{Inva} = (P_1 - P_4)/2 * V_{dc}$ ---------- (19)
$V_{Invb} = (P_3 - P_6)/2 * V_{dc}$ ---------- (20)
$V_{Invc} = (P_5 - P_2)/2 * V_{dc}$ ---------- (21)
$V_{Invn} = (P_7 - P_8)/2 * V_{dc}$ ---------- (22)

Similarly the charging currents I_{Invad}, I_{Invbd}, I_{Invcd} and I_{Invnd} on dc bus to the each leg of inverter can be expressed as

$I_{Invad} = I_{Inva}\,(P_1 - P_4)$ ---------- (23)
$I_{Invbd} = I_{Invb}\,(P_3 - P_6)$ ---------- (24)
$I_{Invcd} = I_{Invc}\,(P_5 - P_2)$ ---------- (25)
$I_{Invnd} = I_{Invn}\,(P_7 - P_8)$ ---------- (26)

The switching pattern of each IGBT inside inverter can be formulated on the basis of error between actual and reference current of inverter, which can be explained as:

If $I_{Inva} < (I_{Inva}^* - h_b)$ then upper switch S_1 will be OFF (P_1=0) and lower switch S_4 will be ON (P_4=1) in the phase "a" leg of inverter.

If $I_{Inva} > (I_{Inva}^* - h_b)$, then upper switch S_1 will be ON (P_1=1) and lower switch S_4 will be OFF (P_4=0) in the phase "a" leg of inverter.

Where h_b is the width of the hysteresis band.

4. Simulation Result

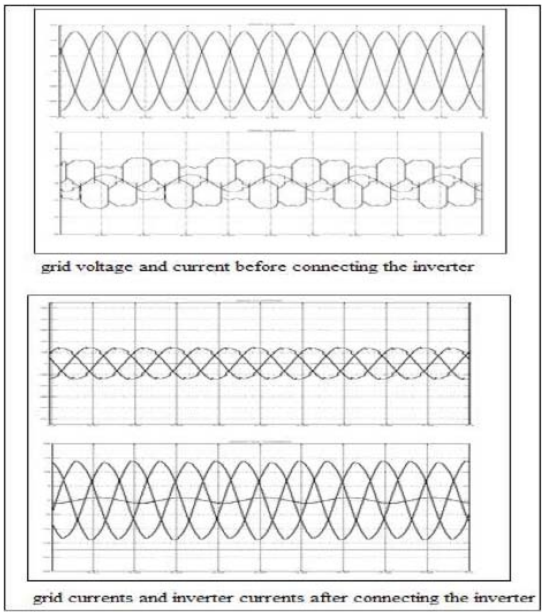

Figure 3: Simulation Results

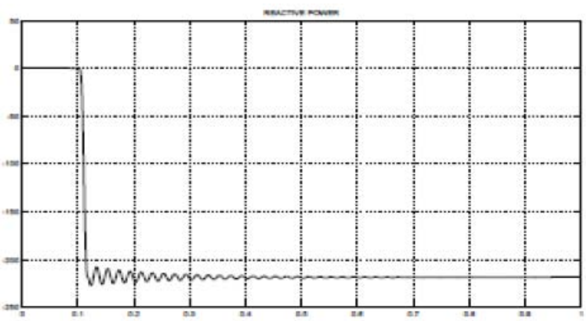

Figure 4: Reactive power of the inverter when PRES=0

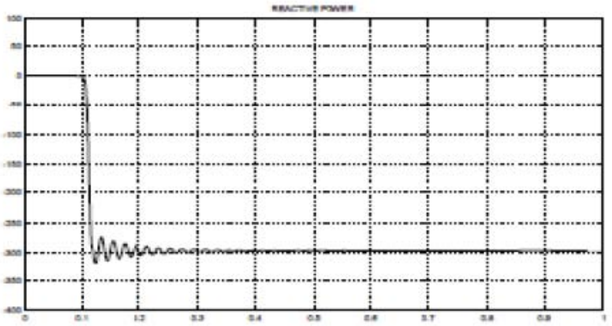

Figure 5: Reactive power of the inverter when PRES<PL

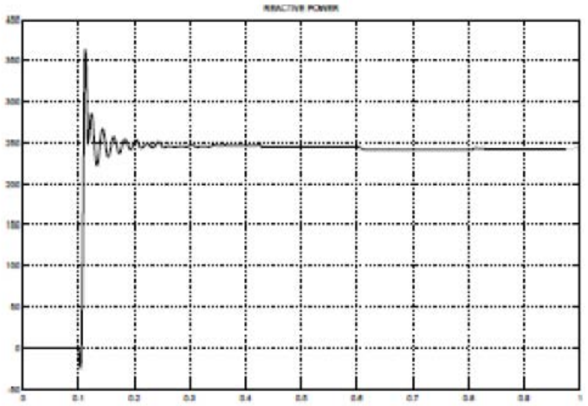

Figure 6: Reactive power of the inverter when PRES>PL

In order to verify the proposed controlling approach an extensive MATLAB simulation is carried out incase of three phase four wire system .A photovoltaic system with variable output power is connected on the DC link of grid interfacing inverter .An unbalanced three phase four wire nonlinear load, whose unbalance, harmonic and reactive power need to be compensated is connected on PCC .The waveform of grid voltage and current with and without four leg inverter is shown in the figure3. Figure 4, 5, 6 shows reactive power of inverter when PRES=0, PRES<PL and PRES>PL respectively. A positive value implies that the power is supplied to the grid and the negative implies that the inverter is absorbing power from the grid.

5. Conclusions

It has been shown in the paper that the grid interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The grid interfacing inverter with the proposed approach can be utilized to inject real power generated from photovoltaic source to the grid and operate as a shunt active power filter (APF).This approach hence eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. The extensive MATLAB/Simulink simulation as well as the DSP based experimental results have validated proposed approach and have shown that the grid interfacing inverter can be utilized as a multifunction device.

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Author Profile

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