ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

Grid Interconnection of Renewable Energy Sources at the Distribution Level with Power Quality Improvement Features

T.Thillainayaki[1], P.Shanthi[2]

PG Scholar[PED], Dept. of EEE, College of Engineering, Guindy, Chennai, Tamilnadu, India [1]

Research Scholar, Dept. of EEE, College of Engineering, Guindy, Chennai, Tamilnadu, India [2]

ABSTRACT: Renewable energy sources are used in distribution systems using power electronic converters. The high penetration level of renewable energy sources produces power quality issues such as current unbalance, current harmonics etc. This paper provides control strategy for grid interfacing inverters when installed in three phase four wire distribution system. The inverter serves multiple functions, it acts as power converter and also as a shunt active power filter to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. For this purpose, this paper analyses current controlled four leg voltage source inverter made of insulated-gate bipolar transistor connected to a combination of three phase non linear and single phase linear and non-linear load. The hysteresis controller is used to produce switching pulses. The reference current generation is based on PQ theory. This control strategy allows the combination of grid interfacing inverter and the three phase four wire linear or nonlinear unbalanced load at point of common coupling appears as balanced linear load to the grid. The four leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal currents at unity power factor (UPF) even the unbalanced nonlinear load is connected to it. This enables the grid to supply or receive sinusoidal and balanced power at UPF. The grid interfacing inverter has been analyzed under three conditions. i. When RES power is zero, it acts as shunt active power filter. ii. When RES power is less than load power demand, it acts as rectifier. iii. When RES power is greater than load power demand, it injects power to the grid and acts as an inverter. This control concept has been simulated using MATLAB/Simulink.

KEYWORDS: Power Quality, Shunt Active Power Filter, Power injection, Grid Interfacing Inverter.

I.INTRODUCTION

Demand for electricity has been considerably increasing in this decade. Renewable energy sources (RES) helps to meet this demand. Even though it serves as an alternative source for fossil fuels, its intermittent nature produces power quality (PQ) problems. These problems can be controlled using the power electronic devices and control strategy. But the extensive use of nonlinear loads produce harmonics and affects power quality. The existence of current harmonics in power systems increases losses in the lines, decreases the power factor and can cause timing errors in sensitive electronic equipment.

The harmonic currents produced by single phase nonlinear loads which are connected between phase and neutral in a three phase four wire system are third order zero sequence harmonics. These triplen harmonics do not cancel but add up arithmetically at the neutral bus. This results in neutral current which will be 1.73 times of phase current. Active power filters can be used to compensate load current harmonics and inverter rating can be utilized to the

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

maximum extent [1]. In control strategy the unity grid voltage vector templates generated using Phase Locked Loop which results in additional hardware cost. Current controlled voltage source inverters can be used to interface renewable energy sources to the grid. In [2] a control strategy was proposed in which inverter serves as an inductor to absorb harmonic current. But it is difficult to calculate the inductance in real time. A similar approach is proposed in [3] where active filter acts as active conductance to damp out harmonics. In [4], pq theory based control strategy was proposed in which both load and inverter current sensing is needed to compensate current harmonics. This paper demonstrates how the grid interfacing inverter serves as an active power filter and injects power under variable renewable energy conditions.

II.SYSTEM DESCRIPTION

The system consists of grid interfacing inverter with the RES and a set of three phase and single phase linear and nonlinear loads. The grid interfacing voltage source inverter delivers the generated power and the RES considered here is a dc source. A shunt active power filter is designed to be connected in parallel with the set of loads to detect the harmonic current. The Active Power Filter (APF) consists of four leg voltage source inverter. The three legs are used to compensate phase currents and one leg is specially designed to compensate the neutral current. The four leg inverter has the advantage of less DC link capacitance and full utilization of DC link voltage. The four leg inverter has eight IGBT switches and switching pulses are provided by using hysteresis controller. The basis block diagram is shown in Fig 1.

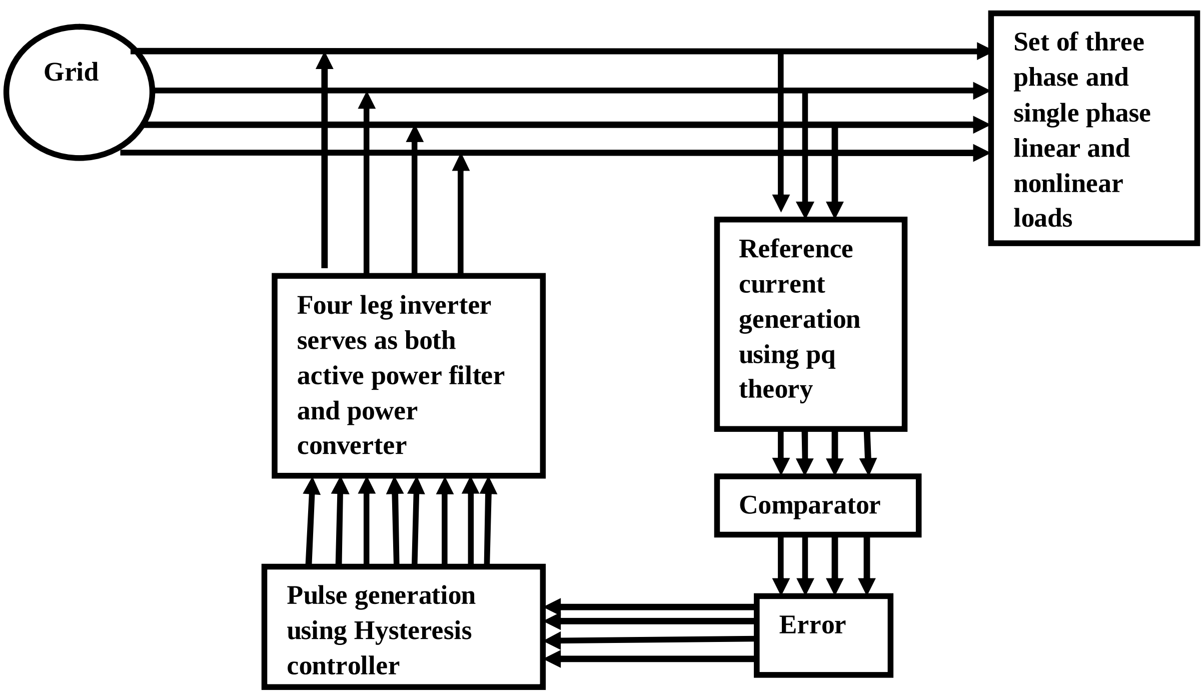


Fig 1 Basic Block diagram

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

III.CONTROL STRATEGY

The control strategy of grid interfacing inverter is based on the p-q theory. The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the *a-b-c* coordinates to the α-β-*0* coordinates, followed by the calculation of the p-q theory instantaneous power components.

By Clarke transformation,
$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \quad (2)$$

where v_{sa}, v_{sb}, v_{sc} are source voltages,
i_{la}, i_{lb}, i_{lc} are load currents.
The instantaneous real power(p), imaginary power(q) and zero sequence power(p_o) are given by,

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

To calculate the reference compensation currents in the α-β coordinates,

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \begin{bmatrix} \frac{1}{v_\alpha^2 + v_\beta^2} \end{bmatrix} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \Delta\bar{p} \\ 0 \end{bmatrix} \quad (4)$$

Since the zero-sequence current must be compensated, the reference compensation current in the *0* coordinate is i_0 itself:

$$i_{c0}^* = i_0 \quad (5)$$

In order to obtain the reference compensation currents in the *a-b-c* coordinates the inverse of the transformation is applied:

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \qquad (6)$$

To cover the VSI losses and to provide energy balance inside the active filter, the additional average real power is given by,

$$\Delta\overline{p} = \overline{p_0} + \overline{p_{loss}} \qquad (7)$$

The reference filter currents are computed as,

$$i_{fa}^* = i_{la} - i_{ca}^* \qquad (8)$$

$$i_{fb}^* = i_{lb} - i_{cb}^* \qquad (9)$$

$$i_{fc}^* = i_{lc} - i_{cc}^* \qquad (10)$$

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

These four reference currents are compared with the active filter's output current. The error is used to trigger the bridge arms through hysteresis controller.The quality of the current waveform generated by a current controlled, voltage source shunt active power filter depends basically on three factors:

(i) The reference signal being generated
(ii) the modulation method used and
(iii) the switching frequency of the PWM modulator.

The hysteresis band is used to control the supply current and determine the switching signals for inverters gates. When the supply current exceeds the upper band, the comparators generate control signals in such a way to decrease the supply current and keep it between the bands. The shunt APF is a device that is connected parallel to compensate the reactive power and to eliminate harmonics from non-linear loads. It is a three-phase inverter, where the capacitor is the main energy storage element and the inductors are used for the control of the filter currents by means of the converter voltages. A PI controller is used also to regulate the DC bus voltage to its reference value and compensates for the inverter losses. The PWM gating pulses for the IGBTs in VSI of APF are generated by indirect current control using hysteresis current controller over reference filter currents (i_{fa}*, i_{fb}*, i_{fc}*, i_{fn}*) and sensed filter currents (i_{fa}, i_{fb}, i_{fc}, i_{fn}). The generated pulses are used to trigger the four leg shunt active power filter.

IV. SIMULATION RESULTS

The proposed system has been verified in two ways, before compensation and after compensation. Before compensation, the grid is connected to a set of three phase nonlinear and single phase linear and nonlinear loads and

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

the grid interfacing inverter is not connected to the network. During this instant, the grid currents and the load currents are equal. The single phase nonlinear load connected to the grid produces neutral current. This neutral current will be 1.732 times the phase current. This is shown in Fig 2(a).

In order to compensate neutral current and to reduce current harmonics, the grid interfacing inverter is now connected to the network. This four leg inverter compensates the neutral current and is shown in Fig 2(b). The grid voltage is maintained constant before and after compensation and is shown in Fig 2(c). The THDs in each phase grid currents before compensation are 14.46%, 6.38% & 11.42% respectively, as shown in Fig 2(d) The THDs of grid currents in each phase has been reduced to 6.27%, 6.17% & 5.97% respectively, as shown in 2(e).

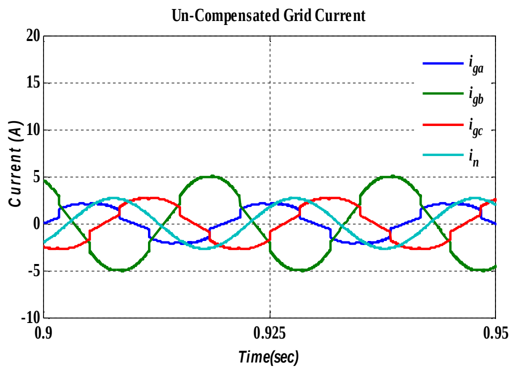


Fig 2(a) Uncompensated Grid current

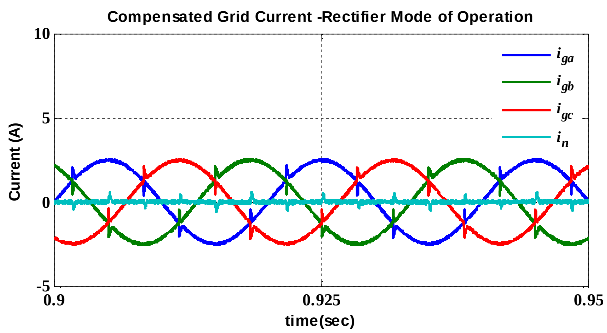


Fig 2(b) Compensated Grid Current

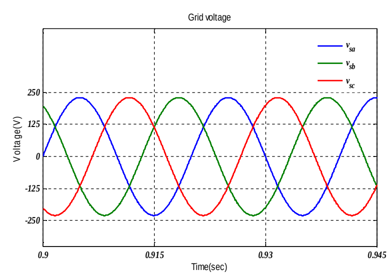


Fig 2(c) Grid voltage

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

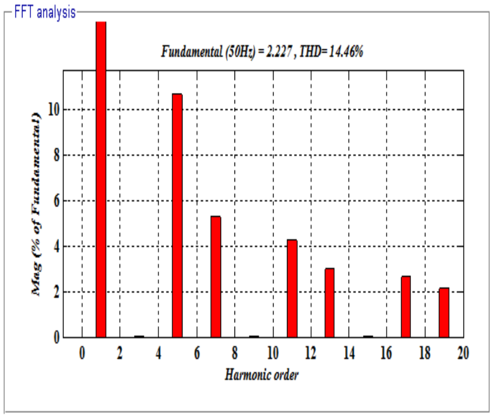


Fig 2(d)(i)THD before compensation – Phase 'a'

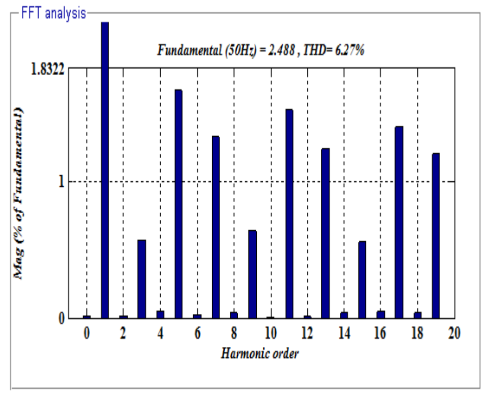


Fig 2(e)(i)THD after compensation – Phase 'a'

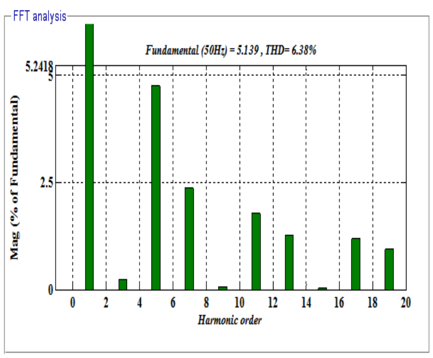


Fig 2(d)(ii)THD before compensation – Phase 'b'

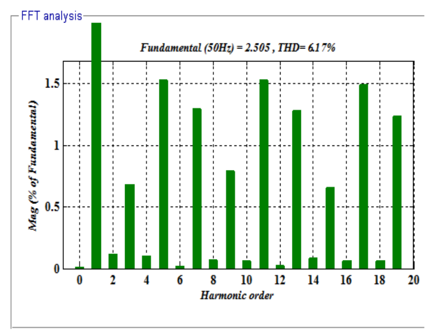


Fig 2(e)(ii)THD after compensation – Phase 'b'

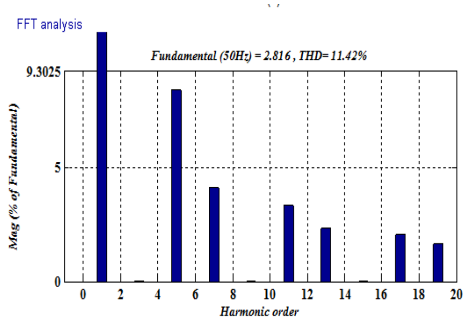


Fig 2(d)(iii)THD before compensation – Phase 'c'

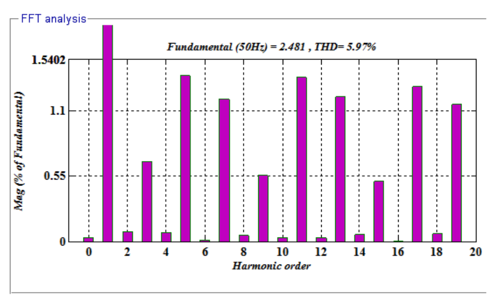


Fig 2(e)(iii)THD after compensation – Phase 'c'

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

After compensation, the grid interfacing inverter is verified under varying renewable energy conditions. (i).When the power from renewable energy source is zero, (ii).when the renewable energy source power is less than the load power and (iii). When the renewable energy source power is greater than the load power.

CONDITION 1 (P_{RES} = 0)

Under this condition, the grid interfacing inverter acts as an active power filter to compensate the neutral current, current harmonics and current unbalance. There is no power injection from RES. In this mode of operation, the inverter consumes a small amount of active power to maintain the dc link voltage and to overcome the losses associated with inverter, while most of the load reactive power need is supported by inverter effectively. The grid voltage is in phase with grid current at unity power factor (UPF) shows that the grid interfacing inverter is in rectifier operation. The UPF waveform is shown in Fig 3(a).

CONDITION 2 ($P_{RES} < P_L$)

Under this condition, the inverter starts injecting power to the grid. The power from the RES is reduced and hence source current is reduced. During this condition, the transition from rectifier mode of operation to inverter mode of operation takes place as shown in Fig 3(b).

CONDITION 3 ($P_{RES} > P_L$)

Under this condition, the generated power at grid interfacing inverter is more than the total load power demand. Therefore, after meeting the load power demand, the additional RES power flows towards grid. The grid current during inverting mode of operation is shown in Fig 3(c). The neutral current profile is also compensated. The grid interfacing inverter now provides the entire load power demand locally and feeds the additional active power to the grid. The exact out of phase relationship between phase-a grid voltage and phase-a grid current shown in Fig 3(d) suggests that this additional power is fed to the grid at UPF. The dc link capacitance voltage is kept constant for both modes of operation as shown in Fig 3(e).

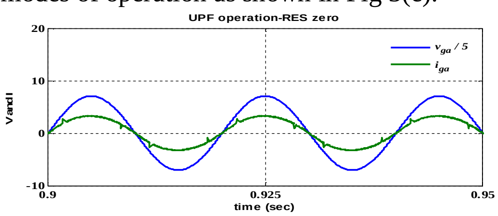


Fig 3(a) UPF Operation when P_{RES}=0

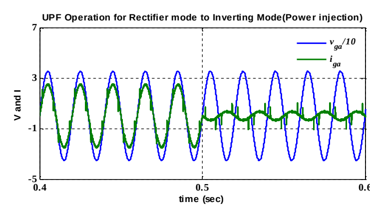
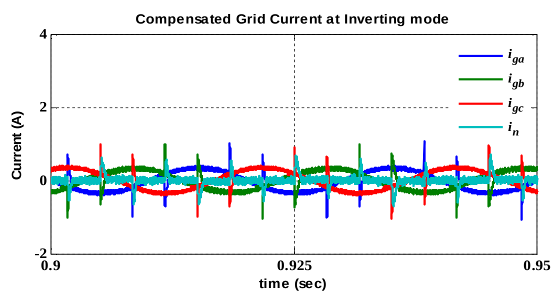


Fig 3(b) Transition from rectifier mode to Inverting mode when $P_{RES} < P_L$



ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

Fig 3(c) Grid current when $P_{RES} > P_L$

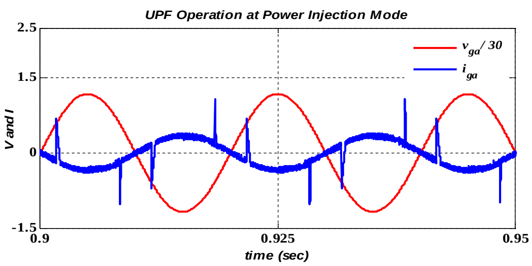


Fig 3(d) UPF operation when $P_{RES} > P_L$

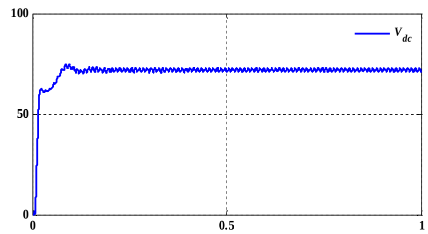


Fig 3(e) DC link capacitor voltage

TABLE I SYSTEM PARAMETER

Grid Voltage	230 V, 50 Hz
3 phase nonlinear load	R = 400 Ω, C = 1 μF
1 phase nonlinear load	R = 400 Ω, C = 1 μF
1 phase linear load	R = 400 Ω
DC link capacitance & Voltage	C_{dc} =2000 μF & V_{dc} = 390 V
Filter Inductance & Resistance	L = 10 mH, R = 1 Ω

V.CONCLUSION

In this paper, the control algorithm for three phase four wire four leg shunt active filter has been proposed to improve the performance of active power filter. The simulation has verified the effectiveness of the control scheme. The simulation results prove that the following objectives have been successfully achieved under unbalanced load conditions. 1).Neutral current Compensation 2).Harmonic reduction and 3).Power injection

Further, it has been proved that the PQ improvement can be achieved under three different conditions, 1) P_{RES}=0, 2) $P_{RES} < P_L$ and 3) $P_{RES} > P_L$. The current unbalance, current harmonics and load reactive power demand are compensated effectively such that the grid currents are always maintained as balanced and sinusoidal at unity power factor. When power generated from RES is more than the load power demand, the grid interfacing inverter delivers power to the grid at unity power factor.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 2, April 2014

REFERENCES

[1] Rajiv K. Varma, Ambrish Chandra, Vinod Khadkikar and Mukhtiar Singh, “Grid interconnection of Renewable Energy Sources at the Distribution level with Power-Quality improvement Features,” IEEE Trans., Power Delivery, vol. 26, No.1, January 2011.

[2] P. Jintakosonwit, H. Fujita, H. Akagi, and S. Ogasawara, “Implementation and performance of cooperative control of shunt active filters for harmonic damping throughout a power distribution system,” *IEEE Trans. Ind. Appl.*, vol. 39, no. 2, pp. 556–564, Mar./Apr. 2003.

[3] U. Borup, F. Blaabjerg, and P. N. Enjeti, “Sharing of nonlinear load in parallel-connected three-phase converters,” *IEEE Trans. Ind. Appl.*, vol. 37, no. 6, pp. 1817–1823, Nov./Dec. 2001.

[4] J. P. Pinto, R. Pregitzer, L. F. C. Monteiro, and J. L. Afonso, “3-phase 4-wire shunt active power filter with renewable energy interface,” presentedat the Conf. IEEE Rnewable Energy & Power Quality, Seville, Spain, 2007.

[5] F. Blaabjerg, R. Teodorescu, M. Liserre, and A. V. Timbus, “Overview of control and grid synchronization for distributed power generation systems,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp. 1398–1409,Oct. 2006.

[6] J. M. Carrasco, L. G. Franquelo, J. T. Bialasiewicz, E. Galván, R. C. P. Guisado, M. Á. M. Prats, J. I. León,and N.M. Alfonso, Power electronic systems for the grid integration of renewable energy sources:A survey,” *IEEE Trans. Ind. Electron.*, vol. 53, no. 4, pp. 1002–1016,Aug. 2006.

[7] B. Renders, K. De Gusseme, W. R. Ryckaert, K. Stockman, L. Vandevelde, and M. H. J. Bollen, “Distributed generation for mitigating voltage dips in low-voltage distribution grids,” *IEEE Trans. Power.Del.*, vol. 23, no. 3, pp. 1581–1588, Jul. 2008.