ANALYSING AND IMPROVING POWER QUALITY IN POWER SYSTEM USING CONTROLLING TECHNIQUES

S.Hariharan[1],D.Nirmal Raj[2],V.Porselvan[3],G.Ranjith Kumar[4],M.Raja Vidya Bharathi[5]

[1234] UG Scholar,Electrical And Electronics Department,DMI College of Engineering,Chennai,Tamilnadu.

[5]Assistant Professor, Electrical And Electronics Department, DMI College of Engineering, Chennai, Tamilnadu.

Abstract— Power supply and power quality has been critical issues in power system recently. One of the main power quality concerns is the existence of harmonics. In order to mitigate current harmonics, voltage harmonics and compensate the reactive power, STATCOM devices are widely used in power distribution grids. In our project, the STATCOM device is controlled by three techniques as Sine PWM, Power Balance Theory and PQ-Theory. Finally, PQ-Theory is our proposed work which is comparing the reduction of harmonic level with other two techniques by waveform and THD level using MATLAB.

Keywords—Shunt Active Power Filters, p-q theory, sine pulse width modulation , power balance theory ,Harmonic Distortion, pulse width modulation controller.

INTRODUCTION

Ideally an electricity supply should fixedly show a perfectly sinusoidal voltage signal at every customer location. However, for a number of reasons, utilities often find it difficult to maintain such desirable condition. For example the widespread use of nonlinear devices likes (microprocessor, variable speed drives, uninterrupted power supplies and electronic lighting) which have become used on a large scale. These modern power electronic devices draw a significant amount of harmonics from the electrical grid; these non-sinusoidal currents interact with the impedance of the power distribution lines creating voltage distortion at the point of common coupling (PCC) that can affect both the distribution system equipment and the user loads connected to it.

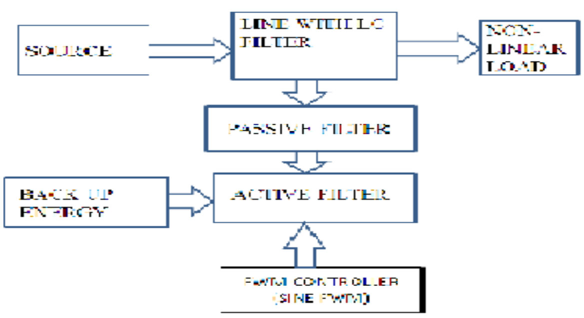
As a result, the utilities obliged to reduce the total harmonic distortion (THD) at the point of common coupling below 5% as given in the IEEE 519-1992 harmonic standard. This can be achieved through the use of the harmonic filters whether passive or active filters. The passive filtering is the simplest classical solution to mitigate the harmonic distortion, these filters consisting of R, L and C elements connected in various configurations. Although simple, these filters have many defects such as fixed compensation, bulky size and resonance so these filters may not be able to achieve the desired performance thus we need to use dynamic and adjustable devices to mitigate the power quality problems such as active power filters.

Active power filters are considered the most ideal solutions to the many of power quality problems such as harmonics, reactive power, regulate terminal voltage, flicker and improve voltage balance in three phase systems. Shunt active power filter is the most important configuration and widely used in active power line conditioners applications. It automatically adapts to changes in the grid and load fluctuations, can compensate for several harmonic orders and eliminating the risk of resonance between the filter and the grid impedance.

Existing control techniques-sine PWM & power balance theory

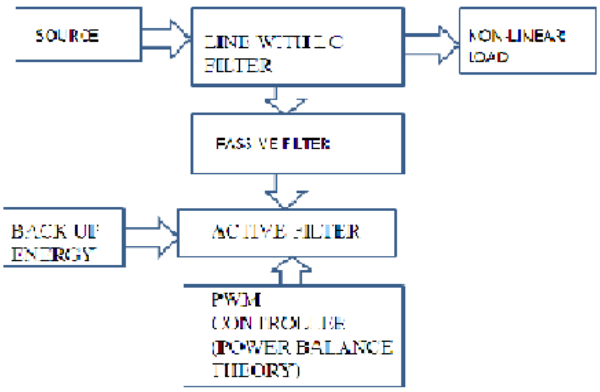
It is based on the control technique that the existing control technique is sine pulse width modulation and power balance theory. The system has to be improved in power compensation and the system undergoing this technique does not have stable voltage.it needs an separate energy storage elements in the circuit.

SINE PWM



In this design the Sinusoidal Pulse Width Modulation (SPWM) technique has been used for controlling the inverter as it can be directly controlled the inverter output voltage and output frequency according to the sine functions . Sinusoidal pulse width modulation (SPWM) is widely used in power electronics to digitize the power so that a sequence of voltage pulses can be generated by the on and off of the power switches. The PWM inverter has been the main choice in power electronic for decades, because of its circuit simplicity and rugged control scheme. Sinusoidal Pulse Width Modulation switching technique is commonly used in industrial applications or solar electric vehicle applications .
SPWM techniques are characterized by constant amplitude pulses with different duty cycles for each period. The width of these pulses are modulated to obtain inverter output voltage control and to reduce its harmonic content. Sinusoidal pulse width modulation is the mostly used method in motor control and inverter application. In SPWM technique three sine waves and a high frequency triangular carrier wave are used to generate PWM signal. Generally, three sinusoidal waves are used for three phase inverter. The sinusoidal waves are called reference signal and they have 1200 phase difference with each other. The frequency of these sinusoidal waves is chosen based on the required inverter output frequency (50/60 Hz). The carrier triangular wave is usually a high frequency (in several KHz) wave. The switching signal is generated by comparing the sinusoidal waves with the triangular wave. The comparator gives out a pulse when sine voltage is greater than the triangular voltage and this pulse is used to trigger the respective inverter switches.

POWER BALANCE THEORY



Power Balance Theory. For extracting reference source currents, PCC voltages (*va,, vb* and *vc*), source currents (*isa, isb* and *isc*), load currents (*iLa*, *iLb* and *iLc*) and DC bus voltage(Vdc) of the STATCOM are sensed in this algorithm. This instantaneous load power has two components. First one is a DC component and second one is an AC component. The DC component of the load power can be filtered by a set of either a low pass filter (cut off frequency 20Hz) or a moving average filter (averaging time 1/2*f* where *f* source frequency). For Power Factor Correction (PFC) mode, only DC component of the load active power must be supplied by the source. For Zero Voltage Regulation (ZVR) mode, some additional reactive power in addition of AC and DC components of reactive component of the load is supplied by the STATCOM to compensate the drop in source impedance. The active power component of the source currents has two parts. First one is *I * smp*, which is required DC component of the load active power and second one is *I* smd* which is required for the self supporting DC bus of STATCOM. Moreover, there active component of the source current has also two parts. First one is *I* snq*, which is required DC component of the load reactive power and second one is *I* sna* which is required for maintaining the amplitude of the PCC voltage.

Proposed control technique-PQ theory

It is based on instantaneous values in three-phase power systems with or without neutral wire, and is valid for steady state or transitory operations, as well as for generic voltage and current waveforms. 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:

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \qquad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

$p_0 = v_0 \cdot i_0$ instantaneous zero-sequence power (2)

$p = v_\alpha \cdot i_\alpha + v_\beta \cdot i_\beta$ instantaneous real power (3)

$q = v_\alpha \cdot i_\beta - v_\beta \cdot i_\alpha$ instantaneous imaginary power (by definition) (4)

The power components *p* and *q* are related to the same *α-β* voltages and currents, and can be written together:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

These quantities are illustrated in Fig 3 for an electrical system represented in *a-b-c* coordinates and have the following physical meaning: $p0$ = mean value of the instantaneous zero-sequence power – corresponds to the energy per time unity which is transferred from the power supply to the load through the zero-sequence components of voltage and current. p_0 ~ = alternated value of the instantaneous zero-sequence power – it means the energy per time unity that is exchanged between the power supply and the load through the zero-sequence components. The zero-sequence power only exists in three-phase systems with neutral wire. Furthermore, the systems must have unbalanced voltages and currents and/or 3^{rd} harmonics in both voltage and current of at least one phase.

p = mean value of the instantaneous real power – corresponds to the energy per time unity which is transferred from the power supply to the load, through the *a-b-c* coordinates, in a balanced way (it is the desired power component). p~ = alternated value of the instantaneous real power – It is the energy per time unity that is exchanged between the power supply and the load, through the *a-b-c* coordinates. q = instantaneous imaginary power – corresponds to the power that is exchanged between the phases of the load. This component does not imply any transference or exchange of energy between the power supply and the load, but is responsible for the existence of undesirable currents, which circulate between the system phases. In the case of a balanced sinusoidal voltage supply and a balanced load, with or without harmonics, q (the mean value of the instantaneous imaginary power) is equal to the conventional reactive power ($q = 3.V .I1 . sin\varphi 1$).

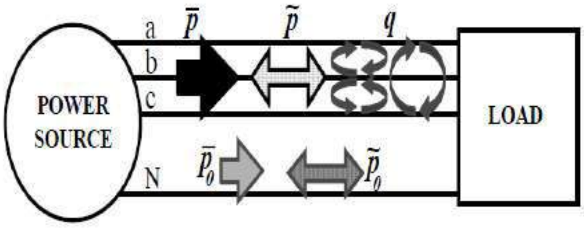


Fig. 3 – Power components of the p-q theory in *a-b-c* coordinates.

The p-q theory applied to shunt active filters

The p-q theory is one of several methods that can be used in the control active filters It presents some
interesting features, namely:

- It is inherently a three-phase system theory;
- It can be applied to any three-phase system (balanced or unbalanced, with orwithout harmonics in both voltages and currents);
- It is based in instantaneous values, allowing excellent dynamic response;
- Its calculations are relatively simple (it only includes algebraic expressions that can be implemented using standard processors);
- It allows two control strategies: constant instantaneous supply power and sinusoidal supply current. As seen before, p is usually the only desirable p-q theory power component. The other quantities can be compensated using a shunt active filter (Fig. 4). As shown by *Watanabe et al*. p_0 can be compensated without the need of any power supply in the shunt active filter. This quantity is delivered from the power supply to the load, through the active filter (see Fig. 4). This means that the energy previously transferred from the source to the load through the zero-sequence components of voltage and current, is now delivered in a balanced way from the source phases. It is also possible to conclude from Fig. 4 that the active filter capacitor is only necessary to compensate p~ and p_0 ~ , since these quantities must be stored in this component at one moment to be later delivered to the load. The instantaneous imaginary power (q), which includes the conventional reactive power, is compensated without the contribution of the capacitor. This means that, the size of the capacitor does not depend on the amount of reactive power to be compensated.

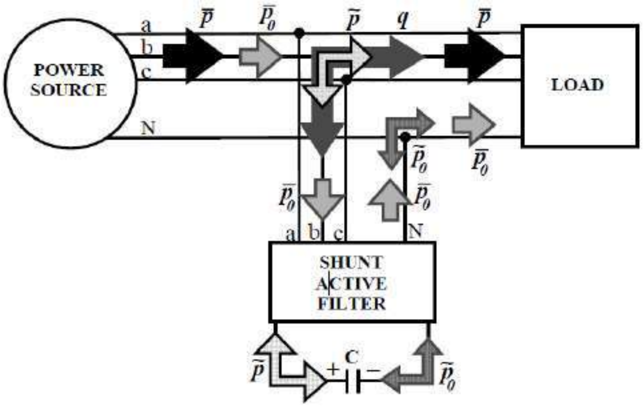


Fig. 4 - Compensation of power components p~ , q, 0 p ~ and p_0 in *a-b-c* coordinates.

To calculate the reference compensation currents in the α-β coordinates, the expression (5) is inverted, and the powers to be compensated (0 p p ~ − and q) are used:

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \cdot \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} - \bar{p}_0 \\ q \end{bmatrix} \quad (6)$$

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

$$i_{c0}^* = i_0$$

In order to obtain the reference compensation currents in the *a-b-c* coordinates the inverse of the transformation given in expression (1) is applied:

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \cdot \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (7)$$

$$i_{cn}^* = -\left(i_{ca}^* + i_{cb}^* + i_{cc}^*\right)$$

The calculations presented so far are synthesized in Fig. 6 and correspond to a shunt active filter control strategy for constant instantaneous supply power. This approach, when applied to a three-phase system with balanced sinusoidal voltages, produces following results:

- the phase supply currents become sinusoidal, balanced, and in phase with the voltages. (in other words, the power supply "sees" the load as a purely resistive symmetrical load);
- the neutral current is made equal to zero (even 3rd order current harmonics are compensated);
- the total instantaneous power supplied,

$$p3s(t) = va \cdot isa + vb \cdot isb + vc \cdot isc \quad (8)$$

is made constant.

In the case of a non-sinusoidal or unbalanced supply voltage, the only difference is that the supply current will include harmonics , but in practical cases the distortion is negligible.

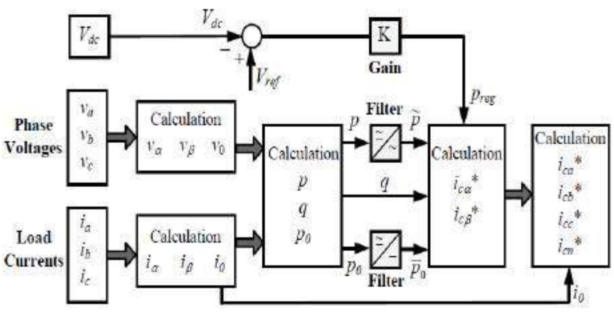


Fig. 5 – Calculations for the constant instantaneous supply power control strategy.

The sinusoidal supply current control strategy must be used when the voltages are distorted or unbalanced and sinusoidal currents are desired. The block diagram of Fig.6 presents the calculations required in this case. When this approach is used the results, illustrated.

- the phase supply currents become sinusoidal, balanced, and in phase with the fundamental voltages;
- the neutral current is made equal to zero (even 3rd order current harmonics are compensated);
- the total instantaneous power supplied ($p3S$) is not made constant, but it presents only a small ripple (much smaller than before compensation).

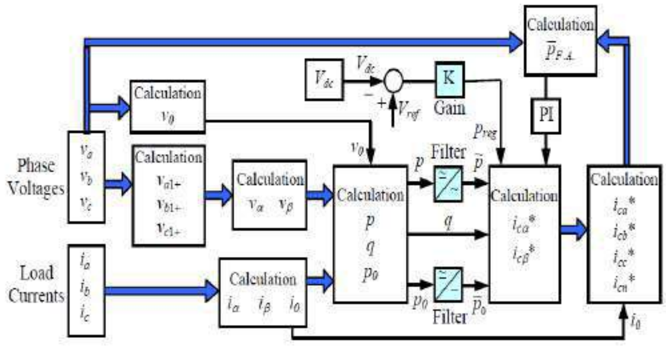
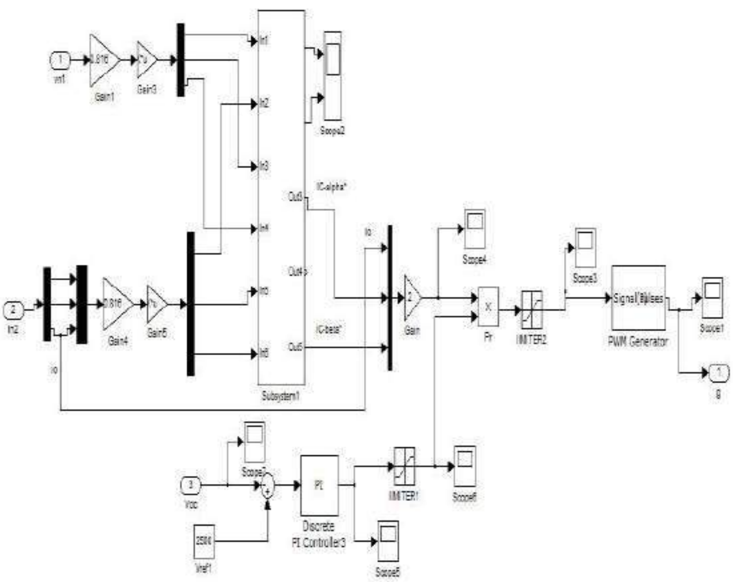


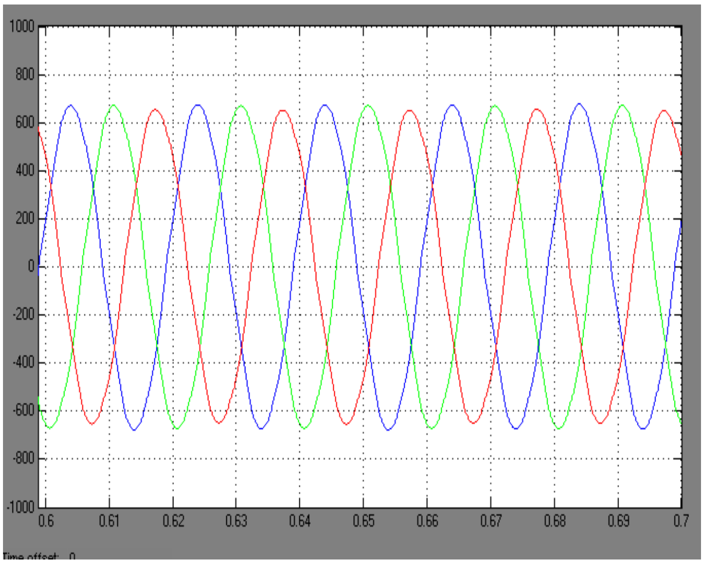
Fig. 6 – Calculations for the sinusoidal supply current control strategy.

The practical implementation of the shunt active filter demands the regulation of the voltage at the inverter DC side (*Vdc* - the capacitor voltage) as suggested in Fig. 5 and Fig. 6, where *Vref* is the reference value required for proper operation of the active filter inverter.

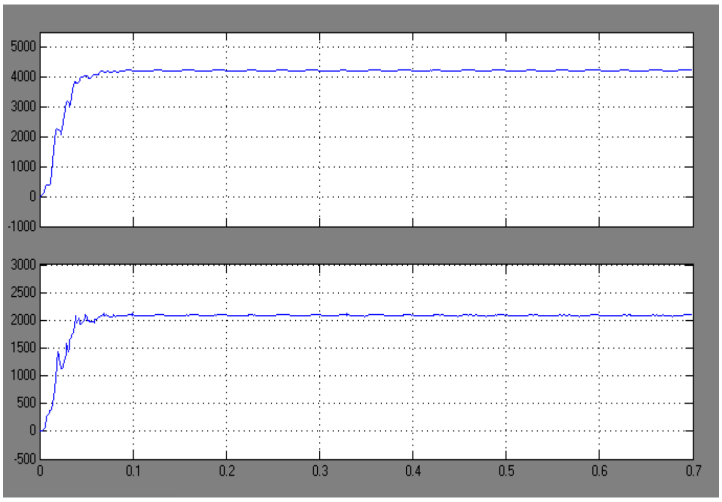
Simulation Results:



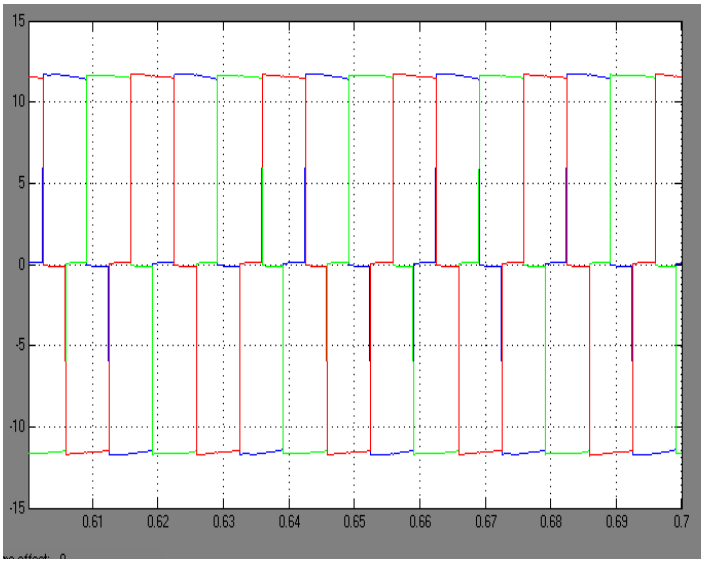
PQ theory controller section



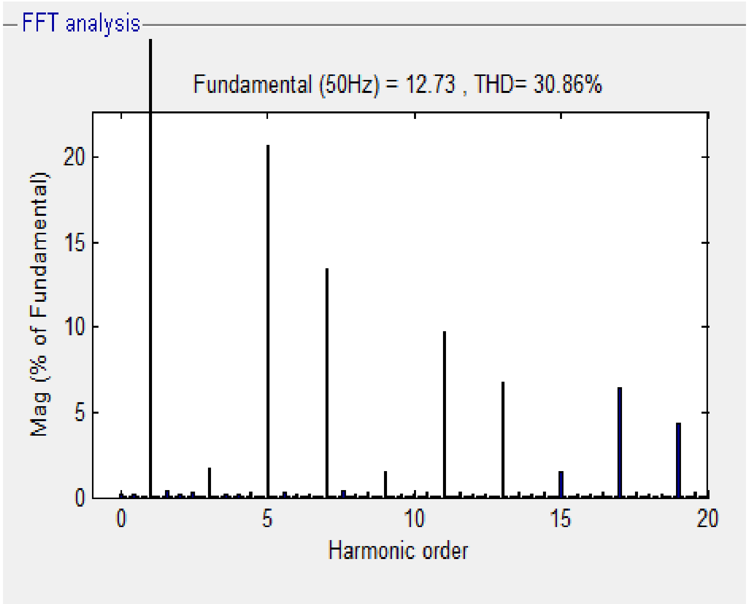
Source voltage



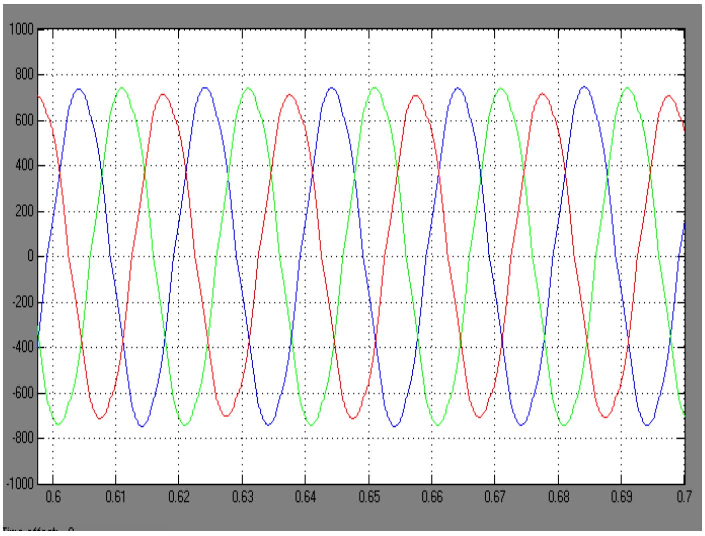
Real and Reactive power



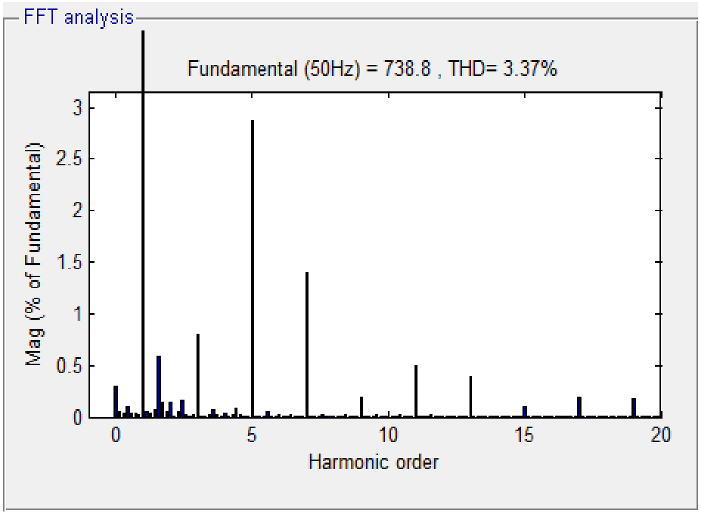
Load current



Non linear Load current harmonic



Load voltage



Non linear load voltage harmonic

Parameters	Line model	SPWM	Power balance theory	PQ theory
Current harmonics (%)	33.12	22.74	18.42	11.53
Voltage harmonics (%)	16.82	3.53	3.12	2.84
Real power (W)	1577	3480	4000	4200
Reactive power (VAR)	1412	1615	2050	2080

Conclusion

Shunt active power filter is the most effective solution to mitigate the current harmonics and compensate the reactive power. In this paper a novel current control strategy based on fuzzy logic for shunt APF was introduced to improve the current controller technique that is the backbone of the shunt active power filter operation. The simulation results have verified the effectiveness of this new technique to fix the modulation frequency of the shunt active power filter compared to the conventional current controller where the modulation frequency changing over a wide range causing many of undesirable effects.

References

1. M. El-Habrouk, M. K. Darwish, and P. Mehta, ``Active power filters: A review,'' *Proc. IEE _ Elect. Power Appl.*, vol. 147, no. 5, pp. 403_413, Sep. 2000.

2. S. Kim, G. Yoo, and J. Song, ``A bi-functional utility connected photo-voltaic system with power factor correction and UPS facility,'' in *Proc. Conf. Rec. 25th IEEE Photovolt. Specialists Conf.*, May 1996, pp. 1363_1368

3. Y.W. Li and J. He, ``Distribution system harmonic compensation methods: An overview of DG-interfacing inverters,'' *IEEE Ind. Electron. Mag*, vol. 8, no. 4, pp. 18_31, Dec. 2014

4. M. G. Villalva, J. R. Gazoli, and E. R. Filho, ``Comprehensive approach to modeling and simulation of photovoltaic arrays,'' *IEEE Trans. Power Electron.*, vol. 24, no. 5, pp. 1198_1208, May 2009.

5. C. Wessels, F. Gebhardt, and F. W. Fuchs, "Fault ride-through of a DFIG wind turbine using a dynamic voltage restorer during symmetrical and asymmetrical grid faults," *IEEE Trans. Power Electr.*, vol. 26, no. 3, pp. 807–815, Mar. 2011.

6. T.-F. Wu, C.-L. Shen, C.-H. Chang, and J. Chiu, ``single phase grid-connection PV power inverter with partial active power filter,'' *IEEE Trans. Aerosp. Electron. Syst.*, vol. 39, no. 2, pp. 635_646, Apr. 2003.

7. Power Electronics, Muhammad H. Rashid.

8. Power Electronics, B.C. Sen.

9. www.ieee.org

10. www.mathwork.com