CHAPTER-V

COMBINED NEGATIVE SEQUENCE, ZERO SEQUENCE & HARMONICS SERIES COMPENSATOR

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5.1 INTRODUCTION TO CHAPTER

This chapter presents a novel and online method, which is also a novel contribution of this research work for detecting negative, zero sequence and harmonic compensation in voltages. It is based on instantaneous Active Reactive Power Theory. Using this concept, negative sequence, zero sequence & harmonics in voltage are computed online. The theory is verified through simulation results.

5.2 INTRODUCTION

In chapter-III series active filter was discussed and in chapter-IV negative & zero sequence compensator was discussed. In both the cases, to detect online & instantaneous voltage harmonic as well as negative sequence voltage harmonics Instantaneous Active Reactive Power Theory was used. After extracting the desired parameter (either voltage harmonic or negative sequence & zero sequence) voltage source inverter was controlled using above parameter so that desired compensation will be achieved. In simple word, the extracted parameter is used as reference along with PI control to control the voltage source inverter to achieve the desired compensation.

Extraction of parameter to be compensated can be done with different method as discussed in chapter-II i.e. IARP Theory, Synchronous Reference Frame Theory, and Sine Multiplication Theory. In chapter-III "Series Active Filter-Solution to Voltage Harmonics & Distortion and chapter-IV "Negative Sequence & Zero Sequence Compensator", Instantaneous Active & Reactive Power Theory is used for extraction of voltage harmonics and for extraction of negative sequence & zero sequence voltage.

In real application, both voltage harmonics and unbalance in voltage are present. The unbalance & harmonics voltage are present in the bus because of the unbalance and/or single phase, nonlinear having high content of harmonics load present in the same bus. This phenomenon is explained in detail in Chapter IV. In such cases these equipment may not compensate for both parameters. In such cases it is desirable to use a control scheme which can extract both the parameter online instantaneous and compensate for the same.

In this chapter, a novel control method with slight modification was introduced which can extract harmonics as well as negative & zero sequence parameter using instantaneous active reactive power theory. Hence extracted signal will be used as reference signals along with PI control to control the voltage source inverter. So that harmonics as well as negative & zero sequence voltages in the sensitive bus will be reduced

5.3 CONTROLLING OF NEGATIVE SEQUENCE COMPENSATOR

To control voltage source inverter and to generate voltages for compensating harmonics, negative & zero sequences a reference signal is required. This reference signal will control the Voltage Source Converter (VSC).

For extracting harmonics, negative sequence and zero sequence from the load bus voltage a novel technique using instantaneous active reactive power theory is used. When signal (reference and actual) are transformed into α-β-0 reference frame, the signals are converted into two phase equivalent. If both reference signal as well as actual signal in α-β-0 reference frame are put through cross & dot products the output leads to all information required to improve the power quality. By selecting proper filter, order of filter and its bandwidth desired signal can be extracted from actual signal. This signal will be used as reference signal to control VSC for desired output

5.4 GENERATION OF REFERENCE SIGNALS FOR COMBINED HARMONICS, NEGATIVE SEQUENCE & ZERO SEQUENCE VOLTAGE

To implement this theory, digitally generates reference unit rms amplitude three phase positive sequence voltages in synchronization with supply voltage v_a, v_b and v_c as follows.

$$v_{ar} = \sqrt{2}\,\sin(\omega t)$$

$$v_{br} = \sqrt{2}\,\sin\left(\omega t - {}^{2\pi}/_{3}\right)$$

$$v_{cr} = \sqrt{2}\,\sin\left(\omega t + {}^{2\pi}/_{3}\right) \qquad (4.4\text{-}1)$$

Convert these reference voltages to α-β-0 reference [J16]-[J19] frame through the transformation matrix as shown below.

$$\begin{bmatrix} v_{0r} \\ v_{\alpha r} \\ v_{\beta r} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{ar} \\ v_{br} \\ v_{cr} \end{bmatrix} \qquad (4.4\text{-}2)$$

Let v_a, v_b and v_c be the phase to neutral unbalanced & distorted three phase voltages of the input power supply. These voltages are sensed through voltage sensor and converted into α-β-0 component through the transformation matrix as below.

$$\begin{bmatrix} v_{0} \\ v_{\alpha} \\ v_{\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_{a} \\ v_{b} \\ v_{c} \end{bmatrix} \qquad (4.4\text{-}3)$$

Now the following calculation is performed using these α-β-0 components.

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_{0r} & 0 & 0 \\ 0 & v_{\alpha r} & v_{\beta r} \\ 0 & -v_{\beta r} & v_{\alpha r} \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \tag{4.4-4}$$

p_o is zero sequence power and p & q can have dc and ac components as function of time.

In the instantaneous p-q theory DC components in p & q are responsible for the fundamental positive sequence or negative sequence power & this depends upon the reference voltage signal. If reference voltage v_{ra}, v_{rb}, v_{rc} are the positive sequence then DC components in the power p & q reflects the positive sequence power otherwise if reference voltage v_{ra}, v_{rb}, v_{rc} are of negative sequence, then DC components in p & q reflects the fundamental negative sequence power.

In Equation (4.4-4), the DC components are due to positive sequence voltages in the bus.

Similarly p_{ac} and q_{ac} are responsible for other than active power components i.e. harmonics, reactive and unbalance in the systems

AC components are filtered out using high pass filter to get the p_{ac} and q_{ac}. The parameters defined for high pass filter are as follows:

Design method:	Elliptic
Filter type:	High pass
Filter Order:	2
Passband edge frequency :	6.14 rads/sec:
Passband ripple in dB:	0.1

Stopband ripple in dB: 60

From p_{ac} and q_{ac} compensating reference signal are computed [J15] using the following transformation.

$$\begin{bmatrix} v_{\alpha c} \\ v_{\beta c} \end{bmatrix} = \begin{bmatrix} v_{\alpha r} & v_{\beta r} \\ -v_{\beta r} & v_{\alpha r} \end{bmatrix}^{-1} \begin{bmatrix} -p_{ac} \\ -q_{ac} \end{bmatrix}$$

$$\begin{bmatrix} v_{\alpha c} \\ v_{\beta c} \end{bmatrix} = \frac{1}{(v_{\alpha r}{}^2 + v_{\beta r}{}^2)} \begin{bmatrix} v_{\alpha r} & -v_{\beta r} \\ v_{\beta r} & v_{\alpha r} \end{bmatrix} \begin{bmatrix} -p_{ac} \\ -q_{ac} \end{bmatrix} \tag{3.5.1-6}$$

$v_{\alpha c}$ and $v_{\beta c}$ are the α, β components of compensating voltage of the supply, which can be transformed back to three-reference voltages for PWM voltage source inverter.

$$\begin{bmatrix} v_{ac} \\ v_{bc} \\ v_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} -v_0 \\ v_{\alpha c} \\ v_{\beta c} \end{bmatrix} \tag{3.5.1-7}$$

Where v_o is the zero sequence voltage component of the three phase bus voltages.

In the above manner, the instantaneous values of compensating voltages (including harmonic, negative sequence & zero sequence components) of phase 'a' phase 'b' and phase 'c' are computed.

When once these three reference signals are obtained they are fed to the voltage source inverter as reference signals to generate corresponding voltages at the output of voltage source inverter which will completely eliminate the harmonics, negative sequence and zero sequence component voltages in the mains supply and will not affect its positive sequence component voltages

Further there will be no additional braking torque on the rotor due to the positive sequence currents flowing through negative sequence compensator, as was the case with the other compensator. So, the mechanical output will not be reduced. The active energy input to harmonics, negative & zero sequence compensator is reduced Only very little amount of power loss takes place in the inverter and transformer. Further more positive sequence voltage applied to the motor can be improved to its rated voltage by adding a portion of the fundamental positive sequence mains voltage to the reference signals of the harmonics, negative & zero sequence compensator schemes.

5.5 SIMULATION

The simulation studies are carried out to predict the performance of the proposed new theory using MATLAB-SIMULINK-POWER SYSTEM BLOCK. For simulation of voltage harmonics and negative & zero sequences compensator a voltage source inverter whose output is changed through sinusoidal pulse width modulated (PWM) voltage source inverter. PWM method utilizes a reference signal (one for each phase), which is compared with a high frequency triangular wave, and the points of intersection of both these signals decide the time of switching on and off the devices connected to that particular phase. Block diagram for simulation is shown in Figure 4.5-1 to Figure 4.5-4.

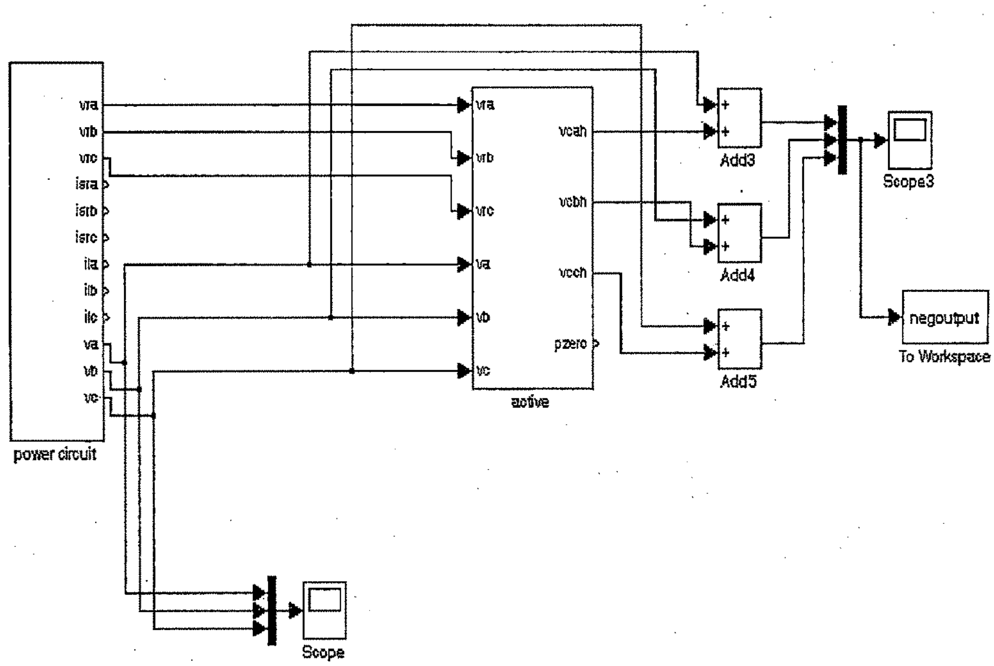

Figure 4.5-1-A: Block Diagram for Simulation

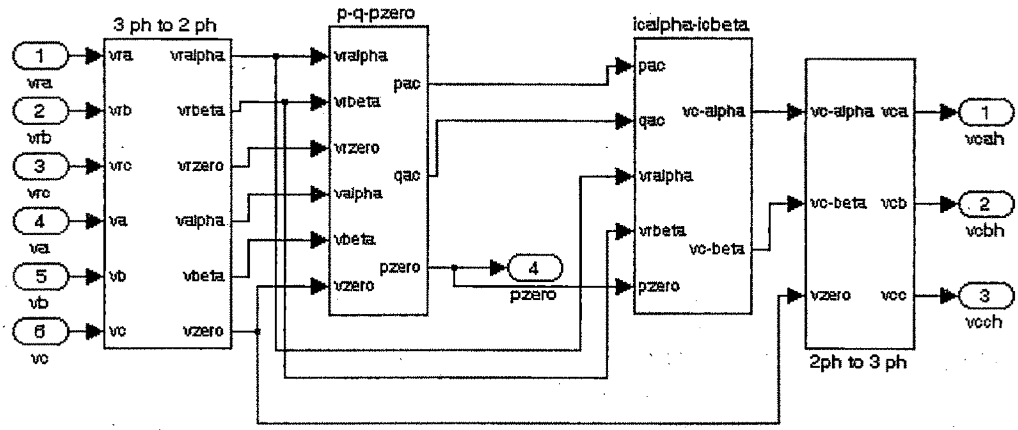

Figure 4.5-1-B: Control Block Diagram for Simulation

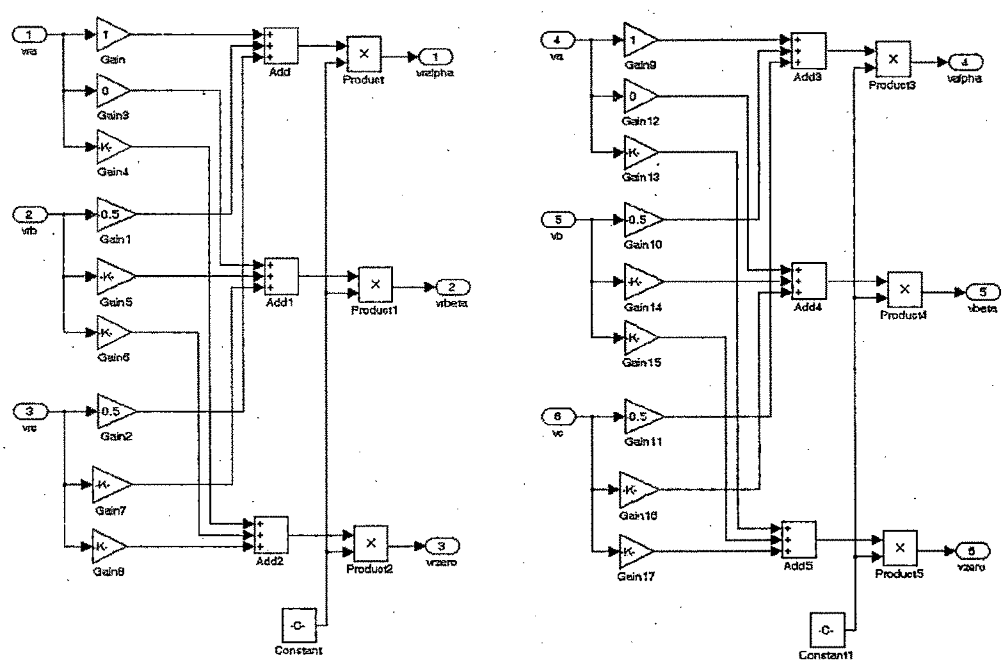

Figure 4.5-2: a-b-c to α-β-0 frame

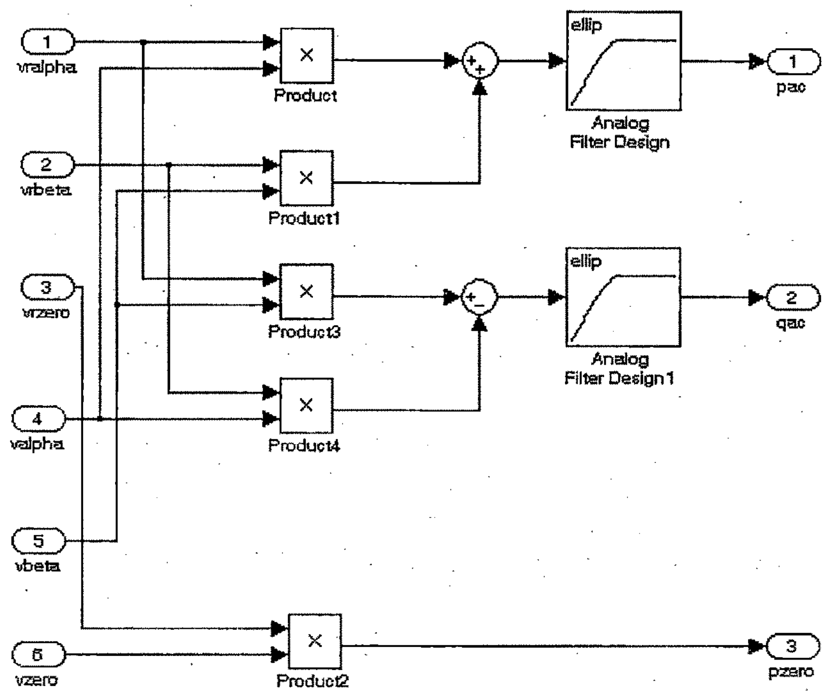

Figure 4.5-3: Cross Product & Dot Product For p_{ac} & q_{ac} of The Signal In α-β-0 Frame

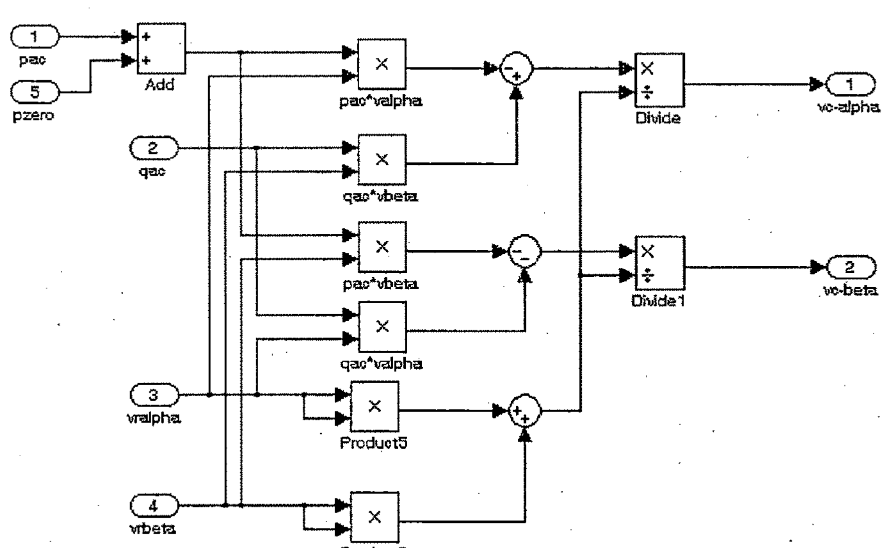

Figure 4.5-4: Compensating Reference Voltage Signal $V_{\alpha C}$ & $V_{\beta C}$ In α-β-0 Frame

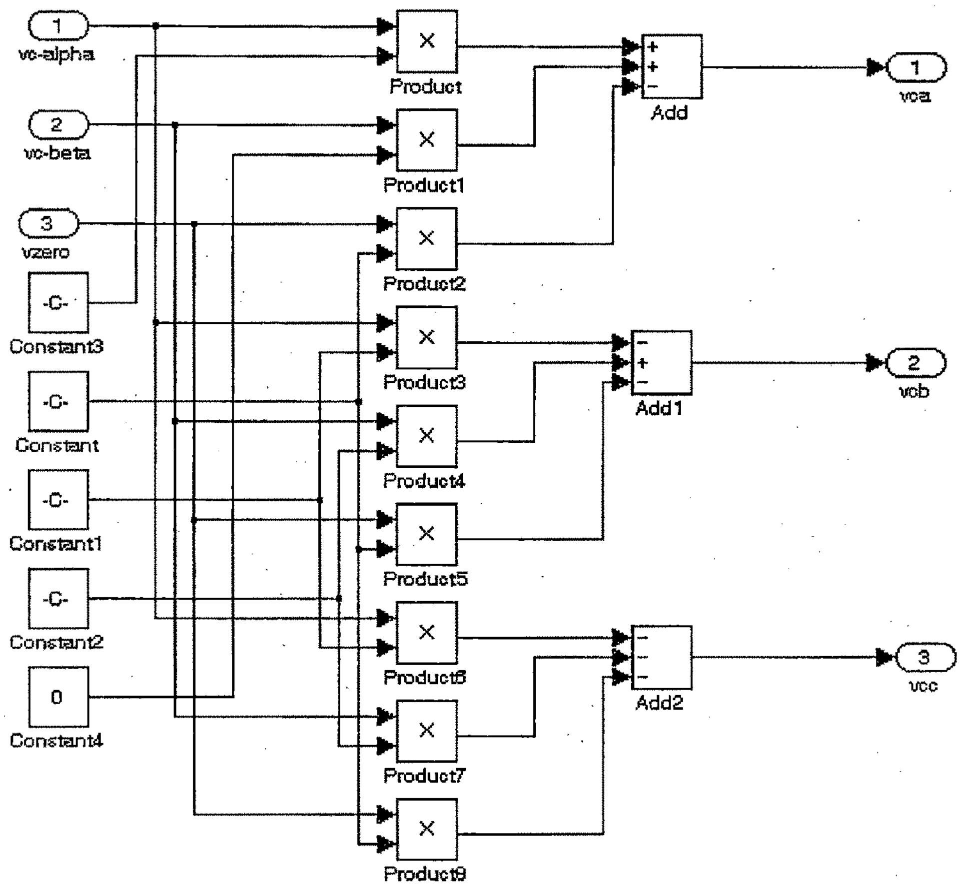

Figure 4.5-4: Compensating Reference Voltage Signal V_{ac}-V_{bc}-V_{cc} In a-b-c Frame

5.6 SIMULATION RESULTS & WAVEFORMS

The simulation results for above method are shown in Figure 4.6-1 to Figure 4.6-6.

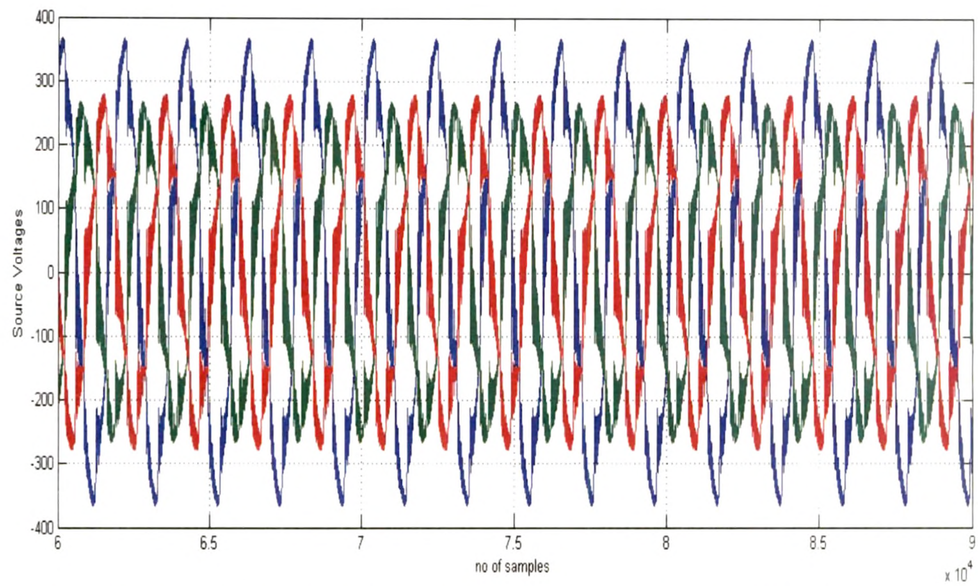

Figure 4.6-1: Input Side Source Voltage Having Distortion & Unbalance

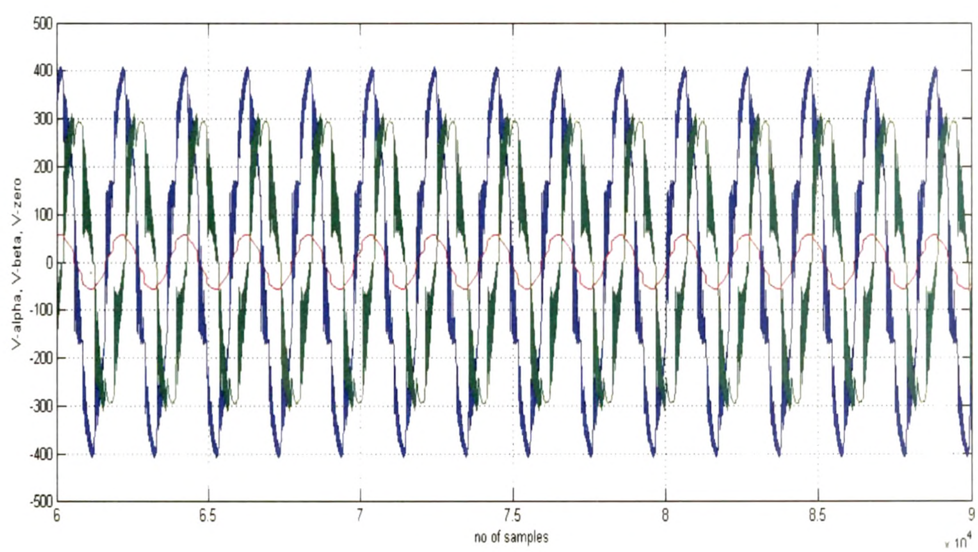

Figure 4.6-2: a-b-c to α-β-0 Conversion (Voltage Signal V_{α} & V_{β} in α-β-0 frame)

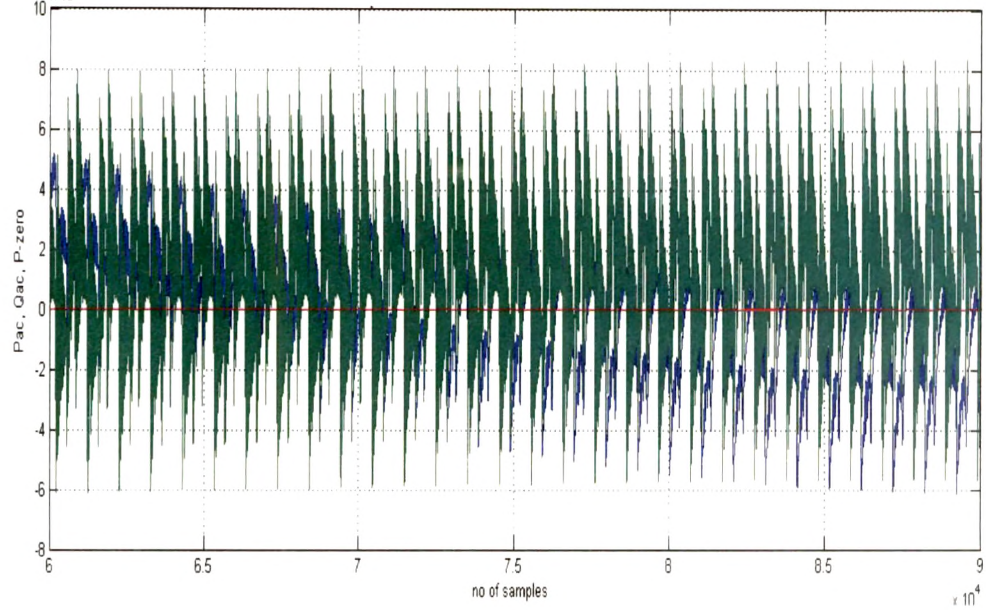

Figure 4.6-3: p_{ac} & q_{ac} of the signal in α-β-0 frame

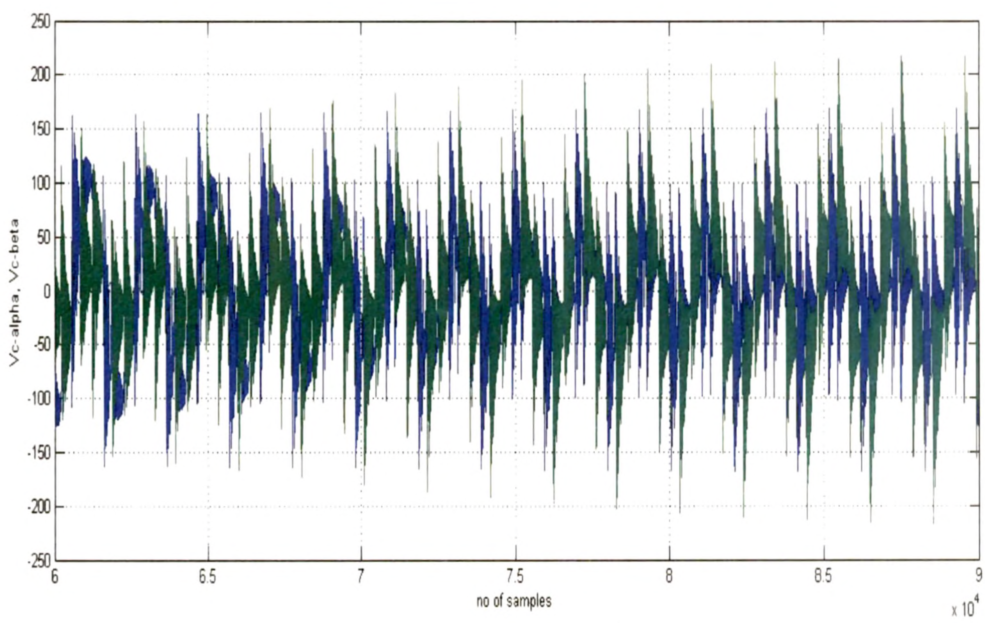

Figure 4.6-4: Compensating Reference Voltage Signal $V_{\alpha C}$ & $V_{\beta C}$ In α-β-0 Frame

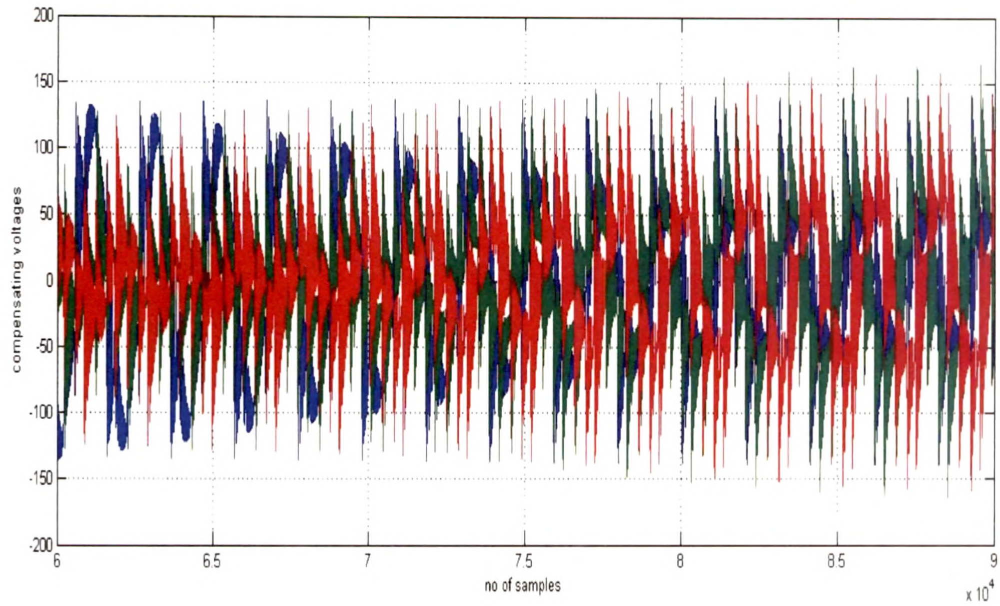

Figure 4.6-5: Compensating Voltage to Compensate Harmonics & Unbalance

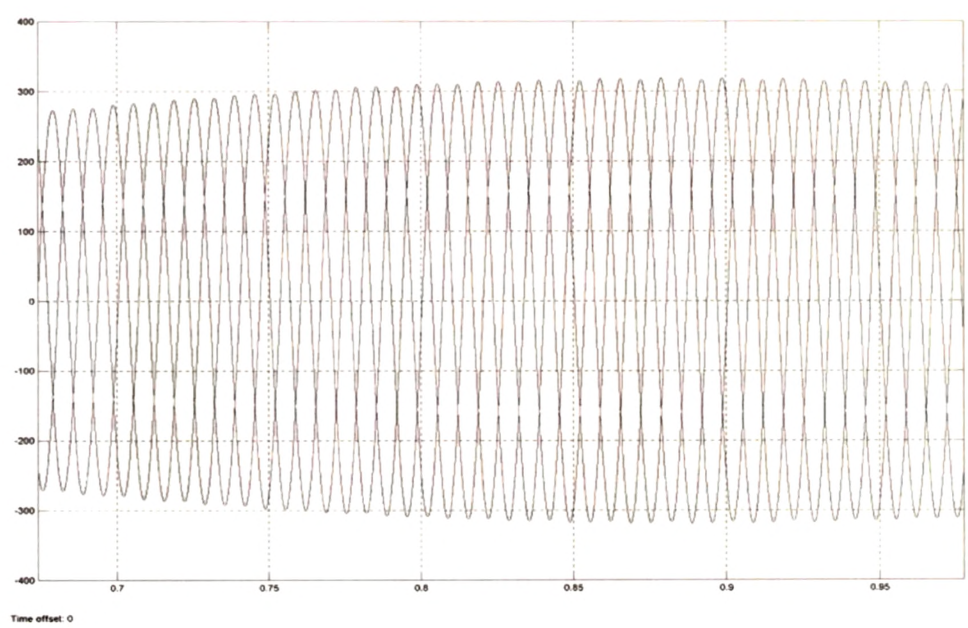

Figure 4.6-6: Load Bus Voltage After Compensation

5.7 CONCLUSION

Simulation results show that this new technique detect online harmonics, negative sequence & zero sequence components and compensate the same using voltage source inverter whose output changes through PWM techniques. Main advantage of detecting the negative sequence component using instantaneous α-β-0 theory is that this can be easily implemented using DSP or analog circuit and no complex algebra is required which is the case using symmetrical components. Implementing the same through DSP hardware is the future scope of work. Now a day's FAST DSP processors with built in ADC & DAC are available which can compute the signal online instantaneous without much delay.