Three Phase, Three Wire Shunt Active Filter with different Compensation Techniques using pq-Theory

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Abstract:

The pq-Theory is equally applicable to any generous voltage and current waveform. So it is equally applicable to linear as well as nonlinear system. For linear system, pq-Theory gives similar results as given by conventional theory. Simulation results are presented under steady state conditions and performance of shunt active filter is compared with two different Voltage Source Inverter used (Three Level- & Five Level Inverter). The controlling of Shunt Active Filter becomes difficult if the supply voltage is non sinusoidal. Under sinusoidal supply voltage Shunt Active Filter can satisfy the three characteristics of power system – sinusoidal source current, constant instantaneous power and unity source power factor. But under non sinusoidal supply voltage one will have to be satisfied with one of the three characteristics. Based on this three compensation techniques were formed.

Introduction:

Shunt active filter is compared with two different Voltage Source Inverter used (Three Level- & Five Level Inverter). The controlling of Shunt Active Filter becomes difficult if the supply voltage is non sinusoidal. Under sinusoidal supply voltage Shunt Active Filter can satisfy the three characteristics of power system - sinusoidal source current, constant instantaneous power and unity source power factor. But under non sinusoidal supply voltage one will have to be satisfied with one of the three characteristics. Based on this three compensation techniques were formed. The development of the alternating current (ac) power system was based on sinusoidal voltage generation at constant frequency. Sinusoidal Voltage with constant frequency has made it easier to design transformers and transmission lines.

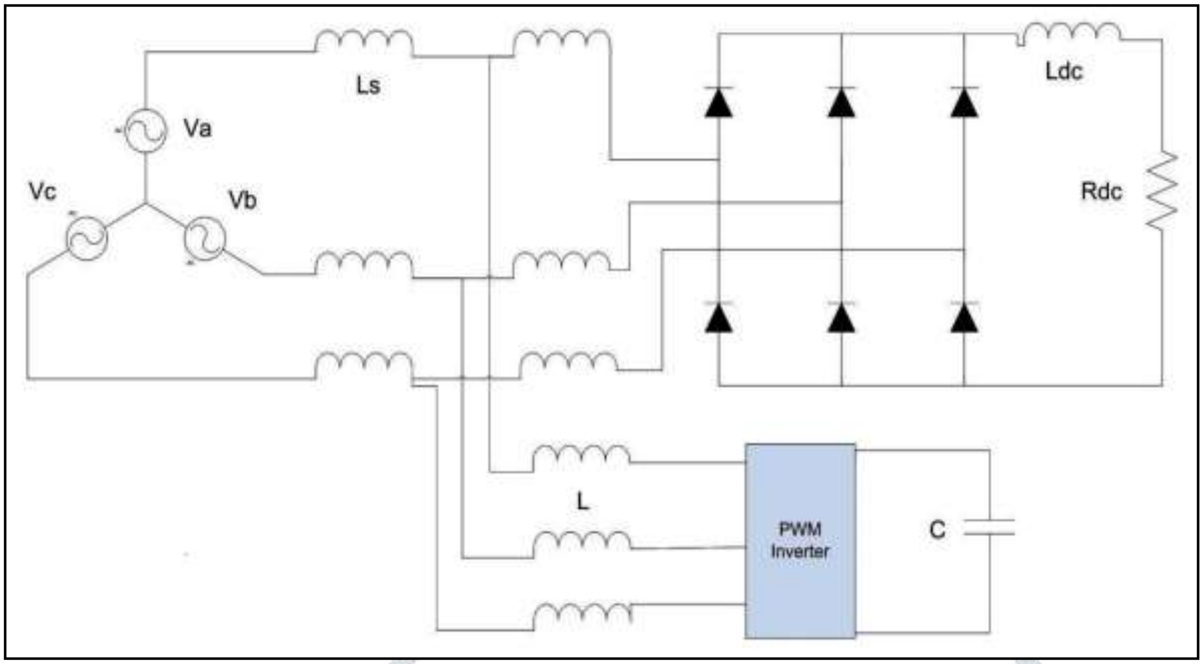

Figure Error! No text of specified style in document. **- Basic Principle of Harmonic Compensation**

H-Bridge, Voltage Source Inverter & PWM Control Technique

Inverter is a Power Electronic module, which is a DC to AC converter. DC input to an inverter could be from batteries, fuel cells, solar cells or rectified dc. The output of these dc sources can be utilized on AC loads using Inverters [17]. Among multilevel inverter topologies Cascaded H-Bridge Inverter is a modular one and simplest to control. It have disadvantage of using multiple dc sources. But it does not require extra capacitors and diodes.

Electrical Power Definitions

A. Power Definitions under Sinusoidal Conditions

An ideal single phase system with a sinusoidal voltage source and a linear (resistive-inductive) load has voltage and current that is represented by

$$v(t) = \sqrt{2}V \sin \omega t \quad (1)$$

$$i(t) = \sqrt{2}I \sin(\omega t - \emptyset) \quad (2)$$

For Non-symmetrical power supply condition the SRF Theory shows the best performance for percentage of THD. On the other hand, the PQ Theory shows the best result percentage of THD after modifying distorted voltage supply. [28]Voltage Source Inverter is efficient than Current Source Inverter either on any type of load. The VSI is fully integrated and CSI is limitedly integrated. So VSI uses small space. VSI has small component count and high reliability where as CSI has high number of component and lower reliability. It is preferable to use VSI instead of CSI. [29]The CSI network offer high damping for frequencies above the cut off frequency, but resonance may be a problem. The advantage and the disadvantage of the VSI network are no resonance and low damping. The concrete result depends upon the network parameters and switching functions of the inverter.

The pq-theory, transforms voltage and current from the abc coordinates to αβo coordinates, and then determine instantaneous powers. In1981, Takahashi and his coauthors in [10 & 41] and gave a hint of the emergence of the pq-theory. The formulation is in fact a subset of the pq-theory.

The Clarke Transformation

The αβo transformation or the Clarke Transformation determines the instantaneous three phase abc voltages into instantaneous voltages on the αβo axes.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} \quad (4)$$

A shunt active filter realizes the principal of load current compensation should also draw an additional harmonic current I_{Sh} to keep the load terminal voltage sinusoidal and equal to $V_T = V_F - X_L . I_{Lf}$. The harmonic voltage drop across the equivalent impedance becomes equal to the source harmonic voltage if $V_{Sh} = X_L . I_{Sh}$. In this case harmonic voltage component cancel out each other and load terminal voltage V_T is kept sinusoidal.

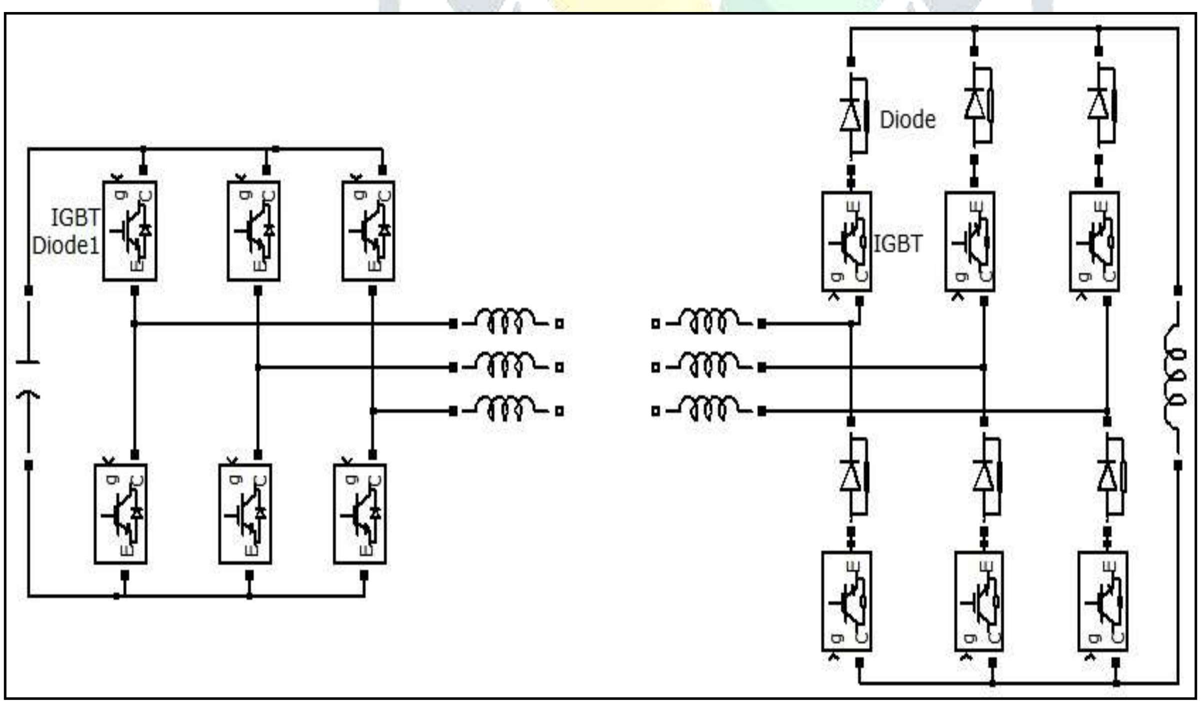

Figure 1- Voltage Source Converter and Current Source Converter

One may prefer CSC due to its robustness or VSC for its high efficiency, low initial coast and smaller physical size [52]. Modern IGBT module has a freewheeling diode in antiparallel with IGBT, which is suitable for VSC in reverse blocking capability. Series connection of traditional IGBT and reverse blocking diode is done to implement CSC. This makes complicated device design and undesirable device characteristic than of IGBT without reverse blocking capability. Multilevel Inverters are also used for better performance of the shunt active filter [53].

4.1 Active Filters for Constant Power Compensation

In order to draw a constant instantaneous power from the source, the shunt active filter must be installed as close as possible to the nonlinear load, and should compensate the oscillating real power $\tilde{p}$ of the load [3, 4].

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (7)$$

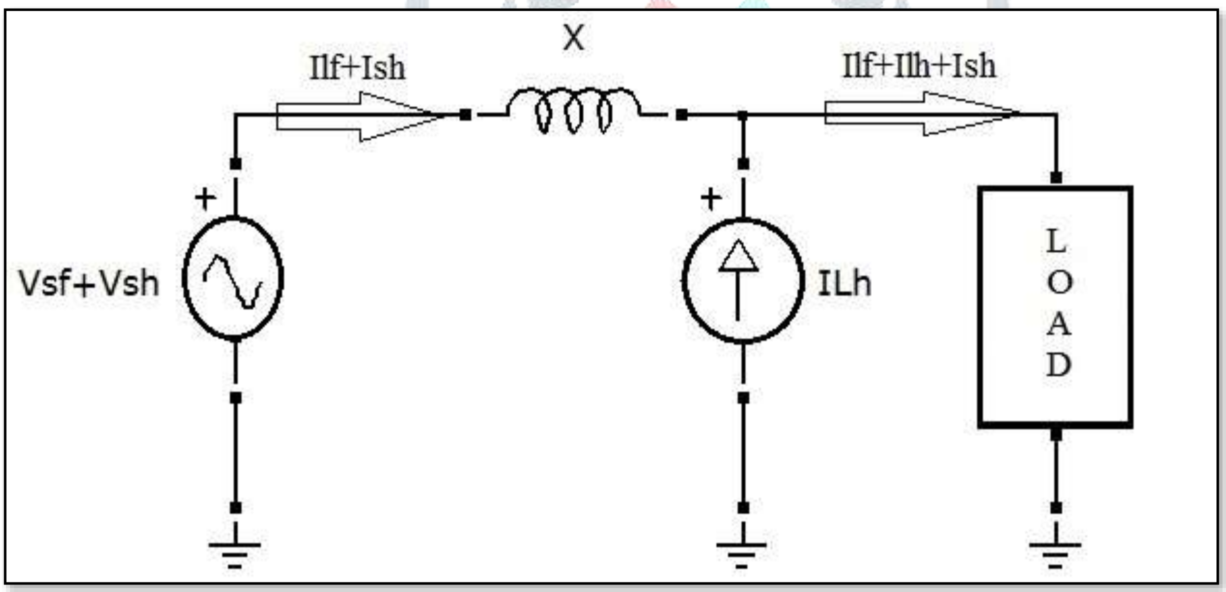

Figure 3 - Harmonic Voltage Generation at PCC due to Load Current and System Impedance

Table 1 - Different Shunt Active Filter Compensation Techniques and their Characteristics

Voltage Source	Shunt Compensation Technique	Source Current	Instantaneous Source Real Power	Source Power Factor
Sinusoidal	General	Sinusoidal	Constant	Unity
Non-Sinusoidal	Constant Instantaneous Power Control	Nonsinusoidal, Not Identical to Source Voltage	Constant	Non Unity
Non-Sinusoidal	Sinusoidal Current Control	Sinusoidal	Not Constant	Non Unity
Non-Sinusoidal	Fryze Current Minimization	Nonsinusoidal, Identical to Source Voltage	Not Constant	Unity

Sinusoidal Current Control Strategy

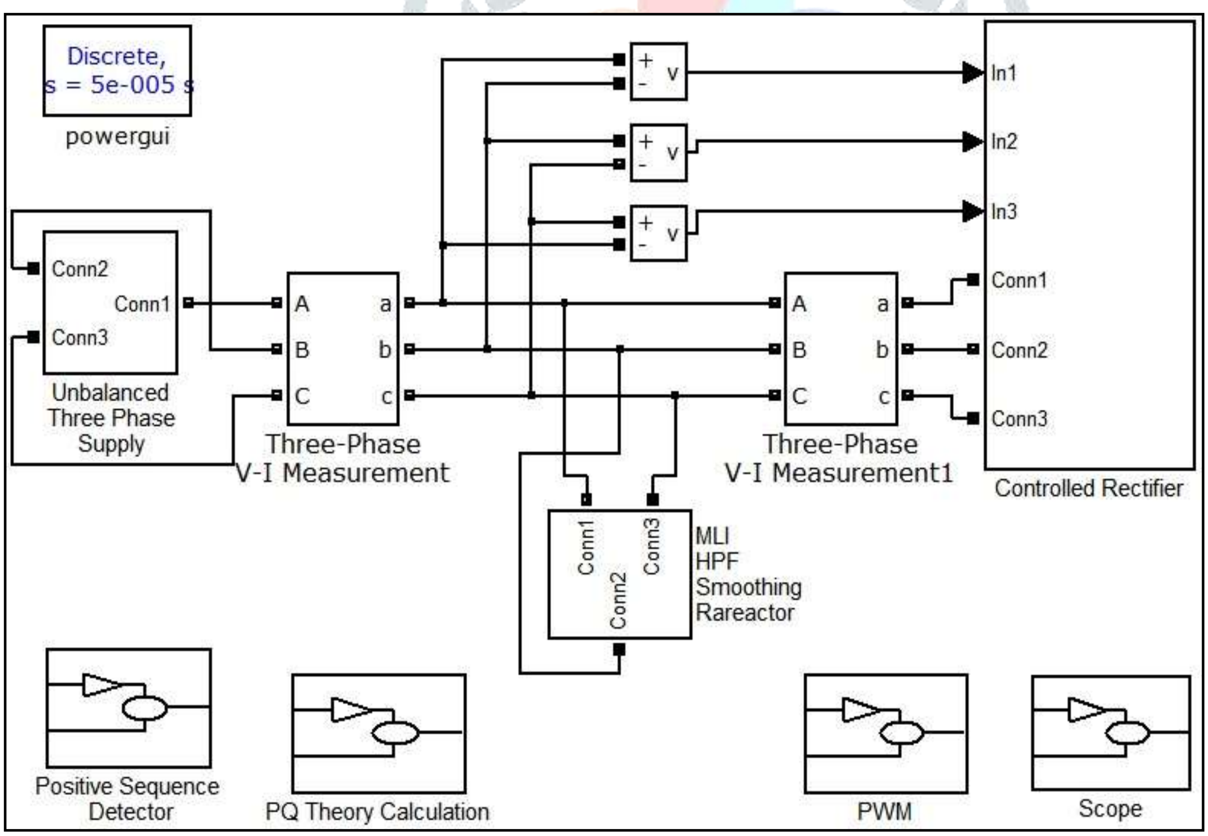

Figure 4 - Simulation Diagram of Shunt Active Filter for Sinusoidal Current Control Strategy

Comparison of pq-Theory and Conventional Theory

A. **Sinusoidal Balanced Three Phase Voltage and Balanced Three Phase Impedance**

B. From results (Figure 5, Figure 6, Figure 7) this can be seen that pq-Theory is equally applicable to three phase balanced and unbalanced system. The pq- Theory gives same results in all three cases of – Three Phase Balanced RL- Load, Three Phase Balanced Capacitive Load and Three Phase Unbalanced Capacitive Load.

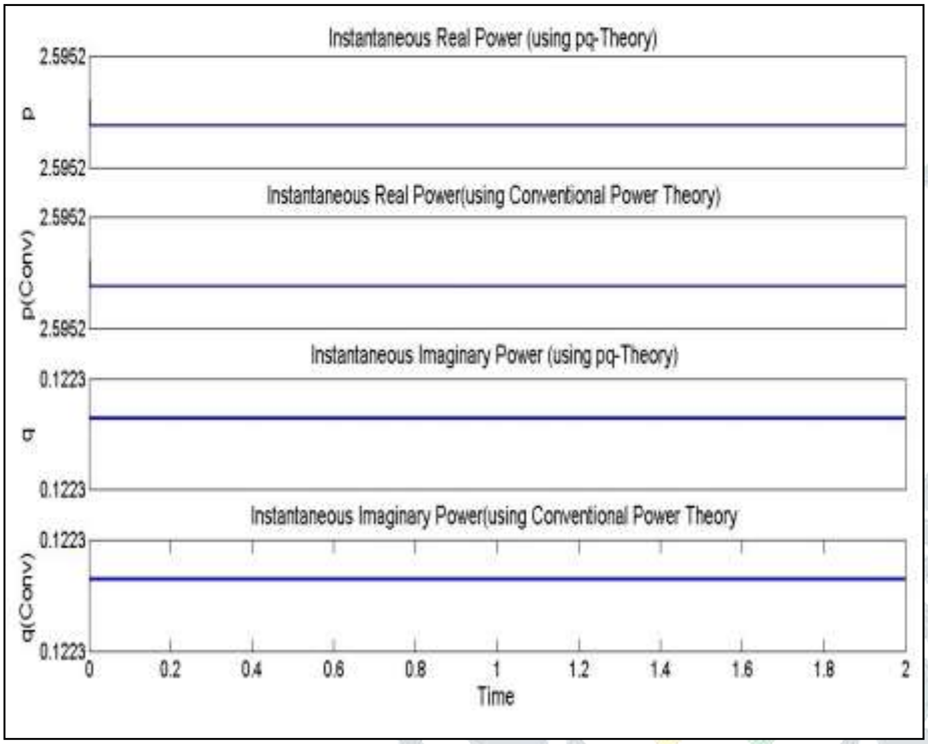

Figure 5 - Instantaneous Real and Imaginary Powers of RL Load

C. **Balanced Voltages and Capacitive Load**

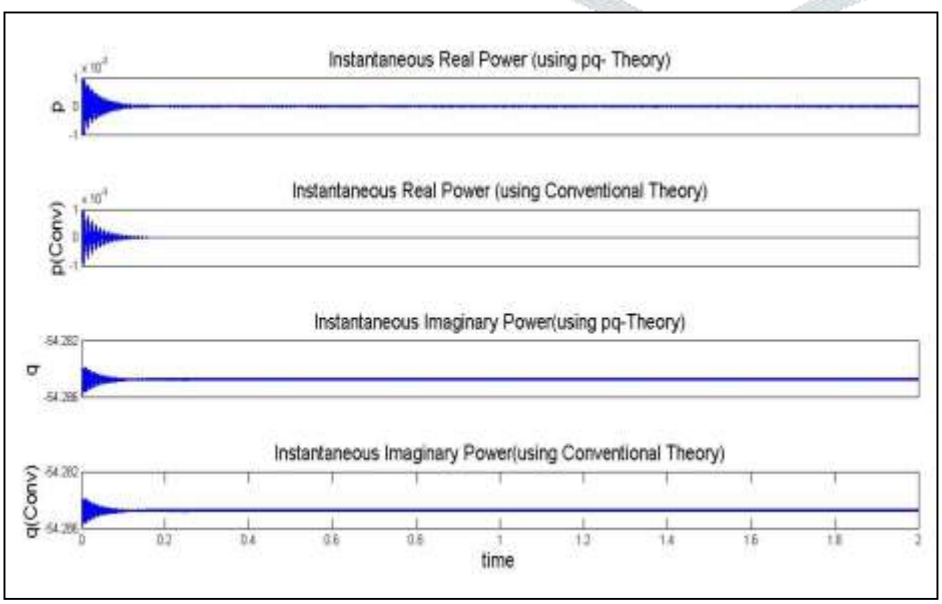

Figure Error! No text of specified style in document. **Instantaneous Real and Imaginary Powers of Balanced Capacitive Load**

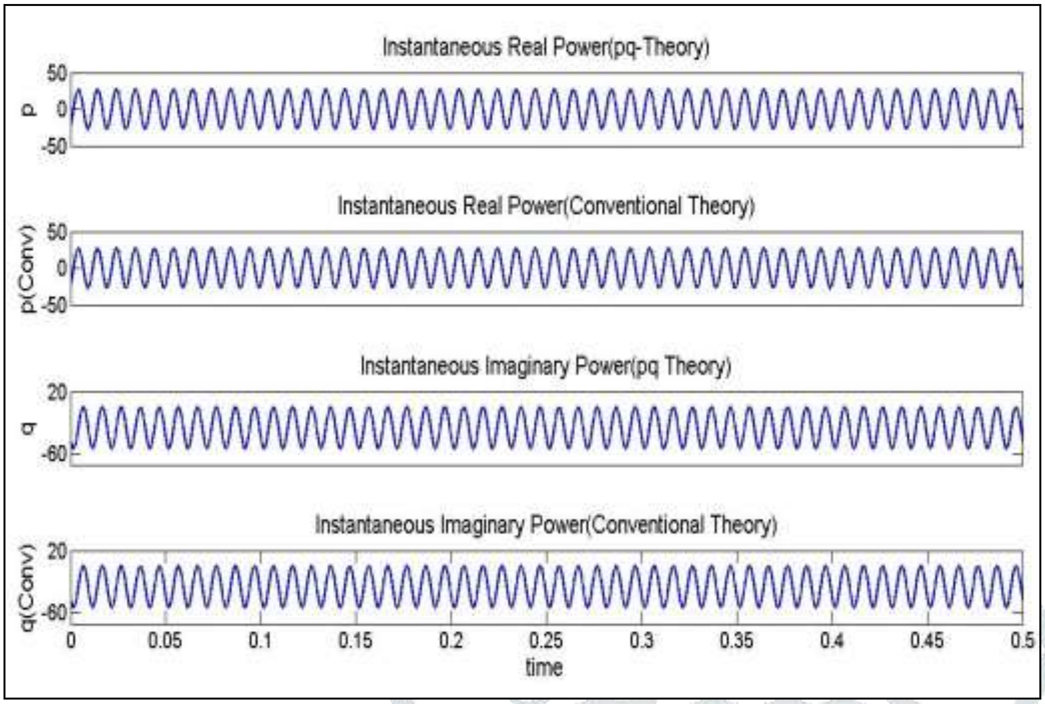

Figure 7 - Instantaneous Real and Imaginary Power of Unbalanced Capacitive Load

Conclusion

The results of power measurement of linear load, this can be concluded that pq-Theory is equally applicable as conventional theory. The results obtained from the two theory are similar to each other. The pq-Theory is able to determine the constant instantaneous power components of real and imaginary powers. So it is also possible to determine the current component responsible for nonlinearity of the load, as in calculation of reference current.

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