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Power Quality Improvement Using Instantaneous Power Theory Based Hybrid

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Abstract:

Power Quality is of key concern for the industry nowadays. The intensive use of power converters and non-linear loads has contributed for the deterioration of power quality, and this affects critical processes, resulting in substantial economic losses. Therefore, the development of equipment that can mitigate the problems that affect electrical installations is of great interest. One such equipment is obtained by the combination of a series active filter and a shunt passive filter called as a Hybrid Filter. This paper proposes a new hybrid filter to improve the quality of power. It presents new technique based on the instantaneous power theory which represents instantaneous powers in time domain. MATLAB/SIMULINK has been used to simulate the proposed system. The simulation results reveal that the proposed method yields better solution for improving power quality.

1. Introduction

The presence of harmonics in the power electrical systems is the main cause of the electrical wave pollution that so many problems carry. The indiscriminate increase of non-linear loads has given rise to investigation into new compensation equipment based on power electronics. The main design target for this equipment is the elimination of the harmonics present in the system. Depending on the application type, series or parallel configurations or combinations of active and passive filters can be proposed.

The presence of harmonics in power lines results in greater power losses in the distribution system, interference problems in communication systems and, sometimes, in operation failures of electronic equipments, which are more and more sensitive since they include micro-electronic control systems, which work with very low energy levels Because of these problems, the issue of the power quality delivered to the end consumers is, more than ever, an object of great concern.The combination of series active filter and shunt passive filter called as Hybrid filter, which uses Instantaneous Power Theory, is presented in the following paper. The series active filter presents functionalities to improve the system stability and to suppress distortions at the system voltages. The shunt passive filter is designed to drain the harmonic currents generated by the non-linear load. The control strategy applied in this network is based on the definitions for instantaneous powers in the reference frame (p-q theory).

2. Instantaneous Power Theory

The Instantaneous power theory or the p-q Theory makes clear physical meaning of instantaneous active and reactive power in three-phase circuits. It provides a clear understanding about how energy flows from source to a load or circulates between phases, in a three-phase circuit.

The PQ theory defines a set of instantaneous powers in the time domain. Since no restrictions are imposed on voltage or current behaviour, it is applicable to three phase system with or without neutral conductors. Thus it is valid not only in steady state but also during transient state. This theory consists of an algebraic transformation (Clark's transformations) of the three phase voltages in the a-b-c coordinates to the α-β-0 coordinates.

The α-β-0 transformation maps the three phase instantaneous voltages in the abc phases i.e. Va, Vb, Vc into the instantaneous voltages on the α-β axes i.e. Vα, Vβ. In instantaneous power theory, three phase currents and voltages are calculated using following equations.

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

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

In equation (1) and (2), α and β are orthogonal coordinates. V_α, and I_α, are on α axis, V_β and I_β are on β axis. In three phases conventional instantaneous power is calculated as follows,

$$p = v_\alpha i_\alpha + v_\beta i_\beta \ldots\ldots\ldots\ldots(3)$$

The active power is given as

$$p = v_a i_a + v_b i_b + v_c i_c \ldots\ldots\ldots(4)$$

Instantaneous real and imaginary powers are calculated as

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

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In equation (5), p and q represent the instantaneous real and reactive powers. Here, v_α, v_β, , i_α, i_β are values of voltages and currents respectively in the orthogonal axes.

The voltage in the α-β reference frame is calculated as follows:

$$\begin{bmatrix} v_\alpha^* \\ v_\beta^* \end{bmatrix} = \frac{1}{i_\alpha^2+i_\beta^2}\begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix}\begin{bmatrix} -\tilde{p} + \overline{p_{loss}} \\ -\bar{q} \end{bmatrix} \ldots.(6)$$

In equation (6), $\tilde{P}$ is the oscillating component of instantaneous real power which is obtained by passing the total instantaneous real power through a band pass filter, $\bar{Q}$ is the total instantaneous imaginary power and $p_{loss}$is the output of the PI controller which maintains the DC voltage across the capacitor of the series active filter constant.

The compensating voltages produced by the series active filter are calculated using the following equations:

$$\begin{bmatrix} v_{Ca}^* \\ v_{Cb}^* \\ v_{Cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} v_\alpha^* \\ v_\beta^* \end{bmatrix} \ldots\ldots\ldots.(7)$$

From equation (7), we obtain the compensating voltages which are injected in series to compensate for the non-linearity in the source voltages produced by the non-linear load.

3. Hybrid Filter

There are two approaches to the mitigation of power quality problems. The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion. The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances. A flexible and versatile solution to voltage quality problems is offered by active power filter. Currently, active power filters are based on PWM converters and connect to low and medium voltage distribution system in shunt or in series. Shunt active power filters operate as a controllable current source and series active power filters operates as a controllable voltage source. Series active power filters must operate in conjunction with shunt passive filters in order to compensate load current harmonics. This combination of a shunt passive filter and a series active filter is generally called a hybrid filter.

The series active filter generates harmonic voltages to cancel the harmonic voltages produced by the non-linear load and the shunt passive filter eliminates harmonic currents generated by the non-linear load. The hybrid filter presented in this paper compensates for the voltage harmonics produced by the non-linear load and also improves the source currents by eliminating the current harmonics to a certain extent. The control technique used in this paper is based on instantaneous power theory.

4. System Configuration

Figure 1 shows the basic block diagram of the hybrid filter presented in this paper. The passive filters were designed to compensate for harmonic currents produced by a 6-pulse thyristor rectifier. A series RL circuit with a 10Ω resistor and 100mH inductor are connected to the dc side of the rectifier, and the thyristors operate with a firing angle of 30º.

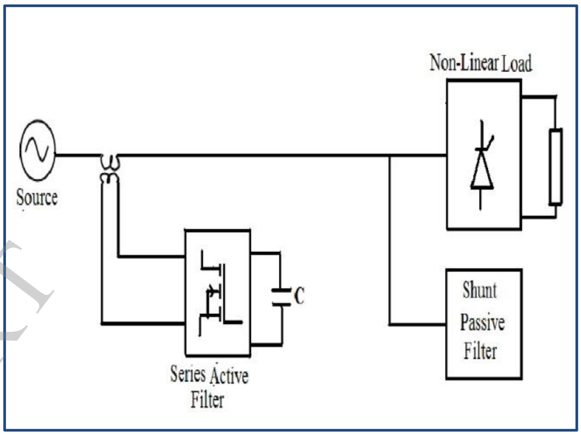

Fig 1: Block Diagram of Hybrid Filter

The series active filter consists of a three-phase voltage-fed PWM inverter connected in series with the power grid through three single-phase transformers. The power converter is a standard 3-leg voltage controlled Voltage Source Inverter (VSI) with a capacitor on the dc side. The dc link capacitor has a value of 1µF with a dc-voltage reference of 415V.

A shunt passive filter is connected to the output of the series active filter inverter in order to smooth the ripples on the generated compensating voltages. The passive filter characteristics are as shown in Table 1. Single phase transformers with a turn ratio 1:1 are used to connect the active filter to the power system.

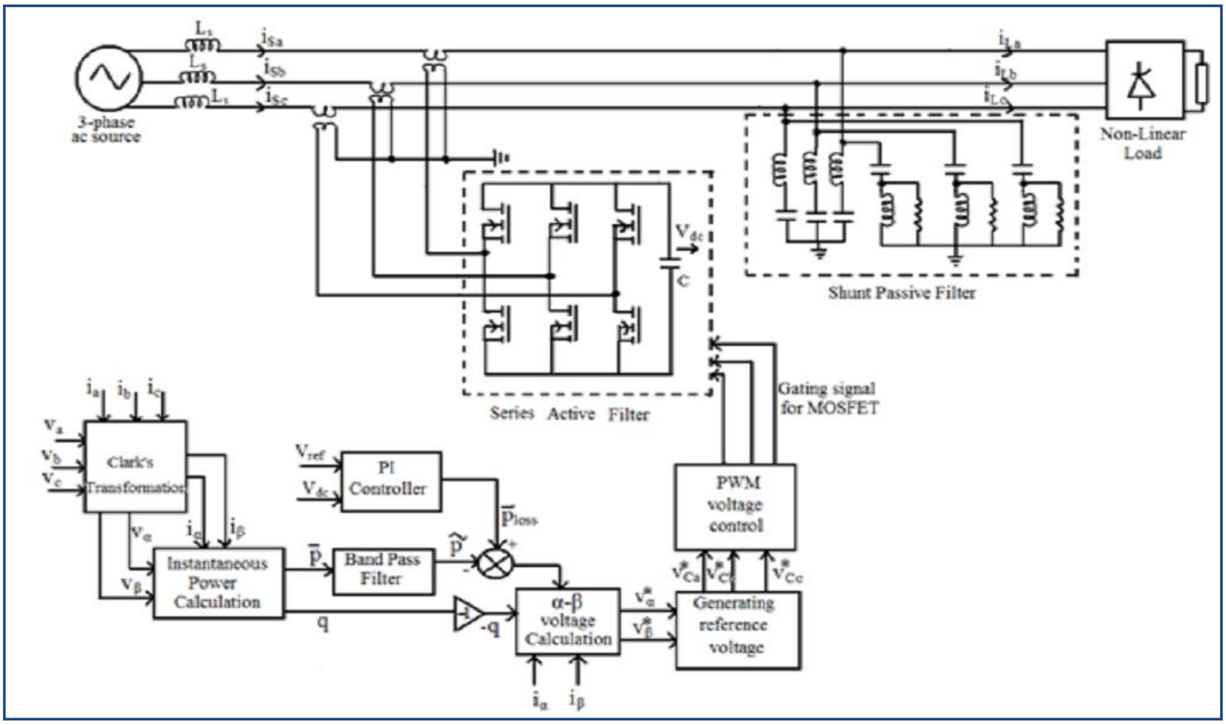

Fig. 2 Block Diagram of Hybrid Filter

5^{th} order Passive Filter (f = 250Hz)	L_5 = 1.2mH C_5 = 170uF
High Pass Filter	L = 1.2mH C = 170uF R = 1Ω

Table 1: Passive Filter Characteristics

The control block, "Series Active Filter", uses as input signals v_a, v_b, v_c and determines, in real time the control signals v_{ref}, that will be synthesized by the power converter. The control block, "PWM Controller", determines and sends the firing pulses to the MOSFET of the power inverter.

5. Proposed Strategy for a 3-Phase 3-wire System

The block diagram as shown in Figure 2 shows the important parts of a three phase three wire hybrid filter. The series active filter controller operates in a closed loop manner, continuously sensing the source voltage v_s and calculating instantaneous values of the compensating voltage reference of the PWM inverter. It should be noted that while introducing the active filter into system the point of common coupling (PCC) should be designed carefully such that the load gets sufficient amount of power. The presented active filter controller consists of four functional blocks:

1. Instantaneous power calculation
2. Power compensating selection
3. Dc voltage regulator
4. Voltage reference calculation

The first block calculates the instantaneous powers of the nonlinear load.

According to the p-q theory only the real and imaginary powers exist because the zero sequence power is always zero for a three wire system. The power compensating selection determines the output of the series active filter. It selects the real (oscillating) and imaginary power of the non-linear load that should be compensated by the series active filter.

Dc voltage regulator determines an extra amount of real power, (switching & conduction losses) represented by P_{loss}, as shown in the fig. It is calculated in order to maintain the voltage across the DC capacitor around a fixed reference value.

For this purpose a PI controller is employed. The gains of PI controller should be selected as it plays a vital role in maintaining the voltage across the DC capacitor. The power Ploss is added to the compensating real power, . The compensating real power together with the compensating imaginary power is passed to the voltage reference calculation block. If the series active filter injects the voltage component that is exactly -Posc of the load, the power system would supply only the constant portion of the real power, p of the load. Apart from the above mentioned blocks, the block diagram consists of shunt passive filter block, which consists of 5^{th} harmonic elimination filter and a High-pass filter, connected to each phase of the three phase three wire system. This passive filter, connected after the series active filter helps in reducing the THD (Total Harmonic Distortion) of the source voltage further.

6. Simulation Results

The presented simulation results were obtained using MATLAB/SIMULINK software for a three phase power system with a Hybrid filter. The source supply is designed with 230 $V_{ph\text{-}rms}$ and frequency of 50 HZ with a phase difference of 120 degrees. A nonlinear load (thyristor rectifier) is included in the system to introduce harmonics into the system. In order to verify the circuit, breakers are used and are switched on and off such that at 0.1s the series active filter is introduced to compensate for the voltage harmonics and at 0.2s the shunt passive filter is introduced which eliminates the current harmonics introduced by the load to a certain extent.

Figures 3 and 4 represent the source voltage and source current of phase a, Figure 5 represents the reference voltages generated of all the phases and figures 6 and 7 represent the output current and voltage respectively.

7. Conclusions

The modern devices behave as non-linear loads and draw significant amount of harmonic currents. Power definitions that are valid under transient conditions are needed. Hence instantaneous power theory which involves analysis in time domain (proposed by Fryze) is found to be more effective. This paper proposes a hybrid filter i.e. the combination of a series active filter and a shunt passive filter, using instantaneous power theory. From the simulation results it can be seen that the combination of a shunt passive filter and a series active filter resulted in a very economic and practical way to filter harmonics. The THD of the source voltage is 18.13 % without any compensation. On the introduction of the series active filter at 0.1s it was observed that the THD is reduced to 6.14% and further when the shunt passive filter was introduced at 0.2s the THD obtained is 2.43%.

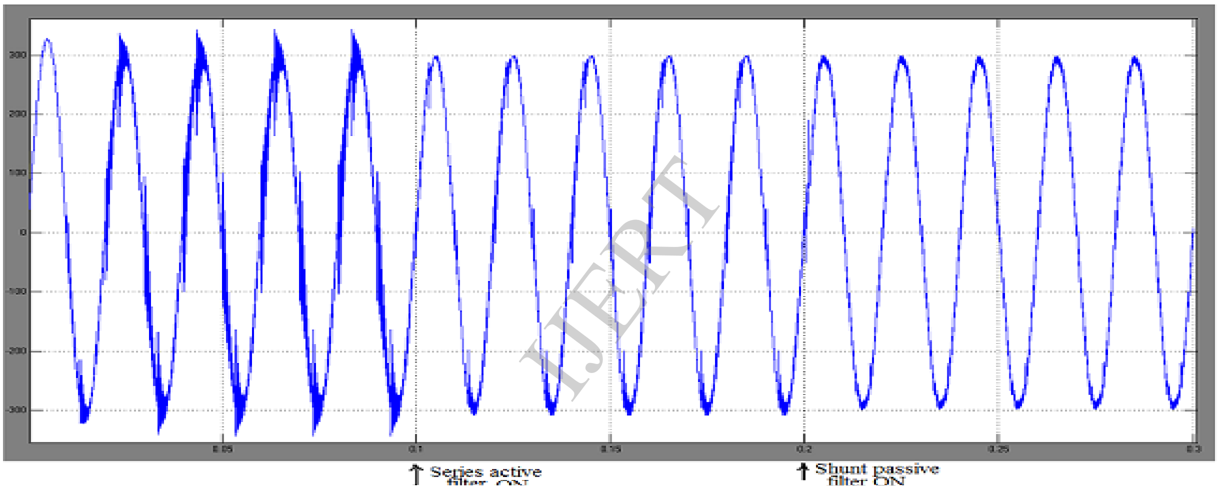

Fig 3 Source Voltage of phase a

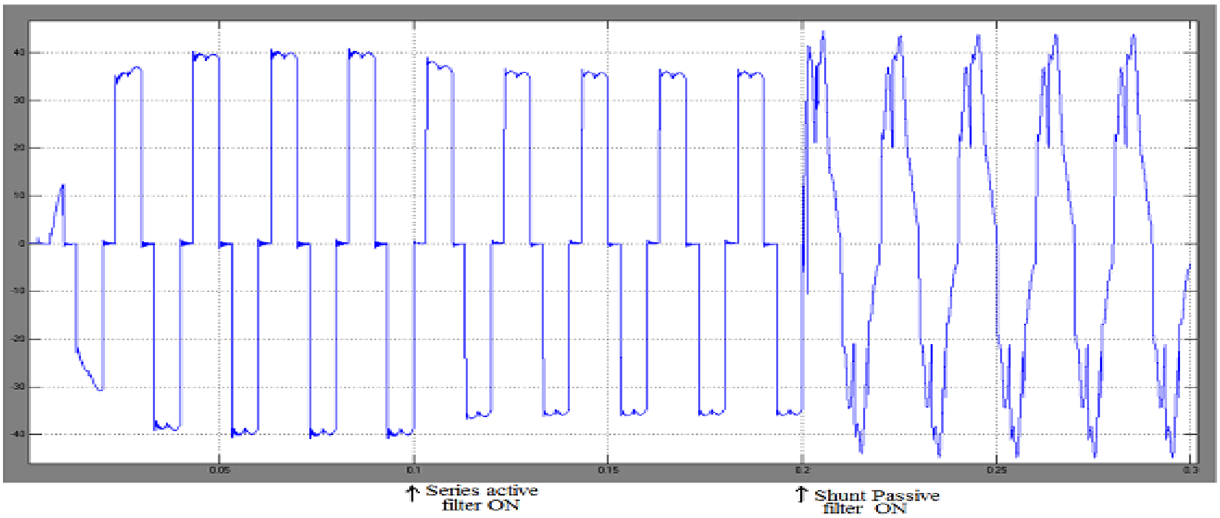

Fig 4 Source Current of phase a

However the results shown are a bit different from the desired result due to overloading of the filter. This problem can be avoided by selecting proper gains of the PI controller in the DC voltage regulator circuit.

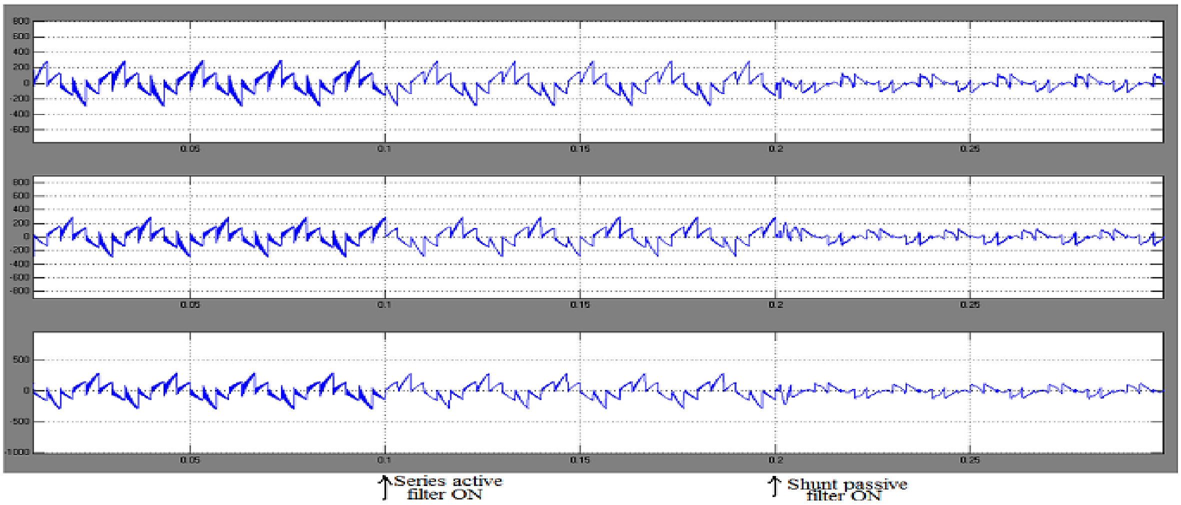

Fig 5 Reference Voltages of all the three phases

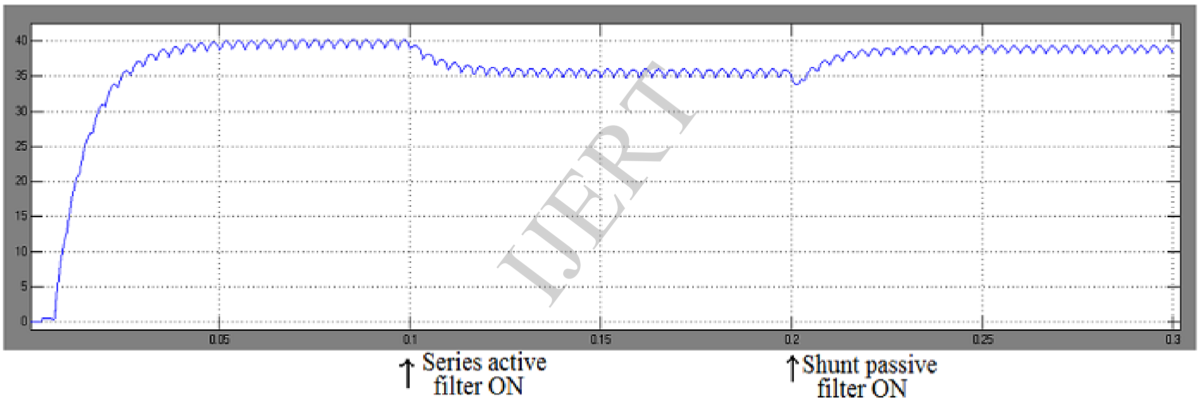

Fig 6 Current taken by Non-Linear load (Rectifier)

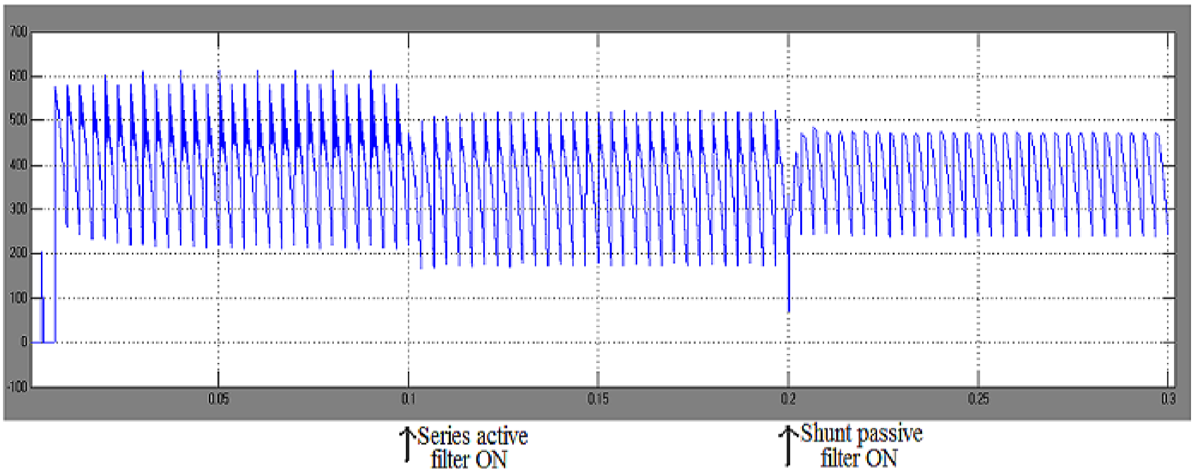

Fig 7 Output Voltage of Non-Linear Load (Rectifier)

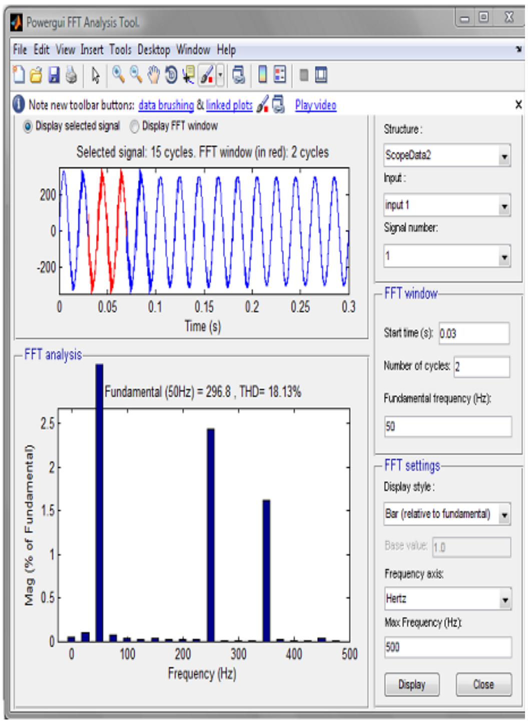

Fig 8 THD analysis without filter for Source Current

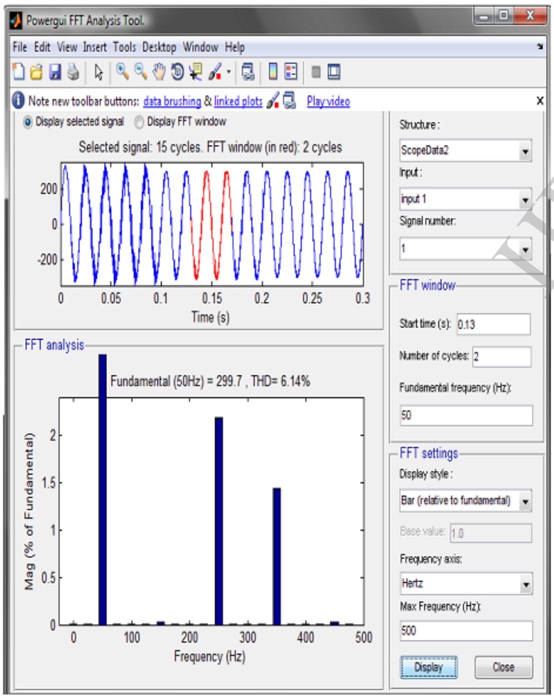

Fig 9 THD analysis with Series Active Filter for Source Current

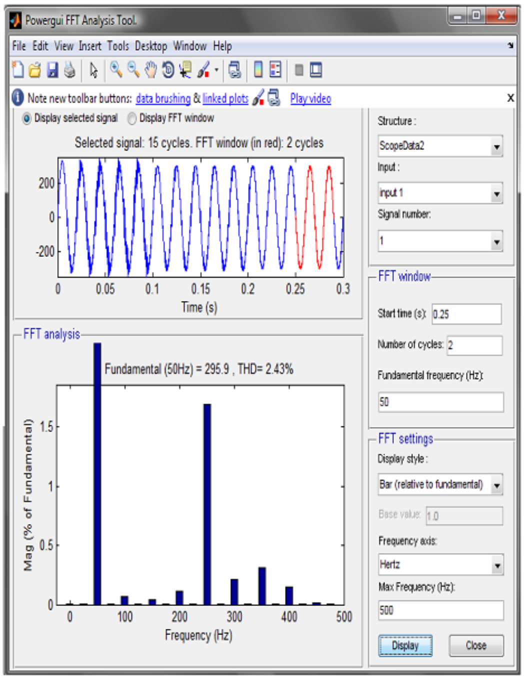

Fig 10 THD analysis with Hybrid Filter ON

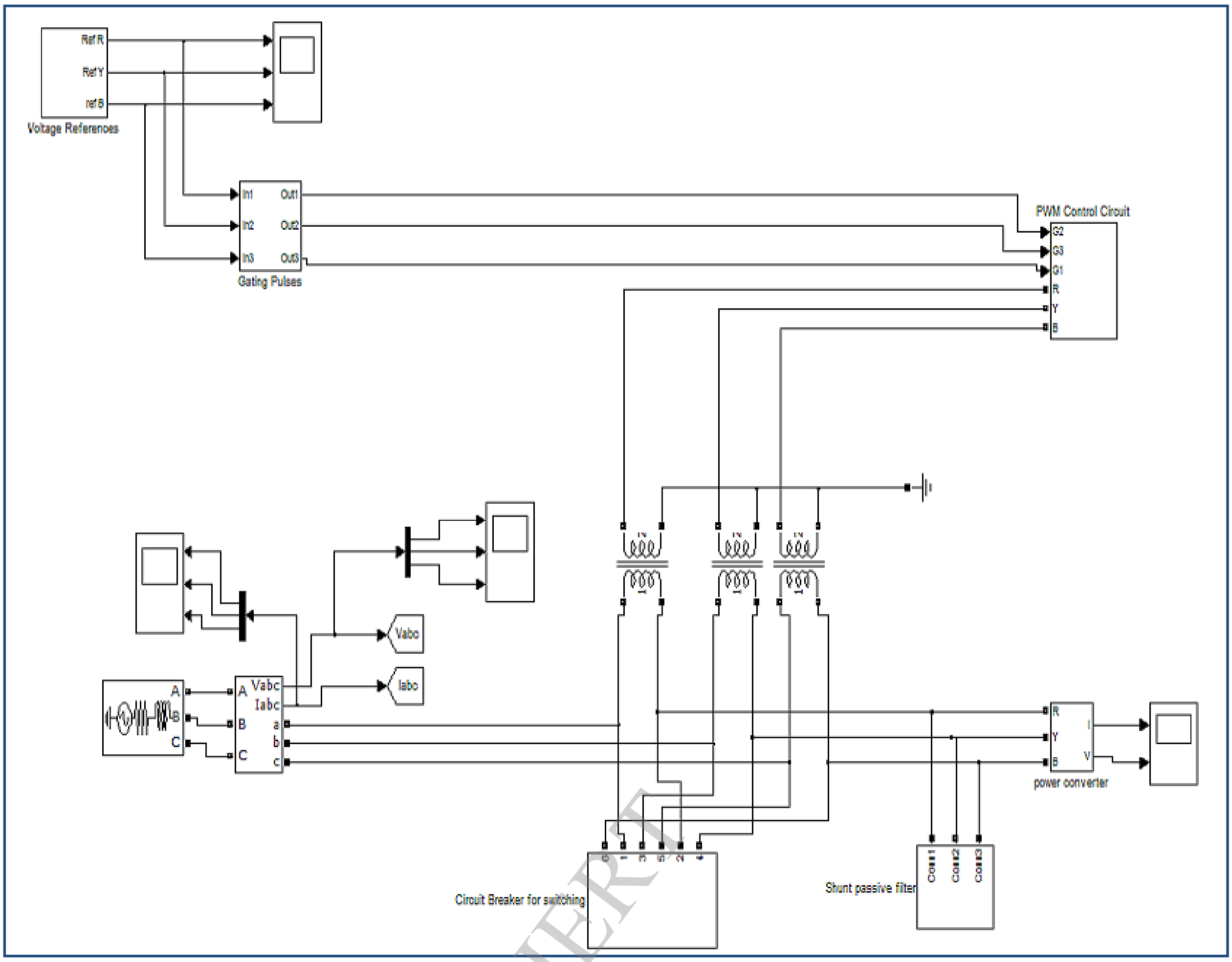

Fig 11 Simulated Model

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