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RESEARCH ARTICLE

ELIMINATION OF HARMONICS IN POWER SYSTEM BY THE COMBINATION OF PASSIVE AND ACTIVE FILTER WITH P-Q CONTROL TECHNIQUE

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ABSTRACT

This paper presents a combination of active and passive filter for the elimination of harmonics produced by non-linear loads. In the proposed technique passive filter is used to eliminate lower order harmonics and active filter is used to eliminate higher order harmonics, and active filter also improves the filtering characteristics of passive filter. By the use this system lesser rating of active filter is required leading to a practical and economical system. The present paper presents a compensation method that is programmed in MATLAB-SIMULINK environment.

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INTRODUCTION

Harmonics in the power system are caused by non- linear loads such as rectifiers, inverters, cycloconverters and arc furnaces etc. Passive filters consisting of bank of tuned LC filters and/or high-pass filter are broadly used to eliminate these harmonics because of their low cost and high efficiency. But passive filters have to suffer following disadvantages:-

1) A passive filter may fall into series resonance with a source so that voltage distortion produces excessive harmonic current flowing into passive filter.
2) Parallel resonance between a source and a passive filter causes amplification of harmonic current on the source side at specific frequencies.
3) Source impedance strongly affects the filtering characteristics (Gyugyi and Strycula, 1976).

By the introduction of high speed semiconductor devices like IGBT's (Insulated gate bipolar transistor) and MOSFET's (Metal oxide semiconductor field effect transistor) active filters came into practical use. Active filter covers all the disadvantages of passive filters (Majid Pakdel and Khalil Rahimi Khoshoei, 2007). Combination of series active and shunt passive filter is shown in Fig.1.

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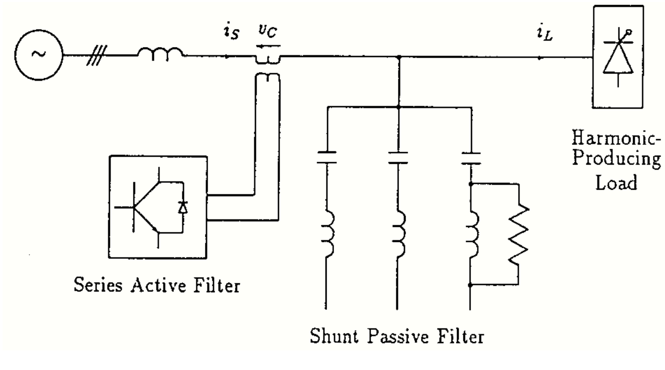

Fig. 1. Combination of series active and shunt passive filter

But active filter have following disadvantages:-

1) Initial and running costs are high.
2) It is difficult to construct large rated current source with rapid current response.

Other techniques for the rating reduction of active have been proposed on the basis of a combination of active filter and passive elements such as capacitors and reactors (Majid Pakdel and Khalil Rahimi Khoshoei, 2007; Akagi *et al*., 1986). Fig. 1 shows a combination of a series active filter and shunt passive filter (Akagi *et al*., 1986). The shunt passive filter connected in parallel with the load eliminates harmonics produced by the load, whereas active filter connected in series with source acts as a harmonic isolator between the source and the load. This paper presents a combination of passive filter and a small rated active filter connected in series with each other. Passive filter eliminates load harmonics whereas active filter acts as a harmonic isolator which improves the filtering characteristics of active filter. As a result, proposed system can solve the problems using passive filter alone. As a result active filter of much smaller rating is required than conventional active filters. This scheme proved to be more economical because passive filters are cheaper than active filter for eliminating lower order harmonics and in this scheme we use passive filter to eliminate lower order harmonics and active filter to eliminate higher order harmonics and also to improve the filtering characteristics of passive filter.

II. System configuration

Fig. 2 is a proposed system of an active filter and a passive filter, which are connected in series with each other. The system is installed in parallel with a harmonic producing non-linear load. Here we had used three phase thyristor bridge converter. Passive filters are fifth and seventh tuned LC filters and a high pass filter. The main circuit of active filter is a three phase current controlled voltage source PWM inverter using six MOSFET's. The PWM inverter has a dc capacitor of 1200 µF. Small rated LC filter (L_R,C_R) are also used to reduce the switching ripples generated by active filter. Table I shows the constants of the passive filter and the small rated LC filter used in the following experiment. Three current transformers of turn ratio 1:10 are connected to match the voltage-current rating of the active filter with that of passive.

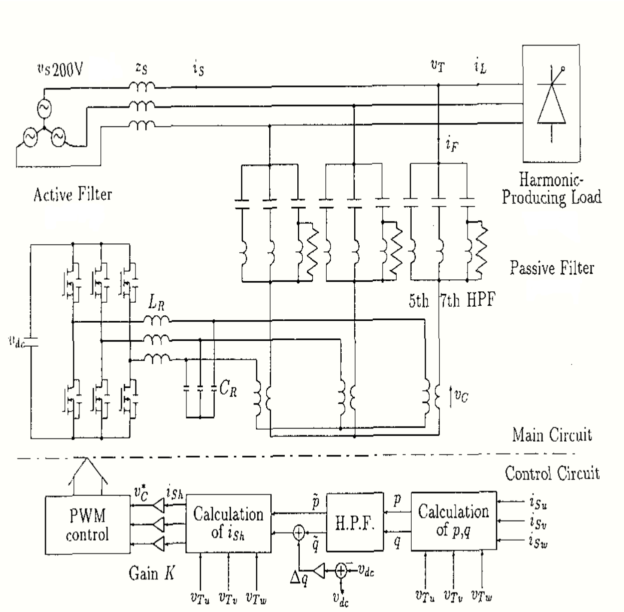

Fig.2. Proposed System Configuration

TABLE I
CIRCUIT CONSTANTS

Passive Filter			
5th	L = 1.2 mH	C = 340 µF	Q = 14
7th	L = 1.2 mH	C = 170 µF	Q = 14
HPF	L = 0.26 mH	C = 300 µF	R = 3Ω
Small-Rated LC Filter			
L_R = 10.0 mH	C_R = 0.1 µF		

III. Control circuit

A control circuit is also shown in Fig. 2. Three phase source current I_{su}, I_{sv} and I_{sw} are detected from the supply and source harmonic current I_{sh} are calculated in each phase by applying p-q theory. Terminal voltages and the source currents are transformed from three to two phase quantities as follows:-

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_u \\ e_v \\ e_w \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{su} \\ i_{sv} \\ i_{sw} \end{bmatrix} \quad (2)$$

Here e_u, e_v and e_w are the fundamental of the terminal voltages v_{tu}, v_{tv} and v_{tw} respectively. Hence the instantaneous real power p and the instantaneous imaginary power q are givwn by:-

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{s\alpha} \\ i_{s\beta} \end{bmatrix} \quad (3)$$

The ac component are extracted by two high-pass filter, and the harmonics of the three phase source currents I_{shu} , I_{shv} and I_{shw} are obtained by the following calculation:

$$\begin{bmatrix} i_{shu} \\ i_{shv} \\ i_{shw} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix}^{-1} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (4)$$

The calculated harmonic current in each phase I_{sh} is amplified by gain K and input to a PWM controller as a reference:-

$$V_c^* = K.i_{sh} \quad (5)$$

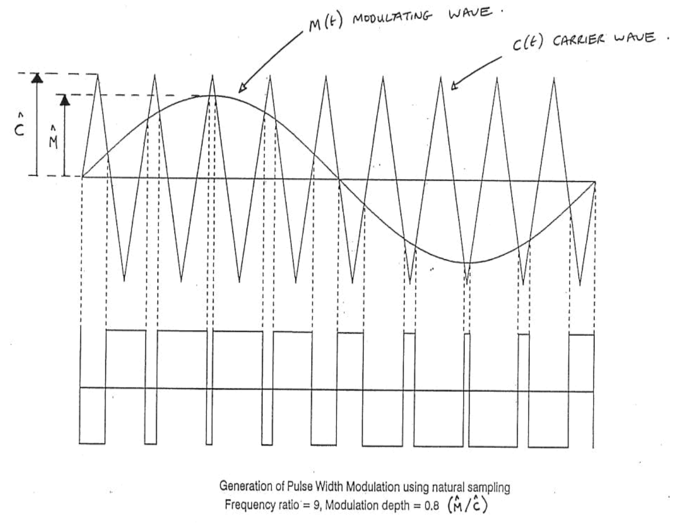

Fig. 3. Switching patterns from PWM technique

To produce PWM switching patterns, the PWM controller compares this reference signal with a triangular carrier wave whose frequency is 20 kHz and pulses are generated at the point of intersection of reference wave and high frequency triangular wave and these pulses are applied to the gate terminal of the inverter for appropriate switching. Fig. 3 shows the switching patterns from PWM technique.

IV. Compensation principle

Fig. 4 shows single-phase equivalent circuit circuits of the proposed system. Assuming that the active filter is an ideal controllable voltage source V_c and that the load is a current source I_L. Fig. 2 can be redrawn as Fig 3(a), where Z_s is a source impedance and Z_F is the total impedance of the passive filter.

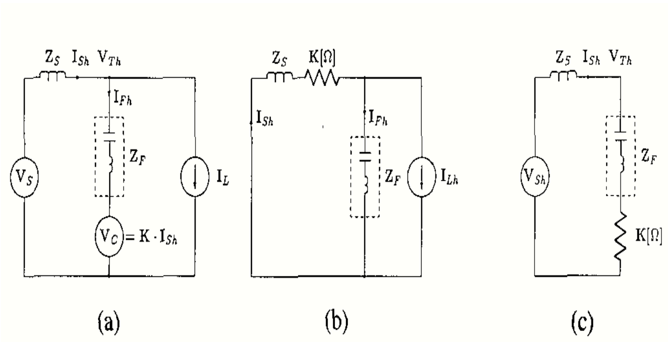

Fig. 4. Equivalent circuit of proposed filter system: (a) Single phase equivalent circuit, (b) Equivalent circuit of I_{lh},(c) Equivalent circuit of V_{sh}

When no active filter is connected (K=0), a load harmonic current L_{Lh} is compensated by passive filter, filtering characteristics of which depends on the ratio of Z_s and Z_F . From Fig. 3, the source harmonic current I_{Sh} is given by:-

$$I_{sh}=\frac{Z_F}{Z_s+Z_F}I_{Lh} \quad (6)$$

If the source impedance is so small ($|Z_s| \approx 0$), or unless the passive filter is tuned to harmonic frequencies generated by the load ($|Z_F| \gg |Z_s|$), desirable filtering characteristics would not be obtained. Moreover parallel resonance between Zs and ZF occurs at specific frequencies ($|Z_F|_+|Z_s| \approx 0$), causing harmonic amplification phenomena. As a result much larger amount of harmonic current flows in the source than in the load. When the active filter is connected, and is controlled as a voltage source.

$$V_c=K.i_{sh} \quad (7)$$

The active filter forces all the harmonic contained in the load current to flow into the passive filter so that no harmonic current flows in the source. The function of the active filter is to solve the problem inherent in using the passive filter alone. In addition, no fundamental voltage is applied to the active filter. This results in a great reduction of the voltage rating of the active filter.

V. Filtering characteristics

Let us consider filtering characteristics for the load harmonic current I_{Lh}. Let us assume that a source voltage V_S, is sinusoidal. The source harmonic current I_{Sh}, the terminal harmonic voltage V_{Th} and the output voltage of the active filter V_c are given by the following three equations:

$$I_{sh}=\frac{Z_F}{K+Z_S+Z_F}I_{Lh} \quad (8)$$

$$V_{Th}=V_{Sh}-Z_sI_{sh}=-\frac{Z_FZ_S}{K+Z_S+Z_F}I_{Lh} \quad (9)$$

$$V_c=KI_{Sh}=\frac{KZ_F}{K+Z_S+Z_F}I_{Lh} \quad (10)$$

Equation (8) tells us that Fig. 4(a) is equivalent in I_{Sh} to Fig. 4(b). This means that a pure resistance K(Ω) is connected in series with Z_S as shown in Fig. 3(b). If K »$|Z_F|$, all the harmonic current produced by the load would sink into the passive filter. If K »$|Z_S|$, K would dominate the filtering characteristics. In addition, K acts as a resistor to damp parallel resonance between Z_S and Z_F.

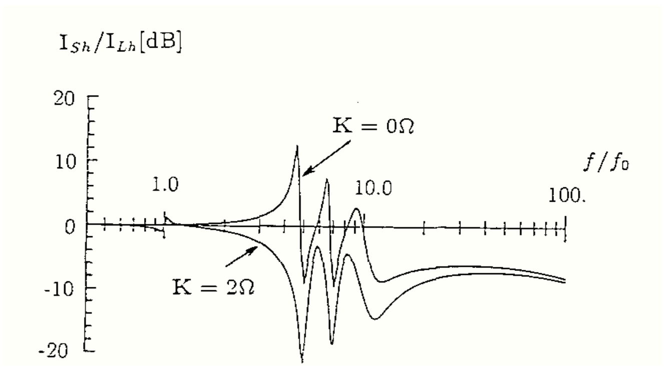

Fig. 5. Filtering characteristics for load harmonic current

In Fig. 5 the vertical axis indicates the ratio of source harmonic current to the load current. In the case of passive filter used alone (K=0), parallel resonance occurs near the fourth harmonic frequency. In the case of proposed system (K=2), the filtering characteristics are improved for all over the harmonic frequencies, and no parallel resonance occurs. Now, let us discuss the harmonics present in the source voltage, assuming there is no load (L_{Lh}=0) in Fig. 4(a). The active filter behaves just like a pure resistor K(Ω) as shown in Fig. 4(c). From Fig. 4(c), the following equations are obtained:

$$I_{sh}=\frac{V_{Sh}}{K+Z_S+Z_F} \quad (11)$$

$$V_{Th}=\frac{K+Z_F}{K+Z_S+Z_F}V_{Sh} \quad (12)$$

$$V_c=\frac{K}{K+Z_S+Z_F}V_{Sh} \quad (13)$$

If K » $|Z_{F+}Z_s|$, V_{sh} would be applied to the active filter. This prevents harmonic currents caused by V_{sh} from following into the passive filter.

VI. Simulink model

Simulink model is shown in Fig.6

VII. Simulation results

Fig. 7 shows terminal voltage waveform and THD analysis without any compensation

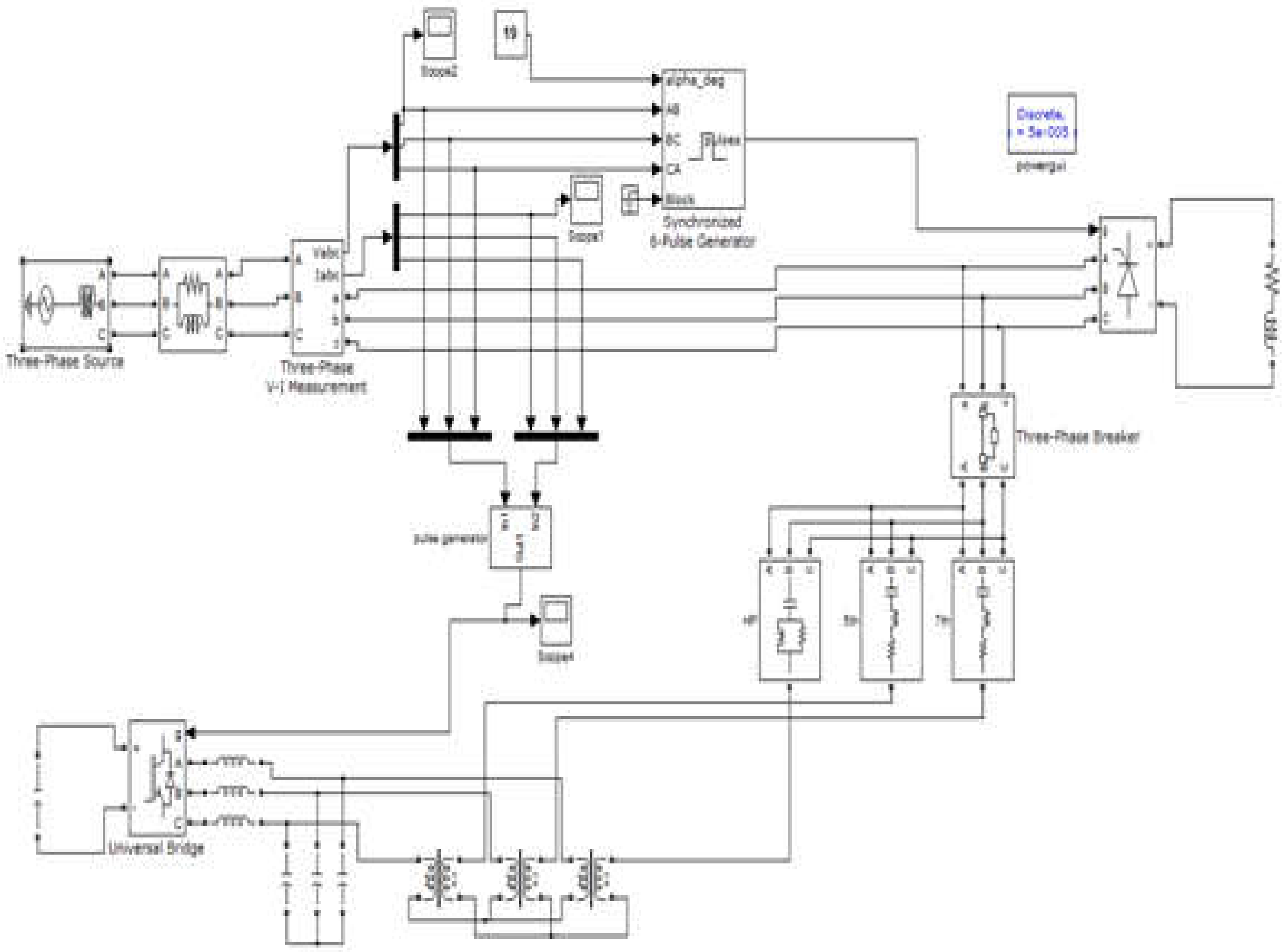

Fig.6. Simulink model

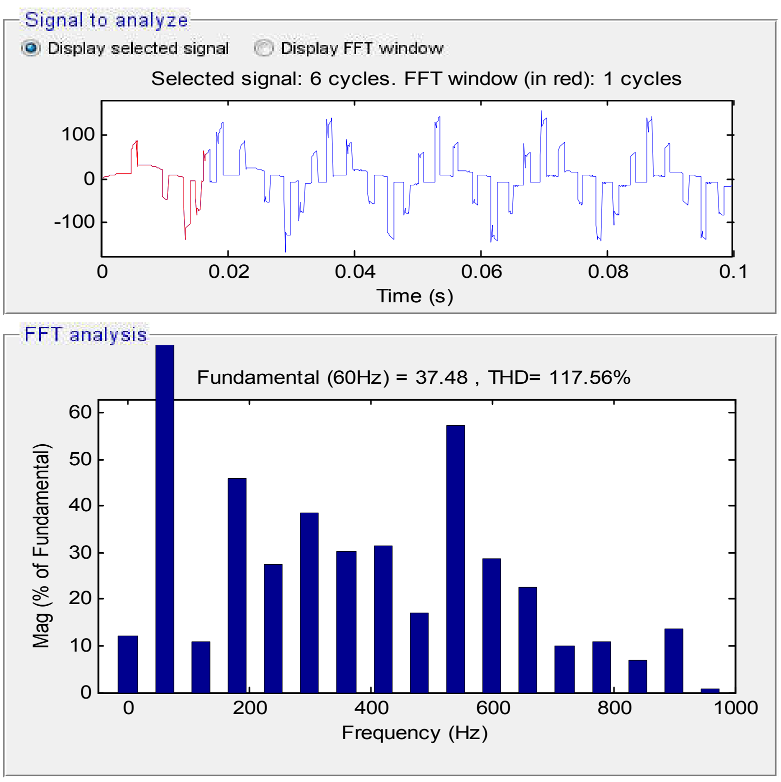

Fig. 7. Terminal Voltage waveform and THD analysis without any compensation

Fig. 8 shows source current waveform and THD analysis without compensation

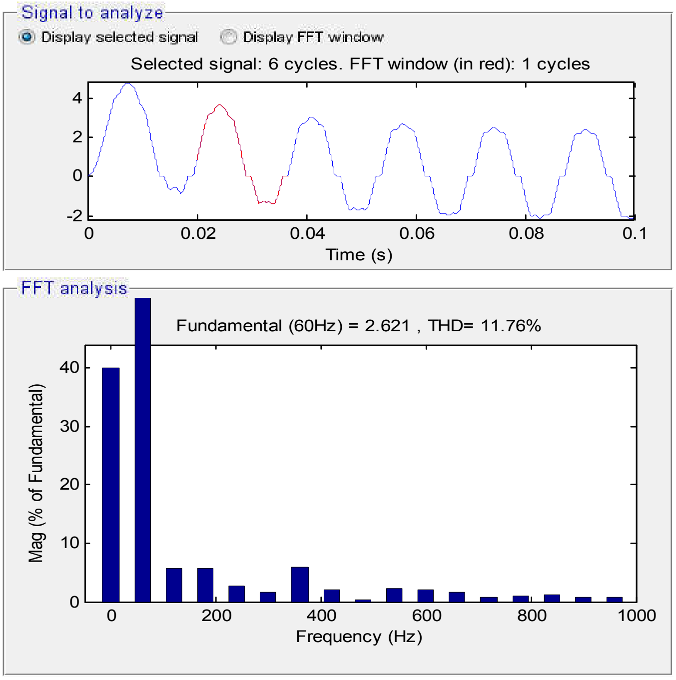

Fig.8. Source current waveform and THD analysis without compensation

Fig. 9 shows terminal voltage waveform and THD analysis after compensation

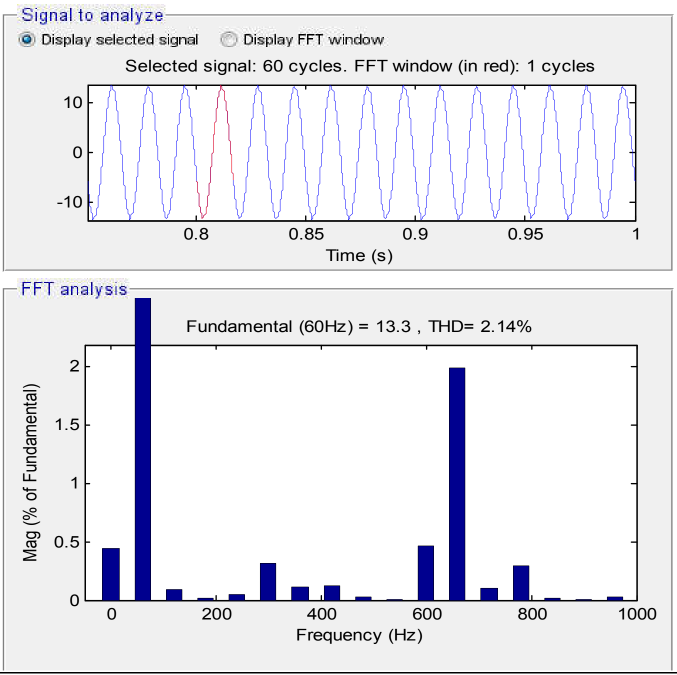

Fig.9. Terminal Voltage waveform and THD analysis after compensation

Fig. 10 shows source current waveform and thd analysis after compensation

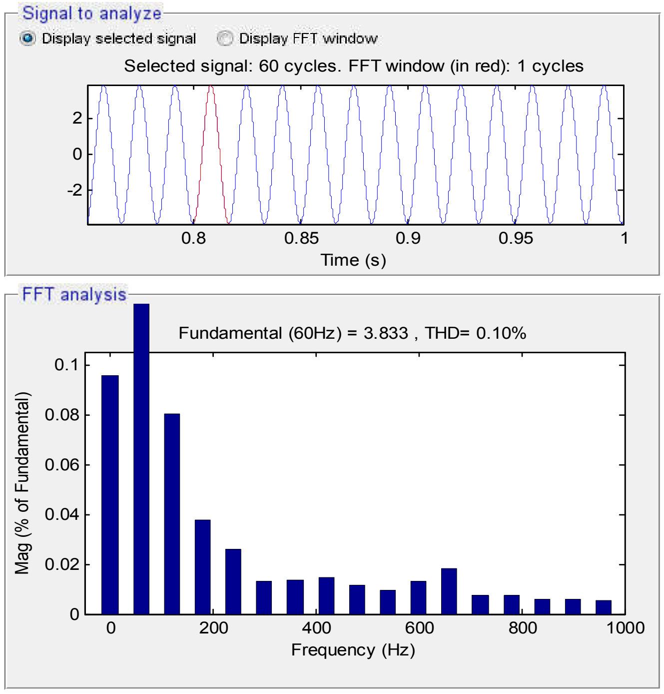

Fig.10. Source current waveform and THD analysis after compensation

VIII. Conclusion

The authors have proposed a combined system of a passive and an active filter, which are connected in series with each other. The theory developed in this paper was verified analytically and experimentally. The features of proposed system are summarized as follows:

1. Filtering characteristics are independent of source impedance.
2. Parallel and series resonance between the source and the passive filter can be damped by the active filter.
3. The required rating of the active filter is much smaller than that of a conventional active filter used alone.

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