International Journal of Advanced Technology in Engineering and Science www.ijates.com
Volume No.03, Issue No. 06, June 2015 ISSN (online): 2348 - 7550

ENHANCEMENT OF THE POWER QUALITY USING ACTIVE AND PASSIVE FILTER

Dharmendra Kumar Singh[1], Neena Godara[2], Anil Kumar Jha[3]

[1]*M.Tech Student, Al-Falah School of Engineering & Technology, Dhauj, Haryana (India)*

[2]*Assistant Professor, Al-Falah University, Dhauj, Haryana (India)*

[3]*Sr. Lecturer, NIET Greater Noida U.P (India)*

ABSTRACT

This paper presents the study of harmonic produced by the non-linear load. With the growth of modern industrial technology a large number of non- linear loads are used in power system, that increases harmonic distortion at the point of common coupling. A three phase hybrid filter is proposed that consists of a shunt passive filter and series active filter. The control technique is based on the instantaneous reactive power theory, so that the voltage injected by the series active power filter is able to compensate the reactive power and load current harmonics. The main objectives of proposed methods are to improve the power factor and to reduce total harmonic distortion to standard limits.

Keywords: Active Power Filter; Total Harmonics Distortion (THD); Shunt Passive Filters; Instantaneous Reactive Power Theory; Power Quality

I. INTRODUCTION

The increase in the number of nonlinear loads due to the proliferation of electronic equipment causes power quality in the power system to worsen. Harmonic current drawn from a supply by the nonlinear load results in the distortion of the supply voltage waveform at the point of common coupling (PCC) due to the source impedance[1]. Distorted current and voltage may causes end-user equipment to malfunction, conductors to be heated and may reduce the efficiency and life of the equipment connected at the PCC.

In recent years there has been considerable interest in the development and applications of active filters because of the increasing concern over electric power quality, both at distribution and consumer levels, and it is necessary to control reactive power and voltage stability at transmission levels. Active power filter of electric power system has now become a advance technology for harmonic and reactive power compensation in two-wire (single phase), three-wire, and four-wire (three - phase with neutral) ac power networks with nonlinear loads[13]. Active and passive filters are the conventional ways of compensating for harmonics. However, both have some drawbacks which are resonance and tuning problems in passive filters with system impedance, and capacity, initial and operating cost increases in active power filters (APF)[6].

Conventionally, a passive LC power filter has been used to attenuate the harmonic currents generated by nonlinear loads due to their low cost and higher efficiency. But, they have some drawbacks such as series and/ parallel resonances with system impedances, compensation characteristics depend on system impedance because in order to eliminate source current harmonics the filter impedance has to be smaller than the source impedance[2]. Only passive filters are not suitable for variable loads, due to variation of the load impedance can detune the filter and also they are designed for a specific reactive power and there is a danger that the passive filter behaves as a harmonic drain of close loads due to circulation of harmonic coming from nonlinear loads connected near the connection point of passive filter[5].

Some active power filter (APF) methods have been developed to suppress the harmonics generated by these loads. An active power filter typically consists of a three-phase pulse width modulation (PWM) voltage source inverter is connected in series to the ac source impedance [16]. Basically this equipment improves the compensation characteristics of the passive filter in parallel connection. System topology is shown in Fig. 1, where v_c is the voltage that the active filter should generate to achieve the objective of control method.

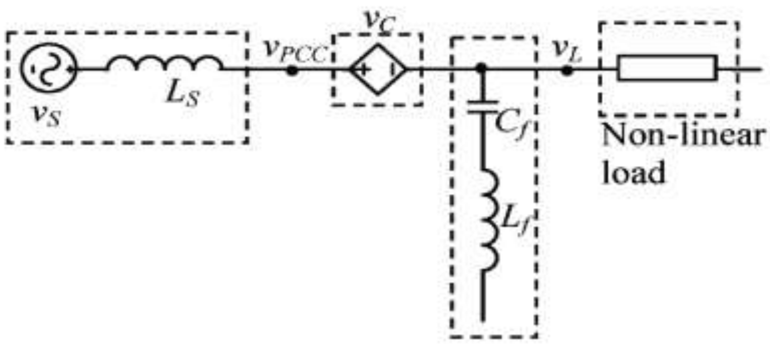


Fig. 1 Series Active and Shunt passive filter

1.1 Electric Power Quality

Power systems are designed to operate at frequencies of 50 or 60 Hz. However, certain types of non-linear loads produce currents and voltages with frequencies that are integer multiple of the fundamental frequency. These frequency components are called as harmonic pollution and are having adverse effect on the power system network[10]. This is generally a consumer driven issue, so PQ problem is defined as, "any occurrence manifested in voltage, current, or frequency deviations that results in damage, failure or misoperation of end use equipment."

1.2 Harmonic Distortion

Due to increased use of nonlinear loads, one of the PQ issues that have been gaining continuous attention is the harmonic distortion. The nonlinear loads control the flow of power by drawing currents only during certain intervals of the fundamental period. Hence the current supplied by the source becomes non-sinusoidal and contains higher percentage of harmonic components [11].

The Total Harmonic Distortion (THD) is the most common measurement index of measuring harmonic distortion [18]. THD applies to both current and voltage and is defined as the root-mean-square (rms) value of harmonics divided by the rms value of the fundamental, and then multiplied by 100% as shown in the following equation:

$$THD = \frac{\sqrt{\sum_{k=2} h_k^2}}{h_1} \times 100 \ \% \tag{1}$$

Where h_k is the rms value of harmonic component k of the quantity h.

II. ANALYSIS OF DIFFERENT CONTROL TECHNIQUES

2.1 Generation of a Voltage Proportional to the Source Current Harmonics

With this control algorithm, the elimination of series and/or parallel resonances with the rest of the system is possible. The active filter can limit the passive filter becoming a harmonics drain on the close loads. Additionally, it can prevent the compensation features depending on the system impedance. The ideal situation would be that the proportionality constant, k, between the active filter output voltage and source current harmonics, had a high value. However, at the limit this would be an infinite value and would mean that the control objective was impossible to achieve. The chosen k value is usually small so as to avoid high power active filters and instabilities in the system. However, the choice of the appropriate k value is an unsolved question since it is related to the passive filter and the source impedance values[4]. But this strategy is not suitable for use in systems with variable loads because the passive filter provides constant reactive power, and therefore, the set compensation equipment and load has a variable power factor.

2.2 Generation of Voltage Proportional to Load Side Harmonics

For this proposed control technique, the active power filter generates a voltage waveform similar to the voltage harmonics at the load side but in opposition [5]. This technique only limits the parallel passive filter depending on the source impedance; the other limitations of the passive filter nevertheless remain and hence it is not so effective.

2.3 Generation of Voltage Proportional to Both Side Harmonics

Other control strategies combining both the above have been proposed to improve the parallel passive filter compensation characteristics [5], [9], but they continue to suffer from the difficulty of finding an appropriate value for the APF gain k.

2.4 Generation of Voltage Which Compensates Passive Filter

Another approach has recently been proposed [11]. It suggests that the active filter generates a voltage which compensates the passive filter and load reactive power, therefore, it allows the current harmonics to be eliminated. Algorithm is based on the instantaneous reactive power theory [14]. The control target is to achieve constant power in the source side. Table. 1 shows the comparison between these control techniques with their drawbacks. Hence, we observe that above mentioned control techniques suffer from one or the other limitations due to which APLC cannot provide the complete and appropriate compensation. Consequently we have to look for a suitable control strategy which gives a promising solution to compensate for the adverse effects of harmonics & reactive power simultaneously and hence improves the compensation characteristics of the filters eliminating the earlier limitations.

Table. 1 Comparision Between Control Technique

S.No	Control Technique	Drawback
1	Generation of a voltage proportional to a source current harmonic	Cannot use in system with variable loads & also limiting value of gain K tends to infinite.
2	Generation of voltage waveform similar to voltage harmonics at the load side in phase opposition.	Possibility of series or parallel resonances with the rest of system.
3	Control strategies combining both the above techniques.	Improves most of characteristics but difficult to find appropriate value for APF gain K.
4	APF generating voltage which compensates passive filters and load reactive power.	Used in cases where control target is only to achieve constant power in the source side.

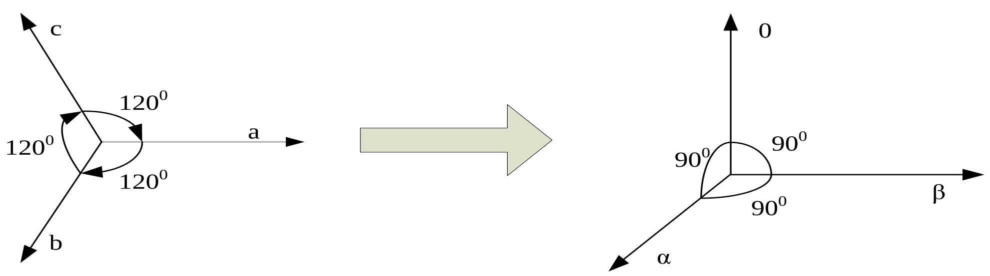


Fig. 2a Transformation from the Phase Reference System (abc)to the $0\alpha\beta$ System

III. THE INSTANTANEOUS REACTIVE POWER THEORY

It is mainly applied to compensation equipment in parallel connection. Basically, this theory is based on a Clarke coordinate transformation from the phase coordinates. In a three-phase system in Fig. 2b, voltage and current vectors can be defined by

$$v = [v_a \quad v_b \quad v_c]^T \qquad i = [i_a \quad i_b \quad i_c]^T \tag{2}$$

The vector transformations from the phase reference system a-b-c to $\alpha-\beta-0$ coordinates can be obtained, thus

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

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{4}$$

The instantaneous real power in the $\alpha-\beta-0$ frame is calculated as follows:

$$p_{3\phi}(t) = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \tag{5}$$

The above power can be written as

$$p_{3\phi}(t) = p + p_0 \tag{6}$$

Where p is the instantaneous real power without zero sequence component and given by

$$p_{3\phi}(t) = v_\alpha i_\alpha + v_\beta i_\beta \tag{7}$$

This can be written in vectorial form by means of dot product

$$p = \bar{i}^T{}_{\alpha\beta}\bar{v}_{\alpha\beta} \tag{8}$$

Where $\bar{i}^T{}_{\alpha\beta}$ is the transposed current vector in $\alpha - \beta$ coordinates

$$\bar{i}_{\alpha\beta} = [i_\alpha \quad i_\beta]^T \tag{9}$$

In the same way, $\bar{v}_{\alpha\beta}$ is the voltage vector in the same coordinates

$$\bar{v}_{\alpha\beta} = [v_\alpha \quad v_\beta]^T \tag{10}$$

In equation (6), p_0 is the zero sequence instantaneous power, calculated as follows:

$$p_0 = v_0 i_0 \tag{11}$$

But in a three-wire system there are no zero-sequence current components, that is, $i_0 = 0$. Therefore, in this case, only the instantaneous power defined on the $\alpha - \beta$ axes exists, because the product $v_0 i_0$ is always zero.

The imaginary instantaneous power is defined by the equation

$$q = v_\alpha i_\beta - v_\beta i_\alpha \tag{12}$$

In accordance with (8), this can be expressed by means of the dot product

$$q = \bar{i}^T{}_{\alpha\beta\perp}\bar{v}_{\alpha\beta} \tag{13}$$

Where $\bar{i}^T{}_{\alpha\beta}$ is the transposed current vector perpendicular to $\bar{i}_{\alpha\beta}$ and it can be defined as follow:

$$\bar{i}_{\alpha\beta\perp} = [i_\beta \quad -i_\alpha]^T \tag{14}$$

Both power variables previously defined can be expressed as

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} \bar{i}^T{}_{\alpha\beta} \\ \bar{i}^T{}_{\alpha\beta\perp} \end{bmatrix} \bar{v}_{\alpha\beta} \tag{15}$$

Now in the $\alpha\beta$ plane, $\bar{i}_{\alpha\beta}$ and $\bar{i}_{\alpha\beta\perp}$ vectors establish two coordinates axes. The voltage vector $\bar{v}_{\alpha\beta}$ can be decomposed in its orthogonal projection on the axis defined by the currents vectors, Fig. 2c. By means of the current vectors and the real and imaginary instantaneous power, So the voltage vector can be calculated as:

$$\bar{v}_{\alpha\beta} = \frac{p}{i^2{}_{\alpha\beta}}\bar{i}_{\alpha\beta} + \frac{q}{i^2{}_{\alpha\beta}}\bar{i}_{\alpha\beta\perp} \tag{16}$$

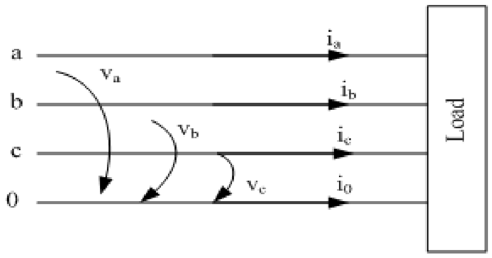


Fig. 2b Three Phase System

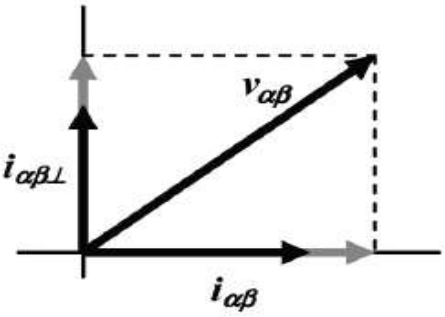


Fig. 2c Decomposition of the Voltage Vector

Since in a four-wire system, the zero sequence instantaneous power p_0 is not null. In this case, (16) would have to include an additional term with the form $({p_0}/{i_0^2})\bar{i}_0$, where $\bar{i}_0$ is the zero sequence current vector.

IV. COMPENSATION STRATEGY FOR HYBRID FILTER

Since all electric companies try to generate electrical power as sinusoidal and balanced voltages so it has been obtained as a reference condition in the supply. Due to this, the compensation target is based on an ideal reference load which must be resistive, linear and balanced. It means, the source currents are collinear to the supply voltages and the system will have unity power factor. If voltages are considered as balanced and sinusoidal which is shown in Fig. 2b, ideal currents will be proportional to the supply voltages as:

$$\bar{v} = R_e \bar{i} \tag{17}$$

R_e is the equivalent resistance, $\bar{v}$ the load voltage vector and $\bar{i}$ the load current vector. The average power supplied by the source will be

$$P_s = I_1^{\,2} R_e \tag{18}$$

In this equation, $I_1^{\,2}$ is the square rms value of the fundamental harmonics of the source current vector. It must be supposed that when voltage is sinusoidal and balanced, only the current fundamental component transports the power consumed by the load.

Compensator instantaneous power is the difference between the total real instantaneous power required by the load and the instantaneous power supplied by the source

$$p_c(t) = p_L(t) - p_s(t) \tag{19}$$

In this equation, the average power exchanged by the compensator has to be null, that is

$$P_c = \frac{1}{T}\int p_c(t)dt = 0 \tag{20}$$

When average values are calculated in (19), and (18) and (20) are taken into account

$$0 = \frac{1}{T}\int p_L(t)dt - I_1^{\,2} R_e \tag{21}$$

Hence, the equivalent resistance can be calculated as

$$R_e = \frac{P_L}{I_1^{\,2}} \tag{22}$$

Where P_L is the load average power, defined as

$$P_L = \frac{1}{T}\int p_L(t)dt \tag{23}$$

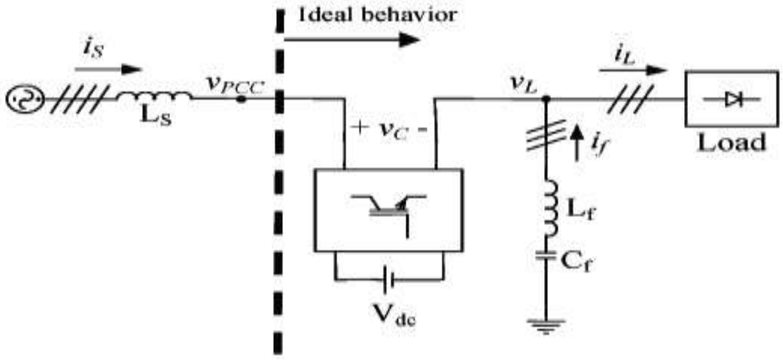


Fig. 3. System with Compensation Equipment

Fig. 3 shows the system with series active filter, parallel passive filter and unbalanced and nonsinusoidal load. The aim is that the set compensation equipment and load has an ideal behavior from the PCC. The voltage at the active filter connection point in $0\alpha\beta$ coordinates can be calculated as follows:

$$\bar{v}_{PCC\alpha\beta} = \frac{P_L}{I_1^{\,2}}\bar{i}_{\alpha\beta} \tag{24}$$

$\bar{i}_{\alpha\beta}$ is the source current in $0\alpha\beta$ coordinates. In this equation, the restriction of null average power exchanged by the active filter is imposed.

The load voltage is given according to equation (16) as:

$$\bar{v}_{L\alpha\beta} = \frac{p_L}{i_{\alpha\beta}^{\;2}}\bar{i}_{\alpha\beta} + \frac{q_L}{i_{\alpha\beta}^{\;2}}\bar{i}_{\alpha\beta\perp} \tag{25}$$

where p_L is the instantaneous real power and q_L is the instantaneous load imaginary power.

The reference signal for the output voltage of the active filter is given as:

$$\bar{v}^*{}_{C\alpha\beta} = \bar{v}_{PCC\alpha\beta} - \bar{v}_{L\alpha\beta} \tag{26}$$

From equation (24) and (25), the compensation voltage is:

$$\bar{v}*_{C\alpha\beta} = \left(\frac{P_L}{I_1^{\,2}} - \frac{p_L}{i^2{}_{\alpha\beta}}\right)\bar{i}_{\alpha\beta} - \frac{q_L}{i^2{}_{\alpha\beta}}\bar{i}_{\alpha\beta\perp} \tag{27}$$

When the active filter supplies this compensation voltage, the set load and compensation equipment behaves as a resistor R_e. Finally, if currents are unbalanced and nonsinusoidal, a balanced resistive load is considered as ideal reference load. Therefore, the equivalent resistance must be defined by the equation

$$R_e = \frac{P_L}{I_1^{+2}} \tag{28}$$

Here I_1^{+2} is the square rms value of the positive sequence fundamental component. So equation (27) is modified, where I_1 is replaced by I_1^+, that is

$$\bar{v}_{c\alpha\beta} = \left(\frac{p_L}{I_1^{+2}} - \frac{p_L}{i_{\alpha\beta}^2} \right) \bar{i}_{\alpha\beta} - \frac{q_L}{i_{\alpha\beta}^2} \bar{i}_{\alpha\beta\perp} \qquad (29)$$

Reference signals are obtained by means of the control scheme as shown in Fig. 4

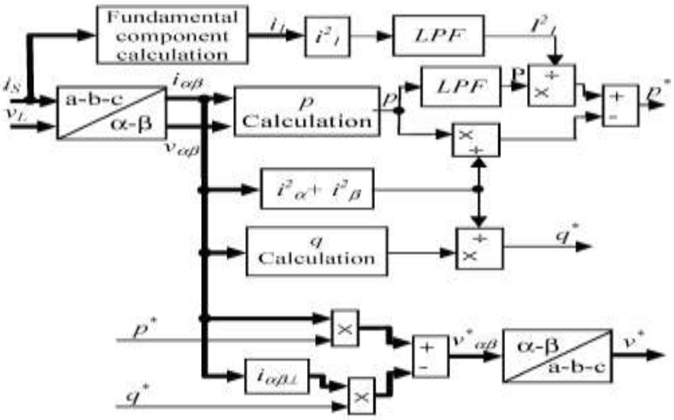


Fig. 4 Control Scheme for Active Power Filter

V. SIMULATION RESULT AND ANALYSIS

The system has been simulated in the Matlab-Simulink platform to verify the proposed control as shown in Fig. 5. Each device has been modeled using the Sim Power System toolbox library. The power circuit is a three-phase system supplied by a sinusoidal balanced three-phase 100-V source with a source inductance of 5.8 mH and a source resistance of 3.6 Ω. In this model the inverter consists of an Insulated Gate Bipolar Transistor (IGBT) bridge. LC filter has been used to eliminate the high frequency components at the output of the inverter. Active filter is connected to the power system by means of three single-phase transformers with a turn ratio of 1:1.

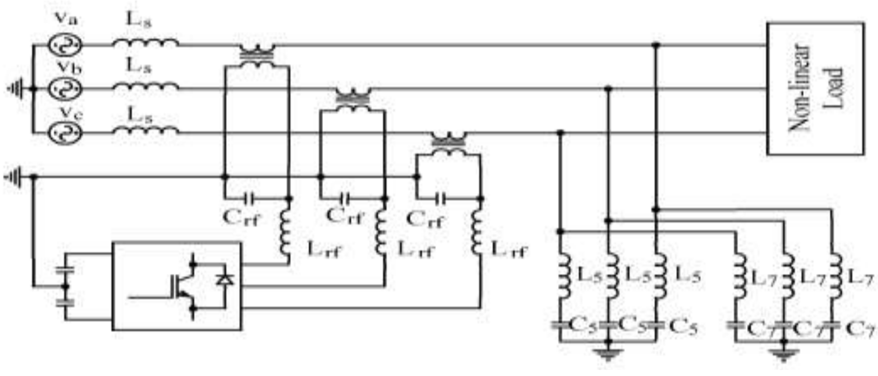


Fig. 5 Series Active and Shunt Passive Filter Topology

Case 1: When only passive filter is connected.

Simulation model of power system with shunt passive filter is shown in Fig. 6. The passive filter is constituted by two LC branches that mitigate the fifth and seventh harmonics. The passive elements value is given in Table 2.

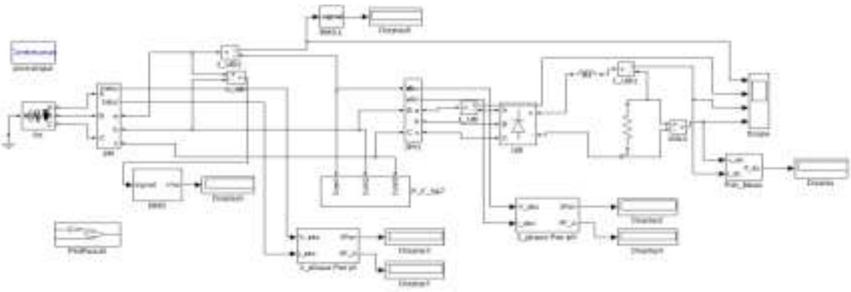


Fig. 6 Simulation Model of Power System with Shunt Passive Filter Connected

In this model, the nonlinear load consists of an uncontrolled three-phase rectifier with an inductance of 55 mH and 20 Ω resistor connected in series on the dc side. For a load resistance 20 Ω, the THD on the source side is 3.49% and THD on the load side is 24.43% as shown in Fig.7a & 7b.

Table. 2 Passive Filter Element Values

Source	L_s= 5.8 mH, R_s=3.6 Ω	
Passive filter	L_5= 13.5 mH	C_5= 30 μF
	L_7= 13.5 mH	C_7= 30 μF
Ripple filter	L_r = 13.5 mH	C_r = 50 μF

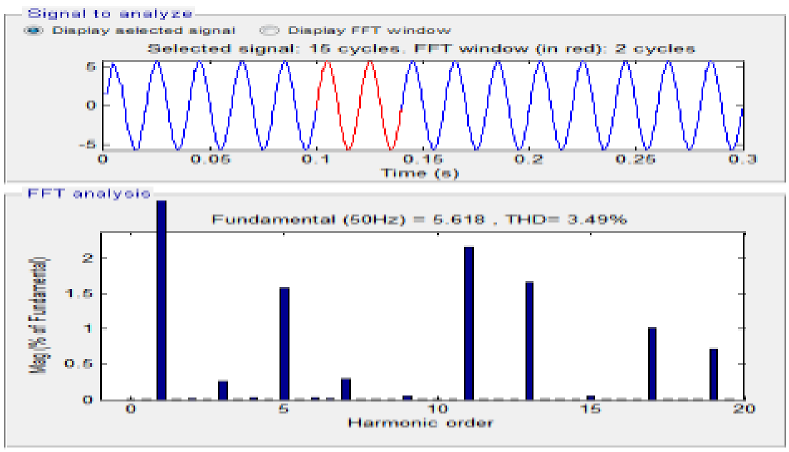


Fig. 7a THD on the Source Side when Passive Filter is Connected

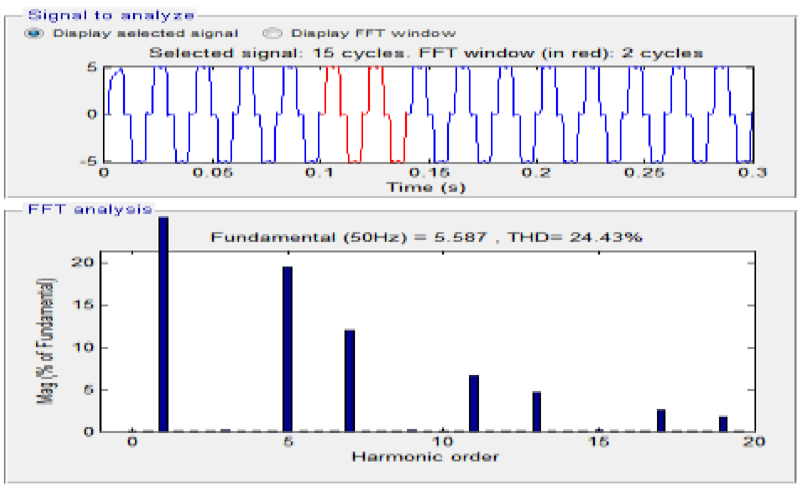


Fig. 7b THD on the Source Side when Passive Filter is Not Connected

The load current total harmonic distortion is 24.43 % and the power factor is 0.9645, when the system is not compensated. The load current waveform of phase “a” with passive is shown in Fig. 8a.

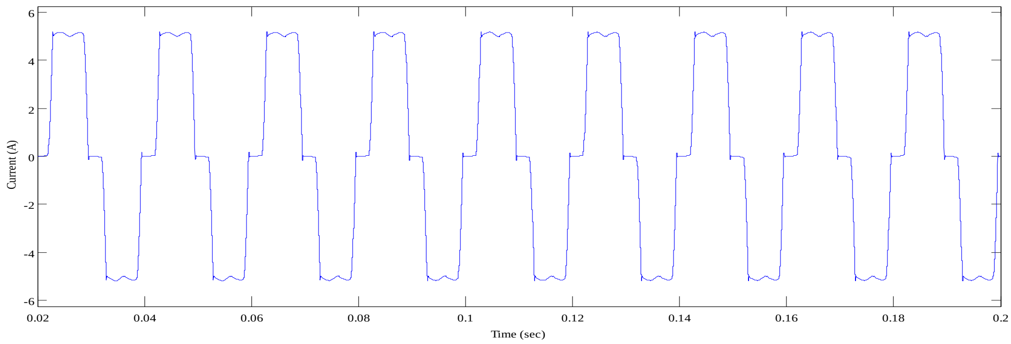


Fig. 8a Load Current of Phase “a” When Passive Filter is not Connected

Since two LC branches were connected to to mitigate the 5th and 7th harmonics. The source current waveform with the passive filter connected is shown in Fig. 8b. The THD falls to 3.49% and power factor of the set load is 0.9869.

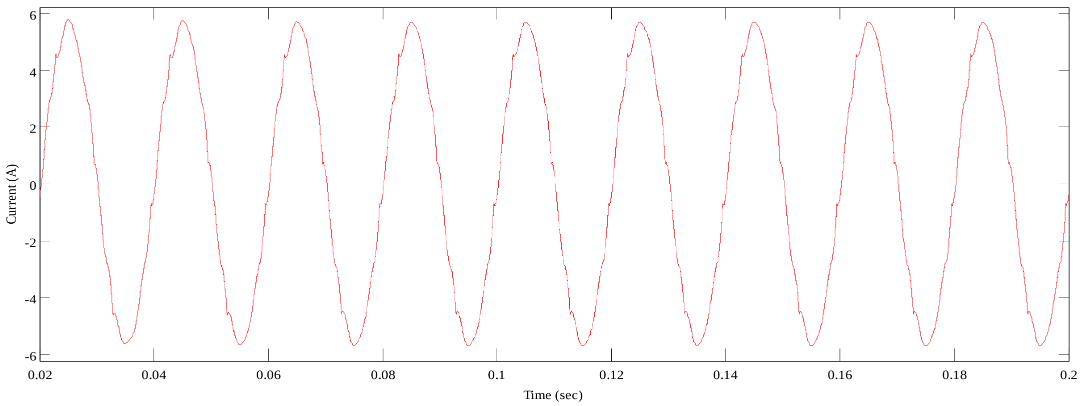
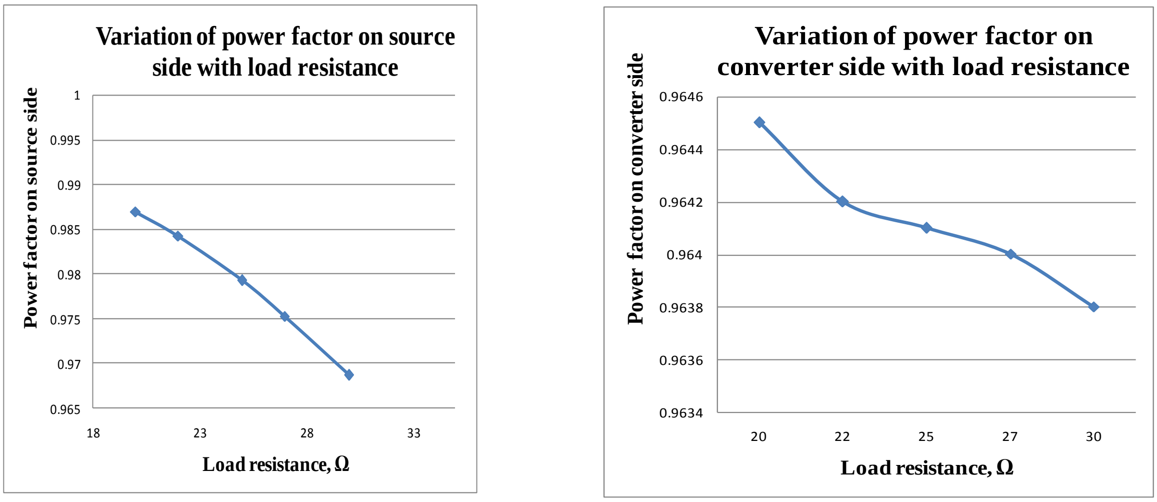


Fig.8b Waveform of Source Current when Passive Filter is Connected

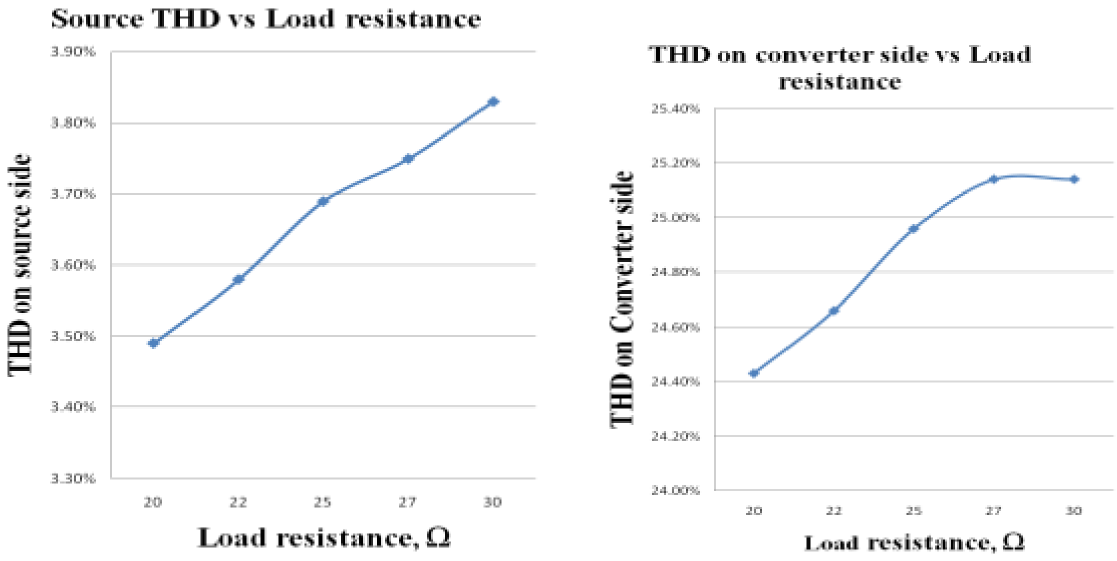
The variation of power factor on the source side and on the converter side is shown in Fig. 9a.



(a) **(b)**

Fig. 9a Variation of Power Factor with Load Resistance

The passive filter was designed only to compensate the source current harmonics and reactive power was not considered in this case. Variation of THD with Load resistance is shown in Fig. 9b. The passive filter impedance has to be lower than the system impedance in order to be effective. The Variation of power factor and THD with different load resistance is shown in Table. 3.



(a) **(b)**

Fig. 9b Variation of THD With Load Resistance

Table.3 Variation of Power Factor and THD with different load resistance

S. No	**Load Resistance (Ω)**	**V_{IN} (V)**	**I_{IN}(A)**		**P_I (W)**	**P_{DC} (W)**	**PF SOURCE**	**PF CONVERTER**	**THD_{iS}**	**Fundamental current (A)**	**THD_{iR}**	**Fundamental Curret (A)**
			Line	***Converter***								
1	20	76.11	3.975	4.067	517.6	517.5	0.9869	0.9645	3.49%	3.9725	24.43%	3.9506
2	22	77.98	3.717	3.793	482.6	482.5	0.9842	0.9642	3.58%	3.7144	24.66%	3.6833
3	25	80.35	3.393	3.446	462.8	462.7	0.9792	0.9641	3.69%	3.3905	24.96%	3.3432
4	27	81.71	3.21	3.247	443.4	443.3	0.9752	0.964	3.75%	3.2074	25.14%	3.1494
5	30	83.46	2.975	2.99	416.9	416.8	0.9686	0.9638	3.83%	3.207	25.14%	3.1494

Case 2: When both Shunt passive and Series active filters are connected.

In this case, the nonlinear load consists of an uncontrolled three-phase rectifier with an inductance of 55 mH and a 25 Ω resistor connected in series on the dc side.

Since as mentioned above the passive filter was designed only to compensate the source current harmonics; the reactive power was not considered. So in order to get the source current without distortion an active filter is connected in series with the load along with parallel passive filter. The passive filter is connected along with active filter in order to reduce internal harmonics generated by the active filter. By means of a calculation block, $\bar{v}_{\alpha\beta}$ and $\bar{i}_{\alpha\beta}$ vectors in $\alpha\beta$ coordinates can be determined.

When the active filter is connected, the source current THD falls to 2.80% and power factor increased to 0.99. The waveform is shown in Fig. 11b. THD and power factor for source current for nonlinear balanced load is shown in Table. 4.

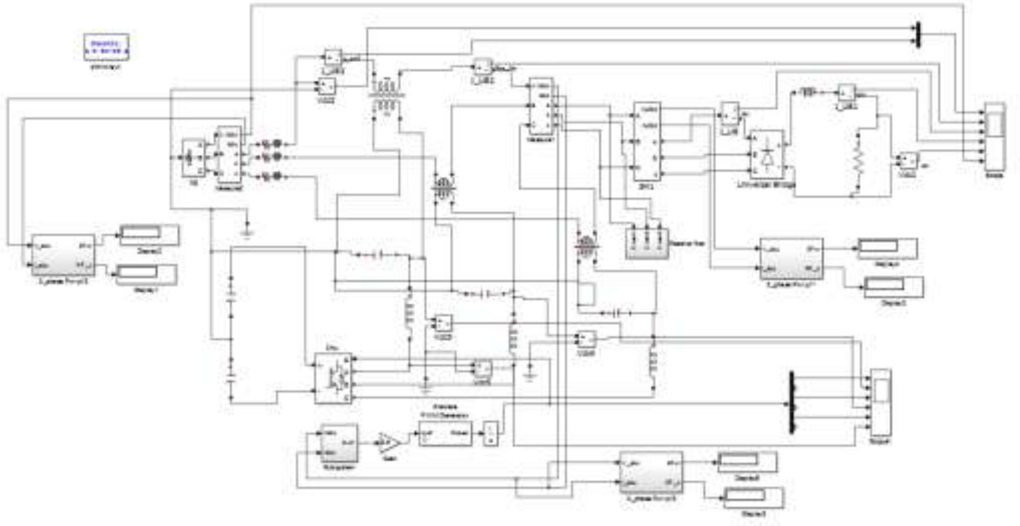


Fig. 10 Simulation Model of Power System with Shunt Passive and Series Active Filters Connected

Table. 4 THD and Power Factor for Source Current for Nonlinear Balanced Load

Source impedance 5.8mH, 3.6Ω	Without filters	With only passive filter	With both active and passive filters
THD	24.96 %	3.69 %	2.80 %
Power factor	0.9641	0.9792	0.99

Table.5 System Parameters for the Simulation

System parameters	**Values**
Source voltage	100 V
Supply frequency	50 Hz
Source Impedance	5.8 mH, 3.6 Ω
Non-Linear load under steady state	55 mH, 25 Ω
Dc side capacitance	40 μF
Base Voltage	100V

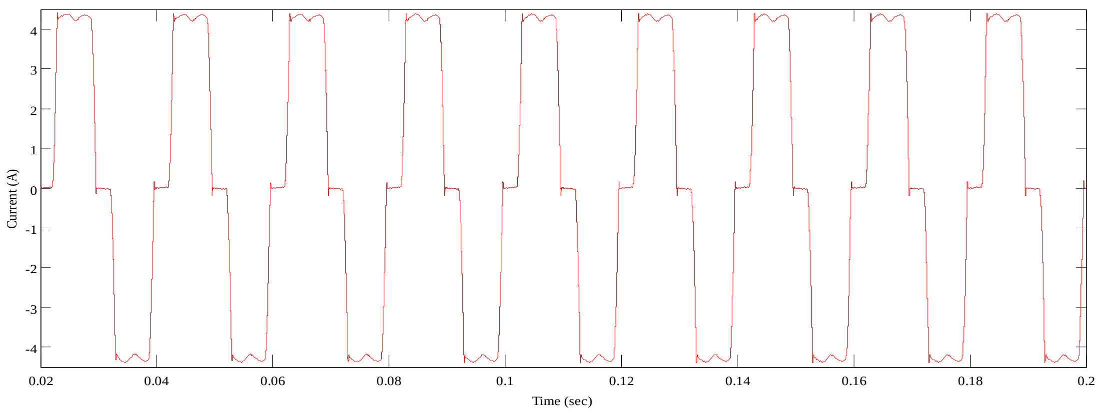


Fig. 11a Waveform of Source Current When the Active Filter is not Connected

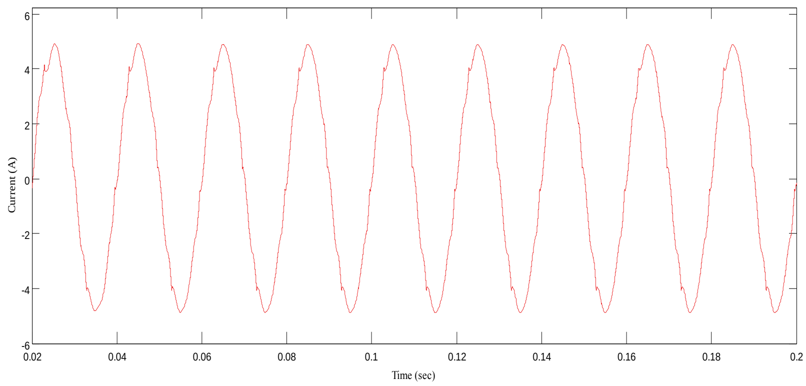


Fig. 11b Waveform of Source Current When the Active Filter is Connected

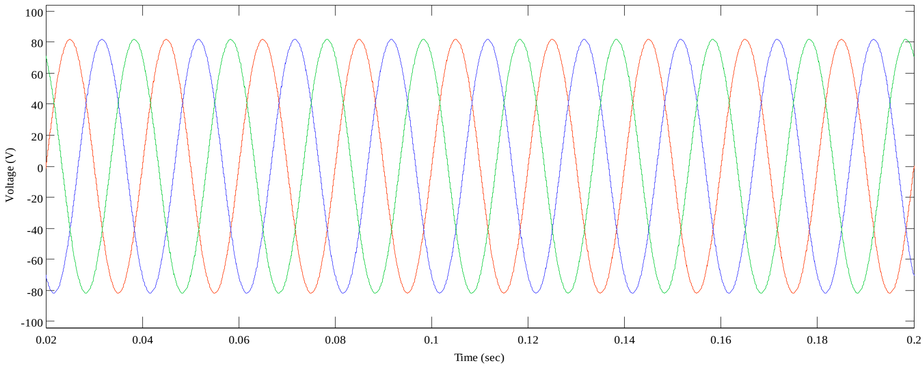


Fig.11c Waveform of Three Phase Voltages

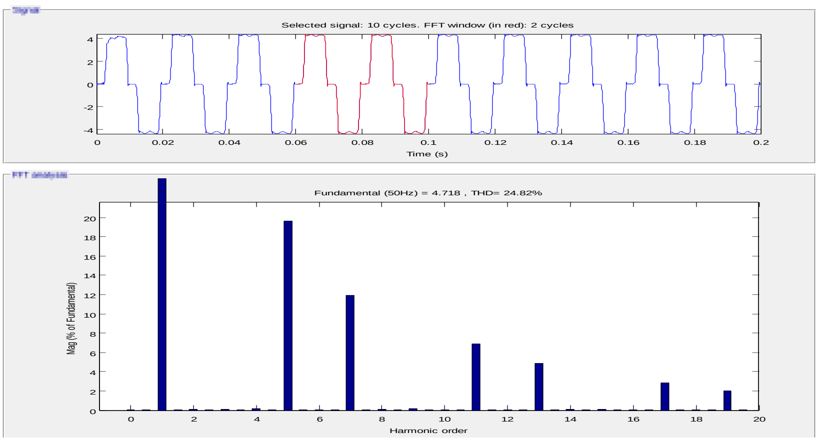


Fig. 12a THD on the Source Side When Series Active Filter is Connected

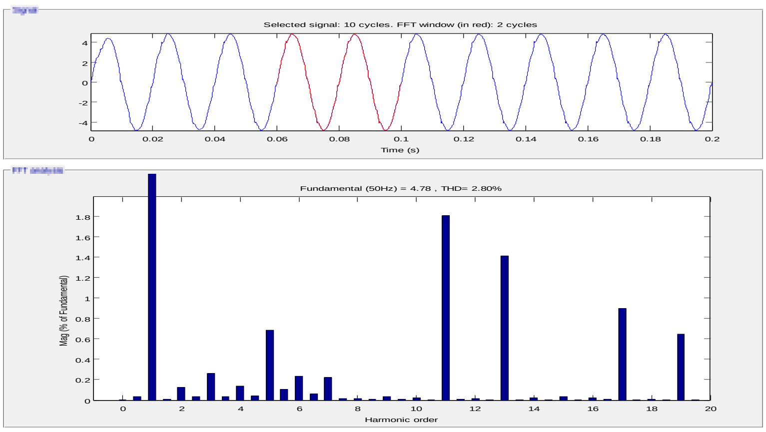


Fig. 12b THD on the Source Side when Series Active Filter is Connected

VI. CONCLUSION

In this paper a control algorithm for a hybrid power filter constituted by a series active filter and a passive filter connected in parallel with the load is proposed. The control strategy is based on the dual vectorial theory of electric power. The compensation principle applied to this system is quite different from conventional shunt passive and series active power filters. With the proposed control algorithm, the active filter improves the harmonic compensation features of the passive filter and the power factor of the load. Simulations with the MATLAB-Simulink platform were performed with different loads.The combined system is the most suitable to harmonic compensation for large rated thyristor converters.

REFERENCES

[1] P. Salmerón and S. P. Litrán, "Improvement of the Electric Power Quality Using Series Active and Shunt Passive Filters" IEEE Trans. Power Delivery, vol.25, no. 2, pp 00781-2008, April 2010.

[2] H. Akagi, "Active harmonic filters," Proc. IEEE, vol. 93, no. 12, pp. 2128–2141, Dec. 2005.

[3] B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," IEEE Trans. Ind. Electron., vol. 46, no. 5, pp. 960–971, Oct. 1999.

[4] Z. Wang, Q. Wang, W. Yao, and J. Liu, "A series active power filter adopting hybrid control approach," IEEE Trans. Power Electron., vol. 16, no. 3, pp. 301–310, May 2001.

[5] F. Z. Peng, H. Akagi, and A. Nabae, "A novel harmonic power filter," in Proc. IEEE/PESC, Apr. 1988, pp. 1151–1159.

[6] Y. S. Kim, J. S. Kim, and S. H. Ko, "Three-phase three-wire series active power filter, which compensates for harmonics and reactive power," IEE Proc. Electric. Power Applications, vol. 151, no. 3, pp.276–282, May 2004.

[7] F. Z. Peng and J. S. Lai, "Generalized instantaneous reactive power theory for three phase power system," IEEE Trans. Instrum.Meas. vol.45, no. 1, pp. 293–297, 1996.

[8] P. Salmerón, R. S. Herrera, and J. R. Vázquez, "Mapping matrices against vectorial frame in the instantaneous reactive power compensation," IET Elect. Power Applic. vol. 1, no. 5, pp. 727–736, Sep. 2007.

[9] Sangsun Kim, Enjeti P.N, "A new hybrid active power filters (APF) topology" IEEE Trans. Power Electronics, vol.17, (2002):pp.48-58.

[10] Hadi Saadat " Power System Analysis" , New York; McGraw-Hill, 1994.

[11] P.Salmeron, S.P.Litran," Power Quality Improvement using filters", IEEE Tn Power Del., vol.25;no.2, April 2010.

[12] W.C.Lee, D.M.Lee, T.K.Lee, "New control scheme for a upqc with minimum active power injection", IEEE Trans. on power del., vol.25, no.2, April 2010.

[13] H. Zhong, P. Chen, Z. Lu, Z. Qian, and H. Ma, "Three-phase four wire series hybrid active power filter with fundamental current bypass channel," in Proc. Industrial Electronics Society (IECON), Nov. 2004, vol. 1, pp. 536–539.

[14] Mendalek N., Al-Haddad K., Fnaiech F and Dessaint L.A., "Nonlinear control technique to enhance dynamic performance of a shunt active power filter" IEEE Trans. Power application, vol. 150, (2003):pp. 373–379.

[15] G.-M. Lee, D.-C. Lee, and J.-K. Seok, "Control of series active power filters compensating for source

voltage unbalance and current harmonics," IEEE Trans. Ind. Electron., vol. 51, no. 1, pp. 132–139, Feb. 2004.

[16] S. Bhattacharya and D. M. Divan, "Hybrid series active/parallel passive power line conditioner with controlled harmonic injection," U.S. Patent 5 465 203, Nov. 1995.

[17] Amoli M. E. and Florence T., "Voltage, current harmonic content of a utility system-A summary of 1120 test measurements," IEEE Trans. Power Delivery, vol. 5:pp. 1552–1557, 1990.

[18] Robert D Henderson, Patrick J. Rose "Harmonics: The effect on power quality and transformer" IEEE Trans. Industry Applications, vol. 30, no.3:pp. 528-53, 1994.

[19] B. Singh, V. Verma, A. Chandra, K. Al-Haddad, "Hybrid filters for power quality improvement," IEEE Proc. on Generation, Transmission and Distribution, Vol. 152, pp. 365-378, 2005.

[20] Peng F. Z., Akagi H., Nabae A., "A new approach to harmonic compensation in power system- a combined system of shunt passive and series active filters " IEEE Trans. Industry Applications, vol. 26, (1990):pp.983-990.

[21] Narain G. Hingorani, Laszlo Gyugyi. 'Understanding FACTS', A John Wiley & Sons, Inc.,

[22] R. C. Dugan, M. F. McGranaghan, S. Santosa, and H. W. Beaty, Electrical Power Systems Quality, 2nd edition, McGraw-Hill, 2002.Publication.