AN IMPROVED HYBRID ACTIVE POWER FILTER FOR POWER QUALITY IMPROVEMENT IN THREE PHASE FOUR WIRE SYSTEM

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Abstract: - This paper presents a hybrid active power filter for a three phase four wire distribution system. The scheme consists of a zigzag transformer, single phase active power filter connected in series with the utility neutral and a coupling capacitor connected in series with a voltage source converter of the active power filter (APF). The addition of coupling capacitor permits the reduction in DC link voltage requirement. This hybrid approach reduces the overall rating of the compensator. The model of topology is developed in the MATLAB / Simulink environment to simulate the performance characteristics. A proportional controller followed by a positive sequence detector is used to generate a reference signal for the VSC. Experimental studies are carried out on the prototype of three-phase four wires active power filter (APF) to validate the simulated response.
Keywords: - power quality, hybrid APF, coupling capacitor, zigzag transformer, DC link voltage

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1. INTRODUCTION

With the development of digital signal processing and power electronics technology, the grid integration of renewable energy sources is continuously increasing in an electrical power distribution system which is one of the sources of harmonics. Due to the increased penetration of the power electronics devices, nonlinear and unbalanced load the power quality in the electrical distribution power system has degraded [1-5]. To improve the quality of power in three phase four wire (3P4W) distribution system, three phase four wire active power filters has been proposed. There are many topologies reported in the literature for three-phase four-wire system[6-23] such as a three single voltage source converter , split capacitor voltage source converter and four leg voltage source converter. These filtering schemes require the large KVA rating of the inverter .And also split capacitor topology suffer from unequal voltages.

The reduced rating hybrid 3P4W topologies based on transformers and 3P3WAPF given in [8-15]. Even though, these topologies can compensate phase harmonics and reduce neutral current to a great extent. But, their compensation performances are dependents on their impedance, location and utility voltage conditions. A hybrid active power filter consists of a zigzag - delta transformer, 3P3W APF and single phase APF are used for compensation of utility neutral current and utility phase current harmonics [16-17], but, no attempt was made to improve the displacement power factor. Also utility currents are not balanced. However, these filtering schemes require a high DC link voltage of 3P3W APF and switching frequency ripple filter.

The compensating performance of the 3P3W APF is largely influenced by DC link voltage [18-21]. In order to compensate harmonics and reactive power effectively at PCC the magnitude of the reference DC link voltage should be greater than the peak voltage of phase to neutral. In actual practice, for harmonics free compensation, the DC link voltage is $\sqrt{6}$ times the peak value of the phase to neutral voltage. When the DC link voltage less than this value, the resultant voltage is insufficient to track the desired response of 3P3W APF. Due to the higher values of the DC link capacitor voltage the rating and the size of the VSI topology becomes bulky, which in turn increase the cost of the APF topology. In recent year, in [22] hybrid power filter has been discussed in drive applications. A hybrid power filter tuned to the seventh harmonic frequency connected to the diode rectifier load. Primarily, this type of hybrid power filter designed for motor drives application.

To address above limitations, in this paper, a three phase four wire active power filter topology with reduced DC-link voltage is proposed. This topology consists of coupling capacitor connected in series with the inductor of shunt active power filter. The series connected coupling capacitor permits reduction in DC-link voltage requirement of the active power filter and at the same time supply the fixed reactive power required by the load, so as to maintain unity power factor [20]. Furthermore, the neutral current compensation is carried out by using a zigzag transformer and single phase APF connected to the utility neutral conductor [10]. The simulation of active power filter is carried out using MATLAB/Simulink simpower system block sets. The simulation of the proposed system is validated through experimental results

2. MODIFIED TOPOLOGY OF HYBRID APF

Fig. 2 shows the modified topology for three phase four wire system. In this topology a coupling capacitor C_f is connected between the point of common coupling and three phase three wire APF. The coupling capacitor supplies the part of the reactive power required by the load, and the active power filter will compensate the harmonics as well as the reactive power of the load. The addition of coupling capacitance in series with the inductor of the shunt active power filter will reduce the DC-link voltage considerably [20]. The LC combination offers the high impedance around the switching frequency, thus no switching filter is needed. The system neutral current compensation is carried out by zigzag transformer and single phase APF. The bypass switch (S) is used to interface the single phase inverter to both utility and load side neutral. Therefore, the reduction of DC link voltage with LC combination and neutral current compensation by zigzag transformer reduce the rating of power electronics component of modified active power filter effectively. The power rating of active power filter saving in modified three phase four wire filter depends on the selection of a value of coupling capacitor C_f .

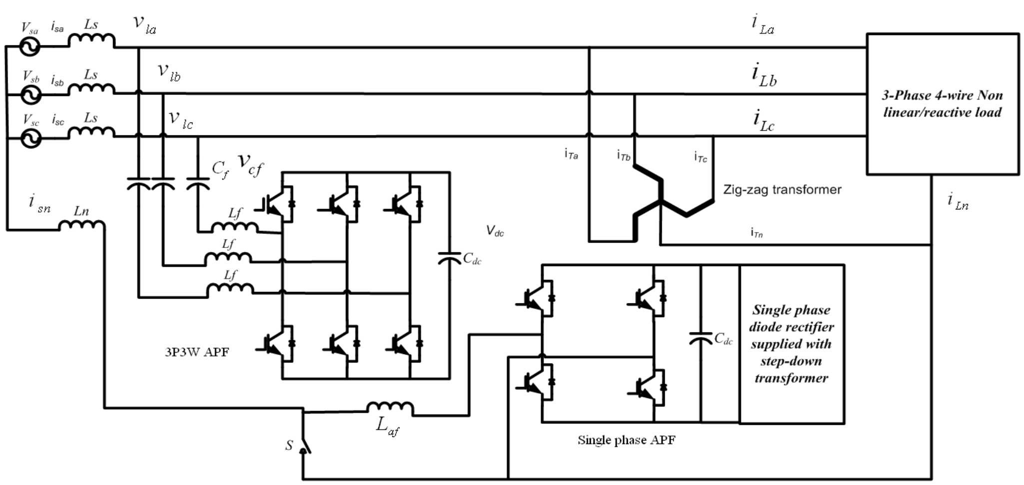

Fig.1. Proposed powers filter with an additional capacitor in conventional APF

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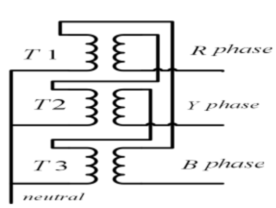


Fig.2. Realization of the zigzag transformer using three single-phase transformers

3. CONTROL STRATEGY FOR THREE PHASE THREE WIRE APF

A number of control strategies have been proposed in the literature for extraction of load harmonic and reactive power component of the currents and they are based on power balance theory, instantaneous reactive power theory (IRPT), symmetrical components based theory, and synchronous reference frame theory (SRFT), etc. [22-24]. In this paper, simple positive sequence detector based control strategy is used.

As the load currents are unbalanced and distorted, therefore the voltages at PCC are imbalanced and distorted. If these PCC voltages are used for generating the filter current references, the control strategy results in erroneous compensation. To eliminate this restriction of the control strategy, positive sequence voltages of the PCC voltages are extracted and used in the control algorithm for three phase three wire (3P3W) active power filter. The control of the DC voltage of the capacitor plays an important role for compensating harmonics and reactive power. The reference DC link voltage is compared with the measured DC link voltage and processed through PI controller. The output of PI controller result in the amplitude of reference signals (i_m).The multiplication of the output of the PI controller (i_m) with unit utility voltage vector template (U_a, U_b and U_c) generate the reference utility currents (i_a^*, i_b^* and i_c^*). The synchronizing unit vector templates obtained from the output of the positive sequence detector are as follows

$$U_a = \frac{v_{La+}}{\sqrt{\frac{2}{3}\left(v_{La+}^2 + v_{Lb+}^2 + v_{Lc+}^2\right)}} \quad (1)$$

$$U_b = \frac{v_{Lb+}}{\sqrt{\frac{2}{3}\left(v_{La+}^2 + v_{Lb+}^2 + v_{Lc+}^2\right)}} \quad (2)$$

$$U_c = \frac{v_{Lc+}}{\sqrt{\frac{2}{3}\left(v_{La+}^2 + v_{Lb+}^2 + v_{Lc+}^2\right)}} \quad (3)$$

The DC link voltage error $v_{dcer(n)}$ at nth sampling instant is as follows

$$v_{dcer(n)} = v_{dc(n)}^* - v_{dc(n)} \quad (4)$$

The PI controller output at nth sampling instant is expressed as

$$i_{m(n)} = i_{m(n-1)} + k_{pv_{dc}}\left(v_{dcer(n)} - v_{dcer(n-1)}\right) + k_{ivdc} v_{dcer(n)} \quad (5)$$

Where $k_p = 0.1$ and $k_i = 0.2$ are the DC controller constant. The reference values of the instantaneous utility currents are as follows

$$i_{aref}^* = i_m . U_a \quad (6)$$

$$i_{bref}^* = i_m . U_b \quad (7)$$

$$i_{cref}^* = i_m . U_c \quad (8)$$

The block diagram of the control strategy is shown in Fig. 3. Once the reference current is calculated then the next step is to subtract the reference current from the measured current before being fed to hysteresis controller. The hysteresis controller generates the required gating pulses for the APF.

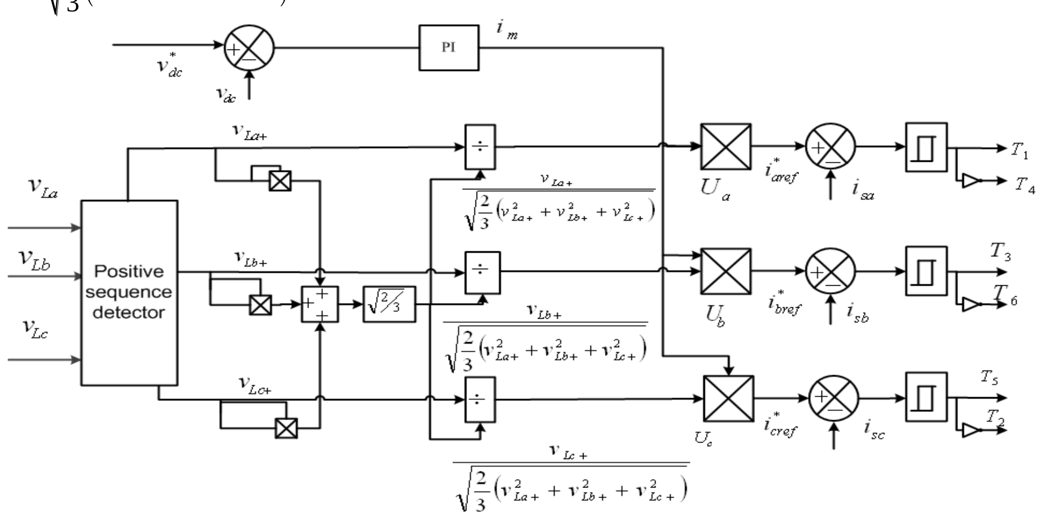


Fig. 3. Control strategy for generation of reference Current.

4. CONTROL SCHEME OF SINGLE PHASE ACTIVE POWER FILTER

Fig. 5 shows the block diagram of the control scheme of single phase active power filter (APF). If the utility neutral current is present even after compensation by the zigzag transformer, the rest of neutral current suppressed by the single phase APF and thus the neutral current shall not be traced from the source. Therefore, the current reference to the control of single phase APF can be taken as zero, this can be expressed as

$$i_{sn}^{*} = 0 \qquad (9)$$

The difference of the source neutral reference current and sensed neutral current is sent to the hysteresis controller to generate the required gating pulses for the single phase APF to attenuate the neutral current present in the utility neutral.

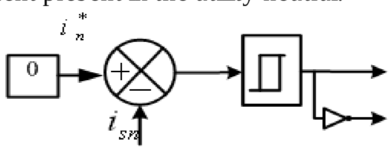


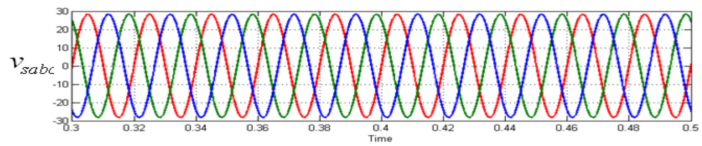
Fig. 4. Control block diagram single phase APF.

5. SIMULATION RESULTS

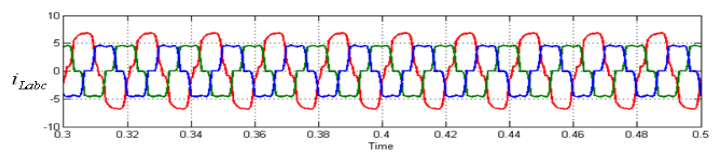
The performance characteristic of the modified topology is simulated using MATLAB/Simulink simpower system block sets to study the viability of the scheme. A three phase four wire nonlinear load is connected to three phase four wire supply system. The simulated response for the modified topology are presented in this section for better understanding of harmonic compensation with the current and voltage waveforms.

The voltage and current waveform of topology before and after compensation are shown in Fig.5. Fig. 5 (a) shows the utility voltage waveform. The load current waveform before compensation is shown in Fig. 5 (b). The load currents are distorted and unbalanced. For the conventional topology, in the beginning, 3P3W APF and zig zag transformer are in operation and single phase APF is connected at t=0. 4 with opening of switch (s). It can also be seen from Fig. 5 (c), when zigzag transformer alone acts as a compensator, the neutral current on the utility side is 1A (RMS), and is 2.5A (RMS) on the load side while switch ('S') closed. The 1.5A (RMS) current is compensated by a zigzag transformer which is not shown in the figure. The unbalance in the utility currents still exists. When the switch ('S') is opened, the single phase APF eliminates the neutral current completely. Therefore, the compensation performance of 3P3W APF is improved with the elimination of utility neutral current. Hence, the source current become sinusoidal and in phase with utility voltages. Fig. 5 (d) shows the current injected by the three phase APF. Fig. 5 (e) shows the utility currents after compensation which is nearly sinusoidal. The DC link voltage of the capacitor is shown in Fig. 5 (f). The DC link voltage is maintained at reference level by using the PI controller and the value of DC link voltage is 30 V. The compensation carried out by 3P3W APF at relatively lower DC link voltage.

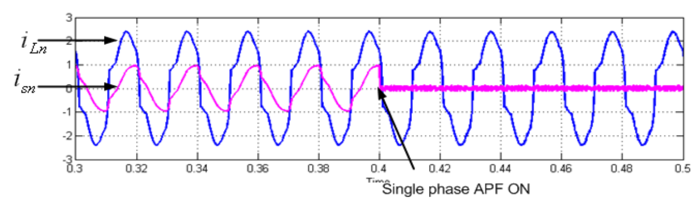
The load side neutral current remains unaffected. The DC link voltage of hybrid 3P3W APF is regulated at 30V. Hence, the DC link voltage is 50% as of the conventional topology which enables to select the switching devices of reduced rating as compared to conventional topology of the APF. Therefore, the power electronic component rating will also reduce to 50% of conventional topology.



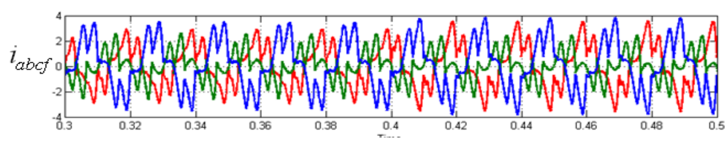
(a) Source voltage



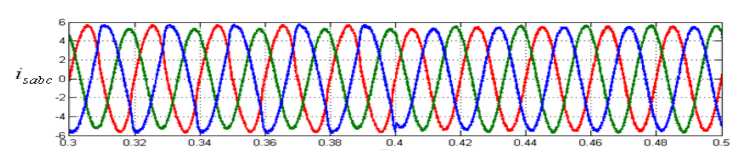
(b) Load current before compensation



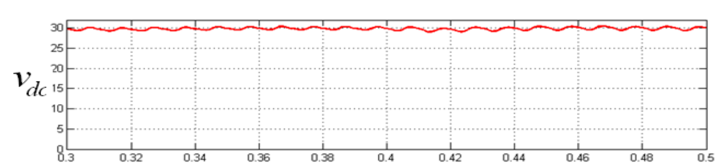
(c) Load and utility neutral current.



d) Current injected by hybrid three phase three wire filter.



(e) Utility current after compensation.



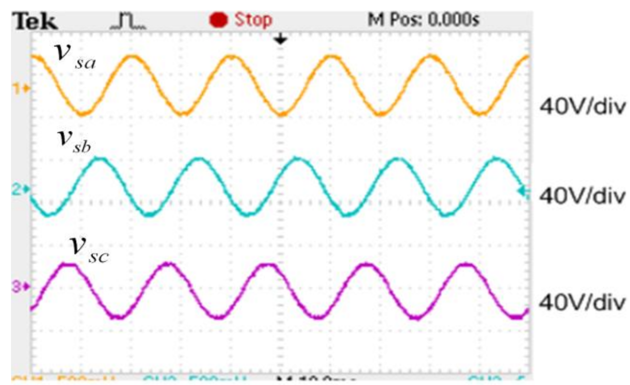
(f) DC link voltage.

Fig 5. Simulated waveforms with the proposed topology.

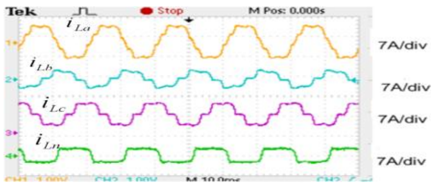
7. Experimental Results

In this section, the experimental prototypes of modified topology is developed to study the compensating performance. For the conventional active power filter, the DC link voltage across the DC link capacitor is maintained at 60V ($2.2 * v_m$) for satisfactory compensation. The DC link voltage across the DC link capacitor of modified topology is taken as 30V, the value of the coupling capacitor chosen as 200μF the same as for simulation studies.

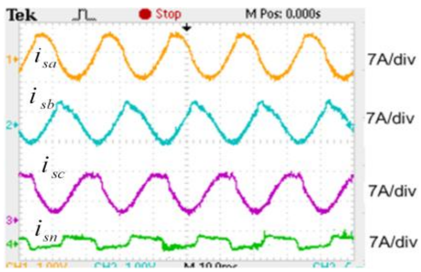
Fig.8 shows the experimental waveform of modified topology. The utility voltage waveforms are shown in Fig. 6 (a). The load current along with the neutral current before compensation is shown in Fig.6 (b). The load current is highly rich in harmonics and unbalance. Initially, 3P3W hybrid APF is in operation along with zigzag transformer being used as a compensator. It can be observed that the neutral current reduced and utility current near to sinusoidal is shown in Fig.6 (c). Fig.6 (d) Shows, the 3P3W APF currents that are injected into PCC to make the utility current near to sinusoidal and balance. It can be seen from Fig.6 (e), when the switch is opened, the single phase APF eliminates the utility neutral current completely to zero. Three phase three wire hybrid APF in combination with zigzag transformer and single phase APF compensate the harmonics and reactive power of utility current and eliminate the neutral current. Fig.6 (f) Shows, the compensating current injected by APF. Fig.8 (g) shows the utility voltage and current along with DC link voltage. The DC link voltage is maintained by the PI controller to the set reference value. The THD spectrum utility current before and after compensation is shown in Fig.7. The THD spectrum of the load current contains higher order harmonics which are eliminated after compensation.



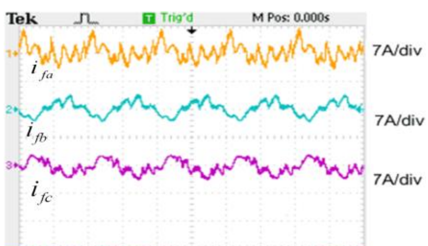
(a) Utility voltage waveform.



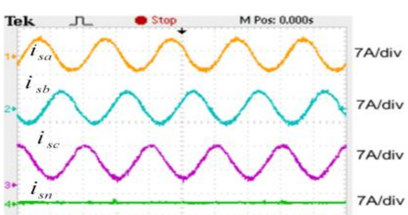
(b) Load current before compensation



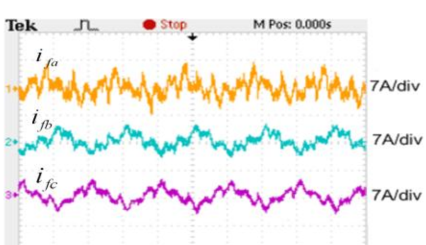
(c) Utility current after compensation with transformer operation.



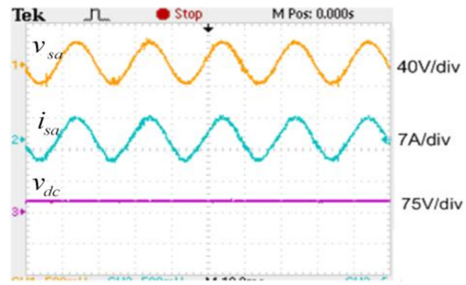
(d) Compensating current injected by hybrid filter with transformer operation.



(e) Utility current after compensation with single phase APF operation.

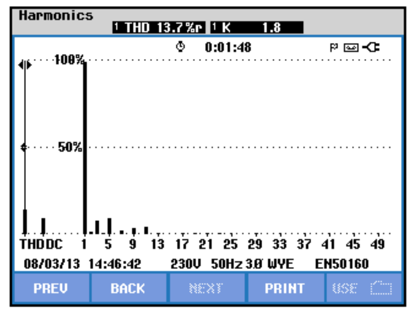


(f) Compensating current injected by a hybrid filter with the single phase APF operation.

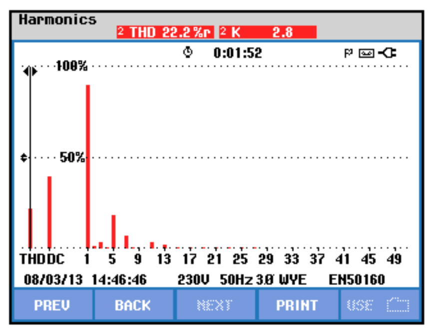


(g) Utility voltage, utility current, DC link voltage and neutral current.

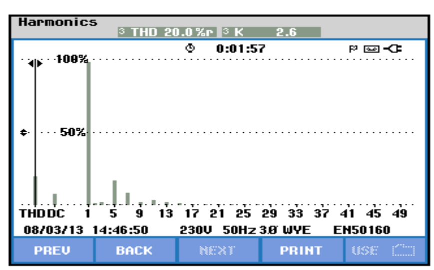
Fig 6. Experimental voltage and current waveform with proposed topology.



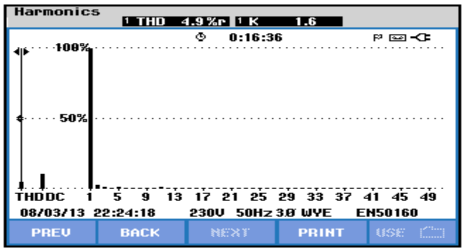
(a) A phase utility current THD before compensation



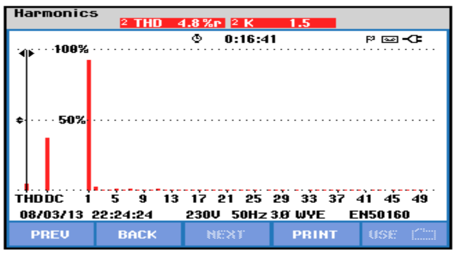
(b) B phase utility current THD before compensation



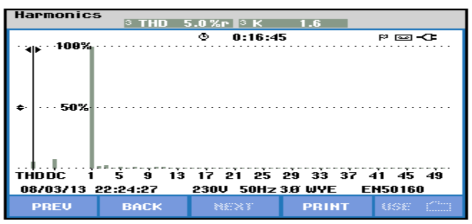
(c) C phase utility current THD before compensation



(d) A phase utility current THD after compensation.



(e) B phase utility current THD after compensation



(f) C phase utility current THD after compensation.

Fig 7. Utility current THD spectrum with proposed topology.

8. Conclusion

In this paper modified topology of hybrid APF with a coupling capacitor for three phase four wire system is proposed, which has the capability to compensate load harmonics and reactive power at reduced DC link voltage. The neutral current compensation is carried out using a zigzag transformer and the single phase APF. A MATLAB/Simulink based model is developed for the topology is to simulate the performance. The simulated response is validated with the experimental setup in the laboratory. The control algorithm is implemented with dSPACE 1104 R&D controller on the prototype. The measured values of the current THDs show the improvement in the source current waveforms after compensation.

Reference

[1]. J. Arrillaga, N.R. Watson, Power System Harmonics, 2nd ed., John Wiley & Sons Ltd., Chichester, U.K., 2003.

[2]. R.C. Dugan, M.F. McGranaghan, H.W. Beaty, Electric Power Systems Quality, 2nd ed., McGraw-Hill, New York, 2006.

[3]. D. Sreenivasarao, P. Agarwal, B. Das, Neutral current compensation in three phase, four-wire systems: a review, Electric Power Systems Research 86 (May) (2012) 170–180.

[4]. T.M. Gruzs, A survey of neutral currents in three-phase computer power systems, IEEE Transactions on Industry Applications 26 (July/August (4)) (1990) 719–725.

[5]. IEEE Recommended Practices and Requirements for Harmonics Control in Electric Power Systems, IEEE Std. 519, 1992.

[6]. Khadkikar V, Chandra A, Singh B. Digital signal processor implementation and performance evaluation of split capacitor, four-leg and three H-bridge-based three-phase four-wire shunt active filters. IET Power Electron.

[7]. Quinn CA, Mohan N. Active filtering of harmonic currents in three-phase, four wire systems with three-phase and single-phase nonlinear loads. Proc IEEE APEC1992:829–35.

[8]. H.-L. Jou, J.-C. Wu, K.-D. Wu, W.-J. Chiang, Y.-H. Chen, Analysis of zig-zag transformer applying in the three-phase four-wire distribution power system, IEEE Transactions on Power Delivery 20 (April (2)) (2005) 1168–1173.

[9]. P.N. Enjeti, W. Shireen, P. Packebush, I.J. Pitel, Analysis and design of a new active power filter to cancel neutral current harmonics in three-phase four wire electric distribution systems, IEEE Transactions on Industry Applications 30 (6) (1994) 1565–1572.

[10]. S. Choi, M. Jang, A reduced-rating hybrid filter to suppress neutral current harmonics in three-phase four-wire systems, IEEE Transactions on Industrial Electronics 51 (August (4)) (2004) 927–930.

[11]. H.-L. Jou, K.-D. Wu, J.-C. Wu, W.-J. Chiang, A three-phase four-wire power filter comprising a three-phase three-wire active

filter and a zig-zag transformer, IEEE Transactions on Power Electronics 23 (January (1)) (2008) 252–259.
[12]. B. Singh, P. Jayaprakash, T.R. Somayajulu, D.P. Kothari, Reduced rating VSC with a zig-zag transformer for current compensation in a three-phase four-wire distribution system, IEEE Transactions on Power Delivery 24 (January (1)) (2009) 249–259.
[13]. B. Singh, P. Jayaprakash, D.P. Kothari, A T-connected transformer and three-leg VSC based DSTATCOM for power quality improvement, IEEE Transactions on Power Electronics 23 (November (6)) (2008) 2710–2718.
[14]. P. Jayaprakash, B. Singh, D.P. Kothari, Three-phase 4-wire DSTATCOM based on H-bridge VSC with a star/hexagon transformer for power quality improvement, in: IEEE Region 10 Colloquium and the Third Int. Conf. on Ind. and Inf. Systems, 2008, pp. 1–6.
[15]. B. Singh, P. Jayaprakash, D.P. Kothari, Three leg VSC with a star-hexagon transformer based DSTATCOM for power quality improvement in three-phase four-wire distribution system, International Journal of Emerging Electric Power 9 (December (8)) (2008), Art. 1.
[16]. G. Kamath, N. Mohan, A novel, reduced rating active filter for 3-phase, 4-wire loads, in: Proc IEEE APEC'94, vol. 2, 1994, pp. 936–940.
[17]. G. Kamath, N. Mohan, V.D. Albertson, Hardware implementation of a novel, reduced rating active filter for 3-phase, 4-wire loads, in: Proc. IEEE APEC'95, vol. 2, 1995, pp. 984–989.
[18]. M.K. Mishra, K. Karthikeyan, Design and analysis of voltage source inverter for active compensators to compensate unbalanced and non-linear loads, in: International Power Engg. Conf., 2007. IPEC 2007., 2007, pp. 649-654.
[19]. S. Srikanthan, M.K. Mishra, DC Capacitor Voltage Equalization in Neutral Clamped Inverters for DSTATCOM Application, IEEE Transaction on Industrial Electron, 57 (2010) 2768-2775.
[20]. S.B. Karanki, G. Nagesh, M.K. Mishra, B.K. Kumar, A hybrid topology for reducing DC link voltage rating in DSTATCOM applications, in: IEEE Energy tech (2011) pp. 1-6.
[21]. C. Wai-Hei, L. Chi-Seng, W. Man-Chung, H. Ying-Duo, Analysis of DC-Link Voltage Controls in Three-Phase Four-Wire Hybrid Active Power Filters, IEEE Transaction on Power Electron, 28 (2013) 2180-2191.
[22]. R. Inzunza, H. Akagi, A 6.6-kV transformerless shunt hybrid active filter for installation on a power distribution system, IEEE Transaction on Power Electron., 20 (2005) 893-900.
[23]. M.C. Benhabib, S. Saadate, New control approach for four-wire active power filter based on the use of synchronous reference frame, Electric Power Systems Research, 73 (2005) 353-362.
[24]. J.C. Wu, H.L. Jou, Simplified control method for the single-phase active power filter, Proc. Institute of Electrical Eng., 143 (1996) 219-224.

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