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Design and development of shunt hybrid power filter for harmonic mitigation

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Abstract : This paper presents design, simulation and development of Shunt Hybrid Power Filter (SHPF) for mitigation of the power quality problem at ac mains in ac-dc power supply feeding to a nonlinear load. The power filter is consisting of a shunt passive filter connected with a shunt active power filter. At first passive filter has been designed to compensate harmonics, and then similarly active filter is designed. The drawback associated with the passive filter like fixed compensation characteristics and resonance problem is tried to solve by SHPF.Simulations has been carried out to verify the proposed filter system. Harmonic contents of the source current has been calculated to demonstrate the influence of harmonic extraction circuit on the harmonic compensation characteristic of the shunt hybrid power filter.

Keywords: *SAPF, SHPF, PI control, THD, Hysteresis control, D-Q reference frame theory.*

1. INTRODUCTION

In recent years, with the increasing use of adjustable speed drives, arc furnace, controlled and uncontrolled rectifiers and other nonlinear loads, the power distribution system is polluted with harmonics. Such harmonics not only create more voltage and current stress but also are responsible for Electromagnetic interference, more losses, capacitor failure due to overloading, harmonic resonance, etc. Introduction of strict legislation such as IEEE519 limits the maximum amount of harmonics (THD-Total Harmonic Distortion) that a supply system can tolerate for a particular type of load. Therefore, use of active or passive type filters is essential. To solve the current harmonic related problems, passive filters connected in several circuit configurations present a low cost solution. However passive filter implementations to filter out the current harmonics have the following disadvantages:

• Possibility of resonances with the source
Impedance
• Supply impedance dependent system performance
• Fixed compensation

In order to diminish the preceding regulation are the main functions of active filters for the improvement of power quality. APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APF performances are independent of the power distribution system properties. On the other hand, APFs have some drawbacks. APF necessitates fast switching of high currents in the power circuit resulting high frequency noise that may cause an electromagnetic interference (EMI) in the power distribution systems .

• It requires D.C power supply for their operation
• Active filter can't handle large amount of power.
• It is only suitable for low or moderate frequiencies.

Akagi, H. proposed the classification of active filters based on their objectives, system configuration, power circuits and control strategy. APF can be mainly connected in three circuit configurations, namely shunt APF, series APF and hybrid APF. Shunt hybrid power filter consisting of shunt active power filter and shunt tuned passive filter connected to the terminals of SAPF at PCC as shown in Fig. 1.1

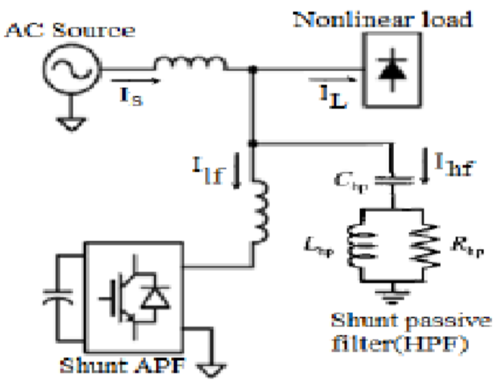

Fig:1.1 Circuit configuration of shunt hybrid power filter

This filter effectively mitigates the problem of a passive and active filter. It provides cost effective harmonic compensation, particularly for high power nonlinear load. Different control techniques are present for extracting harmonic components of the source current. Some of them are synchronous reference frame (SRF) transformation, instantaneous power (p-q) theory, etc. where high pass filters (HPFs) are used or extracting harmonic components of the source current from the fundamental components.

2. OPERATION PRINCIPLE OF THE PROPOSED SHUNT HYBRID APF TOPOLOGY

The operation principle of the proposed shunt hybrid APF topology is illustrated in Fig. 2 (Vdc) must be maintained at a constant value that is higher than the amplitude of the source voltage.

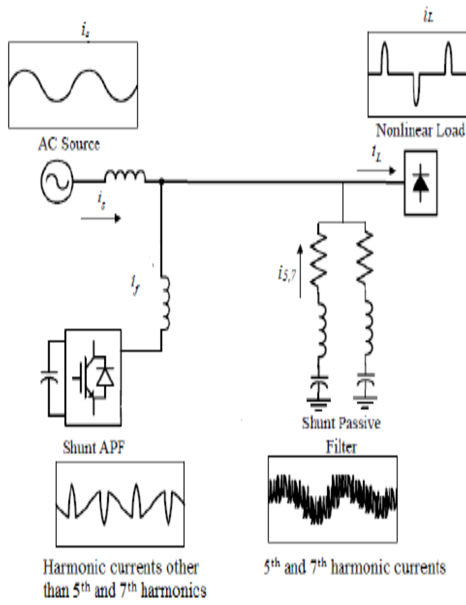

Fig 2.1: Operation Principle of the Basic Shunt Hybrid Power Filter.

The operation principle of the proposed shunt hybrid APF topology is illustrated in Fig. 2.1. It consists of a shunt active filter and tuned passive filters (TPFs) connected in parallel with the nonlinear load which is connected to ac source. The two TPFs are designed to absorb 5th and 7th harmonic currents with the principle of series resonance and SAF compensates remaining harmonics. The SAF generates compensation current (if) equal to harmonic load current (iLh) but in opposite phase to it and injects in to the point of common coupling (PCC) through an interfacing inductor. Therefore source current (is) is desired to be sinusoidal and in phase with the source voltage (Vs) to yield maximum power factor. The SAF is a VSI and a capacitor connected on the DC side acts as storage element.

3. MODELLING OF SHUNT HYBRID POWER FILTER

The low voltage power distribution system of interest consists of a three phase, 400 V (r.m.s), 50 Hz sinusoidal AC voltage source. The source inductor is considered as Ls. A full-bridge diode rectifier with R-L load is selected as the nonlinear load as shown in Fig. 3.1; this interfacing inductor provides isolation from the distribution line. A large interfacing inductor is preferable because it results in small switching ripple. However, the large interfacing inductor limits the dynamic response of the compensation current. Therefore, there is a compromise involved in sizing the interfacing inductor. This VSI uses DC-bus capacitor (Cdc) as the supply source and switches at high-frequency to generate a compensation current that follows the estimated reference current. Therefore the voltage across the DC-bus capacitor (Vdc) must be maintained at a constant value that is higher than the amplitude of the source voltage.

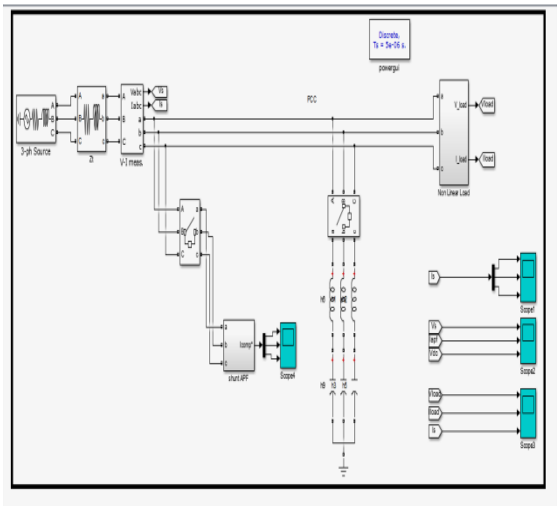

Fig 3.1: Simulink model of shunt hybrid power filter

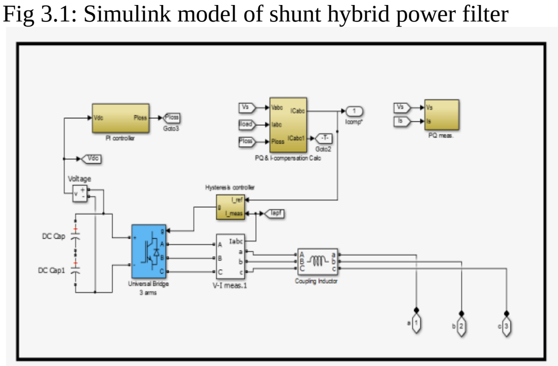

Fig 3.2: Detailed model of shunt active filter

Parameters name	Numerical value
Source voltage Vs	400v, 50hz(line r.m.s.)
DC capacitors	40uF
D.C capacitor reference Voltage	1250v
Sampling time	5-e06
Diode rectifier Non-linear Load resistance and Inductance	25ohm, 55mH
Filter inductance and capacitor	0.9mH, 11.24mF
Source resistance and inductance	0.01ohm, 1uH

Fig 3.3: System parameters of the model

The objective the control strategy of the proposed three-phase shunt hybrid active filter is to produce appropriate gating signals for the switching transistors of VSI. The Overall control system consists of synchronous reference frame theorem based compensation current estimator, hysteresis current controller for gate signal generation and PI controller to maintain the DC bus voltage constant.

3.1. Compensation Current Reference Estimation using d-q-0 Theory

In this control strategy three phase load currents are sensed and transformed from a-b-c reference frame to d-q coordinates which are DC components using park's transformation. Passing these d-q components of load currents through low pass filter, the low frequency fundamental components only will be passed through By transforming these components in d-q reference to a-b-c reference frame using inverse Park's transformation, the information about harmonic current component in a-b-c reference frame is obtained . Suppose the three phase source currents are Isa, Isb, Isc, the nonlinear load currents are ILa, ILb, ILc and active filter compensating currents are Ifa, Ifb, Ifc for phases A, B, C respectively. The load currents in a-b-c synchronous reference frame components can be converted in to d-q reference frame components using Park.s transformation as shown in equation (3.1).

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad \ldots 3.1$$

These currents can be decomposed into fundamental and harmonic components as shown in equations (3.2).

$$Id = Id_{dc} + Id_h, Iq = Iq_{dc} + Iq_h \quad \ldots 3.2$$

The fundamental component of load current will appear as DC quantity in d-q reference frame. Therefore Iddc = Id1 and Iqdc = Iq1. The harmonic component of load current is obtained by subtracting high frequency harmonic current signal from total load current.

$$Id_h = IL - LPF(Id), Iqh = LPF(Iq) \quad \ldots 3.3$$

These reference currents are transformed into a-b-c coordinates by applying Inverse Park's transformation to obtain reference currents in a-b-c coordinates

$$\begin{bmatrix} I_{fa}^* \\ I_{fb}^* \\ I_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3} \begin{bmatrix} \cos\theta & \sin\theta \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix}} \begin{bmatrix} I_{dh} \\ I_{qh} \end{bmatrix} \quad \ldots 3.4$$

These reference currents are applied to hysteresis current controller which produces required gating pulses to switching devices of VSI. Since it deals with mainly DC quantities and computation is instantaneous this theory is considered in this work for estimating reference compensating current.

3.2. Hysteresis Current Control for Switching Signal Generation

In this thesis Hysteresis band Current Controller model is used for generating switching signals for the transistors of VSI, and is illustrated in Fig. 3.2.1.This current control technique imposes a bang-bang type instantaneous control that forces the compensation current to follow its estimated reference. The actual compensation current is subtracted from its estimated reference. The resulting error is sent through a hysteresis controller to determine the appropriate gating signals. In the simulation model, the hysteresis band (H) is chosen as 0.1 A with 0.05 as upper limit and -0.05 as lower limit.

and harmonic component is stopped. By subtracting fundamental component from non-filtered signal will result in harmonic component in load current. Control signal from PI controller is added to this signal to obtain the reference compensating signal in d-q reference frame.

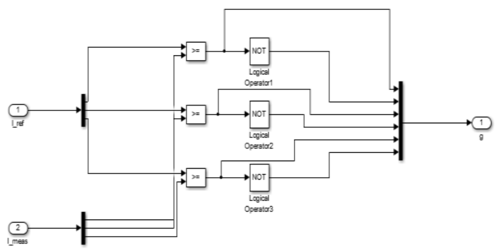

Fig.3.2.1 Simulink model of Hysteresis current controller.

3.3. DC Bus Voltage control by using PI controller

For maintaining DC bus voltage constant at a reference value, Proportional and Integral (PI) Controller is employed in this simulation work as shown in fig 3.3.1. In this control process the dc bus voltage of the active filter is used as feedback signals to PI controller. The reference dc capacitor voltage (850v) is compared with actual capacitor voltage and the error is given to the PI controller . The output of the PI controller provides the reference in-phase components .

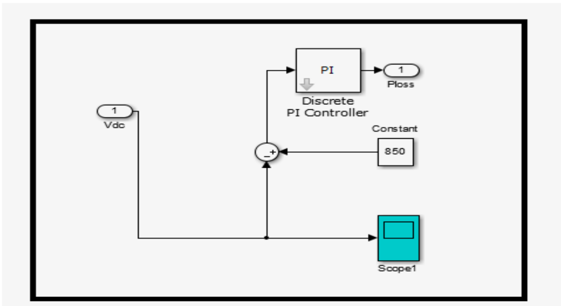

Fig 3.3.1**:** PI controller subsystem

3.4. Tuned Passive Filter

The proposed shunt hybrid active power filter consists of tuned passive filters connected in parallel with the load to absorb specified harmonic currents. The common types of passive harmonic filters include single tuned, double tuned and high pass filters. However for simplicity single tuned filters are considered in this work. The basic shunt passive filtering principle is to trap harmonic currents in LC circuits, tuned up to the harmonic filtering frequency, and to eliminate from power system. A single tuned 1st order filter configuration consists of RLC elements in series. In single-tuned passive filter, the reactance of inductor is equal to that of capacitor at resonant frequency fn. The relationship among L, C, R, Q values are given in Eqn.(3.5)

$$Cn = 1/Ln(2\pi fn)^2 \text{ }, Rn = \frac{Ln(2\pi fn)}{Q}, Q = Rn\sqrt{\left(\frac{Cn}{Ln}\right)} \ldots 3.5$$

Where fn=frequency of harmonic component, n=order of harmonic, Q=Quality factor, Rn=Resistance of nth harmonic filter, Ln=inductance of nth harmonic filter. In the proposed hybrid filter the shunt passive filters are tuned to absorb 5^{th} and 7th harmonic currents and other higher order harmonics are to be suppressed by SAF Hence burden on SAF is reduced resulting in reduced rating of SAF and effective filtering of higher order harmonics. Therefore source needs to supply only fundamental component of load current For 5th harmonic filter the resonance frequency is 250Hz and for 7th harmonic it is 350Hz.

4. RESULTS

4.1. System without any Compensation:

The results of simulation for test system are shown in Fig. 4.1. including source voltage waveforms and source current without any type of compensation, As Shown the current waveforms are more distorted (i.e. not pure sinusoidal) due to presence of non linear load.

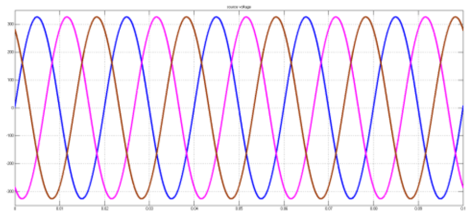

Fig 4.1 Source voltage

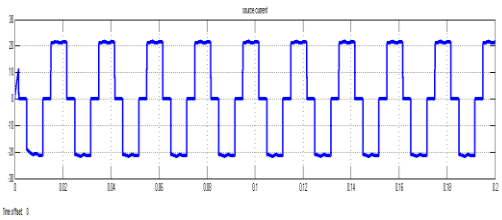

Fig 4.2 source current without filter

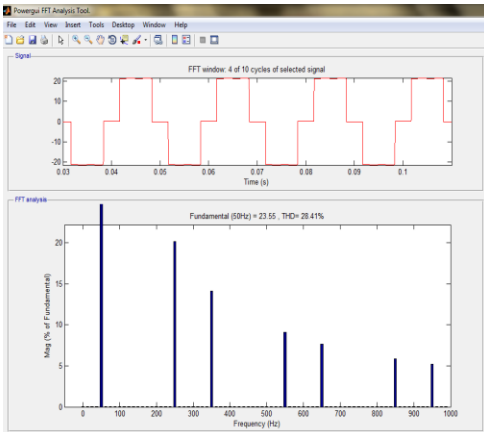

Fig-4.3 Harmonic spectrum of phase-a load current of system without any compensation .

The THD is the most common indicator to determine the quality of AC waveforms. Using the Fast Fourier Transform (FFT), the harmonic spectrum of the source current under different compensation conditions is presented. Then, the THD comparison is carried out for the simulation results and from the spectra plot, it can be seen that the source current contains large amount of harmonic current components (5th & 7th components are higher magnitude i.e 11 and 7 respectively as shown in fig 7) of frequencies below 1 kHz and the THD is 28.41% (According to IEEE-519 standards the THD limits on the magnitude of harmonic current frequencies should be within 5%.

4.2. System with Shunt Hybrid Filter

The three phase SHPF compensating currents and source currents of the proposed system with SHPF compensation are shown in Fig. . It is seen that due to SHPF compensating currents the source currents attained near sinusoidal form. Source voltage and source currents are in-phase as shown in fig 4.2.3 for phase a .

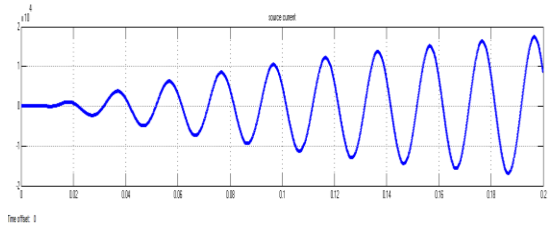

Fig 4.2.1 Source current with compensation

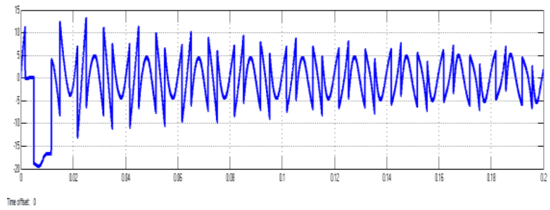

Fig 4.2.2 Compensating current

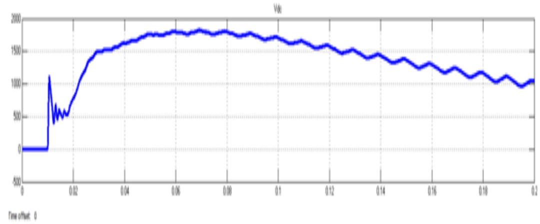

Fig 4.2.3 Dc voltage

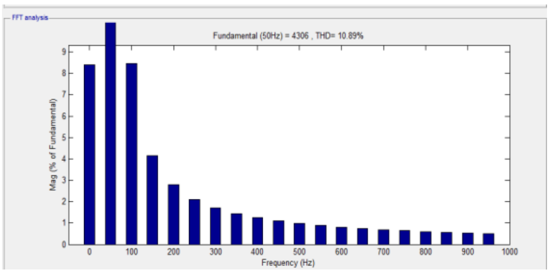

Fig 4.2.4 Harmonic spectrum of source current with compensation

Fig. 4.2.1 shows the simulation results for three phase source current of system model with the proposed Shunt Hybrid Power Filter (SHPF) compensation. When SHPF is applied, the injected compensation current (if)(fig 4.2.2) forces the source current (is) to become near sinusoidal waveform and in phase with the source voltage waveform, resulting in nearly unity power factor.

5. CONCLUSIONS

This Paper presented the results obtained from the simulations of SHPF compensated system. Simulations were conducted aiming to illustrate the effectiveness of the proposed shunt hybrid PF in harmonic mitigation . The effectiveness of d-q theory in estimating compensation reference current is demonstrated. In addition, the effectiveness of PI controller in maintaining DC bus voltage is discussed. The simulation results are analyzed and discussed. Finally, a detailed THD analysis on source current spectrums is carried out to validate the harmonic filtering performance of the proposed SHPF topology in comparison to the without compensation in the system. The source current THD is reduced from 30.4 % to 10.89 % with proposed shunt PF. Thus, the harmonic filtering performance of the proposed SHAF topology is superior compared to the basic shunt APF and which is well below the harmonic limit imposed by IEEE Standard- 519(i.e. THD within 5%)

6.REFERENCES

1.Akagi H and Fugita H, "A practical approach to harmonic compensation in power systems: Series connection of passive and active filters", IEEE Trans. Ind. Appl., vo1.26, no.6, pp. 1020-1025.

2.Akagi H, Peng F.Z & Nabae A., (1990) "A new approach to harmonic compensation in power systems- A combined system of shunt passive and series active filters", IEEE Trans. Ind. Appl., vol. 26 ,no.6, pp 983- 990.

3.Bhim Singh and Kamal Al-Haddad, "A Review of Active Filters for Power Quality Improvement." IEEE Transactions on Industrial Electronics, Vol. 46, No. 5, October 1999.
4.D.Detjen, J. Jacobs,R.W.D.Doncker, andH.G.Mall, "A new hybrid filter to dampen resonances and compensate harmonic currents in industrial power systems with power factor correction equipment," IEEE Trans. Power Electron., vol. 16, no. 6, pp. 821–827, Nov. 2001.

5.Das J C,2004 "Passive filters potentialities and limitations,".IEEE Trans on Industry Application, vol. 40, pp. 232-241. DOI 10.1007/s11708-013-0284-4

6.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.

7.H. Akagi, Y. Kanazawa and A. Nabae, "Instantaneous Reactive Power Compensators Comprising Switching Devices without Energy Storage Components", IEEE Trans. Ind. Applications, Vol. 20 No 3, May/June 1984, pp. 625-630.

8.H.Dalvand, M. T. Nguyen, N. M. Kwok and Q. P. Ha, December 2008, "A New Hybrid Filter for Power Quality Improvement in Unbalanced Load Conditions", 2008 10th Intl. Conf. on Control, Automation, Robotics and Vision Hanoi, Vietnam, 17–20 December 2008.

9.Joshita Gupta and Avadh Pati, 2012, "Improvement in the Quality of Load Current by Various Controlling Techniques in Hybrid Power Filter for Harmonic Compensation and Resonance Suppression", 2012 2nd International Conference on Power, Control and Embedded Systems 978-1-4673-1049-9/12/$31.00 ©2012 IEEE.

10.P.Salmeron and S.P. Litran, (2010) "Improvement of the Electric Power Quality Using Series Active and Shunt Passive Filters", IEEE Transactions on Power Delivery, vo1.25, no.2, pp 1058-1067

11.Sangamesh Bukka1, Mohammad Yunus M Hakim, Sanjeev T.M, S. G. Ankaliki ," Performance analysis of three phase shunt hybrid active power filter", ijret: international journal of research in engineering and technology eissn: 2319-1163 | pissn: 2321-7308 volume: 03 issue: 03, mar-201