

IMPLEMENTATION OF SHUNT HYBRID ACTIVE FILTER (SHAF) FOR POWER QUALITY IMPROVEMENT WITH FUZZY LOGIC CONTROLLER TO MITIGATE CURRENT HARMONICS

Kumar Reddy Cheepati¹, Dr.Sardar Ali², Dr.Surya Kalavathi M³

¹*Asst. Professor, Dept. of E.E.E, S.V.E.C, Tirupathi & Ph.D Scholor at J.N.T.U.K, Kakinada (India)*

²*Principal, R.I.T.S, Chevella (India)*

³*Professor, Dept. of E.E.E, J.N.T.U.H, Hyderabad (India)*

ABSTRACT

Power quality means a perfect power supply would be one that is always available, with in voltage and frequency tolerances and has a pure noise free sinusoidal wave shape. The increased use of power electronic controlled equipment is now causing a major problem through the presence of harmonics in three phase four wire distribution power systems, which is connected to nonlinear loads such as induction motors, high power phase controlled rectifiers, bridge rectifiers etc. A shunt hybrid active filter (SHAF) consisting of a shunt active filter (SAF) and distributed passive filter for power quality improvement in complex power system is presented in this proposed paper. A shunt active filter (SAF) used to mitigate lower order harmonics whereas passive filter is tuned to mitigate higher order harmonics (5th & 7th harmonics) so the overall cost of the proposed SHAF reduces compared to the system with only SAF. In this proposed paper a fuzzy logic controller technique is used with reference current estimator and hysteresis current controller is used as a controlling technique for the SAF. The MATLAB simulation is developed and the results are presented in this paper.

Keywords: *Power Quality, Harmonics, Shunt Active Filter (SAF), Fuzzy Logic Controller, Reference Current Estimator and Hysteresis Current Controller*

I. INTRODUCTION

The growing use of nonlinear loads such as bridge rectifiers, induction motors and high power phase controlled rectifiers leads to an increase in harmonics in the network. This causes various problems in power systems and in domestic appliances such as overheating of equipment, capacitor burning, equipment maloperation, more neutral currents and poor power factor. Shunt Active power filter involving two levels voltage source inverters have been widely used to eliminate harmonics and compensate reactive power in medium power system. The hybrid topologies have been proposed to achieve high power quality with less cost. The performances of different reference current generation strategies under balanced, sinusoidal, alternating current (AC) voltages conditions are well referenced, such as so called p-q theory and Synchronous Reference Frame Theory (SRF)

which provide similar performances. Problem arise when one works under distorted conditions, herethe mains voltages are distorted that decreases filter performance. A suitable Control technique for the controller is the main part of the active power filter operation. Conventional PI voltage and current controllers have been used to control the harmonic current and DC voltage of the shunt active Filter. But, they requires precise linear mathematical model of the system, which is difficult to achieve under variation in parameters, load disturbances and non-linearity. All these limitations are overcome by using fuzzy logic techniques.

In this proposed research, fuzzy logic control technique is adopted with reference current estimator and hysteresis current controller.

The performance of fuzzy logic controller with reference current estimator and hysteresis current controller is evaluated through computer simulations under nonlinear load conditions. The MATLAB results proved that, the proposed SHAF provides a sinusoidal supply current with low harmonic distortion and in phase with the line voltage under distorted conditions, improved power factor and reactive power compensation.

II. SYSTEM CONFIGURATION

The three-phase Shunt hybrid APF topology for harmonic reduction in low and medium voltage power distribution systems consists of a Voltage Source Inverter(VSI) based three phase shunt active filter (SAF) with tuned passive filters (TPF) connected in parallel with the load. This paper discusses the Simulink modelling of shunt active filter and design of filter interfacing VSI inductor, DC bus capacitor, passive filters which are tuned to absorb 5th and 7th harmonics. It also presents the analysis of synchronous reference frame theorem to estimate the compensation reference current and hysteresis current controller for switching signal generation for SAF.

The operation principle of the proposed shunt hybrid APF topology is illustrated in Fig.1.

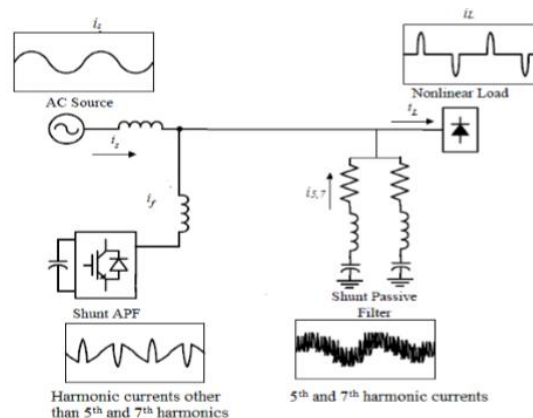


Fig.1.Configuration of the SHAF

It consists of a shunt active filter and tuned passive filters (TPFs) connected in parallel with the nonlinear load which is connected to the supply of 3 phase 3 wire system. The two passive filters are designed to absorb 5th and 7th harmonic currents with the principle of series resonance and SAF compensates remaining harmonics. The Shunt Active Filter generates compensation current (i_f) equal to harmonic load current (i_{Lh}) but in opposite phase to it and injects in to the point of common coupling (PCC) through an interfacing inductor. Therefore source current (i_s) is desired to be sinusoidal and in phase with the source voltage (V_s) to yield maximum power factor. The SAF is a VSI and a capacitor connected on the DC side acts as storage element.

III. THREE PHASE SHUNT ACTIVE FILTER MODEL

The basic SAF scheme considered is depicted in Fig. 2.

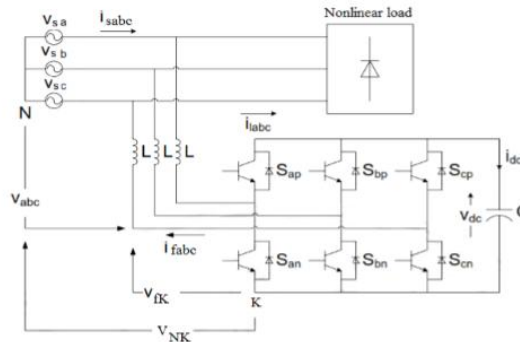


Fig.2. Three Phase Shunt Active Filter Mode;

Practically, it is a three phase AC/DC boost converter, here the main energy storage element is the capacitor C and the inductors L are used to control the filter currents by means of the converter voltages. But the case of a pure voltage converter, the focus for such type of device is on the currents injected into the line which have to compensate for harmonics generated by nonlinear loads. The capacitor voltage has to be constrained into a safe range while it is unimportant the shape of its wave.

IV. PROPOSED SHAF FOR HARMONIC COMPENSATION IN LV POWER DISTRIBUTION SYSTEM

The low voltage power distribution system of interest consists of a 3 line, 2KV(r.m.s), 50 cycles/second sinusoidal AC . The inductor which is connected to source is considered as Ls. The diode full-bridge rectifier with R-L load is selected as the nonlinear load as shown in Fig. 3.

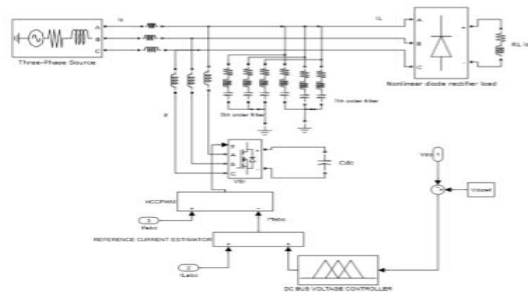


Fig.3.Proposed SHAF

This type of load can be found in most power electronics applications, i.e. switch-mode power supply, industrial motor drive etc .It is used to convert the input AC to DC in an uncontrolled manner. It is well known that this nonlinear load draws highly distorted current from the distribution source current and voltage so it causes a major source of harmonic distortion. A shunt hybrid APF is connected with the distribution line at the PCC through an interfacing inductor (Lf). This interfacing inductor provides isolation from the distribution line. A heavy rating interfacing inductor is preferable because it results in small switching ripple. However, the heavy rating interfacing inductor limits the dynamic response of the compensation current. It requires a compromise involved in sizing the heavy rated Interfacing inductor. So 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. So the voltage across the DC-bus capacitor (V_{dc}) must be maintained at a constant value that is higher than the amplitude of the source voltage.

V. POWER CIRCUIT

The power circuit used in the proposed hybrid APF is an universal full-bridge VSI as shown in Fig. 3. The VSI consists of six transistors, each having an anti-parallel diode for the protection of reverse flowing currents. The transistors are the metal oxide semiconductor field effect transistors (MOSFETs) are selected due to their superior performance characteristics, it gives a very less forward voltage drop, fast switching times and high power carrying capability. Logic inverters ensure that each MOSFET on the same leg complement each other avoiding short circuit problem of the DC-bus capacitor (C_{dc}).

VI. INTERFACING INDUCTOR

The desired compensation current waveform is obtained by controlling the switching of the MOSFETs in the VSI. The switching ripple (i_{sw}) of the compensation current is determined by the size of the interfacing i.e heavy rated inductor, available driving voltage across the inductor, and switching frequency. Here in the proposed paper the driving voltage is the DC-bus voltage (V_{dc}). The bipolar DC-bus voltage across the interfacing inductor determines the peak-to-peak switching ripple ($\Delta I_{sw,p-p}$). Formula for minimum interfacing inductor ($L_{f,min}$) is given by

$$L_{f,min} = \frac{V_{dc}}{2 \cdot (\Delta I_{sw,p-p}) \cdot f_{sw,max}}$$

$f_{sw,max}$ is the maximum frequency of switching ripple and $\Delta I_{sw,p-p}$ is the peak-to-peak switching ripple of compensation current.

VII. DC-BUS CAPACITOR

The DC-bus capacitor (C_{dc}) is used as a temporary energy storage element in the proposed hybrid APF as shown in Fig. 3. Under steady state condition, the reactive and harmonic load currents will charge and discharge the DC-bus capacitor during the source voltage period. The total reactive and harmonic load current to be compensated is the principle factor that causes the DC-bus capacitor voltage fluctuation. To get a good compensation performance, serious voltage fluctuations must be avoided. In such cases the capacitor may have to supply real power demand of the load during one cycle of the utility voltage. This can be achieved by proper sizing of the DC-bus capacitor. The size determination of the DC-bus capacitor is based on the energy-balance principle which means that the stored energy of the capacitor should be equal to sudden change in the load energy for one cycle of supply voltage.

The DC-bus capacitor can be calculated by using this formula

$$C_{dc} \geq \frac{V_{s,max} \Delta I_L T}{|(\Delta V_{dc})^2 - (V_{dc,ref})^2|}$$

VIII. CONTROL STRATEGY

The objective of 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 control system consists of synchronous reference frame theorem based compensation current estimator, hysteresis current controller for gate signal generation and a Fuzzy logic controller to maintain the DC bus voltage constant.

8.1 Compensation Current Reference Estimation Using d-q-0 Theory

In this paper synchronous reference frame (SRF) theory is employed to obtain compensating current reference signal. 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 and harmonic component is stopped. By subtracting fundamental component from non-filtered signal will result in harmonic component in load current. Control signal from Fuzzy logic controller is added to this signal to obtain the reference compensating signal in d-q reference frame. 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.

8.2 Hysteresis Current Control (HCC) for Switching Signal Generation

Fig. 3.4(a) shows a single phase VSI with terminal voltage (V_f) connected to a sinusoidal voltage source (V_s) through an equivalent inductance L and resistance R . Fig. 4 shows its HCC.

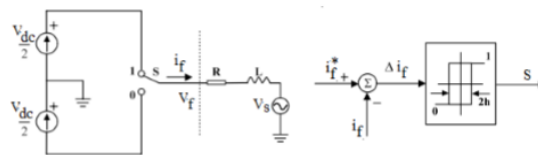


Fig.4. Single Phase VSI, Hysteresis Controller

8.3 Fuzzy Logic based DC Bus Voltage Control

Fuzzy logic has become more popular during past four decades due to its advantages of robustness against parameter variation, popularity, customization, etc. When system is too complex or too poorly understood to be described in precise mathematical terms, fuzzy modeling provides the ability to linguistically specify approximate relationships between the input and desired output. The relationships are represented by a set of fuzzy If-then rules in which the antecedent is an approximate representation of the state of the system and the consequent provides a range of potential responses. In this thesis fuzzy logic controller is used to maintain DC bus voltage constant at a reference value. Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership.

Fuzzy logic allows emulating the human reasoning process in computers, quantifying imprecise information, making decision based on vague and incomplete data, yet by applying a “defuzzification” process, arriving at definite conclusions. The block diagram representation of a fuzzy logic controller (FLC) is shown in Fig. 5

In this proposed paper mamdani membership function with triangular wave was used.

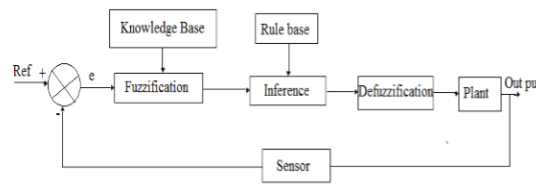


Fig.5 Fuzzy Logic Controller

IX. TUNED PASSIVE FILTER DESIGN

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 as shown in fig6

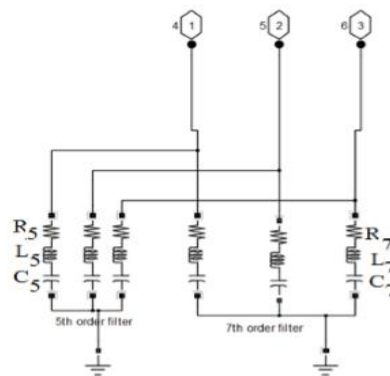


Fig 6. Tuned Passive Filter

X. SIMULATION MODEL

Simulation is performed using system parameters presented in table

System frequency	50Hz
System Voltage	$2000\sqrt{2}$ Vmax
Inductor Lf	3Mh
Capacitance Cf	1 μ F
Inductor Ls	15mH
Resistor Rs	0 Ω
DC Capacitor voltage	4600 μ F
DC bus voltage	4700 V
R5,L5,C5	0.28 Ω ,13.5mH,30 μ F
R5,L7,C7	0.20 Ω ,6.8mH, 30 μ F
Switching frequency	1 KHZ

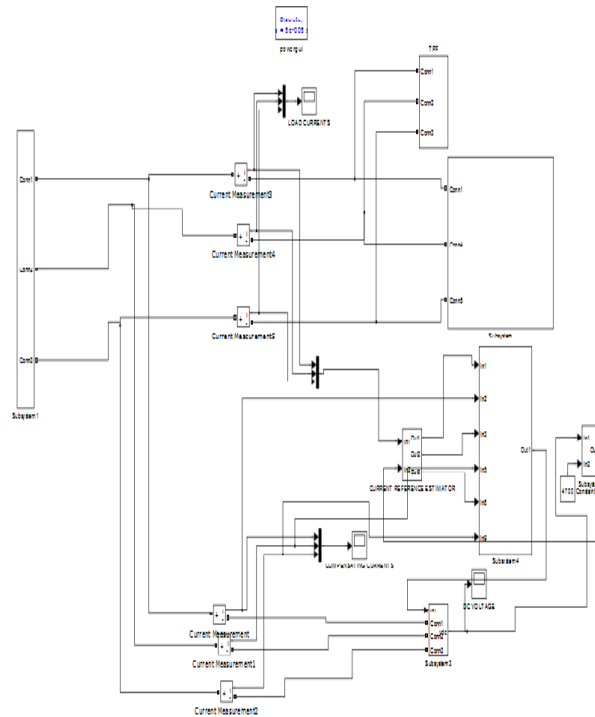


Fig.7 Simulation Model of SHAF

XI. RESULTS AND DISCUSSIONS

The source and load currents of uncompensated system is given by fig.8 and fig.9

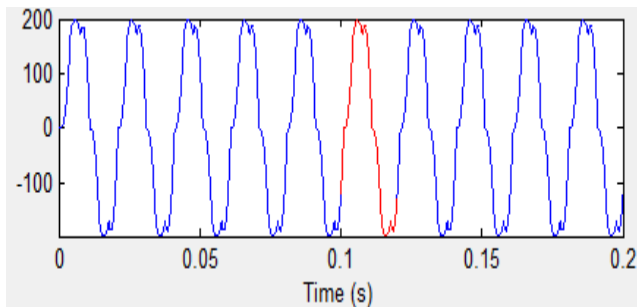


Fig.7 Source Current

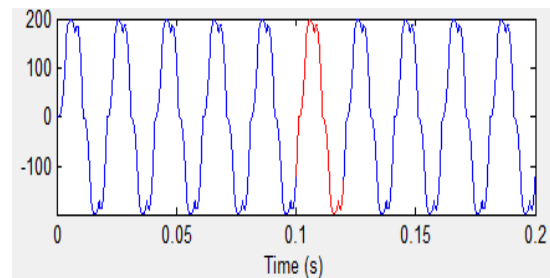


Fig.8 Load Current

FFT analysis of source and load currents of uncompensated system

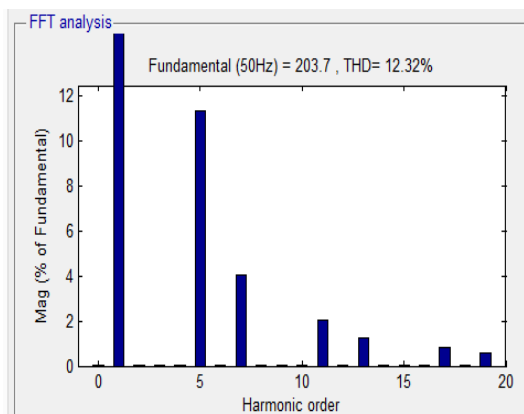


Fig.9 FFT of Source Current

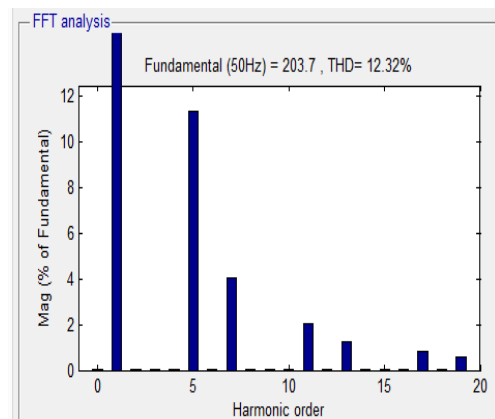


Fig.10 FFT of Load Current

The source current and load current of SHAF compensated system is shown in fig.11 & 12

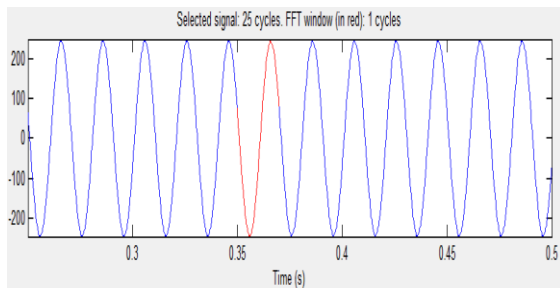


Fig.11 Source Current

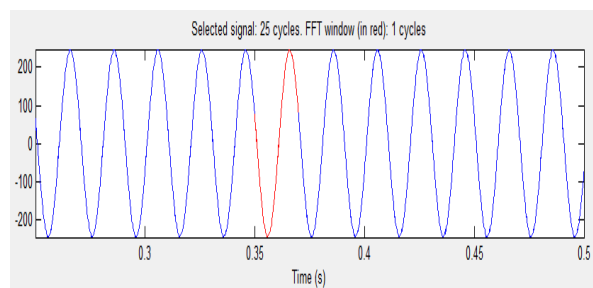


Fig.12 Load Current

FFT analysis of SHAF compensation system is shown in fig.13 & 14

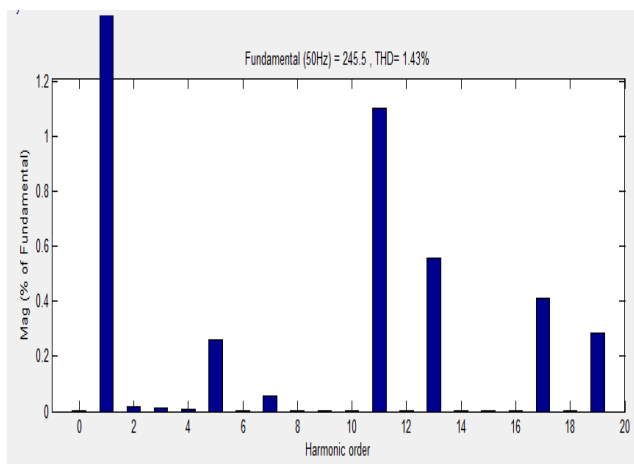


Fig.13 FFT of Source Current

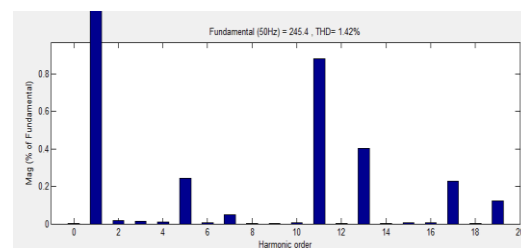


Fig.14 FFT of Load Current

The compensating currents of SAF are shown in fig.15

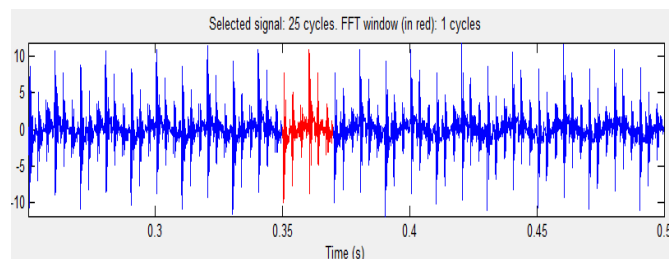


Fig.15 SAF Compensating Currents

From the above results it is evident that by using SHAF the current harmonics can be drastically reduced and are in within limits as per IEEE standard and also the power increased from 0.97 to 0.99 with SHAF compensation

XII. COMPARATIVE ANALYSIS

PARAMETER	%THD	Power factor
Is without compensation	12.32	0.97
II without compensation	12.32	
Is with SHAF compensation	1.43	0.99
II with SHAF compensation	142	

XIII. CONCLUSION & FUTURE WORK

In this paper By using the combination of both Shunt active filter and tuned passive filter with fuzzy logic controller the total harmonic distortion can be effectively reduced in an LV uncompensated distribution system. The higher order harmonics (5^{th} & 7^{th}) can be eliminated by tuned passive filter and the remaining harmonics can be eliminated by shunt active filter .since the higher order harmonics are eliminated by passive filters the rating of the active filter will be less so the overall cost of the proposed SHAF will reduce considerably.

In future instead of 2-level VSI for generating compensating currents for SHAF if we use a multi-level inverter (M.L.I) integrated with renewable energy source the more current harmonics as well as voltage harmonics can be mitigated than 2-level VSI. This type of multi-level inverter technology is more useful in MV system to improve power quality.

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