ELIMINATION OF HARMONIC RESONANCE USING HYBRID ACTIVE FILTER UNIT WITH VARIABLE CONDUCTANCE.

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Abstract - *Abstract—* Harmoni c distortion is mainly due to the tuned passive filter and line inductance which produces resonances in the industrial system. To suppress this above problem hybrid active filter is used. The proposed hybrid filter is operated as variable conductance according to the total harmonic distortion in voltage and current. Thus harmonic distortion can be reduced to an acceptable level in the power system. The hybrid active filter is a combination of seventh tuned passive filter and an active filter in series connection so that the VA rating of the active filter and the dc voltage of the active filter are reduced to acceptable levels and in addition to that hybrid active filter is used because of its filtering capability and the cost. A Design consideration is presented and experimental results are provided to validate the effectiveness of the proposed method.

Keywords— Harmonic resonance, Hybrid active filter,

1. INTRODUCTION

The extensive usage of nonlinear loads such as adjustable speed drives, uninterruptable power supply and battery charging system increases the harmonic pollution. The diodes or rectifiers are used to realize the power conversion because of lower component cost and its simplicity. Moreover rectifiers allow a large amount of harmonic current flow in the system. This excessive power flow produces harmonic distortion which may give rise to malfunction of sensitive equipment. Normally tuned passive filter are located at the secondary side of the distribution transformer to provide low impedance for controlling harmonic current and to correct the power factor for harmonic loads[1],[2].To provide the parametric changes in the passive filters, results in unintended series or parallel resonances that may occur between the passive filter and the line inductance. The functionality of passive filter may become progressively worse and extra calibrating work is needed to maintain the filtering capability.[3],[4].

Various active filtering technique have been presented to indicate the harmonic issues in the power system [5]-[7].The active filter is used for compensating harmonic currents of non-linear loads, but this may not be effective. To improve the performance of the passive filter "active inductance" hybrid filter was introduced [10].The fifth harmonic resonance is present between the power system and the capacitor bank. In order to suppress that fifth harmonic resonance a hybrid shunt active filter with filter –current detecting capability was used. The combination of both the active and the passive filter in series with the capacitor bank by coupling a transformer was used to reduce the harmonic resonance and to balance the harmonic current.[12],[13].This method needs extra transformers or tuned passive filter to maintain the filtering capability

A transformerless hybrid active filter was presented to compensate harmonic current and or fundamental reactive current [14] –[19].A hybrid active filter with damping conductance was proposed to suppress harmonic voltage propagation in distribution power systems [20].The resonance between the passive filter

and the inductance is not considered in the system. The fixed conductance may deteriorate the damping performances. An anti-resonance hybrid filter for delta-connected capacitor bank of power-factor-correction applications is presented [21]. This in circuit was limited to three single-phase inverters, and the filtering performance was not considered. In addition, the hybrid active filter was proposed for the unified Power Quality (PQ) conditioner to address PQ issues in the power distribution system [22]. Several case studies of the hybrid active filter considering optimal voltage or current distortion were conducted in [23].
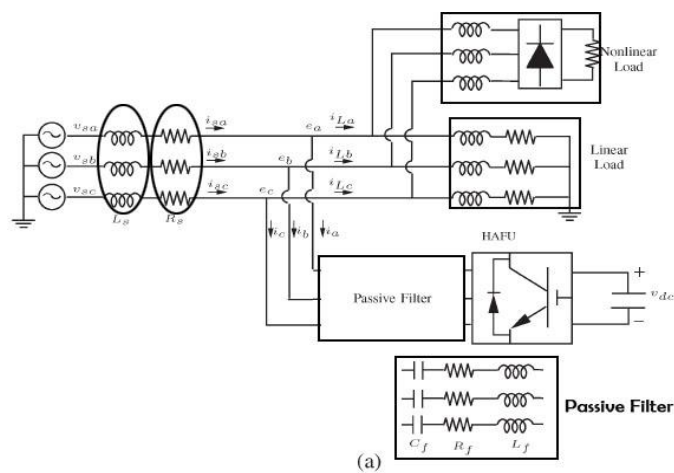

Fig 1(a) Proposed System

1.1 Operating principle

Fig 1(a) shows a simplified circuit diagram considered in

this paper, where L_s represents the line inductance plus the leakage inductance of the transformer. The Hybrid Active Filter Unit (HAFU) is constructed by a seventh-tuned passive filter and a three-phase voltage source inverter connected in series connection. The passive filter is intended for compensating harmonic current and reactive power. The inverter is designed to suppress harmonic resonances and to improve the filtering performances of the passive filter.

1.2 HARMONIC LOOP

To suppress harmonic resonances, the HAFU was proposed to operate as variable conductance at harmonic frequencies as follows:.

$$L^*_h = S^* \cdot e_h \qquad (1)$$

where L^*_h represents the current harmonic command. The conductance command S^* is a variable gain to provide damping for all harmonic frequencies. Harmonic voltage component e_h is obtained by using the SRF transformation [9], where a Phase-Locked Loop (PLL) is realized to determine the fundamental frequency of the power system [28]. In the SRF, the fundamental component becomes a dc value, and other harmonic components are still ac values. Therefore, harmonic voltage component $e^e_{qd,h}$ can be extracted from e^e_{qd} using highpass filters.

1.3 FUNDAMENTAL LOOP

In the paper, the q-axis is aligned to A-phase voltage. Since

the passive filter is capacitive at the fundamental frequency, the passive filter draws leading current from the grid, which is located on the d-axis. The proposed inverter produces the low voltage on the d-axis, which is in phase with the leading current. Therefore, the control of dc bus voltage can be accomplished by exchanging real power with the grid. Thus, the current command $i^e_d{}^*f$ is obtained by a proportional–integral (PI) controller. The fundamental current command i^*_f in the three-phase system is generated by applying the inverse SRF transformation

The harmonic voltage drop on the passive filter due to the compensating current of the HAFU [20], where I represents the maximum harmonic current of the active filter, and the voltage drop on filter resistance Rf can be neglected. As can be seen, a large filter capacitor results in the reduction of the required dc voltage. The filter capacitor determines reactive power compensation of the passive filter at the fundamental frequency. Thus, the dc voltage v^*_{dc} can be determined based on this compromise. Note that the compensating current should be limited to ensure that the hybrid filter operates without undergoing saturation, i.e.,

$$v_{dc} > 2$$

1.4   CURRENT REGULATOR

The current command i^* consist of i^{**}_h and i^*_f Based on the current command $i^*$and the measured current i, the voltage command v^* can be derived by using a proportional controller

as follows:

$$v^* = K_C.(I^*-i) \qquad (2)$$

Where K_c is a proportional gain. According to the voltage

command v_*, space vector pulse width modulation (PWM) is employed to synthesize the required output voltage of the inverter.The computational delay of digital signal processing is equal to one sampling delay T, and PWM delay approximates to half the sampling delay $T/2$. Hence, the proportional gain K_c can be simply evaluated from both open loop and closed-loop gains for suitable stability margin and current tracking capability.

2   EXPERIMENTAL VERIFICATION

The filtering performance of HAFU designed by using equivalent circuit models. The passive filter equivalent harmonics has been changed by harmonic conductance so that the unintentional resonances can be avoided. Here the major concentration is on THD*.

To compensate the inductive loads a capacitor has been used .A filter inductor was chosen to balance the LC filter resonant. The three phase of the inverter is short circuited so that OFF state HAFU corresponds to turning on three upper switches and turning off of three lower switches. At this moment, HAFU acts as a pure passive filter.

2.1   THREE PHASE LOAD

In the case of three phase load system, the filter is designed using pq theory. When HAFU Is in OFF state HAFU becomes a passive filter.
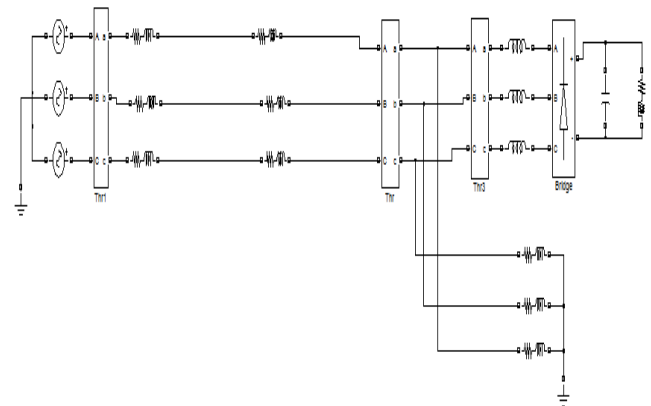

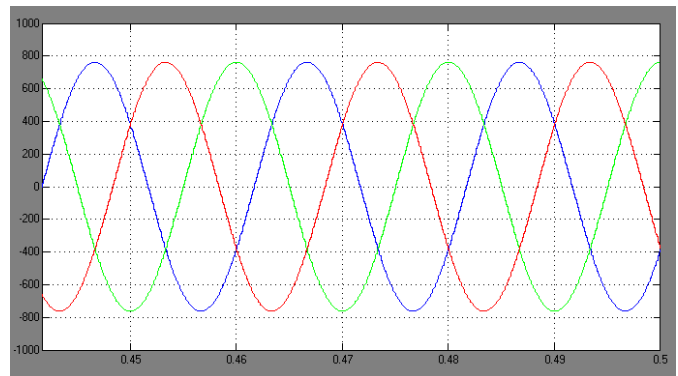**Fig 2(a) Simulation circuit without filter**

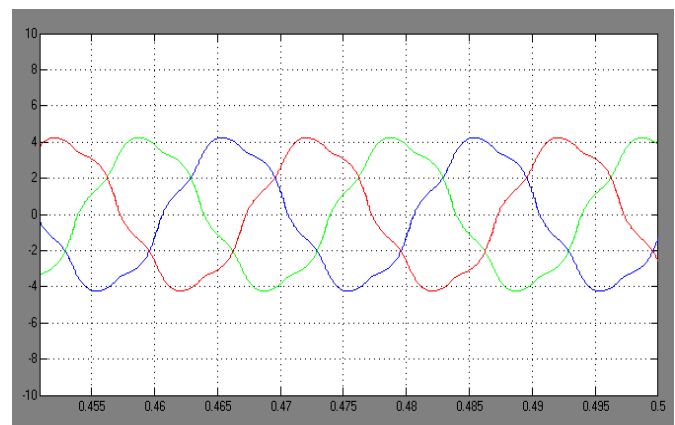**Fig 2(b) source voltage waveform**

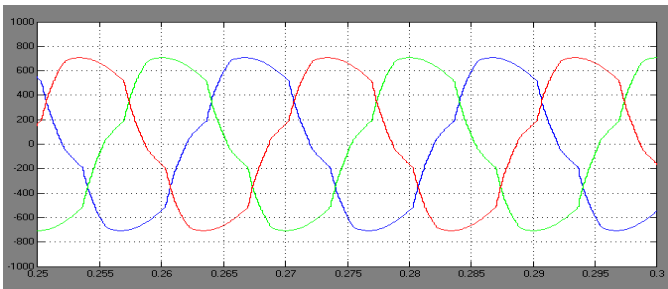**Fig 2(c) load current waveform**

Fig 2(d) load voltage waveform

The simulation was done for the linear loads and the non linear loads and when the HAFU is off the harmonics caused by both loads are very high. In fig2(b) and 2(c) shows the disturbances produced in the sinusoidal waveform which is due to the harmonic disturbance.
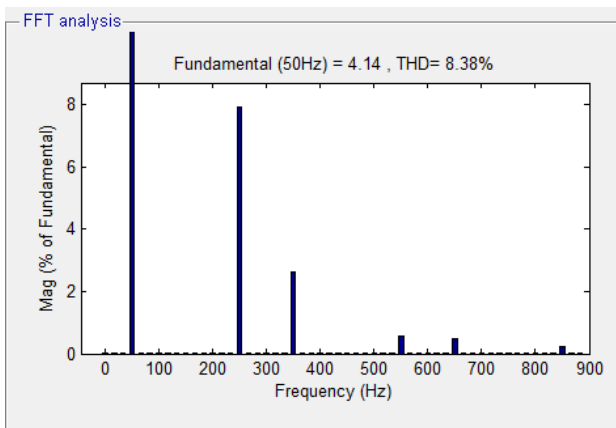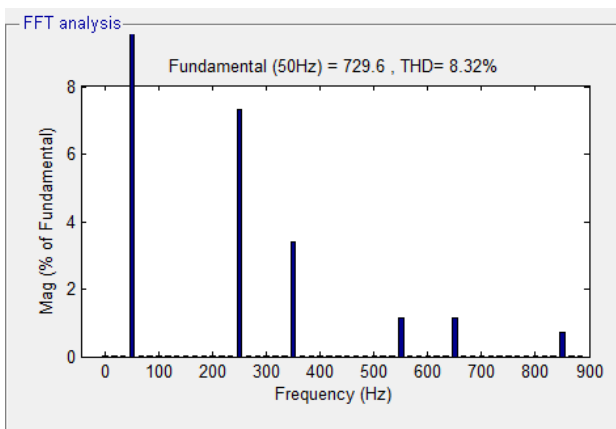

Fig 3(a) FFT analysis for load voltage

Fig 3(b).FFT analysis for load current

TABLE 1

Harmonic distortion for non-linear load (a)Load voltage (b)Load current

	THD	H_5	H_7	H_9	H_{11}
HAFU OFF	8.34	7.32	3.41	0.001	1.16
HAFU ON	2.76	2.72	1.71	0.07	0.50

	THD	H_5	H_7	H_9	H_{11}
HAFU OFF	8.38	7.90	2.63	0.001	0.58
HAFU ON	4.73	2.24	0.93	0.06	0.23

The filter was designed using PQ theory to reduce the harmonics. From the results shown in Table 1,it is clear that with HAFU, harmonic content in load voltage and load current reduces considerably.

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

(3)

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

(4)

The p-q theory consists of an algebraic transformation (Clarke transformation) of the three-phase voltages and currents in the *a-b-c* coordinates to the α-β-*0* coordinates, as shown in equations (3) and (4).The power components are related to voltage and current and the equation is shown as follows

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

(5)

To calculate the reference compensation currents in the α-β coordinates, the equation (5) is inverted, and the

powers to be compensated is shown as follows

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \cdot \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} p & -p_0 \\ & q \end{bmatrix}$$

(6)

Finally the reference compensation current in the a-b-c co-ordinates are obtained through the inverse of transformation

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{c0}^* \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix}$$

(7)

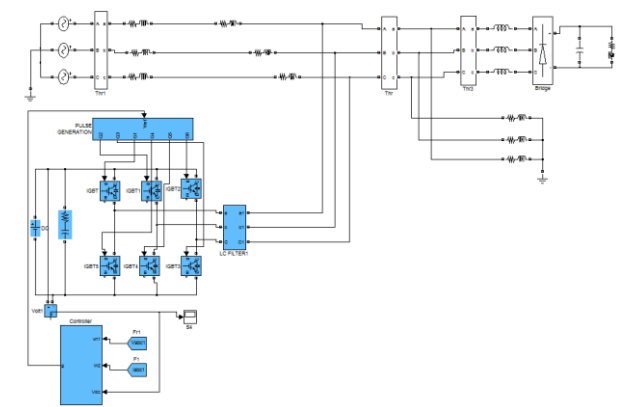By the following steps, the PQ theory based filter is designed, and the overall THD is reduced.
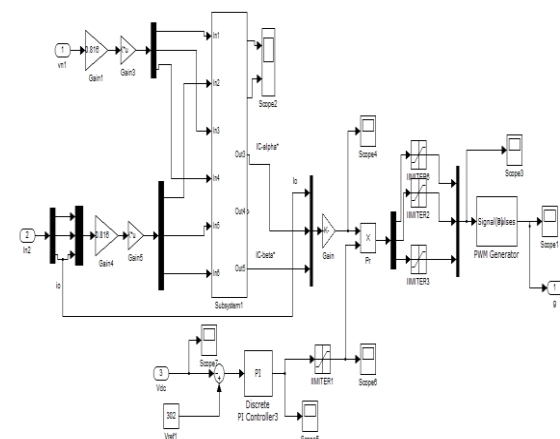

Fig 4(a) simulation circuit with filter blocks

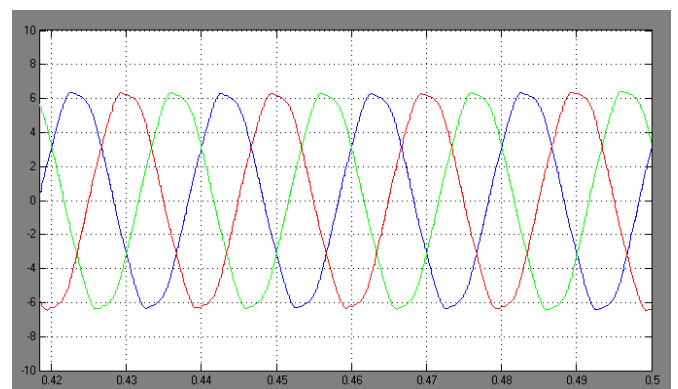
Fig 4(b) PQ theory control blocks
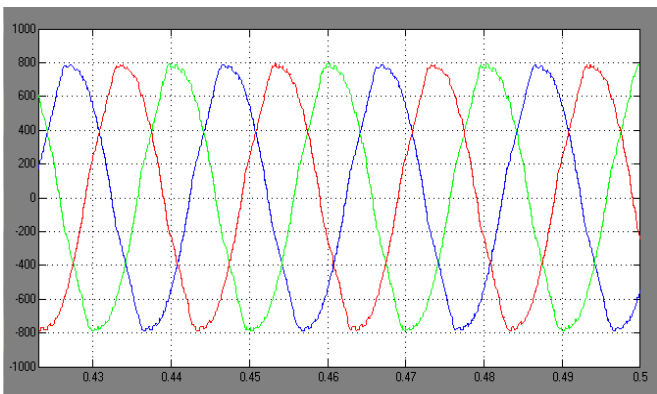

Fig 4(c)Load Current waveform
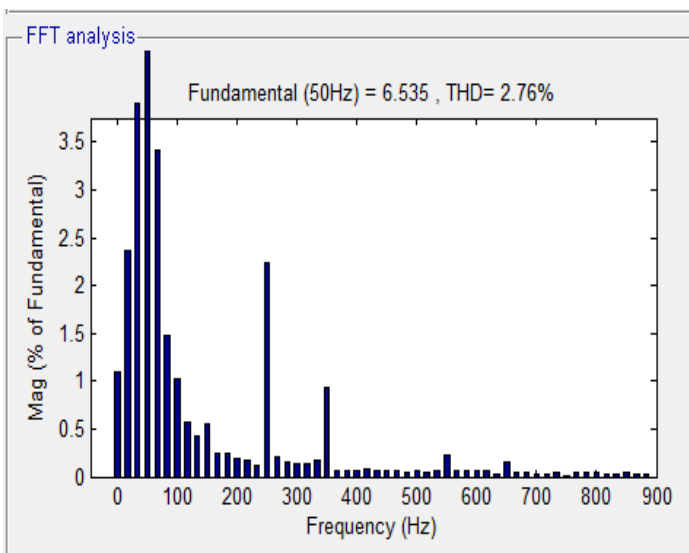
Fig 4(d) load voltage waveform

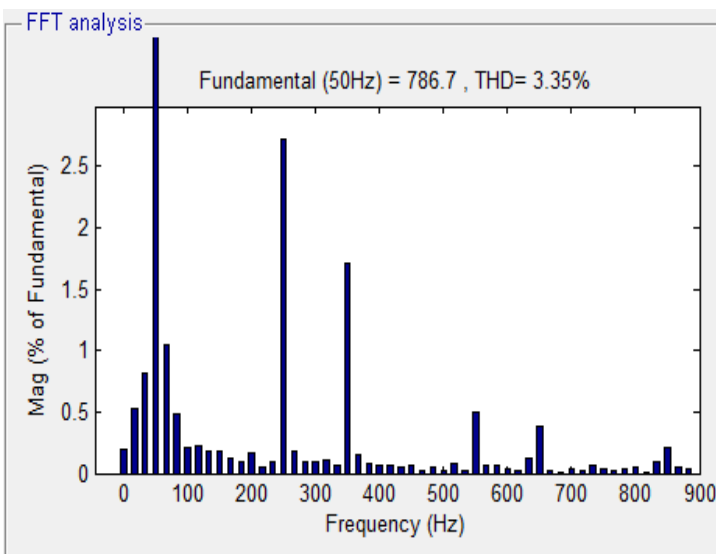**Fig4(e) FFTAnalysis of load current**

Fig 4(f) FFTAnalysis Of load voltage

IV.   CONCLUSION

In yhis paper the role of Hybrid Active Filter unit to suppress the harmonic distortion is discussed.The hybrid active filter is composed of the seventh harmonic tuned passive filter and an active filter in series connection.With the active filter operating as variable harmonic conductance, the filtering performances of the passive filter can be significantly improved. Experimental results verify the effectiveness of the proposed system.

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