ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

Power Quality Improvement Using Hybrid Active Power Filter Based Fuzzy Logic Controller

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Abstract:

The utilization of non-linear loads has become major concern especially in an industrial power system. The operation of these loads creates harmonics. If the harmonic occurs at the same frequency when the power system is at resonance, it could result in amplification of the harmonic distortion (harmonic resonance). The installation of filters is important to avoid permanent damage to the electrical equipment. This paper presents a connection of the hybrid active filter in series with the passive filter without transformer to damp the harmonic resonance as well as to mitigate the harmonic voltages and currents. Also, address the frequency analysis method to observe the effect of parallel and series resonant in power system. The studied system is modelled and simulated using MATLAB/Simulink software.

الملخص:

تعتبر الأحمال الغير خطية هي أكثر الأحمال شيوعا في نظم القوى الكهربية، والتي تتسبب في توليد التوافقيات. إذا كان تردد هذه التوافقيات نفس التردد للموجة الأساسية فإنه يسبب تشوه الموجه الأساسية، وينتج عنه طاقة ملوثة. لذا يعتبر تركيب المرشحات بهدف التخلص من التوافقيات أحد الحلول الأساسية بشكل عام، كذلك للحفاظ على أداء مكونات نظم القوى بشكل عام. يقدم هذا البحث عمل مرشح هجين مكون من مرشح نشط مركب على التوالي في الدائرة، مع مرشح خامد بدون محول بهدف إخماد التوافقيات التي توجد في الجهد والتيار، أيضا يركز البحث على طريقة تحليل التردد لملاحظة تأثير رنين التوالي والتوازي في نظم القوى. تم نمذجة النظام قيد الدراسة وعمل المحاكاة الحاسوبية باستخدام حزم البرامج الجاهزة.MATLAB/Simulink .

Keywords : Non-linear loads, Harmonics, Hybrid active filter (HAF).

I. INTRODUCTION

The operation of non-linear loads creates harmonic currents and voltages throughout the power system. If these harmonics exist at the same frequency where inductive and capacitive of the industrial power system are equal this would become much greater and cause electrical pollution (harmonic distortion). Initially, lossless passive filters have been used to mitigate harmonics and compensate reactive power in nonlinear loads. However, passive filters have the demerits of fixed compensation, large size and resonance with the supply system. Active filers have been explored in shunt and series configurations but their main drawbacks appeared when their rating value are close to the load rating at this condition, they considered useless and a costly option to solve power quality problem. A series of hybrid filters has been evolved and extensively used in practice as a cost-effective solution for the compensation of nonlinear loads. Many shunt active filters consisting of voltage fed pulse width modulated (PWM) inverters using IGBT or GTO thyristors are operating successfully in all over the world. [1-2]. An important technology on active filters is the detecting method of harmonics to reduce the capacity of the energy storage components. Various control strategies have been proposed in recent publications for this type of active filters [3-16]. The control strategy presented in [3] is based on the calculation of the real part of the fundamental load current while this is useful in hybrid series active filter but it cannot compensate reactive power completely and needs many complicate calculations. The active power filter proposed in [4–5] uses a dc capacitor voltage closed-loop control; in [6] using an adaptive method with Kalman filter to predict reference current; in [7] and [8] using a modified phase-locked loop for extraction of the reference current. In the cited references, the computation involves various control parameters or needs complex calculations. Also, the dynamic performance of the compensator is not desire in the case of fast-changing loads. The least compensation current control method presented in [9] is based on detection of the harmonics and reactive current of the active power filter. In [10], genetic algorithm and extended analysis optimization techniques were applied for switched capacitor active filters. A combined genetic

algorithm conventional analysis control technique [11] has been considered as a recent control approach. These control strategies have a common drawback concerning the global stability of the closed-loop system. In [12], the control method is based on the calculation of average power; this needs to know some information about system and requires intense calculation. The sliding-mode control method proposed in [13] solves the stability problem; however, the calculation technique for compensation of current reference is complicated and switching frequency is variable. The paper focuses on solving the phenomenon of harmonic resonance that causes problems in terms of power quality to an industrial power system. A hybrid active filter (HAF) is proposed in this paper intended to mitigate the harmonic resonance. There is also other conventional way to filter the harmonic resonance as well as to suppress the existence of harmonic voltages and currents appear at the customer-utility point of common coupling such as passive filters and active filters. However, passive filters implementation could cause resonance effect if it reacts with the system impedance, thus contributing to amplification of harmonic distortion. Moreover, using active filter could cause other disadvantages such as switching losses and disability to filter higher harmonic order. A hybrid active filter is the combination between passive and active filter. It consists of passive filter connected in series with the active filter. The purpose of combining these filters is to inherit all the advantages and produce a more reliable filter, which operates effectively. The paper focuses on studying the 5^{th} and 7^{th} harmonics this because the voltage distortion or voltage harmonics in the power systems are becoming so seriously and barely acceptable at the customer-utility point of common coupling [14]. Fuzzy logic control (FLC) is one of the significant tools in control design originated by Zadeh which has high robustness, insensitivity to parameters variations, handling of non-linearity and independent on mathematical models. This paper presents a fuzzy logic-controlled shunt APF for the elimination of current harmonics and reactive power compensation of nonlinear load. The control scheme is based on indirect current control scheme in which only source current is sensed for avoiding switching spikes. Three phase voltage and current signal is sensed using two voltage and current sensors. The effectiveness and validity of the proposed FLC is verified through MATLAB simulation. The total harmonic distortion (THD) results between the conventional PI and proposed FLC are presented. It is shown by the simulation results that proposed controller based on fuzzy logic is robust that conventional PI controller for steady-state and transient conditions of load [15-18]. Also, the paper performed the frequency scan analysis technique to analyze the harmonic resonance in power system. The simulation has conducted on the modification of 13 buses Distribution System. The simulation result showed that the effect of adding power factor corrector which results in higher THD can be solved using hybrid active filter.

II. METHODOLOGY AND CASE STUDY

Harmonics expression can be defined as the following Equation

$$x(t) = A_o + \sum_{h=1}^{\infty} A_h \cos(h\omega_1 + \theta_h) \quad (1)$$

where ω_1 is the fundamental frequency, A_O is the DC offset, A_h is the harmonic amplitude, h is the harmonic order and θ_h **is** the phase angle of the harmonics order.

The total harmonics distortion is given by:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty}(I_h^2)}}{I_1} \qquad (2)$$

where Ih is the harmonic amplitude order and I1 is amplitude of fundamental component of current. Figure1 showed the construction of hybrid filter and its important part which is shunt passive L-C filter used in compensation of lower order harmonics. It is able to reduce the voltage and current harmonics at reasonable costs [16]. The control strategies of hybrid active power filter using Fuzzy Based SVPWM Controller and the block diagram of Fuzzy Logic Controller are shown in figure 2 and 3 respectively and then the simulated system in figure 4 is shown.

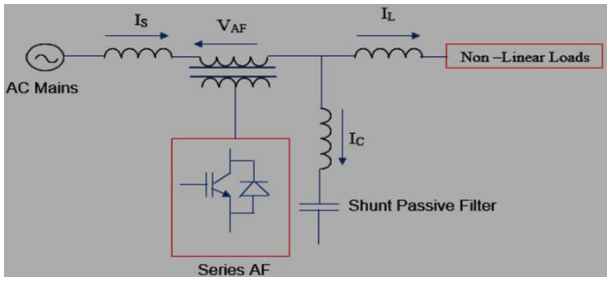

Fig.1 hybrid filter type

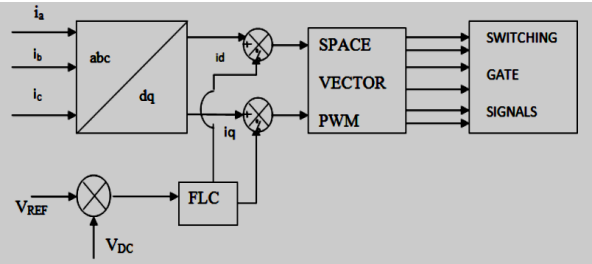

Fig .2 Control block diagram of Fuzzy based SVPWM

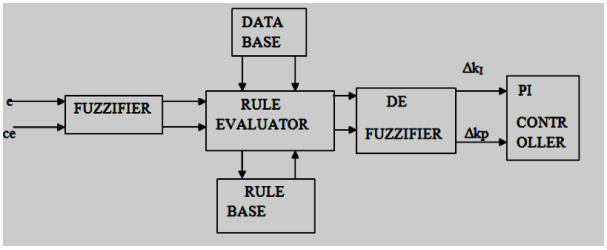

Fig .3 Block diagram of Fuzzy Logic Controller

The current and voltage waveforms are introduced in this section under various kinds of conditions to watch the execution of modern power framework show where 3-stage 6 beat diode rectifier speak to as the consonant creating load. There are three kinds of conditions have been connected to the modern power framework display which are without the present of pay, with the present of aloof channel and with the present of the proposed crossover dynamic channel.

III. SIMULATION RESULTS

Case 1) without Compensation

In view of Figure 5, it tends to be seen that the source voltage and current are indistinguishable with the heap voltage and current as far as waveform, size and stages. This is because of the way that symphonious current, in which is delivered by the consonant creating load, streams all through the power framework. This consonant current makes twisting the line current which will likewise contort line voltage of the mechanical power framework. The absolute consonant mutilation under condition without channel is expanded up to 20.72% for source and burden current while source and burden voltage is expanded up to 1.26%.

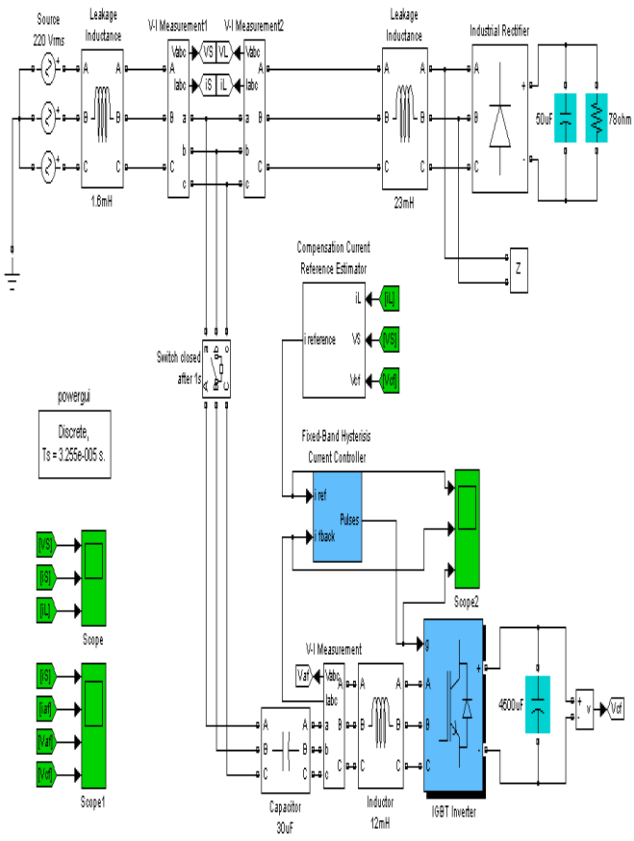

Fig.4 Simulation of Hybrid Active Filter within tested system

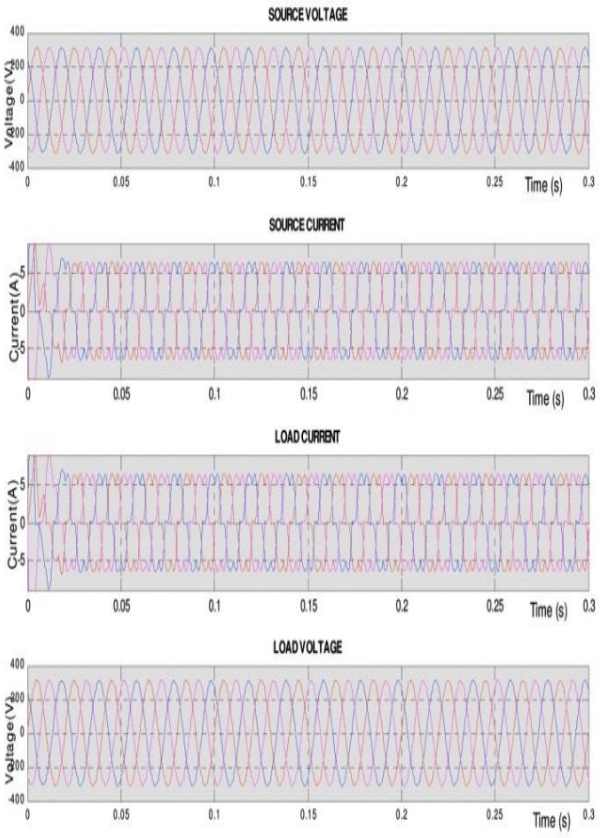

Fig.5 Voltage and current waveform without Compensation

Case 2) Passive Filter (PF) tune to 5th and 7th harmonic

Figure 6, it tends to be seen that the source current isn't indistinguishable with the heap current as far as waveform. With the present of detached channel, the fifth symphonious of the source current is smothered and leaves just the staying consonant current of seventh, eleventh, thirteenth, and another higher consonant segment. The absolute symphonious contortion for the current in light of present conditions is diminished down to 7.27% while the original voltage is decreased to 0.64% which is in contrast with the heap voltage and current THD. There has been critical decrease as far as absolute symphonious contortion when uninvolved channel is tuned to fifth consonant. This is because of certainty that the lower the symphonious segment, the higher the consonant size current which contributed the greater part of the all-out consonant contortion rate.

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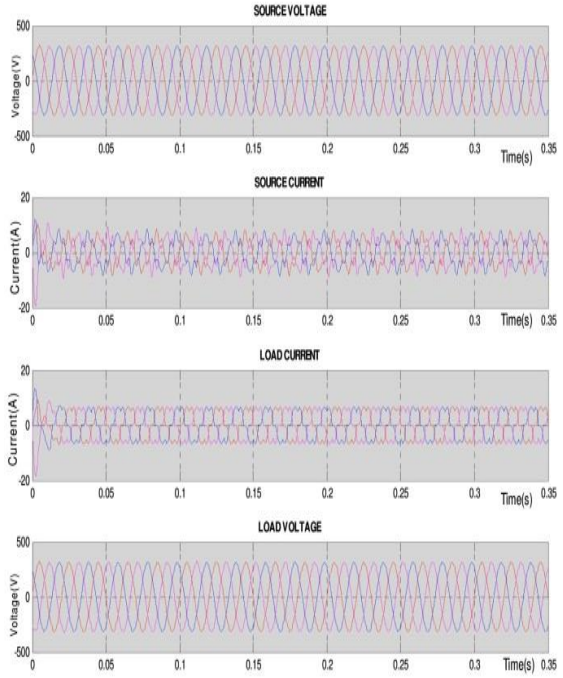


Fig. 6 Voltage and current waveform with 5th-tune passive filter

In light of Figure 7 which present waveform is never again indistinguishable with the heap current waveform. The vast majority of the seventh consonant segment has been smothered by the aloof channel tuned to the seventh symphonious. In spite of the fact that, along these same lines the all-out symphonious bending rate assume to be smothered yet due to somewhat increment in fifth consonant, the all-out harmonic distortion percent consonant mutilation is expanded up to 26.47 for source present and 1.36 for source voltage. The detached channel tuned to the seventh symphonious reason the fifth consonant to be marginally expanded.

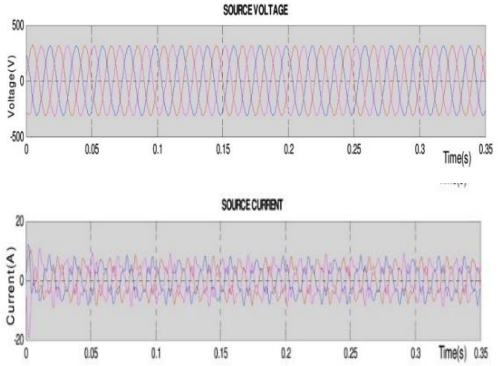


Fig.7 Voltage and current waveform with 7th-tune passive filter

Case 3) Using Hybrid Active Filter (HAF)

Figure 8. shown that the mutilated source current waveform is changed to sinusoidal waveform at 1.1s consistent state condition. The change to sinusoidal waveform showed that the contorted current waveform is effectively redressed. The exchanging clock is intentionally changed in accordance with shut down at 1s to watch the progress among contorted and repaid current condition. There has been transient impact from 1.0s to 1.02s because of the exchanging clock installed.

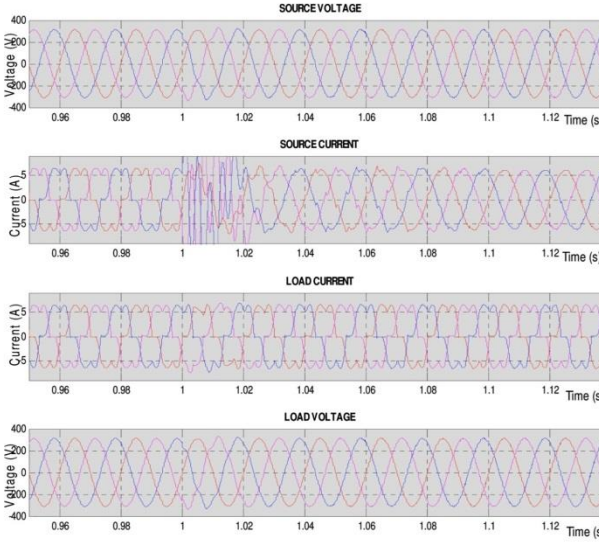


Fig.8 Voltage and current waveform with hybrid active filter

For this circuit plan, the current took around 0.1s to achieve the relentless state condition because of capacitor charging. The all-out consonant twisting for the current along these same lines is decreased down to 1.73% while source voltage is diminished down to 0.18% as contrast with the heap voltage and current THD. The diagram additionally demonstrates that the remunerated current is as yet a similar stage as the source voltage. This recreation is just thinking about the voltage and current under adjusted condition and does not cook the voltage and current change under uneven condition. Based on Figure 9, it seen that the remuneration voltage and current waveform that courses through the IGBT Inverter line.

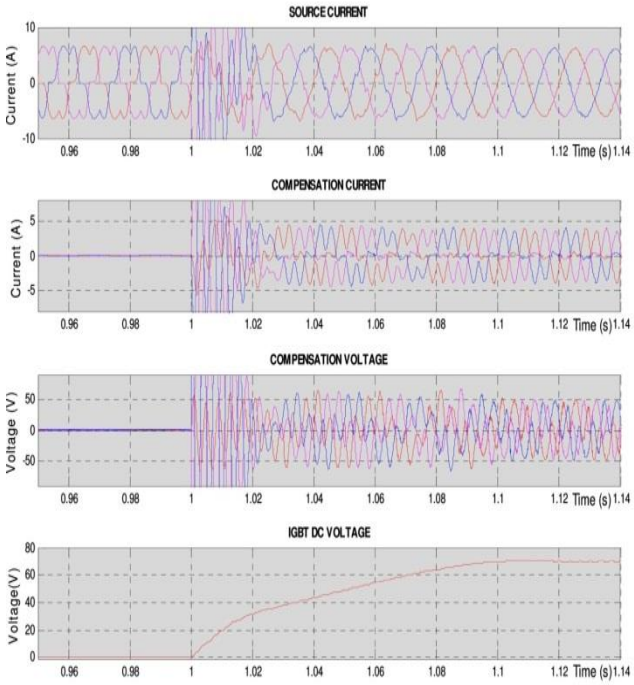


Fig. 9 Voltage and current waveform at IGBT Inverter power line

The chart demonstrates that the pay current waveform is indistinguishable with the present reference estimation as far as waveform and greatness. There have been marginally exchanging swells of the pay current because of changing from the beat generator and IGBT Inverter. The power supply for IGBT Inverter is planned utilizing the capacitor charging and releasing wonder. One of the proposed design merits for financial perspective demonstrated by the voltage expected to driving the IGBT Inverter which is just 70V this considered as an ideal voltage rating of the inverter. From Figure 10 it indicated that the waveform of pay current reference estimation is contrasting than the twisted burden current. This is because of the way that pay current reference contain just symphonious segment of the heap current.

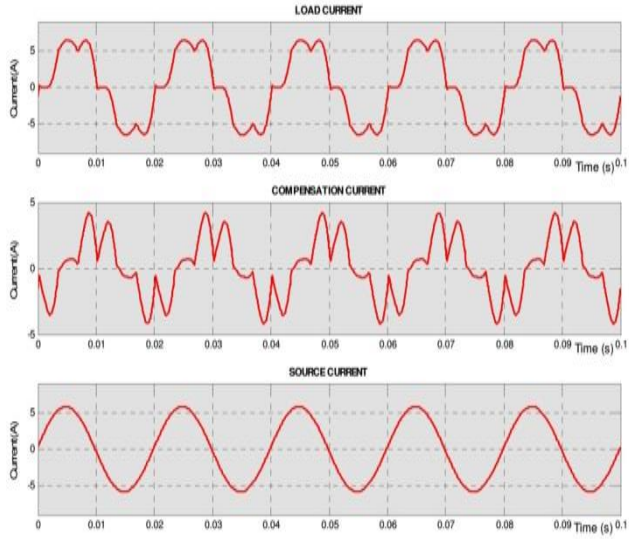


Fig. 10 Current waveform under ideal condition

When contorted burden current is infused to p-q theorem control circuit, it will separate the consonant segment

from the principal component. Under perfect remuneration, the impact of swells because of heartbeat generator and IGBT Inverter exchanging framework is dispensed with. Thus, the viability of remuneration current reference under perfect pay can be watches. Base on Kirchhoff current law, the present streaming to stack (load current) is subtracted to current spilling out of the IGBT Inverter line (remuneration current) to get source current without symphonious part. The complete consonant bending under perfect pay is gotten at 0.5% and the key current sufficiency is at 5.85A.

In light of Table 1 and Table 2, they gave the level of all out symphonious bending of burden current, from Table 1 ,for example, I_{ITHD}(%) of the load current at the estimation is 20.73 , for key segment 6.54A, for fifth symphonious part 1.25A and 0.5A for seventh consonant segment are additionally comparable between the heap current and source current. This is because of the way that symphonious delivering load create consonant current that streams all through the power framework impacting the all-out consonant bending at burden side and source side to increase. From Table 2 when introducing the latent channel is tuned to fifth symphonious, for example, the source current extent of fifth symphonious part is decreased from 1.26A to 0.05A and the THD% rate is decreased down from 20.72 to 7.27 while the heap current from burden side continue as before. At the point when the latent channel is tuned to seventh consonant, the source current size of seventh symphonious part is decreased from 0.5A to 0.01A. The detached channel tuned to seventh consonant makes the present greatness of fifth symphonious segment increment from 1.26A to 1.59A. Henceforth, the THD% rate is increment from 20.73 to 26.47. The tuning of detached channel under this condition is resolved without the thought of existed inductance from source side which causes the power framework thunderous point to be shifted. By thinking about the presence of source inductance, the intensification of fifth or seventh symphonious current segment can be seen by tuning the uninvolved channel to 5.3th or 7.89th consonant. Rather than stifle the symphonious current, the latent channel cause consonant current intensification at the reverberation recurrence. The THD% rate under this condition is altogether expanded up to 303.3% for fifth consonant segment while seventh symphonious segment is expanded up to 171.96%. This condition is independently reproduced by right off the bat tuned the uninvolved channel to 5.3th symphonious and after that to 7.89th harmonic. Based on Table 2, it very well may be seen that the present sizes of fifth and seventh consonant segment are altogether diminished down to 0.05A and 0.07A with the present of Mixture Dynamic Channel. The THD rate is decreased down 1.27% in which. There has been somewhat unique as contrast with perfect remuneration because of exchanging swells cause by heartbeat generator and IGBT Inverter. The basic current of HAF is 6.1A while under perfect pay is 5.85A. The thing that matters is because of the way that IGBT Inverter is given some dynamic power from the power source so as to charge the DC capacitor to the ideal estimation of voltage. In light of Table 3, it tends to be seen that the present extent that courses through the pay line of inactive channel and half-breed dynamic channel. At the point when uninvolved channel is tuned to fifth consonant, the present estimation of IF5 that streams towards the latent channel is 1.3A. At the point when aloof channel is tuned to seventh symphonious, the present estimation of IF7 that streams towards the latent channel is 0.53A. Thus, current at this symphonious segment would not stream toward the source and the consonant segment is said to be suppressed. Instead of symphonious current streams toward pay channel, Half and half Dynamic Channel go about as a present source which produce consonant current to stream toward power framework line and drop the line consonant current. Also, it demonstrates that the HAF create 1.34A of fifth consonant present and 0.47A of seventh symphonious current which result in 0.05A of fifth symphonious present and 0.07A of seventh consonant current at the source side**.**

Case 4) Frequency Analysis

In view of the reenactment result, the diagram of impedance versus recurrence can be plotted just as recurrence range chart as appeared. Table 4 utilizing Quick Fourier Change (FFT) capacity of MATLAB/Simulink programming and demonstrates that without the present of channel, the impedance of generally speaking force framework is straightly expanded regarding recurrence. Under this condition, there is no intensification toward the symphonious current segment due to the missing of parallel resonance. When the uninvolved channel is introduced and tuned to fifth consonant, the chart demonstrates the present of parallel reverberation where the inductive component from power framework is in shunt with the capacitive components from the inactive channel. The parallel reverberation happens at the recurrence of 236.47Hz and cause the diagram to marginally move far from the recurrence of 250Hz where the inactive channel assumes to stifle fifth symphonious current. Harmonic reverberation happens when the aloof channel is tuned to 5.3th consonant and cause the parallel reverberation to happen recurrence of 250Hz. Parallel reverberation cause enhancement to the fifth symphonious current and decline the THD% rate up to 303.02. A similar circumstance is connected to seventh symphonious current intensification when the inactive channel is tuned to 7.98th consonant. With the present of Cross breed Dynamic Channel, the consonant reverberation is moderated.

Table 1 Load Current Harmonic Component of passive and hybrid active filters

	No filter	PF 5th	PF 5.3th	PF 7th	PF 7.89t	HAF
I_{l1}	**6.54**	6.59	6.49	6.58	6.5	6.55
I_{l5}	**1.25**	1.31	0.12	1.21	1.5	1.25
I_{l7}	**0.49**	0.47	0.77	0.52	0.09	0.49
I_{ITHD}%	**20.73**	21.49	12.86	20.41	23.52	20.74
V_L	**309.8**	311.4	311.7	311.3	311.3	311.2

Table 2 Source Current Harmonic Component of passive, hybrid active and ideal filters

	No filter	PF 5	PF 5.3	PF 7	PF 7.89	HAF	Ideal
I_{s1}	6.55	6.09	6.33	6.08	5.96	6.10	5.85
I_{s5}	**1.26**	**0.05**	**23.56**	**1.59**	**1.84**	**0.05**	**0.02**
I_{s7}	0.5	0.38	0.59	0.01	10.07	0.07	0.02
I_{sTHD} %	**20.72**	**7.27**	**303.02**	**26.47**	**171.96**	**1.76**	**0.5**
V_s	309.8	311.4	311.7	311.3	311.3	311.2	-

Table 3 Compensation Harmonic Current Component of passive and hybrid active filters

	PF_{th} 5	PF_{th} 5.5.3	PF_{th} 7	PF_{th} 7.89	HAF
I_{f1}	3.06	3.04	2.99	2.98	2.68
I_{f5}	1.30	22.74	0.39	0.36	1.34
I_{f7}	0.09	0.19	0.53	10.97	0.47

This because of the way that HAF is act as a symphonious remuneration generator which in fuse pay current to the framework. There is no parallel or arrangement reverberation happen and the impedance of in general power framework is directly expanded regarding recurrence. Figure 10 demonstrates the FFT investigation of burden current without APF associated with the framework. Music turn out to be 30.07% in the source current. The bar graph is likewise given portraying the different requests of THD. Figure 11 demonstrates the FFT investigation with APF associated with the framework. It is unmistakably observed that the THD in source current is decreased to 4.36% as it was.

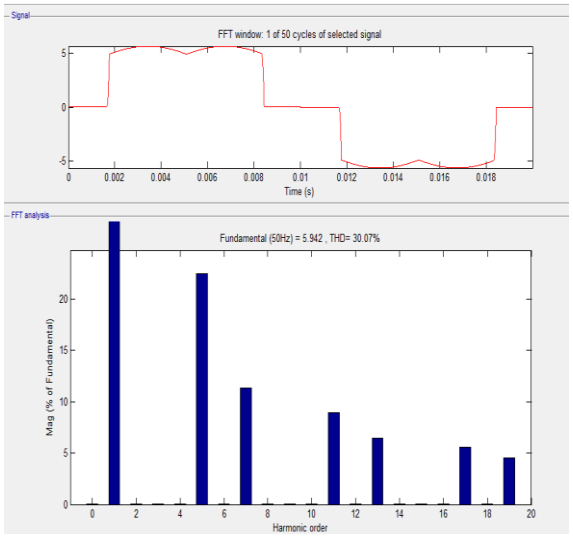


Fig.10 FFT-analysis of load current without APF

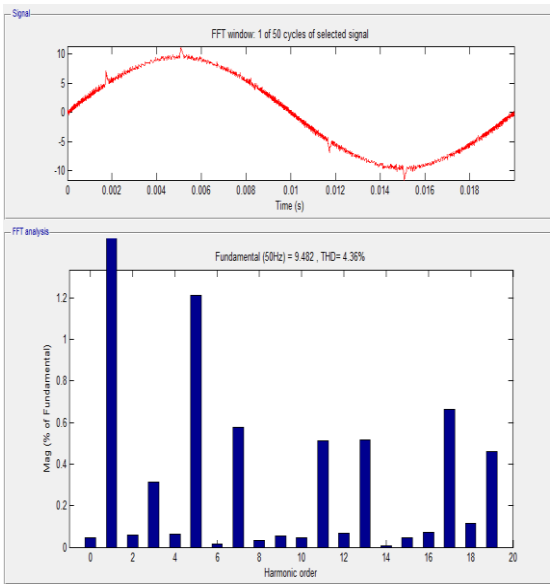
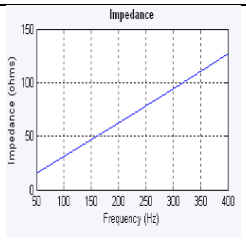
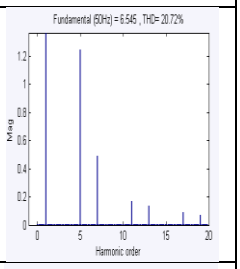
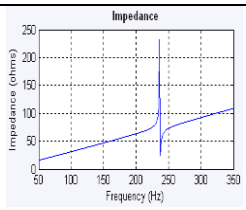
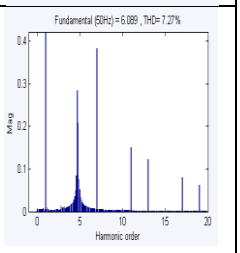
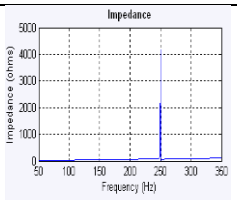
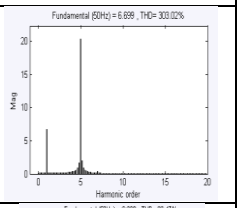
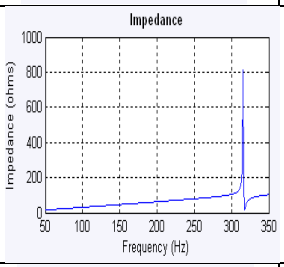
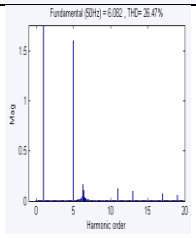
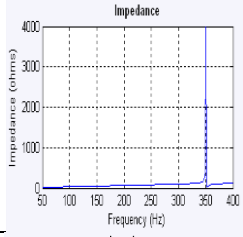
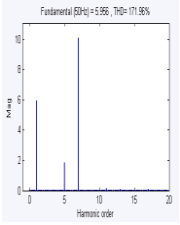
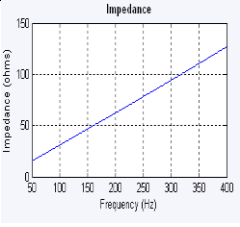
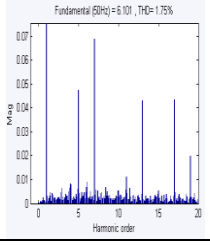


Fig.11 FFT analysis of load current with APF

I. Conclusions

This postulation has introduced the assignment of proposed Cross breed Dynamic Channel constrained just to repay consonant bending under perfect principle voltage condition by utilizing the utilization of p-q hypothesis. From the reproduction result and discourse, it very well may be reasoned that the crossover dynamic channel can improves damping the symphonious reverberation in mechanical power framework, just as to relieve consonant voltage and current. The all-out consonant mutilation of source current has been effectively diminished from 20.73% to 1.73% along these lines, meeting the IEEE 519 suggestion symphonious standard. The p-q hypothesis pay has been appeared to be viable to diminish the complete consonant bending down to 0.5% under perfect condition.

Table 4 Frequency Analysis of Passive Filter (PF) & HAF

	Impedance versus frequency	total harmonic discussion for current source (THD%)
No filter		
PF(5th –tuned)		
PF (5.3 th –tuned)		
PF (7 th –tuned)		
PF(7.89 th –tuned)		
HAF		

REFERENCES

[1] Singh, Bhim, et al. "Hybrid filters for power quality improvement." *IEE Proceedings-Generation, Transmission and Distribution* 152.3 (2005): 365-378.

[2] Peng, Fang Z. "Harmonic sources and filtering approaches." *IEEE industry applications magazine* 7.4 (2001): 18-25.

[3]] Wu, J-C., and H-L. Jou. "Simplified control method for the single-phase active power filter." *IEE Proceedings-Electric Power Applications* 143.3 (1996): 219-224.

[4] Jou, H-L., J-C. Wu, and H-Y. Chu. "New single-phase active power filter." *IEE Proceedings-Electric Power Applications* 141.3 (1994): 129-134.

[5] Hsu, Chin-Yuan, and Horng-Yuan Wu. "A new single-phase active power filter with reduced energy-storage capacity." *IEE Proceedings-Electric Power Applications* 143.1 (1996): 25-30.

[6] Barros, Julio, and Enrique Perez. "An adaptive method for determining the reference compensating current in single-phase shunt active power filters." *IEEE Transactions on Power Delivery* 18.4 (2003): 1578-1580.

[7] Karimi-Ghartemani, Masoud, et al. "A signal processing system for extraction of harmonics and reactive current of single-phase systems." *IEEE transactions on power delivery* 19.3 (2004): 979-986.

[8] Karimi-Ghartemani, Masoud, and M. Reza Iravani. "A nonlinear adaptive filter for online signal analysis in power systems: Applications." *IEEE Power Engineering Review* 22.1 (2002): 72-72.

[9] Zhou, Luowei, and Zicheng Li. "A novel active power filter based on the least compensation current control method." *IEEE Transactions on power Electronics* 15.4 (2000): 655-659.

[10] Welsh, M., P. Mehta, and M. K. Darwish. "Genetic algorithm and extended analysis optimisation techniques for switched capacitor active filters—Comparative study." *IEE Proceedings-Electric Power Applications* 147.1 (2000): 21-26.

[11] El-Habrouk, M. K. D. M., and M. K. Darwish. "A new control technique for active power filters using a combined genetic algorithm/conventional analysis." *IEEE transactions on Industrial Electronics* 49.1 (2002): 58-66.

[12] Kunjumuhammed, Linash P., and Mahesh K. Mishra. "A control algorithm for single-phase active power filter under non-stiff voltage source." *IEEE Transactions on Power Electronics* 21.3 (2006): 822-825.

[13] Torrey, David A., and Adel MAM Al-Zamel. "Single-phase active power filters for multiple nonlinear loads." *IEEE Transactions on Power electronics* 10.3 (1995): 263-272.

[14] Akagi, Hirofumi. "New trends in active filters for power conditioning." *Industry Applications* 32.6 (1996): 1312-1322.

[15] Fuzzy Logic Controller Adaptive Active power filter for Harmonics Minimization and Reactive power compensation under fast load variation. Karuppanan p & kamalakanta mahapatra dept. of national institute of technology-Rourkela, india769008. (International conference on advance in energy conversion technologies (ICAECT 2010), jan07-10-2010).

[16] Wanik, M. Z. C., et al. "Simulation of harmonic resonance phenomena in industrial distribution system." 2004 IEEE Region 10 Conference TENCON 2004.. Vol. 100. IEEE, 2004.

[17] Virali.P.Shah "Fuzzy Logic Based Power Quality Improvement Using Shuntactive Filter " International Journal of Engineering Development and Research 2014 IJEDR | Volume 2, Issue 2 | ISSN: 2321-9939

[18] Kavya Mittal, Ankita Kosti, "Hybrid Active Power Filter For Power Quality Improvement" International Journal Of Emerging Technology And Advanced Engineering Volume 4, Issue 5, May 2014