ISSN: 2208-2735
Volume 08 Issue 01 2025
Available on-line at https://ijreee.com/index.php/eee/issue/view/547

DOI:https://doi.org/10.53555/eee.v8i1.388 Received: 10-January-2025 Accepted: 22-February-2025

Power Quality Improvement using Hybrid Filters

[1]Shitsukane Aggrey Shisiali ,[2]Mathews Ondiek Amuti.

[1]Senior technologist, Department of electrcal and electronic ,Technical University of Mombasa

[2]Senior projects engineer,electrical, Kenya Ports Authority.

Email: [1]kashux1976@gmail.com [2]amutiondiek@yahoo.com

ABSTRACT

This paper presents mitigation of power quality problems introduced by nonlinear loads. Through the expansion of modern industrial technology enormous number of non-linear loads are used in power system, which causes harmonic distortion. Atthe same time the power quality and safe operation becomes substandard. Therefore alleviation of harmonics is very essentialunder this situation. A Hybrid power filter constituting a series active filter and a passive filter coupled in parallel with the loadis proposed to improve the power quality. To validate the developed theoretical analysis, the control strategy is verified bymeans of an experimental prototype using Multisim software. Shunt, hybrid and series active power filters are describedshowing their compensation characteristics and principles of operation. The results to verify the effectiveness of the proposedcontrol algorithm is presented.

Key Words: Passive Filters, Active Filters, Hybrid Filters, Power quality, nonlinear loads.

I. INTRODUCTION

The existence of harmonics in the power electrical systems is the key source of the electrical wave pollution that course somany problems. The indiscriminate escalation of non-linear loads has given rise to research into new compensation equipmentcentered on power electronics. The core design target for this system is the eradication of the harmonic present in the systemand lessening of reactive power. Depending on the application type, series or parallel configurations or combinations of activeand passive filters [1, 2].

Most of the power electronic equipment are used in industrial and domestic purposes, the equipment (ac drives, electronic ballast) have significant impact on the quality of supplied voltage and have increased the harmonic current pollution of the distribution systems. They have many negative effects on the power system equipment's and customers, such as additional

ISSN: 2208-2735

losses in overhead and underground cables, transformers and rotating machines, problems in the operation of the protection systems, over voltages ,error of measuring instruments. This has necessitated improvement on the compensation characteristics required satisfying more stringent harmonic standards.

Passive filters have been used traditionally for mitigating distortion due to harmonic current in industrial power systems, but they have many drawbacks such as resonance problems dependency of their performance on the system impedance, absorption of harmonic current in nonlinear loads, which could lead to further harmonic propagation through the power system [3].To overcome such problems active power filters are introduced, they have no such drawbacks like passive filters, they inject harmonic voltage or current with appropriate magnitudes and phase angle into the system and cancel harmonics of nonlinear loads. It however have such drawback like high initial cost and high power losses due to which it limits its applications especially with high power ratings [4]. To minimize these limitations, we propose a hybrid power filters which is cost effective harmonic compensation particularly in high power nonlinear loads and finally a result for dynamic compensation, obtained from the simulated setup will be presented. Passive power filters, Shunt active power filters, Series active power filters and Hybrid power filters topologies and schemes will be presented and analyzed. The control scheme characteristics for both schemes will be discussed. Finally steady state and transient results for dynamic compensation obtained from simulated under Multisim environment are presented.

LITERATURE REVIEW

POWER QUALITIES IN POWER DISTRIBUTION SYSTEMS

International standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer’s processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer’s equipment [5]. However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. A voltage quality problem relates to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions)of the more important international standards define power quality as the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer’s processes. Therefore, a power quality problem exists if any voltage, current or frequency deviation results in a failure or in a bad operation of customer’s equipment. However, it is important to notice that the quality of power supply implies basically voltage quality and supply reliability. A voltage quality problem relates to any failure of equipment due to deviations of the line voltage from its nominal characteristics, and the supply reliability is characterized by

ISSN: 2208-2735

its adequacy (ability to supply the load), security (ability to withstand sudden disturbances such as system faults) and availability (focusing especially on long interruptions) [6].

Importance of power quality

Power quality is defined by the parameters that express reactive power, harmonic pollution and load unbalance. The best ideal electrical supply would be a sinusoidal voltage waveform which consist of magnitude and frequency, but in reality due to non-zero impedance of the supply systems the large variety of loads may be encountered and of other phenomena such transients and outages, the reality is often different. If the power quality of the network is good, then any load connected to it will run satisfactorily and efficiently. Installation during cost will be minimal. If the power quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will be reduced. The cost of installation and running will be high and operation may not be possible at all [7].

Cost of poor power quality

Poor Power Quality can be described as any event related to the electrical network that ultimately results in financial loss. A possible consequence of poor power quality includes the followings: Unexpected power supply failures (breakers tripping), Equipment failure or malfunctioning, Damage to sensitive equipment (PCs, production line control systems), Electronic communication interferences, Increase of system losses and Penalties imposed by utilities because of site pollutes the supply network [8][9]

HARMONIC DISTORTION

The harmonic pollution is generally characterized by the total Harmonic Distortion or THD which is by definition equal to the ratio of the RMS harmonic content to the fundamental. Harmonic is a signal or wave whose frequency is an integral (whole-number) multiple of the frequency of some reference signal or wave. The term can also refer to the ratio of the frequency of such a signal or wave to the frequency of the reference signal or wave.[10]

Effects of harmonics

The main effects of voltage and current harmonics within the power system are[11]: Amplification of harmonic levels resulting from series and parallel resonance; Reduction of efficiency of power generation, transmission, and utilization; Aging of the installation of electrical plant components and has a consequence the shortening of their useful life; Plant mal-operation; Malfunctioning and failure of electronic equipment; Overheating and failure of electric motors; Overloading, overheating and failure of power factor correction capacitors. Resonance due to interaction of capacitors with harmonics; Overloading and

ISSN: 2208-2735

overheating of distribution transformers and neutral conductors; Excessive measurement errors in metering equipment; Spurious operation of fuses, circuit-breakers and other protective equipment; Voltage glitches in computers systems resulting in lost data. Excessive flicker on VDU's; Electromagnetic interference with TV, radio, communication & telephone systems; a Damage and disruption to standby generators and associated AVR control equipment; Interference with ripple control system [12]

Harmonic sources

The main sources of voltage and current harmonics within the power system are the nonlinear loads [13] listed below among others:-Computers, fax machines, photocopiers, TV's, VCR's, etc. Lighting dimmers & electronic ballasts for high efficiency lighting. Single-phase AC & DC drives. Ultra-violet disinfection systems. UPS systems. Arc furnaces & SCR temperature controllers. Battery chargers. Variable speed AC & DC drives;

SOLUTIONS TO POWER QUALITY PROBLEM

In this project, we concentrate on harmonics as one of the major contributors of poor Electrical power quality and thus concentrate more on methods of harmonic mitigation, there are two approaches to the harmonic mitigation.

The first approach is called load conditioning, which ensures that the equipment is less sensitive to power disturbances, allowing the operation even under significant voltage distortion.

The other solution is to install line conditioning systems that suppress or counteracts the power system disturbances [14]. These include:

- ✓ Passive power Filters
- ✓ Active power Filters
- ✓ Hybrid Power Filter

SHUNT ACTIVE POWER FILTERS

Among active filter topologies, shunt active power filter (SAPF) with its naive implementation is paid more attentions in both time and frequency domains to facilitate the compensation of harmonic currents and reactive power of non-linear loads [15].Shunt active power filter compensate current harmonics by injecting equal-but-opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180 degrees. This principle is applicable to any type of load considered as harmonic source. Moreover, with an appropriate control scheme, the active power filter can also compensate the load power factor [16]. In this way, the

ISSN 2208-2735

power distribution system sees the non-linear load and the active power filter as an ideal resistor. The current compensation characteristic of the shunt active power filter is shown in Fig 1

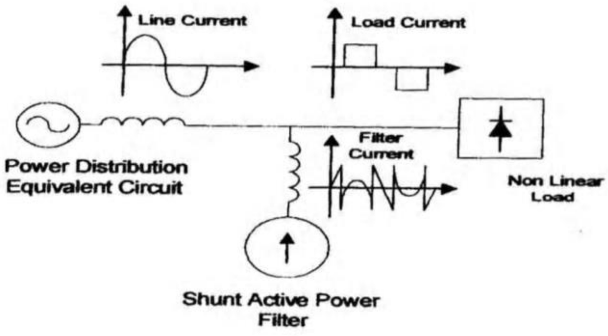


Fig 1. Compensation characteristics of a shunt active power filter**.**

The current reference circuit generates the reference currents required to compensate the load current harmonics and reactive power, and also try to maintain constant the dc voltage across the two electrolytic capacitors. There are many possibilities to develop this type of control.

<u>Power Circuit Topology of Shunt Active Power Filters</u>

Shunt active power filters are normally implemented with pulse-width modulated voltage source inverters. In this type of applications, the PWM-VSI operates as a current controlled voltage source. Traditionally, 2 levels PWM-VSI have been used to implement such system [19]. However, in the past years multilevel PWM voltage source inverters have been proposed to develop active power filters for medium voltage applications.

The use of VSI connected in cascade is an interesting alternative to compensate high power non-linear load. The use of two PWM-VSI of different rated power allows the use of different switching frequencies, reducing switching stresses and commutation losses in the overall compensation system

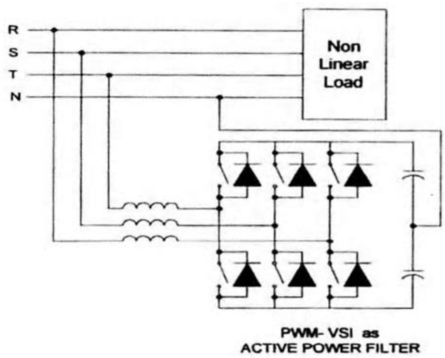


Fig. 2- Shunt active power filter topologies implemented with PWM voltage-source inverters

ISSN: 2208-2735

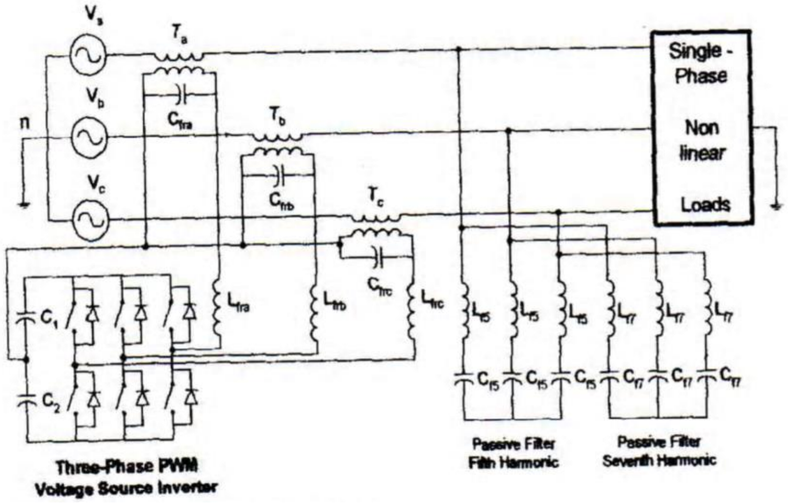


Fig 3.The three-phase series active power filter**.**

HYBRID ACTIVE POWER FILTER.

Passive filters with low impedances at the dominant harmonic frequencies were used to reduce the harmonics for the consideration of hardware cost. However, these circuit configurations have several drawbacks. The passive filters with fixed compensation characteristics are ineffective to filter the current harmonics. The series or parallel resonance does happen between the system impedance and passive filters [17].

The developments and applications of active filters have been researched because of the increasing concern of the power quality at the consumer or distribution side. Active filters overcome the drawbacks of passive filters by using the switching mode power converter to perform the harmonic current elimination. Shunt active filters are developed to suppress the harmonic currents and compensate reactive power simultaneously. The shunt active filters are operated as a current source parallel with the nonlinear load. [20] The power converter of active filter is controlled to generate a compensation current which is equal-but-opposite the harmonic and reactive currents generated from the nonlinear load. In this situation, the mains current is sinusoidal and in phase with mains voltage.

ISSN: 2208-2735

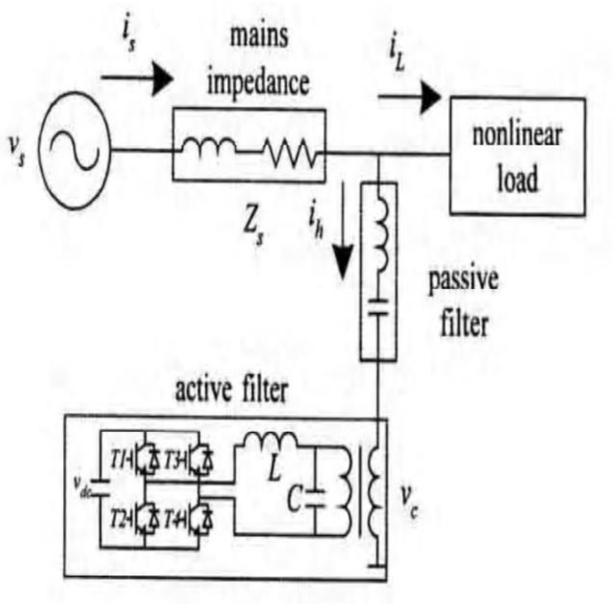


Fig. 4 configuration of the proposed hybrid filter.

EXPERIMENTAL SETUP

A single-phase VSI is employed in the hybrid active filter to perform harmonic suppression and dc voltage regulation. For harmonic suppression, the power converter of active filter is represented as a harmonic resistor to reduce the mains harmonic current.

$$v_{h(t)}=K_h i_{s,h}(t)$$

Where:

$i_{s,h}(t)$ is the harmonic component of mains current,

K_h is the equivalent harmonic resistor at the harmonic frequency.

The active converter is operated as a harmonic resistor at the harmonic frequency, the equivalent mains impedance at the harmonic frequency is increased such that the harmonic current flowing into the mains is decreased because the VSI is operated as a harmonic resistor.Harmonic real power will be consumed in the VSI and the dc-bus voltage of active filter will be fluctuated by this real power and in order to achieve a constant dc-link voltage of VSI, this energy must be sent to the mains by the inverter. At this condition, the dc capacitor of VSI is operated as a buffer to transfer the absorbed harmonic real power into the fundamental real power to the mains. A fundamental voltage component of VSI must be generated and in phase with the fundamental current of hybrid active filter in order to send a real power to the mains.

ISSN: 2208-2735

However, the mains harmonic current is not zero due to the finite harmonic resistor. The mains harmonic current and filter harmonic current $i_{s,h}(t)$ are expressed as

$$i_{s,h}(t) = \frac{Z_p i_{L,h}(t)}{Z_s + K_h + Z_p} + \frac{v_{s,h}(t)}{Z_s + K_h + Z_p}$$

$$i_{h,h}(t) = -\frac{(Z_s + K_h) i_{L,h}(t)}{Z_s + K_h + Z_p} + \frac{v_{s,h}(t)}{Z_s + K_h + Z_p}$$

If the supply voltage is a pure sine wave, then $v_{s,h}(t)$ equals zero.

For the harmonic components, the impedance K_h, is controlled such that

$$K_h \gg Z_p + Z_s.$$

The mains harmonic current is approximately equal to zero and filter harmonic current is equal-but-opposite the harmonic current of nonlinear load. This means that the most of harmonic currents generated from the nonlinear load are blocked by the equivalent harmonic resistor K_h and flowed into the passive filter. Only a small part of nonlinear harmonic current flows into the ac source.

The total harmonic distortion (THD) of mains current is reduced. The nonlinear load current suppression can be performed by controlling the equivalent harmonic resistor K_h.

THE LOW PASS FILTER

LC series-type low pass filter is used while a capacitor has been used with an active power filter in order to reduce the rating of the active filter. However, the capacitor has a fixed amplitude-frequency characteristic when the value is fixed. Normally, the impedance of a capacitor is neither high enough at the mains frequency or low enough at harmonic frequencies. That is, the capacitor cannot prevent the fundamental current and may block some main harmonics like 3rd, 5th and 7th that are produced by the active filter effectively.

In order to simplify the calculation of the L and C values, two parameters, Q and f_0 must be specified in advance, where Q is a quality factor and f_0 is the cut-off frequency.

ISSN: 2208-2735

M= $\frac{1}{Q}$

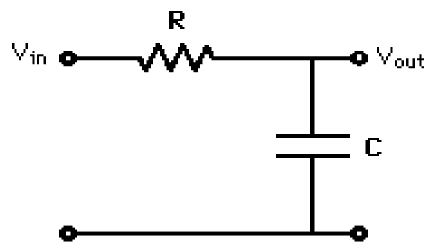
Where M is in the range of 0.5 to 2.

Let f_0 be the cut-off frequency and f_1 be the fundamental frequency.

Thus $f_1 = 50Hz$ and $f_0 = 150Hz$ which is the third harmonic (we consider 3rd harmonic because it's the most destructive harmonic. Other harmonics can also be considered).

CONTROL SECTION REQUIREMENTS.

At this point we need to the harmonic of interest (3rd harmonic) from the source current and use it to produce the equivalent output voltage $v_{c,h}(t)$ that is used to drive the pulse width modulator (PWM) to produce signals which goes to the switches of the active filter. Since capacitive reactance decreases with frequency, the RC circuit shown discriminates against high frequencies. The circuit is an AC voltage divider with an output which falls off at high frequencies at the rate of 6 dB per octave.



$$|V_{out}| = |V_{in}| \frac{1}{\sqrt{1 + \omega^2 R^2 C^2}}$$

The value of the transfer function at different frequencies is given by

$|T(j\omega)| = \frac{1}{\sqrt{1+\omega^2 R^2 C^2}} = \frac{1}{\sqrt{2}} = 0.701$ for $= \frac{1}{RC}$ at the cutoff frequency, where in this case it the fundamental frequency of 50Hz

Therefore $2\pi f_1 = \frac{1}{RC}$; $2\pi \times 50 = \frac{1}{RC}$

ISSN: 2208-2735

If we take R= 1, then C= $\frac{1}{2\pi \times 50} = 0.00318F$

We the scale the parameters so that:

$R = 1K\Omega$ and C =3μF

RESULTS.

Simulation with Passive Filter Only.

The passive filter is operated and the harmonics are therefore the third harmonic current is eliminated basically the passive filter. The mains current contains some high frequency harmonic currents.

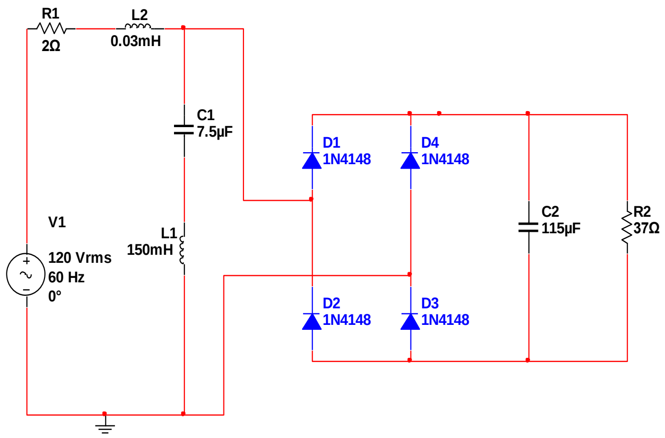


Fig 5: Filter with only Passive operation

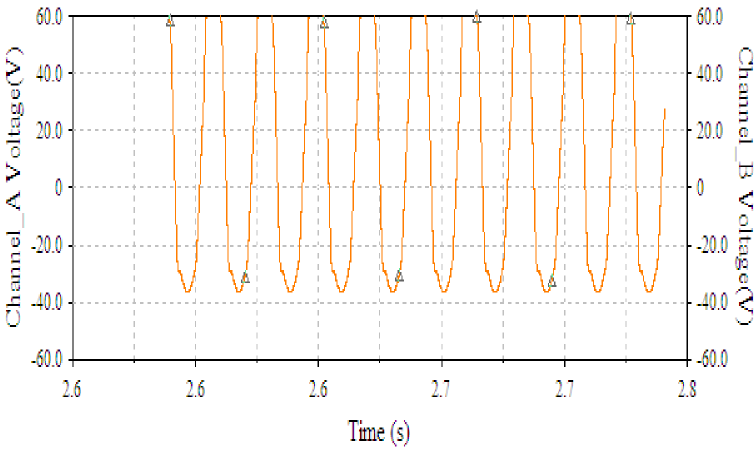


Fig 6. The load current (il) with passive filter only.

ISSN: 2208-2735

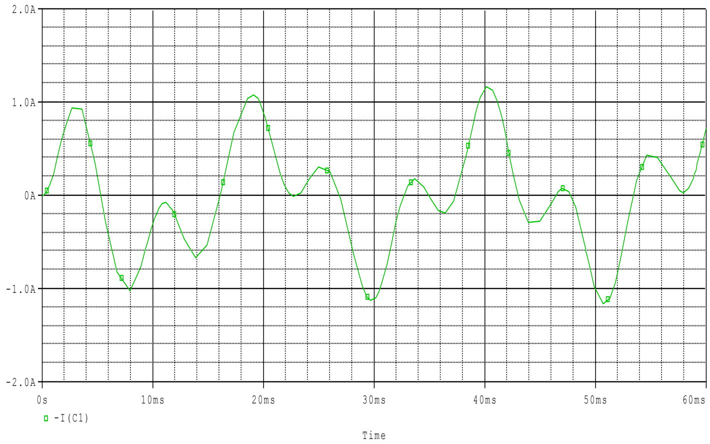


Fig 7. The harmonic (ih) current with only passive filter operational.

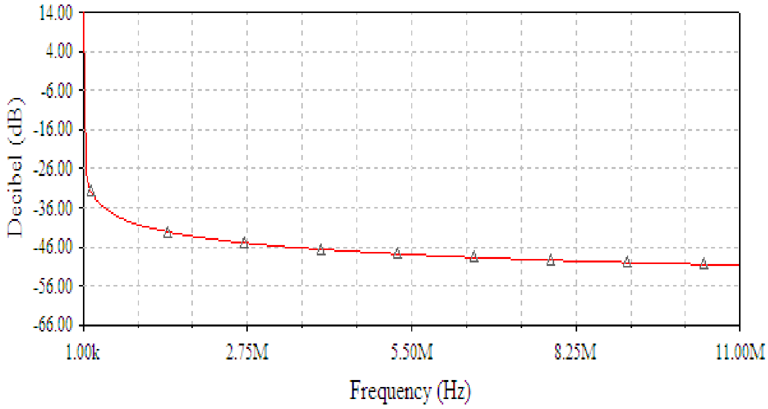


Fig 8. The Frequency spectrum in the source current with passive filters only

<u>5.2: Simulation with only active power filters</u>.

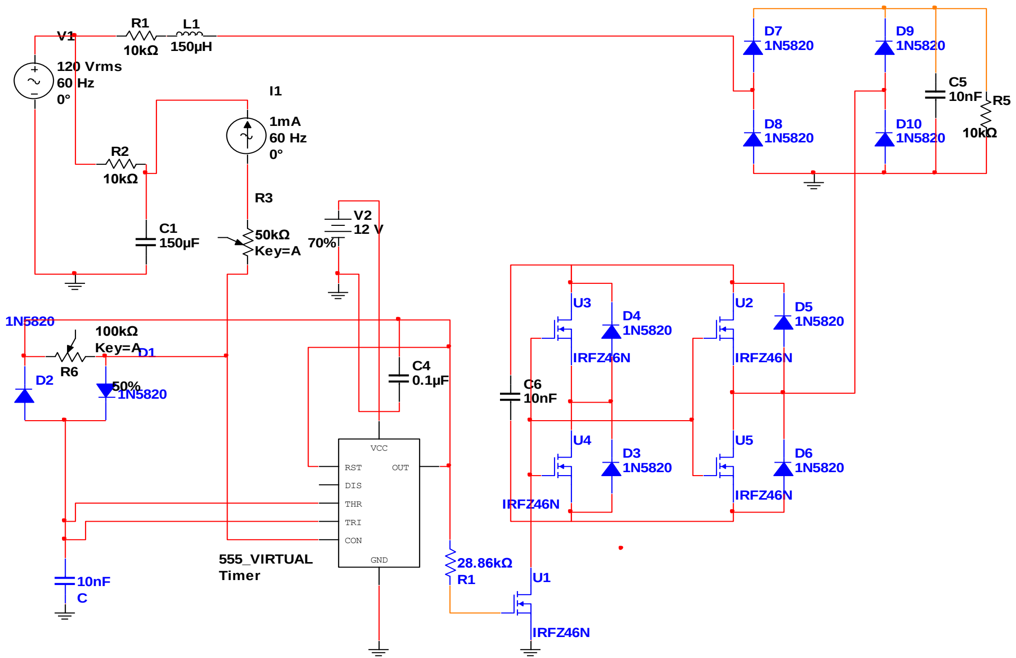


Fig 9. Adopted active power filter in operation.

ISSN: 2208-2735

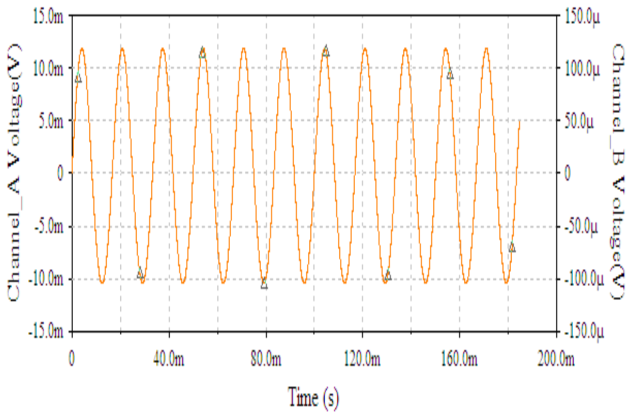


Fig 10: Filters with active filter operation only

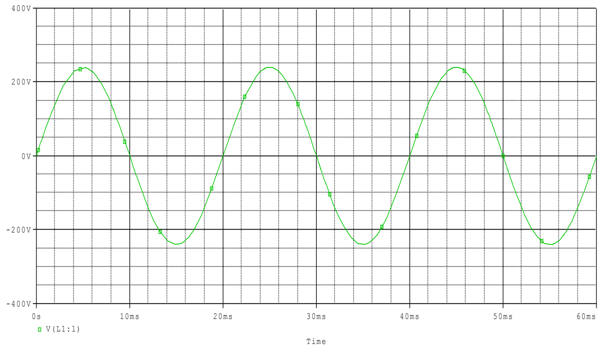


Fig 11. Source current (is) with only active power filter operational.

Simulation the hybrid active filter operation.

In this case both the active power filter and passive power filter are integrated together as shown below

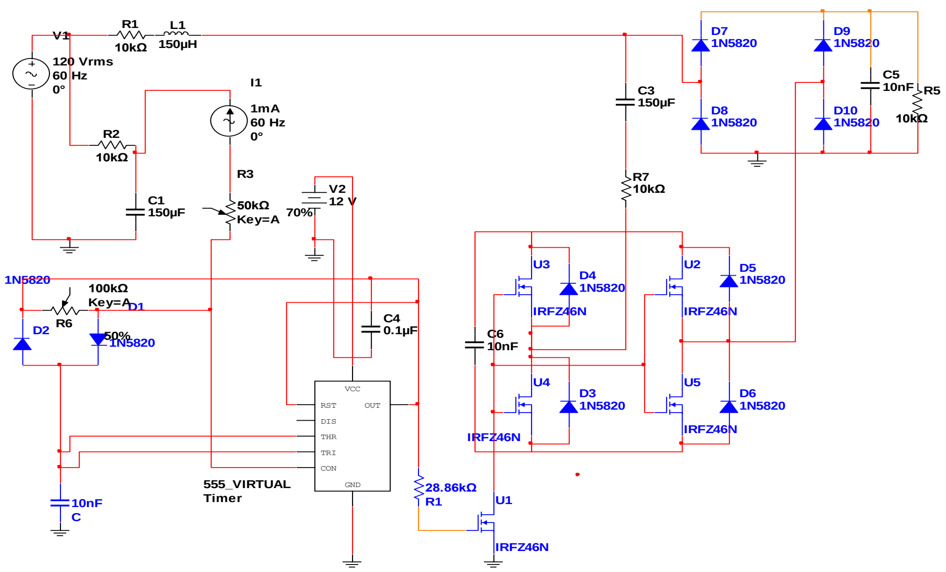


Fig 12. Adopted hybrid active power filter in operation.

ISSN: 2208-2735

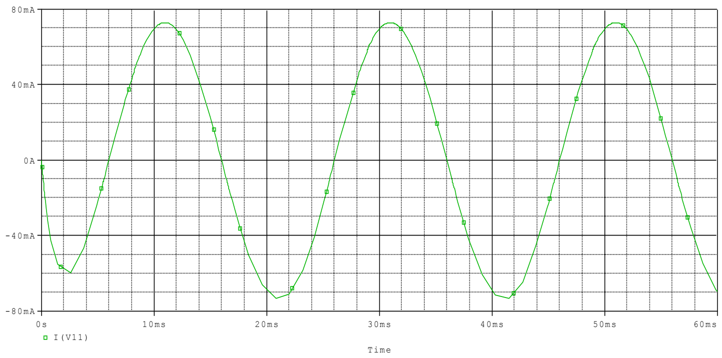


Fig 13 Adopted hybrid active power filter in operation

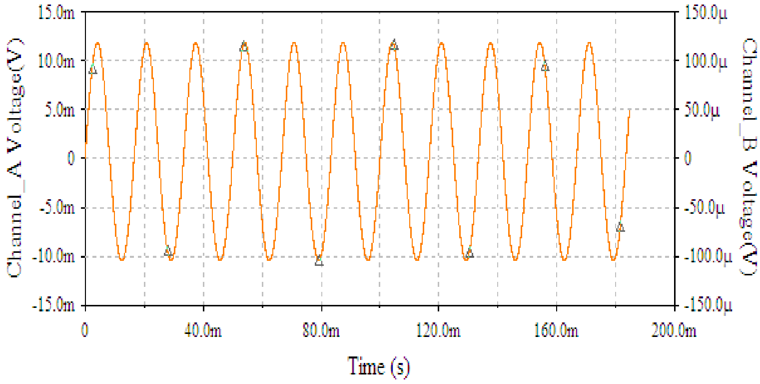


Fig 14. Source current (is) with adopted hybrid active power filter operational.

COMPARISION OF WAVEFORMS RESULTS.

Analysis of results shows the current waveforms that are far from the sinusoidal waveform, this is due to harmonic currents introduced to the power supply system by the nonlinear load i.e. Rectifier. If the load was linear such as a resistive load, the source current, (I_s) waveform would be sinusoidal and corrupted as in this case. Fig 8 is the frequency spectrum in the source current (I_s) with only passive filter operational. Its analysis show that there is a substantial amount of harmonic currents, especially the third harmonic, that gets to the mains supply even when the LC-passive filter is used in attempt to eliminate the harmonics. These results shows beyond all doubts that its factual that nonlinear loads have a very high potential to introduce harmonic currents to the mains and use of passive filters alone is not sufficient to protect this danger. The results obtained above are those of simulation when only an active filter is employed. The source current in this case is sinusoidal wave and its frequency spectrum analysis shows minimal amounts of harmonic components. This shows that active power filters are good in eliminating harmonics originating from nonlinear load. But the bone of contention is the power ratings of the mosfets that have to be employed in the active power filter! It has to be very high and this pushes us to the establishment of the hybrid active power filter. The results obtained when the hybrid active power filter is employed are also shown. It is again clear that the amount of harmonic current in this case is almost negligible. It is clear, from the results, that the harmonic currents generated by the nonlinear load are blocked by the equivalent resistor of the active filter and flowed into the passive filter.

ISSN: 2208-2735

From the simulation results shown, the mains current contains only a small compared with that of the when only the LC-passive filter is in operation. When only a passive filter is in operation, it is tuned at the dominant frequency (150Hz) and thus used to filter the lower order third harmonic. The current distortion is thus observed in the mains current.

The Total Harmonic Distortion (THD) of the line current can be approximated as below

$$THD = \frac{1}{v_{01}} \sqrt[2]{\sum_{n=2.3.4.....}^{\infty} v_{on}^2}$$

$$THD = \frac{1}{218} \sqrt[2]{2.8161} \times 100\% = 7.698\% \approx 8\%$$

Where; THD is the measure of closeness in the shape between a waveform and its fundamental component.

From the simulation where the hybrid active filter is operational, the nonlinear current harmonics are almost suppressed by the active filter as shown. The mains current is a sinusoidal wave. The value of THD of the mains current if calculated would be far much lower compared to the one calculated above. (Approximately 2%).

The power factor of the system is also improved to a range above 0.95.

The efficiency of the adopted hybrid filter is over 80%

CONCLUSION.

In this paper the hybrid active power filter has been presented. The configuration uses an LC-type passive filter and an active filter. Its control strategy to suppress the harmonic current from the mains and to regulate the dc-link voltage of the power converter has successfully been presented. To suppress the harmonic component of nonlinear load the impedance variation method is used to generate the equivalent output voltage of the active filter. A dc-link voltage controller is employed to compensate the converter losses and to supply the necessary fundamental real power to the mains due to the absorbed harmonic real power. It has been confirmed by analysis and simulation together with analysis of results obtained that the harmonic compensation performance is reasonable, and the required rating of the active filter can be reduced maximally. Comparison between this configuration and the existing ones indicates with clarity that this configuration is superior compared to the existing ones on the compensation performance and ratings reduction. The simulation shows that it's effective in eliminating the harmonics. The proposed control scheme can be also applied to the three-phase system with the synchronous

ISSN: 2208-2735

reference system to draw the balanced three-phase line current. The computer simulations and the experimental results can be implemented to verify the effectiveness of the proposed control algorithm.

8 REFERENCES

1. Javadi, A., & Al-Haddad, K. (2015). A single-phase active device for power quality improvement of electrified transportation. *IEEE Transactions on Industrial Electronics*, *62*(5), 3033-3041.

2. Lee, T. L., Wang, Y. C., Li, J. C., & Guerrero, J. M. (2015). Hybrid active filter with variable conductance for harmonic resonance suppression in industrial power systems. *IEEE Transactions on Industrial Electronics*, *62*(2), 746-756.

3. Salmeron, P., & Litran, S. P. (2010). Improvement of the electric power quality using series active and shunt passive filters. *IEEE transactions on power delivery*, *25*(2), 1058-1067.

4. Jou, H. L., Wu, J. C., Chang, Y. J., & Feng, Y. T. (2005). A novel active power filter for harmonic suppression. *IEEE Transactions on Power Delivery*, *20*(2), 1507-1513.

5. Bollen, M. H. (2000). *Understanding power quality problems* (Vol. 3). New York: IEEE press.

6. Grady, W. M., & Santoso, S. (2001). Understanding power system harmonics. *IEEE Power Engineering Review*, *21*(11), 8-11.

7. Sakthivel, K. N., Das, S. K., & Kini, K. R. (2003, December). Importance of quality AC power distribution and understanding of EMC standards IEC 61000-3-2, IEC 61000-3-3 and IEC 61000-3-11. In *Electromagnetic Interference and Compatibility, 2003. INCEMIC 2003. 8th International Conference on* (pp. 423-430). IEEE.

8. De Keulenaer, H. (2003). The hidden cost of poor power quality. *European Copper Institute*.

9. Bhattacharyya, S., Myrzik, J. M. A., & Kling, W. L. (2007, September). Consequences of poor power quality-an overview. In *Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International* (pp. 651-656). IEEE.

10. Levron, Y., Kim, H., & Erickson, R. W. (2014). Design of EMI filters having low harmonic distortion in high-power-factor converters. *IEEE Transactions on Power Electronics*, *29*(7), 3403-3413.

11. De la Rosa, F. (2006). *Harmonics and power systems* (pp. 1-184). CRC press.

12. Das, J. C. (2015). Effects of Harmonics. *Power System Harmonics and Passive Filter Designs*, 331-378.

ISSN: 2208-2735

13. Maswood, A. I., & Haque, M. H. (2002, December). Harmonics, sources, effects and mitigation techniques. In *Second Intl. Conf. on Electrical and Computer Engineering, ICECE, Dhaka, Bangladeh*.

14. Barrero, F., Martinez, S., Yeves, F., & Martinez, P. M. (2000). Active power filters for line conditioning: A critical evaluation. *IEEE Transactions on Power Delivery*, *15*(1), 319-325.

15. Sonnenschein M, Weinhold M. Comparison of time-domain and frequency-domain control schemes for shunt active filters. European Transactions on Electrical Power 1999; 9(1): 5–16P.

16. N.Enjeti, L.Asminoaei Shunt active power filters topology based on parallel interleveaded inverters

17. B.Singh, V.Verma ,Hybrid filters for power quality improvement " IEEE Proc. on Generation, Transmission and Distribution Vol. 152

18. A review for filters for power quality improvement "IEEE Trans. Ind. Electronics Vol 46 1999"

19. Chakrabortty, S. D., & Zaveri, N. (2015). Power Conditioning by Shunt Active Filter. *International Journal for Innovative Research in Science and Technology*, *2*(6), 105-110.

20. Prashna Kurmar Das,B.Srikanth ,Modeling, Analysis and Simulation of Three Phase Hybrid Power Filters for Power Quality Improvement " International Journal of Eng. Research and Application " Prashnta Using Active Power Filters To Improve Power Quality " Luis A. Moran, Juan W. Dixon