

Observer Based Single-Phase Active Current Harmonic Filter for Distributed Industrial Loads

Hanuman, Sanjay Kumar Mathur and Vikram Singh Rajpurohit

Department of Electrical Engineering, Aryabhata College of Engineering & Research Centre, Ajmer, Rajasthan, India

E-mail: hanumanpatel11@gmail.com, skmathur.dr@gmail.com, er.vikramsrajpurohit@gmail.com

(Received 8 June 2022; Revised 30 June 2022; Accepted 24 July 2022; Available online 30 July 2022)

Abstract - Harmonic currents are introduced into power system as use of nonlinear electrical loads increases. Extra losses are caused by harmonic current stream into effective supply lines. A dynamic power filter engenders harmonic compensating current using a switching inverter. Single-phase current into the harmonic filter connects in parallel to load end and inject current harmonic required by the load feeder to avoid harmonic current in the direction of power system. This report discusses harmonic problem, available harmonic mitigation techniques, basic design of filter, control strategy, design steps of major hardware blocks, modelling and simulation of current harmonic filter in MATLAB SIMULINK setting, component selection, hardware implementation and final results. This filter will eliminate harmonic up to 45th order. The control circuit consists of a peak filter, all-pass filter, low pass filter and adders which are used to produce error signal by comparing harmonic current demand of load and injected harmonic current through switching inductor.

Keywords: Power System, MATLAB SIMULINK, Harmonic Current, Switching Inverter

I. INTRODUCTION

On utility systems with a restricted ability to absorb harmonic current, all nonlinear loads have a combined effect. Harmonic control in electric power systems is governed by the IEEE519 standard, which specifies best practices and specifications [1,2]. Active Harmonic filtering is an evaluating technology which needs modification to reduce cost and economical operation for small loads. Passive filters, which are made up of passive elements such as capacitors, inductors, and resistors, have their own set of disadvantages, including bulkiness, harmonic distortion reduction based on harmonic order, and resonance issues [3]. The other solution, active filters, has been spurred by the advent of semiconductor switching devices, sensors, and digital processors to provide superior harmonic filtering over a large frequency spectrum, more versatility, smaller scale, and advanced power supply parameter monitoring compared to passive filter solutions [4].

As a result, this project can be defined as an attempt to construct a parallel active current harmonic filter, which provides an efficient means of mitigating harmonics, reducing process-related voltage fluctuations, and extending the life of equipment and increasing device power. It can be used as part of a harmonic filtering and power factor correction scheme [5].

The specific objectives are to investigate and comprehend the harmonic effect, to select the AHF suitable for current shaping, to design AHF and design simulation, for hardware implementation, and for AHF testing for results. No real-world power supply is perfect and will usually deviate in at least one of the following ways [6]. The filter's use makes it possible to reduce harmonic distortions in line current, line current peak values, rms of current and potentially destructive network interference etc. And, other advantages are, reducing cross-section of power cables, size of fuses and reducing power of generator or inverter used to supply nonlinear loads etc [7]. There is a much attention given for the mitigation of current harmonics in three phase industrial supplies compared to the single phase current harmonic filtering due to the fact that single phase supplies being for low power applications. But current harmonics in single phase consumers such as domestic consumers and small business unit consumers, though the individual consumption is very low compared to the industrial consumers, cumulatively create a huge harmonic problem on power system [8].

There is much attention given for the mitigation of current harmonics in three phase industrial supplies compared to the single phase current harmonic filtering due to the fact that single phase supplies being for low power applications. But current harmonics in single phase consumers such as domestic consumers and small business unit consumers, though the individual consumption is very low compared to the industrial consumers, cumulatively create a huge harmonic problem on power system [9,10]. Moreover that, while the number of electric energy-based household appliances are increasing day by day as efficient solutions to the day-to-day household activities, present trend towards energy efficient household electrical appliances coming up with more electronic systems inside it adding increasingly high number of harmonics to a Watt they consume [11, 12]. Therefore, the persistence of this research is to address current harmonic problem from the single-phase supplies at the consumer end before the current harmonic aggregately create costlier problems on power systems.

II. PARALLEL, SERIES ACTIVE FILTERS

Parallel active filters are more common than series active filters in standings of arrangement and functioning. Figure 1

shows how it is associated in parallel to core power circuit. The filter is arranged to call off load harmonic currents while keeping supply current harmonic-free [13]. Parallel filters have the advantage of only resounding load harmonic current constituents of circuit rather than the entire load current.

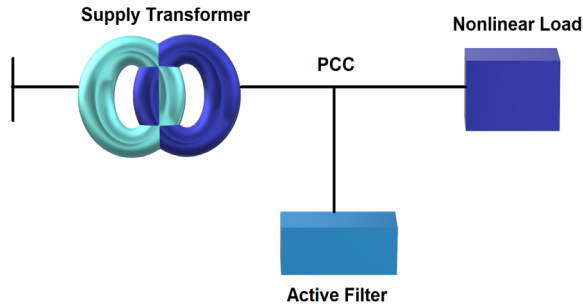


Fig. 1 Parallel active filter

Whereas series active filters reduce voltage harmonic distortions while also improving load voltage quality. In order to accomplish this and give a sine voltage transversely load, a sine pulse width modulated (PWM) voltage is applied crosswise link transformer to account for source

impedance distortion [14]. Series AHF must carry the whole load current in comparison to parallel filters, swelling current ratings and losses, notably over the secondary side.

III. PROPOSED RESEARCH SYSTEM

A. Single Phase Active Current Harmonic Filter

Single phase active current harmonic filter is designed to mitigate harmonic currents drawn by non-linear loads and thereby protect equipment on our power distribution system and reduce other bad effects such as power losses, nuisance tripping of CBs, conductor heating etc. Figure 2 shows the basic configuration of sole phase filter. Power for filter is obtained from same supply source via a voltage doubler and a diode rectifier to produce the necessary DC voltage for operation. By supplying current to load through inverter-inductor in response to controller commands, the inverter essentially converts inverter output into current cause [15]. The rapid line current load draws are tested by the controller as input. The construction of AHF consist of three major components namely, voltage doubling rectifier with smoothing filter, current source inverter and controller.

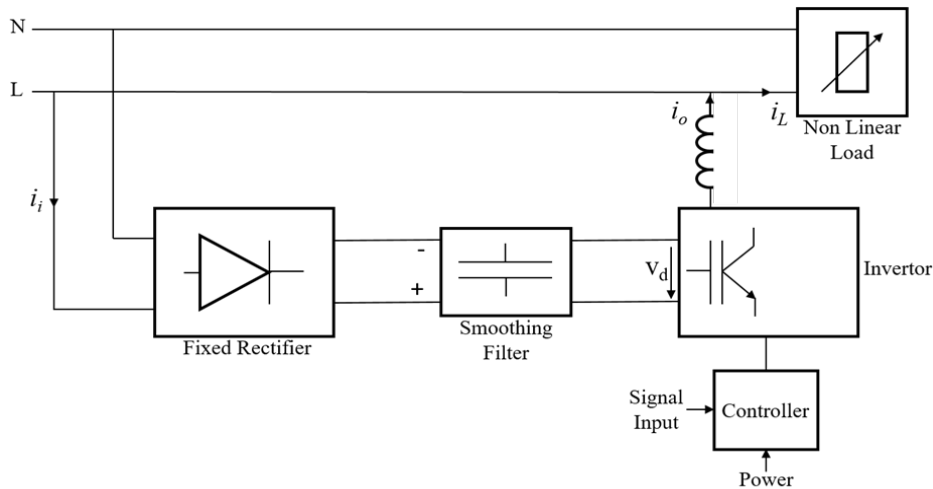


Fig. 2 Block Diagram of single-phase active harmonic filter

Design of active harmonic filter consists of several parameters and numerous values which includes, input dc voltage for inverter, inductance value of the switching inductor, switching frequency for the inverter and capacitor values for voltage doubling circuit.

B. Control Circuit Design

The load's harmonic demand is injected into an active current harmonic filter. For that first we should identify the harmonic signal on the current wave. This is done by a peak filter. But peak filter introduces phase shift to output signal, and it is corrected by an all-pass filter. Then another adder circuit is employed to generate an error signal to be given as input to the comparator circuit.

C. Peak Filter

The Peak filter attenuates signals by only allowing the 50 Hz portion of the current signal's frequency spectrum to pass through. The circuit diagram of the peak filter shows in figure 3. The centre frequency of the peak filter is 50 Hz. The selectivity Q is the ratio of the centre frequency to the bandwidth. Finally, the value of the $R3$ must be calculated to set the centre frequency using following equation [16],

$$f_c = 12 \sqrt{R1 + R3R1R2R3C2R3} = 49.$$

The phase shift introduced to 50 Hz should be corrected to be subtracted from the original signal to identify the harmonic wave form.

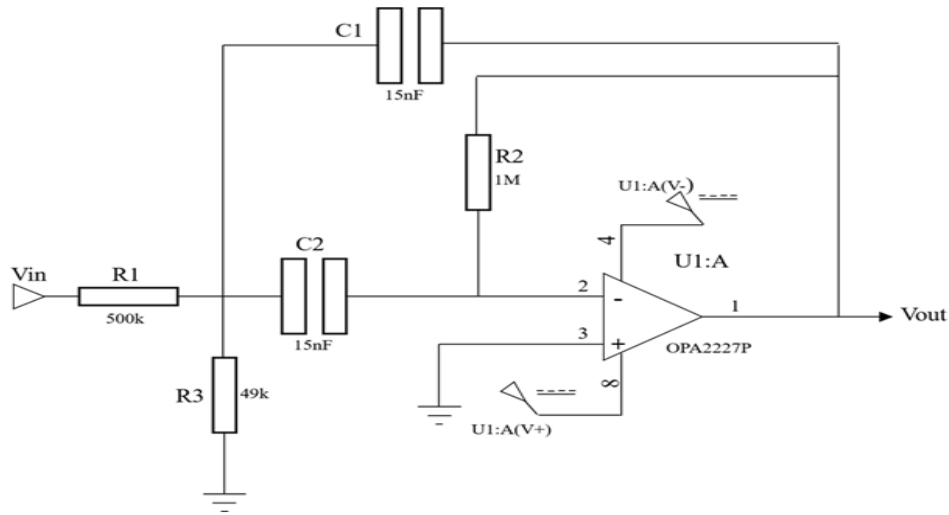


Fig. 3 Circuit diagram of peak filter

The Centre frequency of the peak filter is 50 Hz. We decide lower frequency and the high frequency using,

$$f_c = \sqrt{f_l \times f_h}$$

Which gives $f_l = 40 \text{ Hz}$ and $f_h = 63 \text{ Hz}$. Then,

$$\Delta f = f_h - f_l = 23 \text{ Hz}$$

The selectivity Q is the ratio of the centre frequency to the bandwidth.

$$Q = \frac{f_c}{\Delta f} = \frac{50 \text{ Hz}}{23 \text{ Hz}} = 2.17$$

Since $1 < Q < 10$, this is within the limits of single op amp band pass filter. In such filter,

$$Q = \frac{R_2 \omega_0 C}{2} = \frac{f_c}{\Delta f} \rightarrow \Delta f = \frac{1}{\pi R_2 C}$$

Where $C_1 = C_2 = C$. In peak filter,

$$R_2 C = \frac{1}{\pi \Delta f} = 0.014$$

We select $R_2 = 1 \text{ M}\Omega$ and $C = 100 \text{ nF}$ giving $R_2 C = 0.015$. The gain of peak filter is given by,

$$A_0 = \frac{-R_2}{2R_1}$$

Since we want to maintain unity gain,

$$A_0 = -1 = -\frac{R_2}{2R_1} \rightarrow R_1 = 500 \text{ k}\Omega$$

Finally, the value of the R_3 must be calculated to set the centre frequency using following equation,

$$f_c = 12\sqrt{R_1 + R_3 R_1 R_2 R_3 C_2 R_3} = 49.$$

Peak filter introduces phase shift between input and the output signal. The phase shift introduced to 50 Hz should be corrected to be subtracted from the original signal to identify the harmonic wave form. For that all pass filter is used.

D. Low Pass Filter

The aim of a low pass filter is to eliminate noise from the original signal. The schematic diagram of an op amp low pass filter is depicted in figure 4. To minimize the phase change of output with respect to input signal, we used a higher cut off frequency [17].

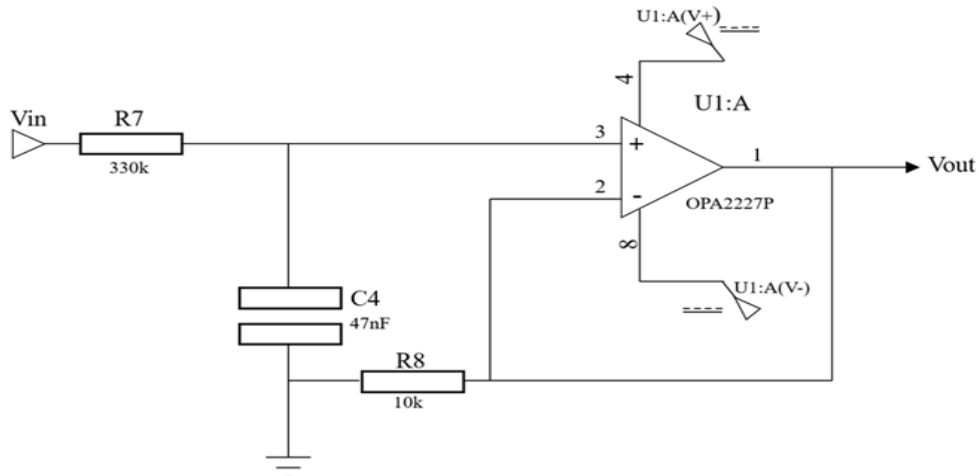


Fig. 4 Schematic of an op amp low pass filter

The cut-off frequency of a 1st order low pass filter is given by following equation:

$$f_c = \frac{1}{2\pi R_7 C_4}$$

We select $f_c=10$ kHz, then RC constant value is,

$$R_7 C_4 = \frac{1}{2\pi f_c} = \frac{1}{2\pi \times 10\text{kHz}} = 1.592 \times 10^{-5}$$

We select $R_7=330\Omega$ and $C_4=47$ nF giving RC constant equals to 1.551×10^{-5} which is 2.5% range from required RC constant. Since we need not a gain between input and output inverting input is directly connected to the output.

$$K = \frac{R_f}{R_g} + 1 = 0 + 1 = 1$$

E. Adder Circuit

To identify the harmonic waveform 50 Hz signal should be reduced from the original line waveform. Since output of peak filter and all pass filter combination gives a 50 Hz output with negative polarity with respect to input signal, a

simple adder circuit can be used to obtain the harmonic signal waveform [18]. Harmonic signal flow through the low pass filter to filter out noises contained in input signal and output of low pass filter gives required harmonic demand by the load. Error signal should be generated by reducing inductor switching current from this signal.

Since, output of the adder circuit 1 gives negative polarity with respect to input signal and low pass filter do not introduce polarity change again simple adder circuit is used to generate error signal to comparator. Therefore, control circuit includes two adder circuits. Figure 5 shows schematic of an op amp adder circuit.

The output of an adder circuit is given by following equation [45]

$$V_0 = -(V_1 + V_2) = -\left(\frac{R_{F1}}{S_1} V_1 + \frac{R_{F1}}{S_2} V_2\right)$$

We select $R_{F1} = S_1 = S_2 = 10$ kΩ to maintain unity gain of the adder.

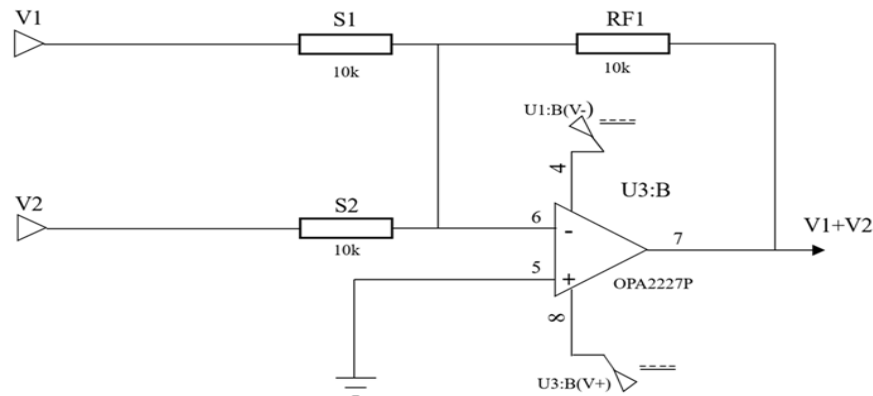


Fig. 5 Schematic of an op amp adder circuit

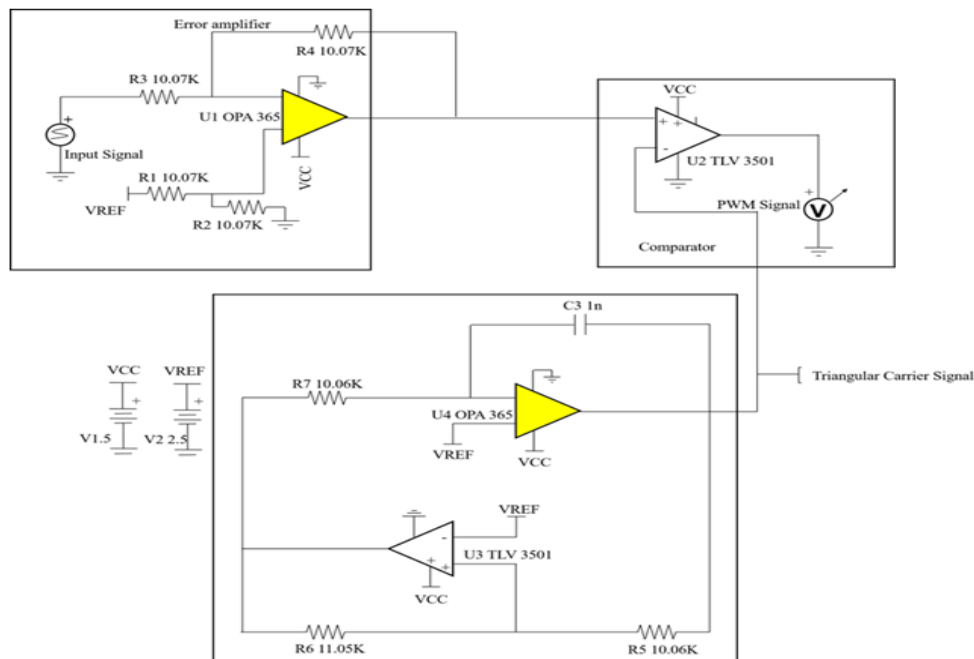


Fig. 6 Comparator circuit schematic with functional portions highlighted.

F. Comparator Circuit Design

A triangle wave generator and comparator are used in this circuit to create a PWM waveform with an inversely proportionate duty cycle to the input voltage. A triangle waveform produced by an op amp and comparator is fed into the inverting input of a second comparator [19].

PWM wave is created by connecting the input voltage to the non-inverting comparator input. Figure 6 shows comparator circuit schematic with functional portions highlighted.

IV. MATLAB SIMULINK SYSTEM MODELLING

Most of the formatting instructions in this document are as per LaTeX style files and Microsoft Word. The Research Publication has used its best efforts to ensure that the templates have the same appearance.

A. Purpose of Simulation

Optimum circuit parameters for the filter should be obtained by minimizing the THD of the main electricity system since

THD was utilized as degree of harmonicity [47, 48]. Simulation was used to verify switching inductor's inductance, voltage of step-up transformer and IGBT switching rate [20]. Simulation program was rather multifaceted because of THD simulated circuit diverges through each of three criterions revealed earlier. Thus, 1st parameter was optimized whereas others were maintained at a lowest sensitivity and when one parameter was optimized, second was optimized for the first parameter's optimum value.

B. Load Modelling

The load studied is modelled in SIMULINK (MATLAB), a piece harmonic current constituent is modelled as current sink and ultimate current constituent as series RLC division. Voltage harmonics were neglected since those are very small compared to current harmonics [21]. Above figure 7 shows the load model up to 15th harmonic current demand. All the harmonic currents up to 43th harmonic were concerned when load is modelling in MATLAB SIMULINK.

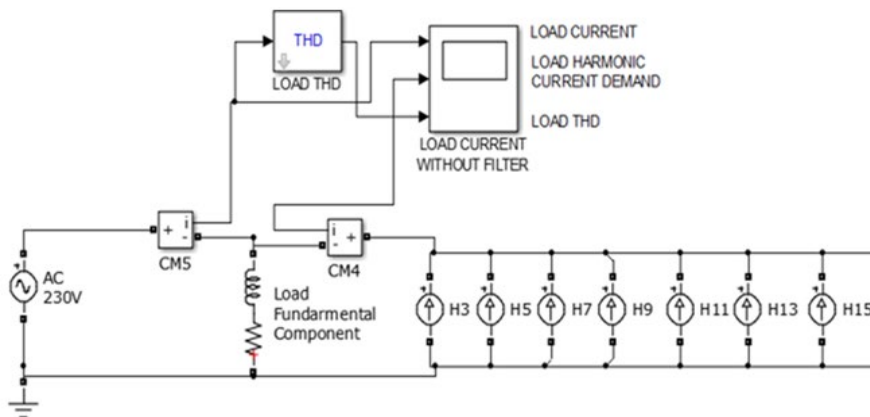


Fig. 7 Sample load model

Figure 8 shows a comparison of the modelled sample load waveform drawn by the voltage source, to confirm the model is tally with the measured data. Total Harmonic Distortion (THD) was the interested parameter which is

shown in figure 9. It should note that in the first cycle of the THD waveform, scope do not show THD value due to calculation time of the MATLAB SIMULINK environment.

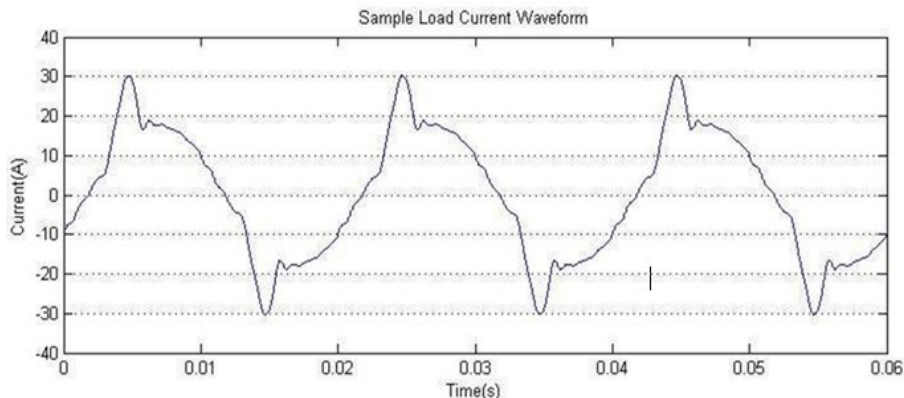


Fig. 8 Current waveform of sample load model

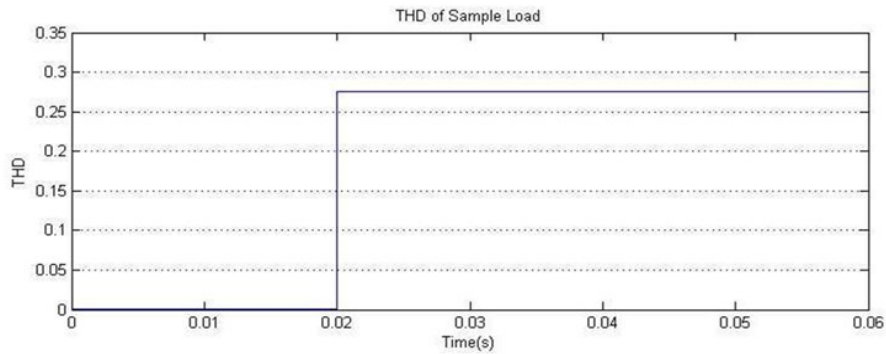


Fig. 9 THD of sample load model

C. Filter Modelling

The active shunt current in harmonic filter needs power from source as well. As a result, a step-up transformer, single phase complete bridge diode rectifier, single phase

IGBT inverter, switching inductor are used to model the filter [22]. Figure 10 shows active current harmonic filter model. In here complete load model has been modelled exclusive to Load subsystem.

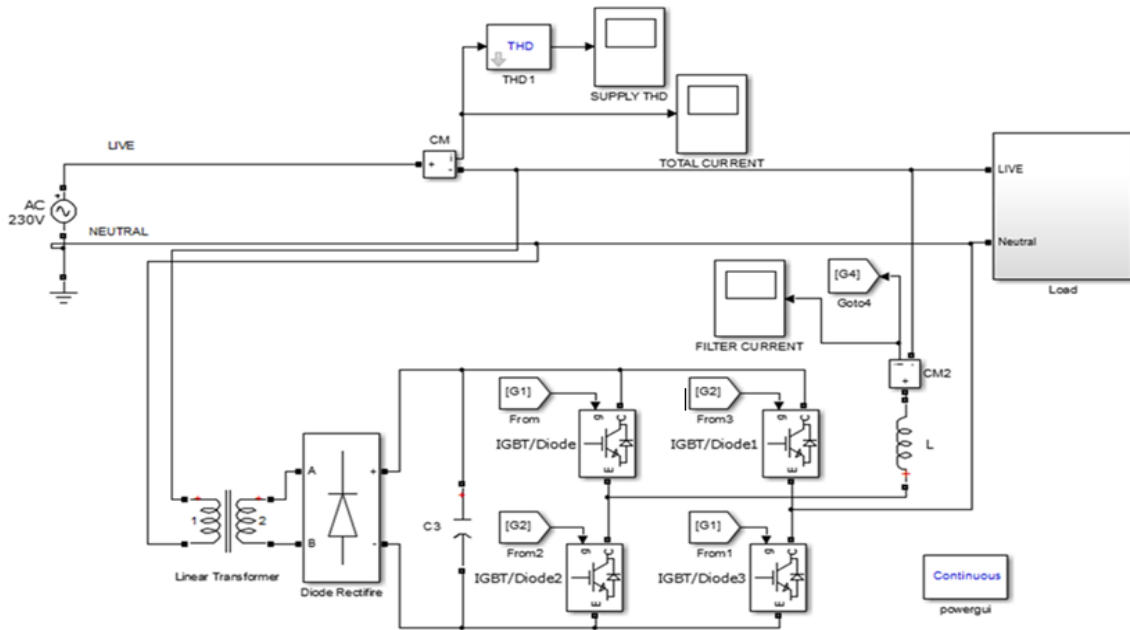


Fig. 10 Active current harmonic filter model

D. Controller Modelling

The current error signal was created via associating actual harmonic current constituents needed through load (shown

in figure 11) with injected current from inductor and was utilized to turn IGBTs [23]. This error signal is used to generate IGBT switching signal via PWM generator using the simple control model shown in figure 12.

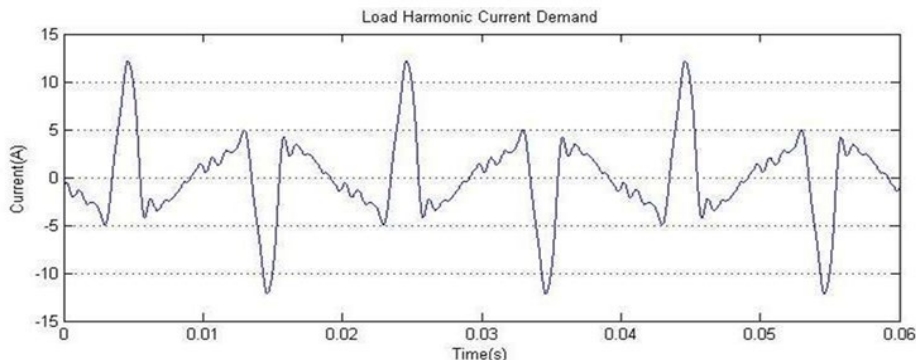


Fig. 11 Harmonic current demand of sample load model

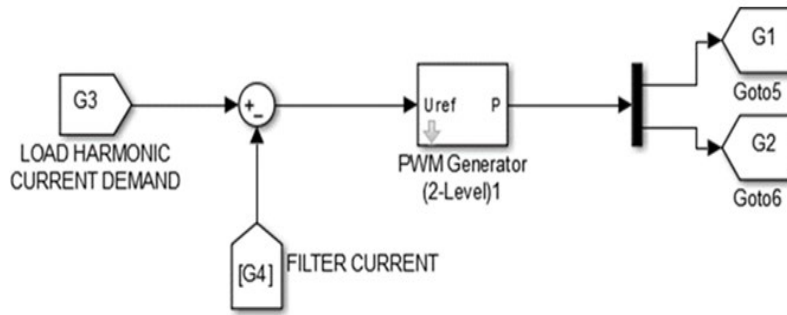


Fig. 12 Filter controller model

E. Simulation for Obtaining Circuit Parameters

The harmonic content was measured using THD. As a result, the active filter’s optimal circuit parameters were determined by minimizing THD. To provide the required electrical charge to the device, the capacitor’s capacitance had to be sufficient. However, due to its physical size and expense, installing a large capacitor is not feasible. In the simulation, the capacitor utilized has a 220 F capacity. The voltage of step-up transformer, switching frequency and inductance of switching inductor were determined by simulation.

On the other hand, all three of the elements listed below have an impact on the THD of the simulated circuit. i.e., the inductor’s inductance, step-up transformer’s output voltage, and IGBTs’ switching frequency. Since all three variables had to be optimized at the same time, the simulation software was extremely complicated [24]. As a result, the first parameter was optimized, while the other two were held as sensitive as possible. The second parameter was optimized for the first parameter’s optimal value once the first had been optimized as previously mentioned.

F. Switching Inductor’s Inductance

Most In a given voltage, the application of the required inductance is critical; higher order harmonics are less effectively suppressed by large inductors. When the inductance is weak, however, the wave signal appears to deviate more from the reference wave. Four distinct arrangements of the transformer voltages, (1) 300 V and (2) 400 V, and the two switching frequencies, (1) 50 kHz and (2) 75 kHz, resulted in a number of inductances from 10 mH up to 50 mH interludes of 10 mH were tested. The supply current waveforms and THD were observed as a result. Table I shows variation of total harmonic distortion with the inductance.

When used in low power applications like the one being examined, high inductance inductors were large and unsuitable, physical parameters of inductor were significant. As a result, inductors with inductances greater than 50 mH were excluded from the simulation.

TABLE I TOTAL HARMONIC DISTORTION WITH THE INDUCTANCE

Inductance (mH)	Transformer voltage (V)	Frequency (kHz)	THD (%)
10	300	50	1.34
		75	1.07
	400	50	1.49
		75	1.11
20	300	50	3.09
		75	3.06
	400	50	1.63
		75	1.54
30	300	50	8.04
		75	8.04
	400	50	5.5
		75	5.49
40	300	50	12.07
		75	12.07
	400	50	9.46
		75	9.46
50	300	50	15.18
		75	15.17
	400	50	12.69
		75	12.69

G. Voltage of Step-Up Transformer

The correct inductance was determined as 10 mH. Higher voltage increases the difficulty of handling, need for insulation, and necessitates the use of equipment with a high rating voltage. Low voltages, on the other hand, were unable to provide the necessary filter current.

Consequently, seven dissimilar transformer voltages 250 V, 300 V, 350 V, 400 V, 450 V, 500 V and 550 V were considered at four swapping frequencies of 25 kHz, 50 kHz, 75 kHz, 100 kHz. Complete harmonic distortion varies with step up transformer voltage, as shown in Table II.

TABLE II HARMONIC DISTORTION VARIATION WITH STEP-UP TRANSFORMER VOLTAGE

Transformer Voltage (V)	Frequency (kHz)	THD (%)
250	25	4.8
	50	4.71
	75	4.69
	100	4.69
300	25	3.26
	50	3.09
	75	3.06
	100	3.05
350	25	2.39
	50	2.11
	75	2.05
	100	2.04
400	25	2.02
	50	1.63
	75	1.54
	100	1.51
450	25	1.93
	50	1.45
	75	1.34
	100	1.3
500	25	1.94
	50	1.41
	75	1.29
	100	1.25
550	25	1.96
	50	1.4
	75	1.27
	100	1.22

H. Switching Frequency

The appropriate inductance and transformer voltage were determined to be 10 mH and 400 V, respectively, as previously stated. At 10 mH inductance and 400 V step up transformer voltage, waveforms and THD were calculated at variety of switching frequencies ranging from 25 kHz to 100 kHz. Although higher switching frequencies were well-thought-out in simulation, achieving them in practice is extremely difficult. Complete harmonic distortion varies with switching frequency, as shown in Table III.

TABLE III TOTAL HARMONIC DISTORTION VARIATION WITH SWITCHING FREQUENCY

Frequency (kHz)	THD (%)
25	2.03
30	1.87
40	1.71
50	1.63
60	1.58
70	1.55
75	1.54
80	1.54
90	1.52
100	1.51

I. Simulation Results

Most By simulation, we choose a switching inductor with a 10 mH inductance, a transformer ratio of 350 V, and a switching frequency of 25 kHz. We replaced the voltage step up transformer by a voltage doubler circuit which can give 650 VDC output voltage. Therefore, final simulation model of the AHF is shown in figure 13.

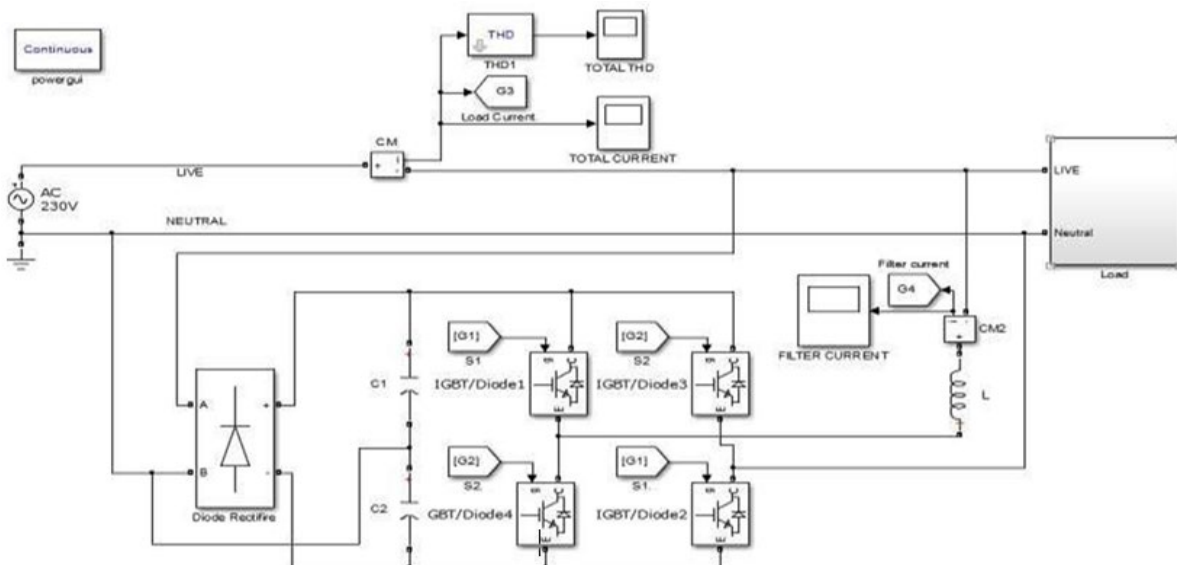


Fig. 13 Final Simulation Model of AHF

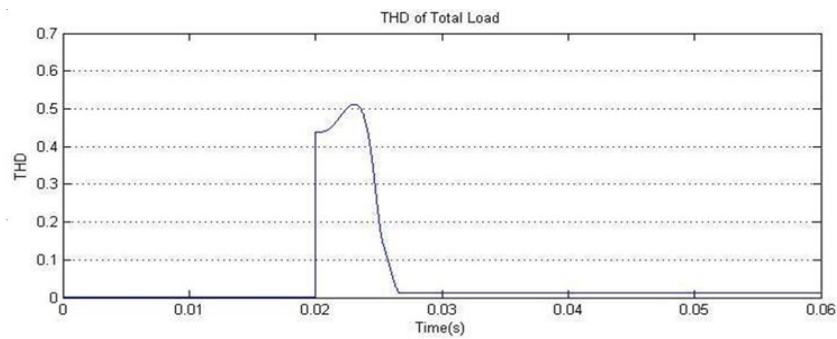


Fig. 14 THD of System Current Waveform

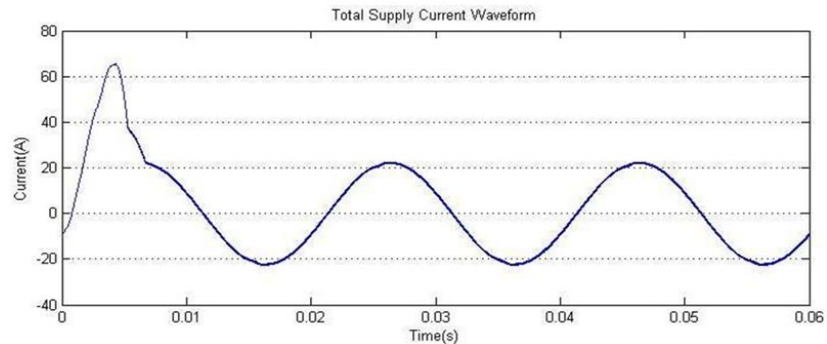


Fig. 15 System Current Waveform

V. CONCLUSION

In this study, a shunt linked single phase active current harmonic filter was designed, modelled, and constructed using MATLAB Simulink. By contrasting actual harmonics required by load with injected harmonics from switching inductor, an error signal is produced to switch four IGBTs. Simulation of the model is used to verify the practicability of the design and it was helpful to decide best parameters to the designed parameters. The THD is reduced to an appropriate level after attaching the sole-phase shunt active current harmonic filter parallel to load, according to simulation results. After the simulation selection of components to implement the system is done according to designed ratings. Main drawback of the existing active harmonic filters is its cost. Therefore, cost effective system could be made which will be flexible in various applications. Analog control system, Comparator and Dead Band circuit were constructed using high speed active components to achieve minimum error. Our system needs additional installation changes when installing it to a particular load. We need to connect current sensor in series with the load to measure load current and there should be a connecting mechanism to connect the filter parallel to the load.

REFERENCES

- [1] Dolar, Alberto, and Sonia Leva, "Power Quality and Harmonic Analysis of End User Devices," *Energies*, Vol. 5, No. 12: 5453-5466, 2012. DOI: <https://doi.org/10.3390/en5125453>.
- [2] IEEE Std 1459-2000: IEEE Trial Use Standard Definitions for Measurement of Electric Power Quantities under Sinusoidal, Non-sinusoidal, Balanced, or Unbalanced Conditions, *Institute of Electrical and Electronics Engineers (IEEE)*, New York, NY, USA, 2000.
- [3] A. Dolar, M. C. Falvo, R. Faranda, U. Grasselli and S. Leva, "Lighting systems: Power Consumptions and Harmonics Monitoring Survey," *In Proceedings of the 3rd International Conference on Clean Electrical Power: Renewable Energy Resources Impact (ICCEP 2011)*, Ischia, Italy, pp. 249-256, 14-16 June 2011.
- [4] "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems," in *IEEE Std 519-2014 (Revision of IEEE Std 519-1992)*, pp. 1-29, 11 June 2014, DOI: 10.1109/IEEE STD.2014.6826459.
- [5] T. M. Blooming and D. J. Carnovale, "Application of IEEE STD 519-1992 Harmonic Limits," *Conference Record of 2006 Annual Pulp and Paper Industry Technical Conference*, 2006, pp. 1-9, DOI: 10.1109/PAPCON.2006.1673767.
- [6] H. Akagi, "Active Harmonic Filters," in *Proceedings of the IEEE*, Vol. 93, No. 12, pp. 2128-2141, Dec. 2005. DOI: 10.1109/JPROC.2005.859603.
- [7] H. Prasad and T. D. Sudhakar, "Design of active filters to reduce harmonics for Power Quality improvement," *2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, pp. 0336-0344, 2015. DOI: 10.1109/ICC PEIC.2015.7259523.
- [8] Prabhu Sekar and G. Muthuveerappan, "A Balanced Maximum Fillet Stresses on Normal Contact Ratio Spur Gears to Improve the Load Carrying Capacity Through Nonstandard Gears," *Mechanics Based Design of Structures and Machines*, Vol. 43, No. 2, pp. 150-163, DOI: 10.1080/15397734.2014.934833.
- [9] N. Suresh and R. S. R. Babu, "Review on Harmonics and its Eliminating Strategies in Power System," 8 July 2015. DOI: 10.17485/ijst/2015/v8i13/56641.
- [10] M. K. Soni, and N. Soni, "Review of Causes and Effect of Harmonics on Power System," Vol. 3, No. 2, pp. 214-220, 2014.
- [11] Sergey F. Garanin, Ekaterina M. Kravets, Vasilii Yu. Dolinskiy, "Instability of Thin Resistive Liners in the Linear Approximation," *IEEE Transactions on Plasma Science*, pp. 1-10, 2020.
- [12] E. P. Yu, T. J. Awe, K. R. Cochrane, K. C. Yates, T. M. Hutchinson, K. J. Peterson, B. S. Bauer, "Use of hydrodynamic theory to estimate electrical current redistribution in metals," *Physics of Plasmas*, Vol. 27, No. 5, pp. 052703, 2020.
- [13] Yassine, Mazen, and Drazen Fabris, "Performance of Commercially Available Supercapacitors," *Energies*, Vol. 10, No. 9, pp. 1340, 2017. DOI: <https://doi.org/10.3390/en10091340>.

- [14] M. E. Valdes, I. Purkayastha and T. Papallo, "The single-processor concept for protection and control of circuit breakers in low-voltage switchgear," in *IEEE Transactions on Industry Applications*, Vol. 40, No. 4, pp. 932-940, July-Aug. 2004. DOI: <https://doi.org/10.1109/TIA.2004.831270>.
- [15] C. Lei, W. Tian, Y. Zhang, R. Fu, R. Jia and R. Winter, "Probability-based circuit breaker modeling for power system fault analysis," *2017 IEEE Applied Power Electronics Conference and Exposition (APEC)*, pp. 979-984, 2017. DOI: 10.1109/APEC.2017.7930815.
- [16] Hsiung-Cheng Lin, Heng-Chuan Zo and Bo-Rong He, "Advanced Fast Large Current Electronic Breaker Using Integration of Surge Current Suppression and Current Divider Sensing Methods", *Journal of Sensors*, Vol. 2019, 8 pages, 2019. DOI: <https://doi.org/10.1155/2019/6256735>.
- [17] T. Robbins, "Fuse Model of Over-Current Protection Simulation of DC Distribution Systems", *15th IEEE International Telecommunications Energy Conference INTELEC '93*, Vol. 2, pp. 336-340.
- [18] W. Tian, C. Lei, Y. Zhang, D. Li and R. Winter, "Data Analysis and Optimal Specification of Fuse Model for Fault Study in Power Systems", *Proceedings of 2016 IEEE Power and Energy Society General Meeting (PESGM)*, July 2016.
- [19] R. Kameswara Rao, G. Ravi Kumar and S. S. Tulasi Ram, "Effective Harmonic Mitigation Techniques Using Wavelets Based Analysis," *International Journal of Engineering Science and Technology*, Vol. 3, pp. 6571-6581, 2011.
- [20] T. C. Sekar and B. J. Rabi, "A review and study of harmonic mitigation techniques," *2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM)*, pp. 93-97, 2012. DOI: 10.1109/ICETEEEM.2012.6494450.
- [21] Laughton, Michael A., and D. F. Warne, "Electrical engineer's reference book, Newnes," Lee, C., Arslan, S., and Frchette, L. 2008, Design Principles and Measured Per, 2003.
- [22] Mayoral, Emmanuel Hernández, *et al.*, "Fourier analysis for harmonic signals in electrical power systems," *Fourier Transforms-High-tech Application and Current Trends*, IntechOpen, 2017.
- [23] A. Kaabeche, M. Belhamel and R. Ibtouen, "Sizing optimization of grid-independent hybrid photovoltaic/wind power generation system," *Energy*, Vol. 36, No. 2, pp. 1214-1222, 2011.
- [24] J. S. Thongam, P. Bouchard, R. Beguenane, and I. Fofana, "Neural network-based wind speed sensorless MPPT controller for variable speed wind energy conversion systems," *In 2010 IEEE Electrical Power & Energy Conference, IEEE*, pp. 1-6, 2010.