IJournals: International Journal of Software & Hardware Research in Engineering
ISSN-2347-4890
Volume 4 Issue 12 December, 2016

Design of a C-type Passive Filter for Reducing Harmonic Distortion and Reactive Power Compensation

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ABSTRACT

Harmonics impact smart grid system operation, protection and control equipment. Harmonics cause overheating, derating, line losses, interference and waveform distortion on industry and operating equipment. Harmonics are produced when nonlinear loads such as rectifiers, converters, static var compensators, drives, arc furnaces, fluorescent lights and welders are connected to distribution system. Modern harmonic sources consist of power electronics-based home appliances such as computer power supplies, electronic lighting ballasts, and uninterruptible power supplies. These appliances are dispersed throughout the low-voltage distribution system, and their collective impact leads to unacceptable levels of voltage and current distortions. Harmonic voltages and currents cause many problems in electrical installations such as overheating of rotating machinery, static cables, efficiency reduction and reduced functionality due to EMI (electromagnetic interference). Harmonic currents from loads flow back into the network and propagate further as harmonic voltages, distorting the supply waveform, increasing network losses, and reducing the reliability of equipment. This research work consists of harmonic simulation based on optimal design of C-type filter using Proteus software and hardware implementation with C-type filter and second order high-pass filter. Simulation study is done and hardware implementation results are obtained using harmonic analyzer to show how filtering reduces current harmonic distortion (I_{THD}).

Keywords: C-type filter, total harmonic distortion, resonance, triplen harmonics

1. INTRODUCTION

Power Quality constitutes a broad range of concerns including transients, interruptions, sag, swell, harmonics, voltage imbalances, voltage fluctuations, and power frequency variations.

Harmonics are associated with nonlinear loads which draw non-sinusoidal currents even from a sinusoidal voltage source. The effect of harmonics is to produce non-sinusoidal currents and voltages in the normally sinusoidal network. In the real world, the grid is filled with single phase and three phase loads that are nonlinear like rectifiers, converters, static var compensators, variable speed/frequency drives for AC or DC motors, arc and induction furnaces, welding machines and power electronics-based appliances such as UPS, SMPS, electronic fluorescent ballasts, compact fluorescent lamps (CFL), lamp dimmers and many other devices that consume current intermittently (in blocks or bursts) causing distortion in the sine wave current of the power grid.

When harmonic currents flow through different impedances present in a power system like source impedance, transformer impedance and cable impedance, this result in voltage drops at that harmonics according to Ohm's Law. Voltage distortion is produced due to addition of these voltages to the source voltage. As the harmonic voltages increase in magnitude, voltage distortion also increases. It is clear that voltage distortion depends on system impedance as well as magnitude of harmonic currents present in the system. It should be noted that voltage distortion is much more at the loads. The reason is that harmonic currents face full system impedance (source, transformer and cables) at the loads. So voltage distortion may be low at the service entrance but it can be too high at the loads. In order to minimize voltage distortion, we have to remove harmonic currents and/or lower the system impedance.

The voltage and current waveforms are pure sinusoids at generator bus when there are only linear loads. The current flowing is proportional to the voltage as the circuit has only resistance which is linear circuit element. A sinusoidal current flows for sinusoidal voltage. Non-sinusoidal current results when the load current is not linearly proportional to the voltage.

According to Fourier theory, sine waves of different amplitudes may be summed up if their frequencies are integer multiples of fundamental frequency to produce a periodic waveform. Each of the constituent frequency is called harmonic frequency [1, 2]. This means that the distorted current waveform is the sum of fundamental current and harmonic currents up to fiftieth harmonic. Origination of harmonics is as currents but they produce harmonic voltages as they flow through the system impedances. The harmonic currents propagate through the installation to electric grid [3]. Harmonic currents and voltages cause following problems.

a. Overheating of neutral conductor
b. Overheating of transformers
c. Nuisance tripping of equipment
d. Possible resonant conditions and over-stressing of PFC capacitors
e. Skin and proximity effects
f. Voltage distortion
g. Conductor losses, Iron losses, heating and mechanical oscillations of motors and generators
h. Zero-crossing errors

IEEE Standard 519-2014, Recommended Practice and Requirements for Harmonic Control in Electric Power Systems, provides guidelines for voltage distortion levels and harmonic currents on transmission and distribution circuits [5]. The intended purpose is to limit voltage distortion on the utility grid by limiting the amount of current injections from individual consumers of electrical power. Meeting the requirements usually requires the application of mitigation methods. One of these methods is the use of passive harmonic filters. These filters have the advantage that they are simplest to design and least expensive [6-8]. Harmonic currents flow in the passive shunt filter and not the supply circuit as it provides low impedance path to harmonics. Passive filters are constructed from simple passive elements (resistor, inductor and capacitor) and are divided into the following categories [9-11].

a. single-tuned (notch) filters
b. damped filters (first order, second order, third order, C-type)

The single-tuned (notch) filters are usually used to remove specific harmonics. Damped filters are used to remove a wide range of frequencies. For small harmonic producing loads, one single-tuned filter is used to eliminate the harmonic current. For large applications like arc furnaces, combination of single-tuned filters and a damped filter are often used. Compared to other passive filters, C-type passive filter is more efficient and cost effective. This research work aims to design and implement C-type passive filter for reducing harmonic distortion.

Fourier series gives a complex mathematical equation to define the relationship by expressing distortion as a percentage of the fundamental component value. This is called Total Harmonic Distortion (THD) and is defined as the ratio of square root of the sum of squares of the RMS values of harmonic components to the RMS value of the fundamental component. THD is a measure of harmonics present in the system. For current waveform, the THD definition is called current harmonic distortion. For voltage waveform, the THD definition is called voltage harmonic distortion [21].

$$I_{THD} = \frac{\sqrt{\sum_{n=2}^{n=\infty} I_n^2}}{I_1} \quad \text{and} \quad V_{THD} = \frac{\sqrt{\sum_{n=2}^{n=\infty} V_n^2}}{V_1}$$

THD is expressed as a percentage. Higher percentage means more distortion in the waveform. Our primary concern is voltage harmonics since voltage is common to all users. The only way to limit voltage harmonics is to minimize current harmonics. When the current harmonics are under control, the voltage harmonics are generally acceptable.

2. PASSIVE HARMONIC FILTERS DESIGN

Harmonic pollution has increased as the use of nonlinear devices has increased in industry and buildings during recent years [18]. Passive harmonic filters are still considered as the most effective and viable solution to reduce harmonic distortions [13]. Many industrial facilities install these filters to ensure that they comply with the harmonic limits specified by the standards adopted by the supply utilities. The C-type filter works by providing low impedance path to the harmonic currents tuned at harmonic frequency and above. This harmonic current is filtered out by the C-type filter and flows to the ground. The C-type filter circuit is shown in Figure 1.

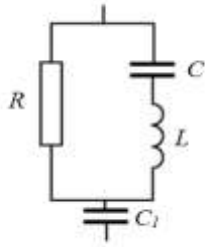


Figure 1 The C-type filter diagram

This research aims to design a practical model of a C-type filter that provides better harmonic filtering as compared to other passive harmonic filters for reducing harmonic distortion. Harmonic simulation is done using Proteus software and based on this simulation, hardware implementation is done. Topologies of passive harmonic filters and common frequency responses are shown in Figure 2 and Figure 3 respectively.

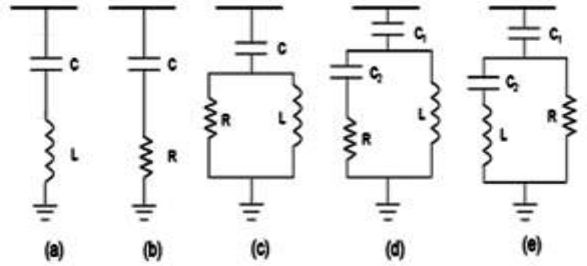


Figure 2 (a) single-tuned (b) first order high-pass (c) second order high-pass (d) third order high-pass (e) C-type

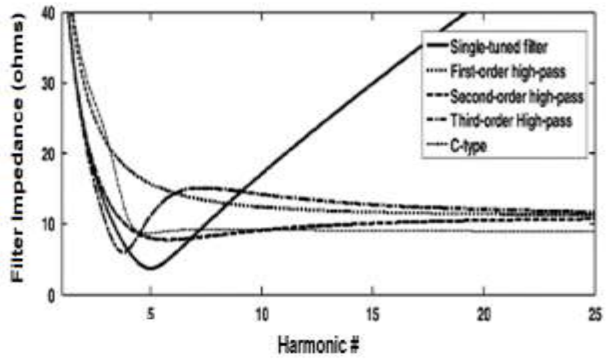


Figure 3 Passive filters frequency response

The single-tuned (notch) filters are usually used to remove specific harmonics. Damped filters are used to remove a wide range of frequencies. For small harmonic producing loads, one single-tuned filter is used to eliminate the harmonic current. For large applications like arc furnaces, combination of single-tuned filters and a damped filter are often used. C-type passive filter is more efficient and cost effective harmonic filter.

2.1 Second Order High-pass Filter Design

To design a second order high-pass filter, the following parameters should be specified first [23].

1. Nominal voltage V
2. Tuning frequency f_h
3. Reactive power Q required from the filter at fundamental frequency

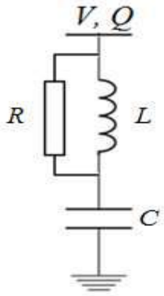


Figure 4 Second order high-pass filter configuration

If power loss due to capacitor and reactor resistance is neglected, equivalent impedance of filter at fundamental frequency *w* is given as

$$Z_{eq} = X_C - \left(\frac{1}{R} + \frac{1}{X_L}\right)^{-1}$$

$$Z_{eq} = X_C - \frac{RX_L}{R + X_L}$$

$$Suppose \quad X_L \gg R$$

$$then \quad X_{eq} = X_C - X_L = \frac{1}{\omega C} - \omega L \tag{1}$$

$$Also \quad X_{eq} = \frac{V^2}{Q} \tag{2}$$

At the tuned frequency w_h (tuned harmonic *h*), filter equivalent reactance is given as

$$X_h = \frac{1}{\omega hC} - \omega hL \tag{3}$$

Filter total reactance should be zero at the tuned frequency

$$X_h = \frac{1}{\omega hC} - \omega hL = 0 \tag{4}$$

Solving the above equation results in the following important equation

$$X_C = h^2 X_L \tag{5}$$

Putting value from equation (5) in (1) results in

$$X_C = \frac{h^2}{h^2 - 1} X_{eq}$$

Putting value from equation (2) in above results in

$$X_C = \frac{h^2}{h^2 - 1} \frac{V^2}{Q} \tag{6}$$

$$\because C = \frac{1}{\omega X_C}$$

Putting value from equation (6) results in important equation for calculating parameter C of the filter and is given as

$$C = \frac{(h^2-1)}{\omega h^2}\frac{Q}{V^2} \tag{7}$$

From equation (5)

$$L = \frac{X_C}{\omega h^2} \tag{8}$$

Putting value from equation (6) in (8) results in another important equation for calculating parameter L of the filter which is as given as

$$L = \frac{1}{h^2-1}\frac{V^2}{\omega Q} \tag{9}$$

The quality factor Q_f of the second order high-pass filter is defined as the ratio of resistance to reactance of the parallel RL circuit at the tuned frequency. The quality factor decides the bandwidth that determines the sharpness at the tuning frequency and is given as

$$Q_f = \frac{R}{\omega_h L}$$

The value of damping resistance is hence calculated as

$$R = Q_f \omega_h L \tag{10}$$

2.2 C-type Filter Design

To design a C-type filter, the following quantities should be specified first [24].

1. Nominal voltage V
2. Tuning frequency f_h
3. Reactive power capacity Q_1 needed from the filter at fundamental frequency

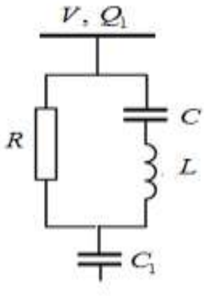


Figure 5 The C-type filter configuration

If power loss due to capacitors and reactor resistance is neglected, equivalent impedance of filter at fundamental frequency *w* is given as

$$Z_{eq} = \left(\frac{1}{R} + \frac{1}{j\omega L - \frac{j}{\omega C}}\right)^{-1} - \frac{j}{\omega C_1}$$

$$Z_{eq} = \frac{R\left(\omega^2 LC-1\right)^2 + jR^2\omega C\left(\omega^2 LC-1\right)}{\left(\omega^2 LC-1\right)^2 + \left(\omega RC\right)^2} - \frac{j}{\omega C_1} \tag{11}$$

L and C are tuned at fundamental frequency to avoid power loss on resistor R. This is given as

$$\omega^2 LC - 1 = 0 \tag{12}$$

So the filter impedance at fundamental frequency becomes

$$Z_{eq} = -\frac{j}{\omega C_1}$$

Also

$$X_{C_1} = -\frac{j}{\omega C_1} = -j\frac{V^2}{Q_1} \tag{13}$$

From equation (13) C_1 may be calculated as follows

$$C_1 = \frac{Q_1}{\omega V^2} \tag{14}$$

At the tuned frequency f_h (tuned harmonic h), total impedance is given as

$$Z_h = \frac{R\left(\omega_h{}^2 LC-1\right)^2 + jR^2\omega_h C\left(\omega_h{}^2 LC-1\right)}{\left(\omega_h{}^2 LC-1\right)^2 + \left(\omega_h RC\right)^2} - \frac{j}{\omega_h C_1}$$

$$Z_h = \frac{R\left(\omega_h{}^2 LC-1\right)^2}{\left(\omega_h{}^2 LC-1\right)^2 + \left(\omega_h RC\right)^2} + j\left(\frac{R^2\omega_h C\left(\omega_h{}^2 LC-1\right)}{\left(\omega_h{}^2 LC-1\right)^2 + \left(\omega_h RC\right)^2} - \frac{1}{\omega_h C_1}\right)$$

………………………………………………….(15)

So the filter total resistance at tuned frequency is

$$r = \frac{R\left(\omega_h{}^2 LC-1\right)^2}{\left(\omega_h{}^2 LC-1\right)^2 + \left(\omega_h RC\right)^2}$$

$$r = \frac{R}{\frac{\left(\omega_h RC\right)^2}{\left(\omega_h{}^2 LC-1\right)^2} + 1} \tag{16}$$

Filter total reactance should be zero at the tuned frequency

$$\frac{R^2\omega_h C\left(\omega_h{}^2 LC-1\right)}{\left(\omega_h{}^2 LC-1\right)^2 + \left(\omega_h RC\right)^2} - \frac{1}{\omega_h C_1} = 0$$

$$\frac{\omega_h RC}{\omega_h{}^2 LC-1} = \frac{1}{r\omega_h C_1} \tag{17}$$

Putting value from equation (17) in (16) results in

$$r = \frac{R}{\frac{1}{\left(r\omega_h C_1\right)^2} + 1} \tag{18}$$

Solving the above gives the following important equation at tuned frequency

$$r^2 - Rr + \frac{1}{\left(\omega_h C_1\right)^2} = 0 \tag{19}$$

Also

$$h = \omega_h / \omega = \omega_h\sqrt{LC} \qquad \because \frac{1}{\omega} = \sqrt{LC} \tag{20}$$

and suppose

$$R_h = \frac{2}{\omega_h C_1} = \frac{2V^2}{hQ_1} \tag{21}$$

Putting value from equation (21) in (19) results in

$$r^2 - Rr + \frac{R_h^2}{4} = 0 \tag{22}$$

The roots of equation (22) are given as

$$r = \frac{R \pm \sqrt{R^2 - R_h^2}}{2} \tag{23}$$

r is filter total resistance that must be a positive real number. This is possible when equation (23) has real roots. In order to get real roots, the discriminant must be greater than or equal to zero.

$$\sqrt{R^2 - R_h^2} \geq 0 \qquad \Rightarrow \qquad R \geq R_h$$

Suppose

$$R = mR_h \qquad for \qquad m \geq 1 \tag{24}$$

So equation (22) becomes

$$r^2 - mR_h r + \frac{R_h^2}{4} = 0 \tag{25}$$

One of the roots of equation (25) is given as

$$r = \frac{m - \sqrt{m^2 - 1}}{2} R_h \tag{26}$$

From equation (20)

$$\omega_h^2 LC = h^2 \tag{27}$$

From equation (21)

$$\omega_h C_1 = \frac{2}{R_h} \tag{28}$$

Putting the values from equation (24), (26), (27) and (28) in (17) results in

$$C = \frac{h^2 - 1}{m^2 - m\sqrt{m^2 - 1}} \frac{1}{\omega_h R_h} \tag{29}$$

From equation (20) and (21)

$$\omega_h R_h = \frac{2\omega V^2}{Q_1} \tag{30}$$

Putting the value from equation (30) in (29) results in important equation for calculating parameter C of the filter that is as follows

$$C = \frac{h^2 - 1}{m^2 - m\sqrt{m^2 - 1}} \frac{Q_1}{2\omega V^2} \tag{31}$$

From equation (22)

$$L = \frac{1}{\omega^2 C} \tag{32}$$

Putting the value of C from equation (31) in (32) results in another important equation for calculating parameter L of the filter that is as given as

$$L = \frac{m^2 - m\sqrt{m^2 - 1}}{h^2 - 1} \frac{2V^2}{\omega Q_1} \tag{33}$$

Till now the parameters C and L of the filter can easily be calculated by selecting any suitable value of m but this will not produce optimal results based on least cost of the parameters C and L.

Optimal parameters based on least cost of the parameters C and L are required. Assume that entire fundamental current will flow through the components C and L of the filter. This fundamental current is determined by voltage and capacitive reactance of C1 and is given as

$$I_1 = V\omega C_1 \tag{34}$$

The reactive power supplied by component C at fundamental frequency is given as

$$Q_C = \frac{I_1^2}{\omega C} = \frac{2Q_1}{h^2 - 1}\left(m^2 - m\sqrt{m^2 - 1}\right) \tag{35}$$

The reactive power provided by component L at fundamental frequency is given as

$$Q_L = I_1^2 \omega L = \frac{2Q_1}{h^2 - 1}\left(m^2 - m\sqrt{m^2 - 1}\right) \tag{36}$$

The above equations show that both of the reactive powers are of same magnitude. Keeping current constant, larger the L (or smaller the C), greater will be the reactive power. Larger size components will result in more cost. So reactive power should be reduced to minimum in order to reduce cost of components.

Consider the function

$$g(m) = m^2 - m\sqrt{m^2 - 1} \tag{37}$$

Taking derivative of this function and solving gives

$$g'(m) = \frac{-\left(m - \sqrt{m^2 - 1}\right)^2}{\sqrt{m^2 - 1}} \qquad (for \quad m > 1)$$

The derivative is always negative which shows that g(m) is a continuously decreasing function. The extremum for $m \rightarrow \infty$ comes out to be 0.5.

Putting this value in equation (31) and (33) to get equations for optimal C and L components.

$$C = \frac{\left(h^2 - 1\right)Q_1}{\omega V^2} \tag{38}$$

$$L = \frac{V^2}{\left(h^2 - 1\right)\omega Q_1} \tag{39}$$

The quality factor Q_f of the C-type filter is defined as the ratio of resistance to reactance of the parallel RL circuit at the tuned frequency. The quality factor decides the bandwidth that determines the sharpness of the tuning frequency and is given as

$$Q_f = \frac{R}{\omega_h L} \tag{40}$$

The damping resistance is thus calculated as

$$R = Q_f \omega_h L \tag{41}$$

In order to carry out the intended research work, first of all nonlinear load is selected that produces harmonics. CRT monitor and SMPS of a computer constitutes such a nonlinear load that generates odd harmonics. To remove the harmonics generated by this load, two harmonic filters are designed. A C-type filter for reducing 3rd harmonic and a second order high-pass filter for reducing 5th harmonic.

The parameters calculated for C-type filter using equations (14), (38), (39) and (41) and for second order high-pass filter using equations (7), (9) and (10) are shown in Table 1.

Table 1 Parameters for Filters

	C-type Filter	Second Order High-pass Filter
Input Parameters	$V = 230V$ $f_h = 150Hz$ $Q_1 = 415\,\mathrm{var}$ $Q_f = 3.66$	$V = 230V$ $f_h = 250Hz$ $Q = 343\,\mathrm{var}$ $Q_f = 3.11$
Calculated Parameters	$C_1 = 25\mu F$ $C = 200\mu F$ $L = 50.7mH$ $R = 175\Omega$	$C = 20\mu F$ $L = 20.5mH$ $R = 100\Omega$

Based on these parameters, simulation is done using Proteus simulation software and then actual hardware is implemented.

3. SIMULATION ANALYSIS

The schematic diagram of C-type filter and second order high-pass filter is shown in Figure 6.

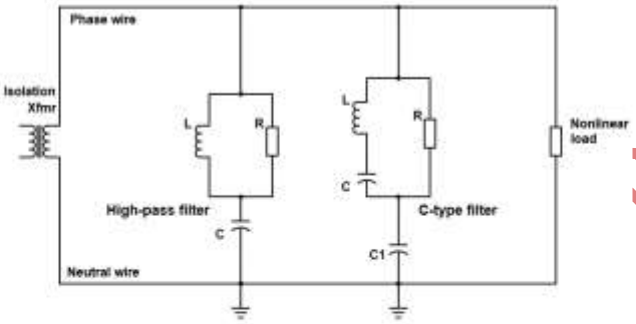


Figure 6 Schematic diagram of C-type filter and second order high-pass filter

Simulation is done in Proteus software using the calculated parameters. Full-wave bridge rectifier with smoothing capacitor and resistor is simulated as nonlinear load in place of SMPS as both exhibit nearly same current waveforms due to the fact that both draw current pulses. The circuit diagram of nonlinear load with C-type filter and second order high-pass filter is shown in Figure 7.

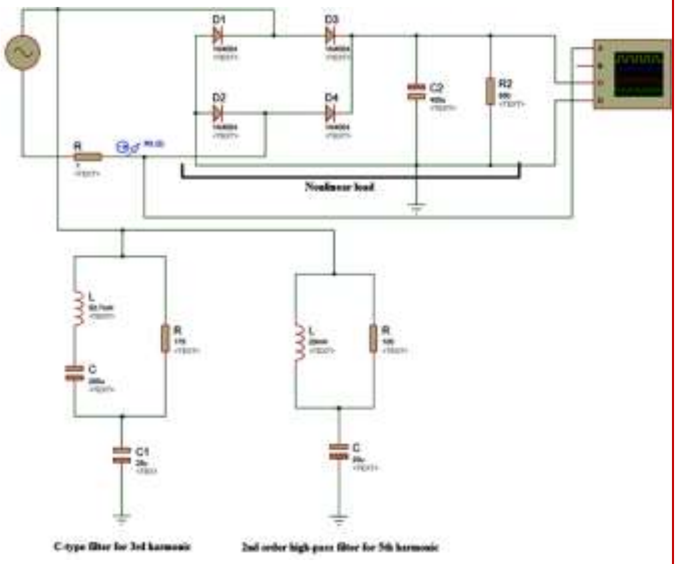


Figure 7 Simulation of C-type filter and second order high-pass filter with nonlinear load

Full-wave bridge rectifier with smoothing capacitor and resistor is our nonlinear load. The current waveform and current harmonic spectrum are shown in Figure 8 and Figure 9 for this nonlinear load without applying any filter.

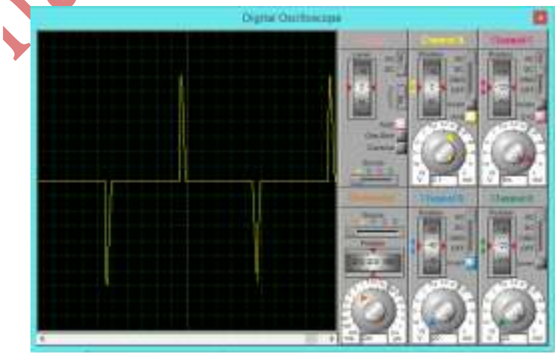


Figure 8 Distorted current waveform without filter

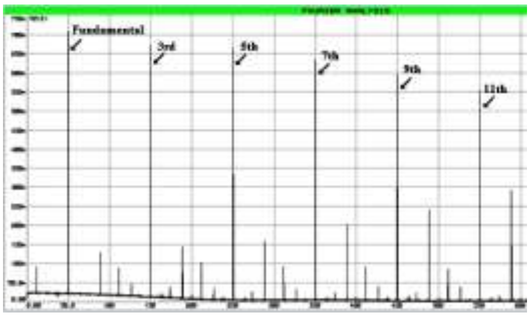


Figure 9 Fast Fourier Transform (FFT) without filter

It can be easily observed that odd harmonic currents are drawn by this nonlinear load.

The current harmonic spectrum and current waveform are shown in Figure 10 and Figure 11 after application of only 3rd harmonic C-type filter. After applying 3rd harmonic C-type filter, the harmonic content decreased as evident from the harmonic spectrum in Figure 10.

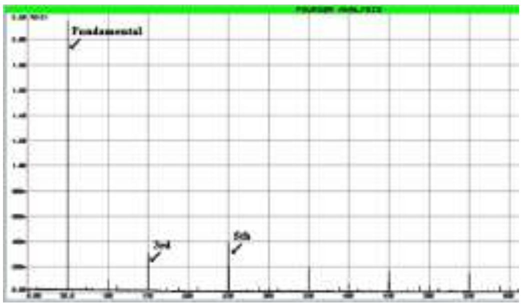


Figure 10 Fast Fourier Transform (FFT) with C-type filter

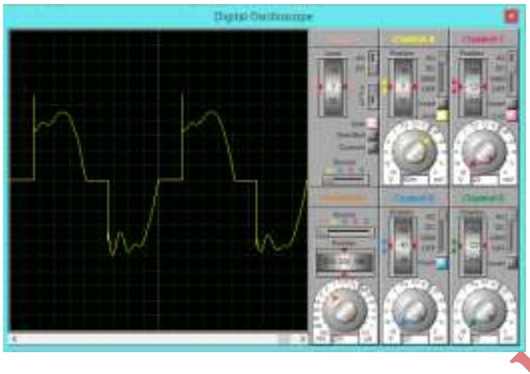


Figure 11 Current waveform after applying C-type filter

The current waveform has also improved than previous as shown in Figure 11. A combination of 3rd and 5th harmonic filters is used to further improve system response.

Figure 12 and Figure 13 show the current harmonic spectrum and current waveform after application of both 3rd harmonic C-type and 5th harmonic second order high-pass filters simultaneously. In this case, the harmonic content further decreased and current waveform further improved as obvious from figures below.

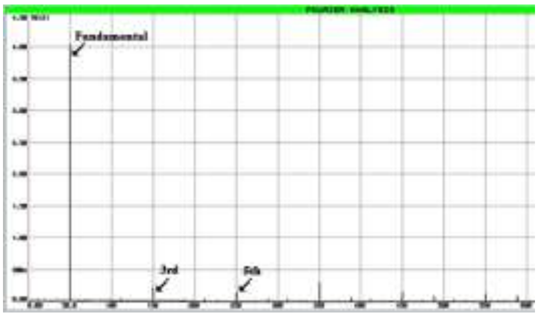


Figure 12 FFT with C-type filter and second order high-pass filter

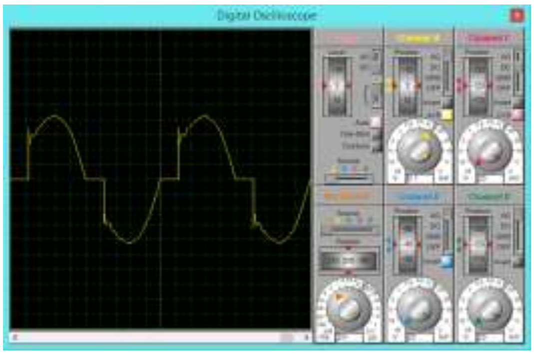


Figure 13 Current waveform after applying C-type filter and second order high-pass filter simultaneously

The simulation results show that harmonic filters reduce harmonic distortions due to harmonic currents. The C-type filter that is designed to filter out 3rd harmonic current from the system works as intended. After applying the C-type filter, the 3rd harmonic contents are reduced and since it is a broadband filter so the other high order harmonics are also reduced.

4. HARDWARE IMPLEMENTATION

Based on the calculated parameters and schematic diagram, actual hardware is implemented as shown in the following figures. Isolation transformer is used to reduce noise and provide constant voltage. Oscilloscope current probe is used for current measurements.

Figure 14 Setup for hardware testing

Figure 15 Current probe clamped on phase wire

The C-type filter and second order high-pass filter are shown in Figure 16. Both harmonic filters are connected with ground.

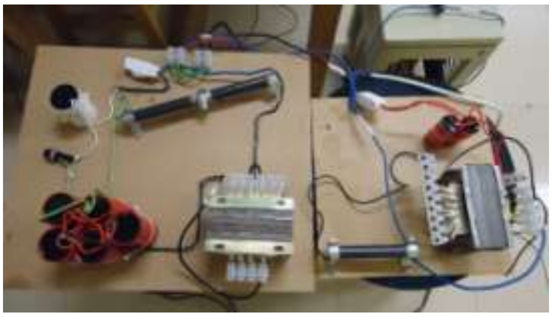


Figure 16 C-type filter for 3rd harmonic (left) and second order high-pass filter for 5th harmonic (right)

Ground/Earth electrode resistance is measured using earth resistance tester. The procedure for ground resistance measurement is explained here. Stick the auxiliary earth spikes into the ground such that they are aligned 5 to 10 meters from the earthed electrode under test as shown in Figure 17. The central spike being auxiliary potential electrode and the other spike being auxiliary current electrode.

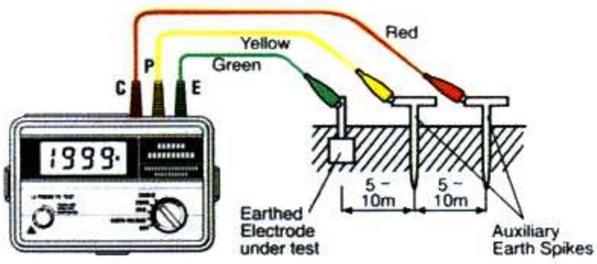


Figure 17 Earth resistance measurement procedure

Figure 18 Ground resistance measurement using Earth Resistance Tester

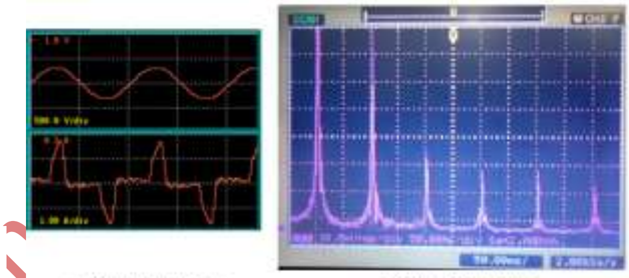
Connect the lead wires to terminals of earth resistance tester and to electrodes as shown. Now turn on the tester and earth resistance value will be indicated on the display. Earth resistance measurement uses fall-of potential method to determine earth resistance value R_e. Constant AC current I is applied between earth electrode and current electrode and the potential difference V between earth electrode and potential electrode is found. R_e is then calculated as follows.

$$R_e = V/I$$

Figure 18 shows earth resistance value measured for EE building ground that comes out to be 0.38Ω.

5. RESULTS AND DISCUSSIONS

CRT monitor and computer with SMPS is our nonlinear load. The current waveform and current harmonic spectrum have been recorded using Hioki 3197 harmonic analyzer. These are shown in the figures below for this nonlinear load without applying any filter. It can be easily observed that odd harmonic currents are drawn by this nonlinear load and as a result current waveform is distorted.

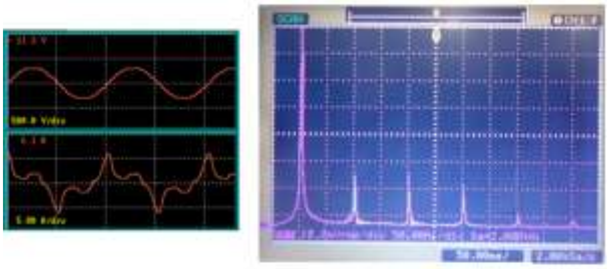


a. Current waveform b. Current Spectrum

Figure 19 Without filter

After installing 3rd harmonic C-type filter, the harmonic currents decreased as the current harmonic distortion (I_{THD}) decreased from 92% to 63%. It is obvious from Figure 20 (b) that 3rd harmonic content has decreased.

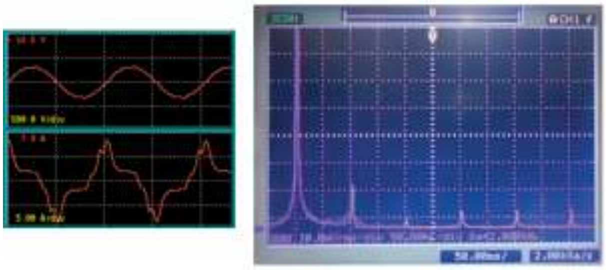
A combination of 3rd and 5th harmonic filters is used to further improve system response.



a. Current waveform b. Current Spectrum

Figure 20 With C-type filter (to remove 3rd harmonic)

Figure 21 shows the current waveform and current harmonic spectrum after application of 3rd harmonic C-type and 5th harmonic second order high-pass filters simultaneously. In this case, the harmonic currents further decreased as the current harmonic distortion (I_{THD}) further decreased from 63% to 41%. It is obvious from Figure 21 (b) that 5th harmonic content has decreased.



a. Current waveform b. Current Spectrum

Figure 21 With C-type filter and second order high-pass filter

The results taken show that harmonic filters reduce harmonic distortions by diverting harmonic currents away from load into ground and consequently current harmonic distortion (I_{THD}) is significantly reduced.

It should also be noted that current waveforms are also improved when harmonic filters are applied to nonlinear load as harmonic distortions are reduced which leads to waveform improvement.

6. CONCLUSION

Harmonic pollution has increased due to the rampant use of nonlinear devices during recent years. Different methods and techniques are presented in the literature for reducing harmonic distortions. Passive harmonic filters are still the most effective and viable solution to reduce harmonic distortions. Many industrial facilities install these filters to ensure that they comply with the harmonic limits specified by the supply utilities. The C-type passive filter is one of more efficient and cost effective passive harmonic filters. The C-type filter works by providing low impedance path to the harmonic currents tuned at harmonic frequency and also filters high frequency harmonic currents thus acting as a broadband filter. The harmonic current is filtered out by the C-type filter and flows to the ground. This research work gives a practical design of C-type passive filter for reducing harmonic distortion. Harmonic simulation is done using Proteus software and based on this simulation, hardware implementation is done. Simulation study and hardware implementation results obtained show that C-type filter significantly reduces current harmonic distortion. The simulation results show that harmonic filters reduce harmonic distortions due to harmonic currents. The C-type filter that is designed to filter out 3rd harmonic current from the system works as intended. After applying the C-type filter, the 3rd harmonic currents reduced and since it is a broadband filter so the other high order harmonics are also reduced. The second order high-pass filter that is designed to filter out 5th harmonic current from the system also works as intended. After applying both C-type filter and second order high-pass filter, the 3rd and 5th harmonic currents are reduced and since both are broadband filters, so the other high order harmonics are also reduced. Hence it is concluded that C-type filter provides better harmonic filtering. The designed passive harmonic filter performance has been verified by experimental results from hardware implementation. When with and without filter installation cases are compared, the current harmonic distortion (I_{THD}) decreased from 92% to 41%. The proposed C-type passive harmonic filter designed in this paper is therefore certified. It should also be noted that current waveforms are also improved when harmonic filters are applied to nonlinear load as harmonic currents are filtered out from the system that causes improvement in the current waveform.

7. ACKNOWLEDGEMENTS

Authors are thankful to lab supervisor Mr. Shahid for providing earth resistance tester to measure lab earth resistance. First author performed experiments and second author conducted theoretical work.

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