Analysis of the Performance of Type C Passive Filters in Anticipating Current Harmonics

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Abstract. This research aims to determine the performance of a passive C-type filter simulated with computer software in reducing harmonic currents. The object of research in this study is a laptop, where laptops are currently no longer tertiary needs but have become primary needs, especially in education circles. Universitas Negeri Medan is one of several campuses in Indonesia which is a means of learning process for students in improving their competence in order to get a decent job. The laptop itself is equipment that is included in the nonlinear load category, where the nonlinear load is a harmonic current generator. From the results of harmonic current measurements on the laptop load, the harmonic current obtained exceeds the standard permitted by the IEC 61000 3-2 standard, which is 0.13 A. To overcome the harmonic current that causes this nonlinear load, a type C passive filter is used. The IEC 61000 3-2 standard states that laptops are included in the class D category because they are equipment that has a power below 600 W. After the simulation, a reduction in harmonics was obtained in the seventh order so that the large harmonic current became 0.07 A, therefore it can be concluded that the seventh order harmonic current was successfully reduced by the type C passive filter and has complied with the IEC 61000 3-2 standard.

Keywords: Type C Passive Filter, THD, IHD, Laptop.

1 Introduction

The results of the survey on the use of ICT and its implications for the socio-cultural aspects of society in Indonesia show that 21.36% of the total Indonesian population owns a laptop. This figure is higher compared to computer ownership which only reached 7.97% or there is a percentage difference of 13.39%. The flexibility offered by laptops that can be carried anywhere and can be used anywhere and anytime is one of the factors that makes this device more popular than computers [1].

The use of laptops in colleges has also been widely used in the learning process. The percentage of students who bring laptops to class is also quite large, almost 80 percent of students in private colleges also use laptops to attend lectures in class. The use of laptops in class provides many benefits, especially in technology and the learning process. Moreover, when learning uses the

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lecture method or interactive discussion, lecturers or students who speak or listen to others must compete with various information and entertainment presented very attractively that is available on the laptop.

Laptops themselves are included in the category of nonlinear loads where this nonlinear load is a harmonic generator in the electric power system [2][3]. Harmonics are frequency components that are multiples of the fundamental frequency [4][5]. The size of the harmonic distortion in the electric power system is presented in the form of total harmonic distortion (THD) either in the form of voltage (THDV) or current (THDI) [6][7]. To determine the amount of harmonic distortion in a laptop, the IEC 61000 3-2 standard is used.

With the presence of harmonic interference, it has an impact on decreasing the quality of power in the power source [8][9]. Not only that, the impact of harmonics can also cause errors in measurements such as KWH meters [10]. Protection equipment will also experience failure in its operation if there is harmonic content in the system that will be protected in the protection equipment [11].

After conducting observations at the electrical engineering workshop of the State University of Medan, it was found that the magnitude of the harmonic distortion in the seventh order exceeded the current limit set by the IEC 61000 3-2 standard caused by the use of laptops. Based on the problems encountered, this study aims to reduce the harmonics in the seventh order caused by the use of laptops in the electrical engineering workshop of the State University of Medan by using a type C passive filter.

2 Methods

The method used in this study is an experimental method where the C-type passive filter is modeled with the help of computer software to see how effective the C-type passive filter is in reducing harmonics. The tool used in this study is a power quality analyzer to measure the parameters of voltage, current, active power, apparent power, reactive power, frequency, cos φ, individual harmonic distortion current (IHD_I) and total harmonic distortion current (THD_I). The first thing to do in designing a type C passive filter is to determine parameters such as voltage, regulated frequency, and reactive power capacity required by the filter at the fundamental frequency (Q_1). Type C passive filter as presented **Fig. 1.**

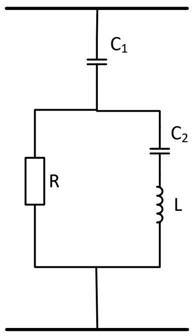

Fig. 1. Type C Passive Filter Diagram.

To calculate the equivalent impedance of the filter at the fundamental frequency by ignoring the power losses due to capacitors and reactor resistance using the equation (1) [12].

$$Z_{eq} = \left(\frac{1}{R} + \frac{1}{j\omega L - \frac{j}{\omega C}}\right)^{-1} - \frac{j}{\omega C1}$$

$$Z_{eq} = \frac{R(\omega^2 LC - a)^2 + jR^2\omega C(\omega^2 LC - 1)}{(\omega^2 LC - 1)^2 + (\omega RC)^2} - \frac{j}{\omega C_1} \quad (1)$$

The next step to avoid power losses in resistor R is to adjust L and C at the basic frequency using the equation (2).

$$\omega^2 LC - 1 = 0 \quad (2)$$

Next, calculate the filter impedance at the fundamental frequency using the equation (3).

$$Z_{eq} = -\frac{j}{\omega C_1} \quad (3)$$

Next, calculate the capacitive reactance using the equation (4).

$$X_{C1} = -\frac{j}{\omega C_1} = -j\frac{V^2}{Q_1} \quad (4)$$

Then calculate the value of C1 from the equation (4) so that the equation is obtained (5).

$$C_1 = \frac{Q_1}{\omega V^2} \quad (5)$$

To calculate the total impedance with a set frequency f_h, the equation is obtained (6).

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

$$Z_h = \frac{R\left(\omega_h^2 LC - 1\right)^2 + jR^2\omega_h C\left(\omega_h^2 LC - 1\right)}{(\omega_h^2 LC - 1)^2 + (\omega_h RC)^2} + j\left(\frac{R^2\omega_h C\left(\omega_h^2 LC - 1\right)}{(\omega_h^2 LC - 1)^2 + (\omega_h RC)^2} - \frac{1}{\omega_h C_1}\right) \quad (6)$$

To calculate the total filter resistance, the equation is used (7).

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

$$r = \frac{R}{\frac{(\omega_h RC)^2}{(\omega_h^2 LC - 1)^2} + 1} \quad (7)$$

At the set frequency the filter reactance must be zero calculated by the equation (8).

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

$$\frac{\omega_h RC}{\omega_h^2 LC - 1} = \frac{1}{r\omega_h C_1} \tag{8}$$

From the equation (7) and equations (8) obtained then the equation is obtained (9).

$$r = \frac{R}{\frac{1}{(r\omega_h C_1)^2} + 1} \tag{9}$$

At the set frequency, the problem above can be solved using the equation (10)

$$r^2 - Rr + \frac{1}{(\omega_h C_1)^2} = 0 \tag{10}$$

Next, we obtain the equation (11).

$$h = \frac{\omega_h}{\omega} = \omega_h\sqrt{LC} \tag{11}$$

By considering,

$$R_h = \frac{2}{\omega_h C_1} = \frac{2V^2}{hQ_1} \tag{12}$$

From the equation (10) and equation (12) obtained the equation (13).

$$r^2 - Rr + \frac{R_h^2}{4} = 0 \tag{13}$$

From the equation (13) The roots obtained are as in equation (14).

$$r = \frac{R \pm \sqrt{R^2 - R_h^2}}{2} \tag{14}$$

It is known that r is a positive real number of the total resistance of the filter. The discriminant must be equal to zero or greater so that the following equation is obtained.

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

By considering,

$$R = mR_h \ untuk \ m \geq 1 \tag{15}$$

From the equation (13) we get a new equation like the equation (16)

$$r^2 - mR_h r + \frac{R_h^2}{4} = 0 \tag{16}$$

Roots of the equation (16) shown in the equation (17).

$$r = \frac{m - \sqrt{m^2 - 1}}{2} R_h \tag{17}$$

From the equation (11) A new equation is obtained as in Equation (18).

$$\omega_h^2 LC = h^2 \tag{18}$$

From the equation (12) A new equation is obtained as in Equation (19).

$$\omega_h C_1 = \frac{2}{R_h} \tag{19}$$

Based on the equation (15), (17), (18), and (19) which is entered into the equation (8) then a new equation is obtained, such as the equation (20).

$$C = \frac{h^2 - 1}{m^2 - m\sqrt{m^2 - 1}} \frac{1}{\omega_h R_h} \tag{20}$$

From the equation (11) and equation (12) A new equation is obtained as in equation,

$$\omega_h R_h = \frac{2\omega V^2}{Q_1} \tag{21}$$

To calculate the C parameter of the filter, you can enter the equation values (21) into the equation (20) so that the equation is obtained (22).

$$C = \frac{h^2 - 1}{m^2 - m\sqrt{m^2 - 1}} \frac{Q_1}{2\omega V^2} \tag{22}$$

From the equation (13) we get a new equation like the equation (23).

$$L = \frac{1}{\omega^2 C} \tag{23}$$

From the equation (22) and equation (23) To enter the C value, the L parameter of the filter can be calculated as shown in the equation (24).

$$L = \frac{m^2 - m\sqrt{m^2 - 1}}{h^2 - 1} \frac{2V^2}{\omega Q_1} \tag{24}$$

To calculate the C and L parameters of the filter can be calculated by choosing the appropriate m value, but the C and L parameters will not produce the optimal value based on the lowest cost. The fundamental current is determined by the voltage of the capacitive reactance C_1 by assuming that all the fundamental current flows through the C and L components of the filter, then it can be shown in the equation (25).

$$I_1 = V\omega C_1 \tag{25}$$

To calculate the reactive power supplied by component C at the fundamental frequency is shown in the equation (26).

$$Q_C = \frac{I_1^2}{\omega C} = \frac{2Q_1}{h^2 - 1}\left(m^2 - m\sqrt{m^2 - 1}\right) \tag{26}$$

To calculate the reactive power provided by component L at the fundamental frequency using the equation (27).

$$Q_L = I_1^2 \omega L = \frac{2Q_1}{h^2 - 1}\left(m^2 - m\sqrt{m^2 - 1}\right) \tag{27}$$

From the equation above, it can be seen that both reactive powers have the same magnitude. If the current is constant, the greater the reactive power and parameter L while the parameter C will be smaller. The use of large components will require large costs so that reactive power must be reduced to a minimum.

$$g(m) = m^2 - m\sqrt{m^2 - 1} \tag{28}$$

Obtained derivative of the equation (28) as follows,

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

If the function g(m) continues to decrease, it shows that its derivative will always be negative. The value $m \rightarrow \infty$ will be 0.5 if the value is extreme. To get the optimal C and L components by entering the equation (22) and equation (24).

$$C = \frac{(h^2 - 1)Q_1}{\omega V^2} \tag{29}$$

$$L = \frac{V^2}{(h^2 - 1)\omega Q_1} \tag{30}$$

The resistance to the reactance of the parallel RL circuit to be regulated is the definition of the quality factor Q_f of a C-type passive filter. The sharpness of the tuning frequency is influenced by the quality factor of the bandwidth.

$$Q_f = \frac{R}{\omega_h L} \tag{31}$$

Thus, the damping resistance can be calculated using the equation (32).

$$R = Q_f \omega_h L \tag{32}$$

To determine the size of the parameters used in a type C passive filter, you can use the equation (5), (29), (30), and (32).

3 Results and Discussion

3.1 Data

This study aims to reduce harmonics in the seventh order so that the research data used is obtained as presented in **Table 1**.

Table 1. Measurement Data.

Input Parameter	Type C Passive Filter
V	229,47 V
F_h	350 Hz
Q_1	68,84 var
Q_f	2
C_1	10 μf
C_2	10 μf
L	0,1 mH
R	200 Ω

3.2 Simulation

The harmonics to be reduced are simulated with a computer device as shown in the picture. In the simulation, the harmonic source is modeled in the form of a current injection where the injected current describes the measurement results of each harmonic order measured by a power quality analyzer measuring instrument starting from the third order to the forty-ninth order. The simulation also models a harmonic filter to reduce the regulated harmonics as presented in **Fig. 2.**

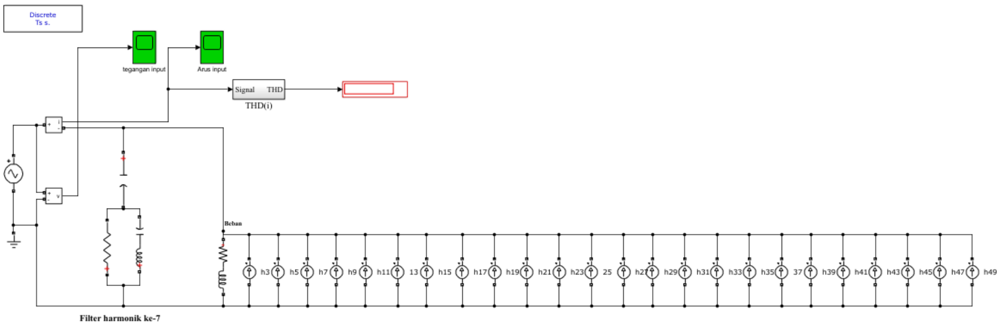

Fig. 2. Type C Passive Filter Simulation Circuit.

From the simulation results of using a type C passive filter to reduce harmonics in the seventh order, the results of the harmonic current reduction can be seen in **Table 2**.

Table 2. Comparison of Harmonic Current Before and After Filter.

Harmonics	IEC 61000 Standard Harmonic Current Limit 3-2 (92 W Laptop)		Harmonic Current Measurement Results	Harmonic Current After Filter
	(mA/W)	(A)	(A)	(A)
1				
3	3,40	0,31	0,24	0,14
5	1,90	0,17	0,19	0,11
7	1,00	0,09	0,13	0,07
9	0,50	0,05	0,02	0,01
11	0,35	0,03	0,02	0,01
13	0,30	0,03	0,01	0,01
15	0,26	0,02	0,01	0,01
17	0,23	0,02	0,01	0,01
19	0,20	0,02	0,01	0,01
21	0,18	0,02	0,01	0,00
23	0,17	0,02	0,01	0,00
25	0,15	0,01	0,01	0,00
27	0,14	0,01	0,01	0,00
29	0,13	0,01	0,01	0,00
31	0,12	0,01	0,01	0,00
33	0,12	0,01	0,01	0,00
35	0,11	0,01	0,01	0,00
37	0,10	0,01	0,00	0,00
39	0,10	0,01	0,00	0,00
41	0,09	0,01	0,00	0,00
43	0,09	0,01	0,00	0,00
45	0,09	0,01	0,00	0,00
47	0,08	0,01	0,00	0,00
49	0,08	0,01	0,00	0,00

Harmonics are wave components whose frequencies are multiples of the fundamental frequency. Before filters are installed, harmonics can interfere with the system by causing distortion and overheating of electrical devices. For example, in an electrical system, harmonics can affect the efficiency and life of equipment. Current wave before filter installation as presesent in **Fig. 3**. After the filter is installed, the harmonic waves will usually be reduced, so that the waveform becomes smoother and closer to the ideal sinusoidal wave. The harmonic filter works by filtering out unwanted or excessive frequencies, so that only the fundamental frequency or certain frequencies are allowed to pass and current wave after filter installation as present in **Fig. 4.**

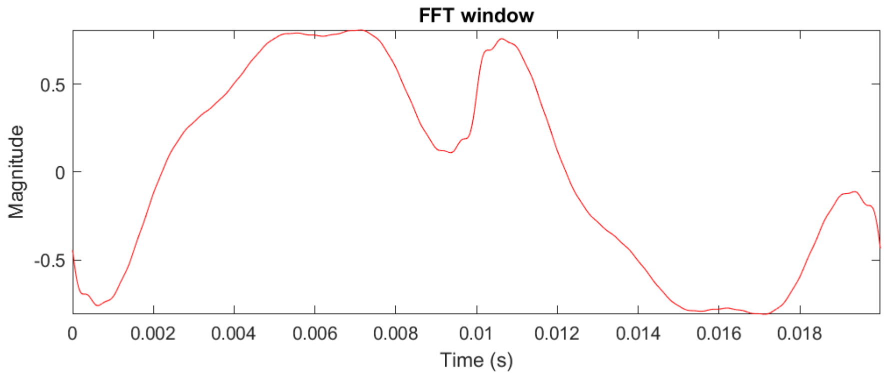

Fig. 3. Current Wave Before Filter Installation.

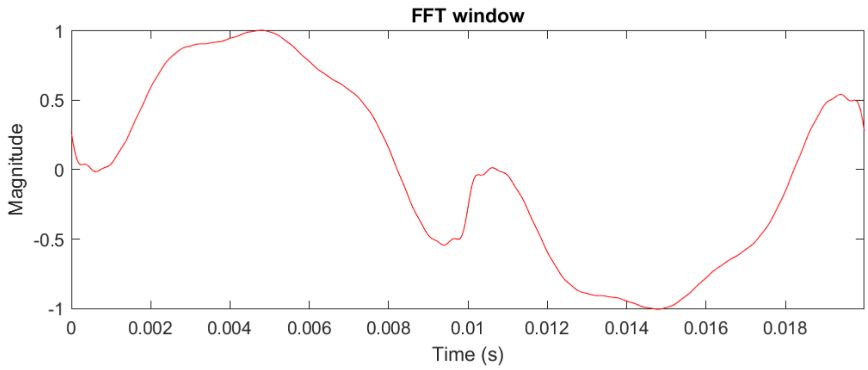

Fig. 4. Current Wave After Filter Installation.

4 Conclusion

This research has shown that the use of a C-type passive filter is effective in reducing harmonics generated by the laptop, especially in the seventh order. The simulation results show a decrease in harmonics in the seventh order to 0.07 A where the magnitude of the harmonic current in the previous seventh order was 0.13 A, which is in accordance with the initial hypothesis. The implication of this finding is an increase in efficiency in the electric power system. However, this study has limitations in the total harmonic distortion current. Therefore, further research is recommended to test the effectiveness of several filters so that they can reduce the harmonic distortion current as a whole.

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