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Effectiveness Of Type C Passive Filters In Reducing Harmonic Currents

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Abstract

This study aims to see how effective the type C passive filter is in reducing harmonic currents generated by the electrodynamometer induction motor trainer. The method used in this study is to model a C-type passive filter and simulate it with computer software. The type C passive filter modeling is designed to reduce harmonics in the thirty-fifth order. From the observation results, it was found that the thirty-fifth order harmonic current was 1.5% while the IEEE 519-2014 standard limits the thirty-fifth order harmonic current to 1.0%, which has exceeded the permitted standard. After the simulation, the type C passive filter successfully reduced the existing harmonics so that the harmonic content was 0.95%. From the results of this simulation, it can be concluded that the type C passive filter successfully reduced the harmonic content in the thirty-fifth order to 36.29%. This harmonic reduction has also been below the maximum value permitted by the IEEE 519 – 2014 standard at the thirty-fifth order so that the passive filter is effective in reducing the thirty-fifth harmonic produced by the electrodynamometer induction motor trainer.

Keywords: Harmonics; Current; Type C Passive Filter.

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1. Introduction

Harmonics in the electric power system can cause various problems such as power loss, equipment interference and even decreased power quality. The use of nonlinear loads at present continues to increase significantly [1]. One of the nonlinear loads is an induction motor. Nonlinearity in induction motors such as in magnetic characteristics or load characteristics can cause harmonics [2]. This nonlinear load can also cause harmonics in the electric power system. The phenomenon of the formation of waves with a fundamental frequency that is a multiplication of integers is often known as harmonics [3]. The efficiency of electrical machines will decrease if harmonics occur in the electrical power system, such as excessive heat and so on [4].

In industrial and commercial applications, induction motors are most commonly used because this type of motor is included in the reliable and popular category. The working principle of this induction motor is by electromagnetic induction. When there is a changing magnetic field generated by the stator, the rotor will be exposed to a magnetic field so that the rotor rotates. The presence of harmonics in the induction motor will affect the efficiency of the electric power system and increase energy losses in the motor so that the temperature in the motor will also increase, which will ultimately shorten the service life of the motor, accelerate wear, and cause problems with control equipment [5].

To prevent and control harmonics in induction motors, harmonic filters can be used. The harmonic filter itself consists of three types, namely passive filters, active filters and hybrid filters. Currently, passive filters are widely used in handling harmonics that appear in electric power systems due to their simple configuration [6]. In this passive

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filter, the frequency whose harmonic content is to be reduced can also be set according to the characteristics of the filter [7].

Type C passive filters consist of a combination of capacitors and inductors arranged in such a way as to dampen harmonics at certain frequencies [8], [9]. This filter works on the principle of resonance, where the filter elements are designed to resonate at the harmonic frequencies that are to be removed [10], [11]. When resonance occurs, the impedance at that frequency becomes very low, so that harmonics can be absorbed by the filter and do not interfere with the electric power system [12]. The main advantage of the type C passive filter is its ability to reduce harmonics without consuming significant reactive power [13]. In addition, this filter can also improve the power factor of the system, which means better efficiency in the use of electrical power [14].

In the Electrical Engineering Workshop of Universitas Negeri Medan, there is a practical course on electrical machines where one of the topics in the practice uses an induction motor trainer. Based on the description of the background of the problem above, the researcher wants to conduct a study on the Effectiveness of Type C Passive Filters on Harmonic Currents.

2. Material and methods

The tool used in this study is the power quality analyzer, which is used to measure electrical quantities such as voltage, current, active power, apparent power, reactive power, frequency, cos φ, individual harmonic distortion current and total harmonic distortion current.

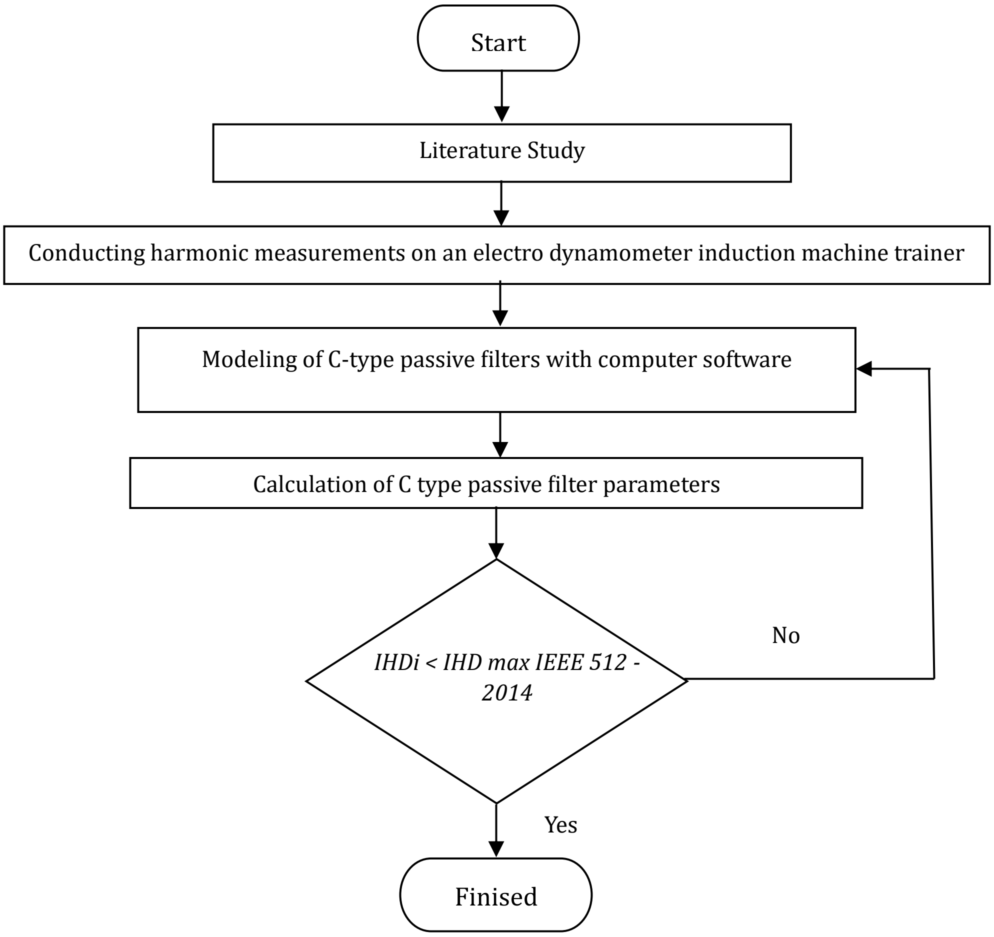

Figure 1: Type C Passive Filter Diagram

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The method used in this study is to create a simulation of a type C passive filter with computer software to reduce harmonics in the thirty-fifth order. The simulation results are used to determine how effective the type C passive filter can reduce the harmonic currents that appear.

2.1 Type C Passive Filter

Type C passive filter is one of several types of filters used to reduce harmonics in the electric power system. This type C passive filter consists of a combination of capacitors and inductors designed to resonate at a certain frequency or within a certain frequency range. The advantage of the type C passive filter is that its elements are selected in such a way that they are capacitive at the fundamental frequency, which ultimately can reduce power losses to a minimum. This type C passive filter can also be used in single-phase and three-phase systems. When resonance occurs, the impedance at that frequency becomes very low, so that harmonics can be absorbed by the filter and do not interfere with the electric power system. The main advantage of the type C passive filter is the ability to reduce harmonics without consuming significant reactive power. In addition, this filter can also improve the power factor of the system, meaning that the efficiency of electric power usage becomes better.

2.2 Type C Passive Filter Design

To design a type C passive filter, first determine the parameters such as voltage, the frequency to be controlled, and the reactive power capacity Q_1 required by the filter at the fundamental frequency.

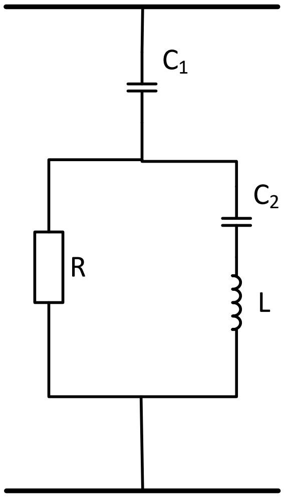

Figure 2: Type C Passive Filter Diagram

If the power loss due to the capacitor and reactor resistance is neglected, the equivalent impedance of the filter at the fundamental frequency can be calculated using the following equation [15] :

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

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

Next, L and C are set at the basic frequency to avoid power losses in the resistor R, to calculate it using the equation (2) :

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

So the filter impedance at the fundamental frequency is calculated by the equation (3):

$$Z_{eq} = -\frac{j}{\omega C_1} \tag{3}$$

Next,

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

From equation (4) The size of C_1 can be calculated using the equation (5) :

$$C_1 = \frac{Q_1}{\omega V^2} \tag{5}$$

At the set frequency f_h, the total impedance can be calculated by the equation (6):

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

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

So the total resistance of the filter at the set frequency can be calculated by the equation (7):

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

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

The total reactance of the filter must be zero at the set frequency as in the equation (8):

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

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

By placing the equation (8) to equation (7) then we get the equation (9):

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

From solving the problem above, we get the following equation (10) the following at the set frequency, namely :

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

So that the equation is obtained (11) :

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

By considering,

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

By placing the equation (12) into the equation (10) then the resulting equation (13):

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

Roots of the equation (14):

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

Where r is the total resistance of the filter which must be a positive real number. This is possible when the equation (14) have real roots. To obtain real roots, the discriminant must be greater than or equal to zero.

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

By considering,

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

So the equation (13) to be equal (16):

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

One of the roots of the equation (16) shown in the equation (17):

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

From equation (11) obtained the equation (18):

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

From equation (12) obtained the equation (19):

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

By entering the values from the equation (15), (17), **Error! Reference source not found.**, and (18) into the equation (8) then we get the equation (20):

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

From equation (11) and (12) then we get the equation :

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

By entering the equation values (21) into the equation (20) will produce an important equation for calculating the C parameter of the filter, namely as follows:

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

From equation (13) obtained the equation (23):

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

By entering the value of C from the equation (22) and (23) yields another important equation for calculating the L parameters of the filter as shown in the equation (24):

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

Now the C and L parameters of the filter can be calculated by choosing an appropriate value of m, but this value does not yield the lowest cost optimum values of the C and L parameters. We need the lowest cost optimum parameters of the C and L parameters. Assuming that all the fundamental current will flow through the C and L components of the filter. This fundamental current is determined by the voltage across the capacitive reactance C1 and is shown as in the equation (25):

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

The reactive power supplied by component C at the fundamental frequency is shown in the equation (26):

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

The reactive power provided by component L at the fundamental frequency is determined by the equation (27):

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

The equation above shows that both reactive powers have the same magnitude. By keeping the current constant, the larger L (or the smaller C) the greater the reactive power. Larger components will result in higher costs. So reactive power must be reduced to a minimum to reduce component costs. By considering the function

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

From equation (28) obtained derivatives as follows:

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

The derivative is always negative indicating that g(m) is a decreasing function. The extreme values for $m \dashrightarrow \infty$ is 0,5. By entering the equation (22) and (24) to obtain equations for the optimal C and L components.

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

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

The quality factor Qf of a C-type passive filter is defined as the ratio of the resistance to the reactance of the parallel RL circuit at the frequency to be tuned. The quality factor determines the bandwidth that affects the sharpness of the tuning frequency which is determined by the equation (31):

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

Therefore, the damping resistance can be calculated using equation (32):

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

To determine the parameters of a type C passive filter using the equation (5), (29), (30), and (32).

3. Results and discussion

This research was carried out by modeling a type C passive filter in Matlab/Simulink computer software, where the type C passive filter diagram schematic can be seen in Figure 3. The simulation of Figure 3 obtained the quantities presented in Table 1.

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Table 1: Simulation results of type C passive filter

Harmonics Order	IEEE 519-2014 standard	Harmonics before filter	Harmonics after filter	Frequency	Information
1		100	100	50	
3	12.0	17,67	11,23	150	Accepted
5	12.0	10,563	6,71	250	Accepted
7	12.0	7,507	4,77	350	Accepted
9	12.0	5,783	3,67	450	Accepted
11	5.5	4,753	3,02	550	Accepted
13	5.5	3,923	2,49	650	Accepted
15	5.5	3,4	2,16	750	Accepted
17	5.0	3,043	1,93	850	Accepted
19	5.0	2,663	1,69	950	Accepted
21	5.0	2,447	1,55	1050	Accepted
23	2.0	2,263	1,44	1150	Accepted
25	2.0	2,063	1,31	1250	Accepted
27	2.0	1,903	1,21	1350	Accepted
29	2.0	1,8	1,14	1450	Accepted
31	2.0	1,697	1,08	1550	Accepted
33	2.0	1,573	1	1650	Accepted
35	1.0	1,5	0,95	1750	Accepted
37	1.0	1,397	0,89	1850	Accepted
39	1.0	1,35	0,86	1950	Accepted
41	1.0	1,26	0,8	2050	Accepted
43	1.0	1,217	0,77	2150	Accepted
45	1.0	1,177	0,75	2250	Accepted
47	1.0	1,13	0,72	2350	Accepted
49	1.0	1,08	0,69	2450	Accepted

3.1 Type C Passive Filter Parameter Values

The first step in determining the parameter value of a type C passive filter is to set the tuning frequency. From the measurement results, the dominant harmonic order is at a frequency of 1750 Hz, which is at the thirty-fifth order. Next, determine the capacitance value of the capacitor using the equation (5):

$$C_1 = \frac{Q_1}{\omega V^2} = \frac{924{,}3}{2\pi \cdot 50 \cdot 233{,}4^2} = 5.4 \ \times 10^{-5}\ F$$

Next, determine the value of the auxiliary capacitor using the equation (29) where in this case the harmonics to be derived are at the thirty-fifth order so that we obtain:

$$C = \frac{(h^2 - 1)Q_1}{\omega V^2} = \frac{(35^2 - 1) \cdot 924{,}3}{2\pi \cdot 50 \cdot 233{,}4^2} = 5.4 \ \times 10^{-5}\ F$$

Next, determine the inductor value using the equation (30):

$$L = \frac{V^2}{(h^2 - 1)\omega Q_1} = \frac{233{,}4^2}{(35^2 - 1)2\pi \cdot 50 \cdot 924{,}3} = 0.00015\ H$$

The final step is to determine the damping resistor value using the equation (32) where the large quality factor is 4 as follows:

$$R = Q_f \omega_h L = 4 \cdot 2\pi \cdot 50 \cdot 0.00015 = 6{,}7\ \Omega$$

A summary of the parameters of the type C passive filter is presented in Table 2.

Table 2: Type C passive filter parameters

Parameter masukan	Filter pasif tipe C
V	233,4 V
F_h	1750 Hz
Q_1	924,3 var
Q_f	4
C_1	$5.4 \times 10^{-5}\ F$
C	$5.4 \times 10^{-5}\ F$
L	$0.00015\ H$
R	$6{,}7\ \Omega$

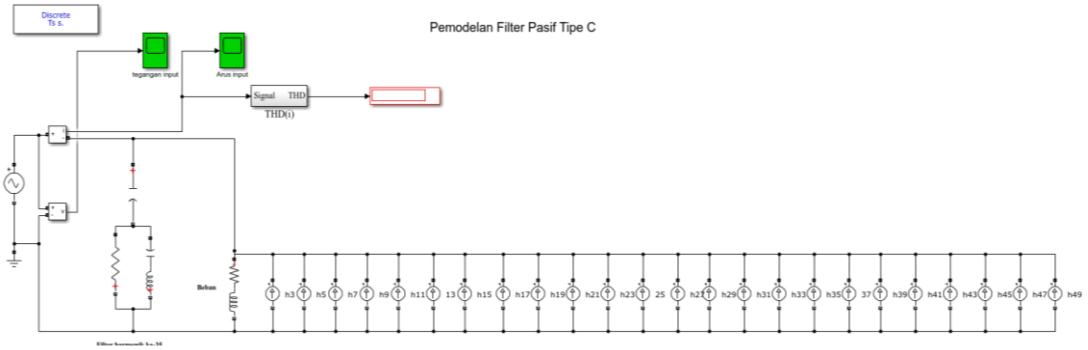

Figure 3: Type C Passive Filter Modeling

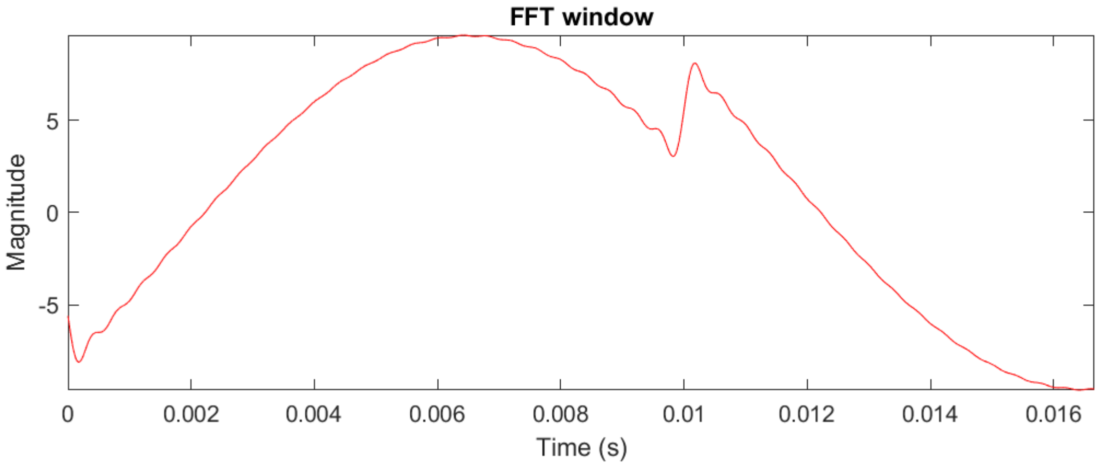

Figure 4: Harmonic Current Waveform Before Filter Installation

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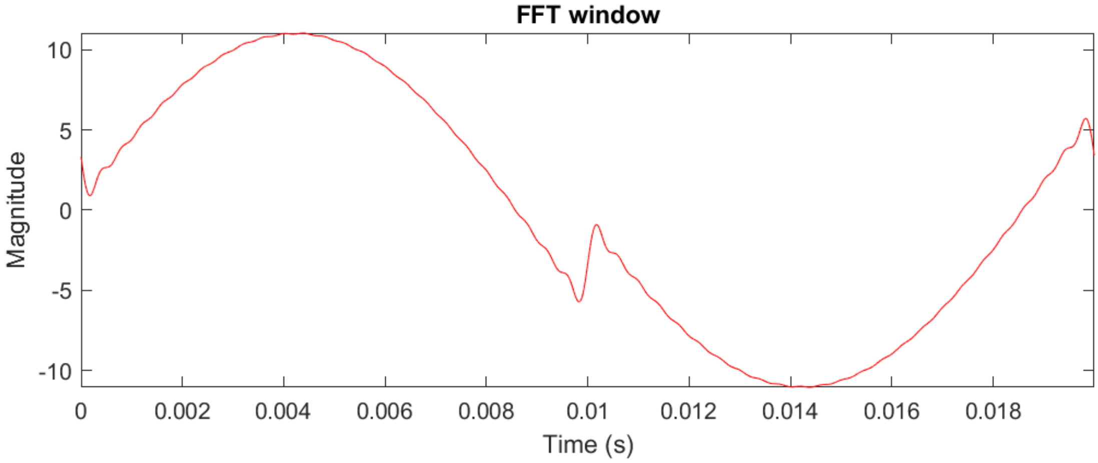

Figure 5: Harmonic Current Waveform After Filter Installation

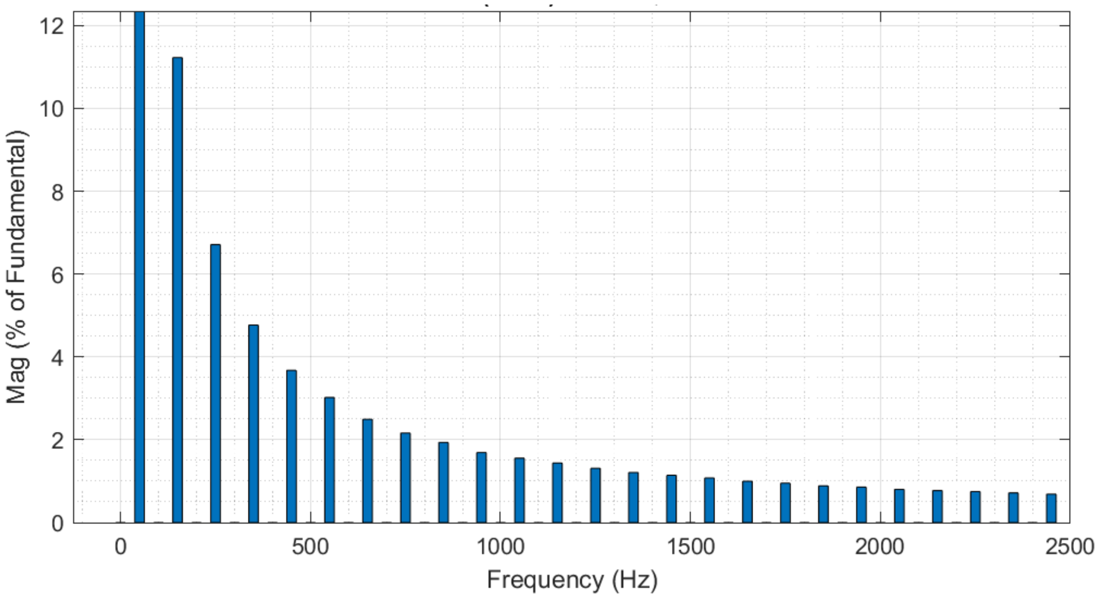

Figure 6: Histogram of Harmonic Current After Installing Filter

4. Conclusion

This study concludes that the type C passive filter is a solution to reduce harmonics produced by the electrodynamometer induction motor trainer. After the simulation, the type C passive filter successfully reduced harmonics to 0.95% at the thirty-fifth order, which indicates that there has been a 36.29% decrease in harmonics. The results of this reduction have also been below the maximum value permitted by the IEEE 519-2014 standard at the thirty-fifth order. To obtain more optimal results, a combination of passive filters is needed so that the power quality in the electric power system at the electrical engineering workshop of the Universitas Negeri Medan is maintained.

Author contribution

Conceptualization and formal analysis: Azmi Rizki Lubis.
Validation: Adi Sutopo.
Methodology and investigation: Marwan Affandi.
Writing: Muchsin Harahap.

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