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Comparative analysis of active filters, inductor-capacitor and inductor-capacitor-inductor passive filters in reducing harmonics

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ABSTRACT

Control equipment at substations requires a rectifier to convert alternative current (AC)-direct current (DC) electric current to provide DC power for relays, motors for disconnector switches and power breaker switches, and telecommunications equipment. Rectifiers have non-linear load characteristics, which can result in a waveform that is not pure sinusoidal due to the interaction of fundamental frequency sinusoidal waves with other waves known as harmonics. Therefore, to not interfere with the equipment's work, a filter is needed to reduce the harmonics produced by the rectifier. In this research, using MATLAB/Simulink, prevention was carried out using active filters, inductor-capacitor (LC), and inductor-capacitor-inductor (LCL) passive filters (T_a, T_c, and T_d designs) separately. After the research was carried out, it was found that the amount of harmonics before installing the filter was 49.61%. Then, after installing the active filter, the harmonics were reduced to 0.29%, the installation of the passive LC filter was reduced to 9.29%, and the installation of the LCL filter (T_a, T_c, and T_d) became 1.44%, 0.29%, and 1.44%.

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1. INTRODUCTION

Direct current (DC) power at substations has an important role in smooth operations to serve the electricity needs of consumers. This aims to provide DC power for relays and driving motors in circuit breakers (CB) and disconnecting switches (DS) and supply power used for telecommunications equipment [1]. The DC source comes from a rectifier and battery connected in parallel to the load. Where a rectifier is a type of rectifier that has non-linear load characteristics, which can cause the input side waveform to not be pure sinusoidal due to the interaction of fundamental frequency sinusoidal waves with other waves known as harmonics. The problem is that high harmonic values can cause several losses, so the harmonics generated by the rectifier need to be reduced so as not to interfere with the equipment's operation. The author hopes one solution is to use active filters and passive harmonic filters [2]–[4].

The results of previous research [5], it is showed that all topology designs could reduce harmonics and reduce power losses. In another study [6], the total harmonic distortion (THD) is reduced with inductor-capacitor-inductor (LCL) type passive filters when compared with inductor-capacitor (LC) filters. Then, research [7] showed that the THD of the inverter side current and the network side current was 6.06% and

1.49%, respectively. The research [8] shows that the shunt active power filter effectively reduces harmonics from 21.51% to 2.51%.

Based on previous research, this study uses MATLAB/Simulink software to compare the use of active filters, passive LC filters, and LCL filters using LCL with Resistor (R) Series damper (Ta), LCL with resistor-inductor-capacitor (RLC) shunt damper (Tc), and LCL with RLC Series damper (Td) designs [9]–[14] to reduce harmonics at the Glugur main substation. The author hopes that the results of several methods can provide the best results for reducing harmonics. This research has never been done before.

2. METHOD

This research uses the MATLAB/Simulink program simulation method to see the effect of installing active filters, LC, and LCL passive filters on the input side of the rectifier at the Glugur substation to reduce harmonics. This research requires six circuits, namely the MATLAB Simulink rectifier model of the Glugur main substation, before installing active filters, passive LC, and LCL filters in Figure 1. Further, Figure 2 shows the MATLAB/Simulink model of the Glugur substation rectifier circuit following active filter installation in Figure 2(a) and active filter modeling in Figure 2(b) [15]–[17]. Then, the circuit after installing the LC passive filter in Figure 3 [6], [18]–[20] and the circuit after installing the LCL passive filter in Figure 4 (design T_a), Figure 5 (design T_c), Figure 6 (design T_d).

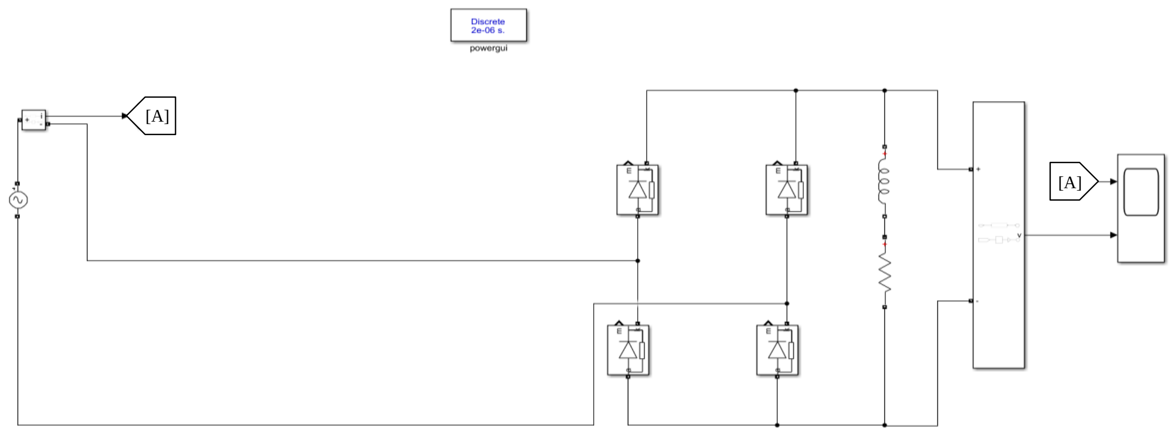
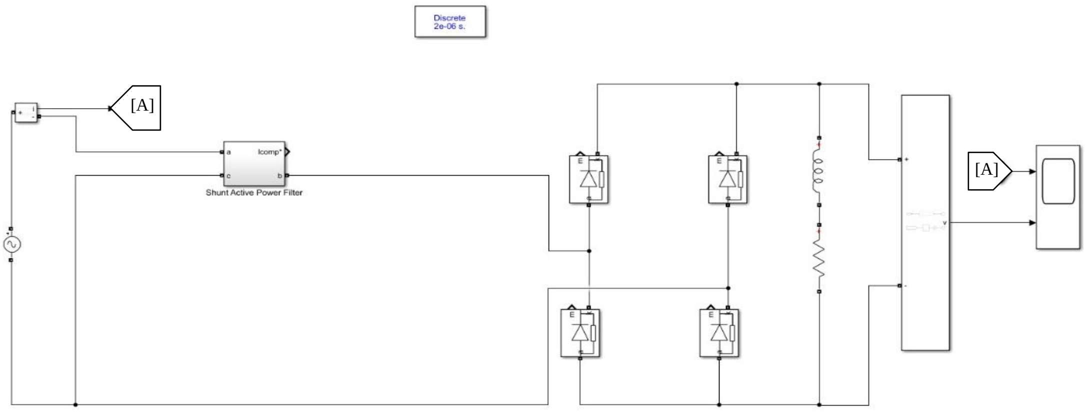


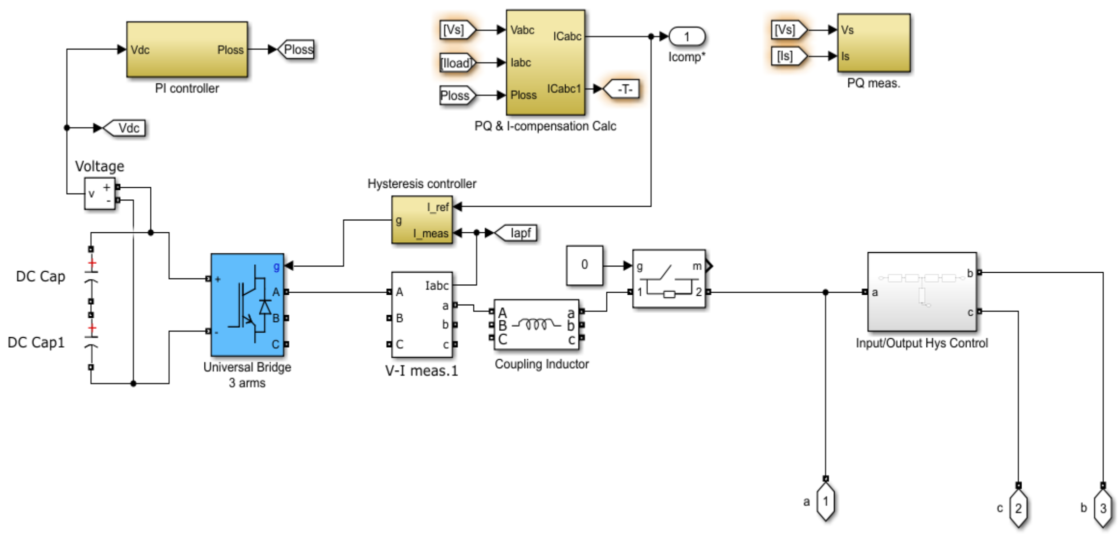
Figure 1. Glugur substation rectifier circuit model in the initial condition

Thus, the simulation steps can be carried out as follows: first, draw the rectifier circuit at the Glugur substation before installing the filter (initial conditions). Next, the Glugur substation rectifier output is connected to the load and determines the power and voltage of the rectifier. Next, run MATLAB/Simulink to see the THDi and IHDi values before installing the filter. On the other hand, the rectifier circuit can be reassembled by inserting an active filter using MATLAB/Simulink. Then, run to see the waveform, THDi, and IHDi values after installing the active filter. Then, calculate the values of C and L as component values in the LC passive filter using (1)-(18), then reassemble the rectifier circuit by inserting the LC passive filter in MATLAB/Simulink and displaying the waveform and THDi and IHDi values after installing the LC filter. After that, calculate the values of Lg, L, and Cf as component values in the LCL passive filter, then reassemble the rectifier circuit by inserting the LCL passive filter designs T_a, T_c, and T_d in MATLAB/Simulink and to see the waveform current and voltage on the input side as well as THDi and IHDi after installing the LC filter [21], [22]. Meanwhile, Figure 7 shows the flow diagram for installing active filters, passive LC filters, and LCL filters on the Glugur substation rectifier.

At a point of common coupling (PCC) between the owner or operator of the electrical system and a user, EEE Std 519 offers rules and recommendations for limiting harmonic voltage and current distortion. The standard acknowledges that electricity users must prevent heavy, non-linear, or distorted currents from deteriorating the voltage quality of the utility. It also acknowledges the utility's obligation to supply consumers with an almost sine-wave voltage. Table 1 display suggested harmonic limits in IEEE STD 519-2014 [23], [24]. The IEEE 519-2014 standard specifies requirements for distortion of voltage and current harmonics when designing electrical systems. It establishes waveform distortion targets for system designers and offers thorough explanations of the current and voltage waveforms already present throughout the system. The standard is updated regularly to keep up with industry developments. Since its introduction in 1981, it has undergone numerous revisions; IEEE 519-2014 is the most recent significant modification. 2022 will see further improvements. With an emphasis on the notable modifications made in the IEEE 519-2014 version, this page discusses statistical evaluation methods and definitions of important terms.



(a)



(b)

Figure 2. Glugur substation rectifier circuit (a) model after installing the active filter using MATLAB/Simulink and (b) modeling of the active filter

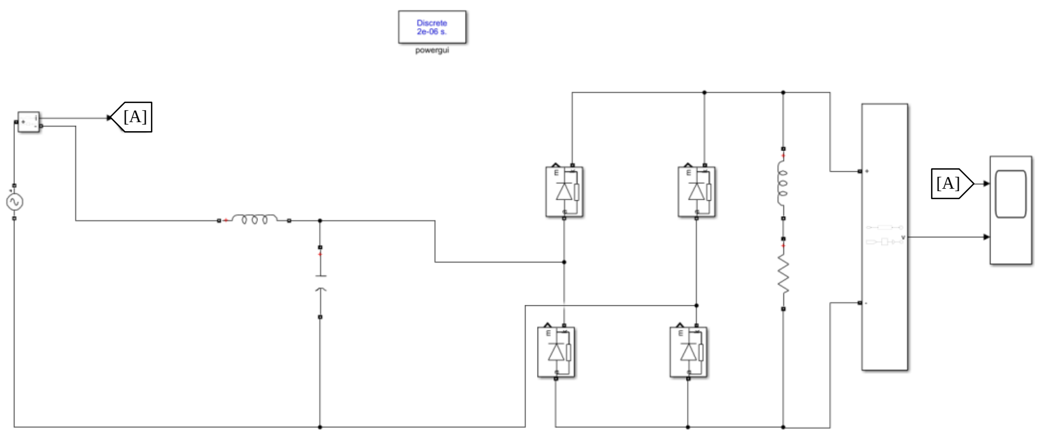


Figure 3. Glugur substation rectifier circuit model after LC filter installation using MATLAB/Simulink

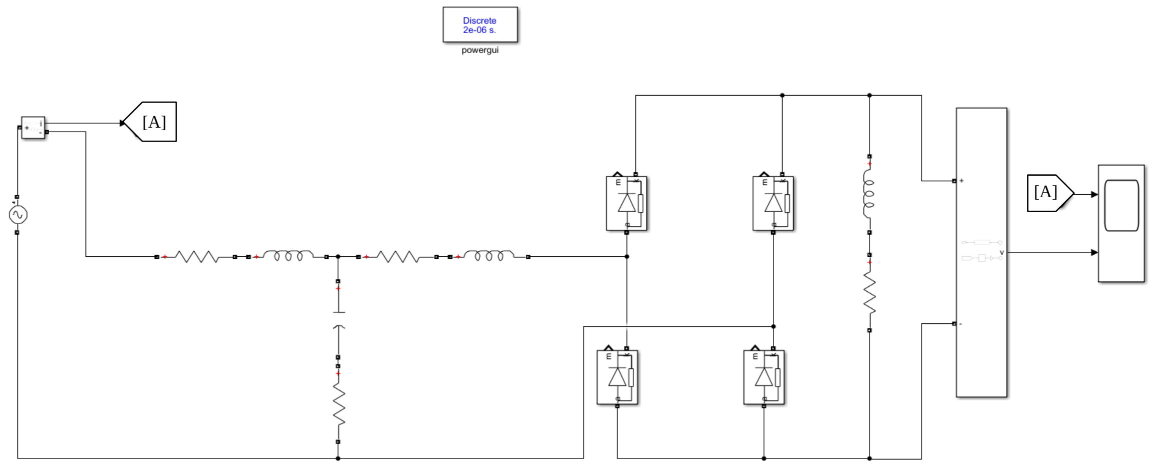


Figure 4. Glugur main substation rectifier circuit model after installing the LCL filter was designed by T_a using MATLAB/Simulink

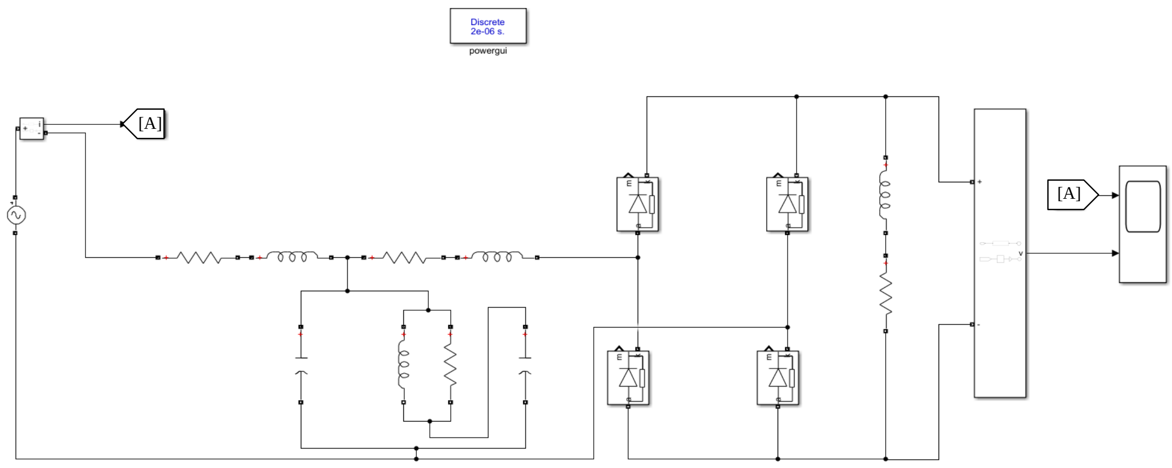


Figure 5. Glugur main substation rectifier circuit model after installing the LCL filter was designed by T_c using MATLAB/Simulink

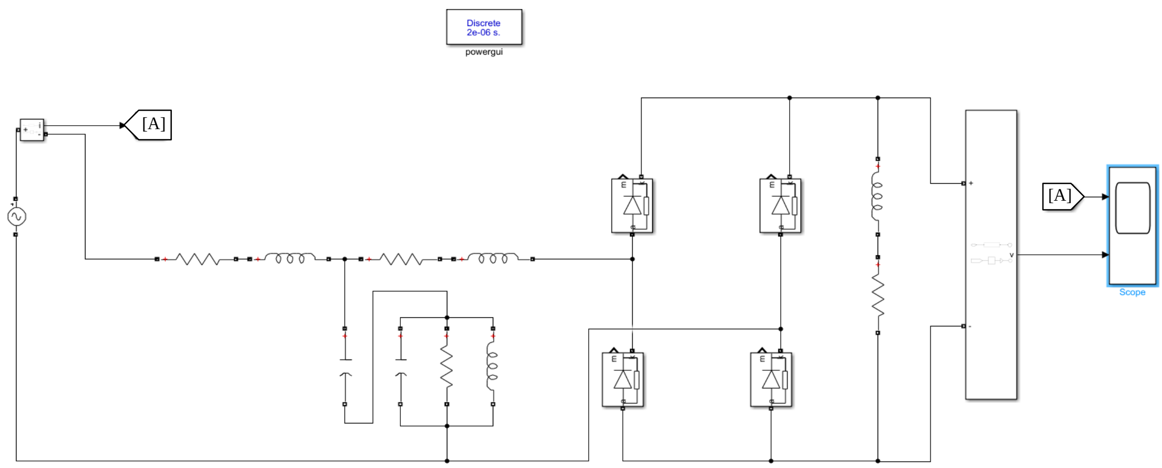


Figure 6. Glugur main substation rectifier circuit model after installing the LCL filter was designed by T_d using MATLAB/Simulink

Table 1. Limitations on voltage distortion in IEEE STD 519-2014

Bus voltage V at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1.0\ kV$	5.0	8.0
$1.0\ kV < V \leq 69\ kV$	3.0	5.0
$69\ kV < V \leq 161\ kV$	1.5	2.5
$< 161\ kV$	1.0	1.5

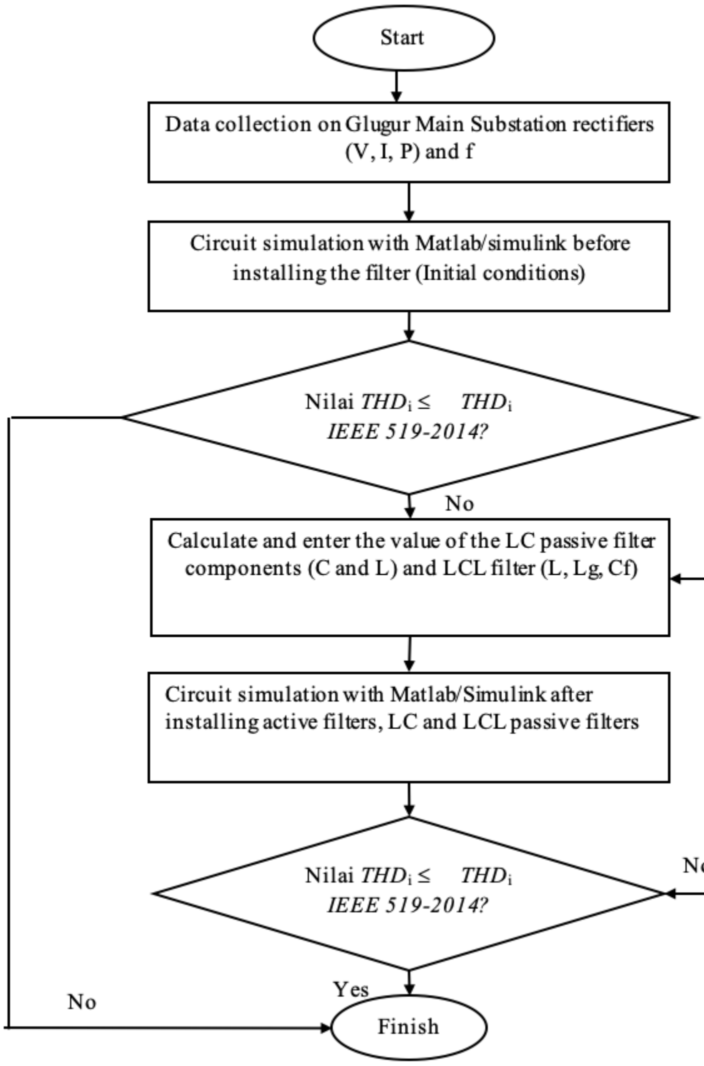
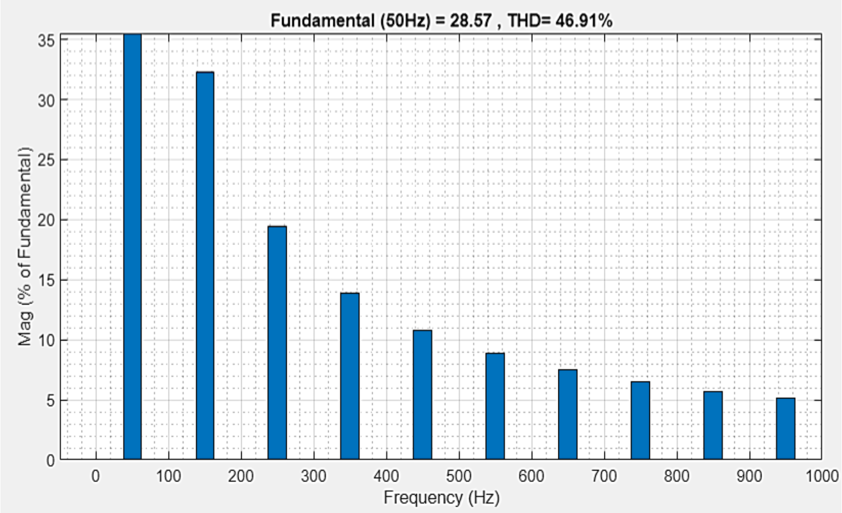


Figure 7. Flow diagram for installing active filters, passive LC filters, and LCL filters at the Glugur substation rectifier

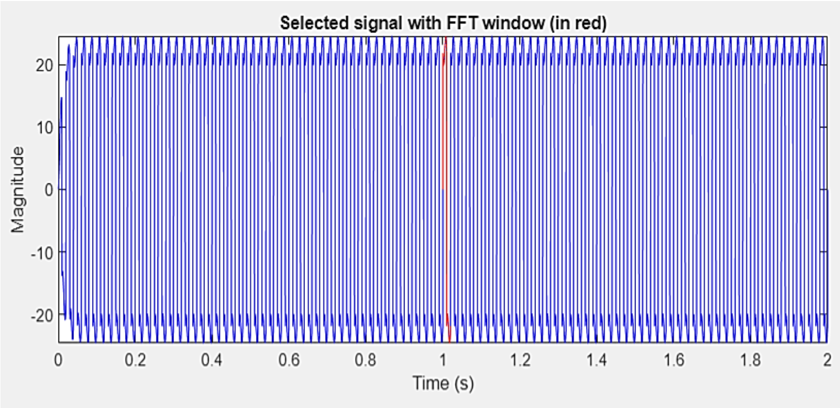
3. RESULTS AND DISCUSSION

3.1. Before filter installation (initial conditions)

Before carrying out the simulation, it is necessary to know the values for each component, such as the input voltage (Vs) value of 125.4 Volts, the current of 5.8 Amperes, the load output power (P_{out}) of 727.32 Watts, and the input frequency of 50 Hz. By entering the simulation data, Figure 8 shows the harmonic spectrum obtained before installing the active, passive LC, and LC filters in Figure 8(a) and current waves in Figure 8(b). Meanwhile, simulation results for the Glugur main substation rectifier before filter installation can be seen in Table 2. Table 2 shows that the value of the harmonic current produced by the rectifier at the Glugur substation before installing the filter does not meet the IEEE 519-2014 standard in odd order. Still, there are no harmonics in even order. So, it is necessary to install a harmonic filter to reduce odd-order harmonics.



(a)



(b)

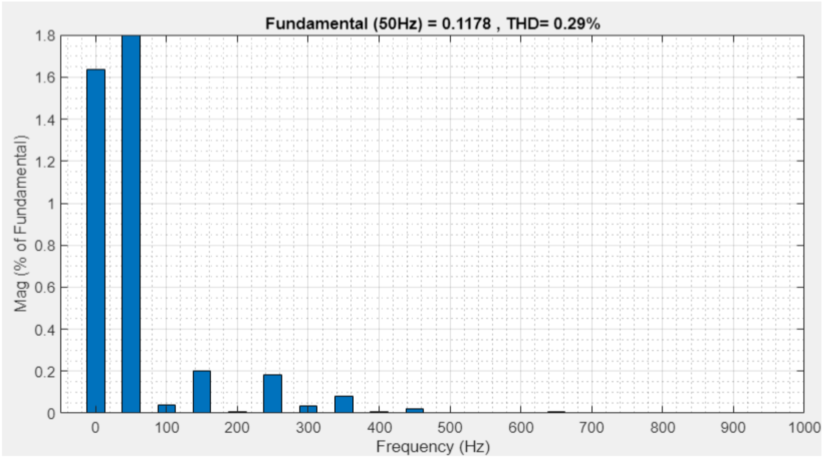
Figure 8. Current harmonic spectrum before (a) filter installation and (b) current waveform

Table 2. Harmonic currents before installing filters on the rectifiers at the Glugur substation

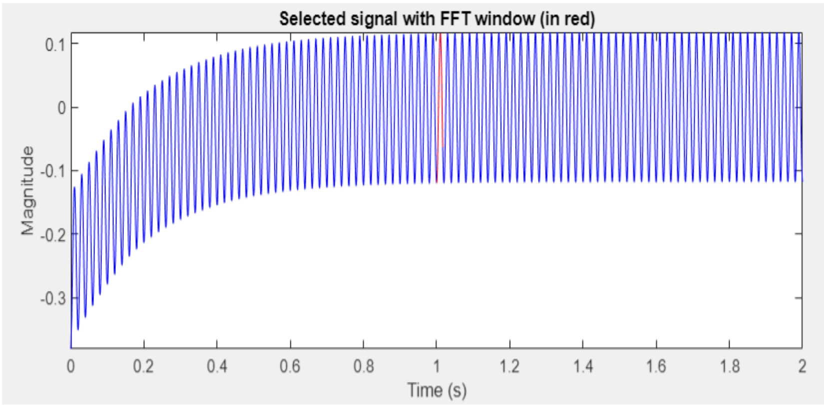
		Harmonics before installing the filter	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		46.91%	5.0%
Individual harmonic input current	Is2	0.00%	4.0%
	Is3	32.29%	4.0%
	Is4	0.00%	4.0%
	Is5	19.44%	4.0%
	Is6	0.00%	4.0%
	Is7	13.90%	4.0%
	Is8	0.00%	4.0%
	Is9	10.82%	4.0%
	Is10	0.00%	4.0%
	Is11	8.85%	2.0%

3.2. After installation of active filter

Figure 9 shows the order spectrum of the MATLAB/Simulink simulation results after installing the active filter on the rectifier at the Glugur substation in Figure 9(a) and the current waveform in Figure 9(b). Meanwhile, simulation results for the Glugur main substation rectifier after installing the active filter can be seen in Table 3. Table 3 shows that the active filter installation follows the IEEE 519-2014 standard. The value of current harmonics in even order has increased, but this can still be tolerated by the IEEE 519-2014 standard, and the value of current harmonics in odd order has decreased to below the IEEE 519-2014 standard. Table 3 shows that the active filter installation follows the IEEE 519-2014 standard. The value of current harmonics in even order has increased, but this can still be tolerated by the IEEE 519-2014 standard, and the value of current harmonics in odd order has decreased to below the IEEE 519-2014 standard.



(a)



(b)

Figure 9. Current harmonic spectrum after (a) filter installation and (b) current waveform

Table 3. Harmonic currents after installing filters on the rectifiers at the Glugur substation

		Harmonics after active filter installation	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		0.29%	5.0%
Individual harmonic input current	Is2	0.04%	4.0%
	Is3	0.20%	4.0%
	Is4	0.00%	4.0%
	Is5	0.18%	4.0%
	Is6	0.03%	4.0%
	Is7	0.08%	4.0%
	Is8	0.01%	4.0%
	Is9	0.02%	4.0%
	Is10	0.00%	4.0%
	Is11	0.00%	2.0%

3.3. Calculation of LC passive filter values

The filter component value must be calculated to reduce harmonics and get the right results. In an LC filter, two components must be calculated: the inductance value (L) and the filter capacitance value (C). The input voltage value (Vs) is 125.4 Volts, the current is 5.8 Amperes, the load output power (Pout) is 727.32 Watts, and the input frequency is 50 Hz. Once the parameter values are known, you can determine the C value using (1) to (3), and the L value using (4) to (8).

$$Q_C = P\{\tan(cos^{-1}pf1) - \tan(cos^{-1}pf2)\}$$
$$Q_C = 727.32\ \{\tan(cos^{-1}0.85) - \tan(cos^{-1}0.95)\}$$
$$Q_C = 727.32\ \{\tan(31.79) - \tan(18.19)\}$$
$$Q_C = 727.32\ (0.62 - 0.33)$$
$$Q_C = 727.32\ (0.29) \quad (1)$$
$$Q_C = 210.92\ VAR$$

$$X_C = \frac{V^2}{Q_C} = \frac{(125.4)^2}{210.92} = 74.56\ \Omega \quad (2)$$

$$C = \frac{1}{2\pi f_0 X_C} = \frac{1}{2\times3.14\times50\times74.56} = 4.27\times10^{-5}\ F \quad (3)$$

From these calculations, it is found that the value of the capacitor used in the LC filter is $4.27\times10^{-5}\ F$.

$$Z = \frac{V_S}{I} = \frac{125.4}{5.8} = 21.62\ \Omega \quad (4)$$

$$X_L = \frac{X_C}{h^2 n} = \frac{74.56}{3^2} = 8.28\ \Omega \quad (5)$$

$$X_n = h_n X_L = 3\times5.28 = 24.84\ \Omega\text{c.} \quad (6)$$

$$R = \frac{X_n}{Q} = \frac{28.84}{100} = 0.248\ \Omega \quad (7)$$

$$L = \frac{\sqrt{Z^2+R^2}}{2\pi f_0} = \frac{\sqrt{(21.62)^2+(0.248)^2}}{2\times3.14\times50} = \frac{21.62}{314} = 6.89\times10^{-2}\ H \quad (8)$$

So, the value of L used in the LC filter is $6.89\times10^{-2}\ H$.

3.4. Calculation of LCL passive filter values

Three components must be calculated in the LCL filter: the converter side inductance value (L), the network side inductance value (Lg), and the filter capacitance value (Cf). The input voltage (Vs) is 125.4 Volts, the current is 5.8 Amperes, the load output power (Pout) is 727.32 Watts, and the input frequency is 50 Hz. After the basic parameters are determined, the next step is to calculate the base impedance (Zb), base inductance (Lb), and base capacitance (Cb).

$$Z_b = \frac{Vs^2}{P_n} = \frac{125.4^2}{727.32} = 21.62\ \Omega \quad (9)$$

$$L_b = \frac{Z_b}{\omega_n} = \frac{21.62}{2\times\pi\times50} = 0.069\ \text{H} \quad (10)$$

$$C_b = \frac{1}{\omega_n . Z_b} = \frac{1}{2\times\pi\times50\times21.62} = 1.47\times10^{-4}\ \text{F} \quad (11)$$

LCL filter parameters can be calculated as follows:
The *x* value is chosen to be 2% of the reactive power absorbed under average conditions.

$$C_f = x.C_b = 0.02\times1.47\times10^{-4} = 0.029\times10^{-4}\ \text{F} \quad (12)$$

Calculate the converter side inductance (L) with a ripple current of 1%

$$0.01 \approx \frac{1}{2\times\pi\times50\times\text{L}} \Rightarrow \text{L} \approx \frac{1}{3.14} \approx 0.318\ \text{H} \quad (13)$$

Select a ripe current attenuation of 20%. After knowing the value of *x*, calculate the ripple current reduction. Ripple attenuation is calculated to determine the *r* index.

$$\frac{\text{i}_\text{g}(\text{h}_\text{sw})}{\text{v}(\text{h}_\text{sw})} = \frac{1}{|1+\text{r}(1-\text{a.x})|} \quad (14)$$

$$a = LC_b\omega_{sw}^2 = 0.318 \times 1.47 \times 10^{-4} \times (2 \times \pi \times 50)^2 = 4.61$$
$$0.2 = \frac{1}{|1+r(1-4.61\times0.02)|} = \frac{1}{|1+r(0.91)|}$$
$$0.2 + r(0.182) = 1 \quad \Rightarrow \quad r = \frac{1-0.2}{0.182} = 4.396 \tag{15}$$

After knowing the converter side inductance (L), then calculate the network side inductance (Lg) with the index *r*, the relationship between the two inductances:

$$L_g = r\,.\,L = 4.396 \times 0.318 = 1.398\ H \tag{16}$$

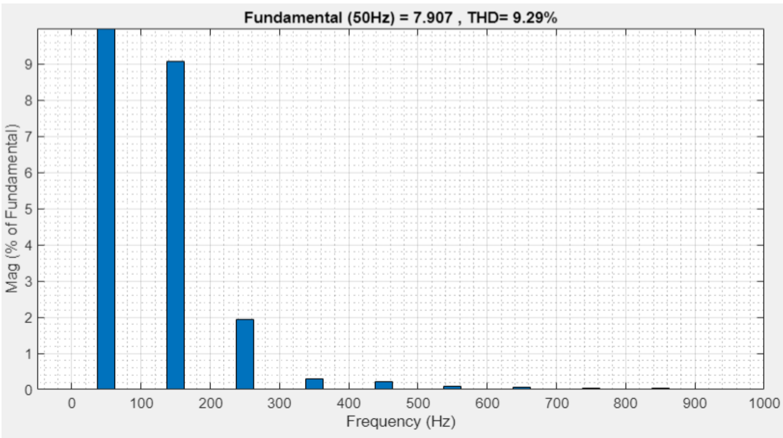
When the value of the LCL filter component is known, the resonance frequency must be calculated before testing.

$$\omega_{res} = \sqrt{\frac{0.318+1.398}{0.318\times1.398\times0.29\ x\ 10^{-5}}} = 1153.36 \tag{17}$$

$$f_{res} = \frac{\omega_{res}}{2\pi} = \frac{1153.36}{2\times\pi} = 183.66\ Hz \tag{18}$$

3.5. Simulation after installation of LC passive filter

Figure 10 shows the order spectrum of the MATLAB/Simulink simulation results after installing the LC passive filter on the rectifier at the Glugur substation in Figure 10(a) and the current waveform in Figure 10(b). Meanwhile, simulation results for the Glugur substation rectifier after installing the LC passive filter can be seen in Table 4. Table 4 is the simulation results after installing the LC passive filter on the Glugur substation rectifier with C of $4.27 \times 10^{-5}\ F$ and L of $6.89 \times 10^{-2}\ H$. In this table it can be seen that the 3rd order THDi and IHDi after installing the LC passive filter are not in accordance with the IEEE 519-standard. 2014. But the 4th order IHDi and beyond comply with the IEEE 519-2014 standard.



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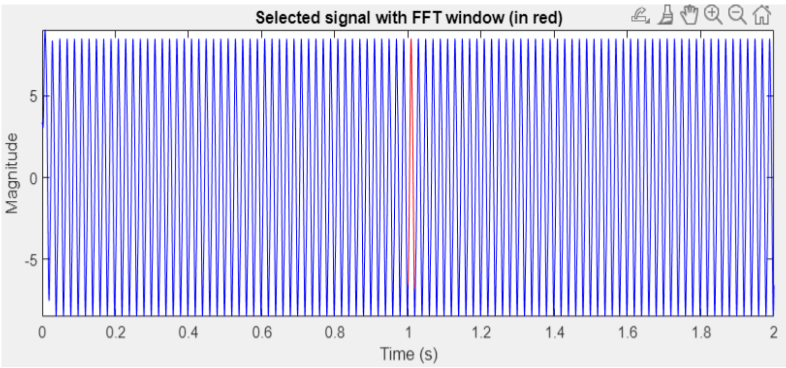


(b)

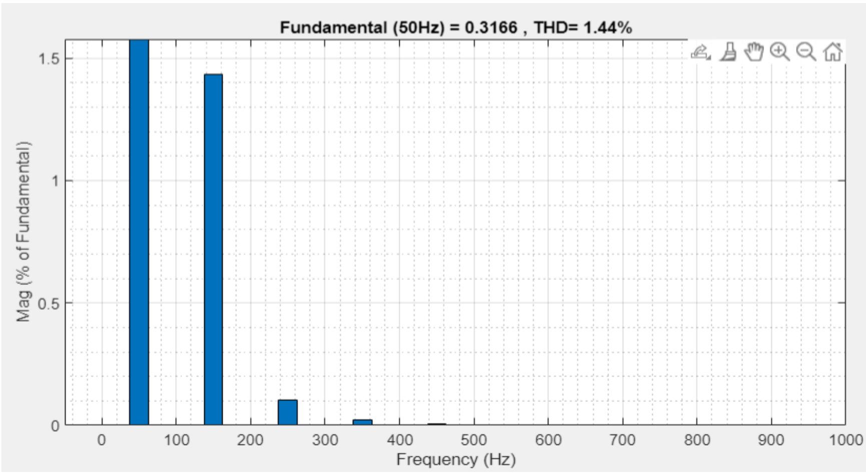
Figure 10. Current harmonic spectrum (a) after installation of LC passive filter and (b) current waveform

Table 4. Harmonic current data after installing the LC passive filter

		Harmonics after LC filter installation	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		9.29%	5.0%
Individual harmonic input current	Is2	0.00%	4.0%
	Is3	9.08%	4.0%
	Is4	0.00%	4.0%
	Is5	1.95%	4.0%
	Is6	0.00%	4.0%
	Is7	0.29%	4.0%
	Is8	0.00%	4.0%
	Is9	0.22%	4.0%
	Is10	0.00%	4.0%
	Is11	0.08%	2.0%

3.6. Simulation after installation of LCL passive filter (design by T_a)

Figure 11 shows the order spectrum of the MATLAB/Simulink simulation results after installing the T_a design LCL passive filter on the Glugur substation rectifier in Figure 11(a) and the current waveform in Figure 11(b). Meanwhile, Table 5 shows simulation results for the Glugur substation rectifier after installation of the Ta design LCL passive filter. Table 5 is the simulation result after installing an LCL filter of T_a design on the Glugur substation rectifier with network side inductance (Lg) 1,398 H, converter side inductance (L) 0.318 H, filter capacitance (Cf) $0.029 \times 10^{-4}\ F$, and Rd 4.396 Ω. The table shows that THDi and IHDi comply with the IEEE 519-2014 standard.



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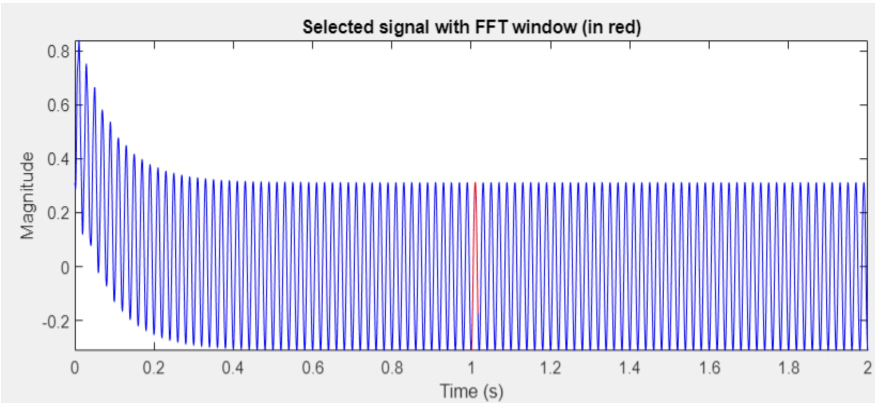


(b)

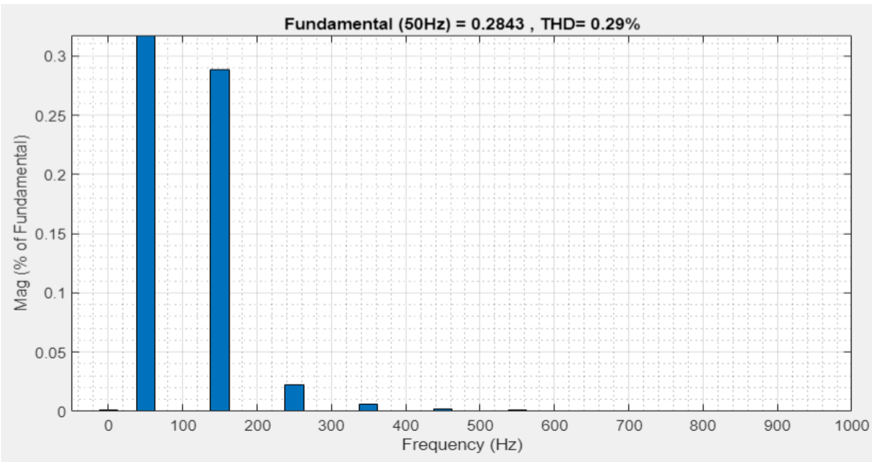
Figure 11. Current harmonic spectrum (a) after installation of LCL passive filter T_a design and (b) current waveform

Table 5. Harmonic current data after installing a T_a design LCL passive filter

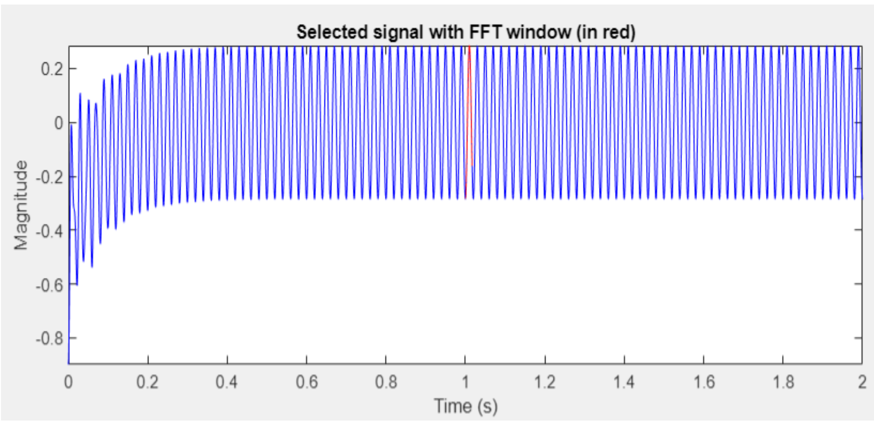
		Harmonics after installation of LCL filter T_a	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		1.44%	5.0%
Individual harmonic input current	Is2	0.00%	4.0%
	Is3	1.43%	4.0%
	Is4	0.00%	4.0%
	Is5	0.10%	4.0%
	Is6	0.00%	4.0%
	Is7	0.02%	4.0%
	Is8	0.00%	4.0%
	Is9	0.01%	4.0%
	Is10	0.00%	4.0%
	Is11	0.00%	2.0%

3.7. Simulation after installation of LCL passive filter (Design by T_c)

Figure 12 shows the order spectrum of the MATLAB/Simulink simulation results after installing the T_c design LCL passive filter on the Glugur substation rectifier in Figure 12(a) and the current waveform in Figure 12(b). Meanwhile, Table 6 shows simulation results for the Glugur substation rectifier after installation of the T_c design LCL passive filter. Table 6 is the simulation result after installing an LCL filter of T_c design on the Glugur substation rectifier with network side inductance (Lg) 1.398 H, converter side inductance (L) 0.318 H, filter capacitance (Cf) $0.029 \times 10^{-4}\ F$, Rd 4.396 Ω and Cd 0.0998 F, Ld 0.98 H. In the Table 5, it can be seen that THDi and IHDi are by IEEE 519-2014 standards.



(a)



(b)

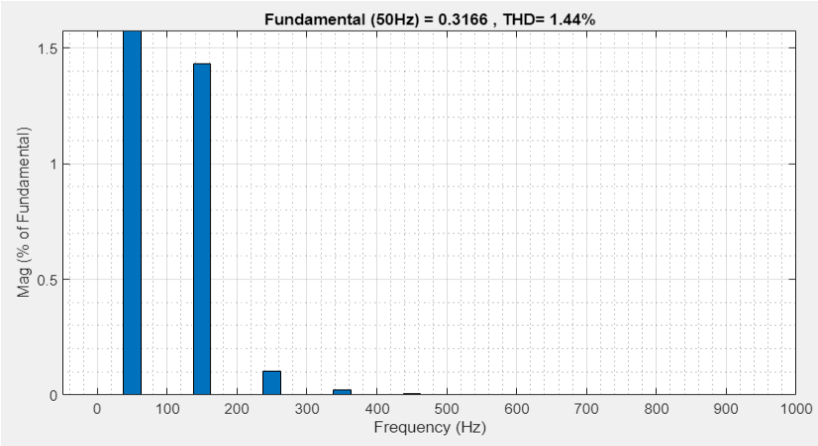
Figure 12. Current harmonic spectrum (a) after LCL passive filter design installation T_c, (b) current waveform

Table 6. Harmonic current data after installation of the T_c design LCL passive filter

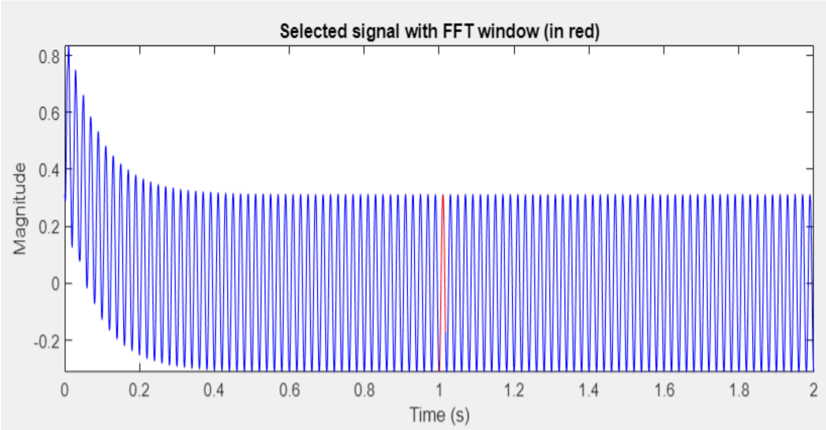
		Harmonics after installation of the LCL T_c filter	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		0.29%	5.0%
Individual harmonic input current	Is2	0.00%	4.0%
	Is3	0.29%	4.0%
	Is4	0.00%	4.0%
	Is5	0.02%	4.0%
	Is6	0.00%	4.0%
	Is7	0.01%	4.0%
	Is8	0.00%	4.0%
	Is9	0.00%	4.0%
	Is10	0.00%	4.0%
	Is11	0.00%	2.0%

3.8. Simulation after installation of LCL passive filter (Design by T_d)

Figure 13 shows the order spectrum of the MATLAB/Simulink simulation results after installing the T_d design LCL passive filter on the Glugur substation rectifier in Figure 13(a) and the current waveform in Figure 13(b). Meanwhile, Table 7 shows simulation results for the Glugur substation rectifier after installation of the T_d design LCL passive filter. Table 7 is the simulation result after installing a T_d design LCL passive filter on the Glugur substation rectifier with network side inductance (Lg) 1.398 H, converter side inductance (L) 0.318 H, filter capacitance (Cf) $0.029 \times 10^{-4}\,F$, Rd 4.396 Ω and Cd 0.0998 F, Ld 0.98 H. The table shows that THDi and IHDi are in accordance with the IEEE 519-2014 standard.



(a)



(b)

Figure 13. Current harmonic spectrum (a) after LCL passive filter design installation T_d and (b) current waveform

Table 7. Harmonic current data after installing a T_d design LCL passive filter

		Harmonics after installation of the T_d LCL filter	Maximum harmonic current permitted
Input voltage (Vs)		125.4 V	
Fundamental current (Is1)		5.8 A	
THDi input		1.44%	5.0%
Individual harmonic input current	Is2	0.00%	4.0%
	Is3	1.43%	4.0%
	Is4	0.00%	4.0%
	Is5	0.10%	4.0%
	Is6	0.00%	4.0%
	Is7	0.02%	4.0%
	Is8	0.00%	4.0%
	Is9	0.01%	4.0%
	Is10	0.00%	4.0%
	Is11	0.00%	2.0%

3.9. Discussion

Simulation results on the Glugur main substation rectifier before filter installation can be seen in Table 1. The harmonic current results exceed the IEEE 519-2014 standard in each harmonic order and total current harmonic distortion. To reduce harmonic currents, it is necessary to install a harmonic filter to comply with the IEEE 519-2014 standard in Table 3. In this research, active filters, LC, and LCL passive filters (Ta, Tc, and Td designs) were used separately to reduce the harmonics generated by the Glugur substation rectifier.

Installation of an active filter can reduce harmonics so that the THDi and IHDi values are below the IEEE-2014 standard. The use of this filter can reduce THDi by 46.62%. However, even if there is an increase, the IEEE 519-2014 standard can still tolerate it. When installing a passive LC filter, THDi before filter installation can be reduced from 46.91% to 9.29%. Using an LC filter cannot reduce THDi according to IEEE 519-2014 standards, but this filter can reduce THDi by 37.62%. Then, the results after installing the T_a design LCL passive filter can be successfully reduced to comply with the IEEE 519-2014 standard. Where THDi can be reduced by 45.47%. Installation of this filter also succeeded in reducing harmonics in all orders so that it complies with the IEEE 519-2014 standard. With the installation of the LCL passive filter, the Tc design proves to be a successful solution. It effectively reduces harmonics, bringing them into compliance with the IEEE 519-2014 standard. The THDi is notably reduced by 46.62%, demonstrating the filter's ability to meet the established standards. Finally, the installation of the Td design LCL passive filter proves to be a successful solution. It effectively reduces THDi and IHDi, bringing them into compliance with the IEEE 519-2014 standards. The THDi is reduced by 45.48%, demonstrating the overall effectiveness of the filters in reducing harmonics. Our research results follow previous research and the standards of IEEE 519-2014 [23], [25]–[27].

The comparison graph of THDi and IHDi before and after installing the active filter, passive filter LC, and LCL (separately) can be seen in Figures 14 and 15, respectively. Figure 14 shows that a passive LC filter has not been able to reduce THDi per the IEEE 519-2014. Meanwhile, Figure 15 shows that the best filter for reducing IHDi is a passive filter of T_c design, and the LC passive filter has not succeeded in reducing 3rd-order harmonics to below IEEE 519-2014 standards.

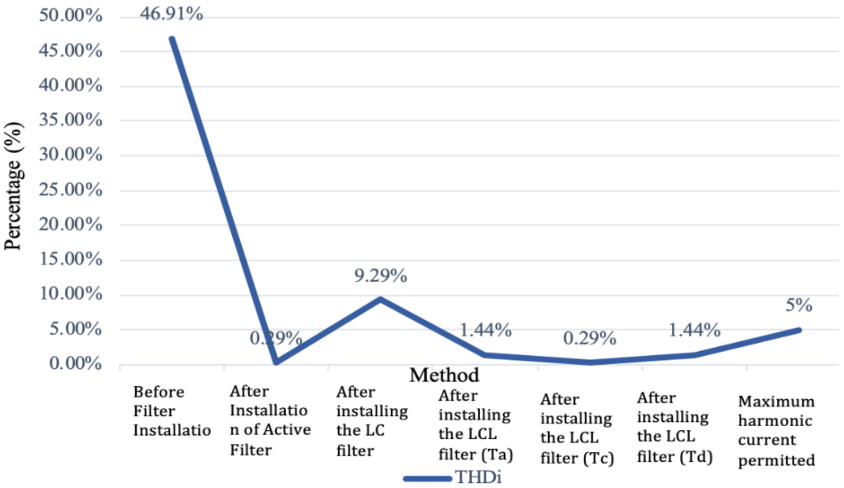


Figure 14. Comparison graph of total harmonic distortion current (THDi)

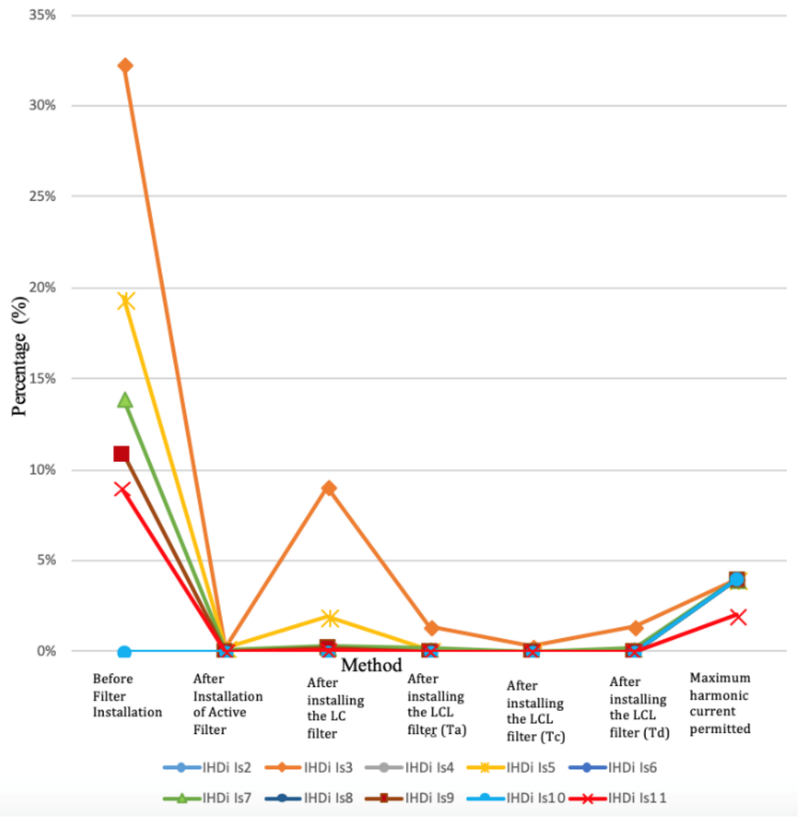


Figure 15. Comparison chart of individual harmonic distortion current (IHDi)

4. CONCLUSION

This research conducted several methods to reduce harmonics, such as the active filter method, passive LC filter, and LCL filter (using T_a, T_c, and T_d design) at the Glugur substation, Medan, North Sumatra, Indonesia. Based on the research results that have been explained, conclusions are obtained, such as that installing a passive LC filter has not been able to reduce THDi, and some IHDi, according to the IEEE 519-2014 standard, have succeeded in reducing THDi by 37.62%. Further, installing active and LCL passive filters of T_a, T_c, and T_d designs reduced THDi to 0.29%, 1.44%, 0.29%, and 1.44%, and all IHDi comply with IEEE 519-2014 standards. Meanwhile, using active and LCL passive filters of T_c design is the best type of filter with a THDi reduction of 46.62% at the Glugur Main Substation. The suggestions for developing this research in future work are reducing low-order harmonics based on negative order capacitor (NOC) and designing and building a resonance detector and controller. The secondary power will connect only the NOC circuit and the inverter's AC side. The NOC circuit can also be enlarged to suppress harmonic current at other frequencies in the system because it can modify zero impedance to particular harmonics. It expands on the idea of a fractional capacitor and uses it in situations where power is disconnected: From conventional positive integer fields, the impedance of a capacitor could be extended to all real number fields. It might be possible to combine inductive and capacitive reactance to address. Meanwhile, the NOC operates in parallel on the DC bus with minimal impact on the output side. The power supply's longevity and stability are significantly increased because the pulsating power is only connected between the AC output side and the NOC branch.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

INFORMED CONSENT

We have obtained informed consent from all individuals included in this study.

DATA AVAILABILITY

Derived data supporting the findings of this study are available from the corresponding author YS on request.

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