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Simulation of Harmonic Mitigation in the Crusher System: A study at A Coal Company in Borneo

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Abstract
In the coal mining industry environment of PT. Baramulti Suksessarana Tbk (BSSR), the issue of electrical energy quality receives special attention, particularly due to the use of non-linear equipment such as induction motors which trigger harmonics. These harmonics impact operational efficiency and affect equipment. This study aims to address this issue by designing a Single tuned passive harmonic filter, following IEEE standards, to handle the increase in Total Harmonic Distortion (THD) of current and voltage. From the initial analysis, the system's THD was recorded at 20.04%, indicating significant harmonic disturbances. With a specific harmonic filter design, including capacitor values, inductive reactance (XL), and resistors, this study successfully reduced the THD to 5.55%, demonstrating the effectiveness of the filter in reducing the negative impact of harmonics. The conclusion of this study highlights the importance of implementing passive harmonic filters in improving the quality of electric power in industrial environments, especially in the BSSR coal mine. This research provides essential guidance for practitioners in designing harmonic filters and contributes to improving the quality of electric power in the coal mining industry.
Keywords: *industrial mining harmonics, single tuned passive filter, Total Harmonic Distortion (THD), IEEE Standards*

Abstrak
Di lingkungan industri tambang batu bara PT. Baramulti Suksessarana Tbk (BSSR), permasalahan kualitas energi listrik menjadi perhatian khusus, terutama akibat penggunaan peralatan non-linier seperti motor induksi yang memicu harmonisa. Dimana harmonisa ini akan berdampak pada penurunan efisiensi operasional dan memberikan dampak pada peralatan. Penelitian ini bertujuan mengatasi isu tersebut dengan merancang *Filter Harmonisa Pasif Single Tuned*, mengikuti standar IEEE, untuk menangani peningkatan Total Harmonic Distortion (THD) arus dan tegangan. Dari analisis awal, THD di sistem tercatat sebesar 20,04%, menandakan adanya gangguan harmonisa yang signifikan. Dengan desain filter harmonisa yang spesifik, termasuk nilai kapasitor, reaktansi induktif (XL), dan resistor, penelitian ini berhasil menurunkan THD menjadi 5,55%, menunjukkan efektivitas filter dalam mengurangi dampak negatif harmonisa. Kesimpulan dari penelitian ini menunjukkan pentingnya penerapan filter harmonisa pasif dalam memperbaiki kualitas daya listrik di lingkungan industri, khususnya di tambang batu bara BSSR. Penelitian ini memberikan panduan penting bagi praktisi dalam mendesain filter harmonisa dan berkontribusi pada peningkatan kualitas daya listrik di sektor industri pertambangan batu bara.
Kata Kunci: *harmonisa industri tambang, filter pasif singel tuned, Total Harmonic Distortion (THD), Standar IEEE*

1. Introduction

The electrical power system is a system consisting of various components, such as generation, transmission, distribution, and loads, which are interconnected and operate simultaneously to provide electrical energy for human needs. One of the factors that affect the performance and quality of the power system is harmonics [1]. Harmonics are sinusoidal wave components with frequencies that are multiples of the fundamental frequency (50 Hz or 60 Hz) found in the voltage or current of the power system. Harmonics can be caused by various sources, such as nonlinear loads (e.g., induction motors, AC-DC converters, fluorescent lamps, computers, etc.), and transient stability [2]. Harmonics can cause various negative impacts on the power system, such as decreased efficiency and lifespan of system components, increased power losses and voltage drops, disturbances in protection and measurement systems, as well as electromagnetic interference [3].

One way to reduce or eliminate harmonics in the power system is by using harmonic filters. Harmonic filters are devices that can absorb or block harmonics, preventing them from entering the system [5]. Passive harmonic filters are filters that utilize passive elements R, L, C (resistor, inductor, capacitor) to form a resonant circuit that has low impedance at specific frequencies, thus attracting harmonic currents or voltages into it [4].

One vital aspect in coal mine operations is the crusher system. Crushers play a crucial role in processing coal, reducing it to smaller sizes for transportation and further processing. The performance of crushers directly impacts the efficiency of coal production, which is critical for achieving company targets. However, the use of induction motors in crushers can generate harmonics, especially due to the use of Variable Speed Drive (VSD) to control motor speed. VSD are essential for adjusting crusher speed during operation and maintenance, but they also increase harmonics, potentially damaging power quality and equipment efficiency. Simulation studies using ETAP software are necessary to analyze the impact of harmonics and design suitable passive harmonic filters for the power system at coal mining companies in East Kalimantan.

2. Literature Review

2.1 Power Factor Improvement

Several devices can be added to address low power factor, such as synchronous generators, syn-chronous condensers, synchronous motors, and capacitors. Among all these options, capacitors are the most cost-effective. To determine the required capacitor size, we need to calculate the reactive power that needs to be compensated. Then, we must determine the appropriate capacitor based on the phase capacitor relationship, as per the formula in equation 1.

$$Q_C = P\,(tan\,\varphi_1 - tan\,\varphi_2) \tag{1}$$

2.2 Harmonics

Harmonics are defined as sinusoidal waveform distortions that occur due to the interaction between pure sinusoidal waveforms and distorted waveforms from their fundamental frequency. The fundamental frequency of a power system is 50 Hz (in Indonesia), so the second harmonic is a waveform with a frequency of 100 Hz, the third harmonic is a waveform with a frequency of 150 Hz, and so on. These waveforms ride on the original waveform, forming a distorted waveform that is a combination of the original waveform with its harmonic waveforms [5], as shown in **Figure 1** below.

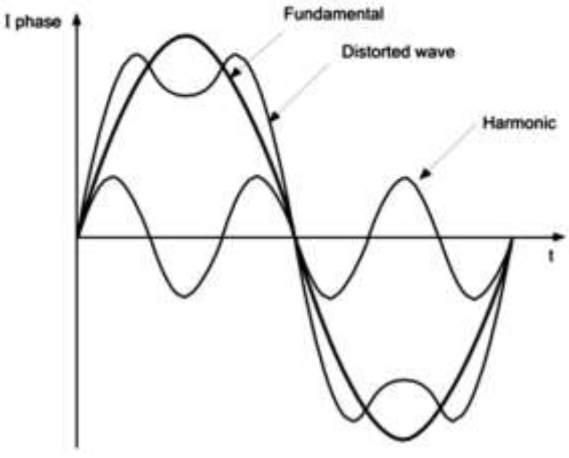

Fig. 1 : The distorted waveform
Source: Elvinda J.R (2015)

The third harmonic can be defined as 3 waveform periods formed when its fundamental waveform is still ongoing within one period. The fifth harmonic is also formed into 5 waveform periods with smaller amplitudes while the fundamental waveform is still ongoing within one period. This can be seen in **Figure 2** below.

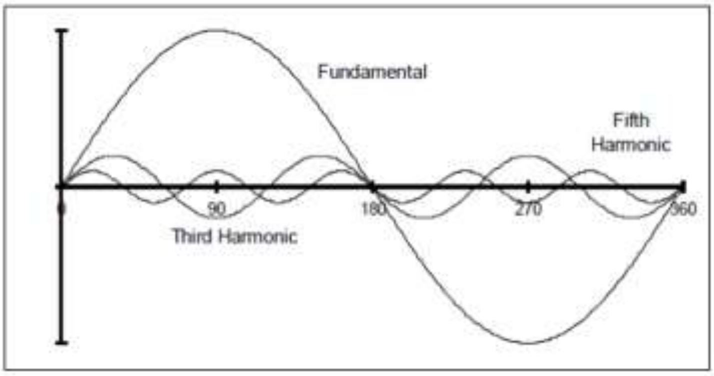

Fig. 2: Fundamental, third, and fifth harmonics
Source: Abraham Olatoke (2021)

Harmonics in the power system can be illustrated through a simple electrical circuit model, as depicted in **Figure 2**. This scheme represents a Thevenin model used to analyze AC power system networks.

2.3 Total Harmonic Distortion

Total Harmonic Distortion (THD) is the most commonly used metric to assess the quality of electrical power. For voltage distortion factor, the total harmonic distortion can be represented as:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \quad (2)$$

Where h is the harmonic order (h = 1 responds to the fundamental voltage), Vn is the rms harmonic voltage at the hth harmonic order, and V1 is the reference voltage at the fundamental frequency in rms. Similarly, for the current distortion factor, the total harmonic distortion can be expressed as:

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \quad (3)$$

Where Ih is the rms harmonic current at the hth harmonic order and I1 is the reference current at the fundamental frequency in rms. There are two criteria used to measure harmonic distortion: THD_I and THD_V. The current harmonic limit is regulated by the ratio I_{SC}/I_L. I_{SC} represents the short-circuit current that occurs at the Point of Common Coupling (PCC), while IL represents the nominal base load current. Conversely, the voltage harmonic limit is determined by the magnitude of the voltage of the system used or installed.

2.4 Total Demand Distortion

Regarding the nonlinear relationship between harmonic components and the percentage of THD, the definition of current THD can lead to confusion in harmonic studies. For instance, a small current may have a high THD value but may not pose a problem to the system. Consequently, different harmonic indices are more frequently used to assess harmonic currents, such as Total Demand Distortion (TDD). This index is defined as follows:

$$TDD = \frac{\sqrt{\sum_{h=2}^{n} I_h^2}}{I_L} \quad (4)$$

Where IL represents the maximum demand load current at the fundamental frequency at the Point of Common Coupling (PCC), and n refers to the total number of harmonics present. Additionally, the PCC is the location where other utility customers besides the object under study can also receive service from the system. **Figure 3** illustrates the concept of the PCC.

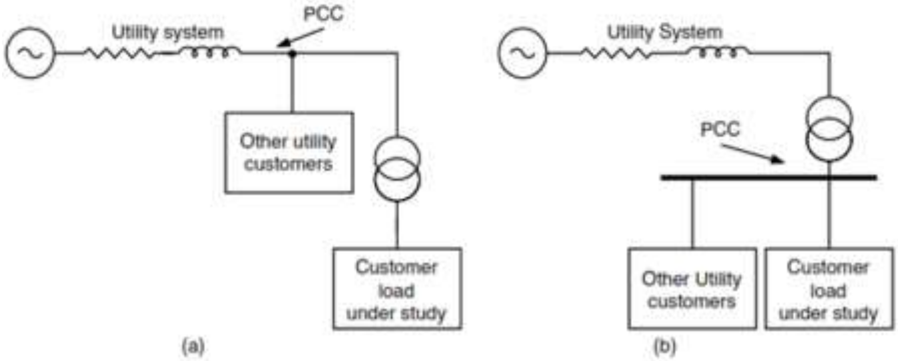

Fig. 3: Selection of PCC
Source: Yuge Wang (2020)

2.5 Harmonic Distortion Limits

When focusing research on harmonics in power distribution systems with primary distribution voltage ranging from 2.4kV to 33kV, we can determine the harmonic distortion limits within this range. In the UK, we typically use 33kV. According to the guidelines in IEEE Std. 519 [9], For systems below 69kV, it is recommended that the voltage THD does not exceed 5% of the fundamental frequency. On the other hand, harmonic current distortion is limited using TDD, as explained in **Table 1**. In this table, the new parameter Isc represents the short-circuit current at the PCC, and Isc=I_L is the actual short-circuit ratio. To comply with standards, utility companies need to understand the level of harmonic distortion in the power distribution system to take appropriate measures. Therefore, harmonic analysis is crucial for utility companies.

Table 1. IEEE 519-1992 Standard Current Harmonic Tolerance Limit

	Harmonic Order (Odd) in %					(TDD)
I_{sc}/I_L	h<11	11≤h<17	17≤h<23	23≤h<35	35≤h<50	
<20	4	2	1.5	0.6	0.3	5
20-50	7	3.5	2.5	1	0.5	8
50-100	10	4.5	4	1.5	0.7	12
100-1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1.4	20

Table 2. IEEE 519-1992 Standard Voltage Total Harmonic Distortion (THD) Tolerance Limit

Voltage Bus PCC	IHDv (%)	THDv (%)
V≤1 kV	5	8
1 kV<V≤69 kV	3	5
69 kV<V≤161 kV	1.5	2.5
161 kV<V	1	1.5

2.6 Passive Single Tuned Filter

Harmonic filters are categorized into two types, namely active filters and passive filters. Active filters consist of power electronic components such as Insulated Gate Bipolar Junction Transistors (IGBTs) or Metal Oxide Field Effect Transistors (MOSFETs). The response of active filters to harmonic currents is generally not influenced by system variables such as impedance. Active filters can be installed in systems either in series or parallel. On the other hand, passive filters consist of a combination of R, L, and C components. Passive filters are classified into four types based on their characteristics: low pass, high pass, band pass, and tuned filters. Like active filters, passive filters can also be configured in series or parallel within a system [10].

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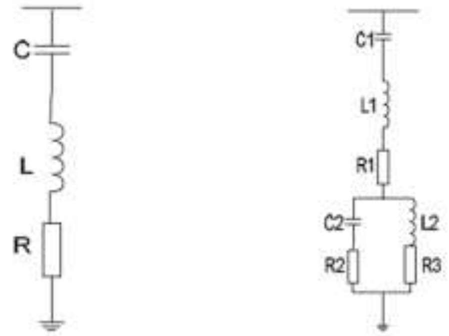

Fig. 4: Topology of tuned filter a. Single Tuned Filters dan b. Double Tuned Filters
Source: Yuge Wang (2020)

Passive filters are used in the electrical industry to reduce the amplitude of specific frequencies that arise due to current and voltage distortion. These filters consist of main components: capacitors, inductors, and resistors arranged in series or parallel according to the effectiveness needed for the load to operate at the design voltage and expected reactive power. The inductor in this filter serves to block high-frequency components or what is known as the skin effect in passive filters [11]. A single tuned filter can only attenuate a single harmonic order. This filter is typically used for low harmonic orders. The impedance of the single tuned circuit is expressed by this equation:

$$Z(w) = R + j\,(\omega L - \frac{1}{\omega C}) \quad (5)$$

The component values (R, L, and C) can be calculated by first determining the value of C using the following equation:

$$X_C = \frac{Vll^2}{Q_c} \quad (6)$$

$$C = \frac{1}{2\pi f Xc} \quad (7)$$

$$X_L = X_C \quad (8)$$

$$L = \frac{1}{(2\pi n f)^2\, C} \quad (9)$$

$$X_L = 2\pi f L \quad (10)$$

The next step in the calculation process is to determine the value of resistance. However, prior knowledge of the quality factor (Q) is required. The range of quality factor (Q) values is typically between 45 and 90, but the commonly used value is 45 [12]. The equation to calculate the resistance value is provided in the following equation:

$$R = \frac{X_L}{Q} \quad (5)$$

3. Results and Discussion

3.1 Electrical System

Modeling the power system at one of the coal mining companies in Kalimantan, designed as a 3-bus network system. This system is modeled in ETAP software to conduct harmonic analysis. With the main source from the 20 kV PLN network stepped down to 380/220 volts, the system is also supported by one 650 kVA genset as backup as shown in **Figure 5**. The main loads in this system consist of electric motors used for conveyor and crusher drives, as well as other loads such as lights and AC in buildings. There are 16 electric motors in the system, each equipped with a VSD, known as the main source of harmonics in the power system.

Jurnal Serambi Engineering JSE
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Table 2. Specifications of Three-Phase Induction Motor in the Crusher System of PT. BSSR

No	Motor Code	Brand	Capacity (kW)	(rpm)	Pole
1.	CV-01	Siemens	75	1.500	4
2.	Crusher-A	Teco	125	1.000	6
3.	Crusher-B	Teco	125	1.000	6
4.	CF	Siemens	110	1.500	4
5.	DS	Siemens	11	3.000	2
6.	CV-02	Siemens	110	1.500	4
7	CV-01 OLC 1	Sumitomo	37	1.500	4
8.	RF	Siemens	90	1.500	4

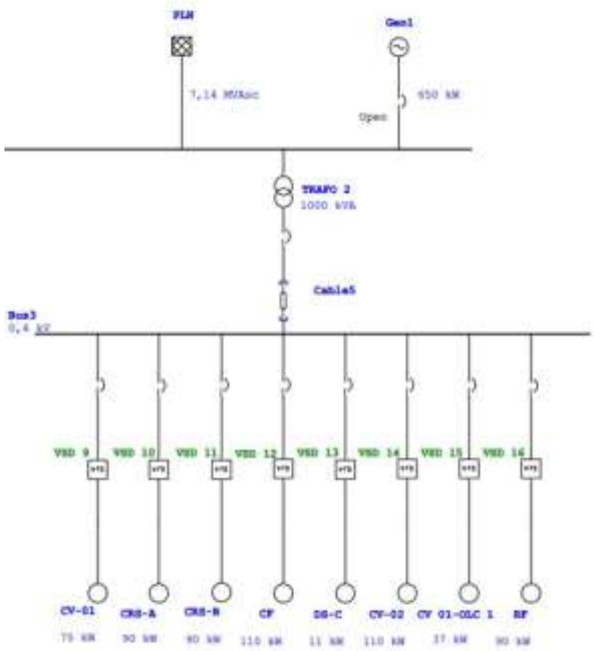

Fig. 5: Design of the electrical one-line diagram

3.2 *Load Flow Analysis*

To accurately determine the size of the filter, understanding MVA values and power factors is crucial, which requires a balanced load flow analysis. This analysis is conducted to calculate critical parameters such as current and voltage at various points in the system, information vital to ensuring the system operates with optimal efficiency and safety. The results of this load flow analysis are then visualized in the form of a one-line diagram, as seen in **Figure 6**, and detailed information can be presented through report management features.

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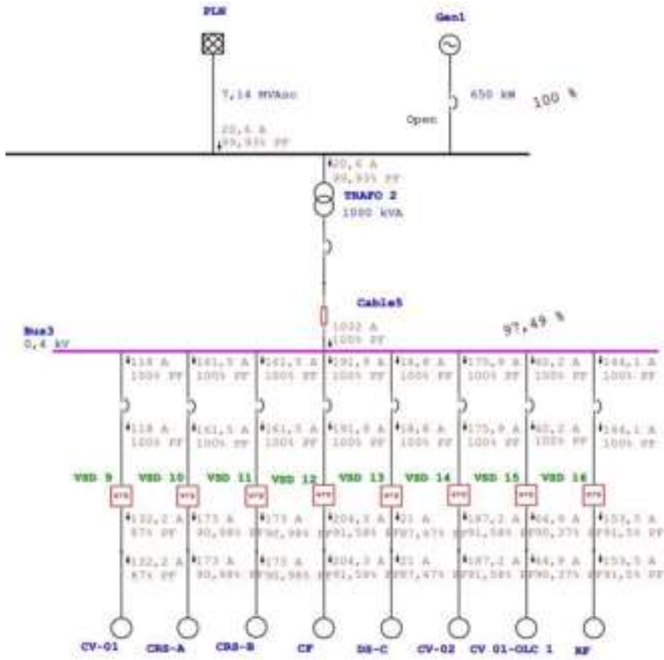

Fig. 6: The results of the load flow simulation for PT. BSSR

3.3 *Load Flow Analysis*

To examine harmonic distortion or the influence of harmonic sources on the power network, it is necessary to conduct an analysis of the harmonic impact generated by non-linear loads. This analysis is typically conducted for ideal load conditions but can be adapted to various or changing operational conditions. It aids in identifying and analyzing the effects of harmonics under different operational conditions of the power network, enabling adjustments or improvements in system design and management to mitigate the negative impact of harmonics on power quality. The results of the harmonic impact analysis are presented in **Figure 7**, showing the simulation outcomes.

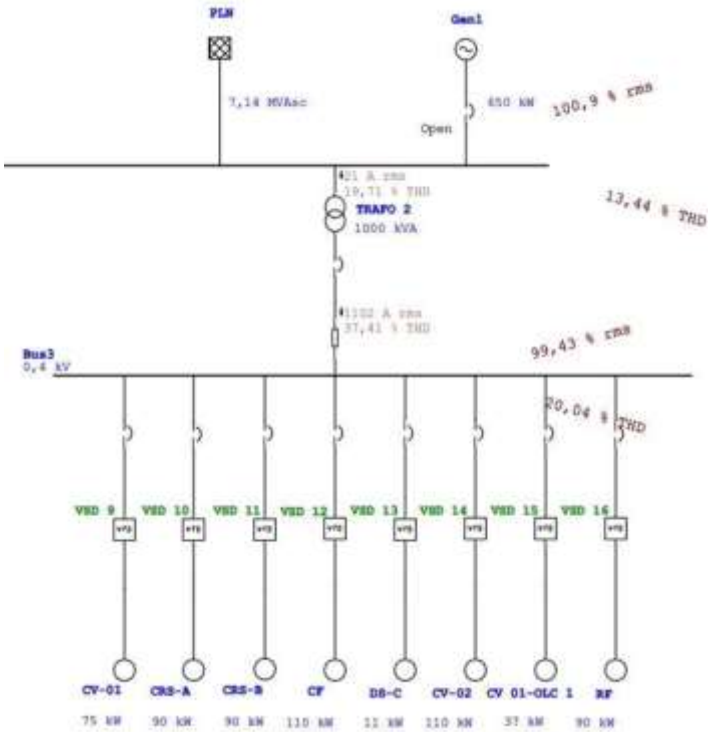

Fig. 7: Harmonic Distortion Simulation

Table 3. The simulation results of THD_V and THD_I on Bus 3

BUS		Voltage Distortion		Current Distortion	
IDE	kV	THD_V %	Standard IEEE THD_V (%)	THD_I %	Standard IEEE THD_I (%)
Bus 3	0,400	20,04	8	19,71	8

$$I_{SC} = \frac{100\ x\ (kVA\ Trafo)}{\sqrt{3}\ x\ V\ x\ Z\ (Trafo)}$$

$$I_{SC} = \frac{100\ x\ (1000)}{\sqrt{3}\ x\ 0{,}4\ x\ 5}$$

$$I_{SC} = 28.868{,}3\ A$$

$$I_L = \frac{kW\ average\ demand}{PF\ x\ \sqrt{3}\ x\ V}$$

$$I_L = \frac{696{,}93\ kW}{0{,}92\ x\ \sqrt{3}\ x\ 0{,}4}$$

$$I_L = 1.093{,}40\ A$$

$$\frac{I_{SC}}{I_L} = \frac{28.868{,}3}{1.093{,}40}$$

$$\frac{I_{SC}}{I_L} = 26{,}40\ A$$

In establishing standard limits, it is important to first determine the values of I_{SC} and I_L. Calculations for both parameters must be done manually. The values of ISC and IL can be computed using specific formulas and calculation processes. Below is the calculation for the value of I_{SC}

3.4 Filter Design to Reduce Harmonics

To address the existing issues, calculations are necessary to determine the specifications of the filter to be used. These filter specifications are calculated based on the required harmonic order. In systems with equipment containing harmonic sources, it is recommended to use passive harmonic filters. Additionally, installing reactive power compensation for power factor correction is recommended using harmonic filters. This allows for the improvement of the system's power factor while serving as a harmonic current absorber in the system. Before designing a single-tuned filter, it is important to first understand the impedance characteristics of the filter. Next, the values of THD and IHD indices at the bus where the filter will be installed need to be determined. The next step is to identify the most dominant harmonic voltage order and frequency, which will then be selected as the frequency for tuning the filter. The following are the filter component calculations using MATLAB.

From **Table 5**, the values of IHD_V and QC required at bus 3 for four different harmonic orders, namely the 5th, 7th, 11th, and 13th orders, are obtained. The analysis indicates that at bus 3, there are four different levels of harmonic distortion. For the 5th order, IHD_V is recorded at 11.04%, requiring a 68 kVAR harmonic capacitor to compensate for this distortion. For the 7th order, IHD_V is higher at 10.32%, requiring an 88 kVAR harmonic capacitor. For the 11th order, a 42 kVAR harmonic capacitor is required, and for the 13th order, a 99 kVAR harmonic capacitor is needed for correction. In the frequency tuning of the 5th order for harmonic reduction of voltage and current distortion, the power factor value is designed to increase up to 94%.

The calculation is as follows;

$$\begin{aligned} \Delta Q &= P \times (\tan(cos^{-1}\varphi \text{ awal}) - \tan(cos^{-1}\varphi \text{ target}) \\ &= 696{,}93 \times (\tan(cos^{-1}\ 0{,}92) - \tan(cos^{-1}\ 0{,}95) \\ &= 696{,}93\ 4 \times (\tan(23{,}07) - \tan(18{,}19) \\ &= 696{,}93 \times (0{,}426 - 0{,}328) \\ &= 696{,}93 \times (0{,}098) \\ &= 68{,}29 \text{ kVAR rounded to 68 kVAR.} \end{aligned}$$

For the tuning frequency of the 7th, 11th, and 13th orders using the same calculation, the results obtained are as shown in **Table 5** below.

Table 4. The reactive power compensation magnitude based on its order

ID	kV	IHD_V(%)	Orde	Q_C (kVAR)
Bus3	0,4	11,04	5	68
Bus3	0,4	10,12	7	88
Bus3	0,4	7,84	11	42
Bus3	0,4	6,60	13	99

Table 6 below presents important data regarding circuit components used for harmonic compensation at various harmonic orders. Each row of the table depicts the component arrangement for a specific harmonic order, with a fixed Quality Factor (Q) value of 60 for all orders. The selection of capacitors, inductors, and resistors is crucial in the design of harmonic filter circuits. For instance, for the 5th order, a capacitor of 1352.817 µF, an inductor of 0.0941 H, and a resistor of 0.0016 Ω are used.

These values vary significantly among different orders, indicating the need for specific component adjustments to address harmonic effects at different frequencies. For instance, in the 7th order, the capacitor capacity increases to 1750.704 µF, while the inductor value decreases to 0.0371 H. This illustrates the necessary adjustments for filter efficiency at higher harmonic frequencies. Overall, this table illustrates the importance of carefully selecting and adjusting circuit component values to optimize harmonic filter performance in the electrical system.

Table 5. Specifications of Bus 3 Filter Design

Orde	Quality Factor (Q)	Capacitor (µF)	Reactance inductive X_L (H)	Resistor (Ω)
5	68	1352,817	0,0941	0,0016
7	88	1750,704	0,0371	0,0006
11	42	835,563	0,0315	0,0005
13	99	1969,542	0,0096	0,002

For the calculation of filter components such as parameters R, L, and C in reducing voltage and current harmonic distortion, it is as follows:

Calculation of single-tuned filter design for the 5th order.

$$X_c = \frac{Vll^2}{Q_c} \quad C = \frac{1}{2\pi f X_c} \quad L = \frac{1}{(2\pi n f)^2 C} \quad X_L = 2\pi f L \quad Q = \frac{X_L}{R}$$

$$X_c = \frac{400^2}{68 \; x \; 10^3} = 2{,}353 \; \Omega$$

$$C = \frac{1}{2 \; x \; 3{,}14 \; x \; 50 \; x \; 2{,}353} = 0{,}001352 \text{ F}$$

$$L = \frac{1}{(2 \; x \; 3{,}14 \; x \; 5 \; x \; 50)^2 x \; (0{,}00135)} = 0{,}00030 \text{ H}$$

$$X_L = 2 \; x \; 3{,}14 \; x \; 50 \; x \; 0{,}00030$$
$$X_L = 0{,}0941 \;\; \Omega$$

The range of quality factor (Q) values for single-tuned filters typically ranges from 30 to 60. The value used in this study is 60, thus the value of R is as follows:

$$R = \frac{X_L}{Q} = \frac{0{,}0941}{60}$$

$$R = \frac{X_L}{Q} = 0{,}0016 \; \Omega$$

Using the same calculation, the values for the filter design at the 7th, 11th, and 13th orders are obtained, as shown in table 6.

3.5 The Effect of Installing Passive Harmonic Filters on Voltage Harmonics

In **Table 7**, we observe a significant decrease in the IHDV values after installing harmonic filters on bus 3. Particularly, at the 5th order harmonics, there is a decrease from 11.04% to 0.26%, indicating highly effective filtering. At the 7th order, the decrease from 10.12% to 0.06% is also remarkable, confirming the effectiveness of the intervention. Furthermore, at the 11th and 13th orders, the IHDV values decrease from 7.84% to 0.03% and from 6.6% to 0.01% respectively, showing that the filters operate well in handling distortion at higher frequencies. Overall, this intervention successfully reduces harmonic distortion to levels well below the IEEE standard, reflecting a significant improvement in the power quality of the electrical power system.

Based on **Table 7** and **Table 8**, it is evident that the use of Single Tuned passive filters to mitigate harmonics on bus 3 has played a significant role. The four 5th, 7th, 11th, and 13th order harmonics have been reduced below the set IEEE standard. These results underscore the importance of installing filters in distribution systems to control and reduce harmonic distortion. By ensuring that the THDv and THDi values are below the threshold set by industry standards, these filters help maintain power system integrity, prolong equipment life, and reduce the risk of damage associated with harmonics. The decrease in THDv and THDi values also indicates a reduction in power losses and an overall improvement in operational efficiency.

Table 6. Comparison of IHD_V (%) values before and after filter installation

No	Orde	IHD_V (%)		
		Before	After	Standard IEEE
1.	3	4,42	4,28	5,00
2.	5	11,04	0,26	5,00
3.	7	10,12	0,06	5,00
4.	9	3,08	2,98	5,00
5.	11	7,84	0,03	5,00
6.	13	6,60	0,01	5,00
7.	15	1,81	1,75	5,00
8.	17	4,73	0,41	5,00
9.	19	3,51	0,39	5,00
10.	23	2,12	0,28	5,00
11.	25	1,66	0,23	5,00

Table 7. Comparison of IHD_I (%) values before and after filter installation

No	Orde	IHDI (%)		
		Before	After	Standard IEEE
1.	5	15,57	0,34	7,00
2.	7	10,17	0,06	7,00
3.	11	4,98	0,02	3,50
No	Orde	IHDI (%)		
		Before	After	Standard IEEE
4.	13	3,53	0,01	3,50
5.	17	1,77	0,16	2,50
6.	19	1,26	0,13	2,50
7.	23	0,62	0,08	1,00
8.	25	0,46	0,06	1,00
9.	29	0,25	0,03	1,00

Table 8. Comparison of THDV and THDi values before and after filter installation

ID	kV	THDv (%)			THDi (%)		
		Before	After	IEEE	Before	After	IEEE
BUS 3	0,4	20,04	5,55	8	19,71	0,42	8

The implementation of Single Tuned passive filters to mitigate harmonics on Bus 3 has shown promising results in reducing both THD_V and THD_I, as recorded in the data before and after the intervention. Initially, Bus 3 recorded a THD_V value of 20.04%, indicating high harmonic distortion that could potentially disrupt the stability and performance of the electrical power system. The presence of such a distortion level exceeded the maximum standard of 8% recommended by IEEE, indicating a far-from-ideal situation that demanded corrective action. The decrease in THD_V to 5.55% after filter installation is a strong indication of the effectiveness of the solution implemented, signaling a significant improvement in power quality and compliance with industry standard criteria.

In **Figure 8**, the waveform shape before the installation of passive filters can be seen. The waveform on Bus bar 3 exhibits clear deviations from the ideal sinusoidal profile, with noticeable distortions in the form of irregular peaks and dips. This condition indicates the presence of harmonic disturbances in the system, which can lead to several operational issues, ranging from inefficient energy losses to risks for sensitive electronic equipment. These distortions depict suboptimal power quality and highlight the need for intervention to improve the situation.

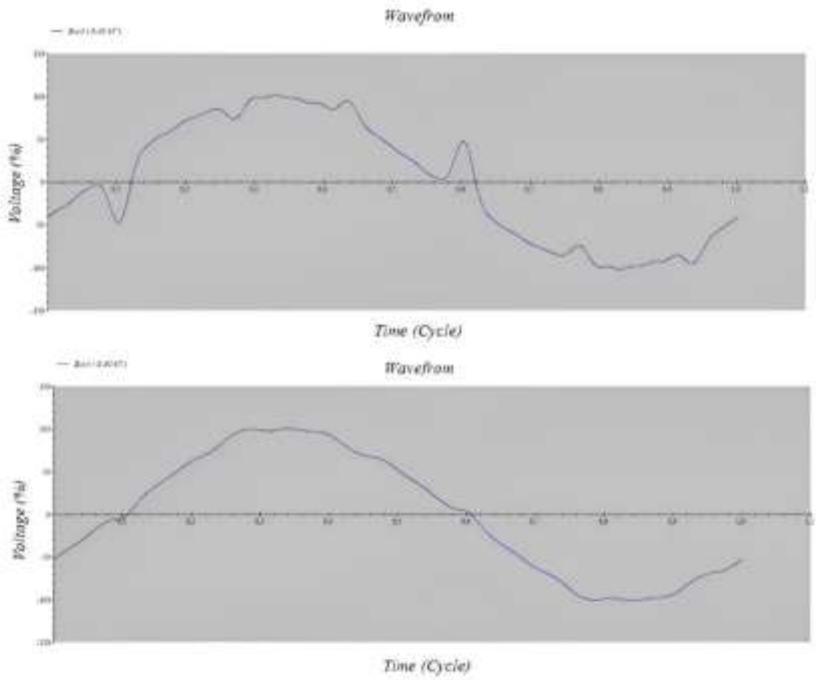

Fig. 8: Differences in Voltage Waveform Shape Before Filter Installation above

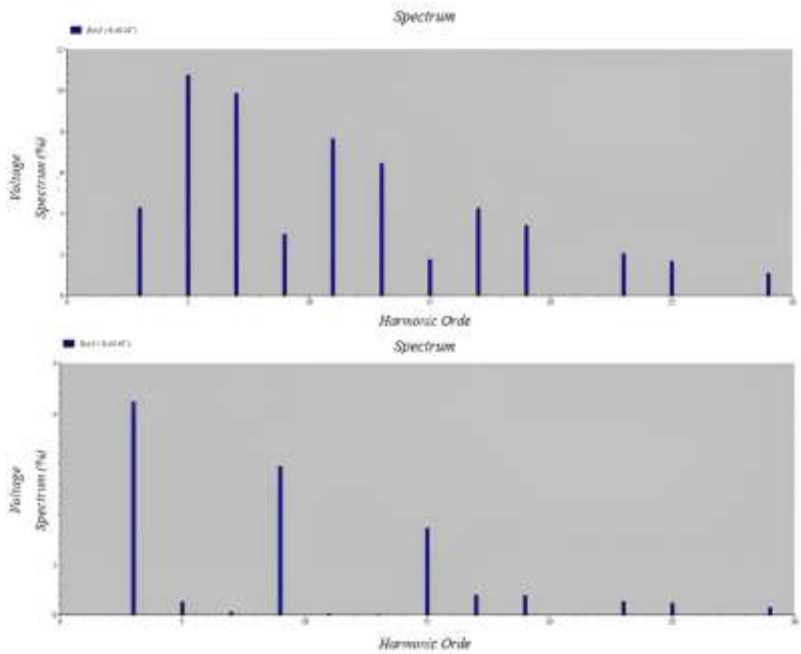

Fig. 9: Spectrum of Voltage without Filter above and with Filter below

After the installation of the filter, there is a substantial change in the waveform shape. The power quality appears to have been dramatically improved, as reflected in the smoother and more consistent waveform, resembling the expected sinusoidal shape. This indicates that the Single Tuned passive filter has succeeded in reducing or even eliminating unwanted harmonics, resulting in a more stable and efficient system. This harmonic filtering not only improves operational performance but also helps extend equipment life and reduce energy losses.

The comparison between the waveform shapes before and after filter installation provides strong evidence of the filter's effectiveness in refining the electrical waveform shape and reducing harmonic disturbances. This is a critical step in power quality management, demonstrating that with the selection and installation of appropriate technology, significant improvements in power system operation can be achieved.

4. Conclusion

Based on the problem formulation and objectives of this research, which focuses on the influence of THD generated by the use of VSD on three-phase induction motors in the crusher system of PT. BSSR, the conclusion is that testing the designed Single Tuned passive filter shows significant results in reducing THD. Simulation results indicate a decrease in THD_V from 20.04% to 5.55%, and THD_I from 19.71% to 0.42%, both of which are below the IEEE standard of 8% for THD_V and 8% for THD_I. This indicates that the installation of the Single Tuned passive filter is not only effective but also relevant and applicable in improving power quality.

5. References

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