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Evaluation of Electrical Harmonics in Building Installations

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Abstract – *This study aims to determine the level of harmonics, and conduct harmonic analysis on the electrical system in the new Building of the Information Technology Department of Samarinda State Polytechnic. Harmonics are electric waves that have frequencies with multiples of the base frequency of the power source (50 Hz in Indonesia). Harmonics can arise due to the use of electronic equipment that has non-linear load properties. This is becoming a major problem for power quality issues and harmonic analysis is required to scrutinize in component modeling to minimize or eliminate these harmonic disturbances. Based on research that the harmonic content in the new building of the Information Technology Department of Samarinda State Polytechnic has not met the standards. In this case, the power quality in such buildings exceeds the specified standards. The method used is the design of passive filter simulation in distribution transformers using ETAP software. The result of this study is a decrease in harmonic currents after installing a passive filter with an initial THDi value in phase S of 59.84% for IHDi values in the 5th order of 57.25% the value does not meet IEEE 519-2014 standards, the use of single-tuned passive filters can reduce the THDi content in phase S to 10.94% and the 5th order phase S down to 10.46 already meets IEEE 519 – 2014 standards, namely THDi 15% and IHDi in the 5th order 12% with SCRatio between 100-1000 A.*

Keywords – *harmonic analysis; power quality; passive filter; THDi; IEEE 519-2014 standards.*

I. Introduction

RELIABILITY of an electrical power system is achieved when it can continuously provide the electrical energy needed by consumers with good power quality in terms of voltage regulation and frequency regulation. Continuous electricity supply is crucial for various sectors, including educational institutions, industrial areas, shopping centers, and households [1–8]. The use of alternative power sources, such as solar and wind energy, can help ensure a reliable and sustainable power supply [1, 2]. However, the intermittent nature of these sources necessitates the use of integrated energy systems [2]. Monitoring and managing energy consumption is also crucial for ensuring a stable power supply [3, 8]. The importance of uninterrupted power supply is particularly emphasized in high-tech power enterprises [4]. The security of electricity supply is a key determinant of sustainable development [6]. In Nigeria, the need for continuous power supply in universities is highlighted, with a focus on energy consumption and demand [7, 8].

In an industrial area, this prevents companies from suffering production losses or "loss of production," which can be financially detrimental. In reality, many problems are faced by an electrical power system in providing continuous electricity. Power quality issues are becoming increasingly important because voltage instability can damage equipment that is sensitive to voltage changes, especially electronic equipment. Non-linear loads are one of the key factors affecting power quality, as they are a source of harmonics that can degrade power quality [9–11].

Voltage sags, a common power system disturbance, can have significant impacts on sensitive equipment, leading to financial losses [12]. These sags are often caused by system faults and can be mitigated through power conditioning or equipment design modifications [13]. The use of a Mini Dynamic Sag Corrector and control level embedded solutions can help equipment ride through voltage sags [12]. The presence of harmonics, another common disturbance, can be reduced through the use of a Dynamic Voltage Restorer with a battery-supported control algorithm [14].

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The detection of these disturbances is crucial, and an uncertainty model approach can be used for this purpose [15]. Reduced power factor and the presence of harmonics also decrease the efficiency of electricity use. Therefore, an evaluation of the electrical system is needed to mitigate the impact of increased production capacity. In power calculations, the power factor plays a crucial role. The power factor is a measure of the power transmitted between the source and the load. The power factor varies between 0 and 1 but is usually expressed as a percentage. The main cause of voltage sags is faults in the system network. Other causes include large loads (especially in industrial systems) and sometimes large inductive loads. Non-linear loads are the main cause of harmonics in the electrical network, which is a very serious problem for large industries. Non-linear loads are power electronic devices such as variable speed drives, rectifiers, and inverters. These power electronics devices cause non-sinusoidal waveforms, which are disrupted by high-frequency waves (harmonics), leading to disturbances in the power system and its equipment. The objective is to study the power quality of the electrical system at an educational institution, specifically in the New Building of the Information Technology Department at Samarinda State Polytechnic, focusing on the power factor and harmonics, model and simulate the electrical system using ETAP software version 16, and analyze the simulation results. Thus, it is expected that there will be an improvement in power quality and electricity usage. The results obtained are expected to be beneficial in the industrial world and applicable to industries with power factor, harmonics, and voltage imbalance issues. This will also enhance mastery of science and technology in power quality improvement [9, 16].

The New Building of the Information Technology Department is an educational facility owned by the government, equipped with electrical equipment to support the work of its staff. This equipment can be damaged if powered by an unstable source. Therefore, a power quality analysis will be conducted under the title "Harmonic Analysis in the New Building of the Information Technology Department at Samarinda State Polytechnic," with the hope that the power supply and system in the New Building of the Information Technology Department at Samarinda State Polytechnic will remain well-maintained, along with the existing equipment. A solution to reduce the impact of harmonics on the distribution system is to use passive filters, which are used to improve the power quality of the electrical system. Various techniques have been implemented to improve harmonics [10, 11, 17, 18].

II. Research Methods

The research conceptual framework is a thought process for researchers related to the scope, material limitations, and results to be achieved in the research stages. In the New Building of the Information Technology Department, there are non-linear loads such as TL lamps, computers, AC, and electric motors. These loads can worsen power quality and cause harmonics, affecting the performance of the system and electrical equipment, impacting current and voltage. A range of studies have demonstrated the effectiveness of harmonic filters in reducing harmonics in electrical systems. Active power filters, such as those simulated by Mudaheranwa [19] and Andang [20], have been shown to significantly decrease harmonic content, with Mudaheranwa achieving a 0 percentage total harmonic distortion. Passive filters, as investigated by Abood [21], have also been found to be effective in reducing harmonics and improving power factor. Active parallel filters, as discussed by Benaouadj [22], have been shown to improve energy quality by decontaminating harmonic pollution. Series active power filters, as utilized by Madhubabu [23], have been effective in reducing harmonics and compensating for voltage distortions. Shunt active power filters, as studied by Sabarimuthu [24], have been found to effectively remove harmonics in electric vehicle charging applications. Hybrid power filters, as tested by Waheed [25], have been shown to reduce current harmonics and improve performance in power systems. Lastly, space vector pulsewidth modulation and shunt active power filters, as applied by Mebrahtu [26], have been effective in mitigating harmonics in industrial sectors. The filter contains a series of RLC components that function to reduce harmonics and improve the power factor due to the capacitor component.

Based on this description, the research conceptual framework related to the targets to be achieved is as follows: First. Model and simulate the electrical power system in the New Building of the Information Technology Department using ETAP software, then test it to ensure the model is ready for analysis using harmonic filters. Second. Implement and analyze the improvement in power quality made before and after installing the harmonic filter.

Figure 1 shows the operational research framework flowchart, indicating that the research process begins with a literature review, including a literature study and case study, followed by obtaining reference and field data from the New Building of the Information Technology Department at Samarinda State Polytechnic. The software used for analysis includes ETAP 16, Microsoft Word, and Microsoft Excel, with the literature review results detailing the specifications and

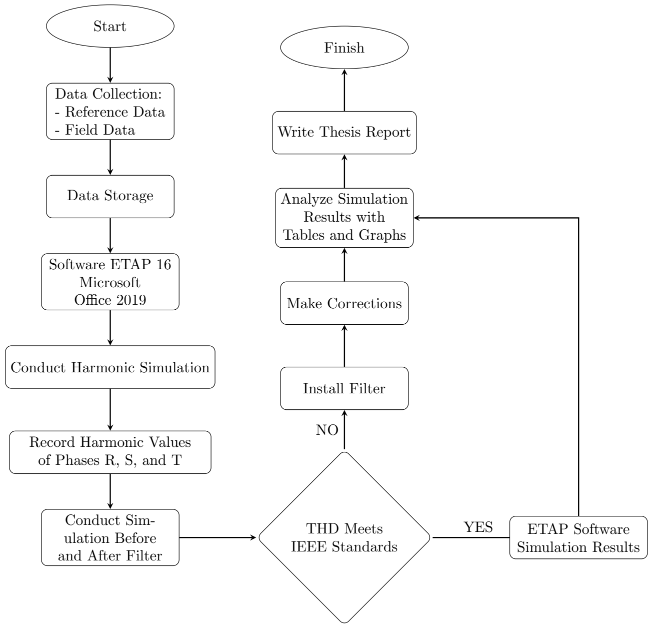

Figure 1: Operational Research Framework

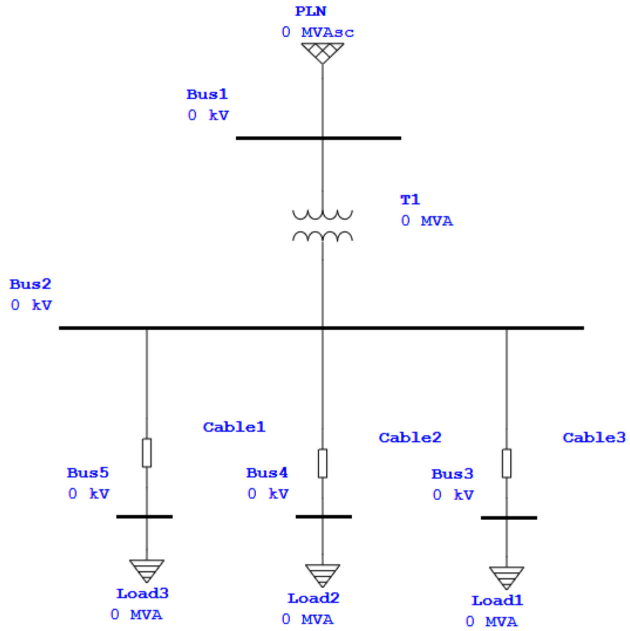

Figure 2: Simple Circuit Design for ETAP Software Simulation

functions of the harmonic filter.

The research continues with data processing, where reference and field data are analyzed using ETAP software, producing processed data in the form of power flow. This processed data is then re-analyzed to determine the harmonic filter capacity. After designing and applying the filter to the circuit, it is checked whether it meets the IEEE THD standard. If it meets the standard, the process continues to the analysis stage; otherwise, it returns to the filter design stage.

The final stage involves simulation results showing the impact of the filter installation, along with an analysis of the simulation results using tables, graphs, and images.

i. ETAP Software Simulation Design

In designing and analyzing an electrical power system, application software is essential to represent real conditions before a system is realized. ETAP (Electric Transient and Analysis Program) is one such application software used to simulate electrical power systems. ETAP can work offline for power system simulations and online for real-time data management or system control.

Before conducting research using ETAP software, it is essential to understand the parameters used in the research process on harmonics. Below is the simple circuit design to be used, with phases R, S, and T represented as the electrical load system in the Information Technology Department Building.

Before running the circuit above, first, fill in the parameters used, starting with the power grid. The power grid or PLN source is an ideal voltage source, meaning it can supply power with a constant voltage even if the absorbed power is significant. The power grid can be a large generator or a substation that is part of a large interconnected power system. Double-click on the power grid, then fill in the data on the Info and Rating tabs with a power grid rating of 20 kV according to field measurement data.

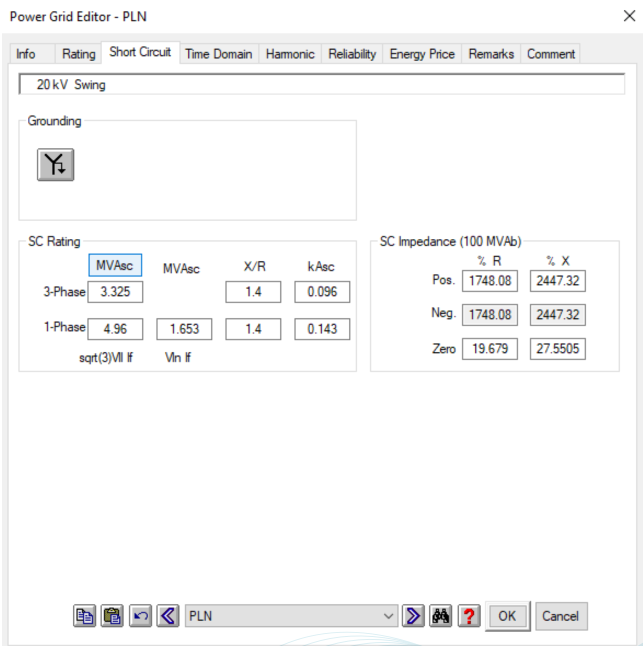

Figure 3: Power Grid Rating Data Tab

Before the transformer, connect the power grid to the bus bar by clicking and dragging the end of the power grid to the bus bar. If done correctly, the bus bar color will change from gray. Below is the bus editor data before the transformer.

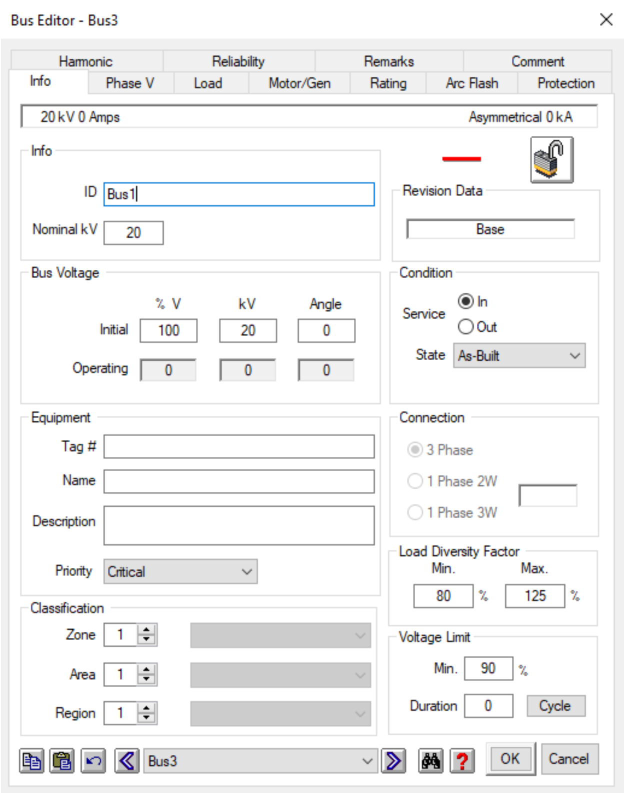

Figure 4: Primary Bus Data Entry

After the bus, the next step is to the transformer. The transformer or trafo is a device to increase or decrease the system voltage from the PLN source. First, set the rating value used according to the data on the transformer in the Information Technology Department Building, which is 200 kVA with a secondary voltage of 400 V or 0.4 kV. Then click typical Z & X/R, and the transformer impedance value will appear automatically.

Next, place the second bus bar after the transformer to distribute power to the three phases R, S, and T. The busbar data will be automatically filled with a secondary voltage of 0.4 kV.

The load will be divided into three, namely phases R, S, and T. Before connecting the bus bar to the load, place a cable on each line as shown Figure 7.

After the cables are installed, double-click, then click Library, and set it according to the data, as shown Figure 8.

Finally, add the static load component to the AC component, setting the rating values of each load according to field measurement data, as shown Figure 9.

After completing the simple circuit and filling in the data for each component, the power flow of the electrical system created can be determined by running the load flow. The simulation results will be shown

Figure 5: Transformer Data Entry

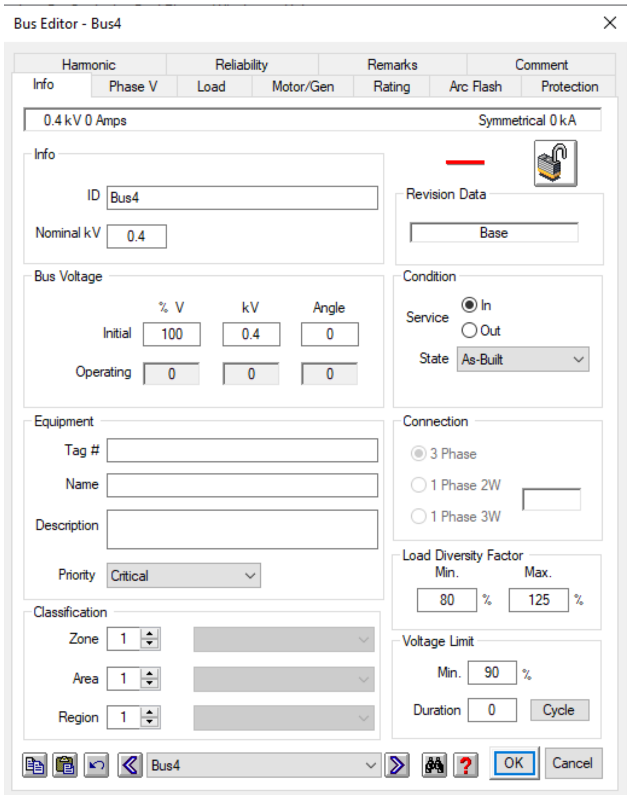

Figure 6: Secondary Bus Data Entry

with red letters as in the Figure 10.

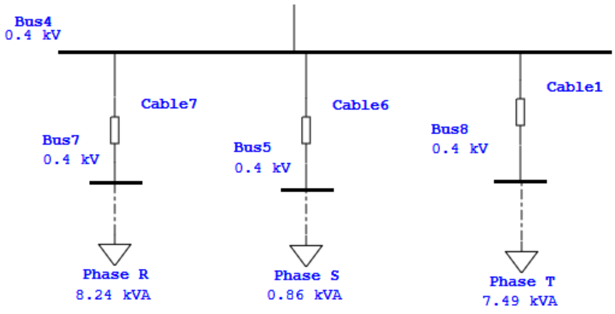

Figure 7: AC Cable Placement

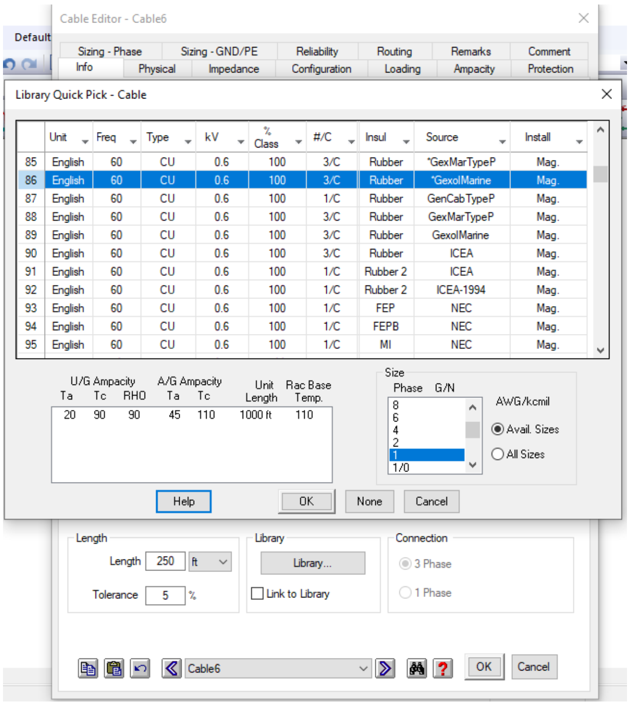

Figure 8: Cable Library

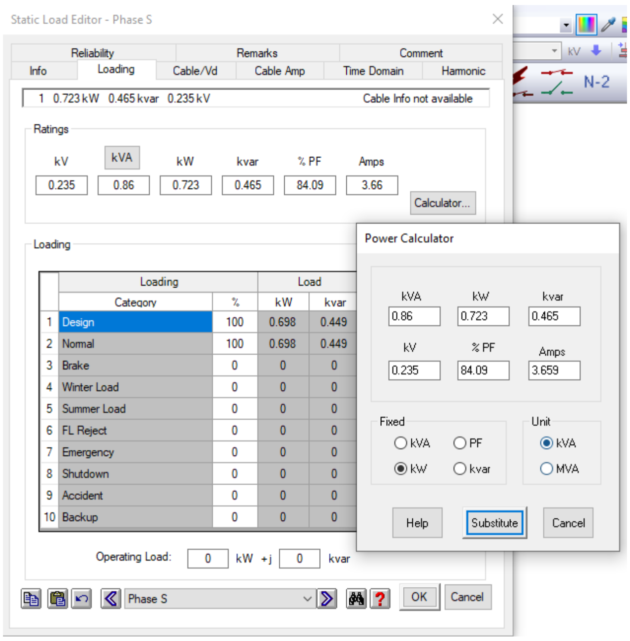

Figure 9: Static Load Data Entry

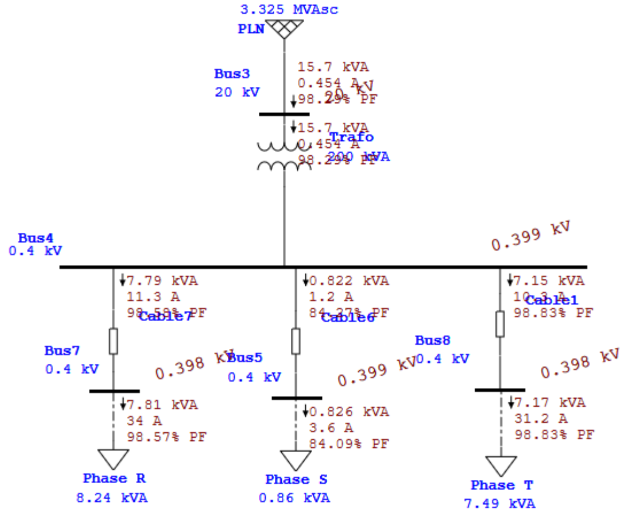

Figure 10: Load Flow Simulation Circuit

III. Results and Discussion

Measurements in the Architecture Building of Samarinda State Polytechnic were conducted for 8 days from August 22, 2023, to August 28, 2023. To perform calculations, simulations, and analysis of the Single-Tuned passive filter used to mitigate harmonics in the electrical network system of the Information Technology Department Building, measurement data from August 22, 2023, at 14:57 WITA was used because it had the highest THD value, as shown in Table 1.

Table 1: Measurement Data on August 22, 2023

Time	THDi (%)	Phase R	Phase S	Phase T
14:57 WITA	59.84	11.38	59.84	14.60

i. Determining Short Circuit Current (ISC)

The short circuit current (ISC) can be calculated using Equation (1) as follows:

$$I_{SC} = \frac{100 \times S_{trafo}}{\sqrt{3} \times V \times Z} \quad (1)$$

First, the data of the distribution transformer system in the New Building of the Information Technology Department of Samarinda State Polytechnic is required. The transformer data used is taken from the ETAP simulation data: the transformer capacity is 200 kVA, the secondary voltage is 400 V, and the transformer impedance is 6.75%. Thus, we have:

$$I_{SC} = \frac{100 \times 200,000}{\sqrt{3} \times 400 \times 6.75} = \frac{20,000}{4.67653} = 4276.66 \text{ A}$$

ii. Determining Maximum Load Current (IL)

To determine the maximum load current, the total active power, power factor, and secondary voltage of the transformer are required. The maximum load current (IL) calculated is the load current on April 5, 2023, at 15:41 WITA because it has the highest THDi value. The maximum load current can be calculated using Equation (2) as follows:

$$I_L = \frac{P}{\sqrt{3} \times V \times \cos\phi} \tag{2}$$

The required data includes the total active power of 16,240 W, a power factor of 0.90, and a secondary voltage of 400 V. Thus, we have:

$$I_L = \frac{16,240 \text{ W}}{\sqrt{3} \times 400 \times 0.9} = \frac{16,240 \text{ W}}{623} = 26.067 \text{ A}$$

iii. Determining Short Circuit Ratio (SCRatio)

With the known short circuit current (ISC) and maximum load current (IL), the short circuit ratio (SCRatio) on August 22, 2023, at 14:57 WITA can be calculated using Equation (3) as follows:

$$SCRatio = \frac{I_{SC}}{I_L} \tag{3}$$

The required data includes a short circuit current of 4276.66 A and a maximum load current of 26.06 A. Thus, we have:

$$SCRatio = \frac{I_{SC}}{I_L} = \frac{4276.66}{26.06} = 276.85$$

Based on the calculated SCRatio, the THDi limit according to IEEE 519-2014 standards is 15% for SCRatio between 100-1000. Among the three phases, harmonics are more dominant in phase S, so phase S data is used as the sample. The comparison of field measurement results with the permissible IEEE 519-2014 standards for the electrical system in the Information Technology Department can be seen in the following Table 2:

Table 2: Comparison of Measured THDi with IEEE 519-2014 Standards

Time	THDi Content			IEEE Standard 519 - 1992
	Field Measurement Phase			
	R	S	T	
Feb 22, 2023	11.38% Meets Standard	59.84% Does Not Meet Standard	14.60% Meets Standard	15%

Table 2 shows the comparison between the measured THDi in the field and the IEEE 519-2014 THDi standard, indicating that each phase has not met the standard, particularly phase S.

iv. Simulation Before Installing Single-Tuned Filter

The following is a simple simulation of the electrical system in the New Building of the Information Technology Department using ETAP software. The load data used in the ETAP simulation is the load data on August 22, 2023, at 14:57 WITA.

Table 3: Comparison of Running THDi and THDv Results in the Information Technology Department

Location	Simulation Results		IEEE Standard 519-2014		Description	
	THDi (%)	THDv (%)	THDi (%)	THDv (%)	THDi	THDv
Phase R	11.38	0.549	15	5.0	Meets	Meets
Phase S	59.84	0.508	15	5.0	Does Not Meet	Meets
Phase T	14.56	0.555	15	5.0	Meets	Meets

As seen in Table 3, the THD current in the electrical system simulation in the Information Technology Department Building has not met the established standard, particularly in phase S, which is very dominant. However, the THD voltage values still meet the IEEE 519-2014 standard, which is below 5%.

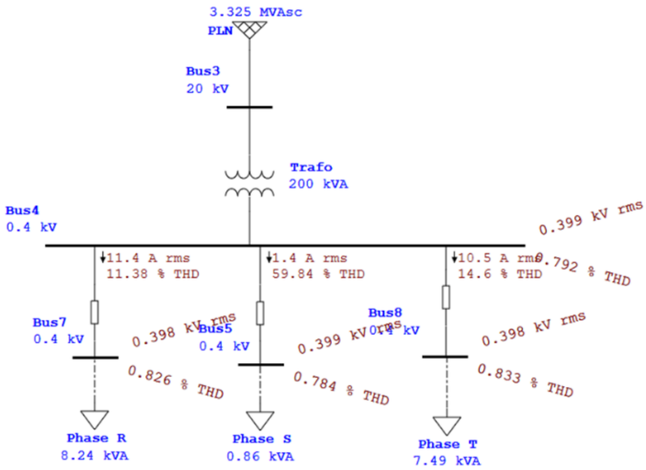

Figure 11: Simulation Results Before Installing Single-Tuned Filter

Based on the simple simulation results using ETAP software, it can be seen that the THDi value in Phase S is 59.84%, the same as the measurement value on Wednesday, February 22, 2023, at 14:57. The THDv value is 0.678%. According to IEEE 519-2014 standards, the simulation does not meet the standard, particularly in Phase S, while phases R and T meet the standard of 15% for ISC/ILoad values between 100-1000 A.

v. Designing a Filter to Reduce Harmonic Distortion

The filter used to reduce harmonic distortion is a single-tuned filter. The calculation will be performed on phase S, which has the highest harmonic current distortion of 59.84%. First, the harmonic order to be eliminated must be determined, which is the 5th order because it has the largest distortion. The calculation can be seen below.

$$
\begin{aligned}
P &= 723.012 \text{ kW} \\
\cos\phi &= 0.84 \\
\theta_1 &= \cos^{-1}(0.84) = 32.83^\circ \\
\theta_2 &= \cos^{-1}(0.99) = 8.10^\circ \\
Q_c &= P(\tan\theta_1 - \tan\theta_2) \\
&= 723.012 \times (\tan 32.83^\circ - \tan 8.10^\circ) \\
&= 363.67 \text{ kVAR}
\end{aligned}
$$

The capacitor value in the simulation will refer to equations 10 and 11 as follows:

$$
\begin{aligned}
X_c &= \frac{kV^2}{kVAR} \\
X_c &= \frac{0.4^2}{363.67} = 0.000439 \text{ k}\Omega = 0.43\Omega \\
C &= \frac{1}{2\pi f X_c}, f = \text{fundamental frequency of 50 Hz} \\
C &= \frac{1}{2 \times 3.14 \times 50 \times 0.43} \\
&= 0.006839 \text{ F} \\
&= 6.839 \times 10^{-3} = 6839\mu F
\end{aligned}
$$

In this simulation, the inductor value will be slightly below the 5th order, at 4.9, to prevent resonance that could disrupt the system. The inductor value will refer to equations 12 and 13 as follows:

$$
\begin{aligned}
L &= \frac{1}{(C)(2\pi f n)^2} \\
L &= \frac{1}{(6.83 \times 10^{-3})(2 \times 3.14 \times 50 \times 4.9)^2} \\
&= 0.0000614 \text{ H} \\
X_L &= 2\pi f L = 2 \times 3.14 \times 50 \times 0.0000614 \\
&= 19.2796\Omega
\end{aligned}
$$

Comparing the harmonic load flow analysis without a filter in Figure 5, the THD current percentage decreased from 59.84% to 10.96%, indicating that the filter significantly reduces THD.

vi. Filter Installation Results

After simulating before and after installing the 5th order single-tuned filter, it was found that the THDi and THDv values in phase S decreased, and phases R and T also showed a reduction in THDi current, although not as significantly as in the phase where the filter was installed. Based on the short circuit ratio calculations

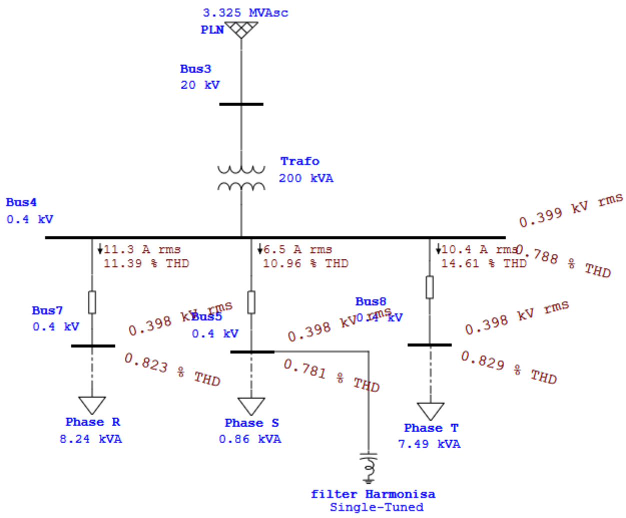

Figure 12: THD Values After Installing the Filter

according to IEEE 519-2014 standards, the following table compares the THDi and THDv values before and after installing the single-tuned filter with the established standard.

Table 4: Comparison of THD Values Before and After Installing the Filter

Phase	Simulation Results with ETAP 16 Software						IEEE Standard 519-1992	
	Before Filter Installation		After Filter Installation		After Installation of 5th Order			
	THDi	THDv	THDi	THDv	IHDi	IHDv	THDi	THDv
R	11.38	0.549	11.4	0.548	10.084	0.33	15%	5%
S	59.84	0.508	10.9	0.507	10.461	0.32	15%	5%
T	14.6	0.555	14.6	0.554	13.237	0.32	15%	5%

From Table 4, it can be seen that the THDi and THDv values before and after installing the filter. The installation of a passive filter can reduce harmonic distortion in the electrical system with a THDi value of 11.4% in phase R, 10.94% in phase S from 59.84%, and in phase T, there was no decrease except for the 5th order, which dropped to 13.23% from 14.6%. These values meet the IEEE 519-2014 standard of 15% for SCRatio between 100-1000.

Similarly, the THDv decreased due to the installation of the passive filter. The THDv value of the electrical system in the Information Technology Department Building still meets the IEEE 519-2014 standard, which is below 5%, with the simulation results showing a THDv value of 0.50% before the installation of the passive filter and 0.33% after the installation of the passive filter.

Table 5 shows that the use of passive filters can reduce current THD by 48.9%, and the 5th order decreases by 46.79%. Similarly, subsequent orders have met the IEEE 519-2014 standard of 15% for SCRatio between 100-1000. With the reduction of current THD,

Table 5: Comparison of THDi Percentage Before and After Installing the Filter in Phase S

	THDi (%) Without Filter	THDi (%) With Filter	Δ THDi (%)
THDi	59.84	10.94	48.9
5th Order	57.254	10.461	46.793
7th Order	14.381	2.626	11.755
11th Order	7.774	1.444	6.33
13th Order	2.975	0.543	2.432
17th Order	3.695	0.668	3.027
19th Order	2.31	0.418	1.892
25th Order	1.418	0.267	1.151

the voltage THD will also decrease, resulting in better voltage quality after installing the passive filter.

IV. Conclusion

Based on the analysis and simulation results of the research, it can be concluded that the voltage harmonic content (%THDv) in the New Building of the Information Technology Department at Samarinda State Polytechnic is generally above the permissible standard (5%), but the current harmonic content (%THDi) is above the permissible standard (15%), even reaching 56.64% during high load usage. This research used ETAP 16 software to determine the percentage of voltage THD and current THD in phase S, which exceeds the IEEE 529-2014 standard. The simulation results show that on February 22, 2023, at 14:57, the current THD percentage in phase S was 59.84%, exceeding the IEEE 519-2014 standard of 15% for the range of 100-1000 A. For more details, see Table 2.4. After designing, simulating, and installing the single-tuned filter in phase S, which has the highest harmonic distortion, the current THD percentage decreased from 59.84% to 10.96%, and the 5th order phase S decreased from 57.254% to 10.461%, meeting the allowable harmonic distortion standard of 15%.

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