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Analysis of Harmonic Improvement in the Computer Laboratory of Samarinda State Polytechnic with the Addition of a Static VAR Compensator

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ABSTRACT: An electrical system is said to have a high level of reliability if it is capable of supplying electrical energy continuously and in accordance with user needs. The quality of electrical power can be disrupted by the use of non-linear loads, such as computer devices, electronic devices, and energy-saving lamps. Harmonic problems in power quality arise due to the interaction between the sinusoidal waves of the system and the characteristics of non-linear loads, such as those found in the Computer Laboratory of the Samarinda State Polytechnic, which results in high harmonic current values. To determine the actual conditions, electrical parameters were measured. The results of the measurements showed a total current harmonic distortion value of 33.65% in phase R, 15.85% in phase S, and 92.99% in phase T. The individual current harmonic distortion in phase R decreased from 28.39% to 4.53%, to 3.76% in phase S, and to 2.63% in phase T on Thursday at 15:00 WITA. To overcome this, the use of a Static Var Compensator (SVC) is proposed as a solution to reduce the level of harmonics in the electrical system at the Computer Laboratory of the Samarinda State Polytechnic. The simulation was conducted using Matlab R2023a software through the Simulink feature. The results obtained show that the Static Var Compensator can reduce harmonics well, as seen from the harmonic values on Thursday, where before the Static Var Compensator was installed, the harmonics in phase R were 9.81%, phase S were 10.98%, and phase T were 9%.

KEYWORDS*:* harmonisa, matlab/simulink, Static Var Compensator.

I. INTRODUCTION

A complete electric power system is classified into generation, transmission, and distribution for easy control and to maintain a reliable and stable system. Utility networks operate depending on generation systems that differ in type, such as conventional or renewable power plants, or a combination of renewable and conventional systems.[1].

The quality of electrical power is influenced by several factors, including voltage, current, frequency, power loss, power factor, harmonics, and grounding systems. Electrical power is said to be of good quality if the voltage, current, and frequency values remain stable in a particular network. However, in practice, these three parameters are not always stable. [2].

Harmonics are periodic distortions that appear in voltage and current waveforms composed of a number of sine waves with frequencies that are integer multiples of the fundamental frequency. As a result of this frequency composition, the waveform becomes less than a pure sine wave. The presence of harmonic distortion can cause losses in electrical systems. [3].

A transformer is an electrical device that functions to transfer and convert electrical energy from one circuit or more to another electrical circuit through magnetic coupling, utilizing the principle of electromagnetic induction. In the industrial world, transformers are used to increase voltage (step-up transformers) and decrease voltage (step-down transformers). [4].

An electrical load is the amount of electrical energy consumed by equipment or devices used in an electrical power system. In general, electrical loads are divided into several types, such as resistive loads (e.g., lights and heaters), inductive loads (e.g., electric motors), and capacitive loads (e.g., capacitors). These loads are very important because they affect the performance and stability of the electrical power system. [5].

Based on the background discussion above, a study was conducted entitled “Analysis of Harmonic Improvement with the Addition of a Static Var Compensator at the Computer Laboratory of the Samarinda State Polytechnic”.

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II. LITERATURE REVIEW

A. General Overview

This section discusses the analysis of a number of previous studies that are relevant to the issues in this study. The findings from these studies were used as a starting point in designing this study. One of the references used was a journal article by Motlanthe and Muremi entitled "Application of Static Var Compensator with Harmonic Filter in the Heavy Industry". This journal discusses the application of Static Var Compensator (SVC) equipped with harmonic filters in the heavy industry sector, particularly mining. The study shows that the use of SVC with harmonic filters can improve power quality by improving the power factor and reducing harmonic distortion at the interconnection point. The results of the study indicate a significant decrease in the Total Harmonic Distortion (THD) value after the installation of the SVC system with filters, proving that this technology is effective in addressing power quality issues in industrial environments. [6].

Research conducted by Gede Kresna Dharma Yudha in his thesis entitled "Simulation of Shunt Active Filter Use with PI Control to Reduce Total Harmonic Distortion (THD) in the Electrical Engineering Building at Udayana University" discusses the application of shunt active filters as a solution to reduce harmonic interference caused by the use of non-linear loads, such as computers, lights, and air conditioners. The study explains that harmonic resonance can cause distortion to increase by 4 to 10 times under full load conditions, thus requiring an effective mitigation strategy. Using simulations on MATLAB Simulink software, the active shunt filter controlled using PI control successfully reduced the Total Harmonic Distortion of current (THDi) from the initial condition, which exceeded the IEEE 519-2014 standard limit, ranging from 14.73% to 13.53%, to 3.29% to 4.53%. Meanwhile, the Total Harmonic Distortion voltage (THDv) value in the system has been within the standard limit since the beginning of testing. These results indicate that the use of an active shunt filter with PI control is effective in suppressing harmonics and improving the quality of electrical power in building installations. [7].

Then, research written by Onur Turan, entitled "Modeling a Static Var Compensator consisting of TCR and TSC," discusses modeling simulation systems using Matlab/Simulink applications to reveal the benefits of Static Var Compensators. Based on the research conducted, it shows that static var compensators can provide stable voltage regulation, correct poor power factors, prevent the need for reactive power sources from the network, and prevent unnecessary power increases, thereby reducing additional costs. Through modeling and simulation using Matlab/Simulink software, this research provides deeper knowledge about the role and usefulness of static var compensators in optimizing the performance of electrical power systems. This research is used as a reference for this thesis to model electrical systems using Matlab/Simulink software. [8].

B. Harmonic

Harmonics are a type of distortion in periodic current, voltage, or power waves, consisting of sinusoidal waves with frequencies that are integer multiples of the fundamental frequency or source frequency, resulting in waveforms that are no longer purely sinusoidal. Harmonics can be defined as interference frequencies that are multiples of the fundamental wave frequency. These waves ride on the fundamental wave and cause the formation of an imperfect waveform, which is the result of a combination of the fundamental wave and the harmonic distortion waves. [9]. especially to the equipment connected to it. The presence of harmonics can cause various effects, increasing the temperature of electrical equipment. [10]. A sinusoidal wave with a frequency that is an integer multiple of the fundamental frequency of the system, where the first harmonic is 50 Hz, the second harmonic has a frequency twice the fundamental frequency, namely 100 Hz, and the third harmonic has a frequency three times the fundamental frequency, namely 150 Hz. [11]. Based on the above description, the sum waveform of the harmonic frequencies can be observed in Figure 1.

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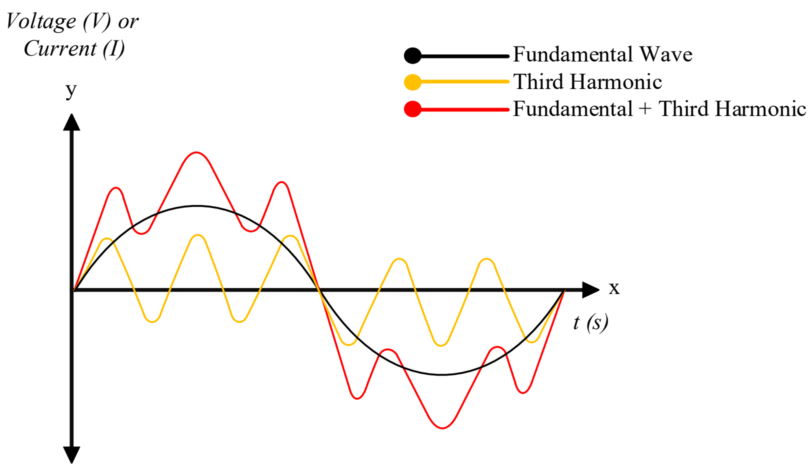

Figure 1 Harmonic waves

The fundamental wave with a frequency of 50 Hz is the base frequency of a periodic signal. This wave has the simplest sinusoidal shape and is the main part of the signal. In the illustration, the black wave represents a pure sinusoidal current wave without harmonic mixing. Meanwhile, the third harmonic wave, which has a frequency of 100 Hz, is three times the fundamental frequency. This wave has a more complex shape and has the potential to interfere with the original signal if not handled properly. This wave is visualized in yellow, where it is the result of a combination between the fundamental wave and the third harmonic (fundamental + third harmonic) with a frequency of 150 Hz, producing a new, more complex waveform. This sum wave is shown in red. [11].

C. Individual Harmonic Distortion (IHDi)

Individual Harmonic Distortion (IHD), also known as harmonic factor (FH), is the ratio between the RMS value of a particular harmonic component and the average value of the fundamental component (first order). [12]. Based on the above description, the IHDi formula is written in the following equation(1).

$$IHDi\ (\%) = \frac{I_h}{I_1} \text{ x } 100\% \qquad (1)$$

Description :

IHD_i = Individua Harmonic Distortion Current (%)

I_h = Current Harmonic Component – h in RMS (I)

I_1 = Current at Fundamental Frequency in RMS (I)

h = Harmonic Order to –

D. Total Demand Distortion (TDD)

$$THDi = \sqrt{\frac{\sum_{h}^{\infty}=2\, I_h^2}{I_L}} \text{ x } 100\% \qquad (2)$$

E. Standard Limit To Harmonic

Harmonic standardization is a guideline that refers to a harmonic limit in an electrical network system with the aim of preventing things that are detrimental to the system itself. The standard used is IEEE std 519-2014, which is a recommended guideline for harmonic control in electrical power systems. This standard aims to assist in designing efficient and reliable electrical systems for both linear and non-linear loads. It describes various possible current waveforms that can appear throughout the system. This standard also sets the desired wave distortion limits as a reference in system design. Furthermore, IEEE 519-2014 regulates the power quality that must be met at the point where the power source is connected to the load. [13].The limits for individual current harmonic distortion given in Table 1, which is the IEEE std 519-2014 standard, are as follows:

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Table I. Harmonic Current Distortion Limits According To Ieee 519 2014 Standard [13].

Maximum harmonic current distortion in percent of I_L Individual harmonic order (odd harmonics) ^{a,b}						
Sc_{ratio}	3≤h<11	11≤h<17	17≤h<23	23≤h<35	35≤h≤50	TDD
<20	4,0	2,0	1,5	0,6	0,3	5,0
20<50	7,0	3,5	2,5	1,0	0,5	8,0
50<100	10,0	4,5	4,0	1,5	0,7	12,0
100<1000	12,0	5,5	5,0	2,0	1,0	15,0
>1000	15,0	7,0	6,0	2,5	1,4	20,0

To determine the THD current limit, the short circuit ratio (〖SC〗_ratio) must be calculated using the equation(3).

$$SC_{ratio} = \frac{I_{SC}}{I_L} \quad (3)$$

Description:

I_SC = Short-circuit current at a specific point in the electrical power system.

I_L = Nominal load current in the system.

However, before calculating the short circuit ratio (〖SC〗_ratio) or the ratio between short circuit capacity and load current, it is necessary to first calculate the short circuit current value at a specific point in the electrical power system and the nominal load current in the system using equations (4) and (5) as follows :

$$I_{SC} = \frac{kVA \times 100}{\sqrt{3} \times kV \times Z} \quad (4)$$

Description :

S_trafo = Transformer Power Capacity (kVA)

Z = Transformer Impedance (%)

V = (Volt)

F. Static Var Compensator (SVC)

A Static Var Compensator (SVC) is an electrical device used to provide fast reactive power compensation in high-voltage power transmission networks. SVCs are part of flexible AC transmission systems that serve to regulate voltage and stabilize the system. The term “static” refers to the fact that there are no moving parts in an SVC during operation or when making compensation changes, as the entire compensation process is fully controlled by a power electronics system. [14].

SVC consists of a capacitor bank controlled by a triac called a Thyristor Switched Capacitor (TSC) and a reactor bank controlled by a triac called a Thyristor Controlled Reactor (TCR). This compensator draws reactive power from the network by regulating voltage, improving stability, controlling overvoltage, and reducing voltage flickers. Because Static Var Compensators use switching for reactive power control, they are also called static VAR (reactive power) switches or systems. [15].

SVC is primarily used in power systems to improve voltage control and system stability. In recent years, many researchers have proposed techniques to improve stability with SVC to suppress electromechanical fluctuations in power systems. Generally, the SVC structure consists of a combination of a thyristor controlled reactor (TCR) and/or a thyristor switched capacitor (TSC) structure. [16]. Figure 2 shows a general schematic block diagram of the SVC control system. In this study, the static VAr compensator formed by the TCR and TSC structures is modeled. The SVC system can be seen in Figure 2.

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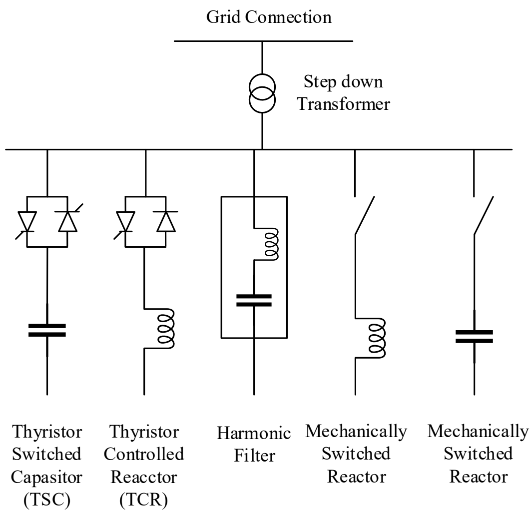

Figure 2 Static Var Compensator System Configuration

1) *Main Component Of SVC*

In an elecrical power system, an svc consists of several core components that play an important role in regulating reactive power. The main components that from part of a Static Var Compensator (SVC) are:

1. Thyristor Controlled Reactor (TCR)
   TCR is an element that functions to control the inductive reactor in the SVC. By adjusting the thyristor firing angle, this component can control the amount of inductive reactive power absorbed by the system.
2. Thyristor Switched Capacitor (TSC)
   TSC utilizes thyristors to connect or disconnect capacitors from the system. These components function to gradually generate capacitive reactive power through controlled switching techniques.
3. Thyristor Switched Reactor (TSR).
   TSC uses thyristors to connect or disconnect capacitors from the system. TSC is used to gradually generate inductive reactive power using a switching method.
4. Harmonic Filter
   Harmonic filters serve to minimize or reduce harmonic distortion caused by SVC control devices such as TCR, TSC, and TSR. Harmonic filters consist of a combination of resistors, inductors, and capacitors that are specifically designed to reduce harmonic content in the system.

III. RESEARCH METHOD

A. Place And Time Research

The research was conducted at the Samarinda State Polytechic by collecting data on the electrical system of the Samarinda State polytechnic Computer Laboratory. The research was conducted from January to June 2025.

B. Types and Sources of Data

Data collection methods are writing techniques used to gather comprehensive, accurate, and easily understandable data and information about activities related to the implementation of a thesis. In this study, quantitative data was used, involving measurements and calculations. The data collected consiste of several power quality parameters, such as voltage, current, frequency, and harmonics.

C. Research Of Stage

The research preparation stage is the initial design stage related to Harmonic Reduction in the electrical system of the Computer Laboratory at the Samarinda State Polytechnic. This stage includes the preparation of a research framework, formulation of hypotheses, operationel definitions and measurement of variables, as well as the research format in the from of , methods and operational framework activities. The research implementation period is from March 18, 2025, to March 21, 2025.

D. Toold And Equipment

Table 2 lists several instruments and equipment used in this study.

Table 2 Equipment and Materials

No	Tool	Material
1	Laptop	Juornal Reference
2	Matlab Simulink Software	IEEE Std 519-2014
3	PQ One Software	
4	Microsoft Office Software	
5	Power Quality Analyser (PQA)	

E. Research Operation Flowchart

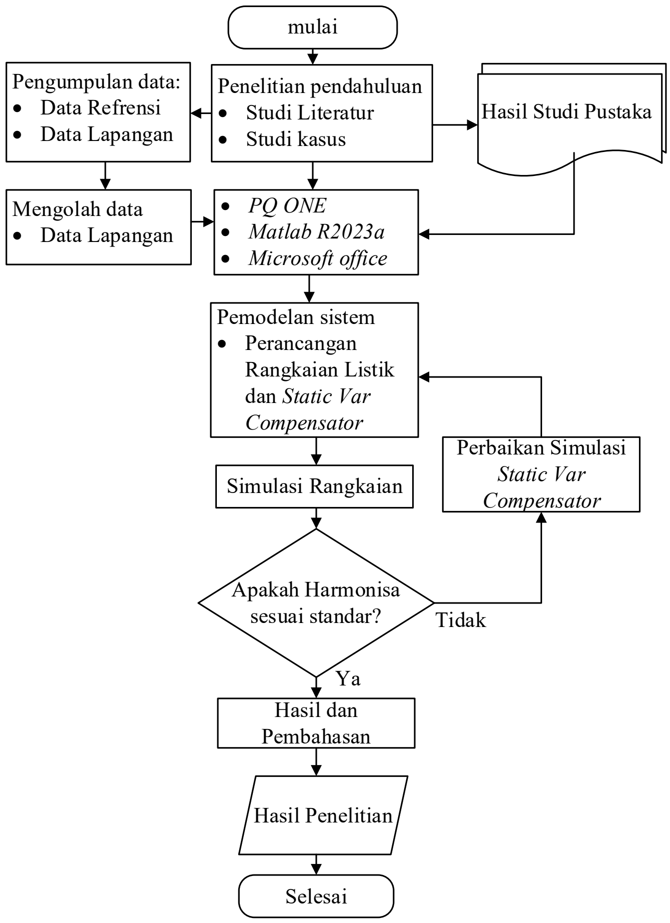

Figure 3 Operational Research Flowchart

Figure 3 shows a flowchart of the research operational framework that serves to describe the stages of research in a systematic and structured manner. This diagram simplifies the issues until the analysis and conclusion drawing process..

The diagram shown in Figure 3 simplifies the problem to the process of analysis and conclusion drawing. It can be seen that the research began with an introduction containing literature studies and case studies, followed by data collection in the form of reference data and field data. The field data itself consisted of load types and power quality parameters found in the Computer Laboratory, with power quality measurement data collected using a Power Quality Analyzer (PQA) measuring device.

After conducting circuit simulation tests and observing the harmonic values before and after using the Static Var Compensator, the research can proceed to the results and discussion if the values have reached the nominal standard limits for sudden voltage drops and surges. If the nominal limits have not been reached, then the Static Var Compensator will be remodeled and the simulation will be repeated. After that, the results of the Static Var Compensator and electrical system modeling simulation will be discussed, along with a discussion of power quality parameters in the Computer Laboratory. The final part of the research concludes with a summary of the research results.

F. Data Collection Stage

Next, the data collection stage involved gathering reference data, field data, and data from literature studies on Harmonisa improvements with the addition of a Static Var Compensator, as follows:

1. The data collection stage involves searching for reference data and data from literature studies related to previous research as a reference for the data needed to perform a Harmonisa improvement analysis with the addition of a Static Var Compensator..
2. Designing comprehensive strategies and work programs aimed at improving the effectiveness and efficiency of activities, including scheduling that supports the smooth collection of data. This step also ensures anticipation of possible obstacles that may arise during the implementation of the research.
3. Then, the location survey and power quality parameter measurement stages at the Computer Laboratory with the following requirements:
   - Permission to collect data and monitor measuring instruments at the Computer Laboratory.
   - Permission to borrow a Power Quality Analyzer (PQA) measuring instrument

***G.* Data Processing Stage**

The data processing stage is an activity carried out to examine the results of testing and measurement modeling to solve problems in this study. This stage includes:

1. Reference data, literature study data, and field data are analyzed using MS Office 2021 software: MS Word. The data is then input into Matlab Simulink software for SVC modeling and electrical system simulation in the Computer Laboratory.
2. The results of data processing in the form of SVC modeling and electrical systems in the Computer Laboratory are analyzed to determine the comparison of harmonics before and after mitigation

***H.* Analysis And Discussion Stage**

The analysis and discussion stage involves reviewing and examining the measurement results. This stage includes:

1. For the analysis stage, the measurement data that has been input into the Matlab Simulink program is compared during the voltage transition stability with the conditions after the Static Var Compensator is installed, thereby producing a simulation model in accordance with the standard nominal harmonic parameter values specified.
2. The final stage consists of the results and discussion, which will show the research results in the form of an electrical simulation model of the Computer Laboratory, and measurement data before and after using the Static Var Compensator based on the test results and analysis using the Matlab Simulink program (software).

***I.* Clossing Stage**

The final stage involves drawing conclusions in the form of a summary of the research results in the form of a simulation model based on the results of analysis and testing of harmonization improvements at the Computer Laboratory, and a summary of suggestions for further development and research.

J. ***Data Collection Results***

1) *Harmonized Data*

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Table 2. Third-Order Individual Harmonic Data on Thursday at 3:00 PM

Order	Thursday, March 20, 2025 at 3:00 PM IHDi-f (%)		
	R	S	T
3	58.34	71.90	60.37
4	25.46	42.33	28.75
5	47.42	51.02	54.05
6	10.77	17.08	14.20
7	32.33	32.86	34.54
8	7.55	11.62	6.34
9	25.81	26.33	24.48
10	4.59	10.05	5.22
11	20.95	22.09	18.58
12	3.46	6.56	3.59
13	18.38	16.95	15.59
14	3.02	5.83	2.70
15	12.46	10.64	12.34
16	2.00	4.42	2.59
17	6.95	6.11	7.23
18	1.54	3.32	1.36
19	8.82	5.67	6.94
20	1.23	3.18	1.21
21	7.04	6.30	7.34
22	1.03	2.29	1.13
23	6.54	4.65	7.88
24	0.80	2.21	0.76
25	4.44	3.64	4.48
26	0.73	1.97	0.84
27	4.44	3.72	3.94
28	0.75	1.70	0.71
29	3.91	3.18	4.76
30	0.63	1.70	0.55
31	3.46	2.31	3.77
32	0.65	1.28	0.64
33	4.18	3.06	4.07
34	0.44	1.24	0.56
35	3.90	3.05	3.20
36	0.46	1.03	0.48
37	3.76	3.17	2.54
38	0.41	0.84	0.65
39	4.68	2.10	2.27
40	0.40	0.94	0.67
41	2.77	1.43	3.85
42	0.39	0.70	0.58
43	4.20	3.19	3.19
44	0.40	0.78	0.43
45	4.19	2.93	1.37

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Order	Thursday, March 20, 2025 at 3:00 PM IHDi-f (%)		
	R	S	T
46	0.39	0.59	0.46
47	1.92	1.23	2.77
48	0.37	0.58	0.51
49	2.86	2.25	2.40
50	0.34	0.66	0.46

2) Computer Laboratory Equipment Data And 800kVA Transformer of Samarinda State Polytechnic

The Samarinda State Polytechnic Computer Laboratory is equipped with various electrical equipment to support lecture activities as shown in Table 4 below

Table 4. Components in a Computer Laboratory

Room	**Peralatan Listrik**
Lab. A	Computers = 29 Air Conditioner 1/2 PK = 2 Air Conditioner 1 PK = 1 Proyektor = 1
Lab. B	Computers = 26 Lamps = 6 Air Conditioner 1 PK = 2 Proyektor = 1 Cctv = 2
Lab. C	Computers = 26 Lamps = 6 Air Conditioner 1 PK = 2 Proyektor = 1 Cctv = 2
Lab. D	Computers = 26 Air Conditioner 1/2PK = 1 Air Conditioner 1 PK = 2 Proyektor = 1
Lab. E	Computers = 26 Air Conditioner 1/2PK = 1 Air Conditioner 1 PK = 2 Proyektor = 1
Technician Room	Computers = 4 Lamps = 5

Table 4 shows data on equipment in the Computer Laboratory of the Samarinda State Polytechnic that supports teaching needs.

3) Name Plate Transformator 800kVA Politeknik Negeri samarinda

The 800kVA transformer at the Samarinda State Polytechnic has a nameplate that provides information on the transformer specifications, which are needed as parameters to determine the full load current in calculating the harmonic value. An image of the nameplate of the 800kVA transformer at the Samarinda State Polytechnic can be seen in Table 5.

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Table 5. Data Name Plate Transformator 800 KVA Politeknik Negeri Samarinda

Parameter	Keterangan
Number of phase	3
Rated Frequency (Hz)	50
Rated Capacity (kVA)	800
Rated Voltage (HV) V	20000
Rated Voltage (LV) V	400
Rated Current (A)	23,09
Rated Current (A)	1154,70
Impedance	4,5

Table 5 shows the name plate of the 800 kVA transformer at the Samarinda State Polytechnic.

IV. RESULT AND DISCUSSION

A. Overview

This chapter explains the results of the analysis and simulation conducted based on research carried out on the electrical system at the Samarinda State Polytechnic Computer Laboratory. From the measurement values obtained over a week, the highest THDi value was recorded on Thursday at 15:00 WITA. The simulation will be carried out on the day when the harmonics are below the applicable standard, with the highest harmonics value being on Thursday at 15:00 WITA. The first step in overcoming this problem is to calculate the short-circuit current (Isc), load current (IL), and SC ratio (Scratio). Next, determine the capacity of the Static Var Compensator (SVC). Then add the Static Var Compensator to the simulation that has been calculated previously, with the aim of achieving the desired conditions to reduce harmonics. This simulation of adding a Static Var Compensator uses MATLAB R2023a software to model the SVC design.

B. Harmonic Standard Calculation Based on IEEE 519 – 2014

To determine the tolerance limit standards for harmonic values in an electrical system, an analysis is conducted based on the provisions listed in the IEEE 519-2014 standard. This standard sets the maximum Total Harmonic Distortion (THD) limit for voltages permitted in electrical systems. This standard also sets the maximum Total Demand Distortion (TDD) for individual harmonics of a certain order. These limits are the ratio between the short-circuit current (Isc) and the maximum load current (IL), known as the short-circuit ratio (SCratio). The SCratio value is used as a reference in determining the system category and setting the permissible TDD threshold. The first step is to calculate the short-circuit current Isc at the PCC (point of common coupling), which is the connection point between the utility system and the load, using equation (5)

$$I_{sc} = \frac{100\ x\ 152kVA}{4{,}5\ x\ \sqrt{3}\ x\ 0{,}4} = 25{,}660\text{ A} \quad (5)$$

Description:

System Voltage = 0.4 kV
Impedance (%) = 4.5%
Total Power = 152 kVA

With the short-circuit current value and maximum load current value obtained from the transformer nameplate, the short-circuit ratio on Thursday at 15:00 WITA can be determined using the following formula:

$$Sc_{ratio} = \frac{25{,}660\ A}{1154{,}7\ A} = 22{,}22\ A \quad (6)$$

Keterangan :

Short Circuit Current Value : 25,660 A
Maximum Load Current Value : 1154,7 A

Based on the calculations that have been carried out, the value obtained for Thursday, as well as for Wednesday and Friday, is 22.22 amperes. According to the IEEE 519-2014 standard, values between 20 and 50 have a TDD standard of 8.0. In addition, this standard also determines the maximum harmonic current limit for each order, namely Individual Harmonic Distortion (IHD). For low-order harmonics, which are in the range of the 3rd to 11th order, the maximum permissible IHD limit is 7%. For the 11th to

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17th orders, it is 3.5%, for the 17th to 23rd orders, it is 2.5%, for the 23rd to 35th orders, it is 1%, and for the 35th to 50th orders, it is 0.5%. The calculation results are for 3 days based on the overall data.standar ini juga menetapkan ambang batas untuk Individual Harmonic Distortion pada tiap orde (IHDi). For each harmonic order component, the maximum permissible value is 5%. The IEEE 519-2014 standard also sets a maximum TDD value limit for SCratio between 20<50 at 8.0%, where the SCrasio value is applied to calculations on Wednesday, Thursday, and Friday.

Table 5. Maximum TDD Value Limit

Hari	Jam	Sc*ratio* Perhitungan	Standar IEEE 519 - 2014	TDD MAX
Rabu	15.00	22,22	20<50	8.0
Kamis	15.00	22,22	20<50	8.0
Jumat	15.00	22,22	20<50	8.0

C. Electrical System Simulation Results at the Samarinda State Polytechnic Computer Laboratory on Thursday Without a Static Var Compensator

In this section, a simulation of a three-phase electrical system without using a Static Var Compensator (SVC) is performed. This simulation is designed to describe the conditions of the electrical system at the Computer Laboratory of the Samarinda State Polytechnic. In this simulation model, the three-phase voltage source is directly connected to the load and equipped with measurements that include voltage, current, active power, reactive power, apparent power, and power factor parameters.

The purpose of this simulation is to obtain initial data on the system conditions before mitigation measures are taken. By comparing the simulation results with field measurement data, it can be determined whether they are consistent or not, so that they can be used as a basis for evaluation and technical recommendations for the electrical system. The data used in the simulation is from Thursday, because on that day the worst harmonic values were recorded. The simulation scheme was built using MATLAB Simulink software, as shown in Figure 4 below

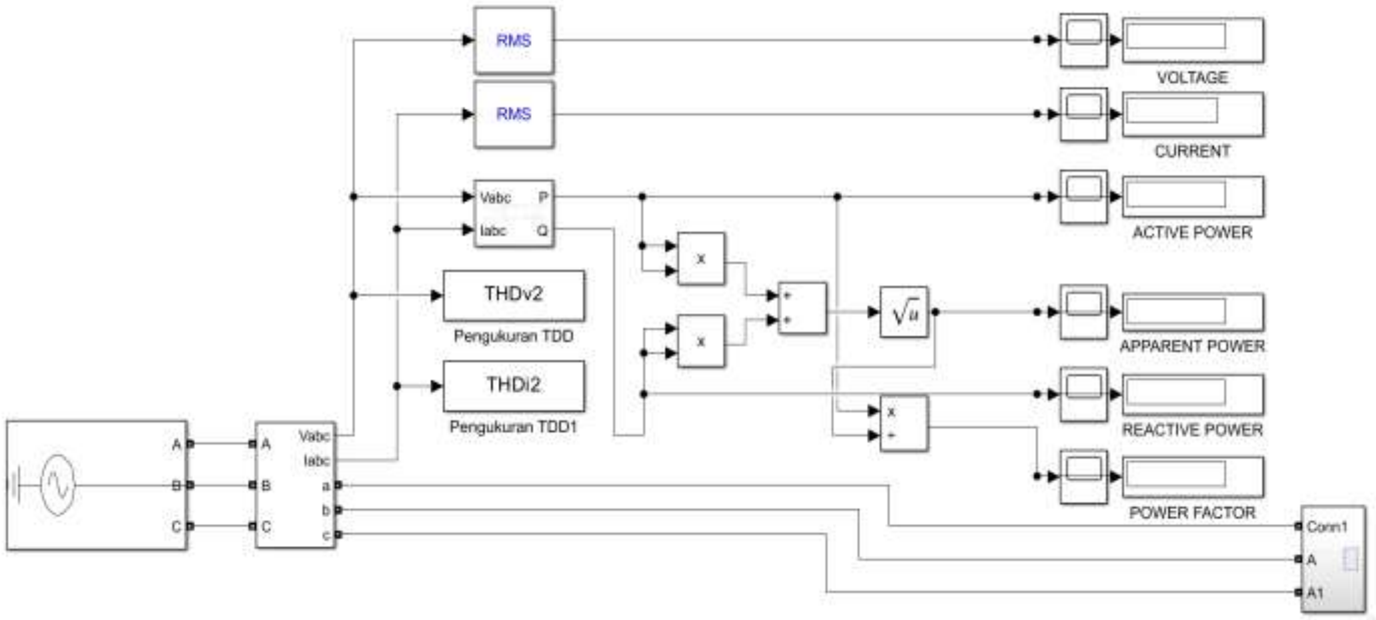

Figure 4 Operational Research Flowchart

From Figure 4, it can be seen that the THDi value in phase R is 33.65, which is the same as the measurement result, meaning that this simulation model is quite good at describing the actual conditions of the system. Referring to the SCratio value obtained

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IJCSRR @ 2025
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previously, the THDi level in phase R is relatively high because it exceeds the standard threshold of 15%. The individual harmonic distortion (IHDi) of phase R during the simulation before mitigation can be seen in Figure 5.

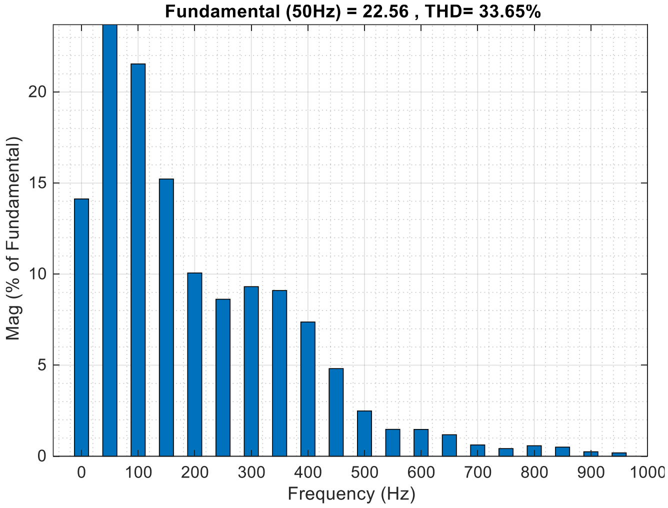

Figure 5 individual harmonic distortion (IHDi) of phase R during the simulation before mitigation

Next, in phase S during measurement and simulation before mitigation, which can be seen in Figure 6, shows the simulation results of the current harmonic values in the system. From these results, it is known that the THDi value in phase S is 15.85%. This value is in accordance with the measurement results that have been carried out and applied in Simulink, where this simulation model is quite good at describing the actual conditions of the system. Based on the previously calculated SCratio value, the THDi value in all three phases is high because it exceeds the standard limit of 15%. The individual harmonic distortion (IHDi) value for phase S during the simulation before mitigation can be seen in Figure 6.

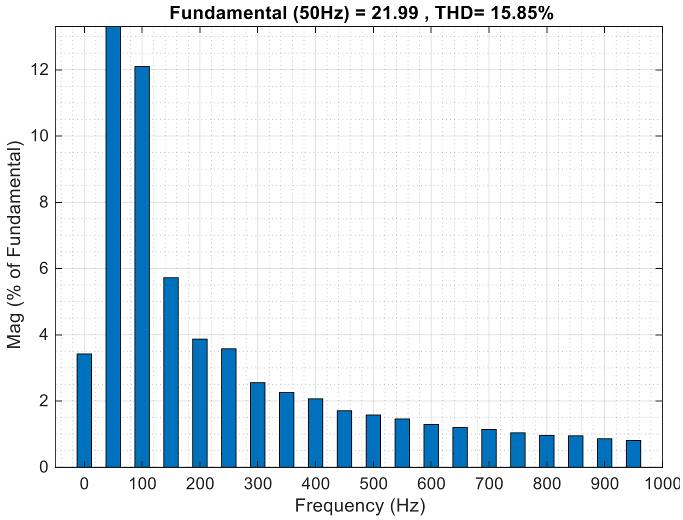

Figure 6 individual harmonic distortion (IHDi) value for phase S during the simulation before mitigation

Furthermore, phase T reached 92.98%. This value is quite close to the field measurement results, which means that this simulation model is quite good at describing the actual conditions of the system.

Although there is a slight difference between the simulation results and the actual data, the difference is not too significant, so the model can still be considered valid. The individual harmonic distortion (IHDi) of phase T during the simulation before mitigation can be seen in Figure 7

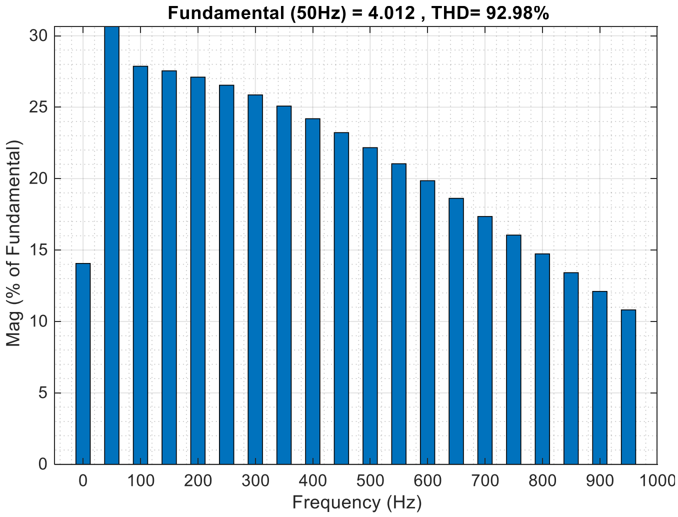

Figure 7 individual harmonic distortion (IHDi) value for phase S during the simulation before mitigation

Next, the comparison graph for the third harmonic order is taken from the phase R measurement value, which can be seen in Figure 8.

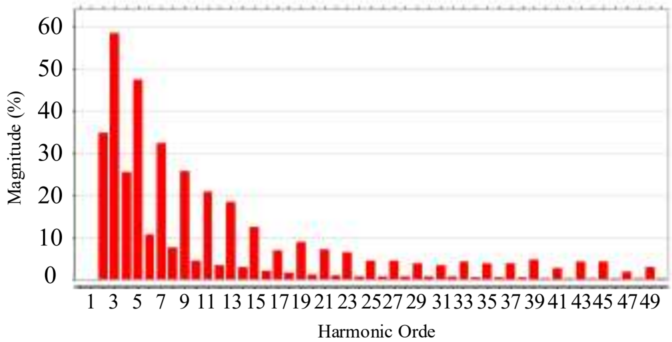

Figure 8 comparison graph for the third harmonic order is taken from the phase R measurement value

From the measurement results graph, it can be seen that the 3rd order phase R in Figure 8 reaches 58.34%. This value is used as a comparison and will be mitigated to improve the individual harmonic distortion (IHDi) value. This value exceeds the harmonics limit allowed according to IEEE 519-2014, which is 7.0%.

Furthermore, for comparison during measurement, the individual harmonic value of the 3rd order phase S can be seen in Figure 9.

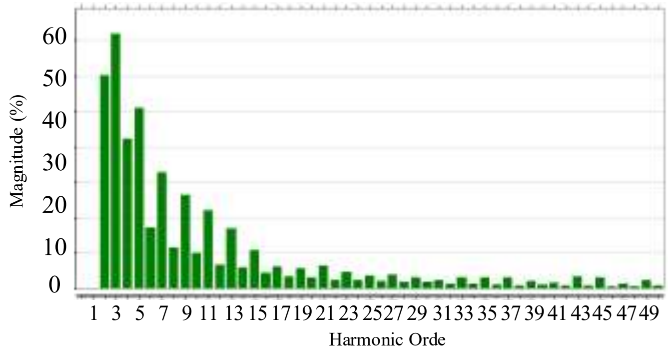

Figure 9 Furthermore, for comparison during measurement, the individual harmonic value of the 3rd order phase S

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IJCSRR @ 2025
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From the measurement results graph, it can be seen that the 3rd order S phase reaches 71.90%. This value is used as a comparison and will be mitigated to improve the individual harmonic distortion (IHDi) value. This value exceeds the harmonics limit allowed according to IEEE 519-2014, which is 7.0%.

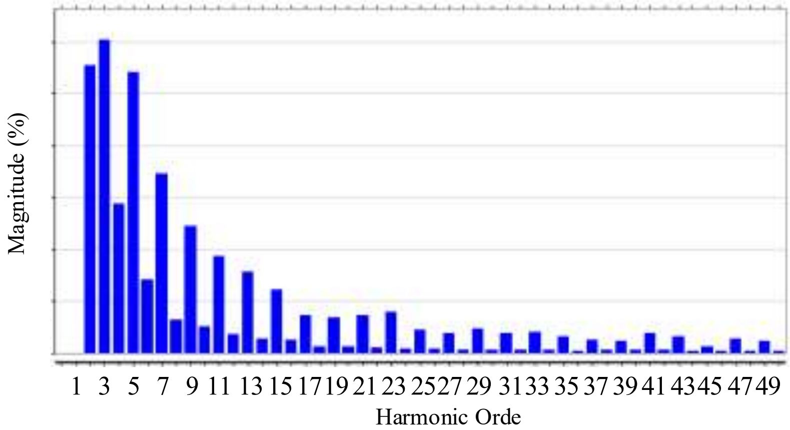

Figure 10

From the measurement results graph, it can be seen in Figure 10 that the third-order T phase reaches 60.37%. This value is used as a comparison and will be mitigated to improve the individual harmonic distortion (IHDi) value. This value exceeds the harmonics limit allowed according to IEEE 519-2014, which is 7.0%.

The IEEE 514-2014 standard uses Total Demand Distortion (TDD) as a reference, not Total Harmonic Distortion (THD) as is usually displayed by measuring instruments. This means that if we only have THD data from the measurement results, that data cannot be directly compared with the limits in the standard. Therefore, the THD value must first be converted to a TDD value using the following equation:

Phase R : TDDi = $\frac{33{,}65 \ x\ 14{,}22}{1154} = 0{,}414\%$

Phase S : TDDi = $\frac{15{,}85 \ x\ 13{,}26}{1154} = 0{,}182\%$ (7)

Phase T : TDDi = $\frac{92{,}99 \ x\ 2{,}68}{1154} = 0{,}215\%$

From the value calculation, the TDD limit for this system is 8%. The above calculation results show that the TDD values for all phases are well below this threshold.

Although the overall TDD meets the standard, the standard set by IEEE 514-2024 also sets limits for harmonics at each order or Individual Harmonic Distortion (IHDi). This analysis is important to identify orders that exceed the standard limits, or are quite high, such as order 3, which is quite high in all three phases in the measurement graph shown in Figures 8 to 10.

D. Static Var Compensation Planning

It is known from the simulation results that before the Static Var Compensator was installed, the harmonic current (THD) value exceeded the IEEE 519-1014 standard by 15%. Therefore, a Static Var Compensator was planned to reduce the high harmonic value. To determine the C value in the static var compensator, the following formula can be used:

$QC = P\,(\tan\varphi 1 - \tan\varphi 2)$ (8)

Where :

P = 2161 Watts

Cos φ1 = 0,96 then Tan φ1 = 0,291

Cos φ2 = 0,99 then Tan φ2 = 0,142

Therefore:

Qc = 2161 (0,291 – 0,142)

= 321,98 Var

Since three stages are used, the total reactive power requirement is divided by 3, so 321.98/3 = 107.32 Var per stage. With the above reactive power compensation value, the capacity value can be calculated as follows:

$Ic = \frac{Qc}{V}$ (9)

Where:

Reactive Power = 107,32 Var
Voltage = 220 Volt
Frequency = 50 Hz

Therefore :

$$Ic = \frac{107,32}{220} = 0,487\ A$$

After determining the capacitor current value, calculate the capacitive reactance (Xc) using equation (8).

$Xc = \frac{V}{Ic}$ (10)

therefore :

$$Xc = \frac{220}{0,451} = 451,74\ ohm$$

After calculating and determining the reactive power requirements, capacitor current values, and capacitive reactance values, the last step is to calculate the capacitor capacity (C) used with the equation

$C = \frac{1}{2\pi FXc}$ (11)

therefore :

$C = \frac{1}{2\ x\ 3,14\ x\ 50\ x\ 451,74} = 70,49\mu F$ (12)

E. Electrical System Simulation Using Static Var Compensator

This repair simulation was carried out using a reactive power compensation device, namely a Static Var Compensator (SVC) consisting of three Thyristor Switched Capacitor (TSC) units. The purpose of this simulation was to reduce harmonic values that exceeded standard limits with the help of SVC. The simulation process was run using MATLAB Simulink software, with the same circuit configuration as in the previous simulation without SVC. Thus, the simulation results could be directly compared to see the difference in electrical system performance before and after installing SVC.

This simulation was designed to describe the conditions of the electrical system at the Samarinda State Polytechnic Computer Laboratory and to improve the harmonic values that previously exceeded standard limits. The results showed a significant improvement in harmonics. The results of this simulation will be analyzed based on the harmonic parameters shown in Figure 11.

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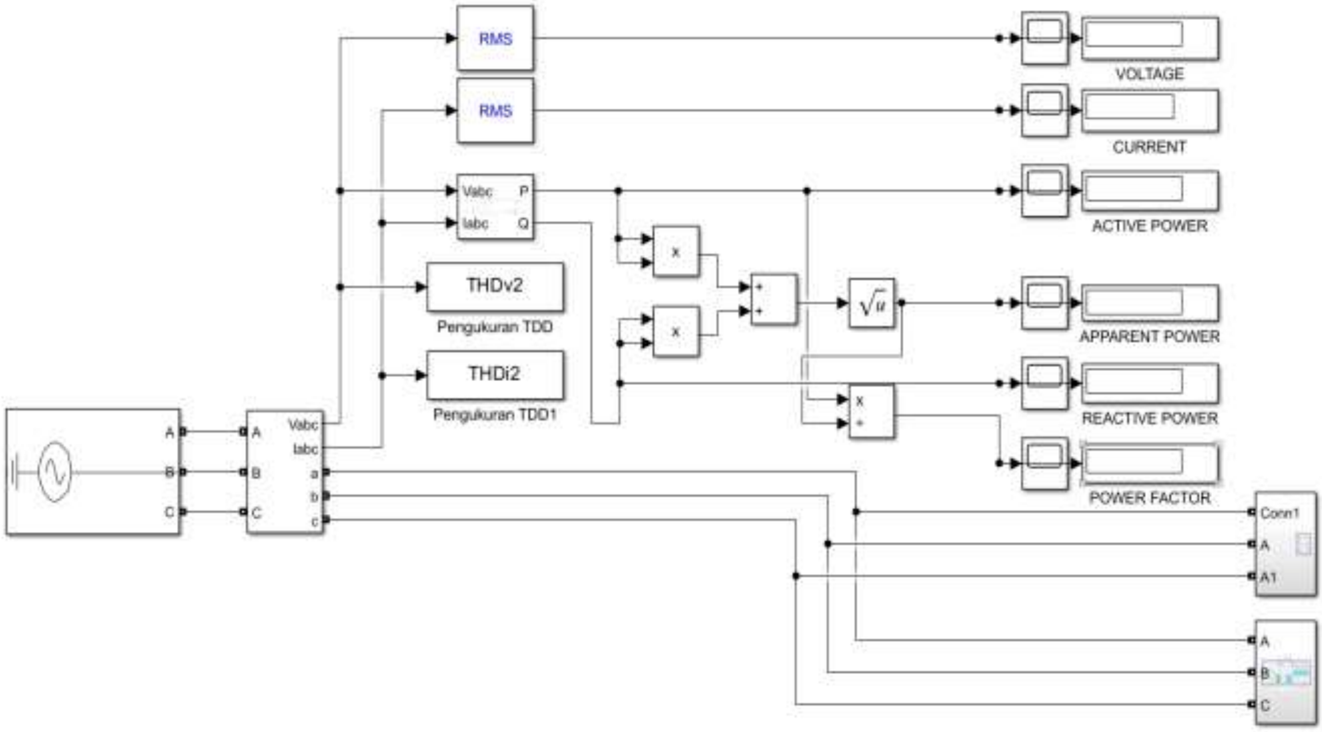

Figure 11 Operational Research Flowchart

Reactive power compensation is a crucial strategy in maintaining the stability and efficiency of electrical systems. In this context, simulations of electrical system improvements have been carried out using Static Var Compensators (SVCs). The simulated SVC consists of three Thyristor Switched Capacitor (TSC) units, each with a capacity of 107.32 VAr. This component is designed to automatically compensate for the system's reactive power requirements through integrated control.

The main objective of this simulation is to analyze and optimize the performance of the electrical system by reducing harmonics and improving the power factor that does not meet standards. To achieve this goal, the simulation was run using MATLAB Simulink software. The approach used was to compare the performance of the electrical system before and after the integration of the SVC module. This allowed for an evaluation of the impact of SVC on critical system parameters.

The simulation design included the integration of the SVC module into the electrical system of the Samarinda State Polytechnic computer laboratory. In addition to SVC, a step-down transformer was also used to ensure the system voltage was compatible with the SVC module specifications. This study involved comprehensive electrical parameter measurements, such as Individual Harmonic Distortion (IHDi) and Total Harmonic Distortion (THD), to obtain a complete picture of the effectiveness of SVC implementation.

The THD and IHDi values in the simulation with the addition of a Static Var Compensator can be seen in Figure 12. Based on Figure 12, which shows the FFT (Fast Fourier Transform) Analyzer, the R phase harmonics after the installation of the Static Var Compensator, whereas before the installation of the Static Var Compensator in Figure 5, the harmonics value was 33.65%. However, after installing the Static Var Compensator in the electrical system simulation at the Samarinda State Polytechnic Computer Laboratory on Thursday at 3:00 PM WITA, the harmonic value improved, falling below the specified standard value with a harmonic value of 9.81%, a reduction of 23.84%.

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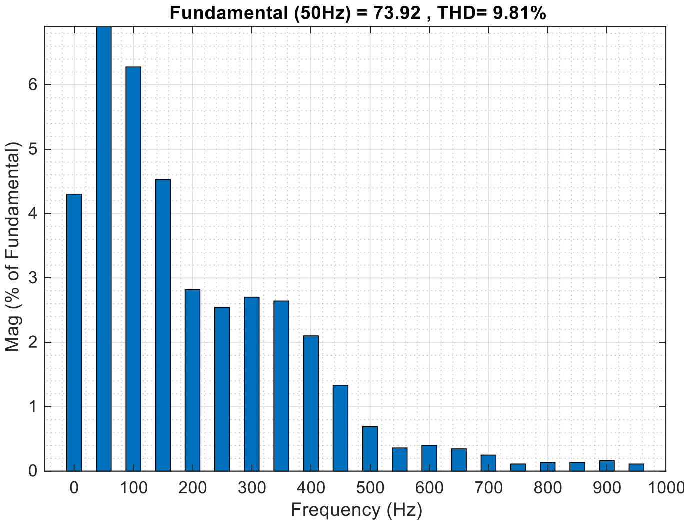

Figure 12

Based on Figure 13, which shows the FFT (Fast Fourier Transform) Analyzer, the R phase harmonics after the installation of the Static Var Compensator, whereas before the installation of the Static Var Compensator in Figure 6, the harmonics value was 15.85%. However, after installing the Static Var Compensator in the electrical system simulation at the Samarinda State Polytechnic Computer Laboratory on Thursday at 3:00 p.m. WITA, the harmonic value improved, falling below the specified standard value to 10.98%, a reduction of 4.87%.

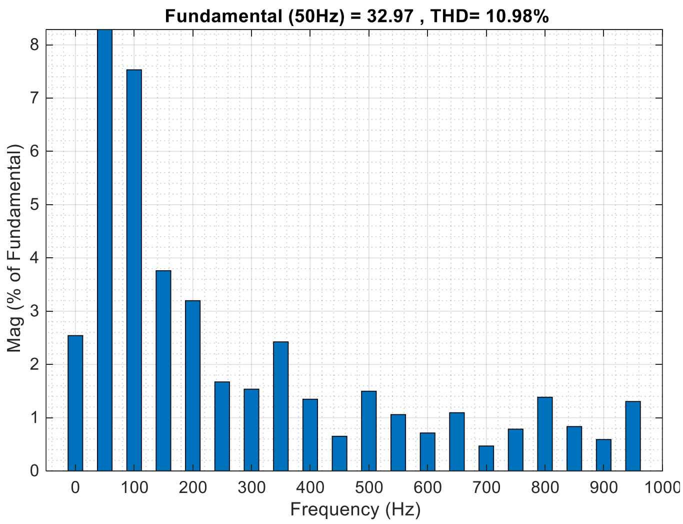

Figure 13

Based on Figure 13, which shows the FFT (Fast Fourier Transform) Analyzer, the harmonic phase T after the installation of the Static Var Compensator, whereas before the installation of the Static Var Compensator in Figure 7, the harmonic value was 92.98%. However, after installing the Static Var Compensator in the electrical system simulation at the Samarinda State Polytechnic Computer Laboratory on Thursday at 3:00 p.m. WITA, the harmonic value improved, falling below the specified standard value of 9% with a harmonic value reduction of 83.98%.

Phase T Harmonic Results in the Simulation After Using SVC

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F. Comparison Results Before and After Using the Static Var Compensator

After conducting an electrical system simulation at the Computer Laboratory of the Samarinda State Polytechnic, both with and without the use of a Static Var Compensator, the results showed significant differences in various parameters. The comparison between the conditions before and after using SVC aims to assess the effectiveness of the reactive power compensation method using SVC, in terms of energy efficiency, system stability, and the quality of the electrical power produced.

Before installing SVC, the system experienced power quality problems, such as high levels of harmonic distortion in the current. This condition indicates that the system was not working efficiently. After the installation of the SVC, which consisted of three Thyristor Switched Capacitors (TSCs), the system underwent significant changes. The reactive power compensation performed by the capacitors in the SVC was able to reduce system harmonics more efficiently. Table 6 below presents a complete comparison of system parameters before and after the installation of the SVC.

The purpose of this test is to test the accuracy of the current reading results on the PZEM-004Tv30 current sensor with an Ampere meter measuring device. The test results of the PZEM-004Tv30 current sensor can be seen in Figure 9.

Table 6. Comparison of Electrical Parameters Before and After Installation of Static VAR Compensator

parameters	Before Using SVC	After Using SVC
R Phase Voltage (V)	235,60	235,60
S Phase Voltage (V)	233,56	233,56
T Phase Voltage (V)	237,06	237,06
R Phase Current (A)	14,22	50,14
S Phase Current (A)	13,26	24,77
T Phase Current (A)	2,68	30,74
Active Power (W)	6484,26	8203,56
Daya Apparent (VA)	6723,78	8562,78
Reactive Power (VAR)	1778,67	2454,13
THDi *Phase* R	33,65	9,81
THDi *Phase* S	15,85	10,98
THDi *Phase* T	92,99	9
IHDi 3rd (%) *phase* R	28,39	4,53
IHDi 3rd (%) *phase* S	8,5	3,76
IHDi 3rd (%) *phase* T	57,50	2,63
TDD (%) *Phase* R	0,414	0,120
TDD (%) *Phase* S	0,182	0,126
TDD (%) *Phase* T	0,125	0,020

The installation of SVC has a significant effect on reducing Total Harmonic Distortion (THDi). In phase R, THDi decreased from 33.65% to 9.81%, in phase S from 15.85% to 10.98%, and in phase T from 92.98% to 9%. The third-order Individual Harmonic Distortion (IHDi) value in phase R decreased from 28.39% to 4.53, in phase S from 8.75% to 3.76%, and in phase T from 57.50% to 2.63%. Total Demand Distortion (TDD) decreased from 0.414% to 0.120% in phase R and from 0.125% to 0.020% in phase T. Thus, after installing the SVC, all phases met the applicable harmonics standards.

In addition, there was an increase in current in all phases after the use of SVC. The current in phase R increased from 14.22 A to 50.14 A, phase S from 13.26 A to 24.77 A, and phase T from 2.68 A to 30.74 A. This increase in current was a result of the increase in active power in the system. Although there was an increase in current, this was not considered a disturbance, but rather a consequence of improved system efficiency.

Considering all of the above parameters, it can be concluded that the installation of a Static Var Compensator (SVC) has a positive impact on the power quality of the electrical system at the Samarinda State Polytechnic Computer Laboratory. The use of SVC has been proven to increase power efficiency and reduce harmonic distortion to within the established standard limits.

V. CONCLUSIONS AND RECOMMENDATION

A. Conclusions

Based on the results and discussion in terms of reducing harmonic values in the electrical system of the Samarinda State Polytechnic Computer Laboratory, as explained in Chapter IV above, the following conclusions can be drawn: Simulasi sistem kelistrikan sebelum menggunakan Static Var Compensator pada Laboratorium Komputer Politeknik Negeri Samarinda. Hasilnya mendekati dengan hasil pengukuran yang dilakukan.

1. Simulation of the electrical system before using a Static Var Compensator in the Samarinda State Polytechnic Computer Laboratory. The results are close to the measurement results.
2. The condition of the electrical system at the Computer Laboratory of the Samarinda State Polytechnic, according to the IEEE 519-2014 standard, is that the Total Demand Distortion is 8%, and from the calculations obtained, the TDD value is far below the specified limit, but in the 3rd order, the Individual Harmonic Distortion (IHDi) limit can be reduced well below the required standard of 7%. During the simulation, with the addition of SVC, the IHDi value in phase R, which was previously 28.39%, can be reduced to 4.53%, in phase S from 8.75% to 3.76%, and in phase T from 56.50% to 2.63%. This indicates that SVC can reduce harmonics at certain orders and total harmonic distortion of current.

B. Recommendations

The installation of a Static Var Compensator in the electrical simulation of the Samarinda State Polytechnic Computer Laboratory requires a total reactive power compensation of 321.98 Var, divided into 3 stages, so that each stage requires a compensation of 107.32 Var, using capacitors with a capacity of

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