ESTIMATION AND MINIMIZATION OF HARMONICS IN IEEE 13 BUS DISTRIBUTION SYSTEM WITH ADJUSTABLE SPEED DRIVE LOADS USING PASSIVE FILTERS

Nureni[1)], Sofyan Sofyan[1,3)], Satriani Said Akhmad[1)], Kurniawati Naim[1)], Andi Fitiati[1)] Lari Andres Sanjaya[4)]

[1]Departmet of Electrical Engineering, State Polytechnic of Ujung Pandang, Makassar, 90234, Indonesia.
[2]Departmet of Mechatronics Engineering, Polytechnic of Bosowa, Makassar, 90234, Indonesia.
[3]Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor, Johor, Malaysia.
[4]Department of Physics Education, Faculty of Mathematics and Natural Sciences, Universitas Negeri Jakarta, Jakarta, Indonesia

email: nureni7887@gmail.com; sofyantato@poliupg.ac.id; satrianisaid86@gmail.com; nianaim@poliupg.ac.id; afitriati@politeknikbosowa.ac.id; lasanjaya@unj.ac.id

Abstract

Improving power quality in electrical distribution systems is increasingly important with the increasing use of nonlinear loads, such as Adjustable Speed Drive (ASD), which can produce harmonies. This harmonic has the potential to damage equipment, reduce system efficiency, and interfere with power quality. Distribution systems such as IEEE 13 Bus are often used for power quality management analysis. Through simulation, researchers can identify the source and impact of harmonics and evaluate solutions, such as the application of passive filters that absorb or divert harmonic currents, to reduce their negative effects in the distribution system. In this study, two power sources, several transformers, static loads, and nonlinear loads in the form of Adjustable Speed Drive (ASD) were used. The simulation was carried out using Simulink R2019b to model the distribution network, generators, transformers, and loads. The simulation results show that the Adjustable Speed Drive (ASD) load can produce a total harmonic current distortion (THDi) of 24.62% in bus 7, while the total harmonic voltage distortion (THDv) is 0.97%. To minimize harmonic values, passive filters with variations of RL, RC, LC, and RLC are used. The results show that the use of RL passive filters is more effective in reducing THDi and THDv values in bus 7 by 24.47% and 0.97%.

Keywords: *Harmonics, Adjustable Speed Drive, passive filters, THDi, THDv.*

I. INTRODUCTION

Currently, the community's need for electrical energy has increased significantly. Almost all daily activities are highly dependent on the availability of electrical energy [1]. This increase in demand goes hand in hand with the advancement of science and technology in the field of power electronics. Developments in science and technology have resulted in increasingly sophisticated electronic equipment. The impact of this more modern electronic equipment also affects the types of electrical loads used [2].

In an electric power system, there are two main types of loads, namely linear loads and non-linear loads [3]. Linear loads are loads that have a sinusoidal current waveform, whereas non-linear loads produce non-sinusoidal current waveforms due to distortions caused by harmonic currents arising from various electronic devices [4].

Harmonic distortion in the electric power system causes losses in the form of deterioration in the quality of the electric power system. Previous research has shown that harmonics can significantly affect power quality. According to Gupta et al. [5], the application of active filters can reduce total harmonic distortion (THD) by up to 50% in affected distribution systems. Some examples of the negative impact of this degradation include increased temperatures in electrical equipment, decreased power factors, and resonance issues, among other issues [6]. To improve the quality of the electric power system, harmonic distortion needs to be suppressed to a minimum. According to research conducted by S. Sulis, P. A. Pegoraro, A. V. Solinas, and D. Carta, One effective method to reduce harmonics is to use a filter [7].

Therefore, this study aims to analyze the harmonic content produced by the nonlinear load, namely Adjustable Speed Drive (ASD), and then design a single tuned passive filter to reduce the harmonics to meet the IEEE 519-2014 standard.

II. LITERATURE REVIEW

A. Harmonics in the Distribution System

Harmonics can be expressed as a disturbance that occurs in the electrical power distribution system due to the distortion of current and voltage waves so that waves with frequencies of round multiples of the fundamental frequency occur [8].

In an electric power system, the standard operating frequency is 50 Hz or 60 Hz. However, in practice, based on the type of load used, the frequency of current and voltage can change from the normal value or become a multiple of the standard frequency of 50/60 Hz. This phenomenon is known as harmonic [9].

Harmonics are caused by the presence of nonlinear loads used in electric power systems. Equipment such as converters, rectifiers, adjustable speed drives to control industrial motors, as well as various equipment based on the switching process can create harmonization [10].

B. *Adjustable Speed Drive (ASD)*

A Variable Speed Drive (ASD) is a device that utilizes a diode as a rectifier to convert alternating current voltage into direct voltage, which is then converted back into alternating voltage. According to the IEEE 519-2014 standard, ASD belongs to the category of nonlinear loads that can cause harmonic waves [11].

ASD consists of an induction motor fed by a variable AC voltage obtained from a converter. Therefore, ASD consists of three main components: the first is the front end, which is usually a 6 or 12-pulse rectifier. The second component is an inverter that converts the generated DC voltage into a controllable frequency and the AC voltage to control the speed of the motor [12].

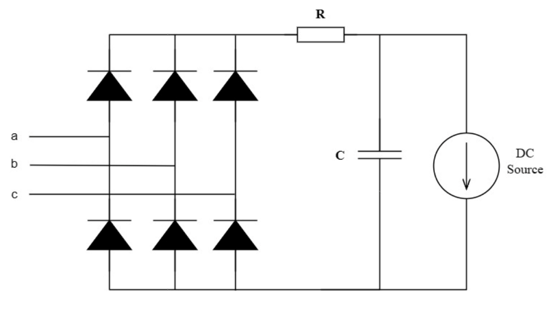

Figure 1 Generic Converter Network for ASD

The harmonics injected by the inverter largely depend on the inverter topology and the characteristics of the motor. Therefore, ASD can be modeled with a common three-phase bridge converter circuit along with a DC link circuit and a harmonic current source to represent the inverter and motor [13] as shown in Figure 1.

C. IEEE 519-2014 Standardization

Harmonic standards set limits on harmonic values in electrical systems with the aim of minimizing the negative impact caused by harmonics. One of the institutions that set harmonised standards is the IEEE (Institute of Electrical and Electronics Engineers). IEEE is an international organization in the field of engineering responsible for developing reference standards in electrical and electronics and accelerating the adoption of new technologies in industry and engineering. Harmonic value limits for voltage and current waves are regulated in the IEEE 519-2014 standard [5].

Based on IEEE 519-2014, to evaluate harmonic standards there are two criteria used, namely the limit for voltage harmonic (THDv) and the limit for current harmonic (THDi). The limit for voltage harmonics (THDV) is determined by the amount of voltage the system is installed in. Meanwhile, the current harmonics (THDI) are determined by the ISC/IL comparison, where ISC is the short-circuit current in the PCC (Point of Common Coupling), and IL is the nominal fundamental load current [14]. The value of the short link (SC_{ratio}) can be determined by using the following formula: [15]

$$SC_{ratio} = \frac{I_{SC}}{I_L} \quad (1)$$

$$I_{sc} = \frac{1000 \times MVA}{\sqrt{3} \times KV} \quad (2)$$

$$I_L = \frac{kW}{PF \times \sqrt{3} \times KV} \quad (3)$$

where:
SC ratio = Short circuit ratio
Isc = Maximum short-circuit current (A)
IL = Maximum load current (A)
kW = Total active power (Watts)
PF = System power factor

The harmonic distortion standards used based on IEEE standards for voltage and current can be seen in the following table: [16]

Table 1 Harmonic Standards for Voltage

Maximum Distortion (in %)	System Voltage		
	Under 69kv	69-138 kv	>138 kv
Individual Harmonics	3	1,5	1
Total Harmonics	5	2,5	1,5

Table 2 Harmonic Standards For Current

I_{sc}/I_{load}	Orde of Harmonisa (In %)					Total Harmonics
	<11	11-16	17-22	23-24	>35	
<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

D. Passive Filter Design

A commonly used method for harmonic compensation involves applying different types of filters, including active, hybrid, and passive filters. Passive filters show performance reliability, cost efficiency, and easy maintenance so they are widely chosen for harmonic mitigation, in addition to reducing harmonics, passive filters also function as reactive power compensators [17].

The most commonly used passive filter for harmonic mitigation is the single tuned (STF) filter, which can function as a low pass or band pass filter. This filter is the simplest type in terms of design and the most economical in its application. This filter consists of R (resistance), L (Inductance), and C (Capacitance) values arranged in series [18].

E. *Matrik Laboratory* (MATLAB) R2019b

Matlab is computer software designed to solve a variety of mathematical problems that are often encountered in the field of engineering. Matlab stands for Matrix Laboratory. In this study, the R2019b version from Matlab was used.

One of the tools that is very useful in MATLAB is FFT (Fast Fourier Transform) analysis. FFT is a numerical method that allows users to convert signals from the time domain to the frequency domain with high efficiency. Using FFT, users can analyze the frequency components of the signal, which is particularly useful in various applications such as signal processing, vibration analysis, and audio programming [19].

MATLAB provides easy-to-use FFT functionality, allowing researchers and engineers to perform spectral analysis quickly and accurately. The tool also comes with a variety of additional features for data visualization, such as spectrum and power spectrum graphs, which help in better understanding and interpreting the results of frequency analysis [20].

III. RESEARCH METHODS

The research procedure begins with the collection of data regarding the distribution network and the type of load that exists. Next, simulations are carried out to evaluate the presence of harmonic injection into the system. When harmonics are not detected, the design of the network and nonlinear load models is developed using Simulink MATLAB. Conversely, if harmonics are detected, the filter will be installed on a specific bus in the system. After the installation of the filter, an analysis is carried out to determine if there is a reduction in harmonics. When a reduction in harmonics is achieved, the process is considered complete. However, if the reduction of harmonics is not sufficient, the previous steps will be repeated until the harmonics can be effectively reduced. This flowchart serves to ensure that the electricity distribution system operates efficiently and harmoniously can be optimally minimized.

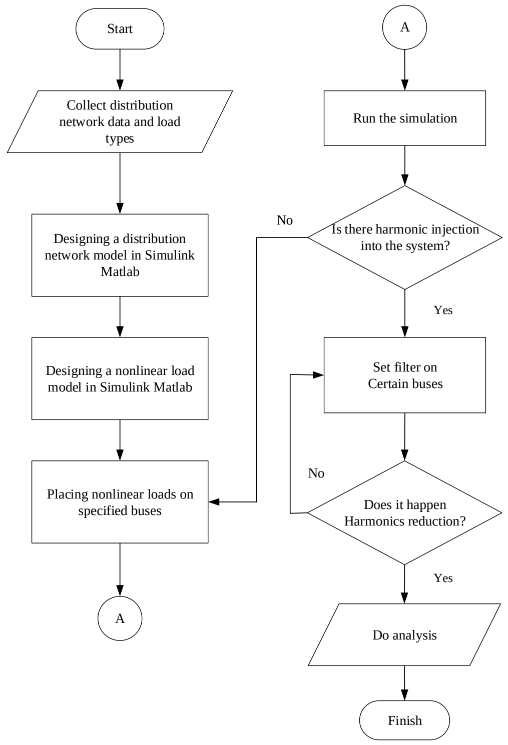

Figure 2 Flowchart of Research Procedures

IV. RESULT AND DISCUSSION

A. Harmonic Distortion of Current On Bus 7

In this study, two passive filter placement scenarios were carried out, the first of which was to place 1 filter on the main bus (bus three), while for the second scenario, namely to place 2 filters, the first filter was placed on bus three which was the main bus, and the second filter was placed on bus four which was the bus on the utility generator. After the placement of the filter, an analysis was carried out using FFT (Fast Fourier Transform).

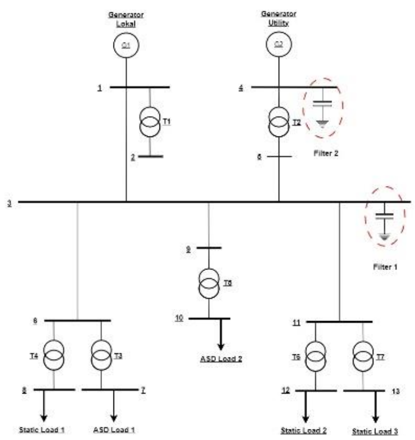

Figure 3 Passive Filter Placement

Table 3 THDi Data on Bus 7 with RL Filter

BUS 7	THDi Before filtering (%)	THDi After Filtering (%)
1 filter	24,62	0,30
2 filter	24,62	0,15

Table 4 THDv Data on Bus 7 with RL Filter

BUS 7	THDv Before filtering (%)	THDv After Filtering (%)
1 filter	0,97	0,10
2 filter	0,97	0,05

Based on tables 3 and 4, it can be seen that the use of one RL filter can reduce the harmonic value of current (THDi) on bus 7 from 24.62% to 0.30% (by 24.32%), in addition, the use of one RL filter can also reduce the harmonic value of voltage (THDv) on bus 7 from 0.97% to 0.10% (by 0.87%).

Meanwhile, by using two RL filters, the harmonic value of current (THDi) on bus 7 was reduced from 24.62% to 0.15% (by 24.47%) and the harmonics value of voltage (THDv) on bus 7 was reduced from 0.97% to 0.05% (by 0.92%).

From these results, it can be seen that the use of RL filters placed on bus 3 can reduce the harmonic value, as well as by using two RL filters placed on bus 3 and bus 4, the harmonic value that can be reduced becomes larger. This indicates that the use of two RL filters is more effective in reducing the harmonic value of current and voltage on bus 7.

B. Assessment of THD and IHD Current and Voltage Based on Standard IEEE 519-2014

The calculation of the value of the short-circuit current (I_sc) at the Point of Common Coupling (PCC) uses equation (1), then the maximum short-circuit current value at the PCC is:

$$I_{sc} = \frac{1000 \times MVA}{\sqrt{3} \times KV}$$
$$= \frac{1000 \times 100}{\sqrt{3} \times 69}$$
$$= \frac{100.000}{119,51}$$
$$= 836,75 \text{ A}$$

The load current (I_L) can be determined by equation 6:

$$I_L = \frac{kW}{PF \times \sqrt{3} \times KV}$$

$$= \frac{29,8}{0,8 \times \sqrt{3} \times 69}$$

$$= \frac{29,8}{95,19}$$

$$= 0,313 \text{ A}$$

SC_{ratio} can be found using equation 4:

$$SC_{ratio} = \frac{I_{SC}}{I_L}$$

$$= \frac{836,75}{0,313}$$

$$= 2.673,32 \text{ A}$$

According to the IEEE 519-2014 standard listed in Table 2, the short-circuit ratio value (SC_{ratio}) is at the ratio value of >1000, then the maximum allowable current THD value is 20%.

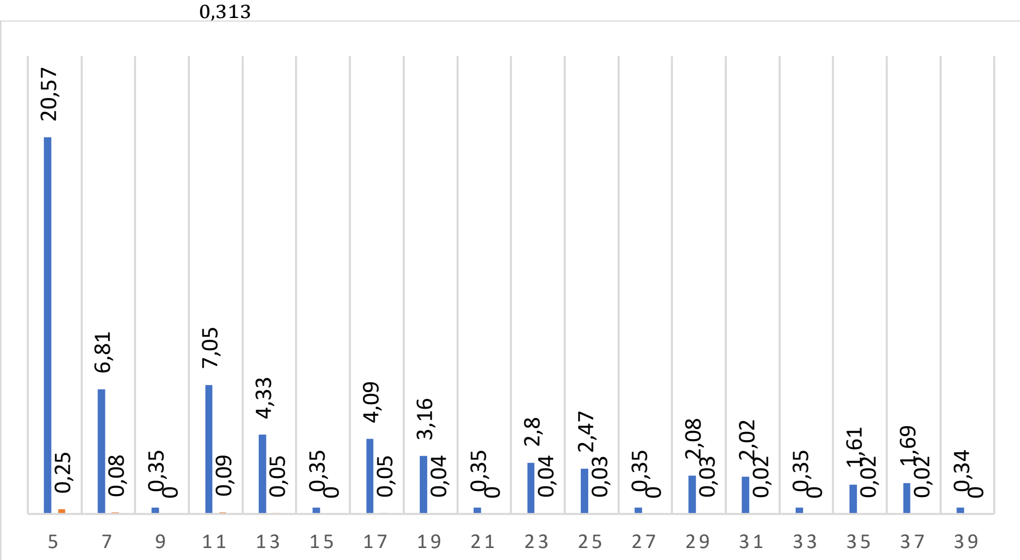

Figure 4 IHDi Comparison Chart before and after the application of RL filters

Based on the graph in figure 4, it can be seen that by using the RL passive filter, the IHDi at the 5th harmonic on bus 7 before the use of the filter, which is 20.57%, can be reduced to 0.25%, the decrease in harmonic value also occurs in other odd orders and the harmonic value obtained is in accordance with the IEEE 519-2014 standard.

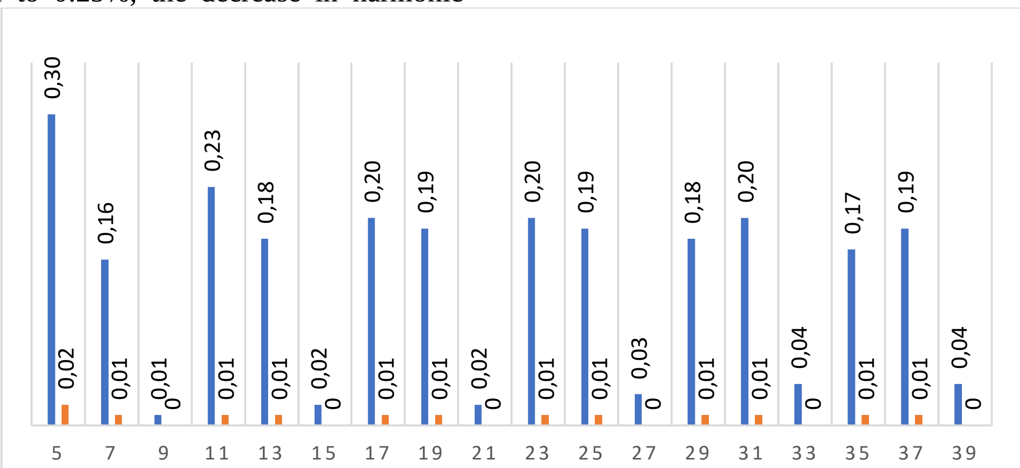

Figure 5 Harmonic Voltage Comparison Chart Before and After the Application of RL Passive Filter

The IHDv value on bus 7 can be seen from the graph in figure 5, from this graph it can be seen that the highest IHDv value is in the 5th order of 0.30%. Meanwhile, the lowest IHDv value was found in the 9th order at 0.1%. After the use of the RL passive filter, the IHDv value in the 5th order decreased to 0.2%, as well as in the 9th order it decreased to 0%.

V. CONCLUSION

Based on the results of the simulations that have been carried out, it can be concluded that:

1) Load Adjustable Speed Drive can produce THD current and voltage on bus 7 by 24.62% and 0.97%.
2) From the selection of the type of filter placed on buses 3 and 4, it can be seen that the use of RL filters is most effective in reducing the harmonic current and voltage generated by the Adjustable Speed Drive load. The RL passive filter is able to reduce the harmonic value of current by 24.44% and is able to reduce the harmonic value of voltage by 1.06%.

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