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Harmonic Mitigation with Active Filter in Coal Boiler Plant PT. Salim Ivomas Pratama

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Abstract

Coal Boiler Plant at PT. Salim Ivomas Pratama is a plant for making steam, almost all activities in the cooking oil and margarine production process utilize electrical energy, such as submersible and centrifugal electric motors with controllers, computers, AC inverters, and many others which include non-linear loads. Electrical load whose correlation between voltage and current is unbalanced, this non-linear load will result in harmonic disturbances in the electric power system which causes a reduction in the service life of electrical equipment. Harmonics are defined as voltage and current frequency distortions that are not sinusoidal from pure frequencies. This study aims to determine how effective the active filter design simulated with the PSIM Software is in reducing harmonics with a non-linear load of 3 VSD connected to a 55 kW, 0.37 kW, and 7.5 kW induction motor. The results of measurements and analysis show that there are harmonics on the panel. SDP with a current harmonic value for phase R of 26.6%, phase S of 27.5%, and phase T of 25.5%, when compared with standard harmonics, all phases exceed the standard SPLN with a standard value of 20%. Then it is necessary to reduce harmonics with an active filter, after designing and simulating it in the PSIM software the simulation results show that the current harmonics have changed for phase R by 3.3%, phase S by 4.0%, and phase T by 3,4 %. This shows that the design of the active filter is quite effective in mitigating a harmonic, to then be applied in practice at PT. Salim Ivomas Pratama in reduction the harmonics in a coal boiler plant.

Keywords: *Active Filter, Harmonics, Power Quality*

1. Introduction

In an electric power system, power quality is an important factor that must be considered. Power quality includes continuity in the supply of electrical energy, frequency, and voltage stability as well as the quality of the power factor [1]. These four things are the focus of power quality, so that these four things must be maintained for reliability. However, technological developments on the load side that lead to increased efficiency of equipment in the use of electrical energy affect the reliability of power quality [2]. Various types of equipment that can affect the reliability of power quality include air conditioners, refrigerators, energy-saving lamps, computers, laptops, and the use of converters, both rectifiers and inverters. Such equipment is increasingly being used both in households and in industry. The electronic equipment above generally requires direct current so that in its provision it requires current rectification. These types of loads make the current in the power grid no longer be in the form of a pure sinusoidal wave [3]. Waves like this are not only composed of fundamental frequencies but are also overlaid by integer multiples of the fundamental frequency which are defined as harmonics. With the presence of harmonics,

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current and voltage waves that should be sinusoidal in shape turn into distorted sinusoidal waves [4]. When wave distortion occurs, the quality of the voltage and frequency changes, so that it is not in accordance with regulations. Harmonics not only interfere with voltage quality and frequency stability but also cause other problems [5]. Among them, increased losses in the conductor, the emergence of currents in the neutral cable, the occurrence of error readings on the kWh meter, the protection equipment does not work in the power system and makes the power factor low. With the detrimental effects caused by harmonics, a method is needed to reduce these harmonics. One of the methods used in reducing harmonics is the installation of filters. With the filter we can reduce the harmonics that occur [6].

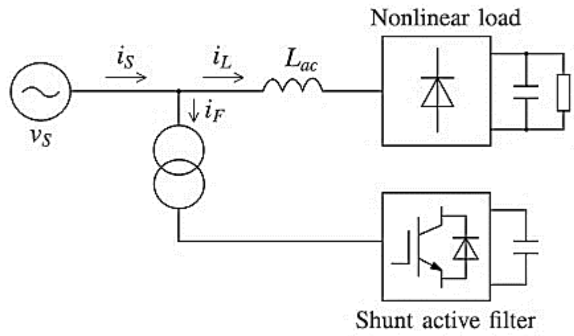

Figure 1. Active Filter Circuit

Active filter is a type for harmonic elimination filter equipment in power system. This filter is composed of power electronics equipment. The main components contained in the active filter are the inverter and the controller circuit [7]. In addition to functioning as a DC-AC converter, the inverter also functions as a harmonic generator. The harmonics of the inverter are regulated in such a way by using electronic control circuits such as PID, band pass filters, limiters and comparators so as to produce harmonics that are the same magnitude as load harmonics but have a different phase angle of 180° [8]. Figure 1 shows a simple block diagram of an active filter.

The complete schematic of the active filter control circuit is shown in Figure 2. The simple way of working of the control circuit is that the harmonic currents from the load are sensed using a current sensor then the harmonics enter the band pass filter to adjust the order of the harmonics to be reduced [9]. The next stage is that the waveforms of harmonic orders will be corrected with the PI controller so as to produce the appropriate shape. Before entering the inverter, the amplitude of the resulting harmonic waves will be adjusted using a limiter [10].

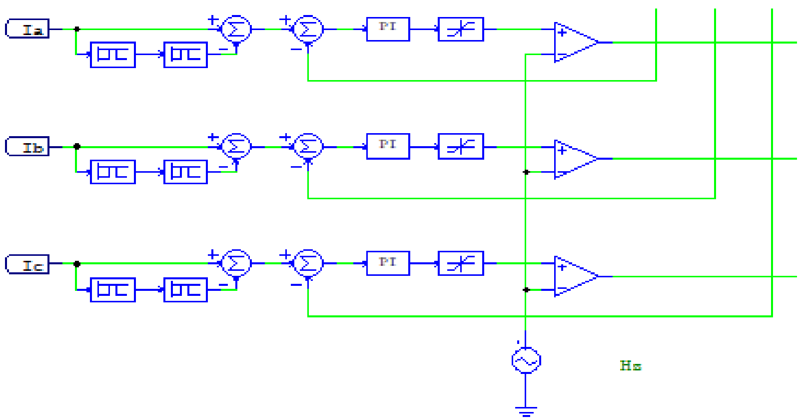

Figure 2. Active Filter Control Circuit

In the inverter there is a capacitor that is installed parallel to the DC voltage source which functions to produce a stable output. The inverter output is also determined by the switching speed and the capabilities of the electronic components. The electronic components used in today's inverters are IGBT, GTO or power transistors [11]. These components have their respective advantages depending on the needs. One of the most common methods for reducing harmonics in industry is to use a single-tuned passive filter technique or a band-pass filter. A single-tuned passive filter can be designed as a single-tuned element that provides a low-impedance path to pass harmonic currents at the tuned frequency [12]. The use of a passive filter circuit aims to manipulate the waveform output from the inverter.

From research on Active Power Filters (APF), several authors have studied and analyzed it from various angles. Grady et al. [13] conducted an initial literature review and divided active power line conditioning (APLC) functions into time domain and frequency domain mitigation techniques, highlighting the advantages and disadvantages of each mitigation strategy. Furthermore, Singh et al. [14] divided a large number of reported APFs into groups based on converter type, applied topology, power system features, control algorithm, and intended application. In [15], Peng gives a total of 22 power filter designs, including basic power filters and all possible combinations of basic power filters referred to as hybrid power filters. If we briefly analyze the ideal quality and usability for each setting. El-Habrouk et al. [16] conducted another review focusing on APF classification, where existing work on APFs was categorized according to the operating power system power rating, power circuit configuration, mitigation objectives (such as current harmonics, power factor, and unbalance), control algorithms used. used, and the reference current/voltage generation approach.

Shunt type APFs (SAPFs) are the most effective for dealing with harmonic current distortion, according to literature evaluations that have been carried out [17]–[19]. In addition, they can improve pf performance [20]–[21] by reducing the load caused by reactive power on the energy system and minimizing harmonic currents. Additionally, SAPF is known to have been marketed to meet customer demand for addressing challenging power quality issues that may arise in industrial and commercial environments. The three functions of load balancing, reactive charging and placement harmonic filtering are usually the goals of commercial SAPF development. To accommodate a wide range of applications in low-voltage and medium-voltage networks, they are available in a variety of current ratings and are intended for three-phase systems. They can also dynamically adapt to shifting network and load conditions, resulting in consistently optimal compensation performance. Instead, each organization may have a different controller topology that can be implemented for SAPF. The power module is driven by pulse width modulation (PWM) pulses generated by a digital closed-loop controller, for example, which controls an ABB active filter [22]. Meanwhile, a digital controller that combines Fast Fourier Transform (FFT) analysis controls the active Schaffner filter function [23].

The research objective to be achieved is to simulate the effect of installing an active filter on the electrical system, especially regarding harmonic mitigation, by modeling and simulating the electrical system with ETAP software. How to design an active filter that suits system requirements (standards issued by IEEE) in order to reduce harmonic distortion contained in the system and also function as a reactive power compensator. In this way, it is hoped that the quality of electrical power will improve and the use of electrical power will become optimal.

2. Research Methods

This research was conducted using the PSIM simulation program. The data collection process was carried out by measuring the coal boiler SDP plant using the help of a Fluke 43B power quality analyzer. Retrieval of actual data is data from measurements or actual data on energy use and harmonics from both the transformer and the SDP. This data collection was carried out to find out how many harmonics there were, this measurement was carried out for two weeks. Figure 3 shows the design of a harmonic source simulation using PSIM. The bridge type rectifier was chosen because in general the load on the Coal Boiler Plant of PT. Salim Ivomas Pratama requires direct current so that a rectifier is installed in the load equipment. With this assumption, the choice of bridge type rectifier used in the simulation is considered to represent the behavior of the load at the PT. Salim Ivomas Pratama Coal Boiler Plant.

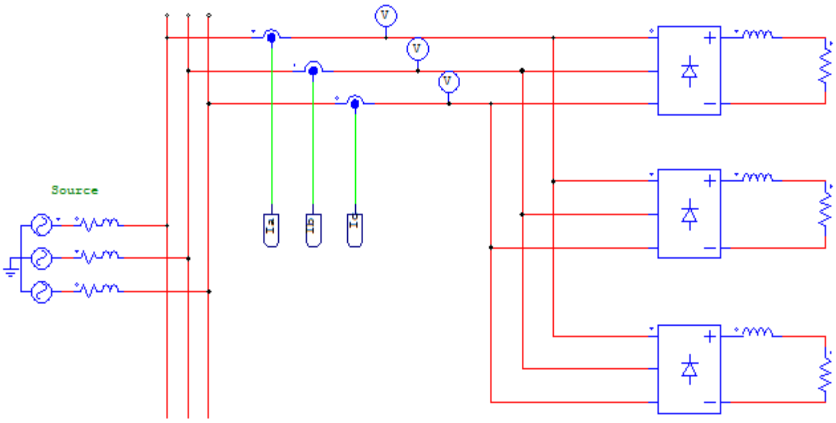

Figure 3. Harmonic Source Design Model in 3 Phase System

2.1 System Configuration and Basic Compensation Principle

The basic compensation principle of a APF is shown in Figure 4. It is controlled to supply a compensating current, so that it cancels current harmonics on AC side, and makes the source current in phase with the different waveforms. Curve A is the non-linear load current waveform and curve B is the desired mains current. Curve C shows the compensating current injected by the active filter containing all harmonics, to make mains current sinusoidal [24].

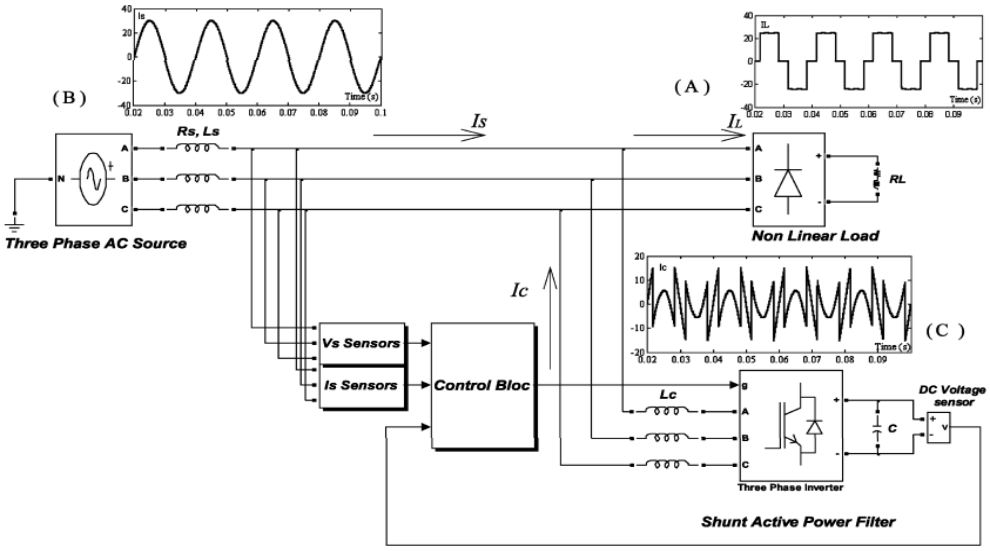

Figure 4. Active Power Filter Configuration [25]

2.2 Current Supplied by the Active Filter

The source voltage is given by:

$$v_s(t) = V_m \sin(\omega t) \tag{1}$$

The source current can be written as

$$i_s(t) = i_L(t) - i_C(t) \tag{2}$$

Where $i_L(t), i_C(t)$ are the load and the filter currents, respectively.

The load current will contain a fundamental and harmonics component, which can be written as

$$i_L(t) = \sum_{n=1}^{\infty} i_n \sin(n\omega t + \emptyset n)$$

$$= I_1 \sin(n\omega t + \emptyset_1) + \textstyle\sum_{n=2}^{\infty} I_n \sin(n\omega t + \emptyset n) \quad (3)$$

In (3), there are three terms

$$i_L(t) = I_{1a}\sin(\omega t) + I_{1r}\cos(\omega t) + \sum_{n=2}^{\infty} I_n \sin(n\omega t + \emptyset n),$$

Where $I_{1a} = I_1 \cos \emptyset_1$ and $I_{1r} = I_1 \sin \emptyset_1$

The real (fundamental) power drawn by the load is [26]:

$$pf(t) = V_m I_{1a} sin^2(\omega t) = v_s(t) \times I_s(t) \quad (4)$$

From (4), the source current after compensation, is [26]:

$$i_s(t) = \frac{pf(t)}{v_s(t)} = I_{1a}\sin(\omega t) = I_{sm}\sin(\omega t) \quad (5)$$

Where $I_{sm} = I_1 cos\emptyset_1$

There are also some switching losses in the PWM inverter, and the control law must consider an additional current for the capacitor leakage and converter switching losses. The total peak current supplied by the source is, therefore.

$$I_{sp} = I_{sm} + I_{sl} \quad (6)$$

If the APF provides the total reactive and harmonic power, $I_s(t)$ will be in phase with utility voltage and will be purely sinusoidal. In this case, the APF must provide the following compensation current:

$$i_c(t) = i_L(t) - i_s(t) \quad (7)$$

Hence, for accurate and instantaneous compensation of reactive power and harmonic currents, it is necessary to estimate the fundamental component of the load current [27].

3. Result and Analysis

3.1 Simulation without Active Filter

The circuit simulated here is the initial circuit which only consists of a generating source and a non-linear load 3 motors with an inverter made with a replacement circuit as a three-phase rectifier with a load R, L which is used to produce the 5th and 7th harmonics, this is to see disturbance character in the form of waves and harmonic spectrum. Measurements are made at the point of the current source. Figure 5 it can be explained that the source current should be pure sinusoidal but due to the use of a rectifier, harmonics arise so that the current wave is distorted.

The harmonic spectrum graph that appears is shown in figure 6, where large harmonic currents occur in the 5th order harmonics (250Hz) = 48.9 A and the 7th order harmonics (350Hz) = 34.5 A. Therefore attention is focused on reducing the current the harmonics.

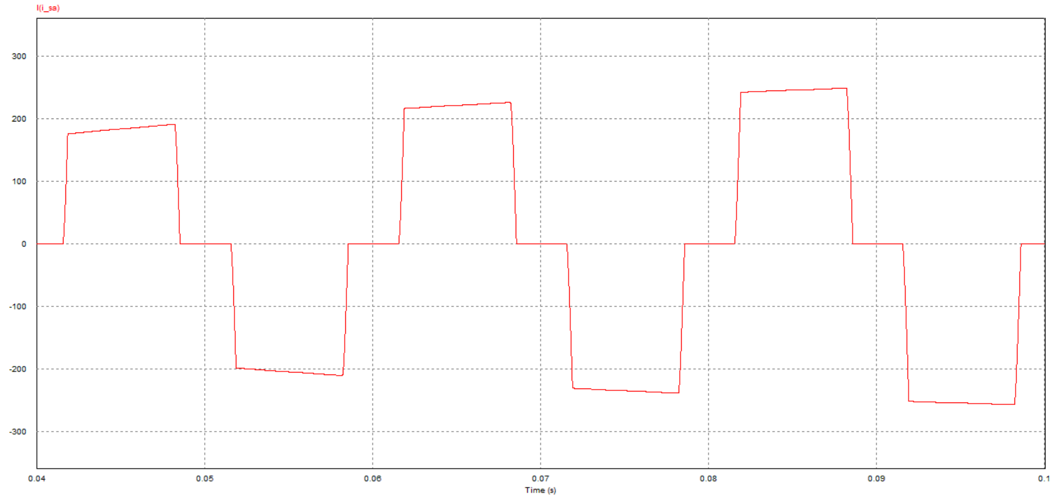

Figure 5. Current Waveform from Without Active Filter

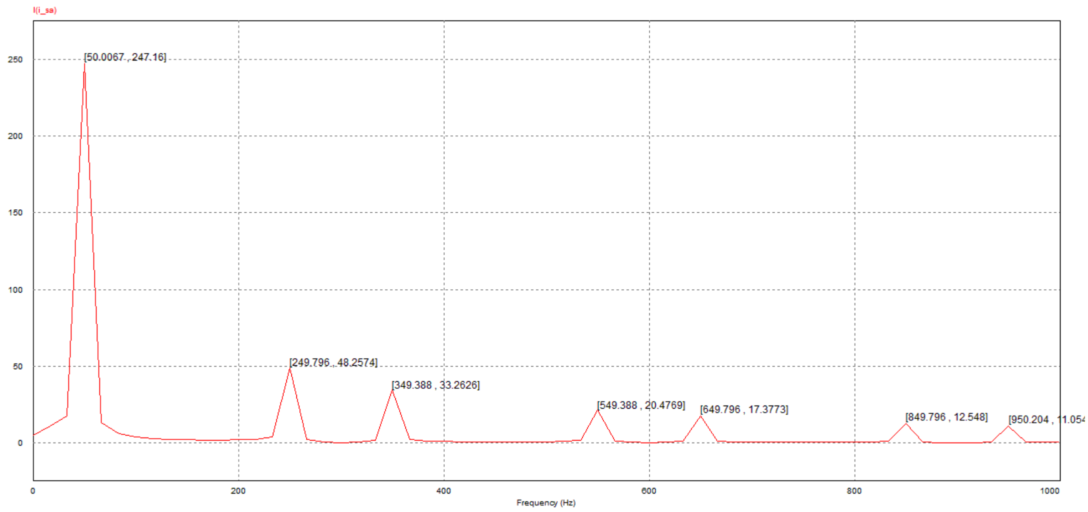

Figure 6. Current Spectrum without Active Filter

3.2 Simulation with Active Filter

In this section, a simulation is made to see the effect of an active filter on harmonic damping. The following circuit is a simulation circuit that uses an active filter to dampen harmonics, which is serialized with an LC filter to reduce interference in the waveform caused by the high frequency generated by the active filter, the value of this LC filter is determined. Active filter modeling with PI control using PSIM can be seen in figure 7.

Figures 8 and 9 show the output current from the active filter and the system improve current after installing the active filter. From Figure 9 the harmonics of order 3^{rd}, 5^{th}, 7^{th}, 9^{th} etc. are almost lost due to the injection of counter current from the active filter. As for the fundamental component, it has doubled, this is due to the addition of the fundamental current from the active filter.

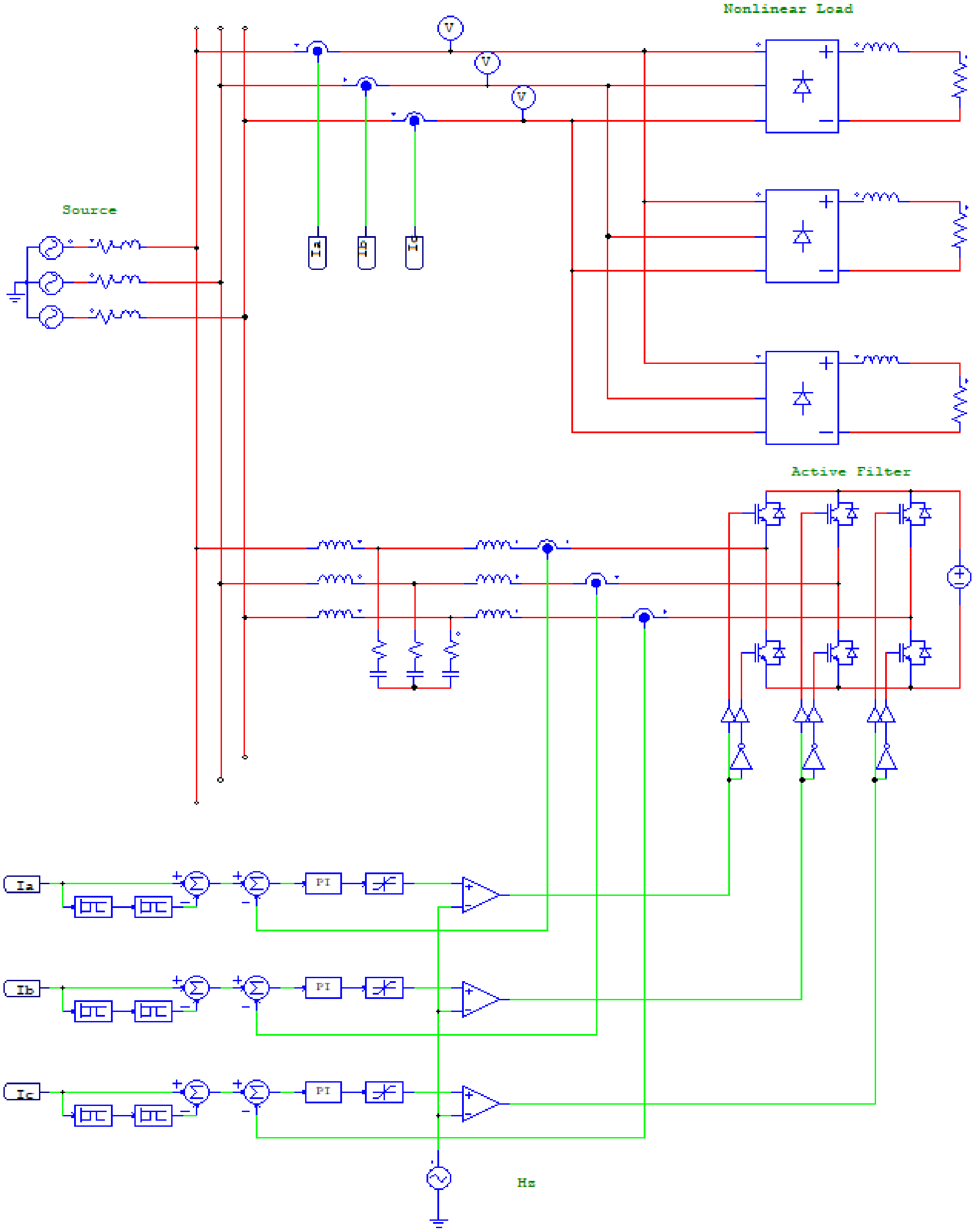

Figure 7. Active Filter System Modeling Circuit with PSIM Software

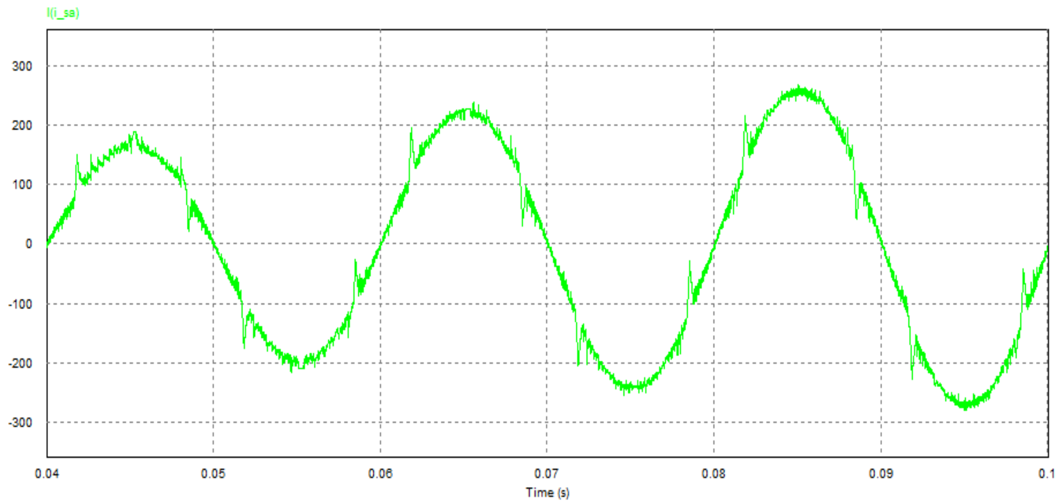

Figure 8. Current Waveform from with Active Filter

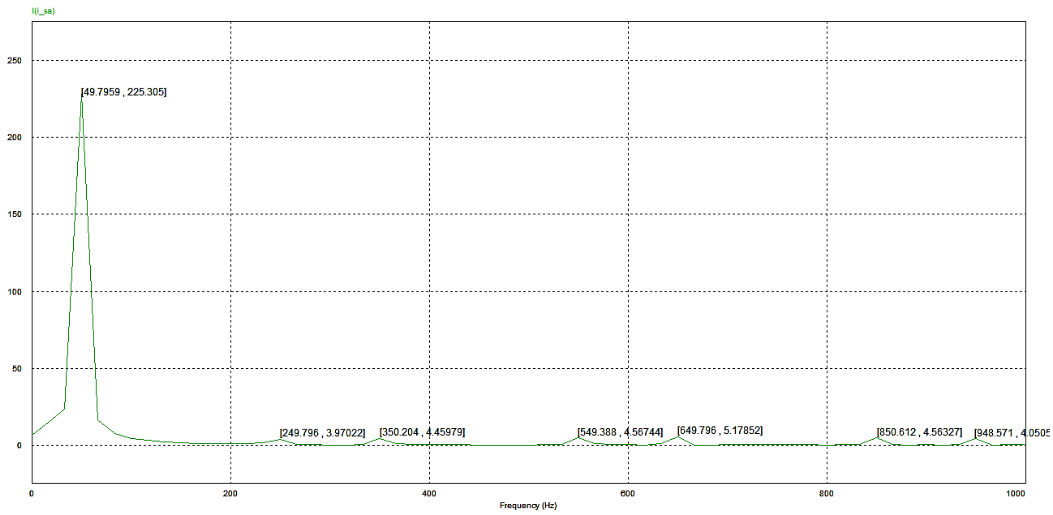

Figure 9. Current Spectrum with Active Filter

From these data the current THD value is acceptable because the THD standard for current is 20% at a voltage below 69 kV. With Isc based on calculations of 3849001.74 Amp and IL of 67.8 Amp, Isc/IL = 56769.9372 > 1000 is obtained (SPLN, 2012). After simulating an active filter with PSIM software and the results show that the active filter is quite effective in minimizing current harmonics, it can then be applied to PT. Salim Ivomas Pratama to carry out real damping using active filters at SDP Coal Boiler Plants. Active filter design suitable for reducing harmonics in the Coal Boiler Plant PT. Salim Ivomas Pratama is using an active filter with SPWM control, proportional controller (K) with a Kp value of 2 and integral (I) with a Ti value of 0.0001 and choosing to use IGBT as a switching component. It is important to note that active harmonic reducing filters usually have to be carefully adjusted and programmed according to the requirements of a specific electrical system. In addition, factors such as power capacity, and predominant harmonic type need to be considered in selecting and installing these filters.

Table 1. Results of Mitigation Current Harmonics

THD Value	Measurement THDi (%)		
	Fluke 43B	Result using PSIM	
Current	Without Active Filter	Without Active Filter	With Active Filter
R	26,6	26,6	3,3
S	27,5	27,5	4,0
T	25,5	25,5	3,4

From table 1 regarding the results of the harmonic damping simulation, it can be analyzed that the results of measurements with fluke 43B in unfiltered conditions that have been analyzed for current THD values show R, S, T respectively of 26.6%, 27.5% and 25, 5%. Furthermore, the simulation results using the PSIM software without filtering the current value show R, S, T respectively of 26.6%, 27.5% and 25.5%. After designing an active filter and simulating it in the PSIM software, the current THD values become R, S, T respectively of 3.3%, 4.0%, 3.4%. From the active filter system that has been simulated it can function properly so that the current THD value meets the standard.

4. Conclusion

The main objective of this research is to provide a complete description of the simulation results regarding the working principles of active filters and their control algorithms using PI control, so that readers can understand the basics of active filters and at the same time compare and evaluate the use of PI control algorithms in filters. subjectively active and ultimately benefit in further research. The results of measurement and analysis of the content of current and voltage harmonics at PT. Salim Ivomas Pratama at SDP Plant Boiler coal shows that the value of current harmonics that exceeds the SPLN value of the phase current harmonics R, S, T respectively by 26.6%, 27.5% and 25.5%. Caused by 3 VSDs connected to 3 phase induction motors of 55 kW, 0.37 kW and 7.5 kW. After designing an active filter and simulating it using PSIM software the results of the current harmonic values are R, S, T respectively of 3.3%, 4.0%, 3.4%.

5. References

[1] Das, B., Panigrahi, P. K., Das, S. R., Mishra, D. P., & Salkuti, S. R. (2022). Power quality improvement in a photovoltaic based microgrid integrated network using multilevel inverter. *International Journal of Emerging Electric Power Systems*, *23*(2), 197-209.

[2] Mahela, O. P., & Shaik, A. G. (2016). Topological aspects of power quality improvement techniques: A comprehensive overview. *Renewable and Sustainable Energy Reviews*, *58*, 1129-1142.

[3] Sadiq, M. A., Husain, N., Shaukat, F., Yahya, A., & Ahmad, Z. (2022). Prominence of Filtering Techniques for Harmonics Mitigation in Advanced Power Electronics Systems.

[4] El Ghaly, A., Tarnini, M., Moubayed, N., & Chahine, K. (2022). A Filter-Less Time-Domain Method for Reference Signal Extraction in Shunt Active Power Filters. *Energies*, *15*(15), 5568.

[5] Echalih, S., Abouloifa, A., Lachkar, I., Guerrero, J. M., Hekss, Z., & Giri, F. (2021). Hybrid automaton-fuzzy control of single phase dual buck half bridge shunt active power filter for shoot through elimination and power quality improvement. *International Journal of Electrical Power & Energy Systems*, *131*, 106986.

[6] Sujith, M., & Padma, S. (2020). Optimization of harmonics with active power filter based on ADALINE neural network. *Microprocessors and Microsystems*, *73*, 102976.

[7] Thakur, K. D., & Chichate, K. R. (2019). Investigation of various Power Quality Issues & its solution in grid connected distributed power system. *IJRAT*, *7*(6).

[8] Imam, A. A., Sreerama Kumar, R., & Al-Turki, Y. A. (2020). Modeling and simulation of a PI controlled shunt active power filter for power quality enhancement based on PQ theory. *Electronics*, *9*(4), 637.

[9] Rameshkumar, K., & Indragandhi, V. (2020). Real time implementation and analysis of enhanced artificial bee colony algorithm optimized PI control algorithm for single phase shunt active power filter. *Journal of Electrical Engineering & Technology*, *15*, 1541-1554.

[10] Li, Z., Ren, M., Chen, Z., Liu, G., & Feng, D. (2022). A Bi-Sliding Mode PI Control of DC-Link Voltage of Three-Phase Three-Wire Shunt Active Power Filter. *IEEE Journal of Emerging and Selected Topics in Power Electronics*, *10*(6), 7581-7588.

[11] Umadevi, A., Lakshminarasimman, L., & Sakthivel, A. (2023). Optimal design of shunt active power filter for mitigation of interharmonics in grid tied photovoltaic system. *Electric Power Systems Research*, *220*, 109232.

[12] Tamer, A., Zellouma, L., Benchouia, M. T., & Krama, A. (2021). Adaptive linear neuron control of three-phase shunt active power filter with anti-windup PI controller optimized by particle swarm optimization. *Computers & Electrical Engineering*, *96*, 107471.

[13] Grady, W. M., Samotyj, M. J., & Noyola, A. H. (1990). Survey of active power line conditioning methodologies. *IEEE transactions on power delivery*, *5*(3), 1536-1542.

[14] Singh, B., Al-Haddad, K., & Chandra, A. (1999). A review of active filters for power quality improvement. *IEEE transactions on industrial electronics*, *46*(5), 960-971.

[15] Peng, F. Z. (2001). Harmonic sources and filtering approaches. *IEEE industry applications magazine*, *7*(4), 18-25.

[16] El-Habrouk, M., Darwish, M. K., & Mehta, P. (2000). Active power filters: A review. *IEE Proceedings-Electric Power Applications*, *147*(5), 403-413.

[17] Hoon, Y., Mohd Radzi, M. A., Hassan, M. K., & Mailah, N. F. (2017). Control algorithms of shunt active power filter for harmonics mitigation: A review. *Energies*, *10*(12), 2038.

[18] Hoon, Y., Mohd Radzi, M. A., Mohd Zainuri, M. A. A., & Zawawi, M. A. M. (2019). Shunt active power filter: A review on phase synchronization control techniques. *Electronics*, *8*(7), 791.

[19] Singh, H., Kour, M., Thanki, D. V., & Kumar, P. (2018). A review on Shunt active power filter control strategies. *International Journal of Engineering & Technology*, *7*(4.5), 121-125.

[20] Gali, V., Gupta, N., & Gupta, R. A. (2017, June). Mitigation of power quality problems using shunt active power filters: A comprehensive review. In *2017 12th IEEE Conference on Industrial Electronics and Applications (ICIEA)* (pp. 1100-1105). IEEE.

[21] Hadi, A. M., Thjeel, E. M., & Nahar, A. K. (2022). A review of control technique applied in shunt active power filter (SAPF). *Engineering and Technology Journal*, *40*(8), 140-149.

[22] Patel, P. J., Patel, R. M., & Patel, V. (2017). Implementation of FFT Algorithm using DSP TMS320F28335 for Shunt Active Power Filter. *Journal of The Institution of Engineers (India): Series B*, *98*, 321-327.

[23] Geethalakshmi, B., & Kavitha, M. (2011). Comparison of reference current extraction methods for shunt active power filters. *International Journal of Computer and Electrical Engineering*, *3*(3), 322.

[24] Dobariya, D. R., & Upadhyay, P. A. (2015, January). Simulation and comparison between hybrid active power filter and shunt active power filter. In *Intern. Conf. Electrical, Electronics, Signals, Communication and Optimization (EESCO)* (pp. 1-6).

[25] Hoo, D. S., Chua, K. H., Lim, Y. S., Chen, T. H., Chan, M. E., Ching, K. J., ... & Khan, M. S. A. (2021, November). Mitigation of Harmonic Distortions with Shunt Active Harmonic Filter using SVPWM Technique. In *2021 Innovations in Power and Advanced Computing Technologies (i-PACT)* (pp. 1-6). IEEE.

[26] Benzahia, A., Boualaga, R., Moussi, A., Zellouma, L., Meriem, M., & Chaima, B. (2019). A PV powered shunt active power filter for power quality improvement. *Global Energy Interconnection*, *2*(2), 143-149.

[27] Hadi, A. M., Thajeel, E. M., & Nahar, A. K. (2022). A novel optimizing PI control of shunt active power filter for power quality enhancement. *Bulletin of Electrical Engineering and Informatics*, *11*(3), 1194-1202.