Improvement of Electric Power Quality Due To Non Liniear Load in Industry Using Model of Passive Filter, Series Active Filter, and Three Phase Hybrid Active Filter

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Improvement of Electric Power Quality Due To Non Liniear Load in Industry Using Model of Passive Filter, Series Active Filter, and Three Phase Hybrid Active Filter

Peningkatan Kualitas Daya Listrik Akibat Beban Non-Linier di Industri Menggunakan Model Filter Pasif, Filter Aktif Seri, dan Filter Aktif Hibrid Tiga Phasa

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ABSTRAK

Tujuan penelitian adalah meningkatkan kualitas daya listrik akibat beban non linier di industri menggunakan model filter pasif, filter aktif seri, dan filter hibrid tiga phasa. Ada dua mode operasi beban yaitu rangkaian terhubung pada beban non-linier seimbang dan tidak seimbang. Rangkaian filter dimodelkan secara matematis dengan teknik kendali arus menggunakan pulse width modulation (PWM) dan Teori Dual Instantaneous Reactive Power. Parameter penelitian adalah THD tegangan dan arus sumber, arus dan tegangan tidak seimbang, perbaikan faktor daya rangkaian terhubung beban non-linier (seimbang dan tidak seimbang) berdasarkan Standar IEEE-519, ANSI/IEEE 241-1990, dan Standar PLN. Hasil penelitian adalah rangkaian sistem pada empat kondisi kompensasi terhubung beban non-linier tidak seimbang, menghasilkan THD rata-rata arus lebih rendah dibandingkan sistem terhubung beban non-linier seimbang. Penggunaan filter aktif seri mampu menurunkan THD arus sesuai Standar IEEE 519–1992. Pada kondisi sistem sama, rangkaian terhubung beban non-linier tidak seimbang, menghasilkan nilai arus tidak seimbang lebih besar, dibandingkan sistem terhubung beban non-linier seimbang. Rangkaian terhubung beban non-linier tidak seimbang, mampu menghasilkan nilai faktor daya sedikit lebih tinggi dibandingkan beban non-linier seimbang. Nilai THD tegangan sistem berbeban non linier seimbang dan tidak seimbang untuk semua kondisi tanpa dan menggunakan kompensasi, nilainya relatif kecil dan berada di bawah level 1% serta sudah memenuhi batas harmonisa tegangan sesuai Standar IEEE 519–1992. Nilai tegangan tidak seimbang kondisi tanpa dan menggunakan filter pada dua mode relatif stabil. Sistem terhubung dua mode beban non linier mampu meningkatkan nilai harmonisa arus dan arus tidak seimbang, tapi tidak berdampak signifikan pada perubahan harmonisa tegangan dan tegangan tidak seimbang.

Kata kunci: *Filter Pasif, Filter Aktif Seri, Filter Aktif Hibrid, Harmonisa, Faktor Daya, Beban Non-Linier, Industri*

ABSTRACT

The purpose of research was to improve electric power quality due to non linear load in industry using passive filter, series active filter, and three phase hybrid active filter. There were two operation modes, namely circuit connected to balanced and unbalanced non-linear load. The filter circuit was modeled mathematically using current control techniques with pulse width modulation (PWM) and Dual of Instantaneous Reactive Power Theory. Power quality parameters were source current dan voltage THD, current dan voltage unbalanced, and input power factor of sytem based on IEEE-519 Standard, ANSI/IEEE 241-1990 and PLN Standards. The research shows that the system on four compensations connected unbalance non linear load, produces average THD current smaller than the system connected balanced non-linear. The use of series active filter and hybrid active filter was able to decrease source current THD in accordance with 519-1992 IEEE Standard. At the same condition of the circuit has been connected unbalance non linear load, then unbalanced source current is greater than the system connected balanced non linear load. The circuit connected unbalanced non linear load was able to generate input power factor is slightly higher than balanced non-linear load. The value of source voltage THD of system connected balanced and unbalanced non-linear load for all conditions was relatively small, below 1% level, and have already met voltage harmonic limit within of IEEE 519-1992 Standard. The value of unbalanced source voltage without and with filters on both modes were relatively stable. The systems connected two modes of non linear load only was able to increase source current harmonics and unbalanced current, but has no significant impact on changes of voltage harmonics and unbalanced voltage.

Key words: *Passive Filter, Series Active Filter, Hybrid Active Filter, Harmonic, Power Factor, Non Liniear Load, Industry*

INTRODUCTION

Today electrical load is more sensitive to harmonics, sag, swell, and several other disturbances. Among a number of parameters, harmonic current has become a major concern in development of electric power quality. One issue of power quality is reactive power compensation. Reactive power is needed to repair voltage to send active power. When there is no sufficient reactive power, sag voltage appears and may not meet demand by load trough the network. Although reactive power is needed to carry on a number of electrical equipment, these equipment can cause loss to a number of electrical appliances. Therefore, reactive power compensation is very important in power system. So that power quality eventually also become very important issues in power system.

In the mid-1940s passive power filter has been used widely to reduce current harmonics and compensate reactive power in distribution system due to its low cost, simple, and has high efficiency characteristic.[1] However, passive power filter has a number of disadvantages such as low dynamic performance, some resonance problems, and filtering characteristics are easily influenced by small changes in system parameters.[2,3] Since the concept of an AC active power filter first introduced in 1976,[1,4] a number of studies on active power filter for current quality compensation get more attention. Active power filter is able to overcome weakness of passive power filter, but initial cost and operation relatively expensive. One type of active power filter is a series active filter. These conditions led to decrease in applications on a wide scale in distribution network.

Furthermore, different topology of hybrid active filter which consisting of active and passive components either connected in series or parallel has been proposed with the aim to improve compensation characteristics of passive power filter while reducing rating voltage, current, and cost of active power filter,[2,6] Hybrid active filter topology[2,5] consists of a number of passive components, namely transformer, capacitor, reactor and resistor, thus increasing size and cost of overall system. Research on hybrid active filter to damp harmonic resonance in industrial electrical systems has been done.[7] Hybrid active filter consists of a low power active filter and 5th harmonic order passive filter. The use of hybrid active filter is capable of reducing 5th harmonic voltage that still appears on point of common coupling (PCC) bus if circuit is still only using passive filters.

Research on the use of control strategy using two vectorial formulas and instantaneous reactive theory with three phase active power filter has been done.[8] The hybrid active filter consists of a series active filter and passive filter is connected in parallel with load. If the system is connected to balanced non linear load, source current THD value on phase A, between using filter, connect to passive filter, and connect to combination of series active filter and passive filter (hybrid active filter) are 18.6%, 4.9%, and 1.8% respectively. The use of passive, series active, and hybrid active filter also able to improve input power factor are 0.947, 0.91, and 0.99 respectively. THD value of source current on the system connected unbalance non linear before compensated in phase "a", "b" and "c" are 18.8%, 35% and 37.6% respectively. The use of series active filter on the same conditions will result in improved source current THD value of 1.4%, 0.85% and 1.3% in the phase "a", "b" and "c" respectively. The weakness of research is not to discuss improvement of input power factor due to the use of passive filters and hybrid active filters.

The use of control method of two formulas for system compensation using hybrid active filter consists of a series active filter and shunt passive filter in three phase four wire system has been done.[2] The control method is applied to a resistive balanced load as the ideal load. The strategy is able to improve characteristics of a passive filter compensation without depending on system impedance. The compensation also can be applied to variable load and does not affect the possibility of turning off passive filter. Research on comparative analysis of performance of shunt active filter with active filter on system using resistive load has been done.[9] Three phase shunt active and a hybrid active power filter is able to reduce current THD and power factor of a non linear rectifier system connected using different firing angle. Simulation shows that if system has used hybrid active power filter with different firing angle, the greater firing angle value, then current THD also increased. While at the same firing angle, use of hybrid active power filter is able of reducing current THD and improve input power factor better than without filter and with active power filter. The disadvantage is current THD in phase A and B (5.22% and 6,18) still does not meet IEEE 519–1992 Standart as 5%.

The purpose of research is to improve power quality using a model of a passive filter, series active filter, and three phase hybrid active power filter due to non linear load in the industry. There are two operation modes, namely the circuit connected to balanced non linear load and unbalanced non linear load in the industry. The parameters studied are source voltage and current THD, unbalanced source voltage and current, and input power factor based on IEEE 519, ANSI/IEEE 241–1990, and PLN Standard. The rest of this paper is organized as follow. Section theory shows shunt passive filter, series active filter, dual instantaneous reactive power theory, compensation method, non linear load, modelling of non linear load in industry, power quality, harmonic, unbalance current and voltage, as well as power factor correction. Section research method is proposed model and parameters a passive filter, series active filter, and three phase hybrid active filter connected to non linear load (balance and unbalance) in industry. Section result and discussion describes variation of power quality parameter results (harmonic, unbalance current and voltage, as well as power factor correction) in two modes of non liniear load. In this section. Example cases studied are presented and the results are verified with those of Matlab/Simulink. Finally, the paper is summarized in section conclusion.

THEORY

Shunt Passive Filter

Shunt passive filter uses passive component and offers a better harmonics reduction, especially in 3rd, 5th, and 7th harmonics. Some models of shunt passive filter are band pass filter (single or double tuned), high pass filters (first, second, third-order or C-type), and composite filter.[10] All types of filters are connected in parallel to circuit as shown in Figure 1.[11] Increase of order harmonics creates filter become more efficient but reduces easiness when designed. They provide a low impedance at desired frequency. When connected shunt, passive filters are designed to reduce current harmonics. Because connected shunt, causes filter to function as a load to supply 30–50% load current when flows to electric drive device.

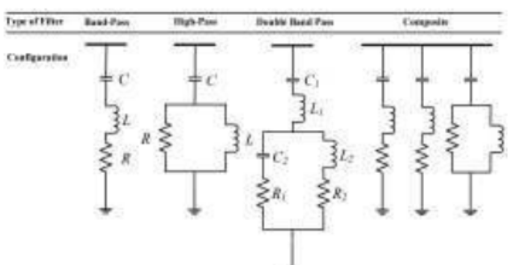

Figure 1. Models of Passive Filter.

Series Active Filter

Series active filter circuit as shown in Figure 2[12] can be used to compensate two parameters at once are harmonic distortion and unbalance source voltage. Both voltage on source and load side, can be compensated in accordance with the desired value. Nevertheless, research of series active filter only related to the application of load is sensitive to voltage waveform quality. So that compensation using an active filter series is only performed on the load side. Compensation is required to eliminate harmonics voltage and to create a balanced system, obtained by injecting compensating voltage on secondary coil of transformer in series with lines.

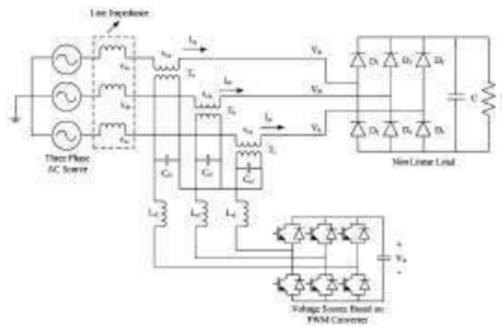

Figure 2. Model of series active filter.

Where (i) T_a, T_b, and T_c is tranformator compensation, (ii) V_{sa}, V_{sb} and V_{sc} is source phase voltage, (iii) V_{la}, V_{lb}, and V_{lc} is load voltage, (iv) V_{ca}, V_{cb}, and V_{cc} is compensating voltage of transformer secondary T_a, T_b, and T_c.

Dual Instantaneous Reactive Power Theory

Instantaneous Reactive Power Dual theory most widely is used as a control strategy for active power filter. This method is mainly applied for compensation equipment in parallel. This theory is based on Clarke coordinate transformation of phase coordinate as shown in Figure 3.[8]

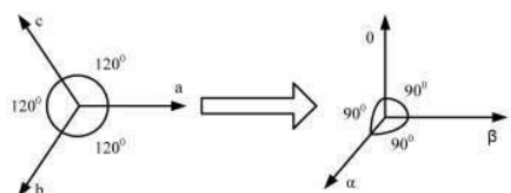

Figure 3. Transformation from phase reference system (abc) to 0αβ system.

In a three-phase system that showed in Figure 4, voltage and current vectors can be defined by:

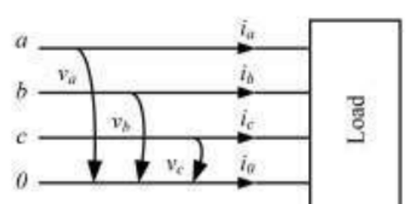

Figure 4. Three phase system (abc).

$v = [v_a \quad v_b \quad v_c]^T \; i = [i_a \quad i_b \quad i_c]^T$ .... (1)

The vector transformation from the phase reference system a-b-c to 0-α-β coordination can be obtained, thus

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\alpha \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\alpha \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (3)$$

The instantaneous real power in $\alpha - \beta - 0$ coordinate is calculated as follows:

$$p_{3\phi}(t) = v_\alpha i_\alpha + v_\beta i_\beta + v_0 i_0 \quad (4)$$

This equation can be written in vectorial from by means of dot product

$$p = i_{\alpha\beta}^T v_{\alpha\beta} \quad (5)$$

In the plane $\alpha\beta$, vector $i_{\alpha\beta}^T$ and $i_{\alpha\beta\perp}^T$ vectors establish two coordinates axes. The voltage vector $v_{\alpha\beta}$ can be decomposed in its orthogonal projection on the axis defined by the currents vectors, Figure 5. By means of the current vectors and the real and imaginary instantaneous power, the voltage vector can be calculated

$$v_{\alpha\beta} = \frac{p}{i_{\alpha\beta}^2} i_{\alpha\beta} + \frac{q}{i_{\alpha\beta}^2} i_{\alpha\beta\perp} \quad (6)$$

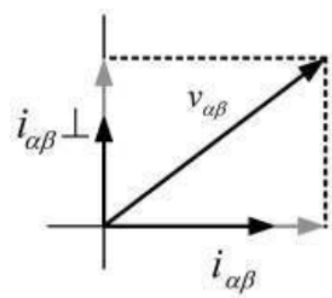

Figure 5. Decomposition of the voltage vector.

Compensation Method

Electric companies try to generate electrical power as sinusoidal and balanced voltages so it has been obtained as a reference condition in the supply. Due to this fact, the compensation target is based on an ideal reference load which must be resistive, balanced and linear. It means that the source currents are collinear to the supply voltages and the system will have unity power factor. If, in Figure 6, voltages are considered as balanced and sinusoidal, ideal currents will be proportional to the supply voltages (Patricio Salmeron R, *et al*., 2010).

$$v = R_e i \quad (7)$$

R_e is the equivalent resistanse, v the load voltage vector, i the load current vector.

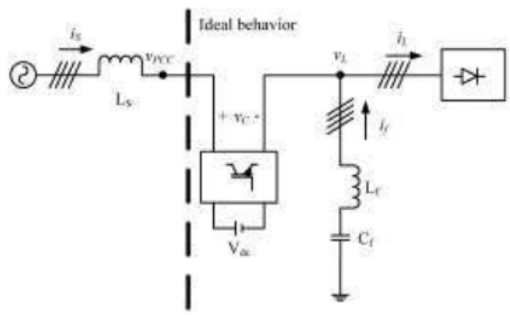

Figure 6. System with compensation equipment.

The average power supplied by the source will be

$$P_S = I_1^2 R_e \quad (8)$$

Figure 5 shows the system with series active filter, parallel passive filter and unbalanced and nonsinusoidal load. The aim is that the set compensation equipment and load has an ideal behavior from the PCC. The voltage at the active filter connection point in $0\alpha\beta$ coordinates can be calculated as follows:

$$v_{PCC\alpha\beta} = \frac{P_L}{I_1^2} i_{\alpha\beta} \quad (9)$$

$i_{\alpha\beta}$ is the current source in $0\alpha\beta$ coordinates.
The load voltage is given according to Equation 6 by

$$v_{L\alpha\beta} = \frac{p_L}{i_{\alpha\beta}^2} i_{\alpha\beta} + \frac{q_L}{i_{\alpha\beta}^2} i_{\alpha\beta\perp} \quad (10)$$

where p_L is the real instantaneous power and q_L is the load imaginary instantaneous power.

The reference signal for the output voltage of the active filter is

$$v_{C\alpha\beta}^* = v_{PCC\alpha\beta} - v_{L\alpha\beta} \quad (11)$$

Considering Equation 9 and 10, the compensation voltage is

$$v_{C\alpha\beta}^* = \left(\frac{P_L}{I_1^2} - \frac{p_L}{i_{\alpha\beta}^2} \right) i_{\alpha\beta} - \frac{q_L}{i_{\alpha\beta}^2} i_{\alpha\beta\perp} \quad (12)$$

When the active filter supplies this compensation voltage, the set load and compensation equipment behaves as a resistor R_e. Therefore, the equivalent resistance must be defined by the equation

$$R_e = \frac{P_L}{I_1^{+2}} \quad (13)$$

Here, I_1^{+2} is the square rms value of the positive sequence fundamental component. In this case, Equation 12 is modified, where I_1 is replaced by I_1^+, that is

$$v_{C\alpha\beta}^* = \left(\frac{P_L}{I_1^{+2}} - \frac{p_L}{i_{\alpha\beta}^2}\right) i_{\alpha\beta} - \frac{q_L}{i_{\alpha\beta}^2} i_{\alpha\beta\perp} \quad (14)$$

Reference signals are obtained by means of the reference calculator shown in Figure 7 and 8. In the case of unbalanced loads, the block "fundamental component calculation" in Figure 7 is replaced by the scheme shown in Figure 9, which calculates the current positive sequence fundamental component.

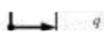

Figure 7. Control scheme.

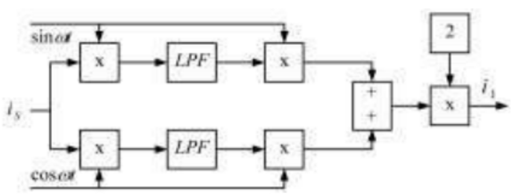

Figure 8. Calculation fundamental component.

The control scheme for the active filter shown in Figure 7, is modified for unbalanced loads. The block "fundamental component calculation" in Figure 7 is replaced by the scheme shown in Figure 9. Now the average power P is divided by the square rms value of positive sequence fundamental component. In this case, the positive sequence component is calculated by means of the block "positive sequence component", where the operator necessary to implement the Fortescue transformation is obtained with an all pass filter. Subsequently, its fundamental value is calculated and the Fortescue inverse transformation applied.

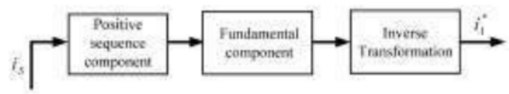

Figure 9. Modification in control scheme for unbalanced load.

Non Linear Load

The non linear loads are electrical loads which gets sinusoidal AC supply voltage, but the input current form of non-sinusoidal. Household appliances which are categorized as non-linear is all devices that uses switching principle and semiconductor switch, or based on power electronics. Some examples of non-linear loads are televisions, LED lights and energy saving lamps. The currents generated by the loads is shaped sinusioda which means which contains a frequency 50 Hz and harmonics current or high frequency current integer multiples of 50 Hz. Assuming that harmonics have extreme phase angle, it can be drawn that fundamental current to flow into the equipment, while harmonic current flowing out of equipment to the electrical grid system.[13]

Load Modelling in Industry

Figure 10 shows an industrial power system which has linear and non linear load, capacitors for power factor correction and harmonic filter connected to a common bus. The main part of a distribution transformer installed on the consumers is connected to Point of Common Coupling (PCC), while the secondary supplies the linear and non linear connected load on the common bus. Power system may generate harmonic propagation as a result of series and/or parallel resonances between the power capacitor and the leakage inductor of the distribution transformer.[7]

Figure 11 shows a single phase circuit equivalent to power system under the assumption that only a 5th harmonic voltage appears on PCC bus. Here, L_T is leaking transformer inductance, capacitance; C of capacitors to improve power factor, R_L is the equivalent resistance of the load. A common bus voltage V_{BUS} includes a 5th harmonic voltage V_{BUS5} which is given by

$$V_{Bus5} = \frac{1}{1-(5\omega)^2 L_T C + \dfrac{j5\omega L_T}{R_L}} V_{S5} \quad (15)$$

Where ω is angular frequency of the line voltage.

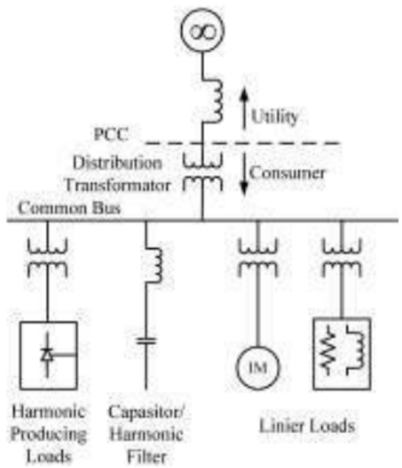

Figure 10. Industrial power system.

A no-load condition $R_L = \infty$ yields a relationship of $V_{BUS5} > V_{S5}$. This implies that harmonic propagation occurs in the industrial power system. When the resonant frequency between L_T and C parallel happens with the 5th harmonic, Equation 15 is simplified below:

$$V_{Bus5} = \frac{R_L}{j5\omega L_T} V_{S5} \quad (16)$$

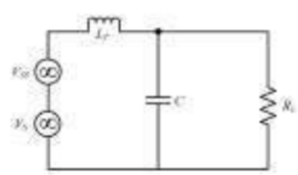

Figure 11. Single phase equivalent circuit.

Harmonic resonance can magnify the 5th-harmonic voltage by 4–0 times in full load condition because L_T has an inductance of 2–5%.

Power Quality

Power quality means quality of voltage and current. Quality is determined based on the voltage and current value or the tolerance limit of equipment used. In general, current and voltage wave form of pure sinusoidal waves. One problem that occurs is non sinusoida or distorted current and voltage waves generated by harmonics in the power system.[16]

Harmonic

Harmonic is distorted periodic steady state wave caused by the interaction between the shape of a sine wave at the fundamental frequency system with another wave component which is an integer multiples frequency of fundamental frequency. The most common harmonic index, which relates to the voltage waveform, is the THD, which is defined as the root mean square (rms) of the harmonics expressed as a percentage of fundamental component as showed in Equation 17. For most applications, it is sufficient to consider the harmonic range from the 2nd to 25th, but most standards specify up to the 50th.[14] Second harmonic index is current THD means the ratio of rms harmonic current value to rms fundamental current which expressed in Equation 18[15]

$$THD_V = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1} \times 100\ \% \quad (17)$$

$$THD_I = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} \times 100\ \% \quad (18)$$

where V_n and I_n (the rms voltage and current at harmonic n), V_1 and I_1 (the fundamental rms voltage and current), N (the maximum harmonic order to be considered).

The allowable maximum THD value for each country is different depending on the standard used. THD standards most often used in electric power system is IEEE Standard 519–1992. There are two criteria used in the analysis of harmonic distortion that voltage distortion limit and current distortion limit.[16]

Unbalance Voltage and Current

There are several standards that can be used to determine the level of voltage unbalance in three-phase systems, e.g. IEC, NEMA, and IEEE. In this study, the value of unbalance voltage use Equation 11 is based as follows:[17]

$$V(\%) = \frac{\left| V_{avarage} - V_{a,b,c\,\min\,or\,\max} \right|}{V_{avarage}} \times 100\ \% \quad (19)$$

By using Equation 19, value of unbalance voltage expressed in percent (%) and is defined as follows; $V_{avarage}$ is the average value of maximum voltage on phase a, b, c, (volt), $V_{a,b,c\,min}$ is minimum voltage on phase a, b, c, (volt), $V_{a,b,c\,max}$ is maximum voltage on phase a, b, c (volt). By using the same equation, then percentage of unbalance current can be calculated by replacing voltage into current magnitude.

Power Factor Correction

The value of input power factor can be obtained based on the value of source current THD. Equation 20 shows value of input power factor as a function of source current THD.[9]

$$PF = \frac{1}{\sqrt{1 + \left(\frac{THD_I(\%)}{100} \right)^2}} \quad (20)$$

Where PF is the power factor and THD_I is harmonic current value (%).

RESEARCH METHOD

Proposed Method

Figure 12 shows a series of three-phase power system supplied by 380 Volts and 50 Hz a three-phase balance sinusoidal voltage is connected with a series of non-linear loads in the industry through a series hybrid active power filter. Hybrid active power filter circuit consists of a series active filter and passive filter. The series active filter includes a bridge circuit of Insulated Gate Bipolar Transistor (IGBT) with DC side connected to two DC voltage source. The circuit is also connected to power system through acurrent transformer with transformation ratio of 1:1. The series active filter includes of pulse width modulation (PWM) and three-phase voltage source inverter (VSI). Passive filter circuit is represented by two double LC filter that serves to eliminate high frequency components such as 5th and 7th harmonic at inverter output. The active filter is connected in series with AC source impedance and able to improve characteristics of LC filter in parallel.

The model of passive filter, series active filter, and hybrid active filter is used as compensation circuit connected non-linear load. The voltage compensation is needed to eliminate harmonic voltage and to create a balanced system, which injects a voltage compensation through secondary coil of current transformer in series with the line. The filter circuit is used to reduce unbalanced source current and voltage, improve input power factor, and reducing harmonic as well as lowering THD current and voltage. The series active filter is modeled mathematically by voltage and current control using PWM technique. The parameter that will be studied are value migitation of current and voltage THD on PCC bus, unbalanced current and voltage, and input power factor on the conditions before and after installed passive filters, active filters series, and three-phase hybrid active filter. There are two operation modes, namely the system connected to balanced non-linear load and unbalanced non-linear load in the industry. The passive filter, series active filter, and three phase hybrid active filter are modeled using Matlab/Simulink. The results are used as a performance evaluation of three filter models refers source voltage and current THD voltage (IEEE 519-1992), current and voltage unbalanced (ANSI/IEEE 241-1990), and input power factor (PLN).

Simulation Parameter

Table 1 shows devices, parameters, and design value of simulation model of three phase system using passive filter and series active filter connected to non linear load in industry.

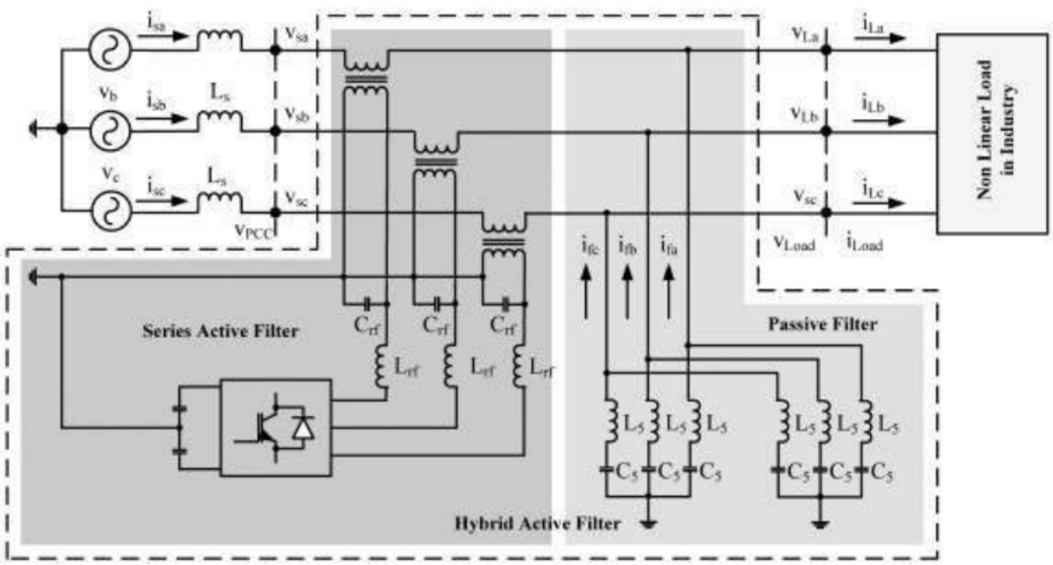

Figure 12. Filter Circuit Topology.

Table 1. Simulation Parameter

No.	Devices	Parameters	Design Value
1.	Three phase balanced source	Voltage (phase-phase)	380 V
		Frequency	50 Hz
2.	Source impedance	Resistance	0,01 Ohm
		Induktance	1 μH
3.	Ripple filter	Capacitance	50 μF
		Induktance	14 mH
4.	DC source on series active filter	Capacitance 1	40 μF
		Capacitance 2	40 μF
5.	Current transformator on series active filter	Transformation ratio	1: 1
6.	Passive filter (LC)	Inductance 5th order	14 mH
		Capacitance 5th order	30 μF
		Inductance 7th order	7 mH
		Capacitance 7th order	30 μF
7.	Non linear load (DC side)	Series inductance	1 mH
		Parallel capacitance	1 μF
		Parallel resistance	10 Ohm
8.	Balanced load	Resistance on phase a	24 Ohm
		Resistance on phase b	24 Ohm
		Resistance on phase c	24 Ohm
10.	Unbalanced load	Resistance on phase a	6 Ohm
		Resistance on phase b	12 Ohm
		Resistance on phase c	24 Ohm

RESULT AND DISCUSSION

Balanced and Unbalanced Non Linear Load Modes

On balanced non-linear load mode, a three-phase system is connected to non linear load in industry of a three-phase uncontrolled rectifier circuit with series induktance 1 mH as well as connected to load parallel capacitance and resistance 1 μF and 10 ohm respectively. The circuit is also connected to balanced load of three load resistances 24 ohm each. The passive filter, series active filter, and hybrid active filter are three combination compensation filters on the three-phase system connected balanced non linear load in industry. Parameters of power quality studied are source current and voltage THD, voltage and current unbalance, and input power factor. The initial step is to determine source current and voltage THD in each phase and determine their average THD values before and after using three models filter compensation. The second step is to determine maximum and minimum values of source current and voltage in each phase as well as determine unbalanced current and voltage values by using Equation 19. The third step is to determine input power factor using Equation 20 based on source current THD value which has been achieved in the first step before. Table 2 shows current and voltage THD, unbalanced current and voltage, and input power factor on source side (PCC bus), before and after using compensation filters.

Figure 13 shows source voltage and current curve of three phase system connected to balanced non linear load in the industry, without compensation, using passive filters, series active filters, and hybrid active filter. Figure 14 shows harmonic source current spectrum on phase A of three phase system connected to balanced non linear loads in industry, without compensation, using passive filters, series active filters, and hybrid active filter.

Table 2 shows that the average value of source current THD of system connected balanced non linear load without compensation, using passive filter, series active filter, and hybrid active filter are 24.52%, 24.277%, 4.56%, and 4.5734% respectively. The simulation result shows system without compensation filter and using passive filter produces an average THD of source current relatively high and have exceeded IEEE519-1992 Standard. Whereas the use of series active filter and hybrid active filter can reduce source current THD or improve current quality under IEEE 519-1992 Standard. The value of source voltage harmonic system connected to balance non linear load for all compensation conditions were relatively small below level of 1% and have met IEEE 519-1992 Standard. The condition indicates that the presence of balance non-linear load only affects on sources current harmonic and does not have a significant impact on source voltage harmonic. Both unbalanced current value of system without compensation and using passive filter are 0%, while using series active filter and hybrid active filter, the value will increase to 29.9% and 37.50%. The value of unbalanced source voltage for all compensation conditions are relatively stable at 0%. The input power factor of system connected balanced non linear load on four compensation conditions increases smoothly from 97.123%, 97.2%, 99.894%, to 99.896 respectively.

Table 3 shows that the average value of source current THD of system connected balanced non linear load without compensation, using passive filter, series active filter, and hybrid active filter are 20.697%, 20.424%, 2.737%, and 3.294%. The simulation result shows system without filter compensation and using passive filter results an average source current THD higher than IEEE Standard 519–1992 of current THD as 5%. While the use of series active filter and hybrid active filter is able to migitate source current harmonic under IEEE Standard 519–1992. The unbalanced source current of system without compensation, using passive filter, series active filter, and hybrid active filter, its value increase began from 8.511%, 10.127%, 30.693%, to 42.268. The value of unbalanced source voltage on four compensation conditions are relatively stable as 0%. These results indicate that the system is connected to unbalanced non linear load contribute unbalanced current higher than unbalanced voltage. The input power factor of circuit connected to unbalanced non linear load on four compensation conditions are 97.925%, 97.977%, 99.963%, and 99.946 respectively.

Table 2. Power quality parameters on balanced non liniear load

No	Compensation Types	Phase	THD (%)	Avg THD (%)	Maximum Value	Unbalanced Value (%)	Power Factor (%)	Avg Power Factor (%)
	Source Current (Ampere)							
1	Without Compensation	a	24.52	24.520	64	0	97.123	97.123
		b	24.52		64		97.123	
		c	24.52		64		97.123	
2	Passive Filter	a	24.17	24.177	66.6	0	97.202	97.200
		b	24.19		66.6		97.197	
		c	24.17		66.6		97.202	
3	Series Active Filter	a	3.98	4.5640	17	29.90	99.921	99.894
		b	5.77		38		99.834	
		c	3.94		42		99.928	
4	Hybrid active Filter	a	2.35	4.5734	16	37.50	99.973	99.896
		b	7.58		36		99.714	
		c	3.79		44		99.929	
	Source Voltage (Volt)							
1	Without Compensation	a	0.07	0.07	310	0	-	-
		b	0.07		310		-	
		c	0.07		310		-	
2	Passive Filter	a	0.07	0.07	309.7	0	-	-
		b	0.07		309.7		-	
		c	0.07		309.7		-	
3	Series Active Filter	a	0.00	0.0034	310	0	-	-
		b	0.01		310		-	
		c	0.00		310		-	
4	Hybrid active Filter	a	0.00	0.0034	310	0	-	-
		b	0.01		310		-	
		c	0.00		310		-	

Table 3. Power quality parameters on unbalanced non liniear load

No	Compensation Types	Phase	THD (%)	Avg THD (%)	Maximum Value	Unbalanced Value (%)	Power Factor (%)	Avg Power Factor (%)
	Source Current (Ampere)							
1	Without Compensation	a	18.85	20.697	85	8.511	98.269	97.925
		b	20.01		81		98.056	
		c	23.23		69		97.407	
2	Passive Filter	a	18.52	20.424	87	10.127	98.328	97.977
		b	19.93		79		98.072	
		c	22.82		71		97.494	
3	Series Active Filter	a	1.04	2.737	17	30.693	99.995	99.963
		b	3.35		40		99.944	
		c	3.82		44		99.927	
4	Hybrid active Filter	a	1.59	3.294	14	42.268	99.987	99.946
		b	4.76		37		99.887	
		c	3.53		46		99.938	
	Source Voltage (Volt)							
1	Without Compensation	a	0.07	0.07	310	0	-	-
		b	0.07		310		-	
		c	0.07		310		-	
2	Passive Filter	a	0.06	0.067	310	0	-	-
		b	0.06		310		-	
		c	0.07		310		-	
3	Series Active Filter	a	0.00	0	310	0	-	-
		b	0.00		310		-	
		c	0.00		310		-	
4	Hybrid active Filter	a	0.00	0	310	0	-	-
		b	0.00		310		-	
		c	0.00		310		-	

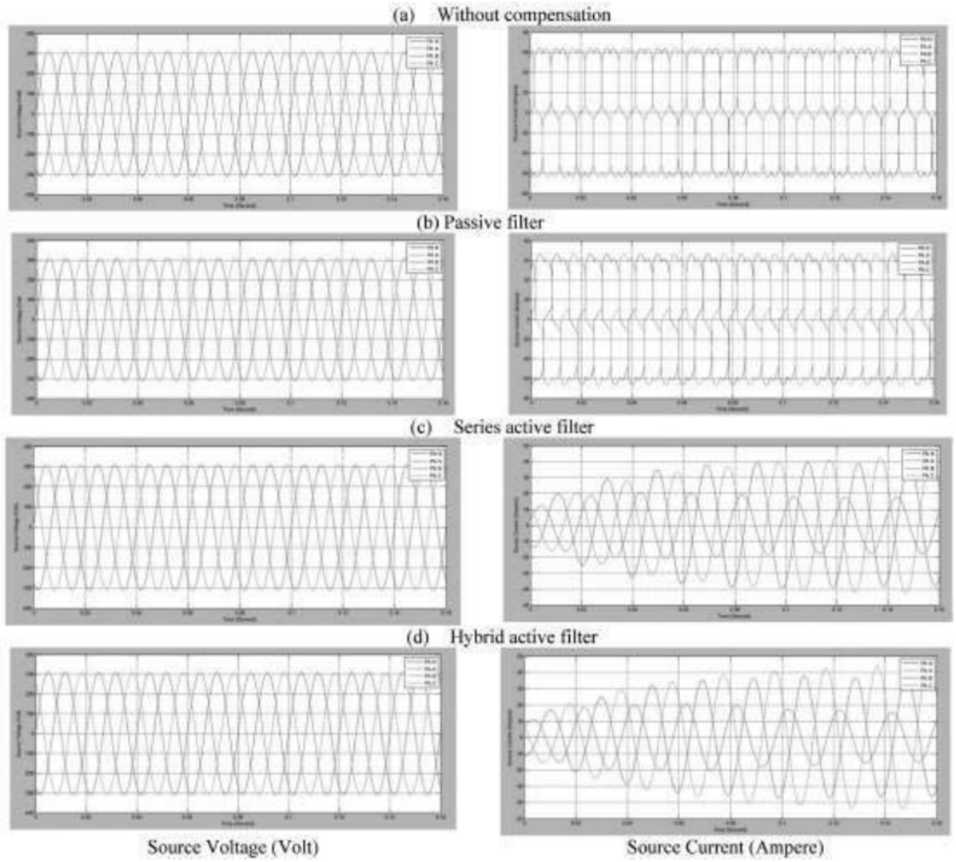

Figure 13. Source voltage and current of three phase system connected balanced non linear load.

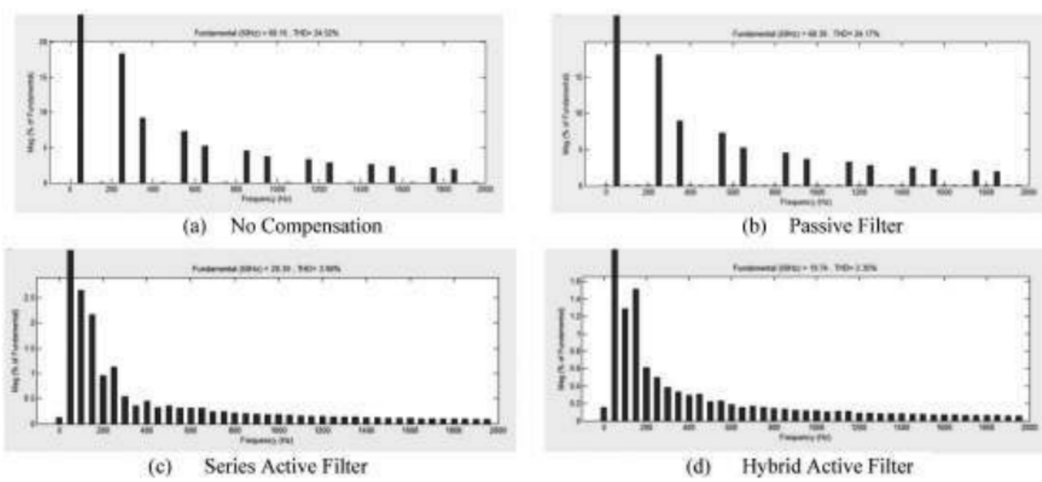

Figure 14. Source current spectrum on phase A connected balanced non linear load.

Source Current Harmonic, Unbalanced Current, and Input Power Factor

Figure 15.a shows the variation of average source current THD of system without compensation, using passive filter, series active filter, and hybrid active filter on two non-linear load modes. Figure 15.b and 15.c show the variation of unbalance current and power factor at the same conditions.

Figure 15.a shows the average value of source current THD of system connected to balanced non-linear load without compensation, using passive filter, series active filter, and hybrid active filter are 24.52%, 24.277%, 4.56%, and 4.5734% respectively. The same value for system connected unbalanced non-linear load are 20.697%, 20.424%, 2.737%, and 3.294%. Figure 15.b shows both balanced source current without compensation and using passive filter are 0%, whereas if using series active filter and hybrid active filter increased to 29.9% and 37.5%. The unbalanced source current of circuit without compensation, using passive filter, series active filter, and hybrid active filter rises from 8.511%, 10.127% 30.693%, to 42,268% respectively. Based on Figure 15.c we can see that the value of input power factor of system connected balanced non linear load without compensation, using passive filter, series active filter, and hybrid active filter increases slowly by 97.123%, 97.2%, 99.894%, and 99,896% respectively. On the same condition for system connected unbalance non linear load on four compensation conditions, its value roses smoothly respectively by 97.925%, 97.977%, 99.963%, and 99,964%.

CONCLUSSION

The system is connected unbalanced non linear load produces an average source current THD smaller than system connected balanced non linear load. The use of three-phase series active filter and hybrid active filter can reduce source current THD or improve source current quality by IEEE Standard 519–1992. At the same conditions, the system connected unbalanced non linear load results unbalanced source current value greater than the system connected balanced non linear load. The circuit connected unbalanced non-linear is able to generate input power factor value slightly higher than the system connected balanced non liniear load. The value of source voltage harmonic caused by balanced and unbalanced non linear load to all compensation conditions is relatively small and is below the level of 1%. The unbalance source voltage unbalance without and using filters on two modes were relatively stable at 0%. The system connected two non-linear load modes is only able to increase source current harmonic and unbalanced source current, but has no significant impact on changes of source voltage harmonic and unbalance voltage.

ACKNOWLEDGEMENTS

The authors would like to acknowledge to Directorate of Research and Community Service, Ministry of Research, Technology, and Higher Education, Republic of Indonesia, for financial support through Beginner Lecturer Research or "Penelitian Dosen Pemula" (PDP) base on Letter Number 0299/E3/2016 date 27 Januari 2016.

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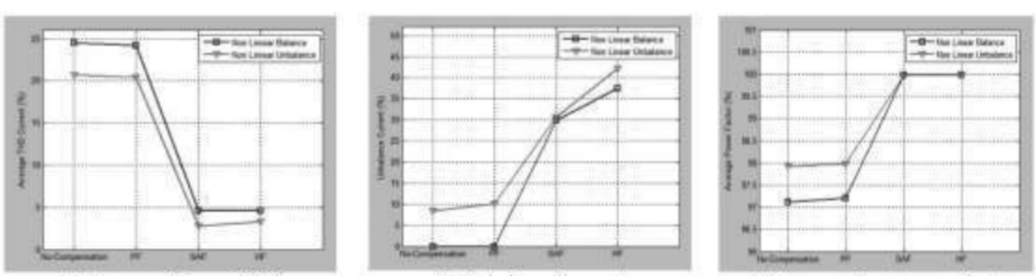

(a) Average Current THD (b) Unbalanced current (c.) Average input power factor

Figure 15. Variation of average current THD, unbalanced current, and average input power factor.

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