

Single Phase Power Factor Improvement Based Instantaneous Power P Q Theorm

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ABSTRACT

This paper presents how to harmonic disturbance reduce on single phase power system. One of the most popular method is harmonic signal extraction with instantaneous power p q theorm. This algorithm implemented to harmonic cencellation by active power filter circuit be paralld with the non linier load. This filter generates of current compensation that are injected into the grid to improve power quality. This Filter is built by an inverter circuit that consists of a mosfet switch array and capasitor mounted on DC link side. Two types of loads are resitive inductive and resistive capasitive produce of current source wave form that close pure sinusoid. Simulation results show the THD index fell to the level of 2.7% in accordance with IEEE 519 standard rules which states that the harmonics content of the power system may occur below 4%, indicating that the power system can be categorized as having good quality.

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1. INTRODUCTION

Harmonic presence on the power system has become a seriously problem. This signal occurs caused by used of many non linier loads such as variable frequency motor drives, inverter, converter, electronic equipment that consist semiconductor devaises. The non linier loads generate of electrical current with non sinusoid wave form caused by performance of solid stade switching. The harmonic effect are power losses, over heating of transformer, noise, interference telecommunication lines, electrical performance disturbance. harmonics can be reduced with a filter. There are two types of filters, namely passive filters and active filters. Passive filters have a simple form but cannot keep up with changes in load. Active filters have advantages over passive filters but have a more complicated circuit. The topology of active power filter is classified into three types[14] [15]

- a. Series active power filters
- b. Shunt active power filters
- c. Hybrid active power filters.

In 1976 Gyugi and Strycula introduced the concept of parallel active filters using a transistor device as an active switch device to inject antiharmonic currents into the grid. Figure 1 is an active power filter designed to eliminate harmonic interference signals. in Figure 1 is a simple concept that explains how an active filter generates an anti-harmonics current that is injected into the grid to maintain the source current to keep it sinusoidal even though the load current is non sinusoidal [1][16].

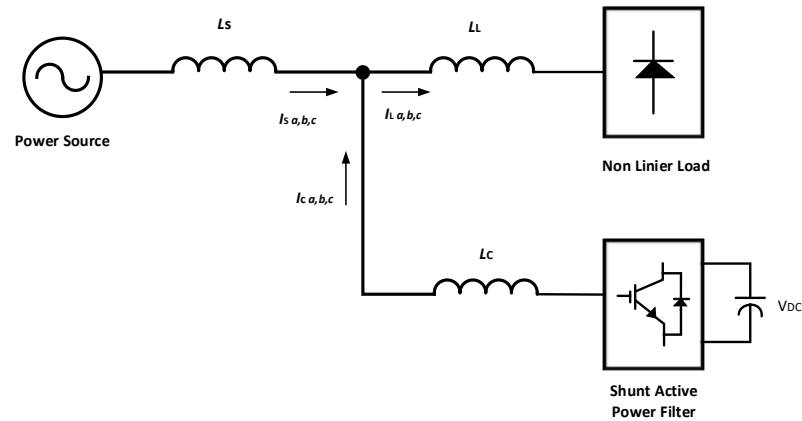


Figure 1. A shunt of active power filter

This filter has the ability to eliminate harmonic signals dynamically even though there are still ripple values but the signal permitted on use. In other words, this active filter can maintain the source current or voltage in the form of sinusoidal waves by injecting reactive power into single phase power system for harmonic component cancellation.

There are several methods for generating reference currents for harmonic reduction, including:

1. The FBD method (Frize Buchholz Depenbrock) is a method that calculates the ratio between the average power consumed and the voltage rms value, then the compensation current is calculated by the average value multiplied by the input voltage and minus the line source current.
2. Synchronous Reference Frame Method

This method is used to determine the components of the reference current through the calculation of park transform where the three reference currents are represented by alpha beta coordinates. then with the sudud rotation reference is changed to the coordinates of the i_d and i_q . This method is used to determine the components of the reference current through the calculation of park transform where the three reference currents are represented by alpha beta coordinates. then with the sudud rotation reference is changed to the coordinates of the i_d and i_q . The power component required by the electricity network can be found by removing the ac component from each power using a filter.

3. P-q Theory

This theory, also known as instantaneous power theory was proposed in 1983 by Akagi. This theory is based on the instantaneous value of the three-phase power system and contains algebraic equations which will be explained in the next sub-chapter (2.1) of this paper. some of the strengths of this theory are:

- It is inherently a three phase system theory
- It can be applied to any three phase system (balance or unbalanced, with or without harmonic in both voltage and current)
- Have a good dynamic response
- Has a relatively simple calculation
- This theory can control two quantities at once, namely instant instantaneous power supply and sinusoidal current sources [27]

The control strategy used in this paper is based on the calculation of intantaneous power pq extraction who proposed by Akagi (1984). Akagi said that to get the value of the current that is injected into the electricity grid by extracting of active and reactive power p and q . p and q contain two components, namely positive components and negative components. The positive component is the value of power taken and the negative component is an element that is not needed or thrown away. These values of quantities are then processed through the transformation of abc to $\alpha\text{-}\beta\text{-}0$ to and the transformation back of $\alpha\text{-}\beta$ to abc will get the reference current amount to be injected into the electricity network [2]. Some other literature was also used in the development of this control strategy. Figure 2 is an active power filter system that is implemented on a single-phase grid.

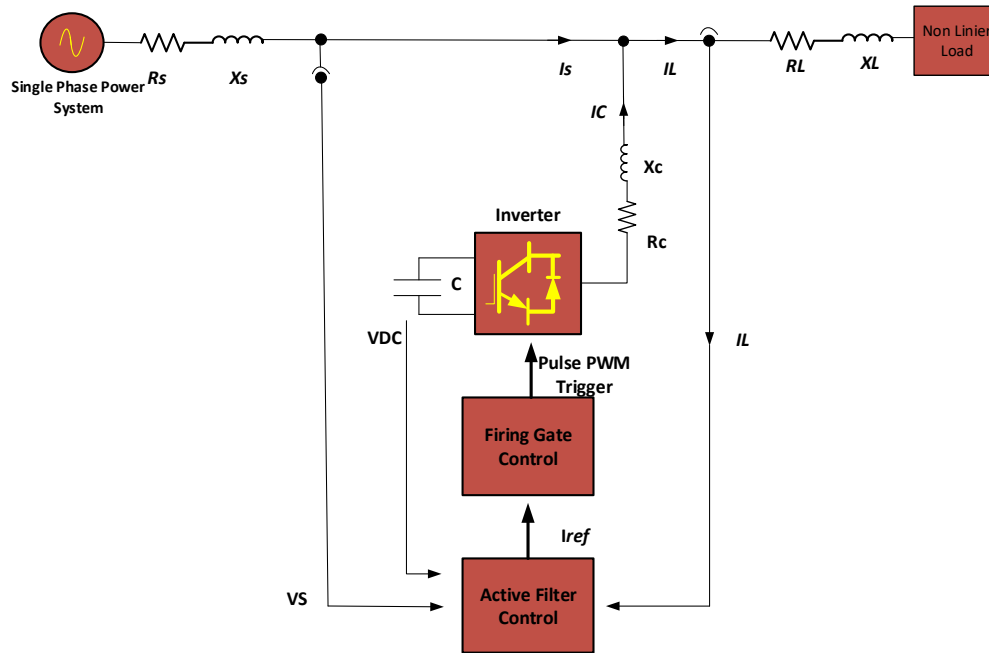


Figure 2. A shunt active filter system on a single-phase power system

The single-phase voltage source is set at 220 V frequency of 50 Hz, R_s and X_s are lines impedance, R_L and X_L as load impedance and R_c , X_c as reactor compensator impedance of the inverter. I_s , I_L , I_{ref} and I_c are source current, load current, reference current and compensation current. V_s , V_{DC} and I_L are voltage source, DC voltage capacitor and load current measured or calculated which are used for input processing of the active filter controller. The output signal from the active filter (I_{ref}) is used to generate pulse signal triggering of inverter switches. The inverter consists one leg of IGBTs devices that work in opposite directions. Reactive power obtained from the capacitor is injected into the grid in the form of I_c compensation current. The active filter system design was built into Matlab Simulink Tools. There are three types of load used in the simulation, namely non-linear load of single-phase diode rectifier that serves the resistive load, resistive - inductive and resistive – capacitive loads, to test the performance and reliability of the active filter.

1.1. Total Harmonic Distortion (THD)

Total Harmonic Distortion (THD) is a value that represents the magnitude of the distortion of the current and voltage waveforms. Mathematically the THD index is defined as a comparison of the rms value of the harmonic component to its basic component and is expressed in percentage. There are two types of harmonics in electricity, namely voltage harmonics and current harmonics. The THD index for voltage and current can be expressed in the equation:

$$THD_V = \frac{\sqrt{\sum_{h=2}^{\infty} V_h^2}}{V_1} \times 100\% \tag{1}$$

$$THD_I = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^2}}{I_1} \times 100\% \tag{2}$$

In this study the focus is on canceling current harmonics on a single-phase power system. The presence of Harmonics in the power system cannot be eliminated to zero percent, but there are certain limits where harmonics can still be tolerated. The following is a rule that limits the presence of harmonics in the power system according to IEEE Standard 519-1992 shown in table 1 below[26].

Table 1. IEEE Standard 519 – 1992

I_c/I_L	Order of harmonics in % of I_L				
	<11	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h$
<20	4.0	2.0	1.5	0.6	0.3
$20 < 50$	7.0	3.5	2.5	1.0	0.5
$50 < 100$	10.0	4.5	4.0	1.5	0.7
$100 < 1000$	12.0	5.5	5.0	2.0	1.0
>1000	15.0	7.0	6.0	2.5	1.4

2. RESEARCH METHOD

This research designed a simulation model of parallel active power filter series using simulink matlab tools. The simulation results are current source, reference current, and load current. Then this simulation wave is analyzed THD level and compared with IEEE 519 rules. THD values which are in IEEE 519 rules are said to be feasible to be implemented on a power system. The main parts of the system designed include active filter control for reference current generation, VSI (Voltage Source Inverter), and DC link voltage.

2.1. Active Filter Controller and Reference Current Generation

The shunt active power filter controller uses the theory from Akagi which states that to get the reactive power value to be injected into the grid, the voltage values of V_α , V_β and $I_{L\alpha}$, $I_{L\beta}$ are calculated first. with the extraction matrix called the Clark Transform equation, appears in equations [1] – [25].

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

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix} \quad (2)$$

This theory only applies to three-phase power systems, so that for an active filter control strategy parallel to a single-phase electric network requires 2 phase shifting units each with a different phase of 120° from each other.[4] Then combined with the first phase channel so as if this system is a three-phase power system. The relationship between the intantaneous power p and imaginary reactive power q on side load expessed equation 3

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} \quad (3)$$

$$p_L = \bar{p}_L + \hat{p}_L + \tilde{p}_L$$

$$q_L = \bar{q}_L + \hat{q}_L + \tilde{q}_L$$

The intantaneous power p_L and reactive power q_L each other has three component , respectively
Where :

$$\begin{array}{ll} \bar{p}_L, \bar{q}_L & \text{dc component} \\ \hat{p}_L, \hat{q}_L & \text{Low frequency component} \\ \tilde{p}_L, \tilde{q}_L & \text{High frequency component} \end{array}$$

Generally, the real instantaneous power required by the load, while other power components are compensated to the system through shunt active filters. To calculate the reference current injected into the grid , a cold and unwanted cost component is needed. An unwanted power element are expressed in p^* and q^* . \bar{p}_L and \bar{q}_L are the dc load component is the real power that need the load , and \hat{p}_L and \hat{q}_L are the ac load current component related to the harmonics signal that undesired ones on power system. Figure 3 The p q power component is represented by the p^* and q^* notation on the acquisition of an active power filter components.

$$p^* = \tilde{p}_L$$

$$q^* = \tilde{q}_L$$

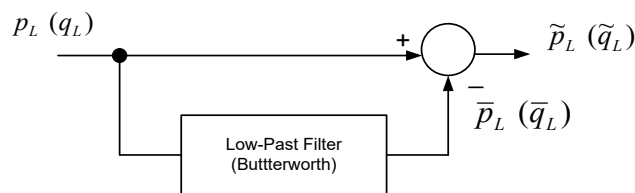


Figure 3. Calculation p^* and q^*

The reference current is obtained by reverse transform from $\alpha - \beta$ to a b c

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ -v_{\beta} & v_{\alpha} \end{bmatrix}^{-1} \begin{bmatrix} p^* \\ q^* \end{bmatrix} \tag{4}$$

In addition to the instantaneous power component determined by the p-q theory, there is also a component, p_{reg} , which is used to regulate the voltage of the capacitor on the dc side with the Proportional integral regulator (PI). Shown in Figure 4 is the process of extracting the desired and undesirable p and q power components to obtain a reference current.

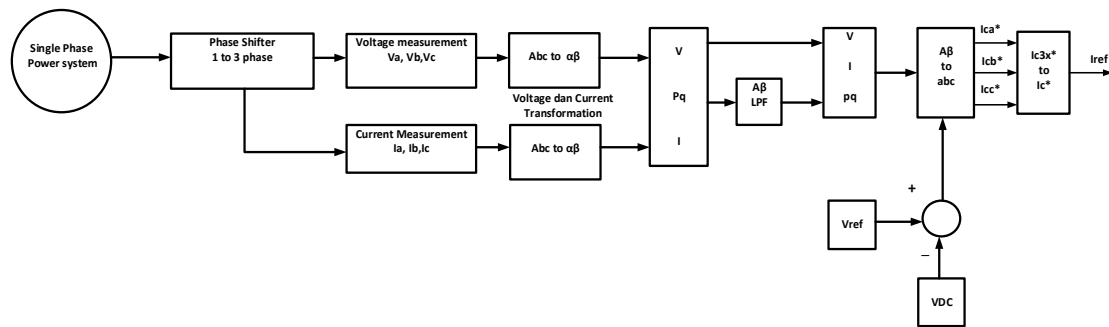


Figure 4. Current Reference Generation

2.2. Voltage Source Inverter (VSI)

The shunt active filters circuit is built using a IGBT switches equipped with anti-parallel diodes. On the DC side the inverter uses a capacitor of 35 uF. The output of the inverter is installed an inductor of 45 mh to reduce ripple that is caused by the inverter switch when working injecting compensation current into the grid. In part of Figure 1 there is a series of inverters that function as a switch to compensate the current flowing from the charge capacitor flow.

2.3. DC Link Voltage

Reactive power compensation is controlled by the dc link capacitor voltage which regulates the flow of DC current to the grid dynamically [13]. The compensation current comes from the capacitor charge which flows through the VSI switch. The DC voltage required by the capacitor to fluctuate is at least the same as the line voltage. In the VSI sequence the capacitor voltage is set at 230 V with a capacity of 4700 uF. This compensation current has the same pattern as the reference current but has a little ripple. To eliminate this ripple wave defect, a series inductor is installed on the VSI output side. DC link voltage regulation is carried out by the PI control. The PI controller is used to compare the actual dc voltage (VDC) with the reference dc voltage (VDCref) where the difference in error voltage is sampled. The transformation H (s) is expressed by:

$$H_s = K_p + \frac{K_i}{s} \tag{5}$$

2.4. Pulse Firing Generation

An important part of active filter is how to built gating signal generation. Figure 5 explains the generation of a pulse pulse through hysteresis band current control. This process of generating the signal pattern for the gate of the inverter switch with PWM modulation. The signal is obtained from a comparator that compares the carrier sinusoidal signal with the reference current. The signal is constructed by adjusting the reference current hysteresis in the comparator to produce a signal pattern [5][15][21][22][24].

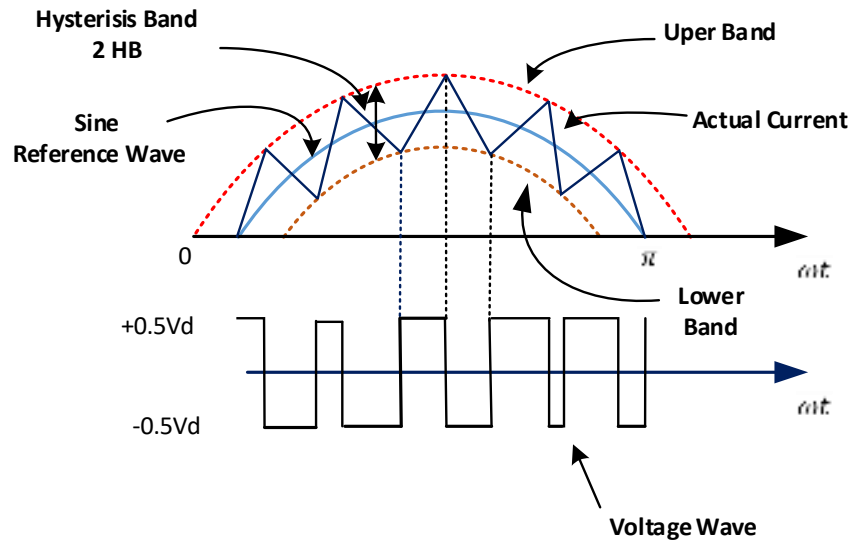


Figure 5. Hysteresis band current controller

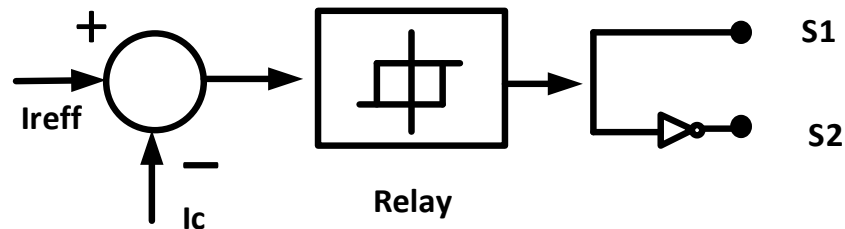


Figure 6. Pulse firing Generation for each switch

In this section the reference current is forced into the sinusoidal path of the carrier signal. So this inverter seems to be a current source that makes the net current become sinusoidal. Figure 6 The gate signal patterns are performed by the comparator which compares the carrier signal with the i_{ref} and i_{act} error signals. According the PWM rules can be explained, If $(i_{act}) > (i_{ref} + hb)$ the top switch (S1) is ON and the bottom switch (S2) is OFF if $(i_{act}) < (i_{ref} - hb)$ the top switch (S1) is OFF and the bottom switch (S2) is ON. In Figure 6, the reference current is compared with the compensation current from the inverter to calculate the error value. This value is modulated with a PWM (Pulse with Modulation) to obtain the signal that is used to firing inverter switch. There is a pair of switches, so only two signals for the gate switch S1 and S2 switch are started which work complementary or opposite. By adding an inverting circuit to the PWM output, two signals that opposite logic with each other will be obtained.

3. SIMULATION DESIGN

Figure 1. a simple power system single phase system with a non linear load diode rectifier. Then this power system is modeled into MATLAB Simulink to see the I_s source current wave format, I_L load current wave format and I_c current wave format on the phase line and injection line of the inverter. The design is shown in Figure 7. The source voltage has an amplitude of 220 V Line - Neutral, 50 Hz frequency with line impedance (Z_s) with $R_s = 0.5$ ohm $L_s =$ and 350 mH, load impedance (Z_L) with $R_L = 20$ ohm $L_L = 500$ mH, Inverter coupling impedance (Z_C) with $R_C = 1$ ohm $L_C = 35$ 35 mH. On the load side is a diode rectifier loaded with inductive Resitive (R_L) and Capacitive (R_C) impedance of $R = 50$ ohms, $L = 500$ H and $C = 15$ uF. The RL and RC loads on the diode rectifier are alternately tested to see the performance of the active filter.

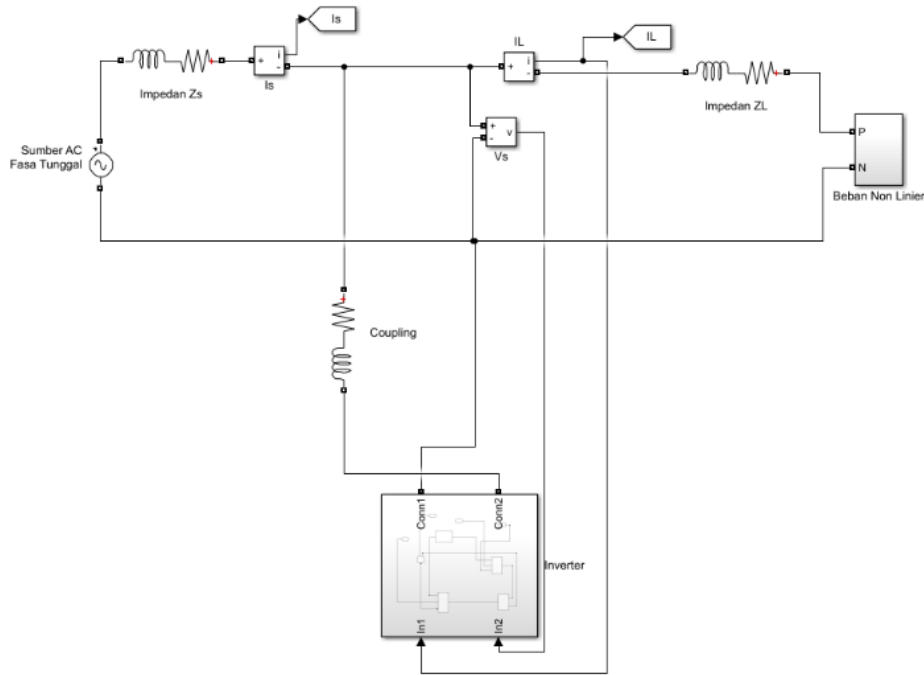


Figure 7. A single-phase active power filter Simulink model

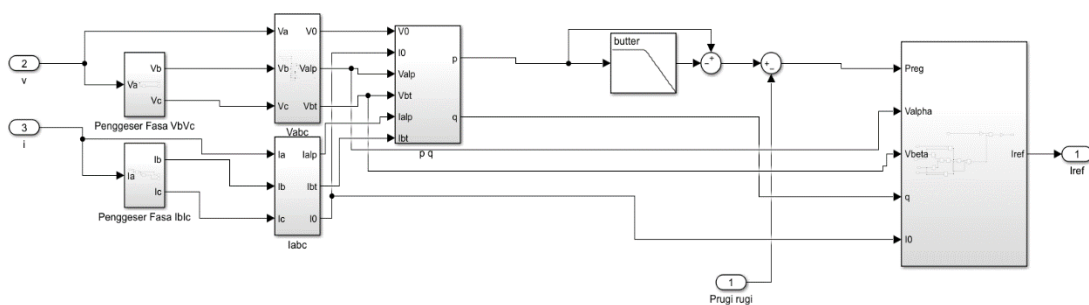


Figure 8 . Current Reference Generation Simulink Model

In Figure 8, the reference signal is generated through several stages: First, is to built a virtual voltage and current source as input voltage and current in equation 1 (clark transformation). The components V_a, V_b, V_c and I_a, I_b, I_c are transformed into the α - β coordinates to get the components p and q . Values of p and q contain unneeded components, removed through a buterwoth filter or low pass filter. The desired p component is still compared to the power loss element obtained from the reactive power calculation on the DC side capacitor of the inverter, which is expressed by P_{reg} . Where $P_{reg} = p$ desired - Prugi loss. While the loss power can be calculated from the V_{DC} capacitor voltage compared to the reference voltage V_{ref} through the proportional Integral regulator (PI). $P_{reg} = K_p (V_{reff} - V_{DC})$

4. RESULTS AND DISCUSSION

The simulation model testing is used to see the source voltage waveform, source current, load current, compensation current, capacitor voltage, and Total Harmonic Distortion Index when the system design is loaded with RL Inductive Resitive and RC Capacitive Resitive.

4.1. Simulation with RL Load

Figure 9. the capacitor voltage is at the level of 800 V then drops and is stationary at the voltage of 795 V when $t = 0.05$ s, at this time also the power loss will start to saturate at 30-Watt power. Current capacitors are insulated like a narrow pulse saw. This is closely related to the charge and discharge time of the capacitor

which is controlled by the performance of the inverter switch. This current is used to force the source current to remain sinusoidal.

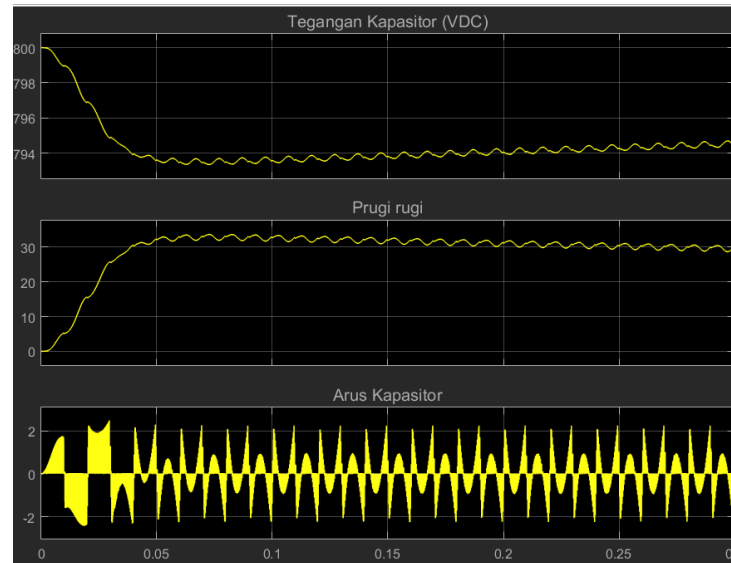


Figure 9 . Capacitor voltage, Poses, Current Capacitor at RL Load

Figure 10a the non-sinusoidal resembling square wave I_L (a) load current is the current drawn by the diode rectifier load. Figure 10 (b) compensation current wave I_c , is the current injected into system. to eliminate distortion wave of source current, or in other words this compensation current is needed so that the source current remains in the form of sinusoid even though the load draws the current in a non sinusoid format.

$$I_L = I_S + I_c, \text{ then}$$

$$I_S = I_L - I_c$$

Figure 10c, it appears that the source current of I_S is almost sinusoid, but there is still a little ripple but the existence of this principle can still be tolerated.

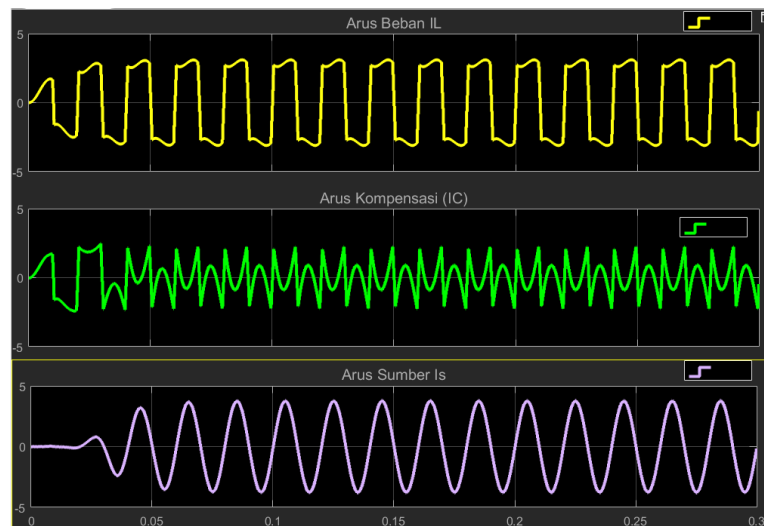


Figure 10. Load Current, Compensasion Current, Source Current Waves with RL Load.

Figure 11 Shows the Total Harmonic Distortion (THD) index of the system before filtered, the source current was shaped like a square wave with a high THD of 37.9%. The disturbing type of harmonics are in the frequency of odd multiples (150 Hz, 250Hz, 750 Hz and so on) or odd order of 3, 5, 7 and so on. Characterized by the amplitude of the order of harmonic 3,5,7 9 11 which is quite high on the graph of the simulation results

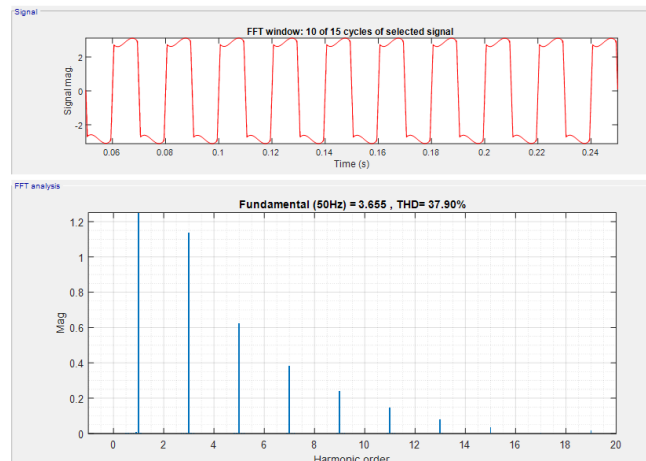


Figure 11. Total Harmonic Index of Current Load before filtered

Figure 12 shows the Total Harmonic Distortion (THD) index of the system that has been given an active filter to thwart the harmonic interference so that the THD content can be reduced significantly, which is around 4.34% with the source current approaching sinusoid.

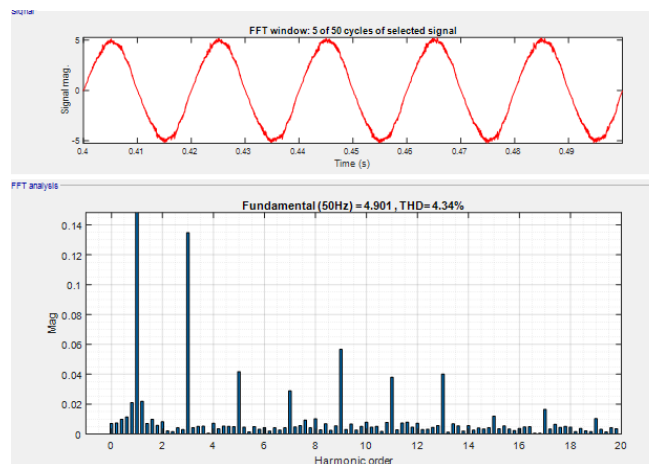


Figure 12. Current source THD index After filtered with RL Load

4.1. Simulation with RL Load

Figure 13. shows the load current I_L (a), I_C compensation current (b) and I_S source current (a) when the system is loaded with Capacitive Resistive load (RC). The load is a diode rectifier connected in parallel with $R = 50$ ohms and a $35 \mu\text{F}$ capacitor. In Figure 12, it appears that the load current, although approaching sine, is still distorted or defective. When injected with compensated current, the source current is sinusoid. Figure 14 shows the capacitor voltage, power loss and capacitor current at the beginning of the simulation, the capacitor voltage rises to stationary at the time of 0.2 s while the power loss drops from the voltage of 820 V and saturates at 720 V. The capacitor current is insulated up and down with maximum amplitude of 5 A and minimum -5A in the form of waves that change change It looks like a sinusoidal wave is distorted and turns into a narrow pulse wave, this happens because of the charging and discharging of the capacitor charge caused by the work of the inverter switch in injecting compensation current into the single phase power system line.

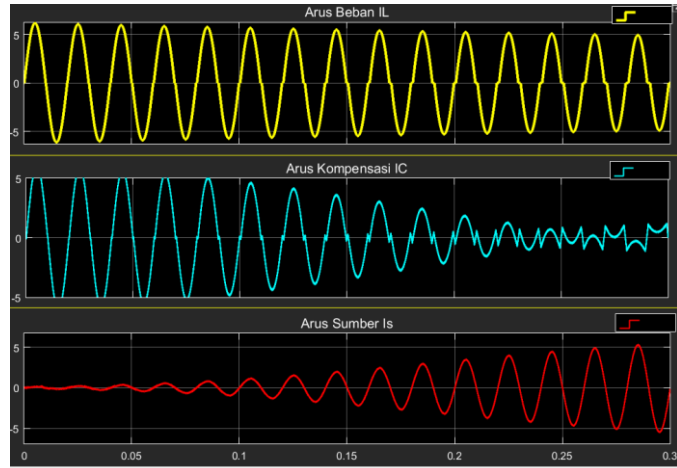


Figure 13. Current Load, Compensation current, and Source Current with RC Load

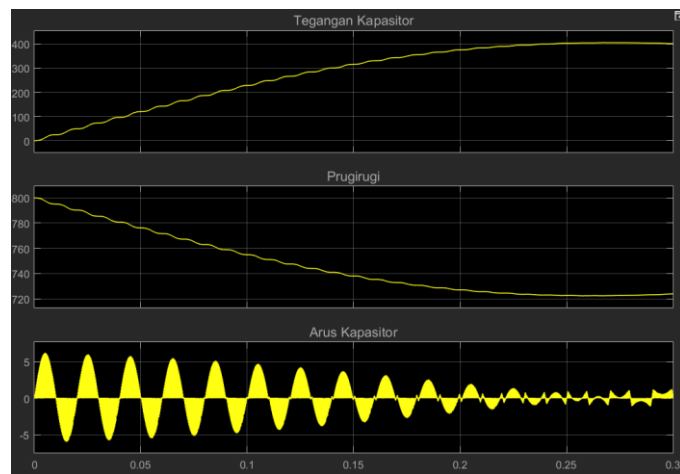


Figure 14. Capacitor voltage, P Losses, Current capacitor with RC Load

In figure 15 the source current is distorted with the THD index of 58.71%. The disturbing harmonic component is in the third order, namely order 3, 5, 7, and so on or the harmonic signal with odd multiple frequency (150 Hz, 250 Hz, 450 Hz and so on) from the source frequency that is 50 Hz. The third harmonics which is very dominating the source current wave defects.

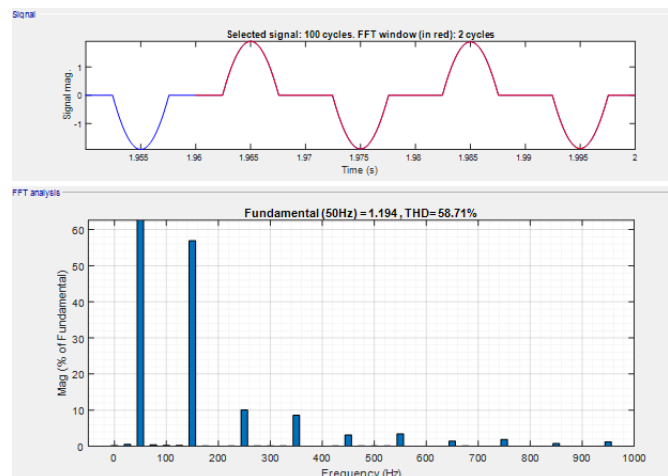


Figure 15 . THD Index of Current Load before Filtered with RC Load

Figure 16 is the source current waveform and THD index after filtered, shows that the source current close to sinusoid and THD index has decreased from 58.71% to 2.70%.

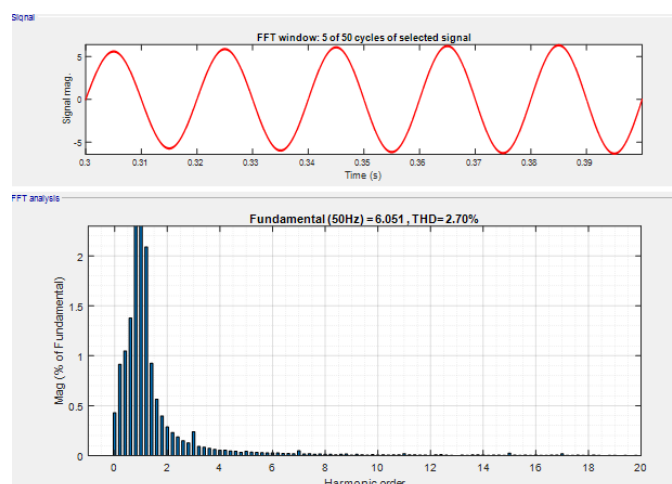


Figure 16. THD index of Current source after filtered with RC Load

5. CONCLUSION

Harmonic signal interference due to the use of non-linear loads in the single-phase power system distorts the source current. This interference current can be suppressed by using an active filter arranged in parallel with the load. Harmonic interference currents are found in odd order harmonics, that is, order 3,5,7,9 and so on. The pattern of injection current or compensation current is obtained from the charging and discharging of the capacitor charge whose performance is determined by the inverter as a regulator of the connection and opening of the switch which aims to force the source current to stay awake in the form of sinusoid. The simulation results on RL load show the THD index dropped significantly from 58.71% to 2.70% or decreased to 56.01%. According to IEEE 519 rules, the maximum THD limit of harmonics under 11 is 4%. So, this modeling is feasible to be implemented as a single-phase power system.

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