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Multi-tuned Active Power Filter Based on p-q Theory for Power Harmonic Supression

Moh. Jauhari[1], Kukuh Widarsono[1], Akhmad A. Kurdianto[1], Ciptian W. Priananda[2], Moch. Machmud Rifadil[1], and Arman Jaya[1]

***Abstract*—The phenomenon of voltage and or current harmonic distortion often occurs in industrial electrical system. The harmonic distortion waveforms are caused by non-linear loads. Active power filters can reduce harmonic distortion on almost any harmonic order that appears. The p-q theory is a widely used method to calculate harmonic reference currents that required. This paper proposes an active power filter controlling method that can determine the desired harmonic order to be compensated specifically. Through this method, only the desired harmonic order will be compensated. This proposed method increases the effectiveness of p-q theory in the calculation of current harmonic suppression. the simulation results show that the proposed method can suppress the desired harmonics to be compensated, ie 3rd order from THD 30% to 0.46%, while in 5th order from 10% to 0.09%.**

***Keywords*—Multi-tuned, APF, Reference Current, Compensation Current.**

I. Introduction

Harmonic distortion is often found in electrical systems that use many non linear loads such as Variable Speed Drive (VSD) and power electronics components in general [1]. Harmonic distortion can cause losses such as heat dissipation even under operatioal on electrical components.

In general, a method that can be used to fix harmonic distortion waveform is the use of power filters [2]. The harmonic power filter works by separating the fundamental waveform with the other waveform order. Based on work and topology, the power filters can be classified into the passive and active power filters (APF) [3].

Passive power filters are one of the earliest methods that used to eliminate harmonics distortion. This passive power filter method works by utilizing the resonance frequency in a combination of RLC circuits to be able to eliminate the desired harmonics orde [4]. The passive power filter only eliminates the prescribed frequency order so that for harmonic distortion consisting of several harmonic orders it needs more passive power filter [5].

Compared to the passive power filters, the active power filters can eliminate on almost all harmonic distortioan waveforms that occur [6]. The active power filter works by generating the harmonic compensation current after calculating the signal waveforms of the voltage and the current of the grid that to be fixed.

Akagi proposed p-q theory in 1983 [7]. This theory explains the simplification of active and reactive power calculation of a three-phase system by using clark transformation. This simplification can shorten the calculation process of active and reactive power of three phases so it is very influential in the calculation phase done by microcontroller device.

The p-q theory can be applied to calculate the reference current which is then used to generate the harmonic compensation current by separating the large signal and the small signal on the three phase active and reactive power that obtained from the p-q theory calculation [8].

This paper proposes a multi-tuned active power filter that controlled by the p-q theory. The proposed method can determine the order of harmonics to be eliminated by the active power filter. The voltage and current signals on the active power filter are filtered with a passband filter (BPF) so that only the desired harmonic order will generate the harmonic compensation current. This method can improve the effectiveness of p-q theory calculation in generating reference current.

II. Configuration System

A. Active power filter based on p-q theory

The p-q theory simplifies the calculation of three-phase active and reactive power so that the calculation process is relatively faster than the conventional calculation [9]. The p-q theory uses the clarke transformation to convert the three-phase *abc* coordianate into two phases *αβ* coordinate. The following equations (1) and (2) are clark transformations at source voltage and current.

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

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

[1]Moh. Jauhari, Kukuh Widarsono, Akhmad A. Kurdianto, Moch. Machmud Rifadil, Arman Jaya are with Department of Industrial Electric Engineering, Politeknik Negeri Madura, Sampang, Indonesia. E-mail: mohjauhari51@gmail.com.
[2]Ciptian Weried Priananda with Department of Industry Mechanical Engineering, Institut Teknologi Sepuluh Nopember, Surabaya, 60111, Indonesia.

The calculation of three phase active and reactive power based on p-q theory can be done by the following equation [10]:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

The active and reactive power of equation (3) consists of small and large signal components so that it can be written as follows [11]:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} P + p\sim \\ Q + q\sim \end{bmatrix} \quad (4)$$

Large signal (P, Q) is a fundamental component of power quantities while the small signals (p ~, q ~) are components at other frequency orde [12].

If the equation (3) is converted, the current on the source side will be obtained as a function of p and q as in the following equation:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \quad (5)$$

Equations (4) and (5) show that to separate the harmonic components at the source current, the active power p uses only small signal components p. To eliminate the reactive power from the source side is to make a negative value of q in (5) [11]. So the equation for calculating the reference current is as follows:

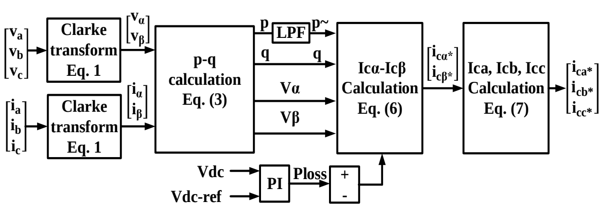

Figure 1. p-q theory calculation.

$$\begin{bmatrix} i_{\alpha\text{-ref}} \\ i_{\beta\text{-ref}} \end{bmatrix} = \frac{1}{{v_\alpha}^2 + {v_\beta}^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} p\sim \\ -q \end{bmatrix} \quad (6)$$

The reference current in equation (6) is then transformed from the αβ coordinate to the abc coordinate using the inverse clark transform. Figure 1 shows the block diagram of the p-q theory calculation in generating the reference current.

$$\begin{bmatrix} i_{a\text{-ref}} \\ i_{b\text{-ref}} \\ i_{c\text{-ref}} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{\alpha\text{-ref}} \\ i_{\beta\text{-ref}} \end{bmatrix} \quad (7)$$

B. Multi-tuned Active Power Filter Based on p-q Theory

Active power filter can eliminate almost at all the harmonic frequency orde that generated by non-linear loads. This paper proposed the multi-tuned active power filters that will eliminate the desired harmonic order specifically so as to increase the effectiveness of the generation of compensation current by active power filters.

The reference current obtained from equation (6) is filtered with a bandpass filter (BPF) to determine the desired harmonic order to be eliminated. Order of harmonics to be eliminated can be single orde or more. Figure 2 shows a schematic of multi-tuned active power filter based on p-q theory with non-linear load.

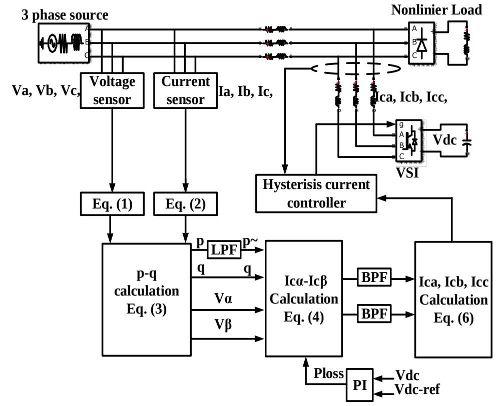

Figure 2. Multi-tuned APF based on p-q Theory.

III. RESULT AND DISCUSSION

To find out the performance of the proposed method, simulations were made on the condition of currents source has harmonic distortion at 3rd and 5th order. Table 1 below shows the parameters that used in the simulation.

TABLE 1.
SIMULATION PARAMETER

Parameter	value
Voltage source	V_{LN} abc = 220 Vrms
Current source	Fundamental = 20A = 100%
	3[th] Orde = 6 A = 30%
	5[th] Orde 5 = 2 A = 10%
Frequency	50 Hz

Figure 4 shows the simulation results of source current waveform, load current and compensation current. The active filter improves the current of the distorted harmonic source due to non-linear load by eliminating the harmonic current.

Simulations are performed at three time intervals. The first 0.2 seconds, the active power filter is not tuned to compensate so that the source current waveform is distorted as in the load current. The 3rd harmonic order is eliminated so that the current waveform is relatively more sinusoidal than the previous interval. Then at the last 0.2 second interval, the 5th harmonic order current is also eliminated so that the source current becomes pure sinusoidal.

Figure 5 shows the harmonic spectrum before the active power filter is tuned for harmonic suppression in the first 0.2 second interval. The source current contains the 3rd and 5th harmonics with Total Harmonic Distortion (THD) is 31.62%.

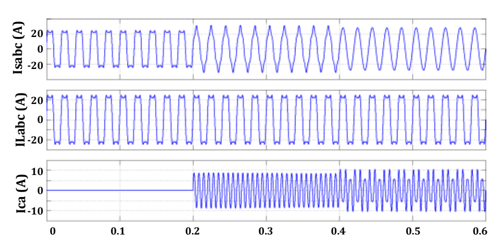

Figure 4. Simulation results.

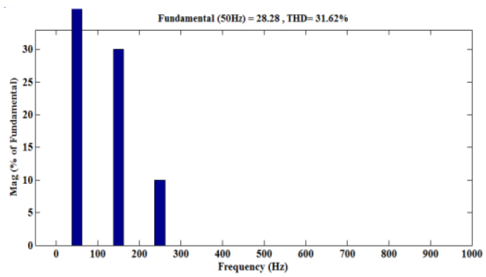

Figure 5. THD of current source at 0-0.2s.

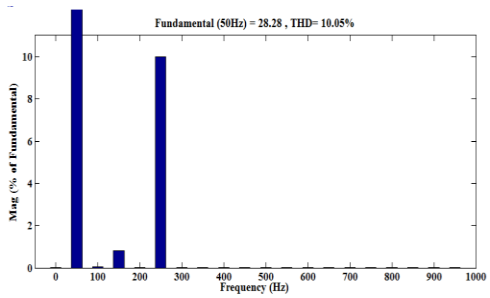

Figure 6. THD of current source at 0.2-0.4s

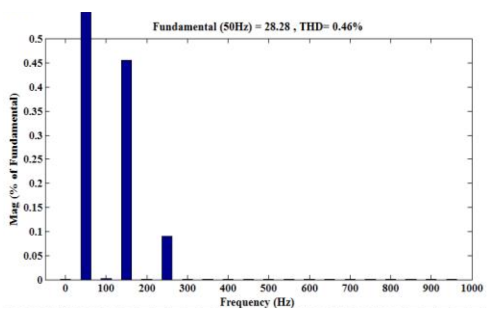

Figure 7. THD of current source at 0.4-0.6s

At the next 0.2 second interval, the active filter is tuned to eliminate the 3rd harmonic order so that the harmonic THD drops to 10.05%. At this time interval, the source current THD is still relatively large because there is still 5th order harmonics that has not been compensated.

Then at the last 0.2 second interval, the 5th harmonic order is eliminated so that the THD of current source becomes 0.46%. Table 2 shows the details of the multi-tuned active power filter results in improving the harmonic distortion on the current source.

TABLE 2.
SIMULATION RESULTS SUMMARY

Time	**0-0.2 s**	**0.2-0.4s**	**0.4-0.6s**
Harmonic orde	Fundamental 3^{th}, 4^{th}	Fundamental 4^{th}	Fundamental -
THD	31.62%	10.05%	0.46%

IV. CONCLUSIONS

The paper briefly described the tuned APF based on p-q Theory. From the simulation results of the test in this paper it can be seen that p-q theory can shorten the calculation of reference currents other than that the multi-tuned APF method proposed specifically can determine the order of harmonics to be eliminated.

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