DESIGN OF DIGITAL CONTROLLER FOR ACTIVE POWER FILTER BASED ON p-q THEORY

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Abstract— In AC electrical systems, harmonic distortion is a common disturbance. This harmonic disturbances can cause the waveform of voltage or current distorted periodically. Active power filter (APF) is one method to repair the distorted waveform by injecting anti-harmonic waveform. This paper describes the use of a digital controller to control the Active power filter in order to obtain anti-harmonic waveforms to eliminate harmonic waveform. Digital controller programming is done using MATLAB® software. p-q Theory is used to separate fundamental components with the harmonic components so that anti-harmonic waveforms can be calculated. Based on the implementation results can be seen that the control system that used is able to generate of anti-harmonic waveform to compensate distorted waveform so that the results are already in sinusoidal conditions.

Index Terms— Harmonic, p-q Thory, Active Power Filter, Reference Current.

I. INTRODUCTION

Harmonics phenomenon is one of the problems that often occur in AC electrical systems. Harmonic disturbances can cause the voltage and or current waveform distorted. The impact of harmonic disturbance can increas the heat and capacitor voltage stress, an arror operation of electronic components, switchgear, relays. Generally, the harmonics can decrease the lifetime of the electrical components [1].
Generally, Harmonics on the electrical system caused by the use of power electronics equipment. The switching process on power electronics that used in the electrical system will affect the waveform of voltage and current. In addition, the harmonics can also caused by saturation condition of electric equipment that usually occurs in transformer, electrical machinery and flourscent lamp. For economic reasons, most of transformers and electrical machines are designed with material that is susceptible to saturation. Saturation conditions will affect the magnetization current that will produce the third order harmonics [2].

Harmonics can be reduced by using passive LC filter, but this filter has the disadvantage of their large size, causing the resonant frequency and only able to reduce harmonics order that has been determined. To overcome these weaknesses, it can be used Active Power Filter (APF). the purpose of this APF is to compensate the current distorted due to the use of power electronics load or non-linier load [3].
This paper describes the control system of APF to generate the compensation current waveform that serves as an anti-harmonic currents. p-q Theory or also known as Instantaneous Power Theory is used to separate the harmonics components of its fundamental components. p-q theory calculations to generate compensation current is done in a platform STM32F4 microcontroller.

II. RESEACH METHODOLOGY

A. Active Power Filter Modelling

Active power filter circuit schematic as shown in Figure 1. The main components of the APF is a Voltage Source Inverter (VSI) and the inductor that serves as a filter of switching VSI. APF is connected to the source and load through Point of Common Coupling (PCC).

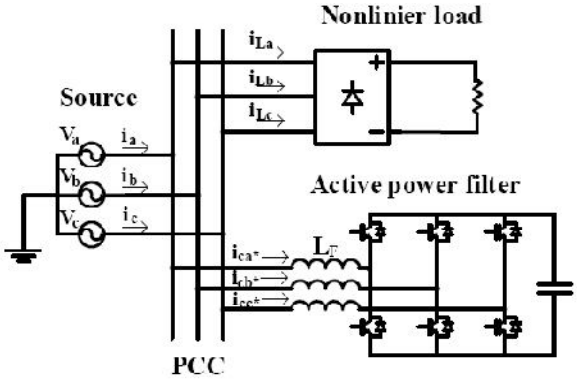


Figure 1.schematic of APF

Three phase voltage and current waveform form the source is used as an input for APF control system. Anti-harmonic signal waveform that generated by the p-q theory will be used as a reference signal for APF switching.

B. p-q Theory

Clarke transformation is used to transform the three-phase coordinate to be two-phase α-β coordinate in equivalent as shown in equation (1) for voltage and equation (2) for current.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

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

Instantaneous power based on the p-q theory is as the following equation.

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

Instantaneous power p and q in equation (3) consists of the AC component (p~ and q~) and DC component (P and Q):

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

current source as a function of p and q is:

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

To eliminate the reactive power from the source, the value of q in equation (5) made negative. While for anti-harmonic waveform generation, the AC component used in power p. P_{loss} represents power losses in the VSI. So the equation (5) becomes as the following equation

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

Compensation current waveform that obtained from equation (6) is transformed into a three-phase coordinates using equation (7) below.

$$\begin{bmatrix} i_{ca^*} \\ i_{cb^*} \\ i_{cc^*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha^*} \\ i_{c\beta^*} \end{bmatrix} \quad (7)$$

p-q theory calculations step to obtain the reference current or compensation current as in equation (7) is shown in Figure 2 below.

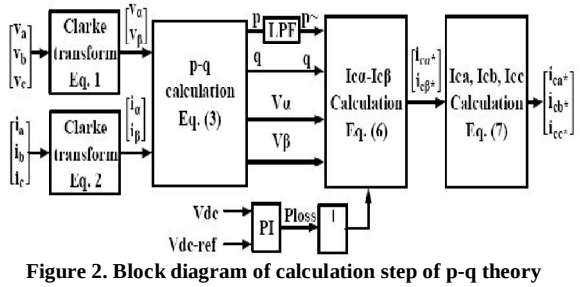


Figure 2. Block diagram of calculation step of p-q theory

III. SYSTEM DESIGN

Configuration of APF control system consists of two main blocks. Sensor block that serves as a input and control block for p-q theory calculation as shown in figure 3.

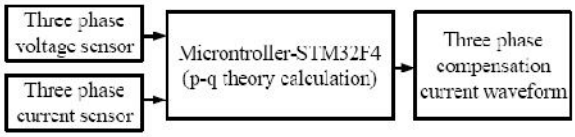


Figure 3. Block diagram of APF control system

A. Sensor Design

Voltage and current sensors are used to get the voltage and current sources waveform. Step-down transformer 220/3 Volt is used for voltage sensor while current sensor uses a current transformer (CT) 50/5 A.

STM32F4 Microcontroller only able to read a DC signal with amplitude limit 0-3Volt. Therefore, the AC signal that obtained from the sensors need to become AC offset before it is processed by a microcontroller. Non inverting adder circuit is used to make the AC offset signal so that the negative values can be read by the microcontroller

B. Microcontroller

STM32F4 is a module of ST Electronic based on microcontroller ARM 32bit architecture with a STM32F407VGT6 processor. STM32F4 Microcontroller consists of programmable 100 pins including ground pin, 3 volts, 4 volts. STM32F407VGT6 Chip has many features that can be used, such as I/O, timer, ADC, and DMA. Its clock speed can reach 168Mhz making it possible to work on the long program command in a relatively short time. Power supply of this microcontroller uses 5 Volt USB voltage [5].

Programming on miktrokontroler using MATLAB/ Simulink with waijung program block sets [6]. Figure 4 shows the calculation step of p-q theory that is programmed with MATLAB/Simulink. Time sampling used in perograman is Ts = 1 / (50 * 10000).

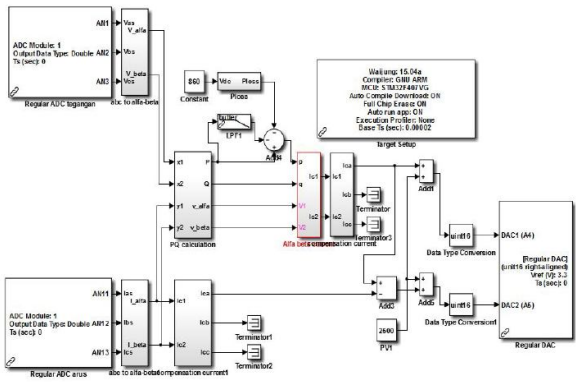


Figure 4. Programming STM32F4 using MATLAB

Table 1 shows the specifications of the equipment that used in APF control system

Table 1. Specifications of APF

Parameter	Value
VSource	220 V/Phase
Frequency	50 Hz
Load	6-pulse Rectifier, 350 Watt

IV. EXPERIMENTAL RESULT

Tests performed on load specifications that has been determined. Variable three phase AC source is used as a voltage source. With resistive load on the DC side of the 6-pulse rectifier. Figure 5 shows the implementation of APF control system. whereas Figure 6 shows the testing process.

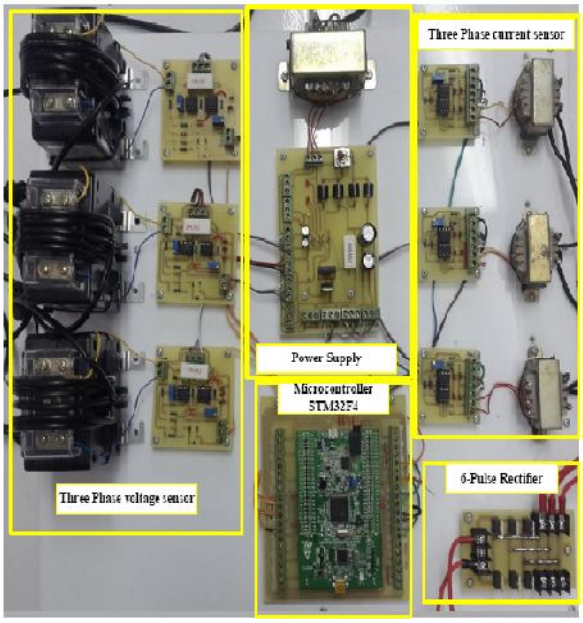


Figure 5.hardware view of APF control system

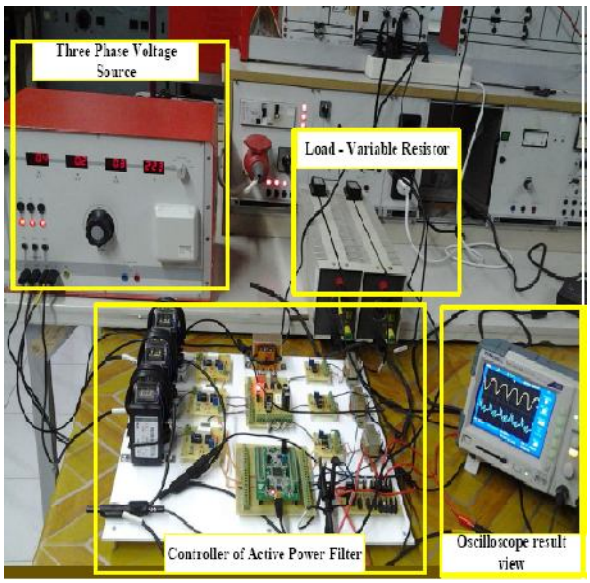


Figure 6. Testing process of APF-control system

A. Sensor Output

Voltage and current waveforms signal that obtained from the sensor readings are very influential on the p-q theory calculation. Therefore, it must be ensured that the voltage and current waveforms from the sensor readings already represent the actual waveform. Figure 7 shows the three-phase voltage waveform (line-neutral), while Figure 8 shows current source waveform with 6-pulse rektifier load.

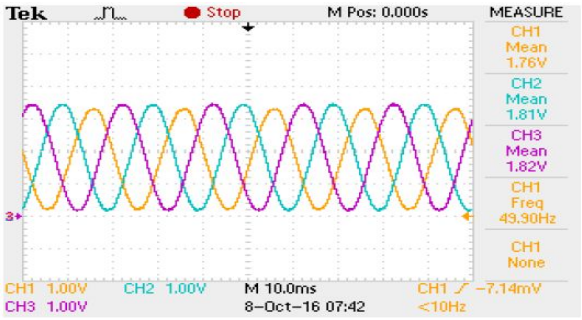


Figure 7.sensor output, three-phase voltage waveform

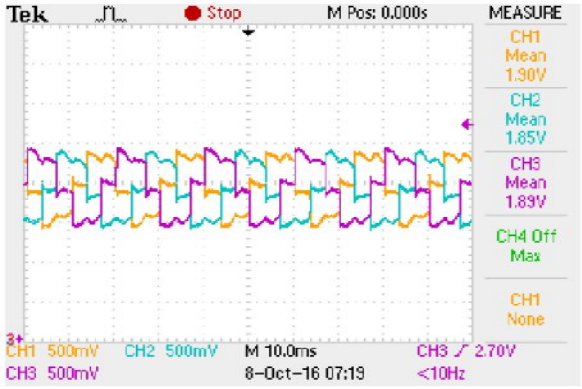


Figure 8.sensor output, three-phase current source waveform with 6-pulse rectifier load.

Testing of sensor output in Figure 7 and Figure 8 is done with Time / div = 10 ms. The figures show that the signal of three-phase voltages and currents have been shaped in AC offset. The waveform of voltage source is already pure sinusoidal at a frequency corresponding to the system frequency. While for current sources waveform is distorted because of non-linier load.

V. APF CONTROLLER PERFORMANCE

Current source waveform at phase a shown in Figure 9. In Figure 9, the current waveform is still not compensated so that the waveform is not sinusoidal. Figure 10 on channel 1 shows the current wave source that has been compensated by the compensation current obtained from the calculation of p-q theory. Figure 10 on channel 2 shows the reference current waveform or compensation current waveform that obtained from p-q theory calculations.

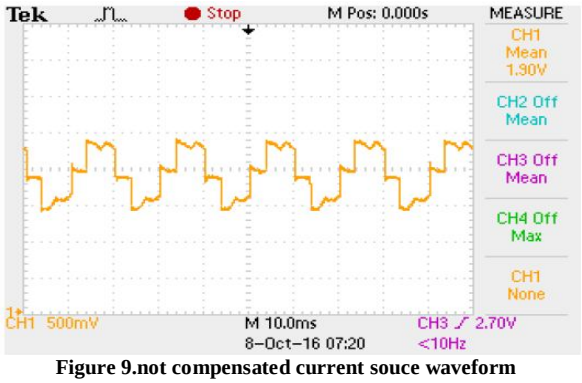


Figure 9.not compensated current souce waveform

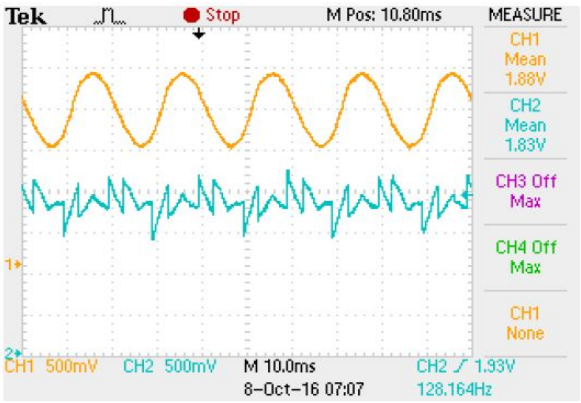


Figure 10.current waveforms. Channel 1, current source after compensated. Channel 2, compensation current or reference current

CONCLUTION

Digital controller has been used to control active power filter. based on the results of the implementation can be obtained the following conclusions:

- p-q theory calculation using STM32F4 microcontroller has been able to generate the compensation of harmonic current
- Compensation currents of harmonics that generated can reduce current harmonic distortion.

This research can be developed such as to improve the accuracy of sensors. Further development may also increase clocking of p-q theory calculation. we plan to conduct testing on larger power so that approached the real conditions.

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