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Analysis and Simulation of Shunt Active Power Filter to Address Power Quality Problems

Yejjala Naveen kumar
Student (M. Tech)
Department of Electrical Engineering
VNIT Nagpur, India

N. Jaykanth
Student (M. Tech)
Department of Electrical Engineering
VNIT Nagpur, India

V. B. Borghate
Associate Professor
Department of Electrical Engineering
VNIT Nagpur, India

***Abstract*—Active power filter (APF) technique is one of the most popular technique that has been used to improve power quality. APF technique will improve power quality by eliminating unwanted harmonic, overcome voltage sag and improves power factor. This paper will discuss and analyze the simulation results for a three-phase shunt active power filter using MATLAB/Simulink program. This simulation will implement a non linear load and compensate line current harmonics under balanced and unbalanced loads. It also includes a bidirectional DC-DC converter as source to inverter. With this simulation, we can say that active power filter is better way to reduce the total harmonic distortion (THD) which is required by quality standards IEEE-519.**

Keywords—active filter; Instantaneous power theory,

Bi-directional converter.

I. INTRODUCTION

Power quality is customer-focused measure and is been greatly affected by the operation of distribution and transmission network. Power quality problems like harmonic distortion, voltage flicker and voltage sag may be compensated with flexible ac transmission systems (FACTS) such as active filters and static synchronous compensators (STATCOM).

In general active filters are used to compensate higher order harmonics and STATCOM to compensate reactive power. The power supply system can only control the quality of voltage, It has no control over the currents that particular loads might draw.

AC power systems are designed to operate at sinusoidal voltage of frequency (typically 50or 60 Hz) and magnitude. Any change in the waveform magnitude, frequency or purity is a power quality problem. Although a near perfect sine-wave voltage is provide, the current passing through the impedance of system may cause disturbance to the voltage. For example
(a)The current resulting from a short circuit causes the voltage to sag or disappear completely.
(b)Currents from lightning strokes passing through power system cause high impulse voltages that frequently flash over insulation and cause short circuits.
(c)Distorted current from harmonics producing loads also distorts the voltage as they pass through system impedance. Therefore while it is the voltage with which we are concerned, we must also concern about the currents to understand the basics of many power quality problems.

Harmonic is defined as sinusoidal component of a periodic wave having a frequency that is an integral multiple of fundamental frequency. Harmonic results are found due to the operation of power electronic converters. Rapid switching can largely reduce the lower order harmonic currents but output is high frequency current and can be easily filtered out. Electrical devices are prone to failure or malfunction when exposed to power quality problems. Devices like electric motor, transformer, generator, computer, printer, communication equipment or any household appliance. All of these devices react to power quality issues and also to the severity of problem.

II. ACTIVE FILTER

An active filter is power electronic based electrical equipment which is installed parallel to the polluting loads, as shown in fig. 1. Line current harmonics as well as customer requirements programmed by the user is monitored by active filters. It generates a compensation current for each harmonic frequency in perfect phased opposition to the polluted current. This monitoring can be done in open loop and closed loop control system. Open and closed loop control system is shown in fig. 2.

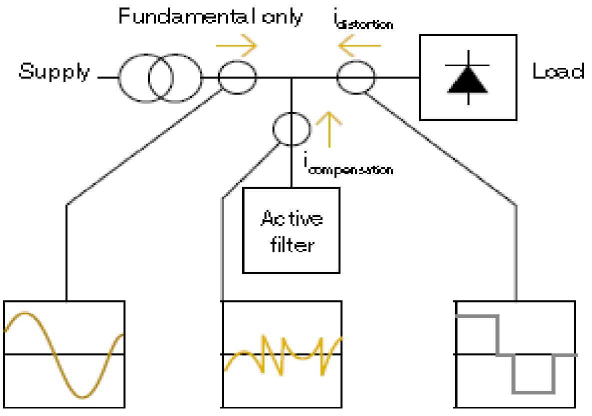

Fig. 1: Diagram illustrating shunt active filter.

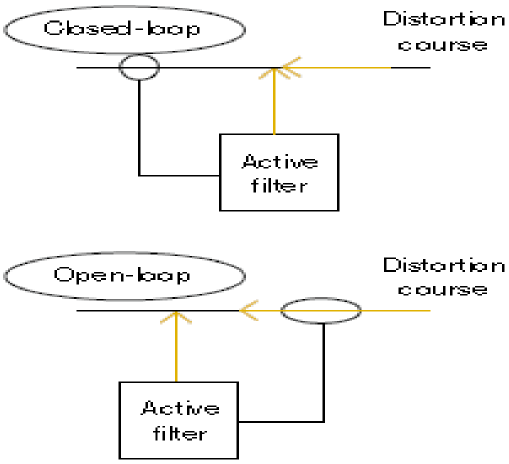

Fig. 2: Figure representing closed and open loop control system.

Closed loop control system is mostly used. The use of closed loop control system is combination with the selection capability of individual harmonic components makes the active filter the most precise active filter in the market. Closed loop control system measures the line current for each harmonic and reactive power component and compares this with the target set by the customer. Any deviation is automatically deviated. The capability of selecting individual harmonic components is the result of advanced control algorithm. For each harmonic selected a compensation current with perfect phase opposition is injected. This ensures optimal cancellation of all harmonic components that are selected by the user.

Active filters can be applied to small, medium or large applications and are suitable for both industrial and commercial installations. They provide load balancing, harmonic mitigation and step less reactive power control for capacitive and inductive loads. Selection from the large choice of ratings that is, from several tens of amps to several thousands of amps enable the optimal solution for each system to be easily defined.

Based on topologies there are two kinds of active filters such as current source and voltage source active filters. Current source active filter employ an inductor while voltage source active filter employ capacitor as storage element to the inverter. Simon Round and friends used a topology based on sinusoidal subtraction by using active filter that makes an inverter more responsive to the harmonics [3].

III. INSTANTANEOUS POWER THEORY

The instantaneous power theory or p-q theory was introduced by Akagi in 1983. This method uses algebra transformation also known as Clarke transformation for three phase voltages and currents. The three phase voltages and currents are converted into α-β using eq. (1) and eq. (2) where i_{abc} and v_{abc} are three phase line currents and voltages. Background of this p-q theory is obtained from [7]. Clarke transformation of three phase voltages and currents are given by

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

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

The instantaneous powers defined in the α-β reference frame are real power (p), the imaginary power (q) and the zero sequence power (Po) given by

$$p = v_\alpha i_\alpha + v_\beta i_\beta + v_o i_o = \tilde{p} + \bar{p} \quad (3)$$

$$q = v_\beta i_\alpha - v_\alpha i_\beta = \tilde{q} + \bar{q} \quad (4)$$

Where “‾” represents the average and “~” represents the oscillating component of each power. The average component can be extracted through low pass filter, as it can be noted in several control algorithms for switching compensators [8]-[12]. Low pass filters will remove the high frequency component and give the fundamental part.

For systems that do not have a neutral connection, the zero sequence does not exist and the mathematical eq. will be represented in eq. (5)

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \quad (5)$$

According to p-q theory the active power is represented by DC part of α-β reference current, which is shown in eq. (6)

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

Three phase actual current reference for active filter might be given as shown in eq. (7)

$$i_{abc}^{*}=\sqrt{\frac{2}{3}}\begin{bmatrix}1 & 0\\ \frac{-1}{2} & \frac{\sqrt{3}}{2}\\ \frac{-1}{2} & \frac{-\sqrt{3}}{2}\end{bmatrix} i_{\alpha\beta}^{*} \qquad (7)$$

Control algorithm based on p-q theory for shunt switching compensators is shown in fig. (3).

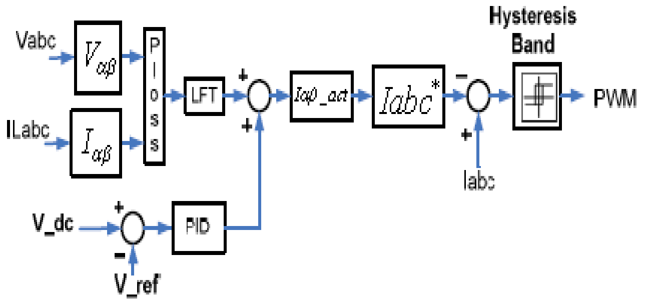

Fig. 3: control strategy for APF.

IV. BIDIRECTIONAL CONVERTER

Battery energy storage system (BESS) is composed of battery bank, a bidirectional DC-DC converter and control system. This is capable of operating in two directions. The battery can be charged to store extra energy and also discharge the energy to the loads. Fig .4 represents a bi-directional DC-DC converter.

The main objective of BESS is to maintain the common DC link voltage constant. No matter the battery is charging or discharging, the common DC link voltage is kept constant and thus the ripple in the capacitor voltage is much less. When charging switch S2 is on and the converter works as buck circuit. Otherwise, when discharging switch S1 is on and the converter works as boost circuit. Fig. (5) represents the control method for the bi-directional converter.

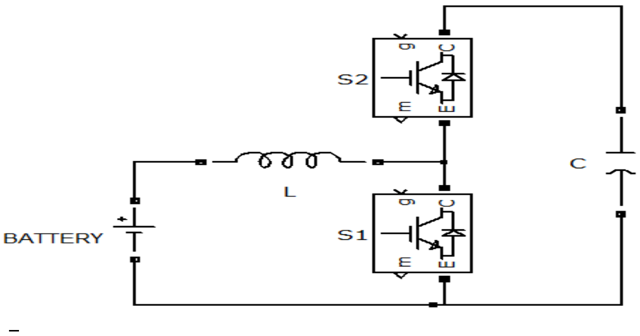

Fig. 4: The Bi-Directional DC-DC converter.

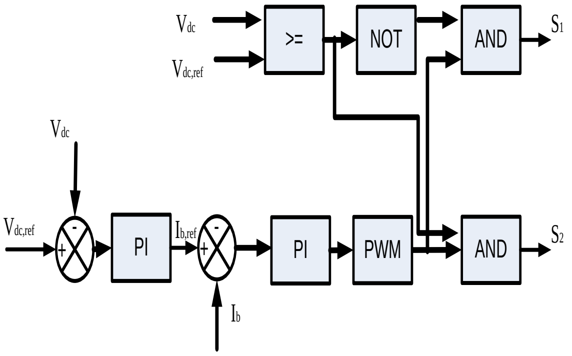

Fig. 5: Control of bi-directional DC-DC converter.

V. SIMULATION AND RESULTS

Shunt acting voltage source active filter has been simulated as shown in fig. 3 and in this simulation constant DC voltage is applied to the inverter input with bi-directional DC-DC converter simulated as shown in fig. 4 with control circuit as shown in fig. 5.

Fig. 6 shows the modeling of an active filter consisting of three phase ac power supply with 415 V rms phase to phase , 50Hz frequency with 120 degrees phase shift and a non-linear load.

In fig. 6 the control circuit block consists of three phase voltage and current transformation from abc to αβ and from αβ to abc transformation followed by hysteresis band generating gate pulses to the inverter as shown in fig. 3.

APF block consists of inverter and gate pulses are given to it from the pulses obtained in fig. 3. Inverter is supplied with bi-directional DC-DC converter.

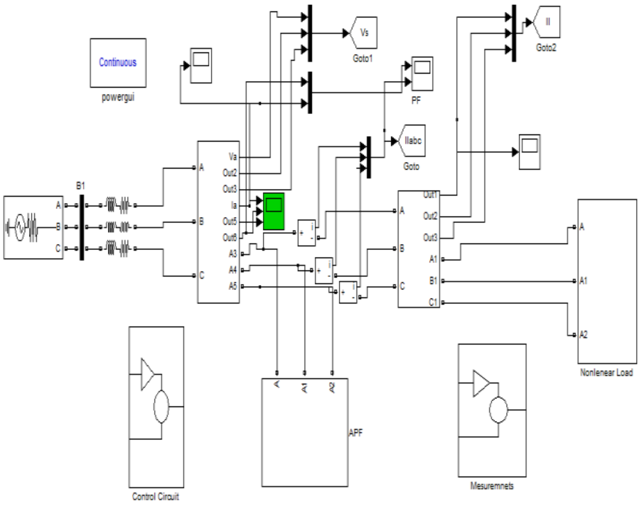

Fig. 6 : Simulink model of active filter.

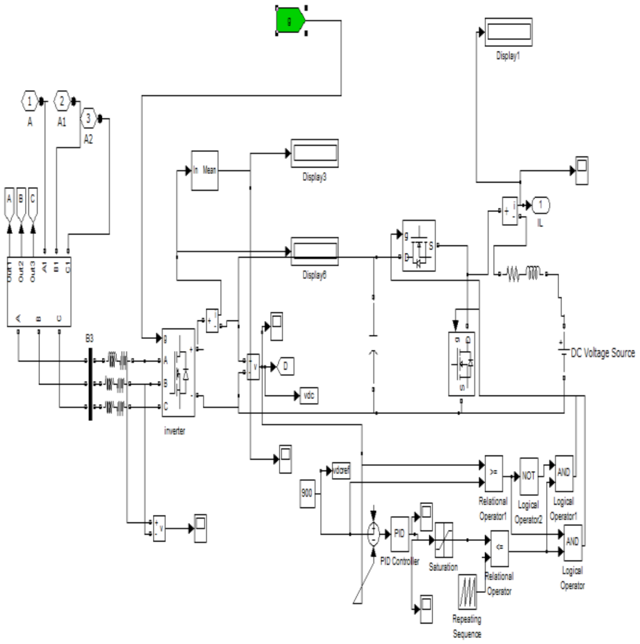

Fig. 7: Simulation of bi-directional DC-DC converter and its control circuit.

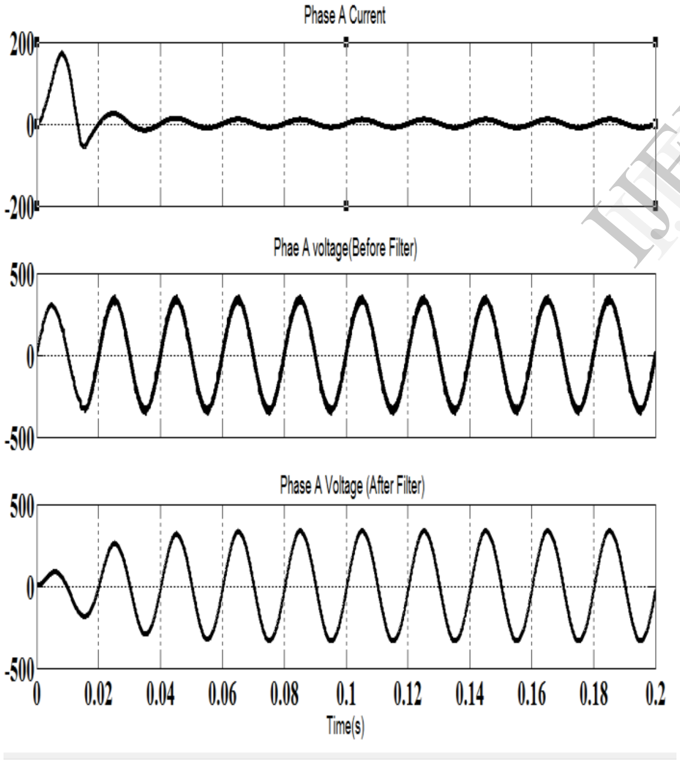

Fig. 8: Phase A current, phase A voltage before and after filter.

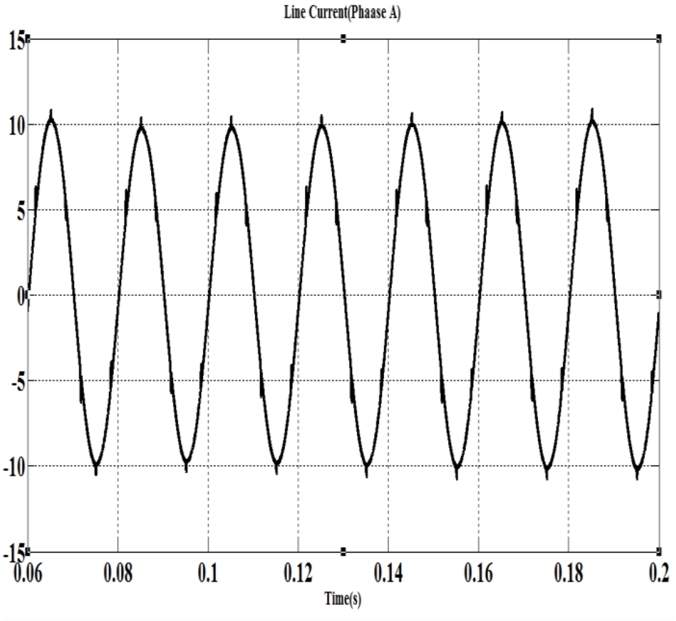

Fig 9: Line current of phase A.

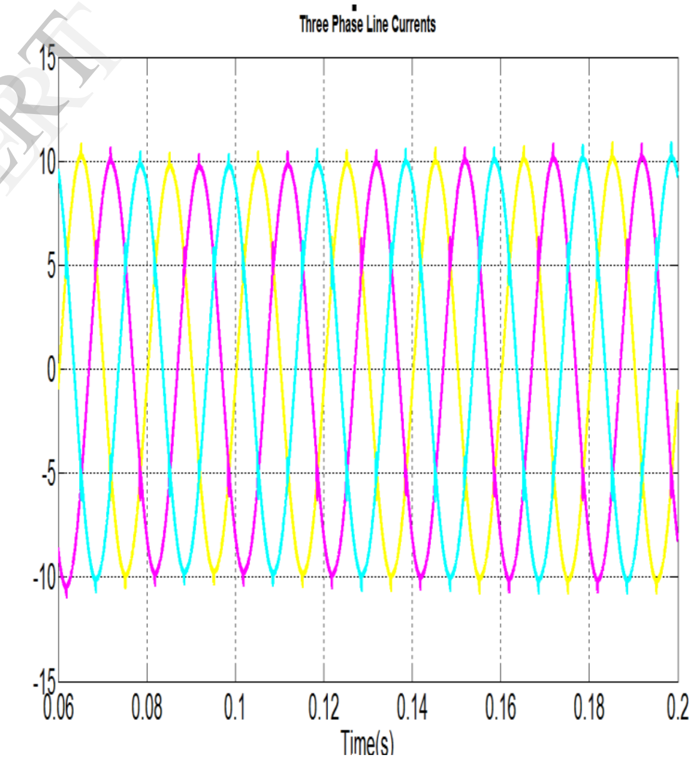

Fig 10: Three phase line currents.

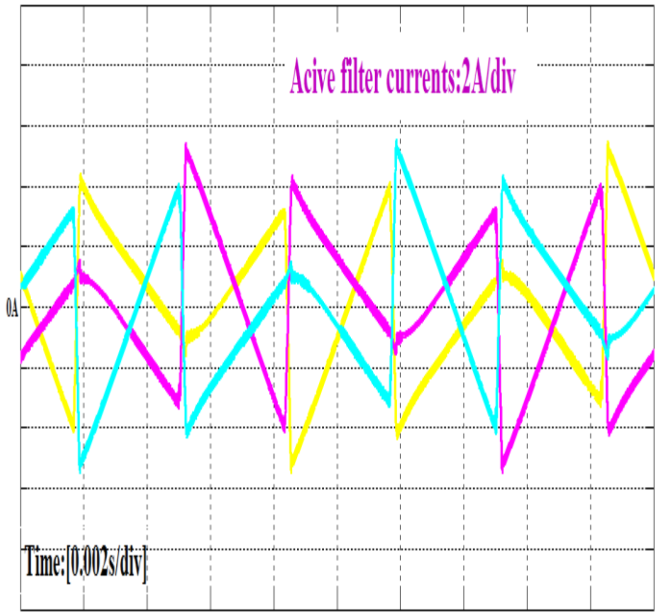

Fig. 11: Active filter currents.

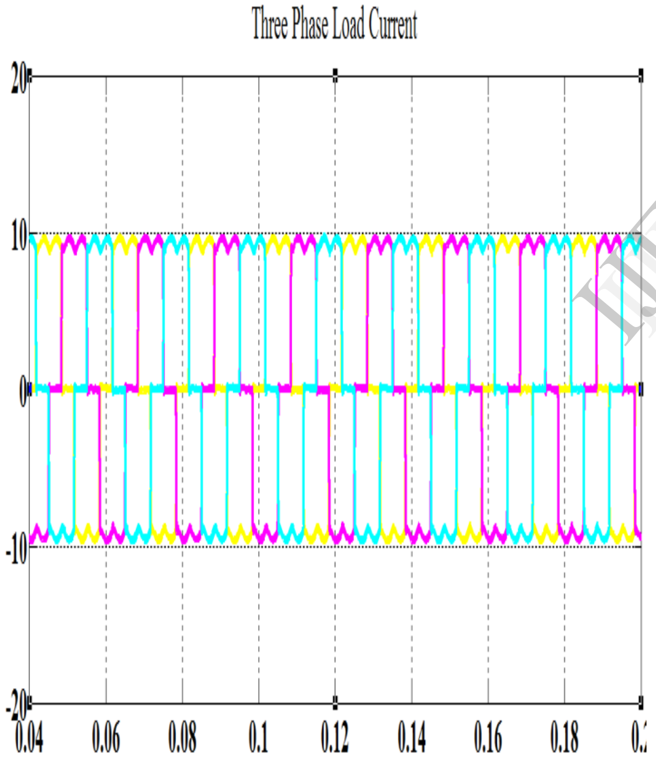

Fig. 12: Three phase load currents.

VI CONCLUSION

The increasing usage of non-linear load mainly produces current and voltage harmonics in electrical power systems and associates harmonic problems affecting power quality. This problem is rectified using shunt active power filters. It has been shown that harmonic mitigation and power factor correction is done by implementing three phase active filter based on p-q theory. So, harmonic mitigation carried out by the active filter meets the IEEE-519 standard requirements.

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