2020 IEEE PES/IAS PowerAfrica

New approach for design shunt active power filter for power quality improvement in a three phase three wire system

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Abstract— **Use of power electronic-based load has increased in the resent decade. These loads draw non-sinusoidal currents and voltages from the utility supply generating harmful harmonics. Injection of harmonic currents and voltages into the utility supply affect the utility supply systems and customer's equipment connected at point of common coupling. Issues of power quality has become an important issue for both users and distributers of electrical power. Active power filters have proven to be efficient method for power quality improvement and reactive power compensation for issues related to harmonics. This work present approach for shunt active filter compensation of harmonics. The different traditional and modern harmonic solutions topologies are presented. Shunt active power filter as the most famous and used active filter type is introduced. The generation of reference signal and control of shunt active filter studied. Deadbeat control methods of APF in addition to PI controller used for DC link voltage control is presented. Three phase three wire system supplying nonlinear load is used to test performance of the proposed filter. It is implemented in MATLAB\Simulink and results discussed.**

Index Terms- **Deadbeat control, Harmonics, Passive filter, Power quality, Shunt active power filter.**

I. INTRODUCTION

The use of nonlinear loads and advanced control of power has increased the problems related to the utility supply power quality issues. Power quality problems mainly concerns the deviations of current, voltage or frequency from prescribed supply standards. Use of power electronics devices in power conversion has affected power quality of the utility supply by introducing harmonic distortion. Harmonics in the utility system causes problems in computers, motors, power supplies and even cause transformer failures due to eddy currents [1] [2]. There are a number of systems or devices available for mitigating harmonic distortions in utility system which includes passive filters (PFs) commonly used for harmonic frequencies attenuation [3, 4]. PFs are simple in design, low cost and easy to maintain. However, they overload utility system, create parallel resonance between the power system and the filter, and de-tune harmonic frequency due aging of passive components. PFs filtering characteristics are dependent on source impedance which is not exactly known rendering this approach inefficient. In the recent years active power filters (APF) has been develop to mitigate harmonics generated by power converters. They offer flexible and versatile solution to power quality issues. Most of APFs are based on pulse width modulation (PWM) voltage source inverters and connected to low and medium voltage distribution at point of common coupling (PCC) in either series or shunt configuration [5] [6]. Since shunt configuration can be implemented for harmonic mitigation without a passive filter is considered in this work.

In this study, a digital control system is applied to control the shunt active power filter for its advantages of accurate and faster response [7] [8], while DC- link voltage regulation is control by PI controller to improve performance in compensation of harmonics generated by nonlinear loads. The theory of reference current in α-β reference frame, deadbeat control method and space vector pulse width modulation for active for shunt active power filter is considered. Simulation results are explained thereafter.

II. SHUNT ACTIVE POWER FILTER

Shunt active power filters mitigate current harmonics by injecting equal but opposite harmonics compensating current as illustrated in fig. 1. The system consists of voltage source inverter, nonlinear load, dc link capacitor and interface inductor. In this approach, the filter operates as a current source injecting harmonic component generated by the nonlinear load

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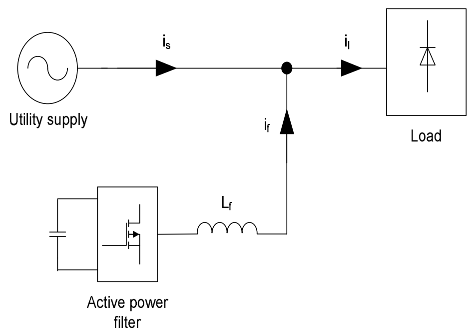

Figure 1: Shunt active power filter structure

The combination of non-linear load and active power filter will be seen by the grid as a linear load connected at PCC. This principle is applicable to any type of load considered as a source of harmful harmonics. With appropriate control scheme, the active power filter can also compensate the load power factor. The grid in this case will see the nonlinear load and active power filter as an ideal resistor.

III. HARMONIC DETECTION STRATEGY

Considering the utility supply is an ideal voltage source, fig. 2 shows the simplified equivalent circuit for ac side of the active power filter in α-β reference frame. Utility voltages in a-b-c reference frame are expressed in (1-3);

$$u_a = U_a \sin(\omega t) \tag{1}$$

$$u_b = U_b \sin(\omega t - \frac{2\pi}{3}) \tag{2}$$

$$u_c = U_c \sin(\omega t + \frac{2\pi}{3}) \tag{3}$$

Using Clark transformations, the three-phase balanced system can be expressed as a two orthogonal phase system (α-β) stationary reference frame. The voltage in α-β stationary reference frame can be expressed in (4);

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \frac{2}{3} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{4}$$

So that,

$$u_\alpha = u_a \tag{5}$$

$$u_\beta = \frac{1}{\sqrt{3}}(u_b - u_c) = \frac{1}{\sqrt{3}}(u_a + 2u_b) \tag{6}$$

and,

$$u_\alpha = U_{max} \sin(\omega t) \tag{7}$$

$$u_\beta = -U_{max} \cos(\omega t) \tag{8}$$

After calculating the reactive power, it is desired that the active filter injects -*Q* reactive power to the PCC so as to compensate the reactive power consumed by the nonlinear load. Finally, reverse Clarke transformation is used to convert reactive power compensating signal from α-β frame to *abc* frame according to (9) and (10).

$$\begin{bmatrix} u_\alpha \\ u_\beta \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \tag{9}$$

$$\begin{bmatrix} i_{p\alpha} \\ i_{p\beta} \end{bmatrix} = \frac{\sqrt{2}}{3} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{pa} \\ i_{pb} \\ i_{pc} \end{bmatrix} \tag{10}$$

The instantaneous real power p_L and the instantaneous imaginary power q_L can be defined using (11).

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_{p\alpha} \\ i_{p\beta} \end{bmatrix} \tag{11}$$

The continuous time model of shunt active power filter in the stationary $\alpha - \beta$ reference frame can be expressed as in (12)

$$u_{\alpha\beta} = V_{\alpha\beta} + L_f \frac{di_{\alpha\beta}}{dt} \tag{12}$$

IV. DEADBEAT CONTROL SCHEME IN A-B REFERENCE FRAME FOR ACTIVE POWER FILTER

The system of shunt active power filter illustrated in fig. 1, has voltage source inverter and DC-link capacitor that need to be accurately controlled in order to effectively compensate harmonics present in the utility supply. The block diagram of reference signal generation with a deadbeat control is shown in fig. 2. The deadbeat is applied to regulate the filter current through a voltage source inverter.

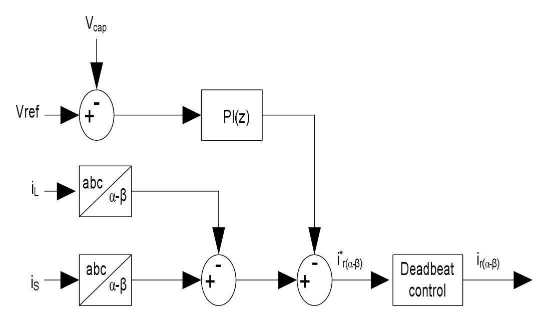

Figure 2: Deadbeat control scheme for active power filter

V. SIMULATION RESULTS AND DISCUSSION

A three phase three wire supply model has been used to demonstrate the effectiveness faster response time and applicability of the proposed method as shown in Fig.2 and the system parameters are listed in table 1. It has been developed and simulated on MATLAB /SIMULINK software.

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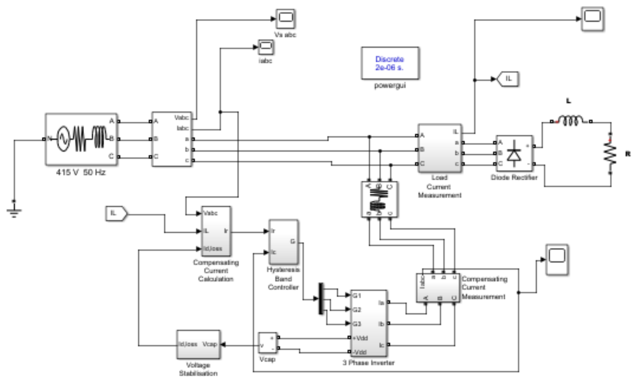

Figure 3: System model with shunt active filter

Table I
Electrical parameters of simulated system

Supply voltage, phase-to-phase	415V
Supply frequency	50Hz
Diode rectifier load	R=3Ω, L=0.15mH
Shunt active filter capacitor	1000μF/500V
Filter interface inductor	R=0.5Ω, L=0.3mH

As observed in Fig. 4 and Fig. 5, the source current obtained is highly distorted. On THD analysis is about 29% as shown in Fig. 6. This is far beyond the permissible IEEE standard.

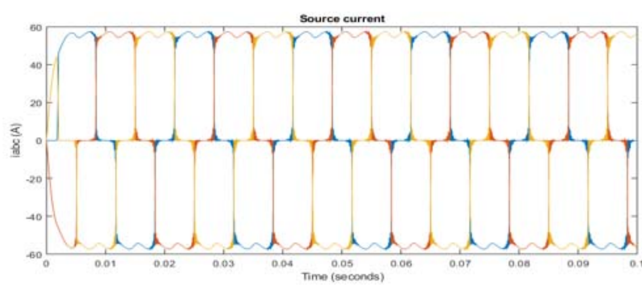

Figure 4: Source current without filter

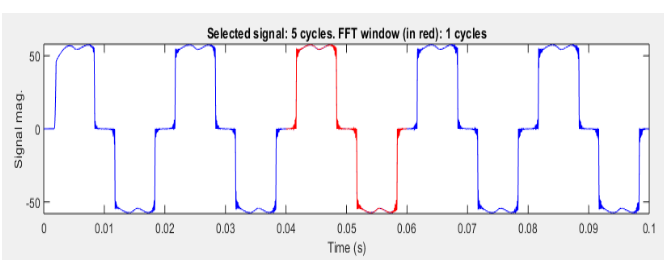

Figure 5: Phase source current

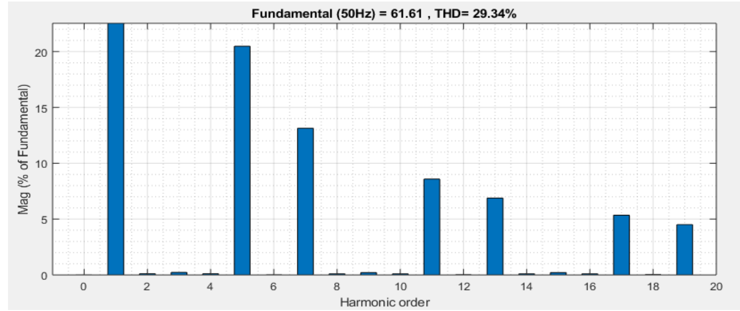

Figure 6: FFT analysis of the source current

Fig.7, shows compensation current injected to the utility supply system at the PCC to correct distortion generated by nonlinear load

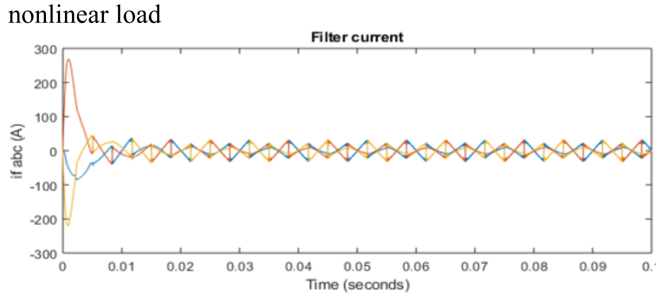

Figure 7: Shunt active filter current

Fig.8 shows the source current when the filter is installed. Fig. 9 is single line current after compensation while Fig.10 shows spectrum analysis of single line source current using FFT analysis, it shows reduction in THD to 1.58%.

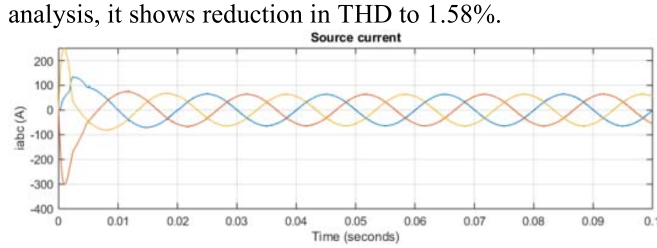

Figure 8: Source current with filter connected

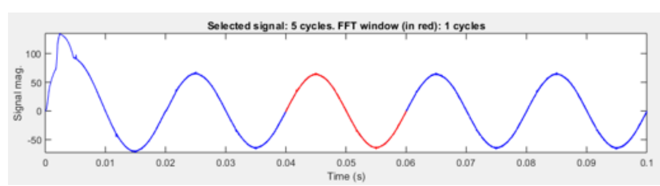

Figure 9: Phase Source current with filter connected

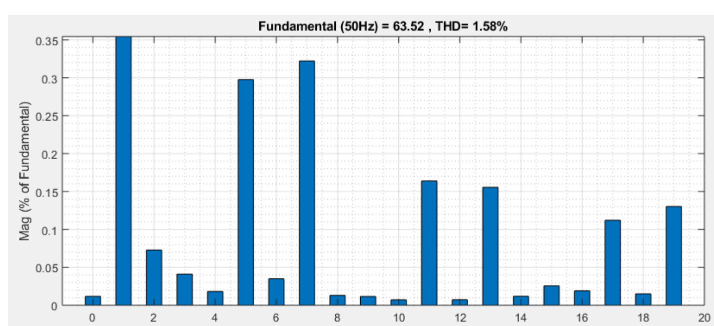

Figure 10: FFT of the source current when the filter connected

VI. CONCLUSSION

The proposed approach for shunt active filters to address harmonic current and reactive power problems in power systems gives satisfactory results, which greatly improves power quality at the PCC. Compared with conventional shunt active power filters, the proposed approach scheme has the advantages of straight forward in design and reduce mathematical conversion improving harmonic compensation. Simulation results show the proposed system has good steady state and dynamical performance. In the future, it will be investigated how artificial intelligence control scheme inform of a deadbeat controller with SVPWM generation of gating pulses in a voltage source inverter as a shunt active power filter to further improve harmonic compensation. The system is able to compensate for highly distorted waveform with 29.34%THD to 1.58%THD that is within required limits as per IEEE harmonic level standards.

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