Elimination of Harmonics Using Active Power Filter Based on DQ Reference Frame Theory

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Abstract-**— Active power filters have the following multiple functions; harmonic filtering, damping, isolation and termination, reactive-power control for power factor correction and voltage regulation, load balancing, voltage-flicker reduction, and/or their combinations. Significant cost reductions in both power semiconductor devices and signal-processing devices have inspired manufactures to put active filters on the market. This paper presents a method for obtaining the desired reference current for Voltage Source Converter (VSC) of the Shunt Active Power Filter (SAPF) using Synchronous Reference Frame Theory. The method relies on the performance of the Proportional-Integral (PI) controller for obtaining the best control performance of the SAPF. Using Reference Frame Transformation, reference signals are transformed from a−b−c stationery frame to 0 − d − q rotating frame. Using the PI controller, the reference signals in the 0 − d − q rotating frame are controlled to get the desired reference signals for the Pulse Width Modulation.**

Keywords— **Pulse Width Modulation (PWM), Shunt Active Power Filter (SAPF), Voltage Source Converter (VSC).**

I. INTRODUCTION

The ever increasing use of power semiconductor switching Devices in power supply for Television, computers and other microprocessor based Power electronic equipment causes harmonics in electric power system. Harmonics may cause serious problems such as excessive heating of electric motors and malfunction of sensitive power electronic gadgets. Filtering of harmonics can be effected by using either passive or active power filters. Traditionally, passive filters have been used for harmonic mitigation purposes. Active filters have been alternatively proposed as an adequate alternative to eliminate harmonic currents generated by nonlinear loads as well as for reactive power compensation. However, the active filters are slightly inferior in cost and operating loss, compared to the passive filters, even at present. Active power filters intended for power conditioning are also referred to as "active power line conditioners".

II. CONVERTER REQUIRED FOR APF

Active Power Filter consists of Voltage Source Converter operating at relatively high frequency to give the output which is used for cancelling low order harmonics in the power system network. With Shunt Active Power Filter, shown in Fig.1 crucial part involves generation of the reference signal used to generate gating signals for the VSC.
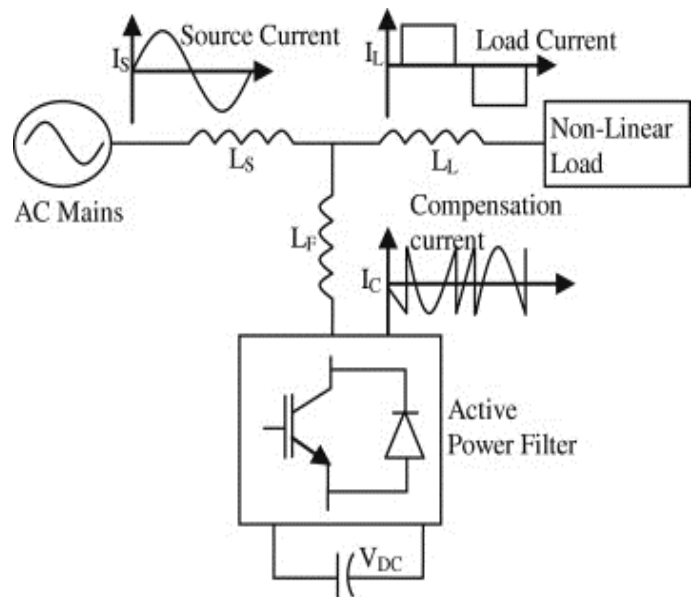

Fig.1 *Shunt Active Power Filter*

The above block diagram illustrates simple Kirchhoff's current law that source current I_S will always be sinusoidal by aiding load current I_L and Compensation Current I_C . Here generating gate signals for Pulse Width Modulated VSC are main thing need to be done to operate VSC as Active

Power Filter. The Block diagram for Voltage Source Converter is shown in Fig-2. Voltage source PWM converter is higher in efficiency, lower in cost, and smaller in physical size than the current-source PWM converter, particularly in terms of comparison between the dc capacitor and the dc inductor. The availability of fast acting semiconductor switches like IGBTs also prefer VSC because a freewheeling diode is connected in anti parallel with IGBT. Moreover the recent switching stress problems are less with Voltage source Converter Compared to Current source Converter.
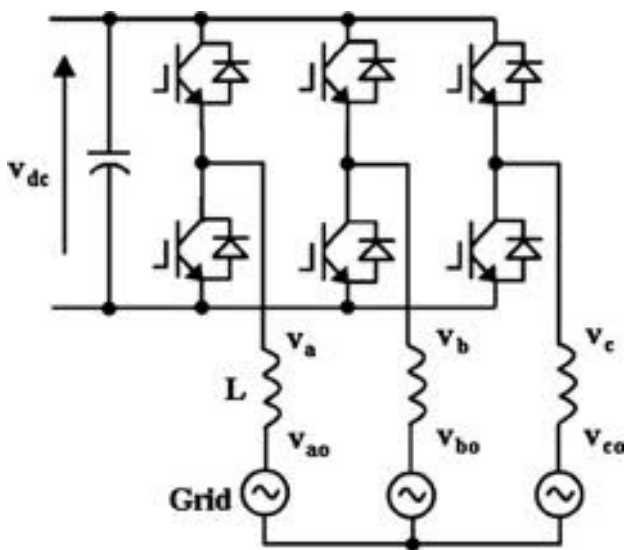

Fig.2 Voltage Source Converters for SAPF

III.   REFERENCE HARMONIC CURRENT

In order to obtain the reference harmonic current first we need to find out the load current. Load current consists of two components fundamental current I_1 and harmonic current I_H. Using the Low pass filter with approximate cut-off frequencies I_1 is extracted from measured system load current Using comparator, as shown in Fig.3, the load current is compared to the fundamental component and the error is the reference harmonics signals.
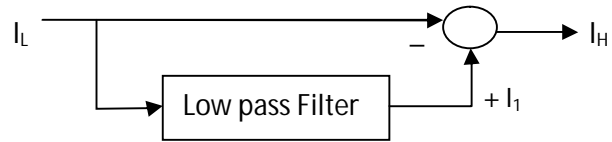

Fig.3 Reference Harmonic Current

The voltage-source PWM converter with a current minor Loop should provide the capability of controlling the compensating current with a frequency bandwidth up to 1 kHz. This leads to harmonic filtering in a range of the most dominant 5th-harmonic current to the 25th-harmonic current. The carrier frequency of the PWM converter is desirable to be as high as 10 kHz. The control circuit should extract the harmonic current from load current with as small errors as possible.

IV.   REFERENCE FRAME TRANSFORMATION

Reference frame transformation refers to transformation from a-b-c to d-q-0 axes. Coordinates from a three-phase a-b-c stationery coordinate system to the d-q-0 rotating coordinate system as shown in Fig.4. Here first transformation is from a-b-c to alpha-beta co-ordinates and then to d-q-0 co ordinates. Two different transformation matrix need to be required Clarks Transformation and parks transformation. The transformation matrices are shown in below Fig.5
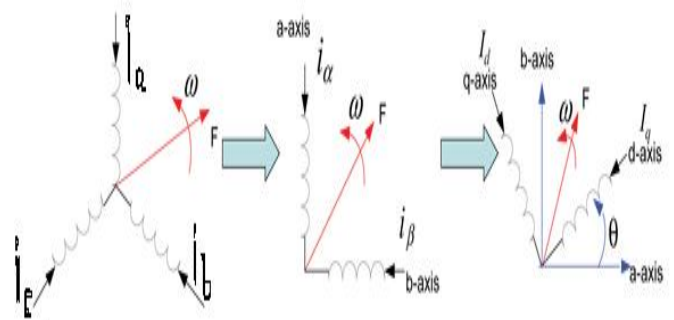

Fig.4 Reference Frame Transformations

$$I_{dqo} = T I_{abc} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ -\sin(\theta) & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} & \frac{\sqrt{2}}{2} \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}$$

Fig.5 Transformation Matrix

In synchronous reference frame PI based controller, integrators are used to eliminate the steady state error of the DC components of the $0 - d - q$ coordinates of the reference signals. In accordance to the $0 - d - q$ frame theory, the current harmonics are represented as DC-components in their corresponding reference frame and the integrators eliminate the steady state error of each harmonic component. Using the Park transformation, reference signals are converted first into $0 -\alpha - \beta$ stationery frame, then into $0 - d - q$ rotating frame. The PI controller is used to eliminate the steady state error, and hence achieving the desired controlled reference signal. The algorithm is further carried a step forward, where the voltage reference signal in $0 - d - q$ rotating frame is Converted back into $a - b - c$ stationery frame, the reference signal for the Pulse Width Modulation (PWM).

V. PROPORTIONAL INTEGRAL CONTROLLER

The PI controller is very important part for the SAPF. It consists of proportional term and integral term. With this element, the best control performance of the SAPF is obtained. PI focuses on the difference (error) between the process variable (PV) and the set-point (SP), the difference between harmonics current reference signal I_H and the filter current I_f . In this paper the PI controller has been implemented. PI controller algorithm involves two separate parameters; the Proportional and the Integral. The Proportional value determines the reaction to the current error; the Integral determines the reaction based on the sum of recent errors. The weighted sum of these two actions is used to adjust the process of the plant. By "tuning" the two constants in the PI controller algorithm, the PI controller can provide control action designed for specific process requirements.
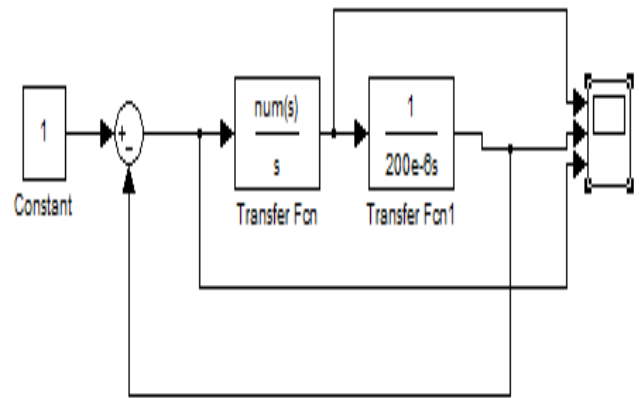

Fig.6 PI Controller Simulink Model

The K_P and K_I in the above Fig.6 simulink model are taken as 0.0175 and 0.3885 respectively. The response of the above simulink can be observed from the scope is shown in Fig.7. By adjusting the Proportional and integral Constants of Controller best Steady state output is achieved. The transfer function of PI controller is achieved by using closed loop control system.
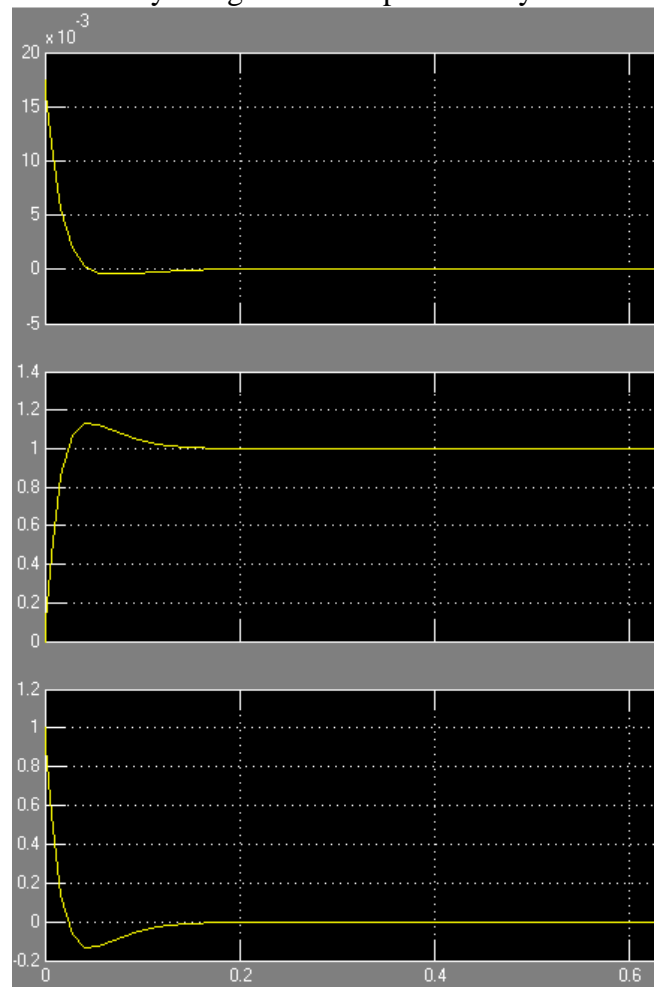

Fig.7 PI Controller Response

VI.   SINUSOIDAL PULSE WIDTH MODULATION

SPWM shown in Fig.8 scheme is used to determine the switching instants of the VSC for the purpose of maintaining Input /Output linearity especially for Active Power Filter Applications. All modulation schemes in principle aim to create trains of switched pulses which have the same fundamental volt-second average (i.e. the integral of the voltage waveform over time) as a target reference waveform at any instant. There are several ways in which switching instants can be decided, at the same time maintaining the minimum harmonics content for the switched waveform. The average value of voltage (and current) fed to the load is controlled by turning the switch between supply and load on and off at a fast pace. The longer the switch is on compared to the off periods, the higher the power supplied to load
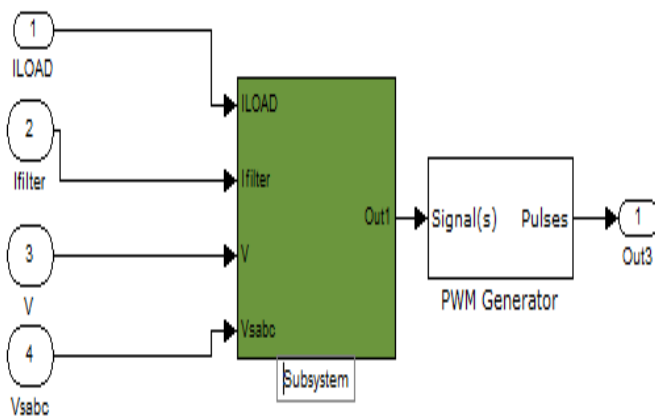
sideband harmonics around each carrier multiple. Significant odd sideband harmonics remain in the inverter output waveform around the odd carrier multiples despite harmonic cancellation between the phase legs. With triangular carrier method the effect for both natural sampling and asymmetrical regular sampling is to totally cancel the sideband harmonics around the odd carrier multiples from the *l-l* waveform. The resulting chopped square waveform contains a replica of the desired waveform in its low frequency components, with the higher frequency components being at frequencies of an close to the carrier frequency. Notice that the root mean square value of the ac voltage waveform is still equal to the dc bus voltage, and hence the total harmonic distortion is not affected by the PWM process. The harmonic components are merely shifted into the higher frequency range and are automatically filtered due to inductances in the ac system.

Simulation of Active Power Filter is done and observations of different scopes are shown as responses.

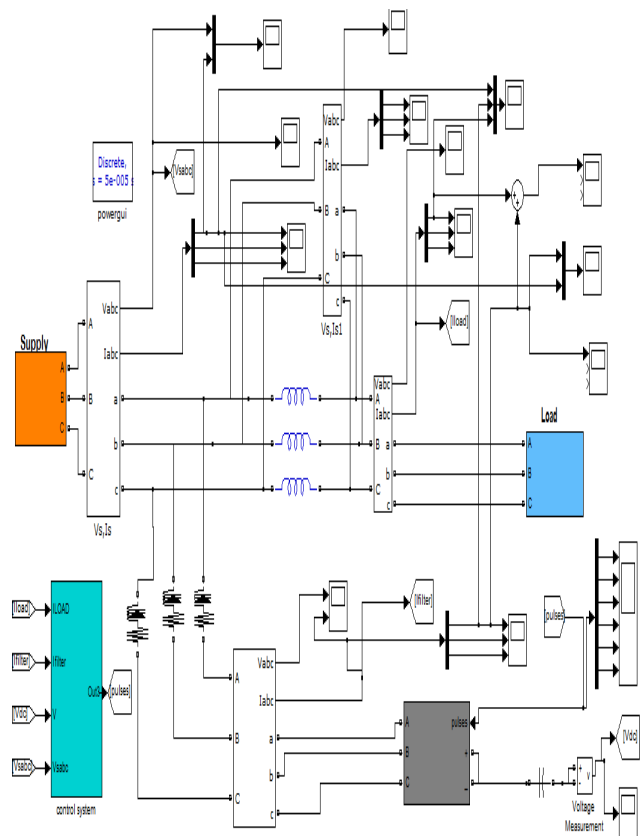## VII.   SIMULINK BLOCK DIAGRAM AND RESULTS

Fig.8 PWM Simulink Model

Carrier based method, causes low order harmonics due to processes such as over-modulation, when M$\geq$ 1and the sampling process. During sampling processes all harmonics where harmonic number *n* is even are cancelled out between phase legs for all carrier/sampling combinations. But when the saw tooth carrier method or asymmetrical regular sampling issued, modulation process produces odd and even

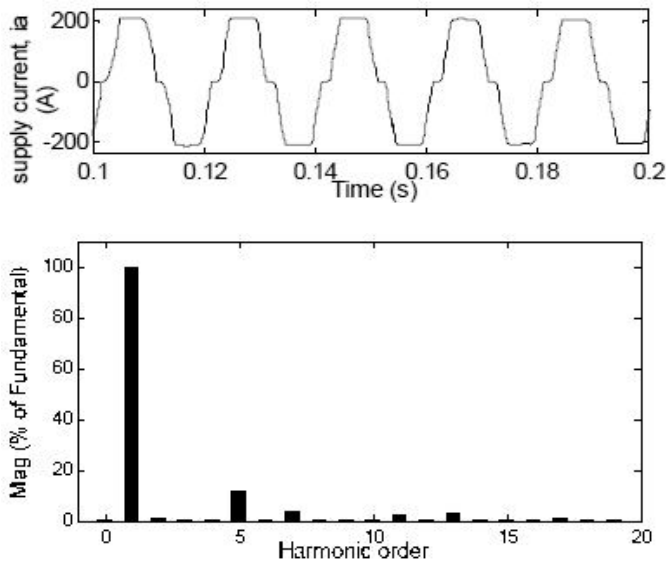*Fig.9 Shunt APF Simulink model*

Fig.10 Supply current and Harmonic order without Compensation
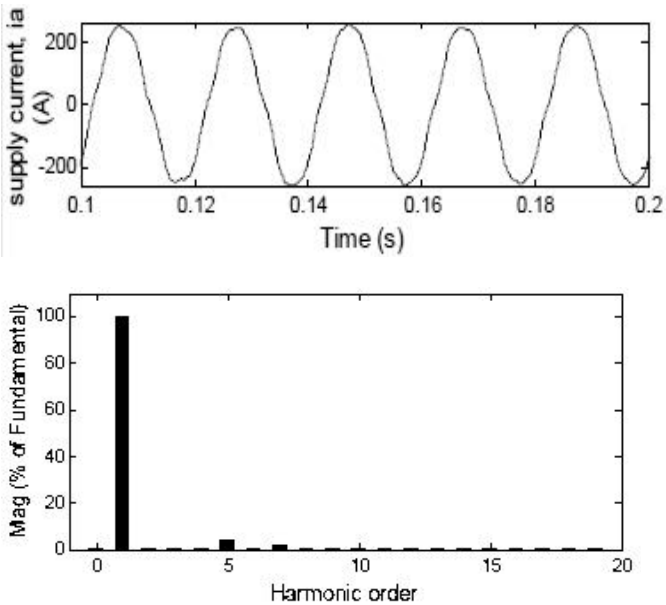

Fig:.11 Supply Current and Harmonic order with Compensation
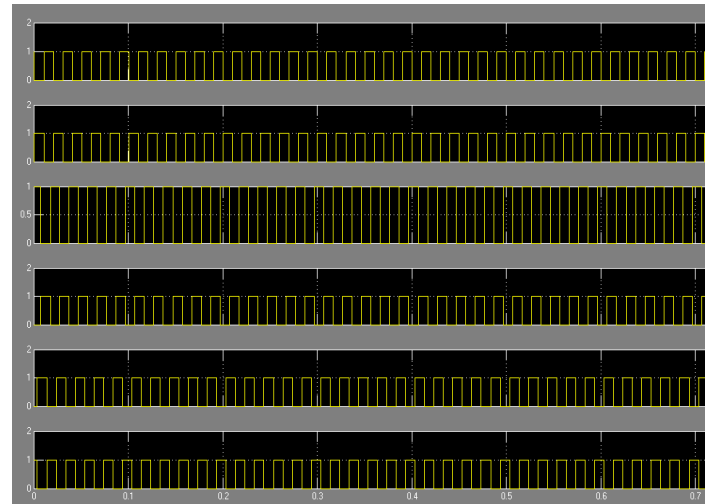

Fig.12 Gate pulse for the Voltage Source Converter

VIII. CONCLUSION

The Shunt Active power filter with PI controller was examined in this paper. The performance of the Shunt Active Power Filter with both proposed controller circuits for reference current generation were examined with simulation model and the results were compared. And achieved the best performance in terms of Active Filtering of Harmonics. FFT analysis is done through powergui block and results compared with standard.

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