RESEARCH ARTICLE OPEN ACCESS

MITIGATION OF HARMONICS IN VOLTAGE SOURCE INVERTER-FED INDUCTION MOTOR USING SHUNT ACTIVE FILTER

G. JYOTHI[1], W.V. JAHNAVI[2]
[1]M.Tech Student, [2]Assistant Professor
SreeVidyanikethan Engineering College, Tirupati, Andhra Pradesh
Email:,[1]jyothigorla994@gmail.com, [2]wvjahnavi@gmail.com
Contact:,[1] 91-9502805165, [2]91-9966987418

Abstract:

Now-a-days variable frequency drives (VFD) are typically utilized in industrial applications and therefore perceive energy saving instrumentation and attain higher operational efficiency. The voltage source inverter (VSI) is utilized to supply a variable frequency and voltage to a 3-Φ induction motor drive throughout a variable speed application. One foremost disadvantage is that, voltage offered by convertor utilized in variable frequency drive (VSI) causes non-sinusoidal output voltage and current as a result of presence of harmonics. For elimination of current harmonics, the shunt active filter (SAF) with VSI topology is projected. This paper concentrates on the design and applications of 3-Φ shunt active filter by p-q theory and $Icos\emptyset$ algorithm. Simulation is performed in MATLAB/SIMULINK environment.

***Index terms*:** Variable frequency drive (VFD), voltage source inverter (VSI), shunt active filter (SAF), p-q theory, $I\cos\phi$ algorithm.

I. INTRODUCTION

The voltage supply of electrical converter (VSI)-fed drives have the advantageous properties like low starting-currents and important energy savings notably in pump and fan applications, such drives are typically used. In industries, the 3 phase induction motor is wide used because of its simple construction, durable mode and low operational costs. The exploitation of squirrel cage induction motor with power semiconductor devices primarily based inverters presents the larger blessings on value and energy efficiency, compared to different industrial solutions for various speed applications. However, the dc power provided by the convertor consists of a diode bridge rectifier feeding associate degree oversized dc capacitance and then, high line current harmonics seen, if the effective inductance for current smoothing is not ample large. These current harmonics manufactured at the inside electrical resistance provide network similar to high voltage harmonics, which might not exceed certain limits among the interest of other tons of this harmonics are injected into the power grid directly, that effects the power quality of the supply system.

A common way to reduce such high current harmonic is to employ an active filter which improves the power quality of the distribution system [1]. Initially, passive filters (combinations of capacitors and inductors) were used to mitigate the power quality issues.

These approaches were extensively utilized in high voltage DC transmission (HVDC) for filtering the harmonics on the AC and DC sides. However, this approach is unsuitable at the distribution level as passive filters can only correct specific load conditions. Thus, the active filter was introduced to compensate harmonics and reactive power.

The purpose of an active filter in a power line conditioner is to repay the utility line current waveform with the goal of approximating a sine wave in phase with the line voltage when a nonlinear load i.e. voltage source inverter-fed adjustable speed drive is connected with the system [2].

This paper uses an approaching up technology with shunt active filter in treating the harmonic distortion among the distribution system by determining low Total Harmonic Distortion (THD) value.

II. VOLTAGE SOURCE INVERTER-FED DRIVES

The voltage source inverter (VSI)-fed drives are widely used particularly in industrial applications characterized by a low-medium horsepower need. Fig.1. shows the basic structure of a VSI-fed drive. It consists of the following:

- A three-phase diode bridge rectifier converts the ac supply voltage to unregulated dc voltage.
- A large shunt capacitor is connected to the dc side of the rectifier to reduce the ripple in the dc Voltage.
- The inverter converts the unregulated dc voltage to adjustable frequency and magnitude voltages for control of motor speed.

The large dc-link capacitance determines associate considerable pulsing element within the dc current [3]. Consequently, the harmonic levels of the line current are considerably different and higher than those caused by current source inverter-fed drives.

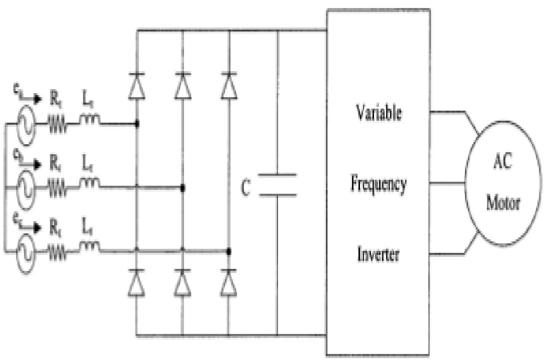

Fig.1. Basic circuit of VSI-fed drive.

III. INDUCTION MOTOR

A natural selection as a drive for industries with a very competitive pricing, the three phase squirrel cage induction motor is used due to its easy construction, efficient and robustness. Induction motors are the most extensively used electric motors for appliances, industrial management, automation and transportation. These electrical motors are often known as the "workhorse" of the Motion trade. Initially, the induction motors are named as constant speed asynchronous motors. But, within the present, lots of applications need variable speed operations [4].

IV. MATHEMATICAL MODELLING OF INDUCTION MOTOR

The direct-quadrature-zero (dq0) transformation is the mathematical tool that is utilized to alter the analysis of three phase circuits. For balanced three phase circuits, the dq0 process converts three AC quantities into two imaginary DC quantities. Further, simplified calculations are typically applied on these imagined DC quantities before applying the inverse method to recover the particular three-phase AC results. It's often utilized in order to change the analysis of three phase induction motor [5]. The mathematical modeling of induction motor is shown in Fig.2.

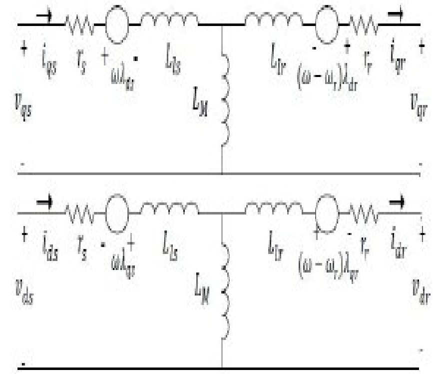

Fig.2. q-axis and d-axis of Induction Motor.

The q-axis and d-axis of the stator voltage equations are given below in equation (1) and (2)

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega\psi_{ds} \quad (1)$$

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \omega\psi_{qs} \quad (2)$$

The q-axis and d-axis of the rotor voltage equations are given below in equation (3) and (4)

$$V'_{qr} = R'_r i'_{qr} + \frac{d\psi'_{qr}}{dt} + (\omega - \omega_r)\psi'_{dr} \quad (3)$$

$$V'_{dr} = R'_r i'_{dr} + \frac{d\psi'_{dr}}{dt} - (\omega - \omega_r)\psi'_{qr} \quad (4)$$

The q-axis and d-axis are obtained from abc to dq conversion.

(1) abc to dq Reference frame

The abc to dq reference frame transformation applied to the induction machine phase-to-phase voltages is given by equations (5) and (6).

$$\begin{bmatrix} V_{qs} \\ V_{ds} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2\cos\theta & \cos\theta + \sqrt{3}\sin\theta \\ 2\sin\theta & \sin\theta - \sqrt{3}\cos\theta \end{bmatrix}\begin{bmatrix} V_{abs} \\ V_{bcs} \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} V'_{qr} \\ V'_{dr} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2\cos\beta & \cos\beta + \sqrt{3}\sin\beta \\ 2\sin\beta & \sin\beta - \sqrt{3}\cos\beta \end{bmatrix}\begin{bmatrix} V'_{abr} \\ V'_{bcr} \end{bmatrix} \quad (6)$$

In the above equations, the angular position of the reference frame is θ and difference between the angular position of the reference frame and position of the rotor is $\beta = \theta - \theta_r$.

(2) dq to abc Reference frame

The dq to abc reference frame applied to the induction machine phase currents are given by equations (7) and (8).

$$\begin{bmatrix} i_{as} \\ i_{bs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ \dfrac{-\cos\theta + \sqrt{3}\sin\theta}{2} & \dfrac{-\sqrt{3}\cos\theta - \sin\theta}{2} \end{bmatrix}\begin{bmatrix} i_{qs} \\ i_{ds} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i'_{ar} \\ i'_{br} \end{bmatrix} = \begin{bmatrix} \cos\beta & \sin\beta \\ \dfrac{-\cos\beta + \sqrt{3}\sin\beta}{2} & \dfrac{-\sqrt{3}\cos\beta - \sin\beta}{2} \end{bmatrix}\begin{bmatrix} i'_{qr} \\ i'_{dr} \end{bmatrix} \quad (8)$$

$$i_{cs} = -i_{as} - i_{bs}$$

$$i'_{cr} = -i'_{ar} - i'_{br}$$

V. SHUNT ACTIVE FILTER

The shunt active filter is connected to the dc bus, acts as self-controller, contains a topology nearly equal to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active filter compensates load current harmonics by injecting equal but opposite harmonic compensating current. Throughout this case, the SAF operates as a current provider injecting the harmonic components generated by the load but half shifted by 180° [6]. Fig.3. shows the association of a SAF compensating the harmonic load currents.

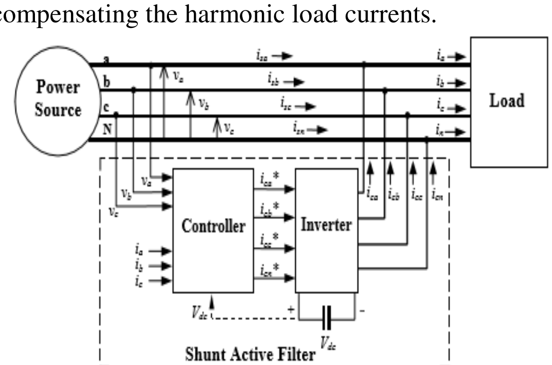

Fig.3. Shunt active filter in a three-phase power system.

VI. DESIGN OF SAF BASED ON P-Q THEORY

The p-q theory is one of several methods which will be utilized within the management of active filters. The moment active and reactive power theory or simply the p-q theory is based on a group of instant values of active and reactive powers printed among the time domain. There are no any restrictions on the voltage or current waveforms, and it would be applied to three-phase systems with or without a neutral wire for three-phase generic voltage and current waveforms. Thus, it's valid not alone inside the steady state, but together with inside the transient state. This theory is improbably economical and versatile in coming up with controllers for power conditioners supported power natural science devices [7].The p-q theory initially uses Clarke transformation to transform voltage and currents from the essential principle to coordinates, thus defines instant power in these coordinates.

The p-q Theory can be defined in three-phase systems with or without a neutral conductor. Three instantaneous powers: the instantaneous zero-sequence power p_0, the instantaneous active power p , and the instantaneous reactive power q are defined from the instantaneous phase voltages and line currents on the αβ0 axes as represented in equation (9).

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & V_\alpha & V_\beta \\ 0 & -V_\beta & V_\alpha \end{bmatrix}\begin{bmatrix} I_0 \\ I_\alpha \\ I_\beta \end{bmatrix} \quad (9)$$

Since zero sequence power in three phase, three wire system is always zero, the equation (9) becomes:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix}\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad (10)$$

α and β currents will be set as functions of voltages and the real power (P) and imaginary power (Q).

VII. DESIGN OF SAF BASED ON $I\cos\phi$ ALGORITHM

The $Icos\emptyset$ algorithm or DC bus voltage control algorithm is a novel technology developed, where the power is balanced in the system as reflected in DC link capacitor voltage. It is used to generate the reference compensation signals for active filter. This algorithm became popular because of its simple computations and due to its capability to work well in all balanced/unbalanced conditions. It uses PI controller which may give solely fastened compensation for varied system conditions. It doesn't have flexibility to tune the controller parameters with dynamic system conditions. In $Icos\emptyset$ algorithm, the source required is to supply only the real or reactive component of the load current, remaining parts of the load current- reactive component and harmonics are to be supplied by active filter. The magnitude of $Icos\emptyset$ is reduced, as the magnitude of the fundamental component of the active part of the load current. Where, I is the amplitude of the fundamental component of load current and $cos\emptyset$ is the displacement power factor of the load [8].The real component of load current can be done by the following extractions:

When balanced 3-$\emptyset$ supply feeds a non-linear load, the load current contains fundamental component and harmonic components. The harmonic components are filtered with active filter. These harmonics are detected with the help of low pass (biquad) filter. Its output is fundamental component delayed by 90^0 (i.e.$I_m\sin(\omega t-\emptyset-90^{\circ})$). At the time of negative zero crossing of the input voltage, i.e. $\omega t=180^{\circ}$, desired source current $|I_s(ref)|$ can be expressed as the three phases of desired (reference) source currents are given as

$$i_{sa}(ref)=|I_s(ref)|\times U_a=|I_s(ref)|\sin\omega t \quad (11)$$

$$i_{sb}(ref)=|I_s(ref)|\times U_b=|I_s(ref)|\sin(\omega t-120^0) \quad (12)$$

$$i_{sc}(ref)=|I_s(ref)|\times U_c=|I_s(ref)|\sin(\omega t+120^0) \quad (13)$$

The compensation currents to be injected by the shunt active filter are the distinction between the particular load currents and therefore the desired supply currents.

$$i_a(comp)=i_{La}-i_{sa}(ref) \quad (14)$$

$$i_b(comp)=i_{Lb}-i_{sb}(ref) \quad (15)$$

$$i_c(comp)=i_{Lc}-i_{sc}(ref) \quad (16)$$

The equivalent block diagram of $I\cos\phi$ algorithm is shown in Fig.4.

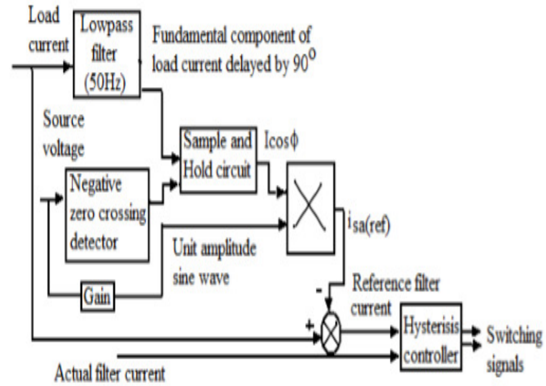

Fig. 4. Block diagram showing implementation of $Icos\emptyset$ algorithm for a phase.

VIII. SIMULATION RESULTS

Performance of shunt active filter is checked with the use of MATLAB software. In the proposed scheme the load is considered as non-linear load i.e. VSI-fed Induction Motor. The shunt active filter is designed with two different control strategies such as p-q theory and $Icos\emptyset$ algorithm.

A.VSI-Fed Induction Motor without SAF

In VSI-fed Induction Motor without SAF, the load current without compensation is shown in Fig. 5. The THD of this current is too high (299.11%) exceeding the IEEE standards as shown in Fig.6.

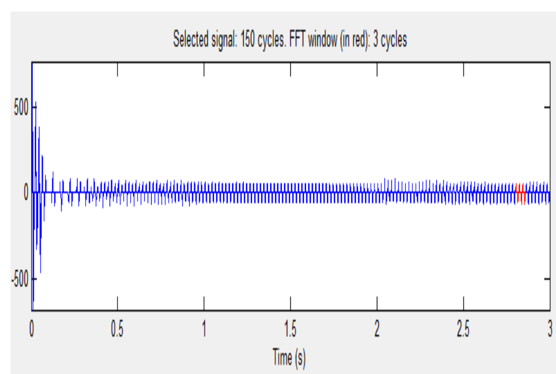

Fig. 5: Source current without any compensation.

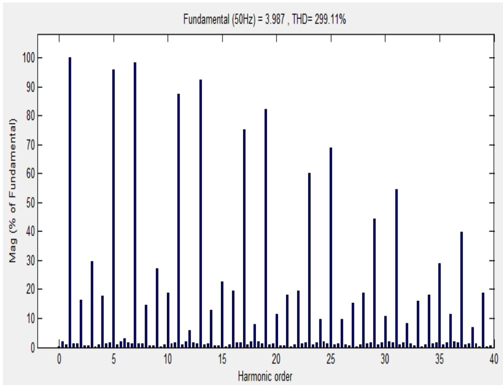

Fig. 6: FFT analysis of source current without SAF.

B. VSI-Fed Induction Motor with SAF using p-q Theory

When active filter is connected between the source and VSI-Fed Induction Motor drive, the harmonics are still reduced as shown in Fig.7 and the source current is almost sinusoidal. Now the THD of the current is less (3.26%) and the harmonic analysis is shown in Fig.8.

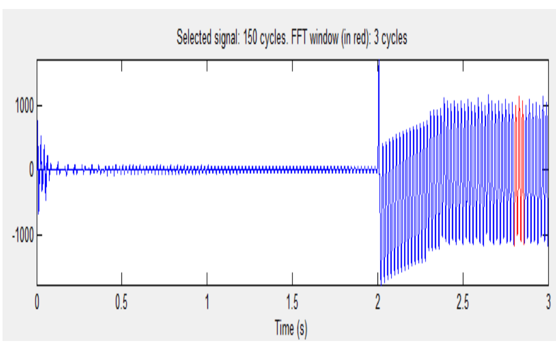

Fig. 7: Source current with compensation using p-q theory.

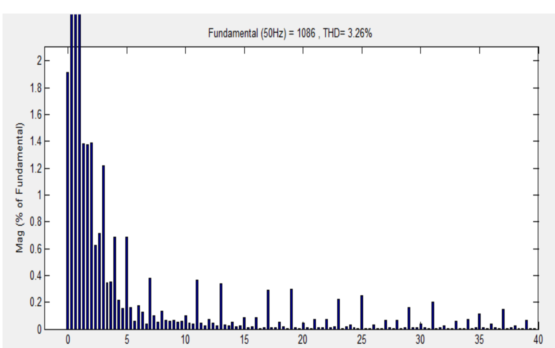

Fig.8: FFT analysis of source current with SAF using p-q theory.

C. VSI-Fed Induction Motor with SAF using $Icos\emptyset$ Algorithm

When active filter is connected between the source and VSI-Fed Induction Motor, the harmonics are reduced as shown in Fig.9 and the source current is almost sinusoidal. Now the THD of the current is very less (1.24%) and the harmonic analysis is shown in Fig.10. The use of shunt active filter increases the performance of the system and also 5^{th} and 7^{th} order harmonics are greatly reduced.

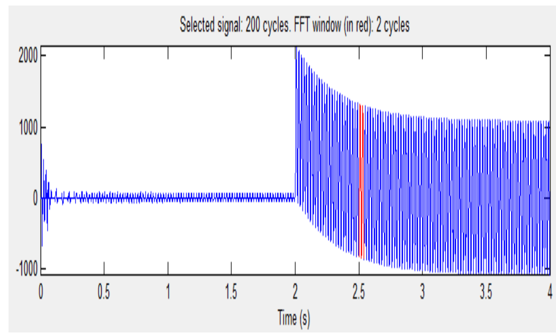

Fig. 9: Source current with compensation using $Icos\emptyset$ algorithm.

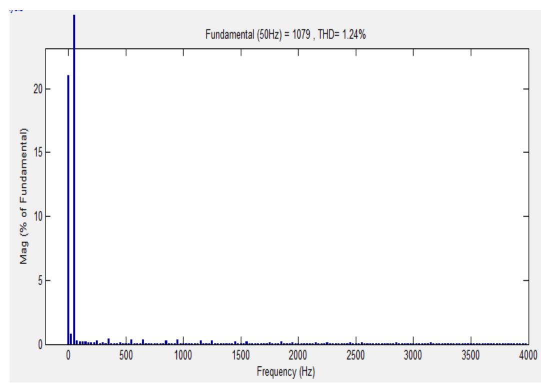

Figure 10: FFT analysis of source current with SAF using $Icos\emptyset$ algorithm.

Table. 1 Comparison of Results

Methods	THD (%)
Without shunt active filter	299.11
With shunt active filter using p-q theory	3.26
With shunt active filter using $Icos\emptyset$ algorithm	1.24

CONCLUSIONS

In this paper the harmonic currents present in Voltage Source Inverter (VSI)-Fed Induction Motor are mitigated by using shunt active filter. Simulation results show the effectiveness of shunt active filter for harmonic elimination in distorted source current. Two types of control strategies have been considered to design the shunt active filter such as p-q theory and $Icos\emptyset$ algorithm. In both the cases THD of source current reduces from 299.11% to 3.26% and 1.24%, which comply with IEEE-519 standard of harmonic control.

REFERENCES

[1] M. Grotzbach and R. Redmann, "Line current harmonics of VSI-fed adjustable-speed drives", *IEEE Trans. Ind. Appl.*, vol. 36, no. 2, pp. 683– 690, Aug. 2002.

[2] D. M. Soomro, M. A. Omran and S. K. Alswed, "Design of a Shunt Active Power to mitigate the harmonics caused by nonlinear loads", *ARPN Journal of Engineering and Applied Sciences*, vol. 10, no. 19, October 2015.

[3] G. Carpinelli, F. Iacovone, A. Russo, P. Varilone and P. Verde, "Analytical modelling for harmonic analysis of line current of VSI-fed drives", *IEEE Trans. Power Del.,* vol. 19, no. 3, pp. 1212–1224, Jun. 2004.

[4] KhadimMoin Siddiqui, KuldeepSahay, V.K.Giri, "Performance and Analysis of Switching Function Based Voltage Source Inverter Fed Induction Motor", *International Electrical Engineering Journal (IEEJ)*, Vol. 5 (2014) No.9, pp. 1545-1552.

[5] Mr. Punit L. Ratnani, Dr. A. G. Thosar, "Mathematical Modeling of a three Phase Induction Motor Using MATLAB/Simulink", *International Journal of Modern Engineering Research (IJMER)*, Vol. 4, Iss. 6, June. 2014.

[6] JoãoAfonso, Carlos Couto, Júlio Martins, "Active Filters with Control Based on the p-q Theory", *IEEE Industrial Electronics Society Newsletter* , vol. 47, no. 3, ISSN: 0746-1240, pp. 5-10, Sept. 2000.

[7] Arpit Shah, NiravVaghela, "Shunt Active Power Filter for Power Quality Improvement in Distribution Systems", *International Journal of Engineering Development and Research (IJEDR)*, ISSN: 2321-9939, 2005.

[8] Sindhu.S, Sindhu M.R, ManjulaG.Nair, Ginnes. John, "Implementation of Three phase Shunt Hybrid Filter Using ICOSφ Algorithm", *Asian Power Electronics Journal,* Vol. 5 No. 1, Aug 2011.