Journal of Theoretical and Applied Information Technology
20th January 2014. Vol. 59 No.2

ISSN: **1992-8645** www.jatit.org E-ISSN: **1817-3195**

A NOVEL APPROACH FOR MITIGATION OF HARMONICS AND INTERHARMONICS IN VARIABLE FREQUENCY DRIVES

[1]PROF.VIJAYAKUMAR.A, [2] DR.MAHENDRA BABU. T.K
[1]Faculty of Electrical and Electronics Engineering, AAM Engineering College, Kovilvenni
[2]Professor and Former Faculty, KLN College of Engineering, Madurai
E-mail: [1] viji1me@gmail.com [2] babutkm2004@yahoo.com

ABSTRACT

Interharmonics are non-integer multiples of the fundamental frequency that causes several undesirable effects. Variable frequency drives are main sources of interharmonics. Also interharmonics are generated when the inverter load is unbalanced or the inverter is operating in overmodulation. In this study, adjustable speed drive employing diode bridge rectifier and voltage source inverter with load unbalance is considered. Propogation of interharmonics in the supply side due to load unbalance is analysed and a novel method for mitiating interharmonics is proposed. The proposed method employs an active filter in supply side which is simulated using PSIM . With the proposed active filter the compensation effectiveness is significantly improved and allows the elimination of passive filters thereby reducing cost and space required.

Keywords: *Interharmonics, Power Quality, Adjustable Speed Drive, Active Filter, Interharmonics Mitigation.*

1. INTRODUCTION

With the advancement of power electronic technologies, voltage source inverter (VSI) fed drives are widely employed in industries generate harmonics and interharmonics resulting in serious power line pollution. Power quality is thus aggravated. The distorted current due to polluted power supply causes some undesirable effects on the power system equipments and load[7]. Harmonics are spectral components that are integer multiples of the fundamental frequency. Harmonics result in overheating of transformer that leads to derating of the transformer. Also it results in pulsating torque in variable frequency drive (VFD) which reduces the efficiency of the drive.

Interharmonics are components that are not an integral multiple of the fundamental frequency[2]. Apart from problems related with harmonics, interharmonics result in various other problems such as low frequency oscillation of mechanical system, telecommunication interference, voltage flicker, saturation of current transformer, reduced life of induction motor[5].

Interharmonics are generated by loads operating in transient state and also when the supply and the load operating frequencies are different.[4] AC-DC-AC conversion systems and cycloconverters are main sources of interharmonics. VFD generates interharmonics when the inverter is operating in overmodulation or the load is unbalanced. As interharmonic frequency is not constant and varies with the load operating frequency, it is difficult to eliminate it using passive filters which are tuned at particular frequency. By using active filters, interharmonics can be eliminated effectively. In this work, VFD with load unbalance is considered and its effect on utility is discussed. A suitable shunt active filter is designed and its effectiveness in eliminating harmonics and interharmonics is justified using PSIM simulation. Also SAF improves the supply side power factor as it compensates the reactive power in the line[8].

2. DETAILED MODEL OF VARIABLE FREQUENCY DRIVE

2.1 Diode-Bridge Rectifier

Three phase six pulse diode bridge rectifier is most commonly used in VFD as a front end converter which is shown in Fig.1. A large dc link capacitor is used to reduce ripples in the rectified output.

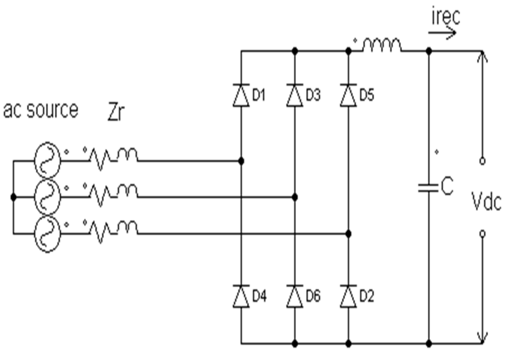

Fig.1: Diode Bridge Rectifier

The three phase supply voltages are expressed as

$$V_a = V_m \sin \omega t$$
$$V_b = V_m \sin(\omega t - 120°)$$
$$V_c = V_m \sin(\omega t - 240°)$$

2.2 Pulse Width Modulation Inverter

Three phase two level PWM inverter is the commonly used inverter in VFD applications. High speed switching devices like IGBT and MOSFET are employed for variable frequency drives. In two level inverter diodes are connected in antiparallel with the main switches. Sinusoidal PWM technique is used in which the output pulse train is produced by directly comparing sinusoidal reference signal with the triangular carrier signal at high frequency[3]. Fig.2 shows the PWM inverter employed for induction motor control.

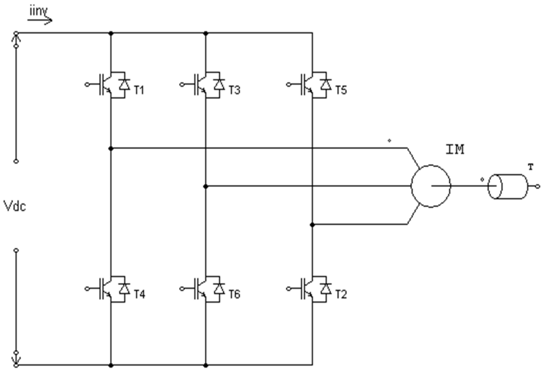

Fig.2: PWM Inverter

2.3 Shunt Active Filter

Shunt active filter (SAF) acts as a current source. When it is properly controlled, it produces harmonic currents that are in opposite phase to that produced by VFD. Therefore when it is connected in the input side of the VFD, almost all the harmonics and interharmonics are eliminated from the supply. A single line diagram of shunt active filter is shown in Fig.3.

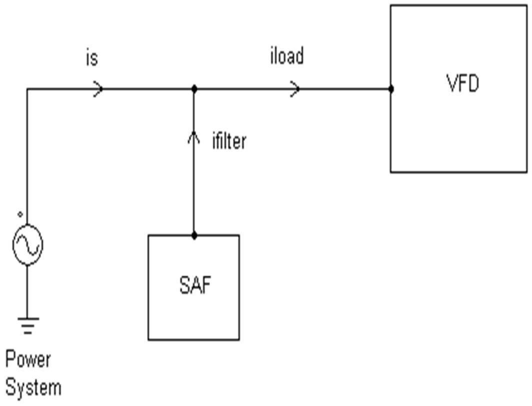

Fig.3:Single Line Diagram Of SAF

3. INTERHARMONIC ANALYSIS

To analyse motor current unbalance, an inducor is connected in series with one of the stator phase windings of the motor[1].

3.1 Harmonic Transfer From The Inverter To The Dc Link

As the motor current is unbalanced, in addition to the positive sequence components, negative sequence components are also present in the motor currents[1]. The motor input current is given by

$$i_{ui} = \mathrm{sqrt}.2(\mathrm{I_p})\cos(\omega t + \varphi_p) + \mathrm{sqrt}.2(\mathrm{I_n})\cos(\omega t + \varphi_n) \qquad (1)$$

Where I_p - positive sequence component of current

I_n - negative sequence component of current

These components of currents have phase shift of φ_p and φ_n

Similarly motor input current equations can be written for the remaining two phases.

The inverter input current is given by

$$i_{inv} = S_{ui} i_{ui} + S_{vi} i_{vi} + S_{wi} i_{wi} \qquad (2)$$

$$i_{inv} = I_{dc} + \sqrt{2}\, I_{inv} \cos(2\omega_{out} + \varphi_n) \quad (3)$$

Where $I_{dc} = \frac{3}{4} m_i \sqrt{2}\, I_p \cos\varphi_p$ (4) and S_{ui}, S_{vi}, S_{wi} are inverter switching functions.

I_{dc} component results in active power transfer. The component I_{inv} is responsible for the change of the inverter dc link current with two times the output frequency

3.2 Harmonic Transfer Through Dc Link

The disturbance in the inverter side dc link is transferred to the dc link of rectifier. The disturbed current at the dc link of the rectifier is given by

$$i_{rect} = I_{dc} + \mathrm{sqrt.2} I_{rect} \cos(2\omega_{out} t + \phi) \qquad (5)$$

Where

$$I_{rect} = k_{dclink} I_{inv} \qquad (6)$$

Where k_{dclink} is the dc link current magnification factor. This magnification occurs at the dc link due to parallel resonance [1]. As the motor output frequency is varied from 0 to f_{out} the rectifier side dc link current fluctuates with the frequency ranging from 0 to 2 f_{out}.

3.3 Harmonic Transfer Through The Rectifier

For this analysis, the rectifier switching functions are considered. The rectifier is assumed to conduct continuously. The input currents of the rectifier considering the switching function are given by

$$\begin{aligned} i_{ar} &= S_{ar} i_{rect} \\ i_{br} &= S_{br} i_{rect} \\ i_{cr} &= S_{cr} i_{rect} \qquad (7) \end{aligned}$$

The switching functions of the rectifier are approximated to their fundamental components as follows

$$\begin{aligned} S_{ar} &= A_1 \cos(\omega_{in} t) \\ S_{br} &= A_1 \cos\left(\omega_{in} t - \frac{2\pi}{3}\right) \\ S_{cr} &= A_1 \cos\left(\omega_{in} t + \frac{2\pi}{3}\right) \qquad (8) \end{aligned}$$

Where A_1 is the amplitude of the fundamental harmonic component and it is given by

$$A_1 = \frac{2\mathrm{sqrt.3}}{\pi} \qquad (9)$$

Thus the derived input current of the rectifier for phase A is

$$\begin{aligned} i_{ar} &= \sqrt{2} I_1 \cos(\omega_{in} t + \varphi_{in}) \\ &+ \sqrt{2} I_H \cos((2\omega_{out} t + \omega_{in})t + \phi) \quad (10) \\ &+ \sqrt{2} I_H \cos((2\omega_{out} t - \omega_{in})t + \phi) \end{aligned}$$

Where

$$I_1 = A_1 I_{dc} \qquad (11)$$

$$I_H = \frac{1}{2} A_1 I_{rect} \qquad (12)$$

Thus the unbalance in the motor current is propagated to the supply with two components which are symmetrical at $2f_{out} \pm f_{in}$.

4. .SYSTEM CONFIGURATION OF SAF

The main objective of SAF is to eliminate harmonics and interharmonics. The active filter current is controlled so that it injects a current in the line opposite to that of the harmonic currents produced by the load.[6] Fig.4 shows the VFD with SAF.

The block diagram of SAF control scheme is shown in Fig.6 which is implemented in PSIM. The reference sinusoidal current is subtracted from the supply current and the filter current is subtracted from the resulting signal and is compared with the high frequency reference signal

Journal of Theoretical and Applied Information Technology
20th January 2014. Vol. 59 No.2

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

to generate triggering pulses for the devices in the SAF.

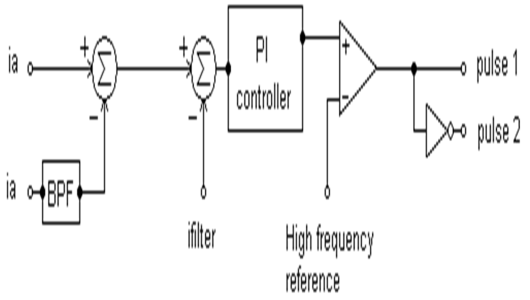

Fig.5 : Block Diagram Of Control Scheme Of SAF

4.1. Simulation Results

For the simulation of load unbalance, an inductor of 0.125mH is connected in series with one of the phase windings. The induction motor considered for simulation is 20kW and 6 pole and the motor operating frequency is 40Hz. To demonstrate the superiority of shunt active filter, measurements are made at the input side with and without SAF.

Simulation is carried out using the parameters listed in Table I

4.1.1 Simulation results without SAF

Measurements are made at the supply side without active filter and are shown in Fig.6.

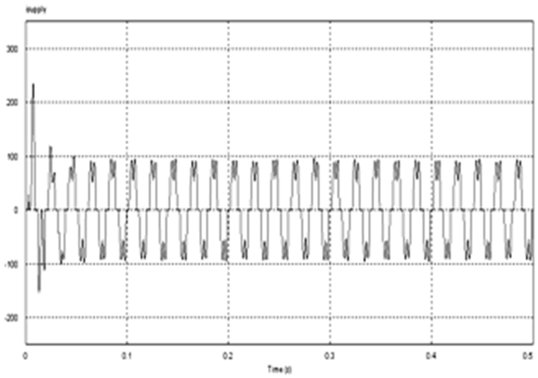

Fig.6: Utility Current

The spectrum of the utility current obtained using FFT is shown in Fig.7.

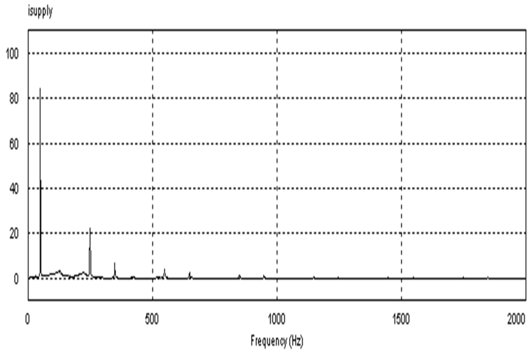

Fig.7 : Spectrum Of Utility Current

According to the analysis made in section 3, for the motor operating frequency of 40Hz, interharmonics will occur at frequencies of $(2f_{out}+f_{in})$ and $(2f_{out}-f_{in})$ ie. At 30Hz and 130Hz respectively in the utility current. The magnitude of these interharmonics are measured and tabulated in Table II. Also harmonics are measured and tabulated in Table III. Interharmonic order is calculated as shown below.

$$\mathit{Interharmonic\,Order} = \frac{\mathit{Interharmonic\,frequency}}{\mathit{Fundamental\,frequency}}$$

TABLE II

Interharmonic order	Interharmonic frequency	Interharmonic magnitude as % of fundamental
0.6	30Hz	1.7
2.6	130Hz	4.2

Table III

Harmonic order	Harmonic frequency	Harmonic magnitude as % of fundamental
5	250Hz	26.7
7	350Hz	7.7

Power factor is also measured in the supply side and is calculated to be 0.69. The relation between utility voltage and current waveform is as shown in Fig.8.

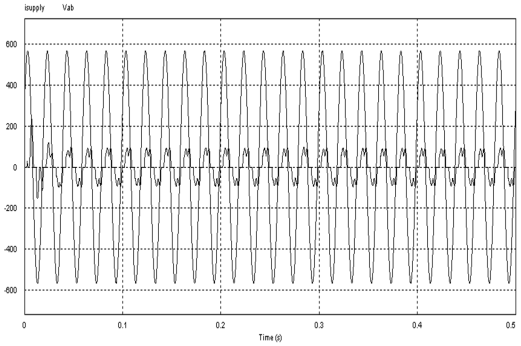

Fig.8 : Relation Between Utility Voltage And Current

4.1.2Simulation results with SAF

Circuit shown in Fig.4 is simulated using PSIM. The utility current , phase a current and active filter current of VFD are measured and are shown in Fig.9.

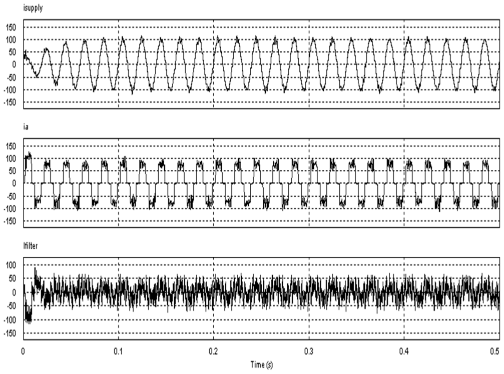

Fig.9: Utility Current, Phase A Current Of VFD And Active Filter Current

The spectrum of utility current obtained using FFT is shown in Fig.10.

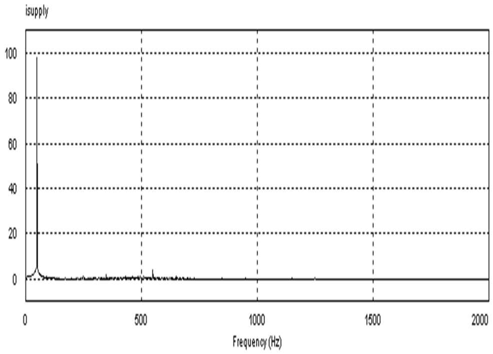

Fig.10 : Spectrum Of Utility Current

The utility current is sinusoidal and the magnitude of the interharmonic component are measured at the utility side and are tabulated in Table IV. Harmonic components are measured and tabulated in table V.

Table IV

Interharmonic order	Interharmonic frequency	Interharmonic magnitude as % of fundamental
0.6	30Hz	1.6
2.6	130Hz	0.13

Table V

Harmonic order	Harmonic frequency	Harmonic magnitude as % of fundamental
5	250Hz	1.27
7	350Hz	1.69

For comparison, the results are tabulated in Table VI.

Table VI

Harmonic and interharmonic frequency of supply current	Without SAF	With SAF
30Hz	1.7	1.6
130Hz	4.2	0.13
250Hz	26.7	1.27
350Hz	7.7	1.69

From the results obtained, it is observed that using active filter fifth harmonic component is reduced from 26.7% to 1.27%. and seventh harmonic component is reduced from 7.7% to 1.69% which shows considerable reduction in harmonics. The magnitude of the interharmonic component at ($2f_{out}+f_{in}$) ie. At 130Hz is reduced from 4.2% to 0.13%. The results show that the SAF is very effective in mitigating both harmonics and interharmonics. Apart from harmonic and interharmonic elimination, SAF improves the supply power factor by reactive power compensation. With SAF power factor is calculate at the supply side which is equal to 0.93. The utility current and voltage waveforms are shown in Fig.11.

By using SAF, the utility power factor is improved from 0.69 to 0.93.

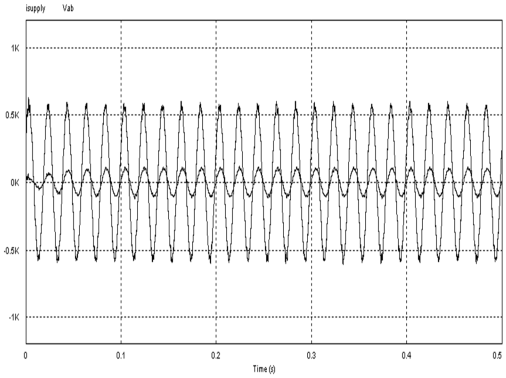

Fig.11 : Utility Voltage And Current With SAF

5. CONCLUSION

In this work, a suitable shunt active filter is proposed to mitigate harmonics and interharmonics from the supply line of variable frequency drive to improve the quality of power supply system. VFD with SAF is simulated in PSIM. The results are compared with those obtained for VFD without SAF. On comparison of the results it can be concluded that the proposed system is effective in reducing both harmonic and interharmonic components. Apart from eliminating harmonics and interharmonics, SAF improves the utility power factor. This shows the superiority of SAF in improving quality of the power supply system.

REFERENCES:

[1] Duro Basic, “Input Current Interharmonics of Variable-Speed Drives due to Motor Current Imbalance,”IEEE Trans. Power Del. Vol.25, no. 4, Oct.2010.

[2] IEEE Interharmonic Task Force, “ Interharmonics: theory and modeling,” IEEE Trans. Power Del.,vol. 22, no. 4, pp. 2355–2348, Oct.2007.

[3] S.K.Chen, H.J.Su and G.W.Chang,”Modelling VSI - fed ASDs by Matlab/Simulink for Harmonic and Interharmonic Assessment”, IEEE Xplore Digital Library, 2010.

[4] R.Yacamini, “Power System Harmonics, part 4 Interharmonics,” Power Eng. J., pp.185-193, Aug. 1996, Tutorial.

[5] F. De Rosa, R. Langella, A. Sollazzo, and A. Testa, “On the Interharmonic Components Generated by Adjustable Speed Drives,” IEEE Transactions on Power Delivery, Vol. 20. No.4, pp. 2535-2543, Oct. 2005

[6] M.B. Rifai T.H. Otmeyer and W.J. McQuillan, “Evaluation of Current Interharmonics from AC drives,” IEEE Transactions on Power Delivery, Vol. 15. No.3, pp. 1094-1098, July 2000

[7] Lorenzo Marconi, Fabio Ronchi, Andrea Tilli, “Robust nonlinear control of shunt active filters for harmonic current compensation,” Science Direct, Automatica 43 (2007) 252 – 263, 2006

[8] Murat Kale , Engin O¨ zdemir, “Harmonic and reactive power compensation with shunt active power filter under non-ideal mains voltage,” Science Direct, Electric Power Systems Research 74 (2005) 363–370, March 2005

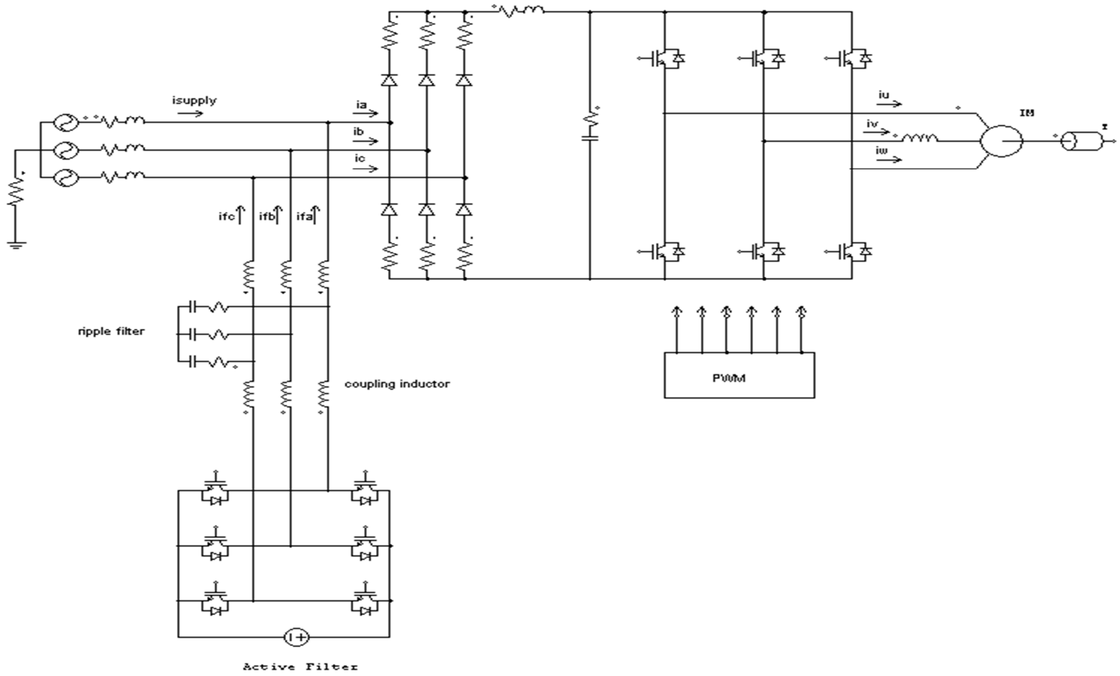

Fig.4: VFD with active filter

Table I

AC Source		Induction Motor	
Voltage	400V	Rated Power	20kW
Frequency	50Hz	Rated Voltage	400V
Resistance	8mΩ	Stator Resistance	0.294Ω
Inductance	0.5mH	Stator Leakage Inductance	0.00139H
DC Link		Rotor Resistance	0.156Ω
Resistance	3.5mΩ	Rotor Leakage Inductance	0.00074H
Inductance	0.001H	Pairs of Poles	3
Capacitance	0.0005F	Motor Operating Frequency	40Hz to 50Hz