MITIGATION OF HARMONICS AND INTERHARMONICS IN ADJUSTABLE SPEED DRIVES

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Abstract- This paper provides an efficient way to mitigate the interharmonics appearing in the input side of the adjustable speed drives which are created by an imbalance in the motor current**.** The adjustable speed drive consists of VSI and diode rectifier. The present work examines how unbalance in the motor current distorts the inverter dc side current and this appears as interharmonic distortion in the input currents of the AC side. C-type filter and AC choke are designed for the proposed method for mitigation of this harmonics and interharmonics. The proposed method is simulated using MATLAB/ SIMULINK software.

Key words- Interharmonics, motor current imbalance, unbalanced load, adjustable speed drives, pulse width modulation, Voltage source inverter (VSI).

I.INTRODUCTION

For Power Quality (PQ) studies it is necessary to analyse harmonic and interharmonic current produced by Voltage Source Inverter fed variable speed drives. Adjustable Speed Drives (ASDs) are generally used as variable speed control devices in industrialized and some housing appliance. An ASD is a frequency converter, that changes an input supply frequency to an output of desired frequency. The block diagram of Voltage source Inverter fed variable speed drive is shown in Fig.1. AC voltage is converted into DC voltage using an uncontrolled bridge rectifier. A DC link is connected after the rectifier to remove ripples in the DC voltage and gives a constant DC output voltage. This DC voltage is converted into AC voltage of variable magnitude and frequency using a PWM inverter for the speed control of induction motor.

The main causes of interharmonics are over modulation of the inverter, if there is any interference created at the output of the inverter then it will propagate as interharmonics at the rectifier AC side. The unequal single phase load distribution in three phase lines is another reason for the appearance of interharmonics. That is, if the load imbalance occurs, over modulation of the inverter is the primary cause for the interharmonics in variable speed drives.

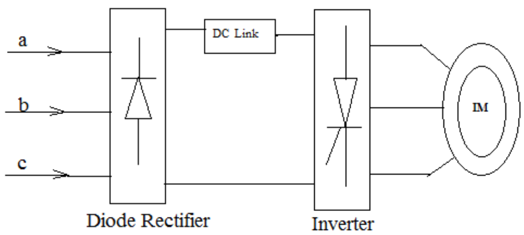

Figure1. Block diagram representation of VSI-fed ASD.

This paper presents the variable speed drive employed with induction motor, which is being affected by interharmonics due to imbalance in the motor current. This manuscript suggests a new method to mitigate interharmonics by different filters whose simulation values are being compared.

II. HARMONIC TRANSMISSION THROUGH THE VSI

This section examines the motor current imbalance that is transferred through the inverter phase by connecting an inductor of 0.12 mH to the stator winding to follow motor winding imbalance.

Before imbalance the balanced current expression is given as

$$I_a=\sqrt{2}I\cos(\omega t) \quad (1)$$

Similarly I_b and I_c currents are shifted by 120^o and 240^o.

For purpose of analysis, a disturbance is created by adding an inductance in phase B with the stator motor winding.

The disturbed motor currents are

$$I_a = \sqrt{2} I_+ cos(\omega t + \varphi_+) + \sqrt{2} I_- cos(\omega t + \varphi_-) \qquad (2)$$

Where I_+ and I_- of the current indicates the + ve and -ve sequence components of the disturbed motor currents. Similarly φ_+ and φ_- of the phase shifts indicates the +ve and –ve sequence components of the disturbed motor currents.

The inverter current expression is

$$I_{invt} = S_u I_a + S_v I_b + S_w I_c \qquad (3)$$

S_u, S_v, S_w are the switching function of the phase u,v,w. Where

$$S_u = \frac{1}{2}(1 + m_i cos(\omega t)) \qquad (4)$$

$$S_v = \frac{1}{2}(1 + m_i cos(\omega t - \frac{2\pi}{3})) \qquad (5)$$

$$S_w = \frac{1}{2}(1 + m_i cos(\omega t + \frac{2\pi}{3})) \qquad (6)$$

The inverter current is expressed as,

$$I_{invt} = \frac{3}{4} m_i(\sqrt{2} I_+ cos(\varphi_+) + \sqrt{2} I_- cos(2\omega_{out} t + \varphi_-)) \qquad (7)$$

$$I_{invt} = I_{dc} + \sqrt{2} I_{-inv} cos(2\omega_{out} t + \varphi_-) \qquad (8)$$

The DC current I_{dc} is responsible for active power transfer.

$$I_{dc} = \frac{3}{4} m_i (\sqrt{2} I_+ cos(\varphi_+) \qquad (9)$$

The inverter current I_{inv} is associated with motor current unbalance. It is not useful for active power transfer but results in energy oscillations at a frequency of $2f_{out}$.

$$I_{invt} = \frac{3}{4} m_i I_- \qquad (10)$$

The DC current and the inverter current depends upon the modulation index m_i.

The corresponding current spectrum is shown in figure.2

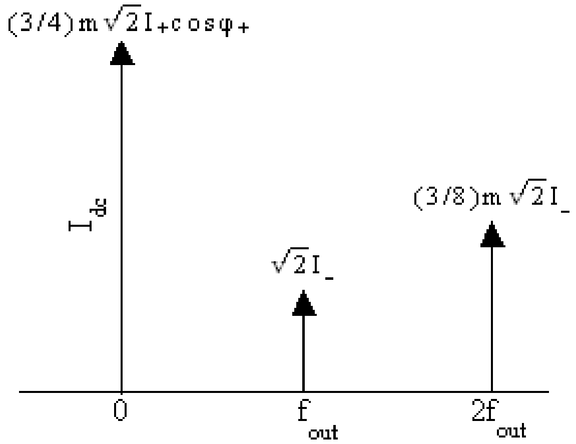

Figure.2 shows the Current Spectrum

III. TRANSMISSION OF HARMONIC THROUGH DC LINK

The motor current imbalance from the output of the inverter propagates through the dc link of the drive. The DC link will act as a resonant circuit thereby increases the magnitude of the disturbed current by a magnification factor K_{dc} at the frequency $2f_{out.}$

$$\text{Magnification factor: } K_{dc} = \left| \frac{C_{dc} + R_c}{R_{dc} + L_{dc}} \right| \qquad (11)$$

The magnified rectifier current at the DC link

$$I_{rect} = K_{dc}\, I_{inv}$$

$$I_{rect}=\left[\frac{3}{4}\,m(\sqrt{2}I_{+}cos\varphi_{+}+\left(\left|\frac{C_{dc}+R_{c}}{R_{dc}+L_{dc}}\right|\right)\frac{3}{4}\,m_{i}\sqrt{2}I_{-}cos(2\omega_{out}t+\Phi)\right] \qquad (12)$$

The term Φ represents $[\varphi_{-} + \varphi_{z}]$ where φ_z represents phase-shift produced by the DC-link.

The corresponding current spectrum is shown below

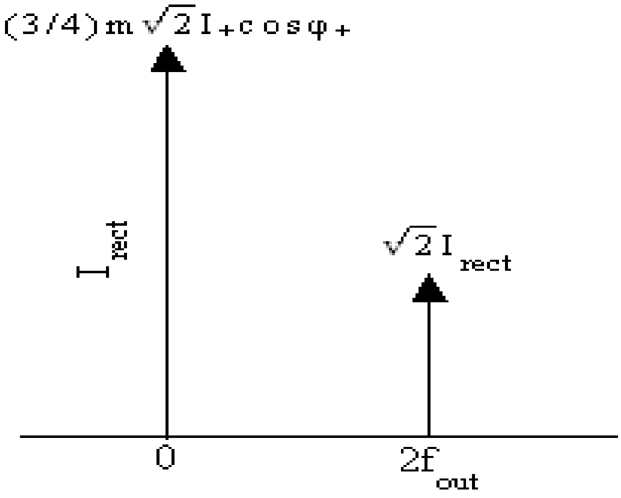

Figure.3 shows the Current Spectrum

IV.HARMONIC TRANSMISSION THROUGH THE DIODE BRIDGE RECTIFIER

The disturbed current at ac side of the rectifier is obtained by switching function of the rectifier. The equation are given as,

$$I_u = S_a\, i_{rec} \qquad (13)$$

$$I_v = S_b\, i_{rec} \qquad (14)$$

$$I_w = S_c\, i_{rec} \qquad (15)$$

Where S_a, S_b, S_c represents the switching function of the rectifier of each phase. It is given as

$$S_a = \sum_n A_n \cos\left(n\omega_{in}t\right) \qquad (16)$$

$$S_b = S_a\left(t - \frac{T}{3}\right) \qquad (17)$$

$$S_c = S_a\left(t + \frac{T}{3}\right) \qquad (18)$$

Switching functions are found using the fourier series expression. They are given as,

$$A_n = \frac{4}{n\pi}\sin\left(\frac{n\pi}{3}\right) \qquad (19)$$

Finally, the input phase currents at the rectifier side is given as,

$$I_a = \sqrt{2}I_1\cos\left(\omega_{in}t + \phi_{in}\right) + \sqrt{2}I_h\cos\left(\left(2\omega_{out}+\omega_{in}\right)t + \phi\right) + \sqrt{2}I_h\cos\left(\left(2\omega_{out}-\omega_{in}\right)t + \phi\right) \qquad (20)$$

The corresponding current spectrum is shown below

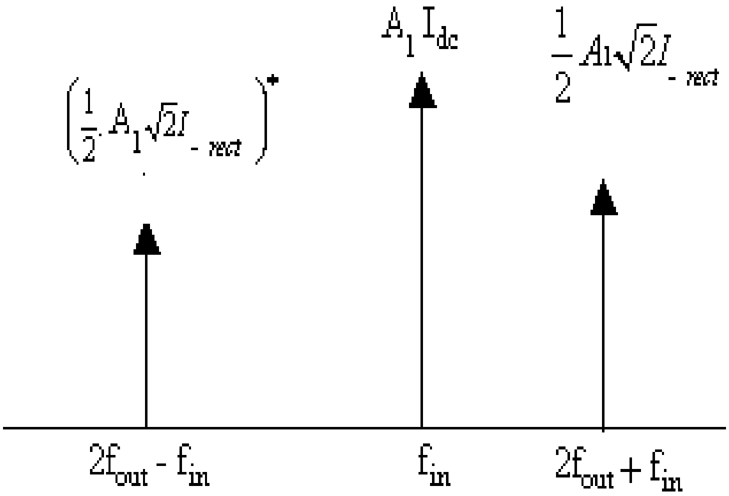

Figure.4 shows the Current Spectrum

IV.SIMULATION

The variable speed of the induction motor is obtained by varying the inverter frequency. The main aim of the paper is to mitigate the interharmonics appearing in ASD. To mitigate interharmonics in the ASD AC choke and C-type filters are designed. The proposed ASD are simulated using the MATLAB/SIMULINK software. Section a presents matlab model without filter, Section b presents matlab model C-type filter,Section c presents matlab model with AC choke.

A. Matlab model without filter

The simulink model without filter is shown in Figure.5. The rectifier input current is shown in Figure.6. The rectifier input current spectrum is shown in Figure.7 which is analysed using FFT.

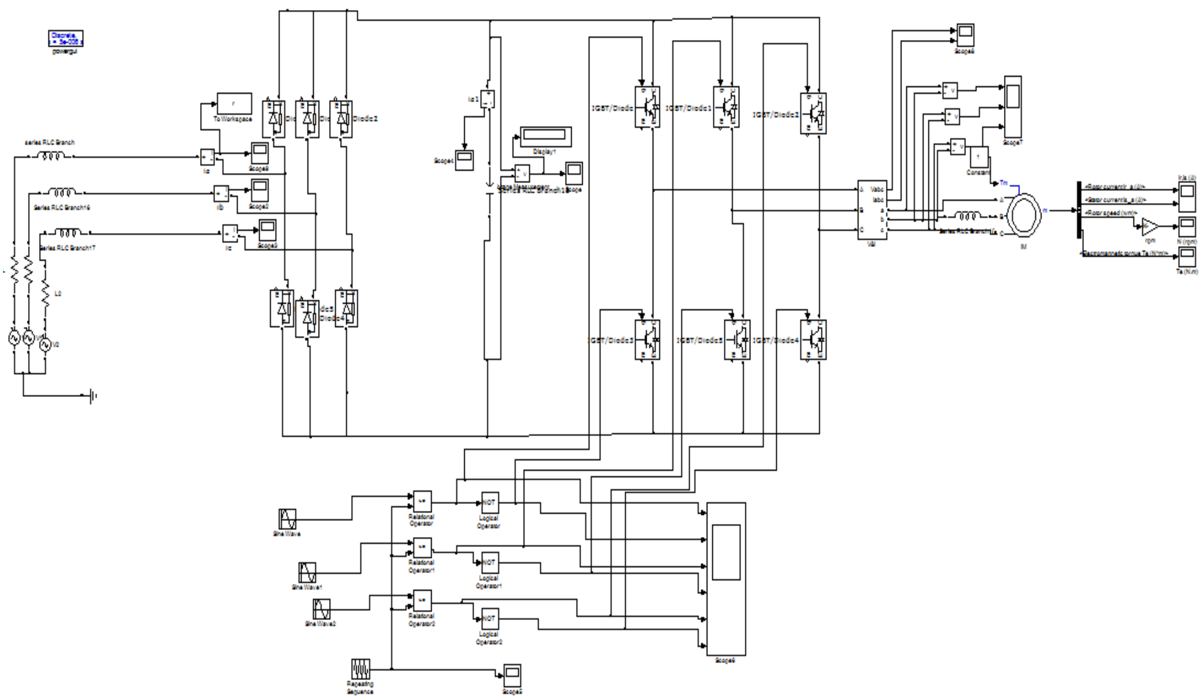

Figure.5 Matlab model without filter

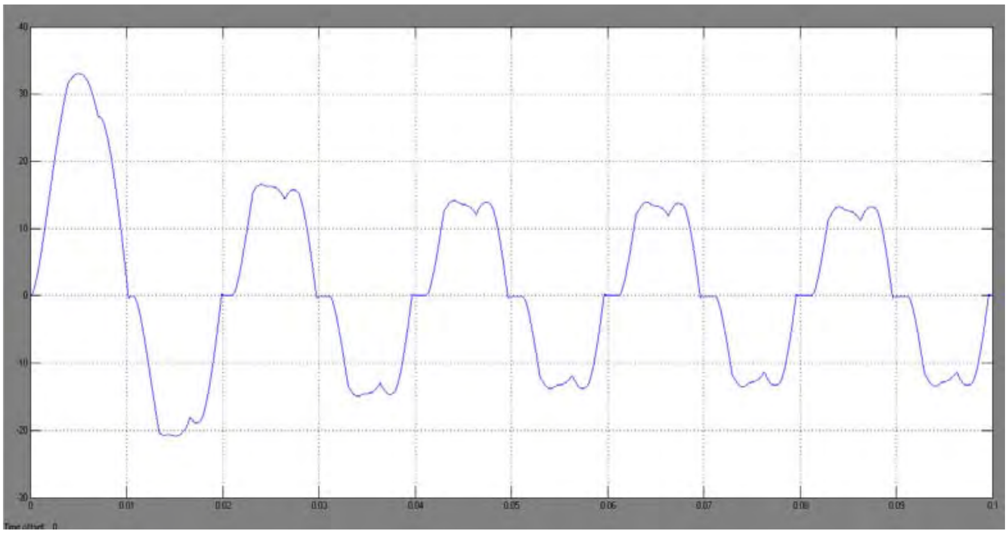

Figure.6 Rectifier Input Current

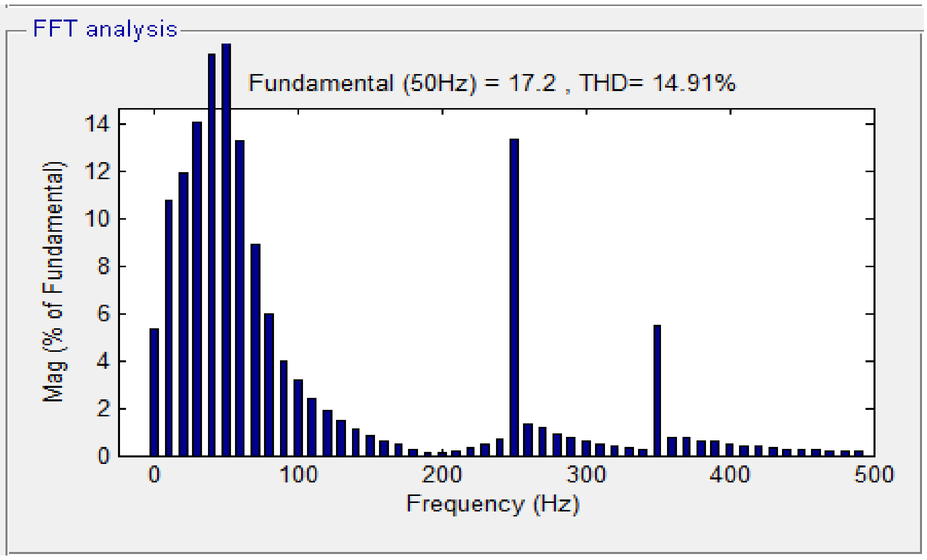

Figure.7 THD analysis for input current of rectifier

The current spectrum of the rectifier input current shown in Figure.7 has the total harmonic distortion of 14.91%. From eqn (20) the interharmonic family is obtained to be $2f_{out}\pm f_{in}$. The inverter output frequency is f_{out} (i.e) 40Hz. So the dominant interharmonic will occur at the frequencies of 130Hz and 30Hz. Magnitude of these interharmonics are14.11% and 1.45%.

B. Matlab model with C-type filter

For mitigation of these interharmonics C-type filter is designed.The passive harmonic filter consists of passive elements like resistors, inductors, and capacitor. C-type damped filter include two capacitors one in series with the inductor and capacitor. Figure.8 shows the block diagram of C-type filter. The value of these passive elements are obtained by trial and error method. The parameters of this filter are C1=50uf, C2=170mf,R=5 ohm,L=1000uH.

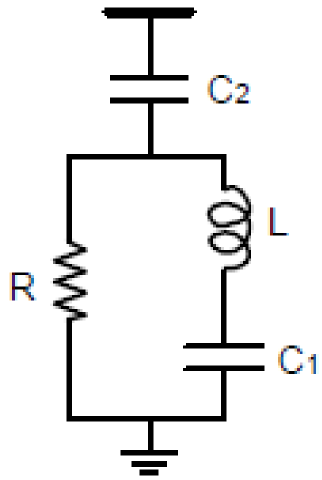

Figure.8 C-type filter

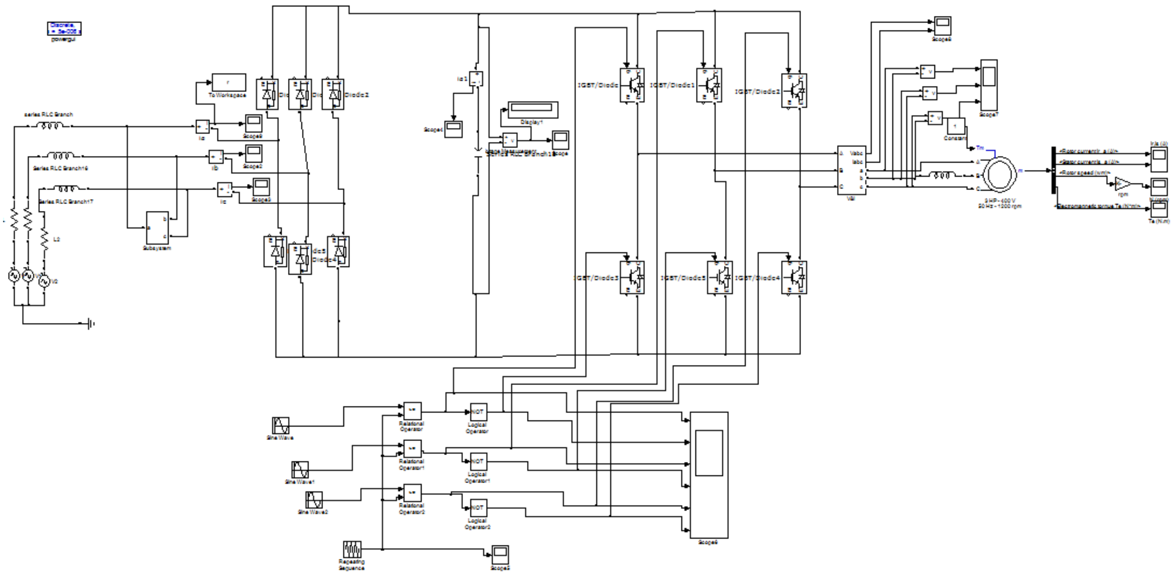

Figure.9 Matlab model for C-type filter

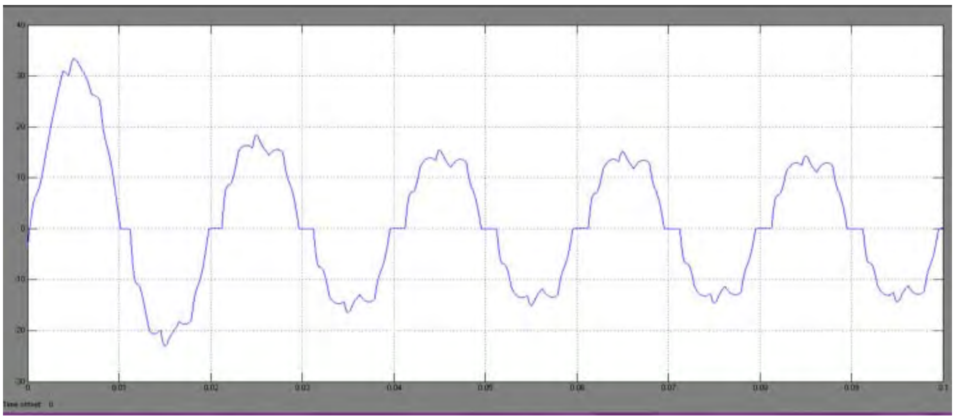

Figure.10 Rectifier Input Current

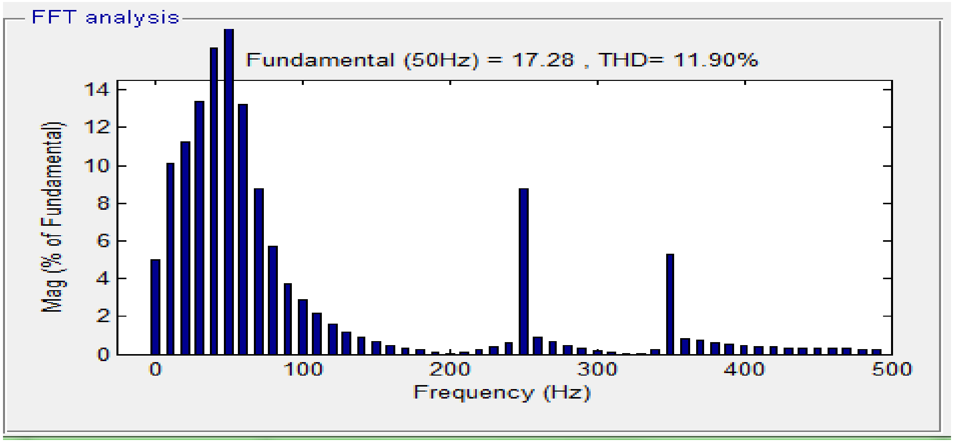

Figure.11 THD analysis for input current of rectifier

The simulink model of C-type filter is shown in Figure.9. Figure.10 shows the input current of rectifier. The rectifier input current spectrum is shown in Figure.11 which has the total harmonic distortion of 11.90%. From eqn (20) the interharmonic family is obtained to be $2f_{out}\pm f_{in}$. The inverter output frequency is f_{out} (i.e) 40Hz. So the dominant interharmonic will occur at the frequencies of 130Hz and 30Hz. Magnitude of these interharmonics are13.35% and 1.20%.

C. Matlab model with AC choke

The AC choke include one resistor and one inductor. This resistor and inductor can be varied to mitigate interharmonics. The inductance rating can be obtained by trial and error method.The parameter of the AC choke are R=3mohm, L=400uH. By increasing the value of inductance in the AC choke interharmonics are mitigated. Usually the inductance value is found in the range between 0.2 to 7mH. The disadvantages such as voltage flicker, sub synchronous oscillation, high distortion in the current waveform occurs if the inductance value exceeds 7mH.

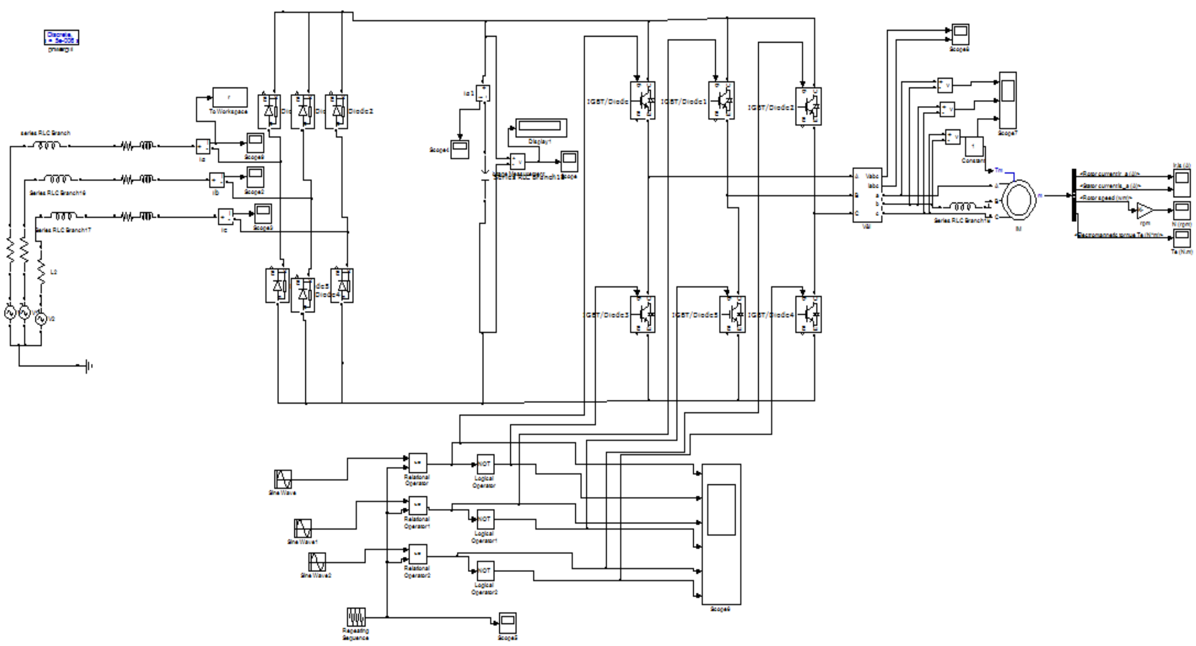

Figure.12 Matlab model for AC choke

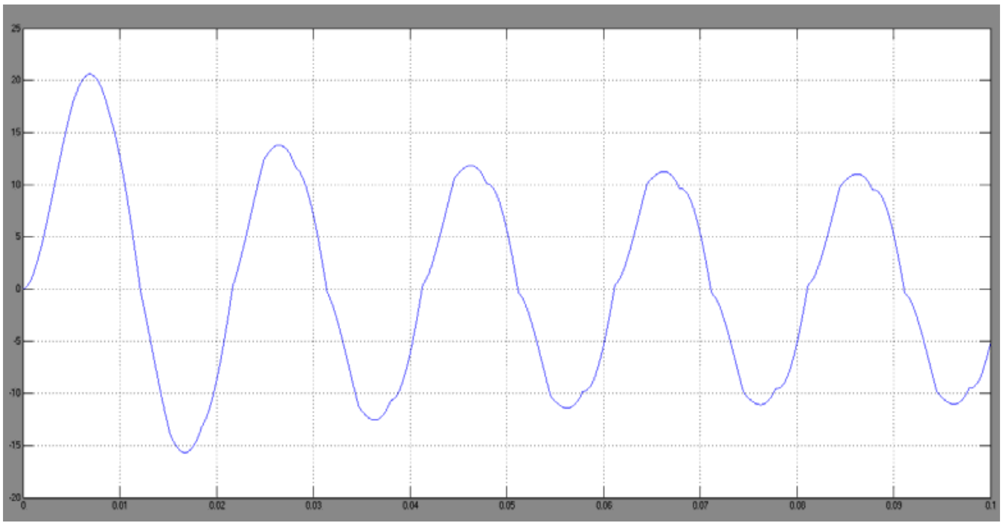

Figure.13 Rectifier Input current

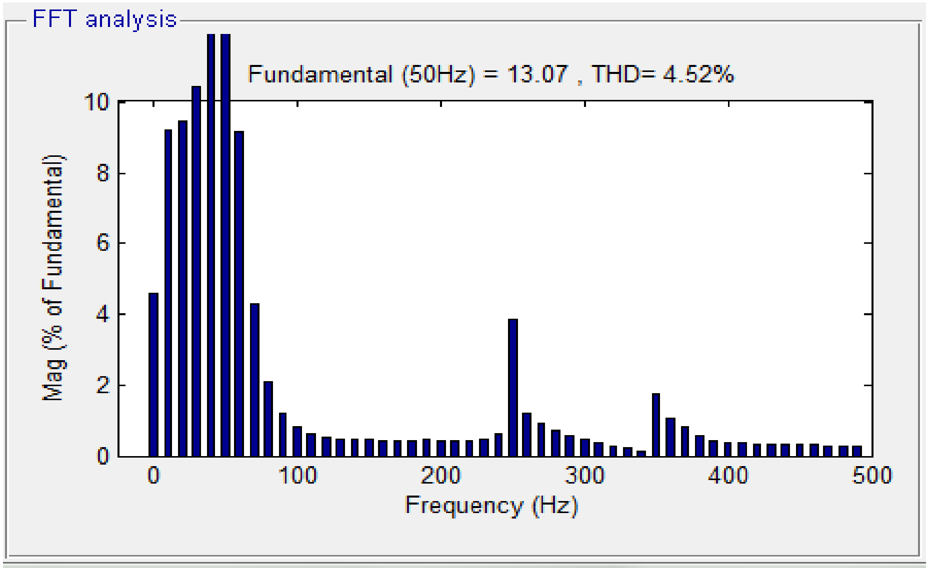

Figure.14 THD Analysis of input current of rectifier

The simulink model of AC choke is shown in Figure.12. Figure.13 shows the input current of rectifier. The rectifier input current spectrum is shown in Figure.14 which has the total harmonic distortion of 4.52%. From eqn (20) the interharmonic family is obtained to be $2f_{out}\pm f_{in}$. The inverter output frequency is f_{out} (i.e) 40Hz. So the dominant interharmonic will occur at the frequencies of 130Hz and 30Hz. Magnitude of these interharmonics are 8.07% and 0.31%. Comparision of all the magnitudes of interharmonics at 30 Hz and 130 Hz are tabulated in V.

V. Magnitude of Interharmonics current in the rectifier input current

Disturbed Current (Irecti)	**Interharmonic Frequency**	**Magnitude of Interharmonic**
Without filter	**30Hz** **130HZ**	**14.11%** **1.45%**
with C-type filter	**30Hz** **130HZ**	**13.35%** **1.20%**
With AC choke	**30Hz** **130HZ**	**8.07%** **0.31%**

The simulation specifications of the VSI fed ASD are given below

Supply Input voltage (V)	220V
Supply frequency (f_i)	50Hz
Modulation Index (m_i)	0.95
Carrier frequency for SPWM	10kHz
Reference frequency of SPWM	40Hz
Rated Input Power of Induction Motor	2.3kw (3 Hp)
Speed of the Motor (N_m)	1200 rpm
Output frequency of the Inverter (f_o)	40Hz
Value of the inductance which creates interharmonics (L)	0.12mH

1.1 Tabulation

VI. Conclusion

This paper analyses the generation of interharmonics in variable speed drives due to motor current imbalance. It is shown theoretically and in simulations that a considerable quantity of interharmonics are produced in the input currents when the motor current is imbalanced. These interharmonics are mitigated by the C-type filter and AC choke. The proposed model is simulated in the MATLAB/SIMULINK. The AC choke is the most efficient filter for mitigation of the harmonic and interharmonic because the magnitudes of the intherharmonic at the dominant frequencies are greatly reduced.

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