Mitigation of Harmonics and Inter-harmonics in VSI-Fed Adjustable Speed Drives

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Abstract **– The components of harmonics are integral multiple of the fundamental component and the components of inter-harmonics are are non integral multiple of the fundamental component. AC-DC-AC conversion systems used in variable speed drive are sources of inter-harmonics. There are several reasons for inter-harmonic generation in variable speed drives. In this paper, the generation of inter-harmonics in the supply side due to indirect frequency converter is considered. A passive filter is designed to mitigate harmonics and inter-harmonics. The accuracy of the proposed method is verified using the simulation tool of PSIM. Simulated results of VSI-fed induction motor with the proposed filter prove the effectiveness of mitigation.**

Keyword — Inter-harmonics, harmonics, adjustable speed drives, passive filter, and series reactor

I. INTRODUCTION

Adjustable speed drives are widely used in various industries. Usually adjustable speed drives make use of cycloconverters or AC-DC-AC conversion systems which is also known as interlinked or indirect frequency converter. Interlinked frequency converters are sources of inter-harmonics. The load current components are present in the dc link which provides a kind of decoupling between the supply frequency and load frequency. The propagation of load current components into the dc link and hence to the supply side results in inter-harmonics. These inter-harmonics do not have fixed frequency but vary with the load frequency [1].

Inter-harmonics cause problems such as oscillations at low frequencies in mechanical systems, interference of this component with control and protection signals, flickering of light even at low amplitudes [2].

In this paper, the generation of inter-harmonics in the supply side due to indirect frequency converter is discussed. The presence of inter-harmonics is analyzed by considering sinusoidal pulse-width-modulated (PWM) inverter at a load frequency of 30Hz. Then suitable mitigation methods are suggested for reducing the inter-harmonics.

II. DESCRIPTION OF THE SYSTEM

The two-stage conversion system is as given in Fig. 1. It has an induction motor fed from a rectifier and an inverter using PWM technique [3].

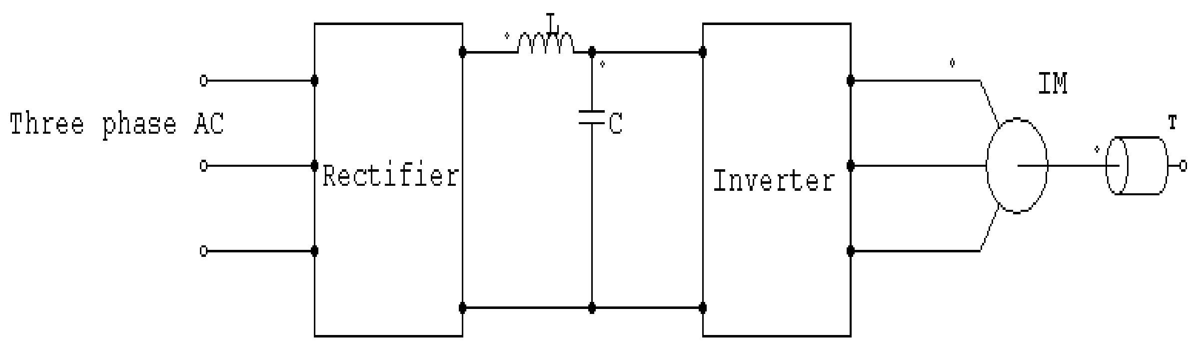


Fig. 1

A. Diode bridge rectifier

It is employed as a supply side converter for the Voltage Source Inverter fed Adjustable Speed Drive (ASD). The dc link capacitor use is large and is employed to reduce the ripple in the dc voltage. Fig.2 shows the commonly used rectifier.

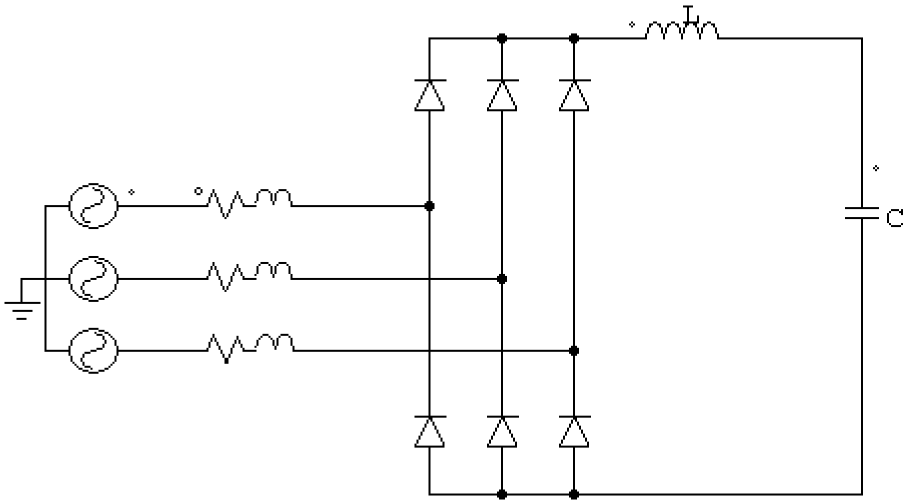


Fig.2

B. PWM inverter

The inverter has six switching devices. Any one type of the switching devices like IGBT, MOSFET can be used. The same leg devices should not conduct at the same time to prevent shoot-through fault. Fig.3 shows the commonly used inverter (modeling VSI-fed ASD). In PWM, the output pulses are produced by comparing a reference signal with a carrier waveform. Sinusoidal PWM technique is used in this work. The inverter input current has harmonics and is reflected into the dc link. This results in non-characteristic components in the supply (impedance based approach). The source current has harmonics with frequencies that are the sum and difference of the source and inverter harmonic frequencies. The inter-harmonic characteristic is given by the following expression.

$$f_{ih} = |(p_1 m \pm 1) f_1 \pm p_2 n f_2| \quad m = 0,1,2,\ldots ; \quad n = 1,2,3,\ldots$$

f_{ih} – inter-harmonic frequency of the source current
p_1 - number of pulses of the rectifier
p_2 - number of pulses of the inverter
f_1 – fundamental frequency of the supply
f_2 - fundamental frequency of the load

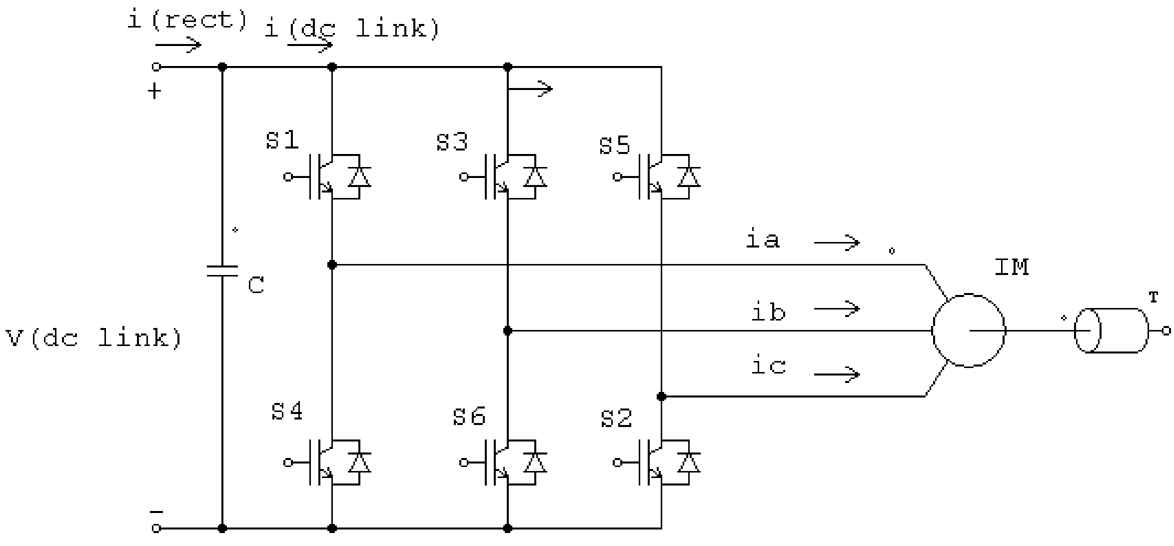


Fig.3

III. SIMULATION RESULTS

Adjustable speed drive discussed above is shown in Fig.4 and simulated in PSIM. All paragraphs must be indented.

A. *Simulation Without Mitigation Methods*

The input current inter-harmonic is analyzed using Fast Fourier Transform. The simulated results are shown in Fig.5 for f_2 = 30Hz.

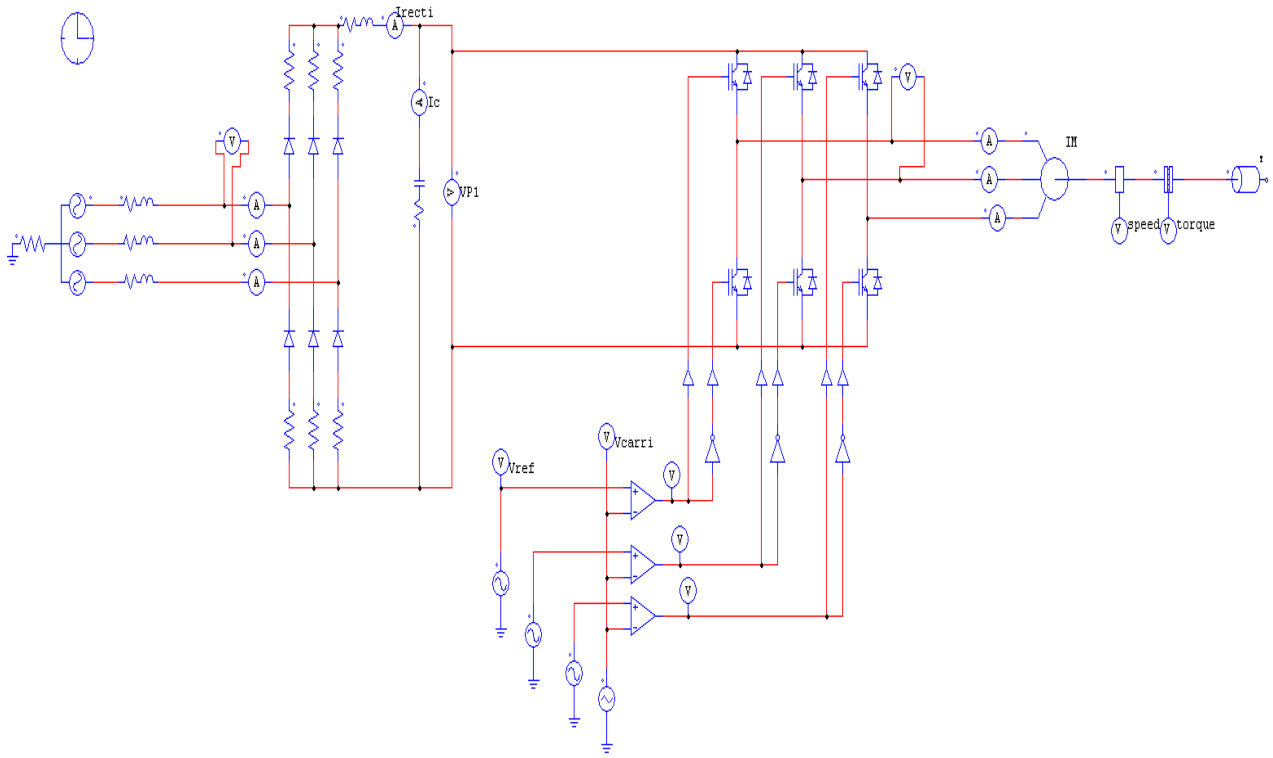
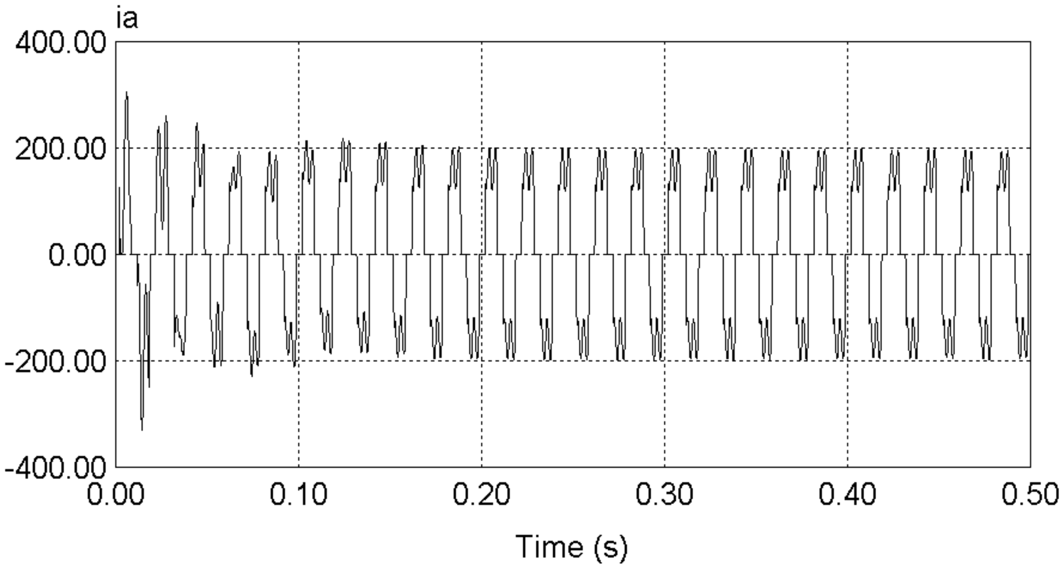
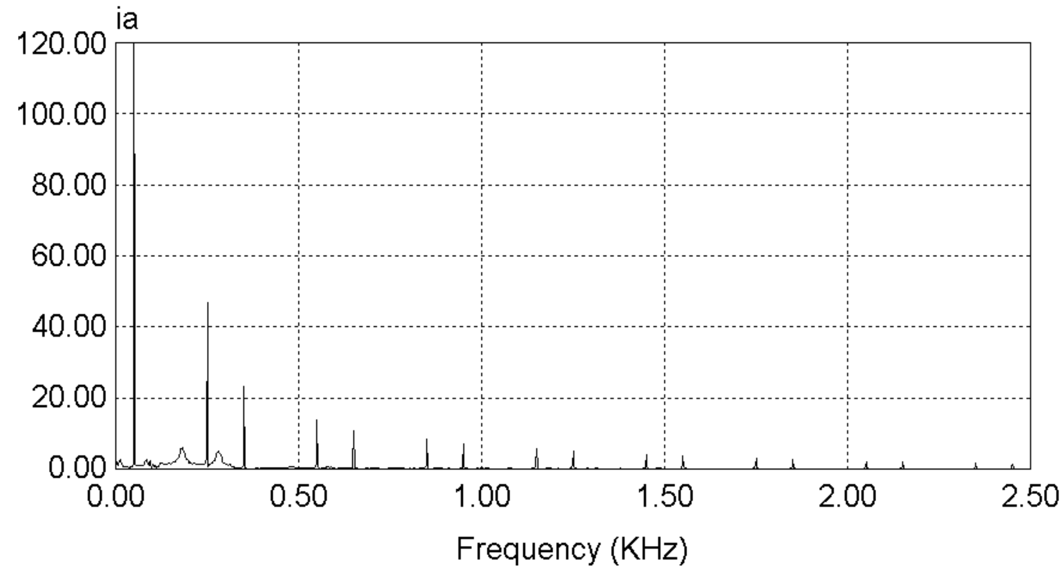


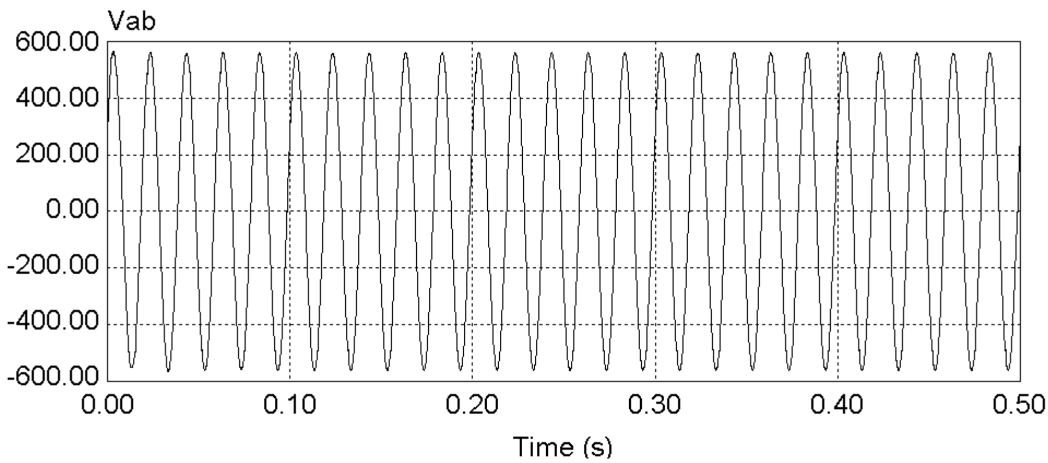
Fig.4



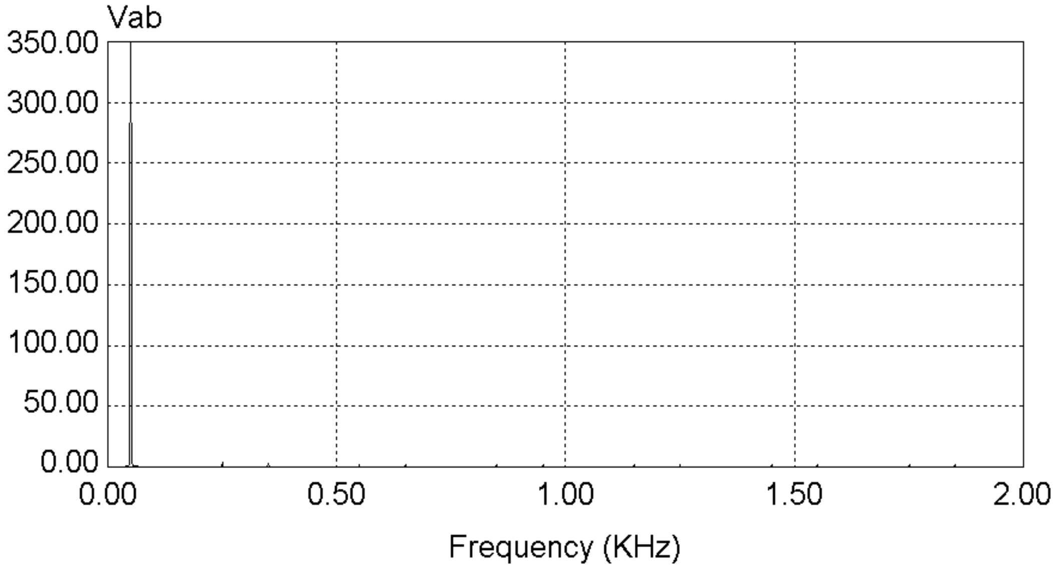
a) Rectifier input current



b) Rectifier input current spectrum



c) Rectifier input line voltage



d) Rectifier input line voltage spectrum

Fig.5

Fig.5 (b) shows the spectrum of rectifier input current. This current has harmonic components. In between harmonic components, there exist frequency components which are non integer multiples of the supply fundamental frequency components. Such components occur as supply and the load operating frequencies are different. Even though their magnitudes are low, they cause problems such as voltage flicker, temperature rise etc. So it is necessary to mitigate inter-harmonic components.

B. *Mitigation Methods*

1) *Series inductor*

A suitable line reactor may be connected in series in the input side to reduce the inter-harmonics [4]. Usage of line reactors for suppression of harmonics and inter-harmonics are simple and low cost method. Apart from reducing inter-harmonics, they absorb voltage transients which may cause unnecessary tripping of the VSD during over voltage. A suitable value of the reactor is selected using trial and error method and the system is simulated in PSIM software. The simulated circuit is shown in Fig.6 and results are given in Fig.7.

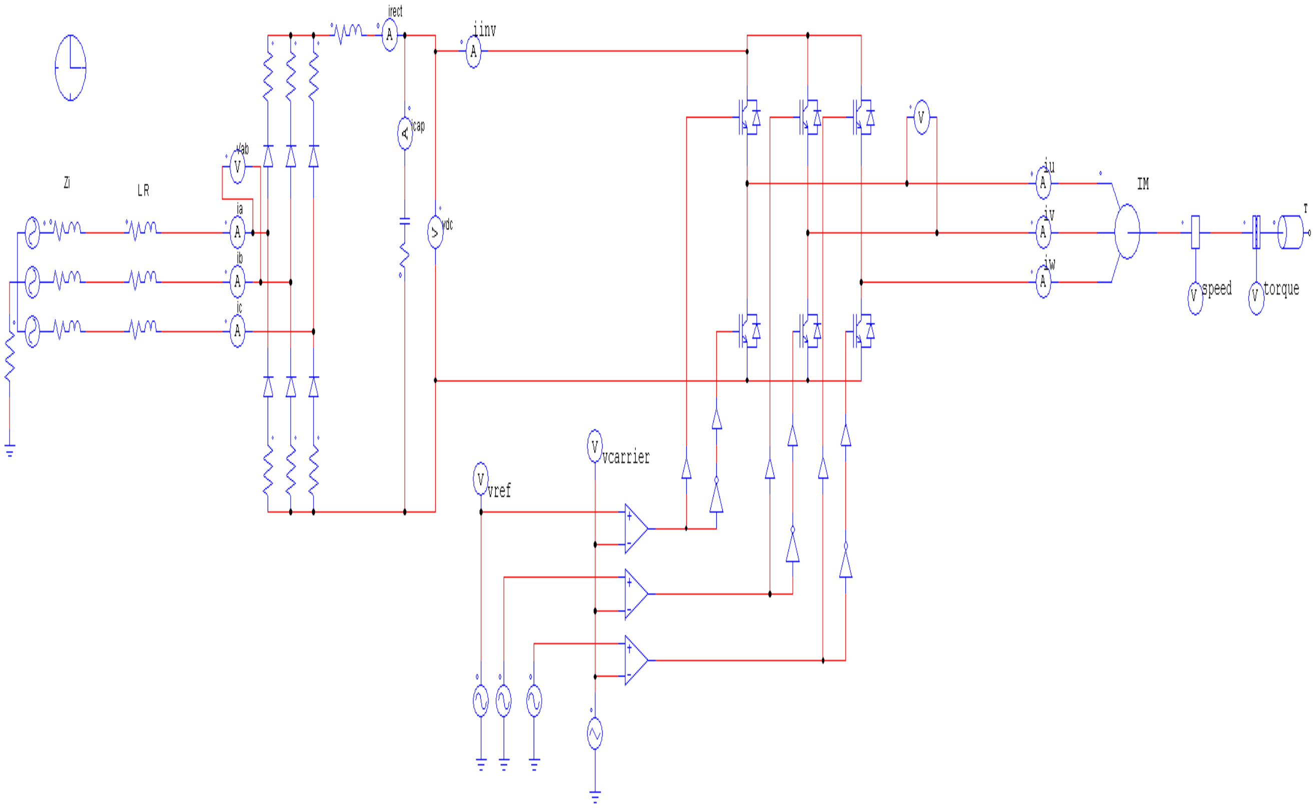
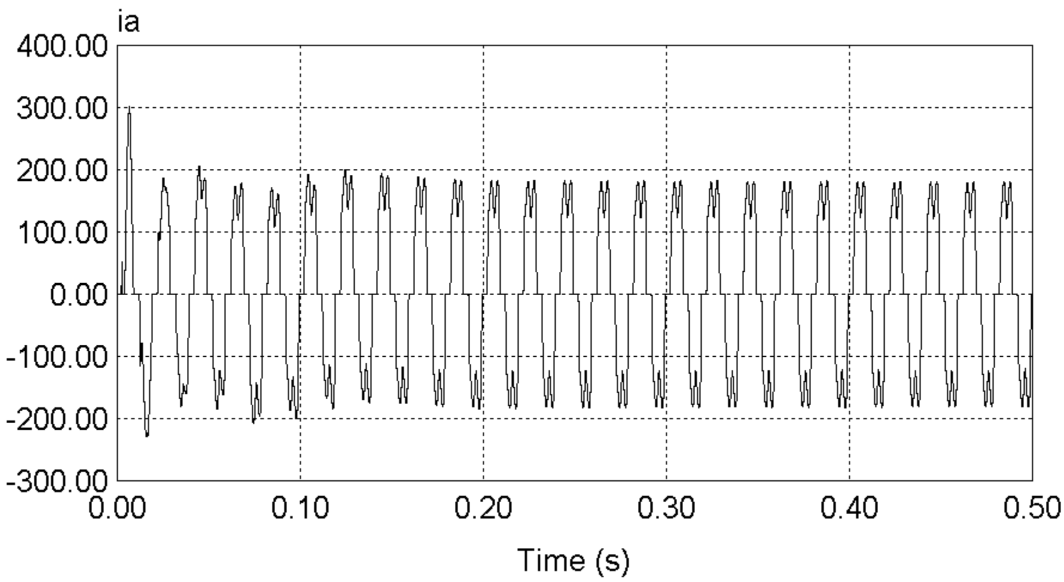
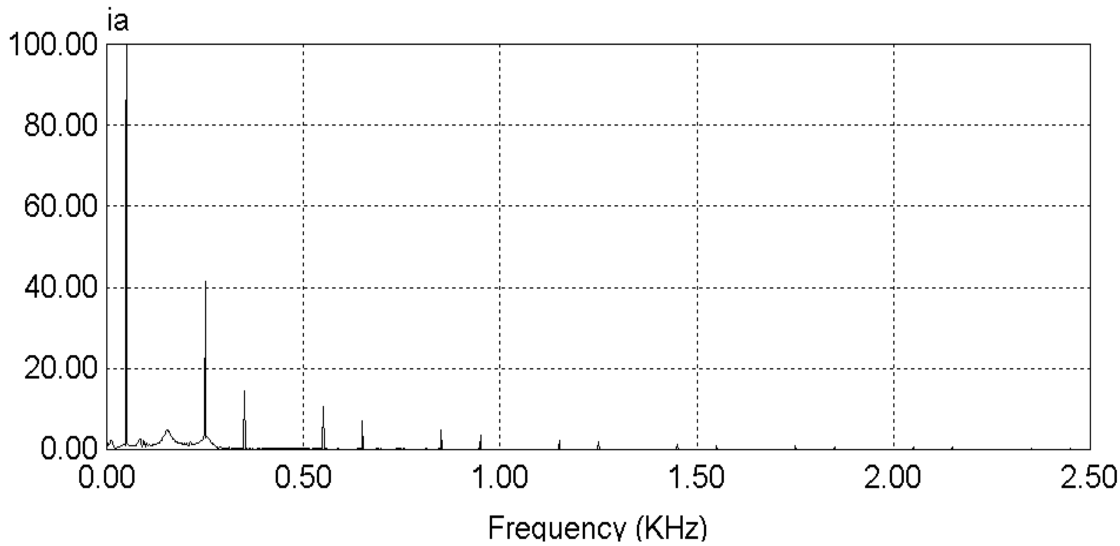


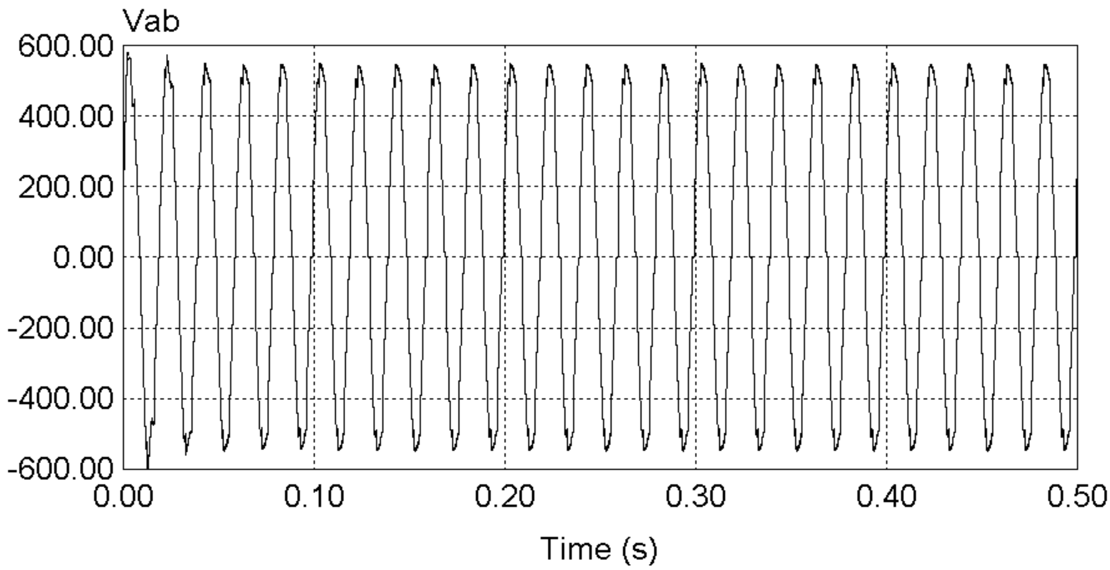
Fig.6



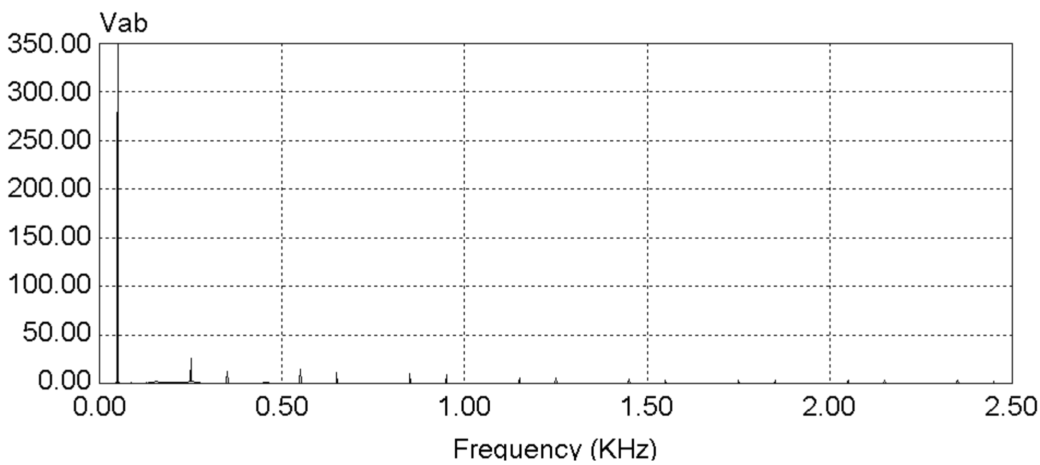
a) Rectifier input current



b) Rectifier input current spectrum



c) Rectifier input line voltage



d) Rectifier input line voltage spectrum

Fig.7

A line reactor 0f 200μH is connected in series. This value of line reactor is selected considering voltage distortion. The current spectrum of the rectifier input current is shown in Fig.7 (b). The inter-harmonic that appears between fifth and seventh harmonic amplitude is reduced.

2) Low pass filter

3) A low pass filter connected in the input side reduces harmonics [4]. Usually a low pass filter consists of one or more series elements and a set of tuned elements. The series element increases the effective input impedance thereby reducing the overall harmonic content in the supply current [4]. The shunt element is tuned to reduce the other dominant harmonic components from the source current. In this work, two series elements with the shunt element tuned at fifth harmonic component is employed [5]. A typical low pass filter is shown in Fig.8. The simulation work is carried out in PSIM software. The simulated circuit is shown in Fig.9. The corresponding results are shown in Fig.10. Parameters of the single tuned element in the low pass filter are given below.

R_s = 1.014Ω, L = 0.0129H, C = 1.256μF

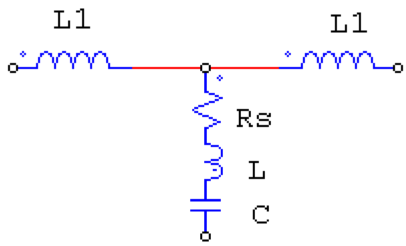


Fig.8

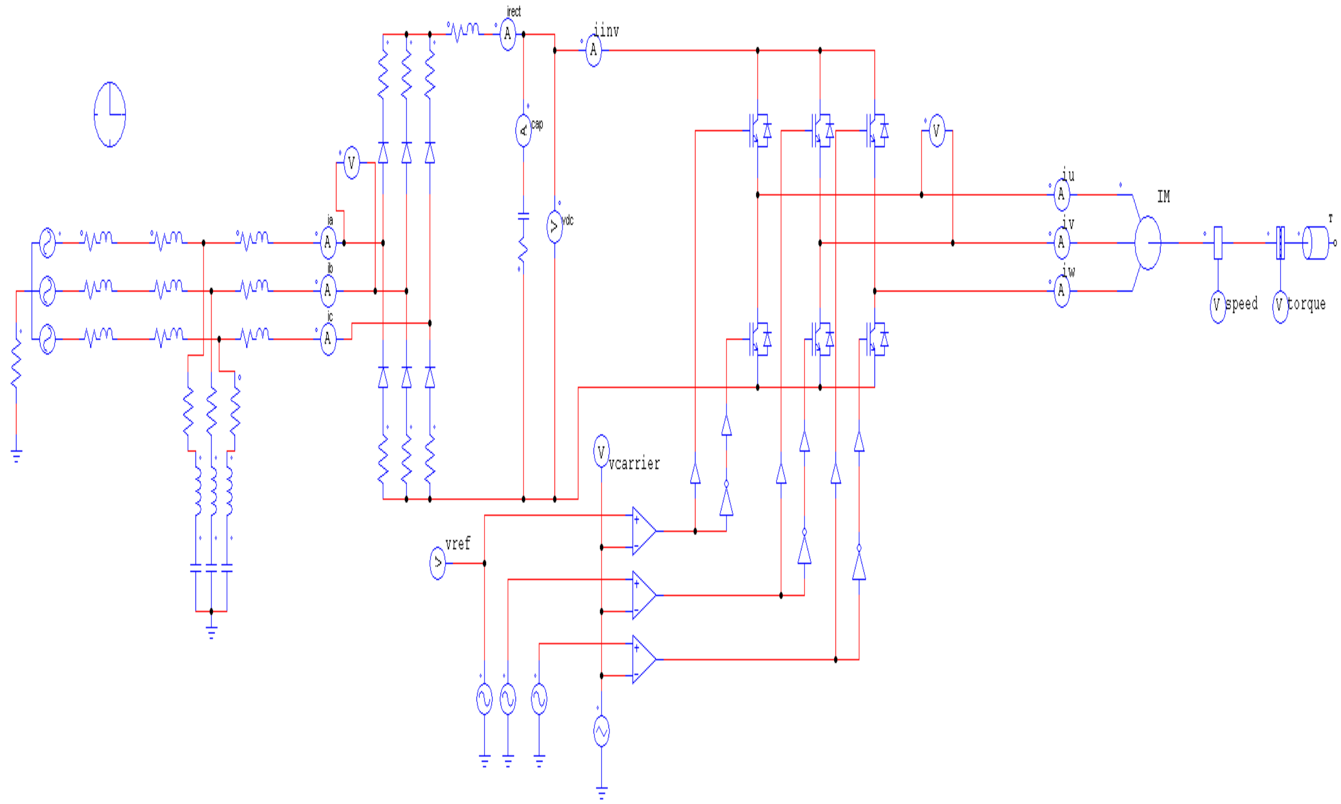
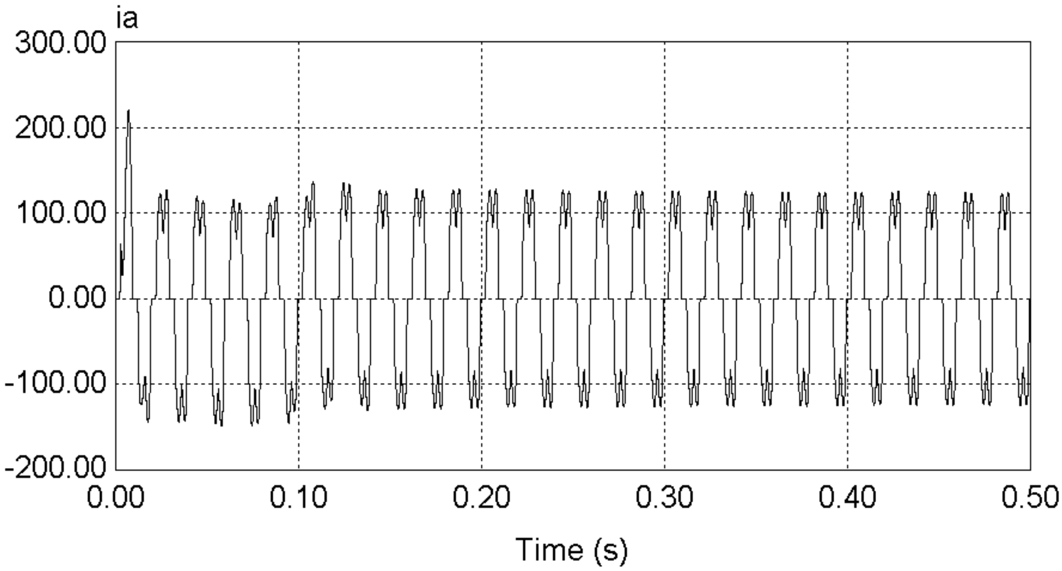
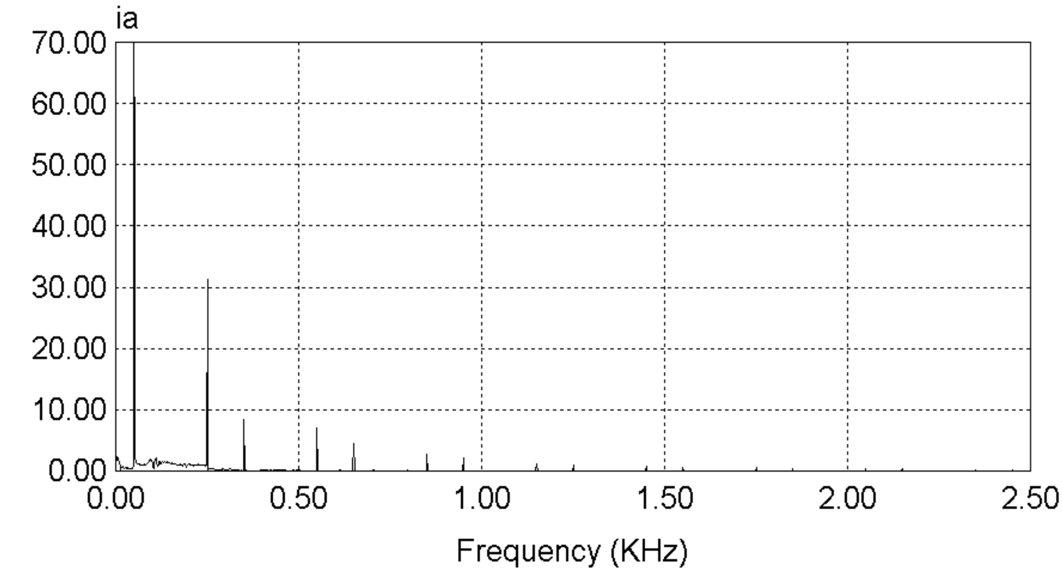


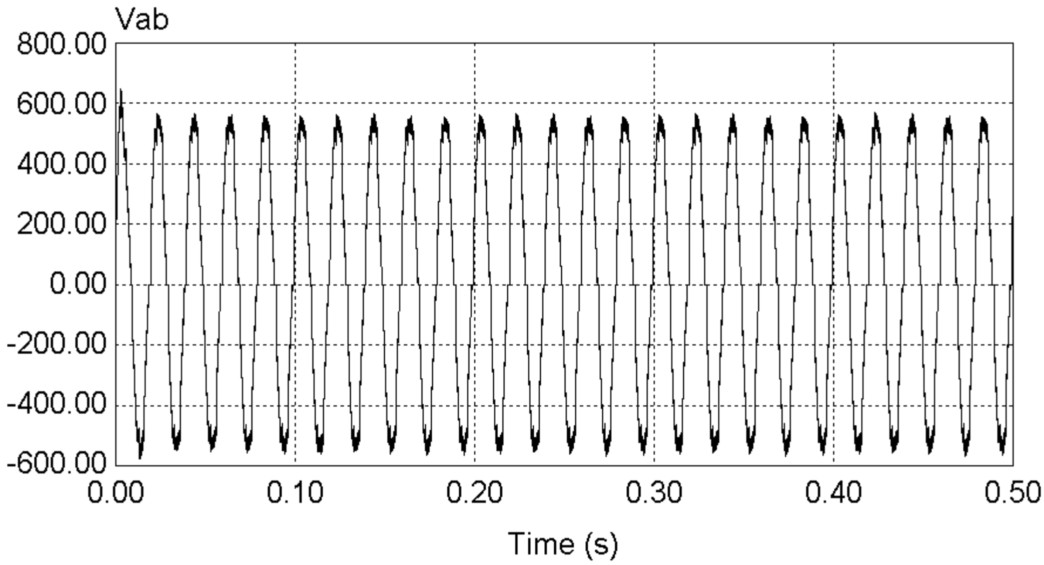
Fig.9



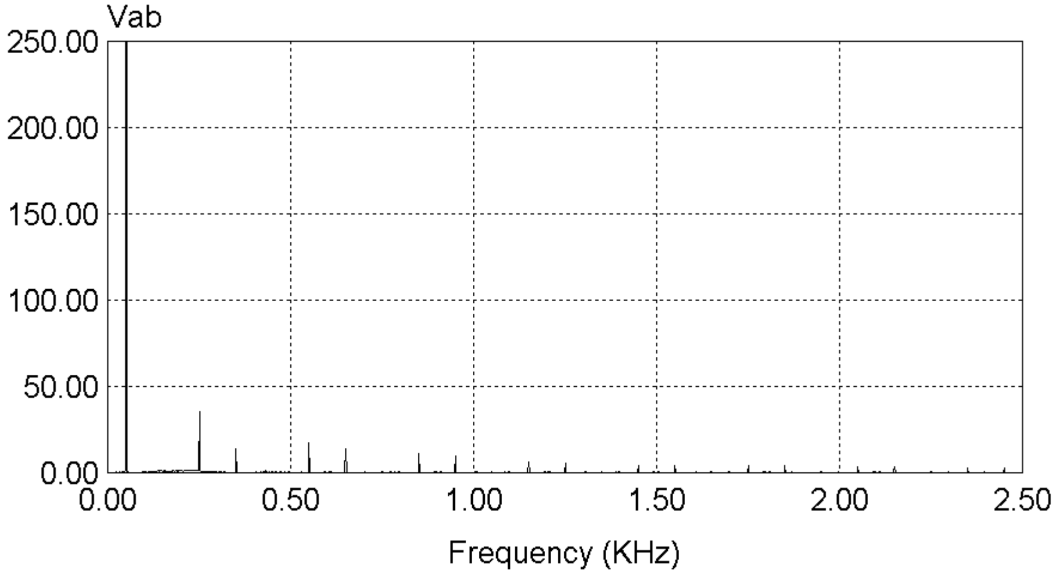
a) Rectifier input current



b) Rectifier input current spectrum



c) Rectifier input line voltage



d) Rectifier input line voltage spectrum

Fig.10

Fig.10(b) gives the rectifier input current spectrum. This shows that the inter-harmonics between fundamental component and the fifth harmonic component are reduced considerably. Also because of the single tuned element tuned at fifth harmonic component, fifth harmonic component magnitude is reduced. This gives a better current spectrum. The distortion in the voltage is also within limits.

IV. CONCLUSIONS

The inter-harmonics in the input current of ASD is analyzed. As the operating frequency of the load is different from the supply frequency, the input current has harmonics and inter-harmonics. Suitable mitigation methods are suggested and simulation results are discussed. The use of line reactor and low pass filter give better supply current. The passive filters are low cost mitigation methods.

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