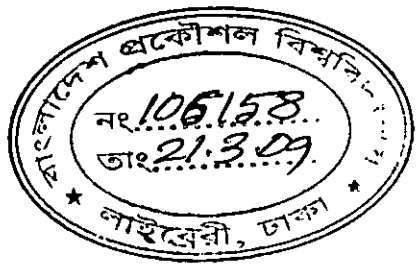
CHARACTERIZATION OF INPUT CURRENT RIPPLE OF A THREE PHASE PWM INVERTER



By

SEHELA SIDDIQUA

A THESIS SUBMITTED TO THE DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING OF BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

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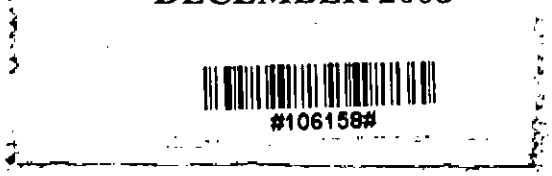

APPROVAL

The thesis entitled "**Characterization of Input Current Ripple Of a Three Phase PWM Inverter**" submitted by Sehela Siddiqua, Roll No. 040306105p, Session April 2003 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of **Master of Science in Electrical and Electronic Engineering** on December 2008.

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LIST OF ABBREVIATION

SMPS	=	Switch Mode Power Supply
PWM	=	Pulse Width Modulation
THD	=	Total Harmonic Distortion
EMI	=	Electromagnetic Interference
DSP	=	Digital Signal Processing
UPS	=	Uninterrupted Power Supply

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ABSTRACT

Static power converters operate in switch mode. As a result their output voltage/s and input current/s are normally nonsinusoidal. To achieve desired waveshapes filters are normally used. Using proper filters require study of voltage and current waveshapes of static converters. Most used static power converter is the PWM inverter, particularly the three phase PWM inverter. Three phase PWM inverters can have pure dc input or maybe rectifier fed. In this thesis work the input currents of PWM inverters with dc and rectifier input has been studied. This is necessary because the input current harmonics are detrimental to power apparatus and lines in terms of losses and over sizing (increasing cost and space) of equipment. Conventional input current synthesis is done by vigorous nonlinear equation solution involving numerical methods. Presently softwares are available to study various aspects of electronic circuits. This research involves simulated study of input current synthesis of three phase inverter currents and proposes techniques to improve the same.

With the help of filter the ripple of the input current can be eliminated, but it requires a large filter. To reduce the size of the filter, intermediate SMPS circuit can be used. Additions of these circuits still have some harmonic components. Using harmonic filter the ripple of the input current can almost be eliminated. Pure DC or AC input current can reduce the supply side losses and increase the efficiency of the power source. With the characterization of input current ripple of a three phase PWM inverter it will be possible to make an effective power converter to be used for regular appliances.

In this thesis work input current synthesis of conventional three phase and immerging three phase inverter with dc and rectifier input has been carried out. Intermediate state SMPS circuit has been proposed to reduce the filter sizes to obtain acceptable input current. Harmonic filter addition is also proposed to get further improvement of the input current. The study and results obtained thus show significant improvement of input current shapes than those obtained by conventional filtering techniques.

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Chapter-1

Introduction

1.1 Introduction

Availability of high power high frequency static switches made possible solid state converters to operate at high frequency. Without any output and input filters, the voltage and currents of static power converters contain harmonics other than desired waveforms. To obtain desired waveforms it is necessary to incorporate filters of necessary size at output and input sides of any static power converter. Input side filter is particularly necessary to shape the current waveform to desired dc or ac, so as to avoid extra power losses in the supply side [1-6].

In modern appliances the power comes from the output of inverters. It is very common to get AC supplies by inverting the output of a rectifier. DC to AC conversion is done by inverter circuits followed by filter. Inverters are nonlinear blocks and hence generate harmonics. Harmonic currents are injected into the ac power lines/ transformers/ sources. The non-sinusoidal shape of the input currents drawn by the inverters causes problems for the power distribution network and for other electrical systems in the vicinity of the rectifier such as,

1) Phase displacement of the current and voltage fundamentals causing increase of reactive power;
2) Input current harmonics and low input power factor;
3) Lower inverter efficiency because of larger r.m.s. value of the input current;
4) If the source is not stiff voltage wave gets distorted;

5) Heat loss due to I^2R drop in wire and eddy-current loss and core loss in machines having ferromagnetic materials increases;
6) Excitation of system resonance at its natural frequency;
7) The inefficient use of electric energy by the bridge rectifier results in high total harmonic distortion (THD) in the input lines and
8) Malfunctioning of the sensitive electrical equipments may take place due to harmonic EMI interference.

As a result, development of inverters with improved waveforms has gained importance due to stringent power quality regulation and strict limit on total harmonic distortion (THD) of input current placed by standards such as IEC 1000-3-2 and IEEE519-1992 [7-9].

Conventional medium and large power ac-dc-ac inverters consist of three-phase rectifier, filter and three-phase inverter. In DC-AC conversion itself the inverter input current is non-dc due to switching of inverter switches. In dc-ac inverters preceded by rectifier, the source is ac and due to dc output filter rectifier the input current is not sinusoidal. In both cases the input currents may be filtered passively to desired dc or ac current with large L and Cs. However, the active filtering approach may reduce the filter size drastically due to high frequency switching between rectifier and inverter section.

Another way is to obtain dc-ac is by ripple cancellation of two back to back switching dc-dc converters. The pulse width modulation (PWM) control is the most commonly used control scheme for voltage source

inverters [10-14]. For PWM control, a sinusoidal reference voltage waveform is compared with a triangular carrier voltage waveform to generate gate signals for the switches of the inverter. A ripple free dc voltage source is needed since the fundamental amplitude and frequency of the inverter output voltage is directly related to the sinusoidal reference voltage and triangular carrier signals. Usually, an ac-dc bridge rectifier with an electrolytic energy storage capacitor as a filter is used to provide the dc voltage source for the dc-ac inverter. Similar to conventional inverters in these types of inverters the use of the energy storage capacitor filter can cause a poor power factor and high harmonic currents of the ac power line [15-16]. In order to obtain a high power factor and low harmonic distortion of the ac power line, a complex and expensive active filter is needed for the rectifier.

The choice of input side filter depends on the ripples of the input current of a particular converter. The ripple is a repetitive waveform refers to the difference between the instantaneous values of the actual waveform and its desired component. The dc or fundamental ac component and the ripple component in a waveform can be separated by applying the principle of superposition to the circuit in study [17-19]. High frequency switching results in a substantially smaller peak ripple current component compared to switching at lower frequencies [20]. However, high frequency switches cause higher switching losses.

1.1.1 Literature review

The ripple of the input current of a power converter is the difference between instantaneous value of the waveform and its desired waveform.

In a three-phase PWM Inverter, only the fundamental frequency component of the voltage and the fundamental frequency component of the current are responsible for real power transfer from input to the output. Since the types of converters are many, in this research a study and analysis is intended on three-phase pulse width modulated inverter only. Pulse width modulated inverter is a dc-ac or ac-dc-ac converter having ac as output with adjustable voltage and frequency.

1.1.2 Inverters

The main objective of static power converter is to produce an ac output waveform from a dc power supply. These are the types of waveforms required in adjustable speed drives (ASDs), uninterruptible power supplies (UPS), static var compensators, active filters, flexible ac transmission systems (FACTS) and voltage compensators, which are only a few applications. For sinusoidal ac outputs, the magnitude, frequency and phase should be controllable. According to the type of ac output waveform, these topologies can be considered as voltage source inverter (VSIs), where the independently controlled ac output is a voltage waveform. These structures are the most widely used because they naturally behave as voltage sources as required by industrial applications, such as adjustable speed drives (ASDs), which are the most popular application of inverters. Similarly these topologies can be found as current source inverter (CSIs), where the independently controlled ac output is a current waveform. These structures are used in medium-voltage industrial applications, where high quality voltage waveforms are required.

Static power converters, specially inverters, are constructed from power switches and the ac output waveforms are therefore made up of discrete values. This leads to the generation of waveforms that feature last transitions rather than smooth ones. Although this waveform is not sinusoidal as expected, its fundamental component behaves as such. This behavior should be ensured by a modulating technique that controls the amount of time and the sequence used to switch the power valves on and off [5].

1.1.3 Pulse Width Modulation

Pulse-width modulation (PWM) of a signal or power source involves the modulation of duty cycle, to convey information over a communications channel or to control the amount of power sent to a load. Pulse-width modulation uses a square wave whose pulse width is modulated resulting in the variation of the average value of the waveform. PWM is also often used to control the supply of electrical power to another device such as in speed control of electric motors, volume control of Class D audio amplifiers or brightness control of light sources and many other power electronics applications [21].

For inverter control PWM gate pulses may be generated either by analog methods or by digital (micro controller or microprocessor based) methods. Presently the later method prevails. There are a large number of approaches that generate sinusoidal PWM with a microprocessor (or DSP). The simplest and most common method is to mimic analogue comparator based PWM generation by comparing the value from a sinusoidal lookup table with a triangular chopping wave (typically just an up/down counter) and thus generate a sinusoidal PWM output

directly. The ease of this method is that the amplitude of the chopping wave or sinusoid (and hence PWM width) can be easily varied by changing registers in the microprocessor and thus a simple adaptive system can be implemented [22].

Another method researched is the use of a random number comparison with the modulating sinusoid [23]. In this case, the modulating sinusoid is compared with a random number generated by the microprocessor instead of the switching triangular wave. The reason for this is that in standard sinusoidal PWM, the output is made up of a fundamental component and a significant high frequency component. This limits the converters effectiveness in terms of interference and EMI. By using random number generation, the high frequency component is spread out over a wider spectrum so that no component has significant magnitude [23]. Complicated coding and high speed switching requirements limit the use of this technique.

1.1.4 Inverter Line Filters

Line filters reduce the high frequency harmonic contents of the line current caused by the switched operation of inverters. Usually, the line filter consists of filter inductors and other combinations of capacitors and inductors such as LC- or LCL, etc.

The L-filter is a first-order filter. Its attenuation is 20 dB/decade over the whole range of frequency. Using this filter, the switching frequency of the converter has to be high to obtain sufficient attenuation of the harmonics caused by the PWM converter.

The LC-filter has been investigated especially in systems using UPS where the loads are resistors in most cases [24]. However, when

connecting systems with this filter to a public grid, the resonance frequency varies over time like the inductance value of the grid.
The passive filter design depends on the attenuation needed in order to reduce the high frequency component of the line current. Standards, such as IEC 1000-3-4 regulation on current harmonic emissions into the power grid, must be used to rate this attenuation. The IEC 1000-3-4 regulation states that current harmonics above the 33rd should be less than 0.6% of the nominal current [25].

1.1.5 Active Filtering of Converter Waveforms

Active filtering involves high frequency switching of converter output so as to make input current high frequency switched one which can be filtered by small passive filter. A three-phase rectifier based on Boost topology has been proposed in [26]. In this work active switching PWM has been used to improve the input side current of a diode rectifier. A single stage push-pull Boost converter has been proposed in [27]. The proposed structure includes a Boost inductor, coupling capacitor and a capacitor network, a step-down transformer and four diodes for switching. An active power factor correction technique for three phase diode rectifiers has been proposed in [28].

Three-phase PWM Buck-Boost rectifier has been proposed in [29]. This structure can process both inversion and rectification function. Here gate pulses are generated by zero voltage space vector realization to control the switching element. A novel high performance voltage regulator for single-phase ac sources has been presented in [30]. It offers both rectification and inversion facility in the same circuit. An ac voltage

regulator based on Buck-Boost conversion principle has been proposed in [31]. The ac Buck-Boost regulator has the ability to regulate the output voltage to desired value.

The power factor correction of a diode bridge rectifier has been proposed in [32]. This rectifier uses duel slope delta modulation technique to generate gate pulses. An improved ac voltage regulator has been proposed in [33]. The proposed configuration can maintain constant output voltage at various input voltage and load. A unity power factor rectifier has been presented in [34]. The control scheme is provided for single phase Boost converter, where, power factor controller is independent of input voltage.

1.1.6 Switch Mode DC-AC Inverter

Probably the most important power converter topology is the conventional voltage source inverter (VSI). It is used in many distinct industrial and commercial applications. The most important among these applications are uninterruptible power supply (UPS) and ac motor drives. One of the characteristics of the buck converter is that the instantaneous average output voltage is always lower than the input dc voltage.

Reference [35] proposes a new voltage source inverter (VSI) referred to as a boost inverter or boost dc-ac converter. This new inverter topology has the fact that it generates an ac output larger than the dc input one, depending on the instantaneous duty cycle. The proposed boost inverter achieves dc-ac conversion by connecting the load differentially across

two dc-dc converters and modulating the dc-dc converter output voltage sinusoidal. The concept has been discussed in [36] and [37].

1.2 Objective of the Thesis

The objective of this thesis is to analyze and study the ways to reduce the ripple factor of the input current of PWM inverters so as to reduce supply side losses. In this thesis it is intended to use active filter combined with small passive filter to shape input current of PWM inverters. It is very important in inverter design, to know the average and rms currents in the switching devices and the rms value of the ripple component of the input current. The inverter switching devices cannot be specified properly without knowing the average and rms currents in inverter switching devices. Information on the rms value of the ripple component of inverter input current is also important to specify the ripple current rating of the dc filter capacitor.

The specific objectives of this thesis are to study the followings:

(a) The ripple of the input current of a PWM Inverter when the source is DC and no filter is used;
(b) The input current of an AC-DC-AC PWM inverter without input current filter;
(c) The cases of both (a) and (b) with input current filter;
(d) The input current of DC-AC and AC-DC-AC PWM inverter with Boost regulator without filter at the input side;
(e) The ripple of the input current of DC-AC and AC-DC-AC PWM inverter with Boost regulator having filter at the input side;
(f) The input current of a Boost DC-AC and AC-DC-AC inverter.

1.3 Outline of the Thesis

This thesis consists of four chapters. Chapter-1 is the introduction of the thesis that includes literature review of inverters, PWM techniques, inverter line filters, active filtering of static power converters and switched mode dc-ac inverter. Chapter-1 also describes in brief the objective of the thesis and provides the outline of the thesis.

Chapter-2 presents the study results of input current waveforms of a conventional 3phase PWM inverter with and without input current filter. This chapter also details the study of active filter with reduced input side passive filter for both dc-ac and ac-dc-ac inverters.

Chapter-3 presents the study of input current of a inverter schemes proposed in recent publications. The presentation provides input current simulation results for dc-ac and ac-dc-ac conversion with passive filter only.

Chapter-4 presents the conclusion on the thesis together with suggestions of future scope of the work.

Chapter-2

Input Current Filtering of Conventional Three Phase PWM Inverter

2.1 Introduction

In this thesis we have used linear resistive load to understand the presence of harmonics in the input current of a three phase inverter. The figures of this chapter are the results of the pspice simulation. Two situations, DC-AC conversion and AC-DC-AC conversion are considered in the study of this chapter.

2.2 Input Current of Three Phase DC-AC Inverters

When dc-ac conversion is done with an inverter, the input current should remain dc. The waveform and the spectrum of PWM inverter of Figure 2.1 with a pure dc source are shown in Figures 2.2 and 2.3. From these figures it is clear that the input current has harmonics.

In Figure 2.4 filter is added at the input side of the inverter to eliminate the unexpected harmonics. The input current ripple is reduced to a great extent. But the filter size is very big. The waveform of the input current and its spectrum is illustrated in Figures 2.5 and 2.6 respectively.

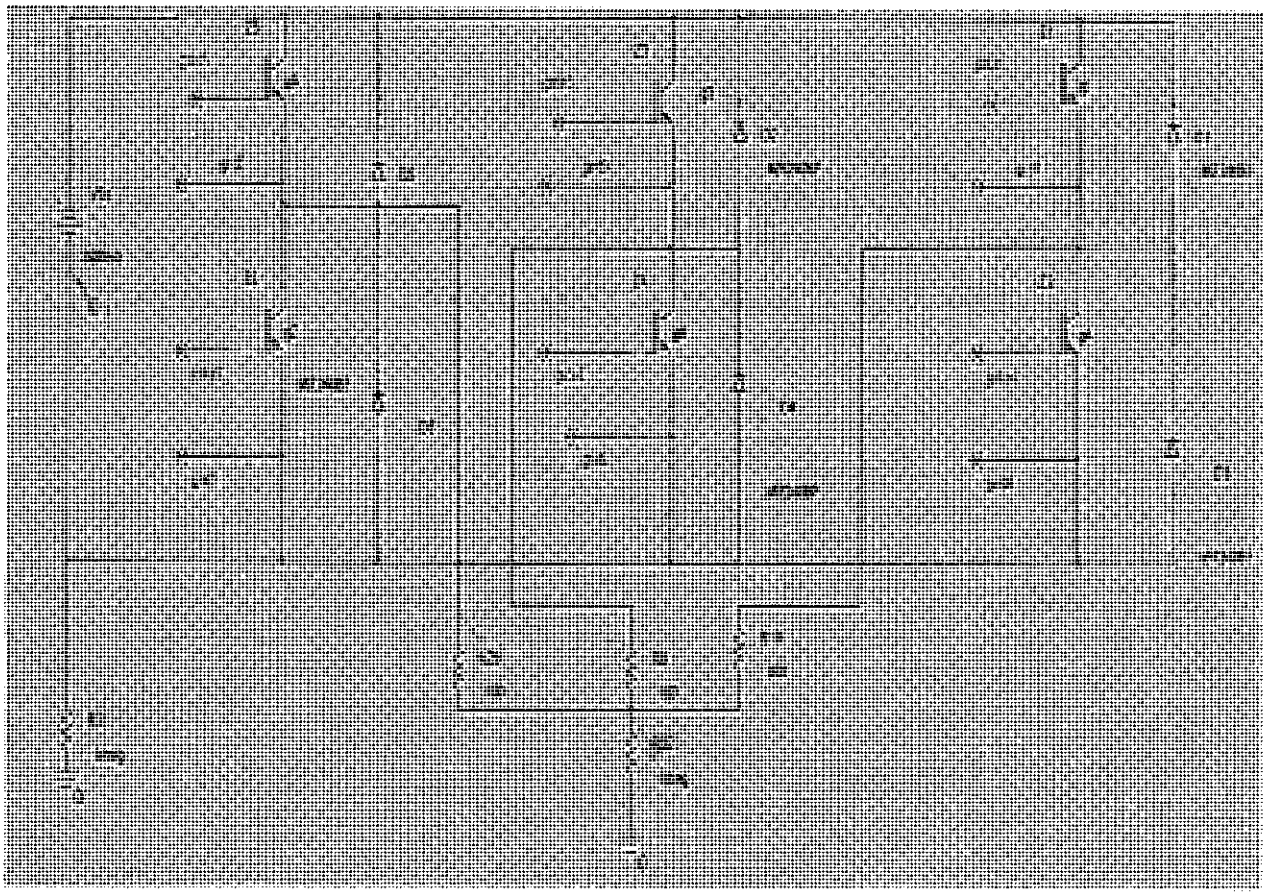
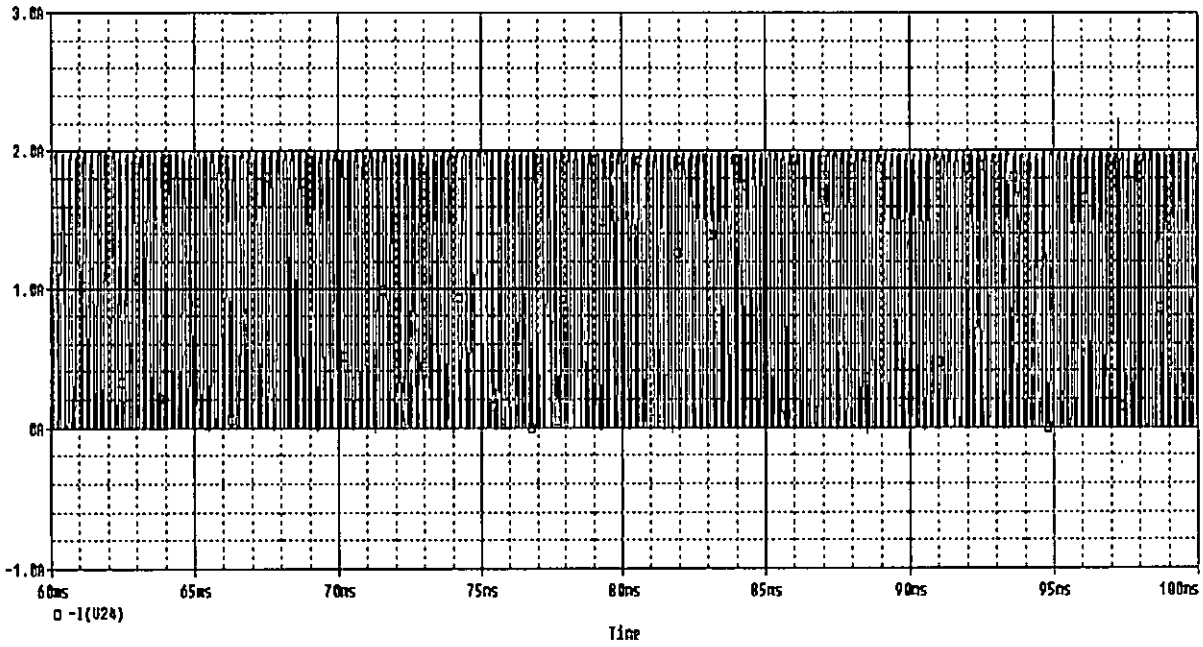
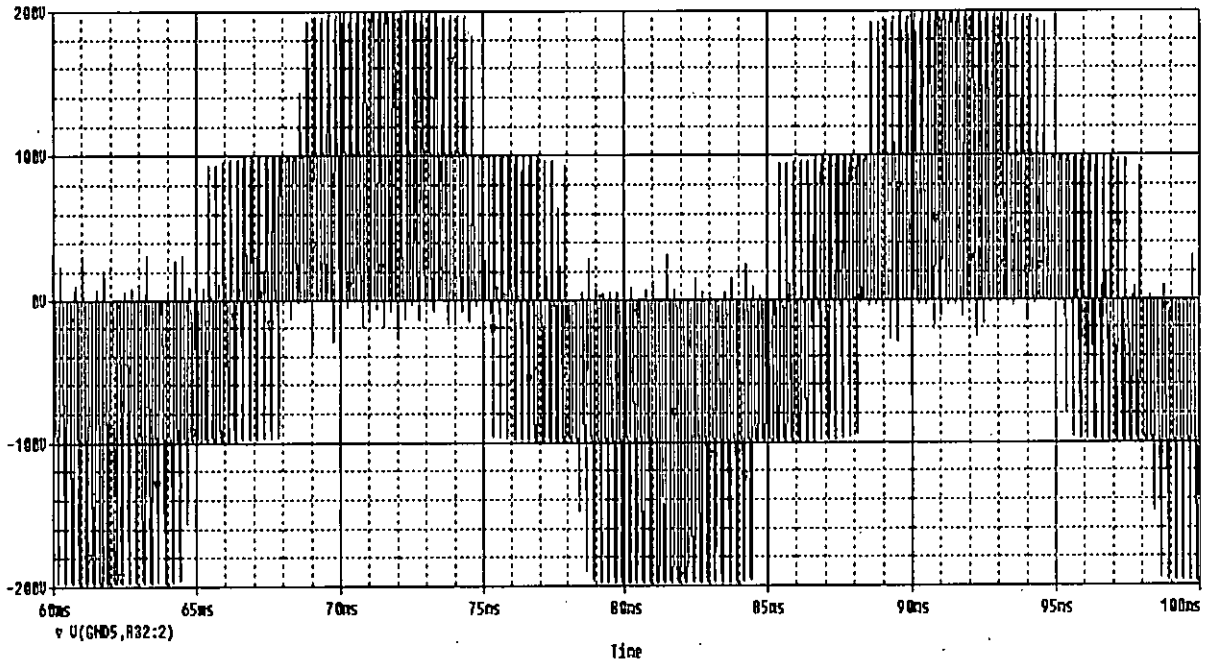


Figure 2.1: Three phase inverter (without input filter) with resistive load. (Input source is DC)

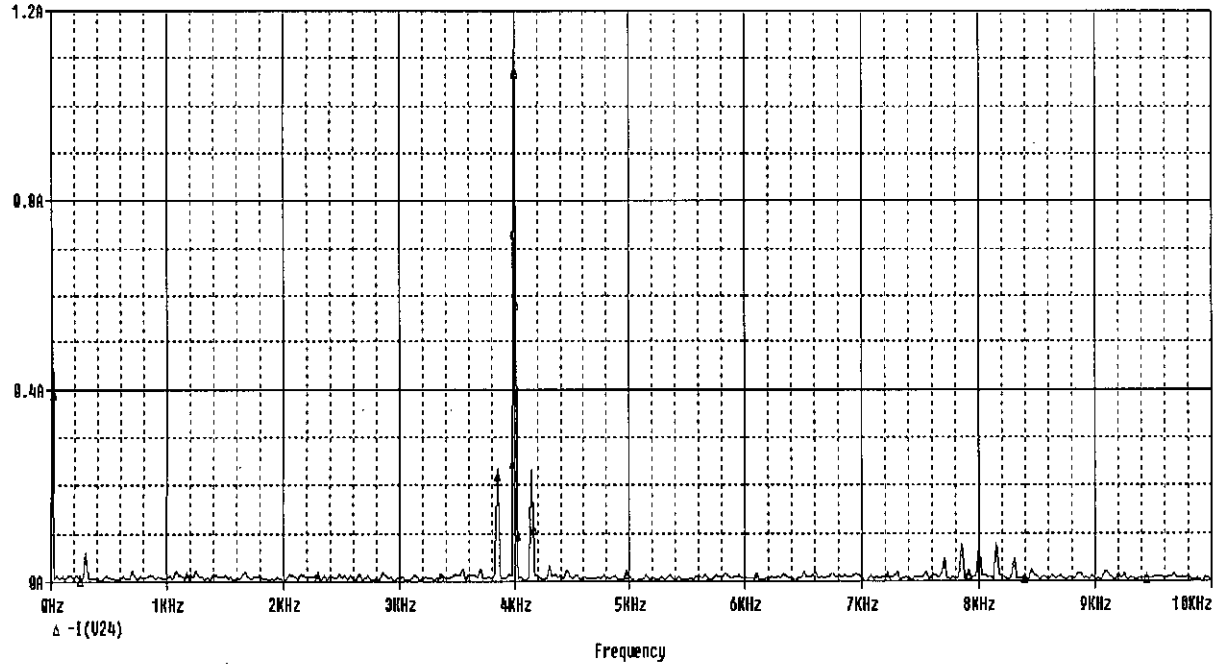


(a) Input Current

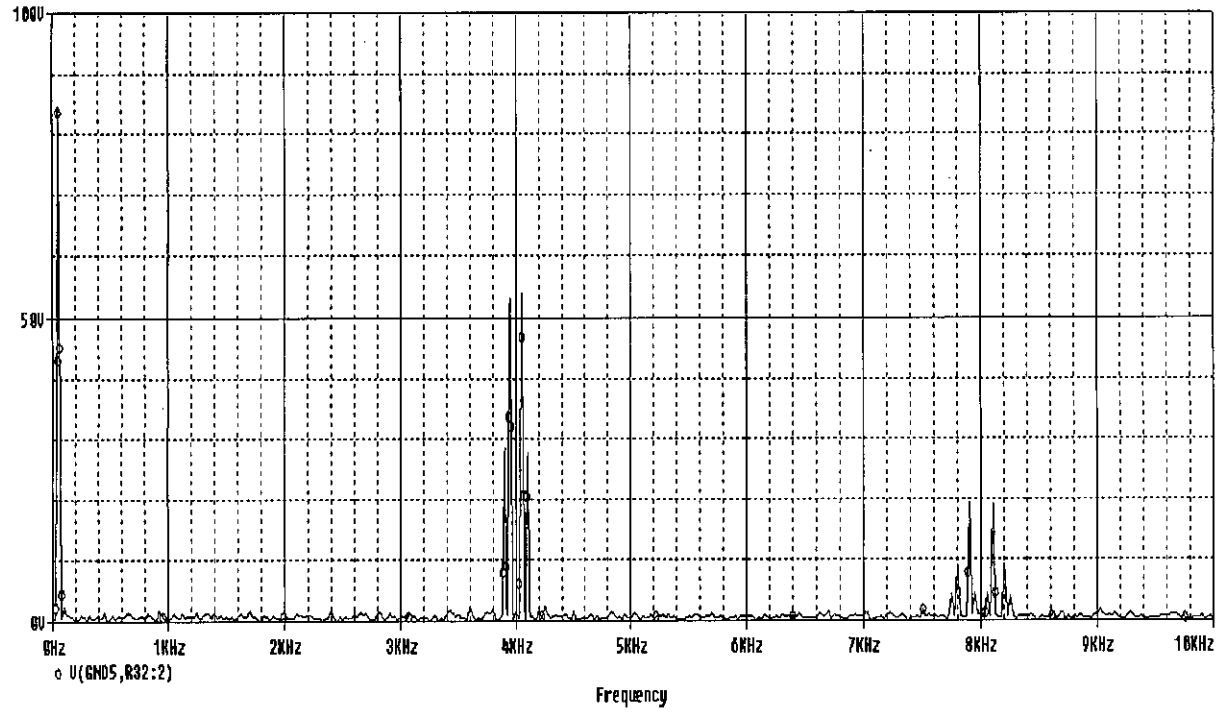


(b) Line to Neutral output voltage

Figure 2.2: Waveforms of three phase inverter with DC input (without input filter)



(a) Spectrum of Input Current



(b) Spectrum of Line to Neutral Voltage

Figure 2.3: Spectrum of waveforms of three phase inverter with DC input (without input filter)

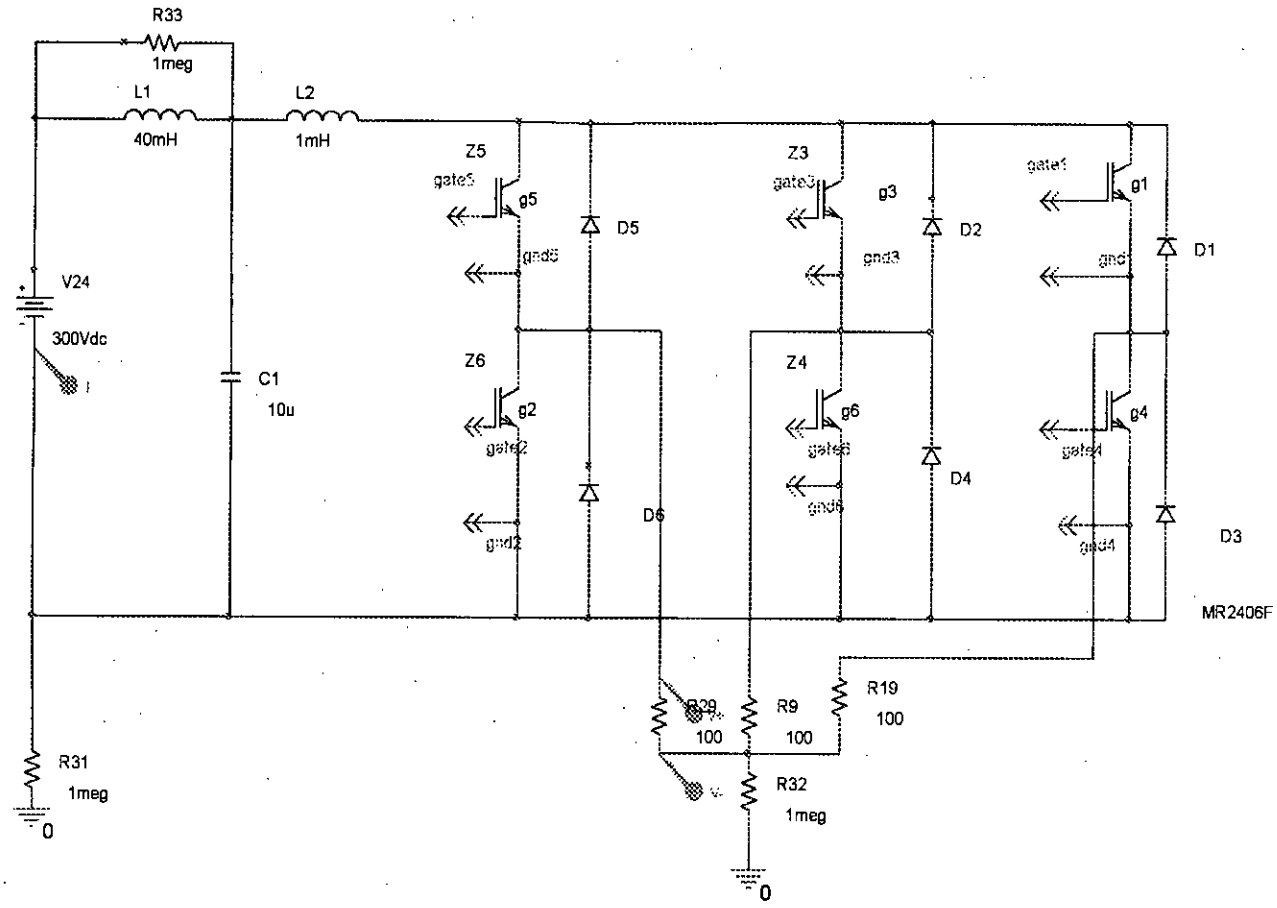


Figure 2.4: Three phase inverter (with input filter) with resistive load. (input source is DC)

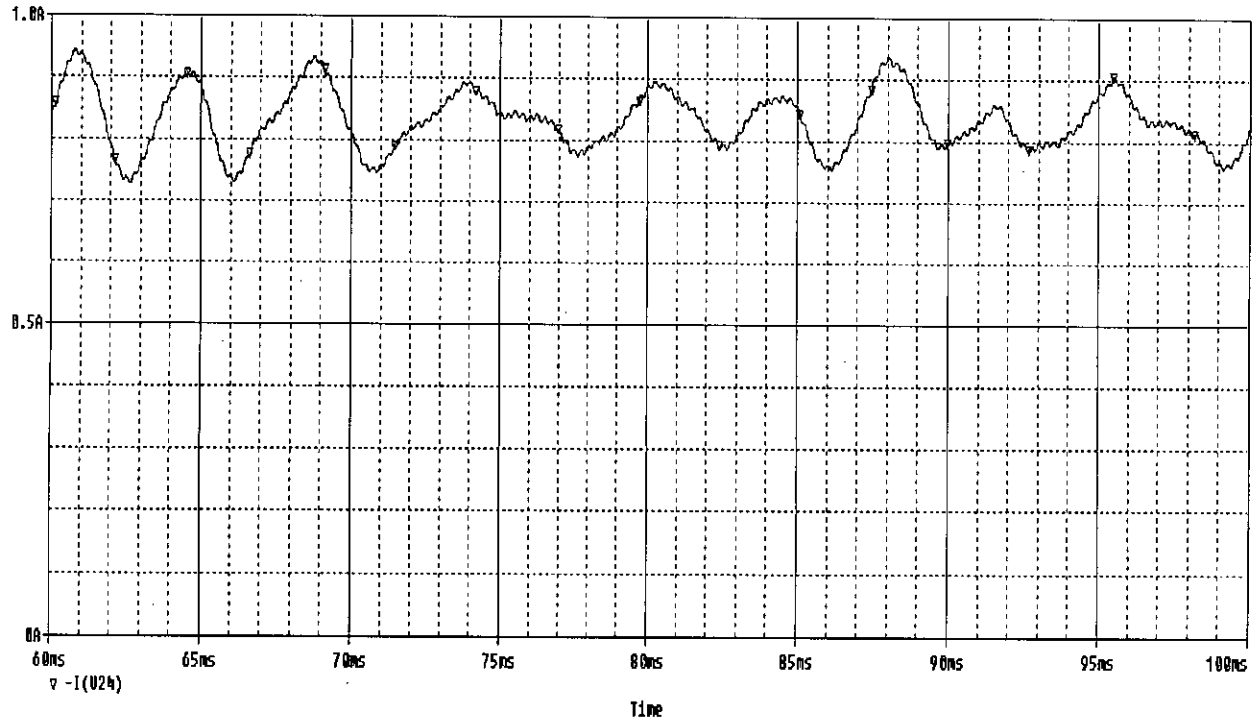


Figure 2.5: Waveform of input current of a three phase inverter (with input filter), input source is DC

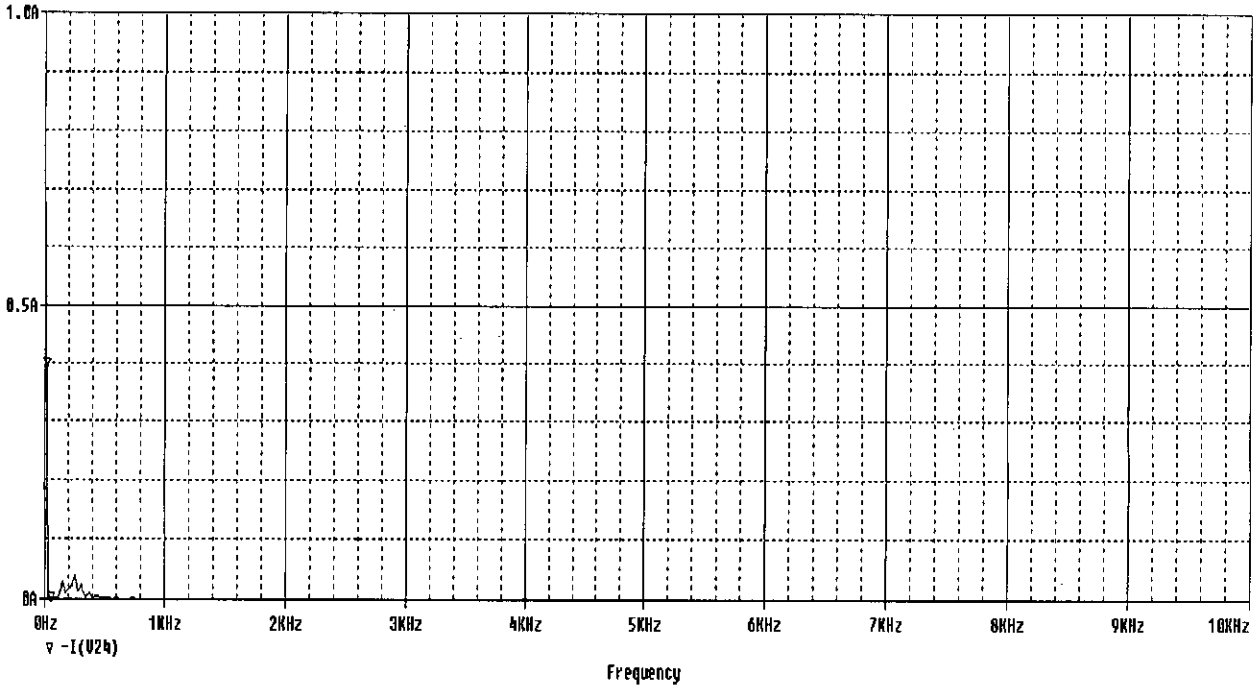


Figure 2.6: Spectrum of input current of a three phase inverter (with input filter), input source is DC

2.3 Input Current of DC-AC Three Phase Inverter With Active Current Shaping by SMPS

Figure 2.7 shows the circuit of a three phase inverter with DC source and input current filter having intermediate SMPS circuit. The SMPS circuit is shown in Figure 2.8. Varying the control voltage of the SMPS circuit it is possible to change the effective value of the filter and thus the input current harmonics. Up to a certain level of control voltage the input current harmonics reduce with the increase of the value of the control voltage, then it again starts increasing. Figure 2.9 to 2.20 describes the fact very clearly. With the help of this SMPS circuit, it was possible to reduce the size of the filter.

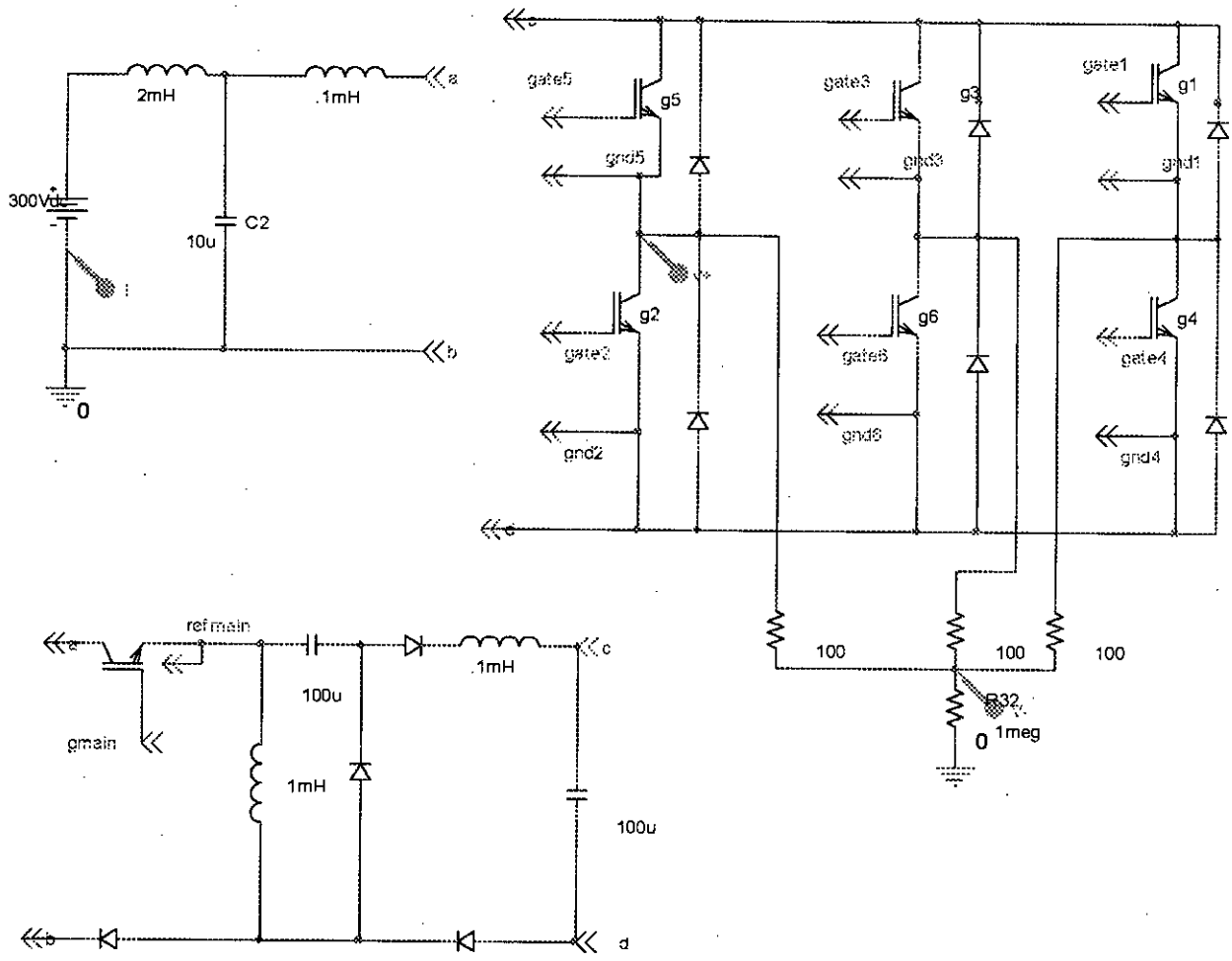


Figure 2.7: Three phase inverter (With DC source and input current filter and intermediate SMPS circuit)

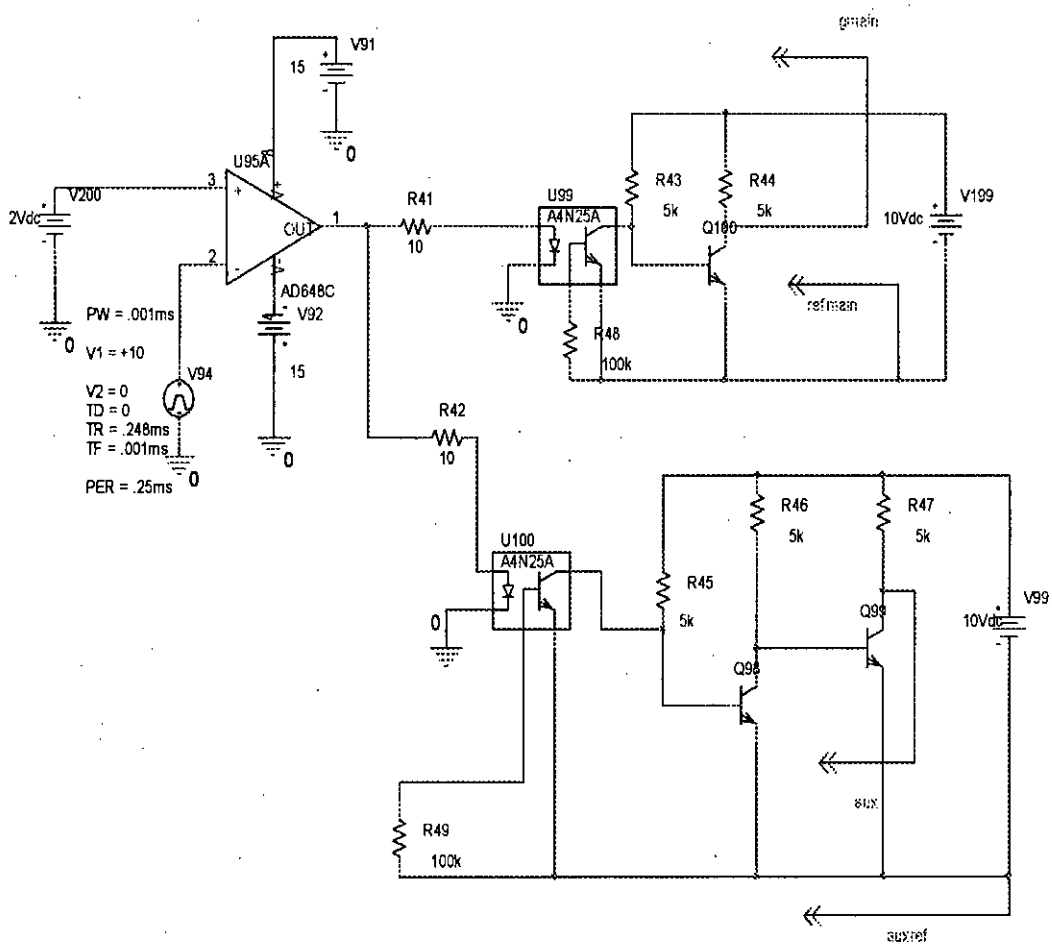


Figure 2.8: SMPS Circuit

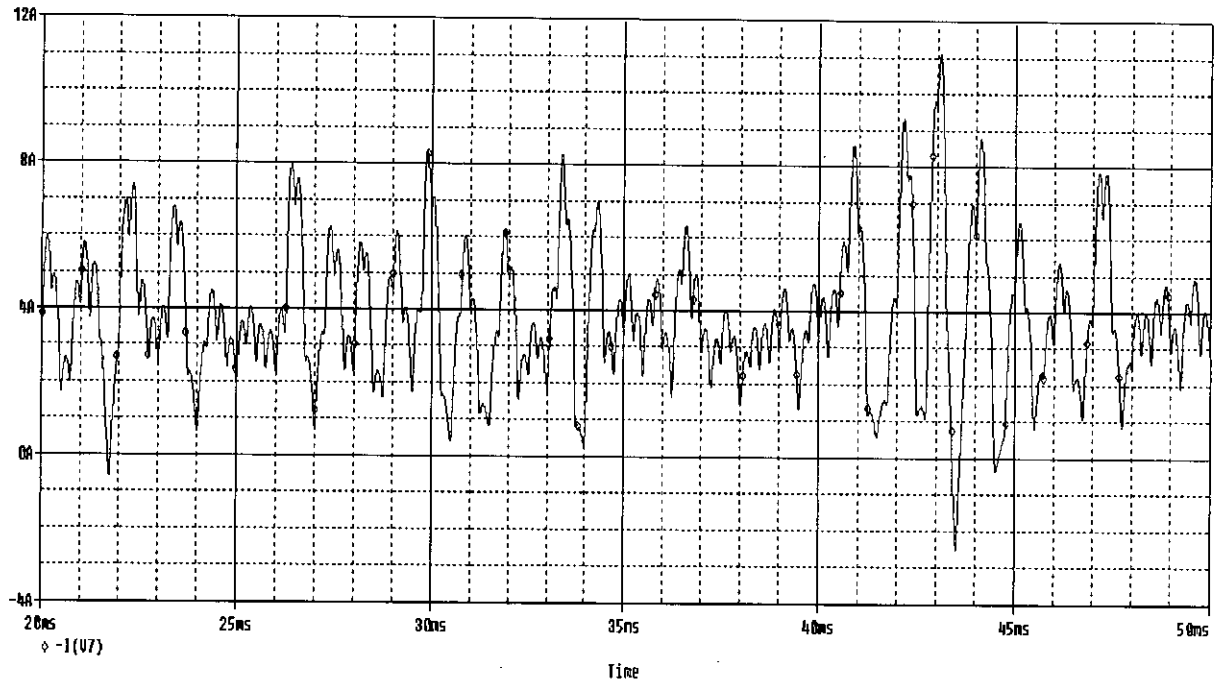


Figure 2.9: Input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.2

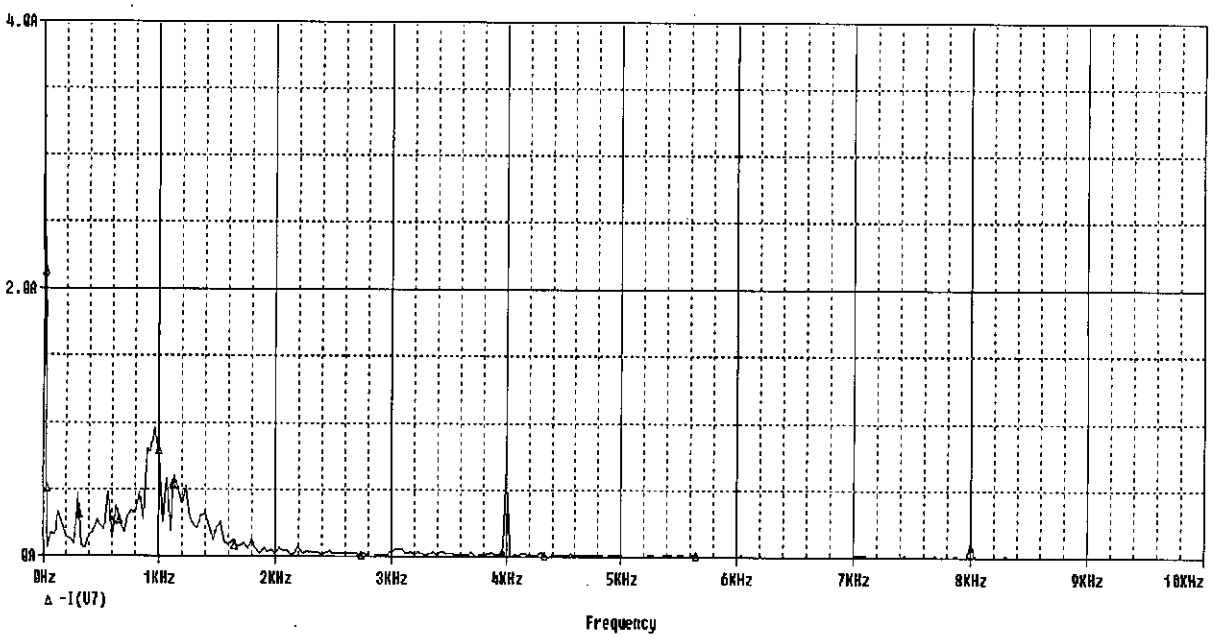


Figure 2.10: Spectrum of input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.2

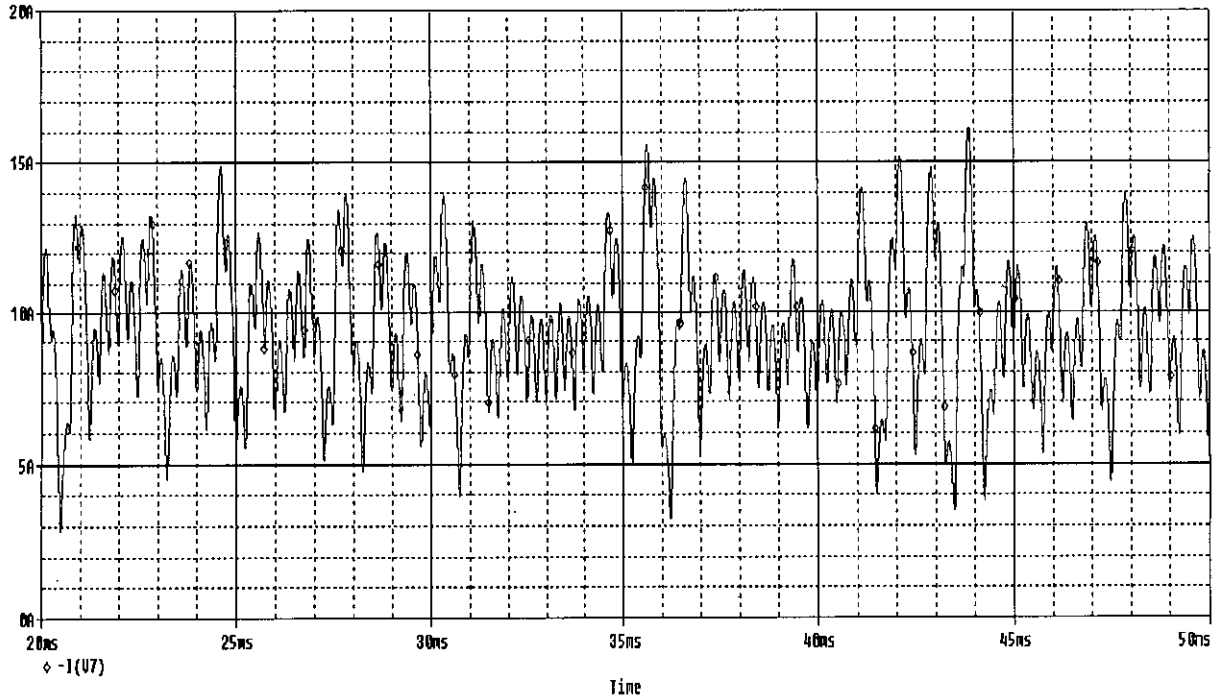


Figure 2.11: Input current waveforms of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.3

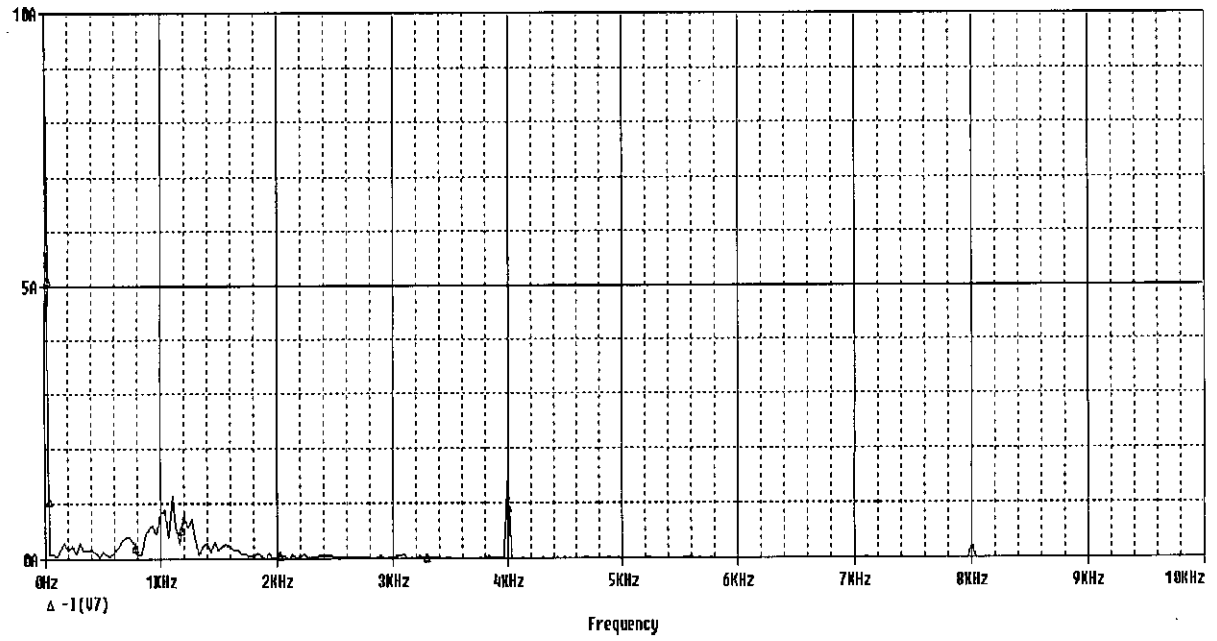
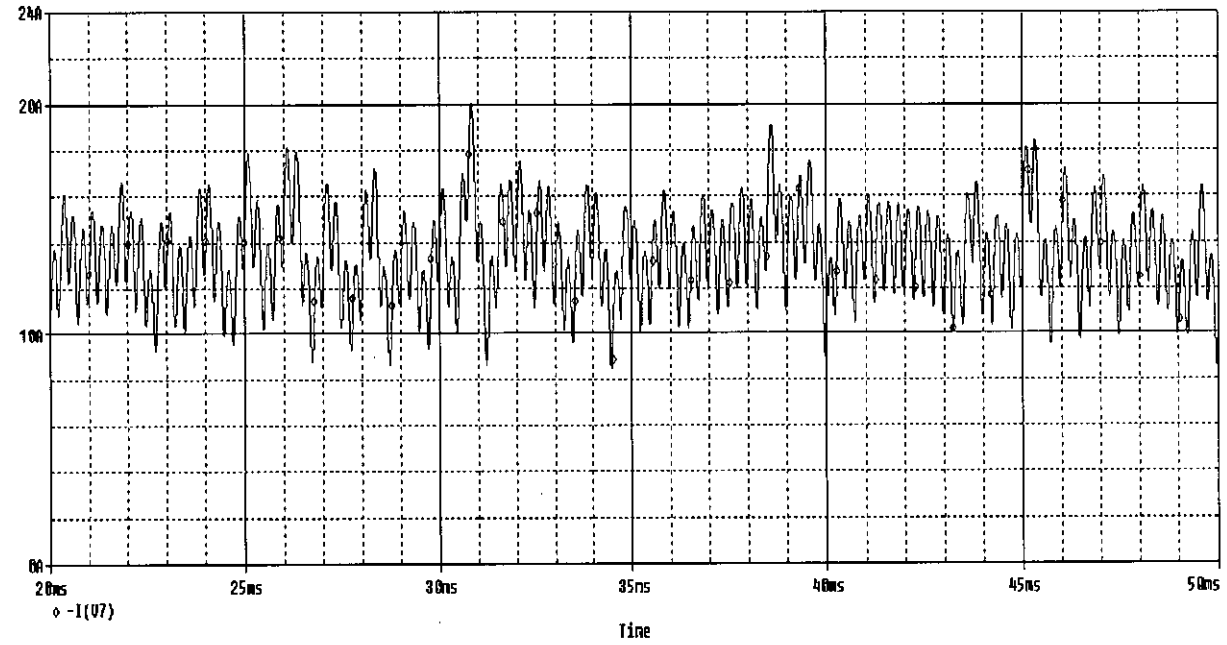


Figure 2.12: Spectrum of input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.3



\Figure 2.13: Input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.4

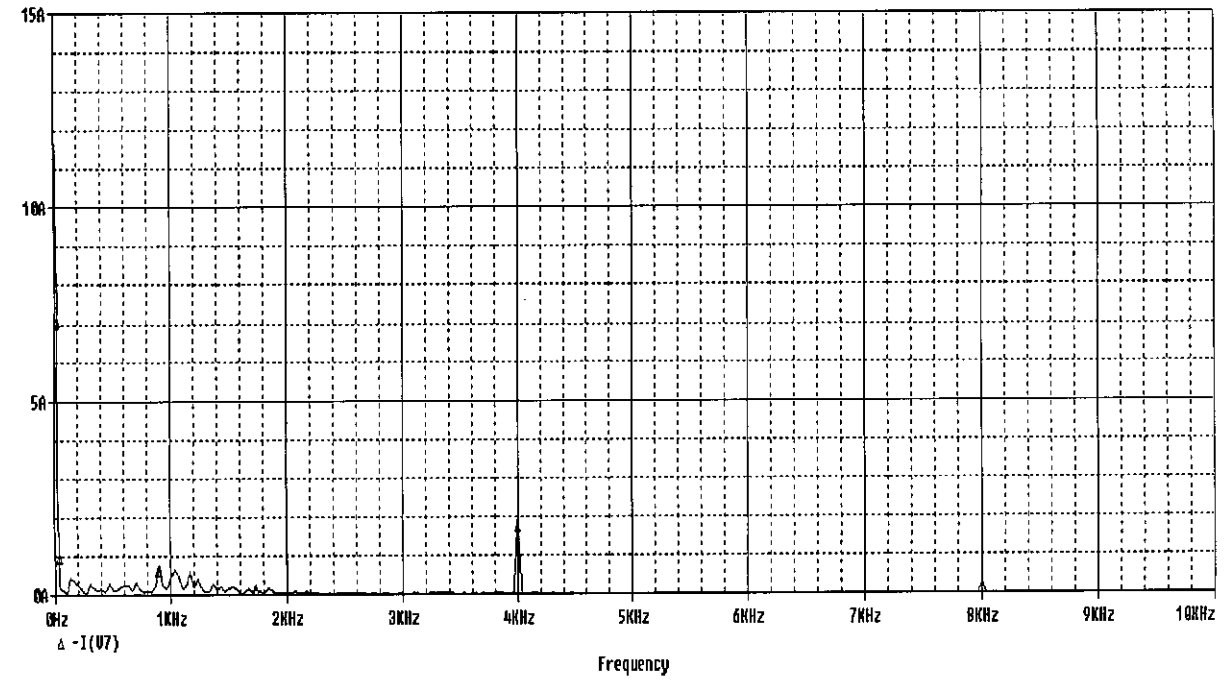


Figure 2.14: Spectrum of input current waveform of a three phase inverter With DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.4

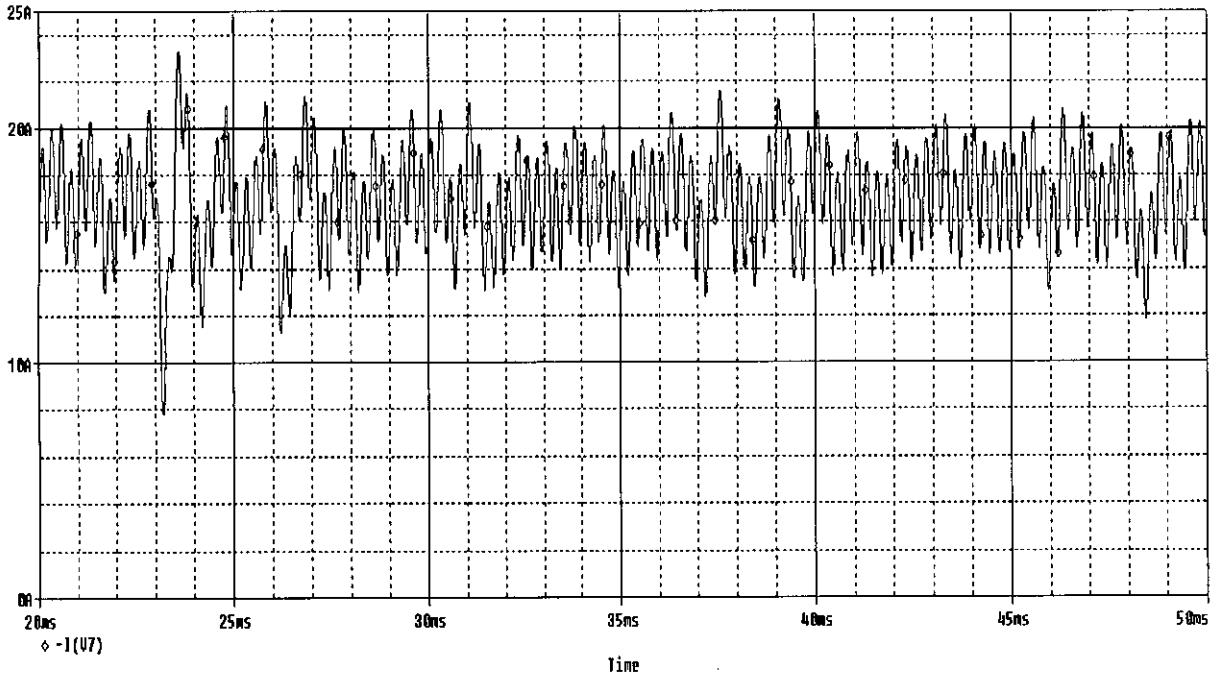


Figure 2.15: Input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.5

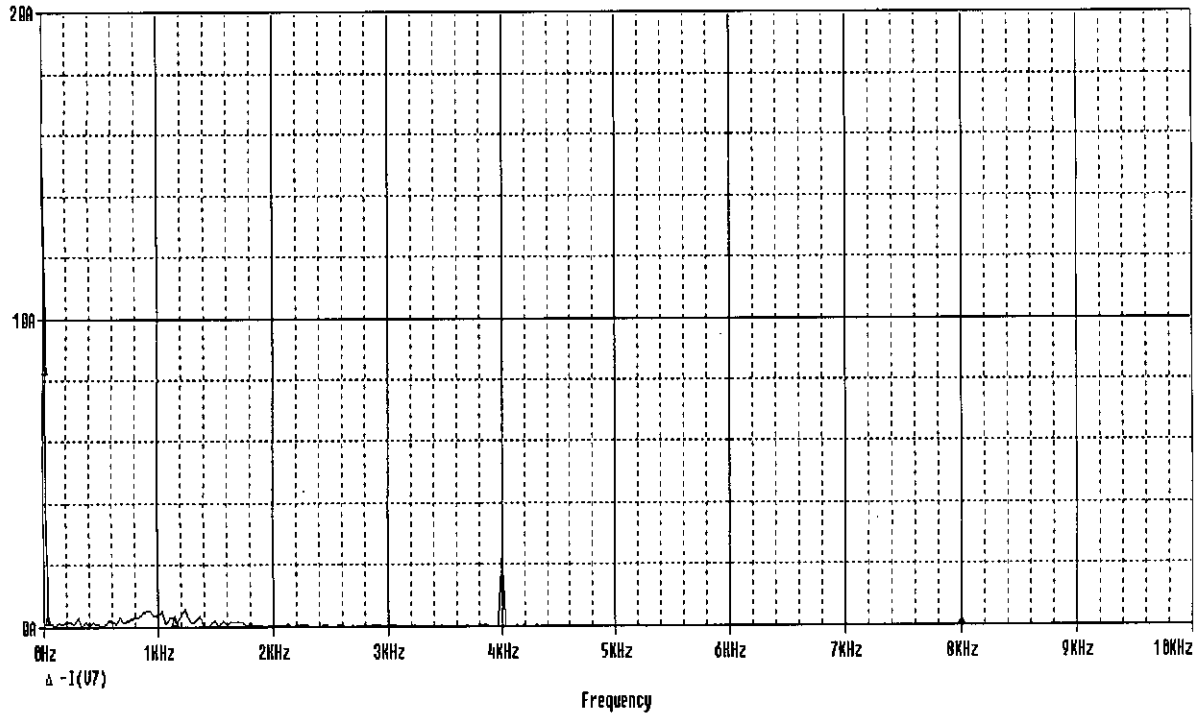


Figure 2.16: Spectrum of input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.5

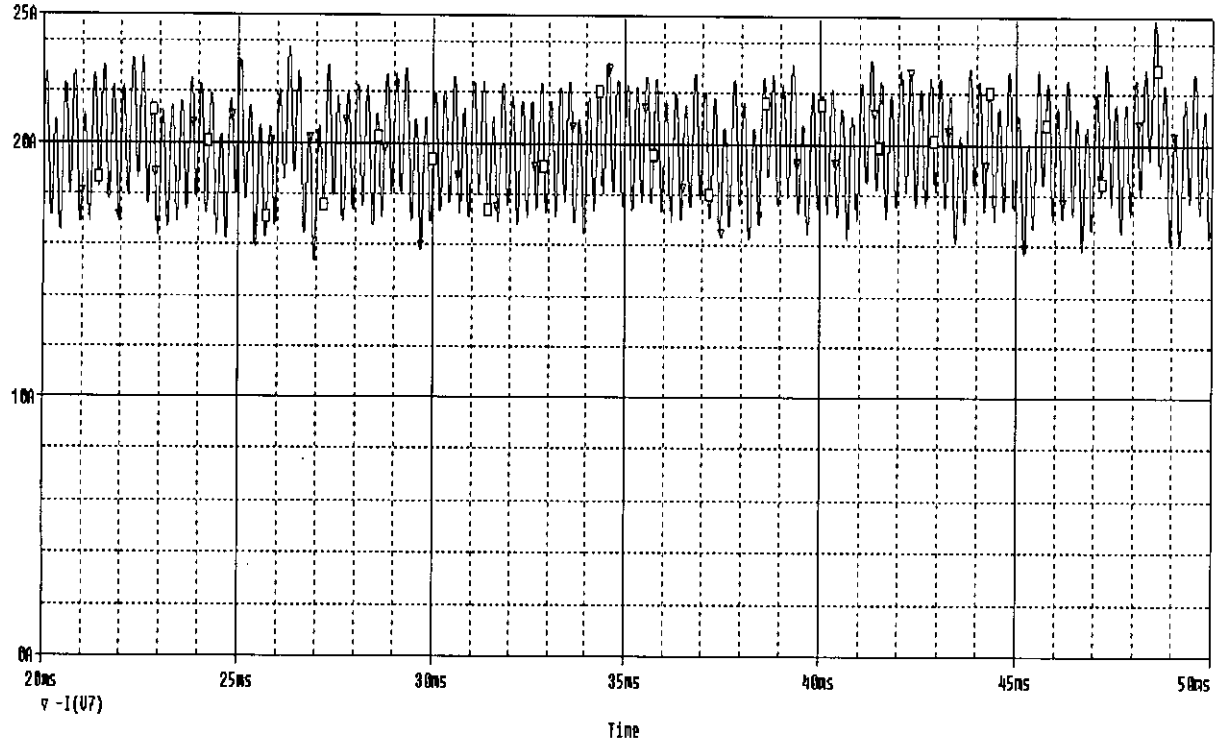


Figure 2.17: Input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.6

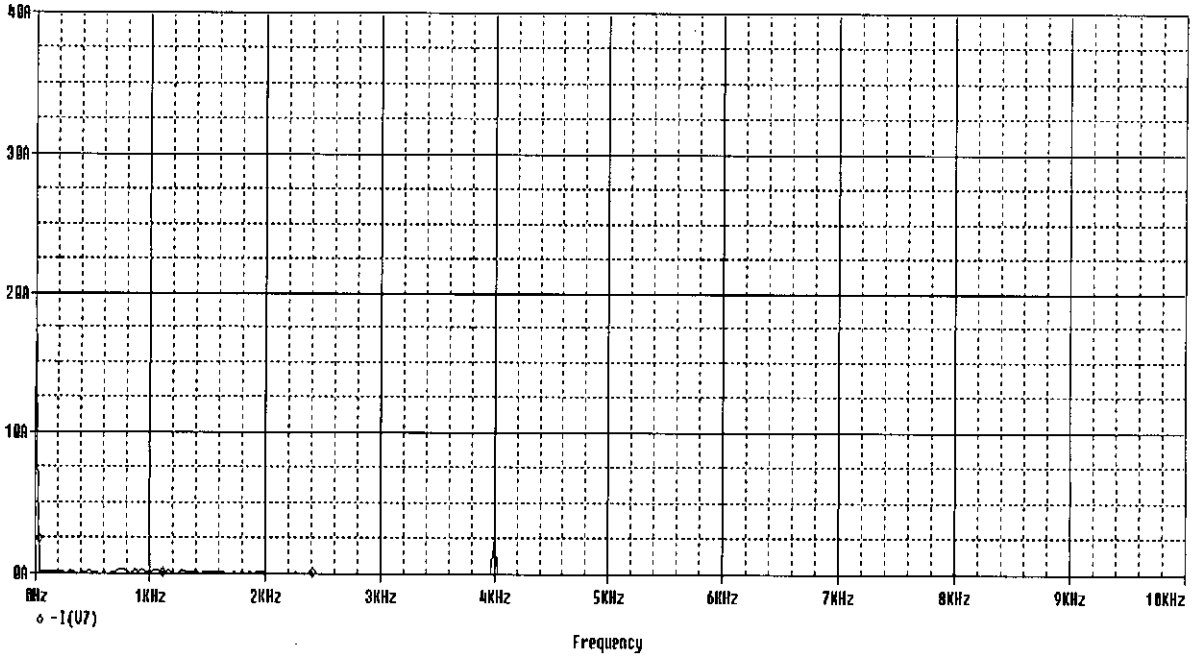


Figure 2.18: Spectrum of input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.6

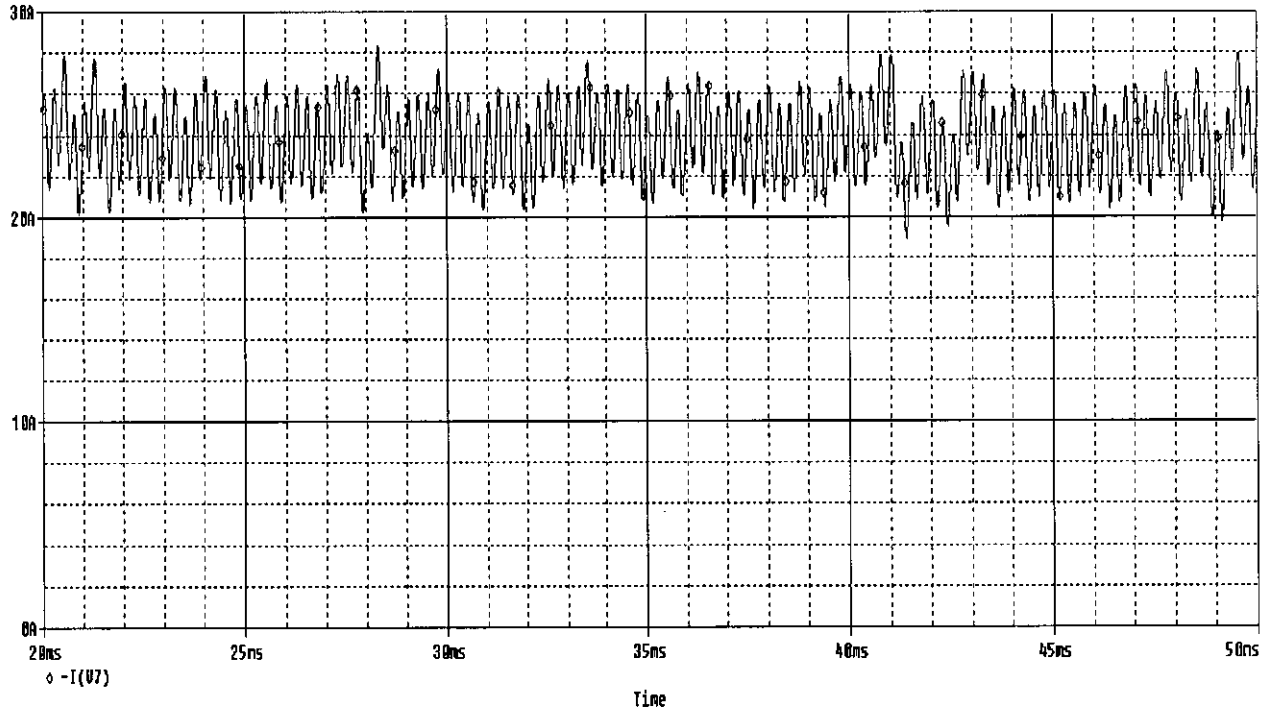


Figure 2.19: Input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.7

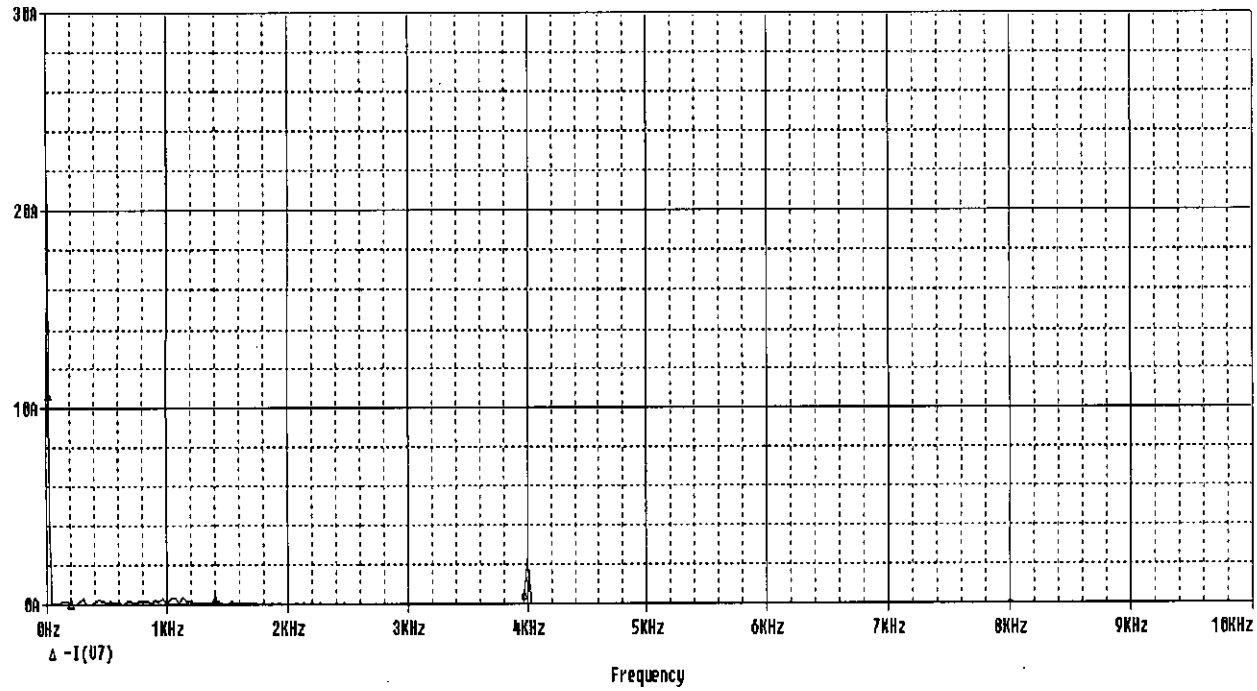


Figure 2.20: Spectrum of input current waveform of a three phase inverter with DC input (Having input current filter and intermediate SMPS circuit), Duty cycle = 0.7

2.4 Input Current of Three Phase AC-DC-AC PWM Inverter

AC-DC-AC conversion is done with circuit shown in Figure 2.21. But the waveform of the input current and the line-to-neutral voltage presented in Figure 2.22 and their spectrum shown in Figure 2.23 reflects that the input current is not purely sinusoid. It was now the concern to make the input current sinusoid.

In the circuit presented in Figure 2.24 filters are used to achieve the goal. The filters worked successfully. The wave shape and the spectrum of the input current and the line-to-neutral voltage presented in Figure 2.25 and 2.26 reflect that the input current of the inverter is shaped perfectly. But the size of the filter is very large.

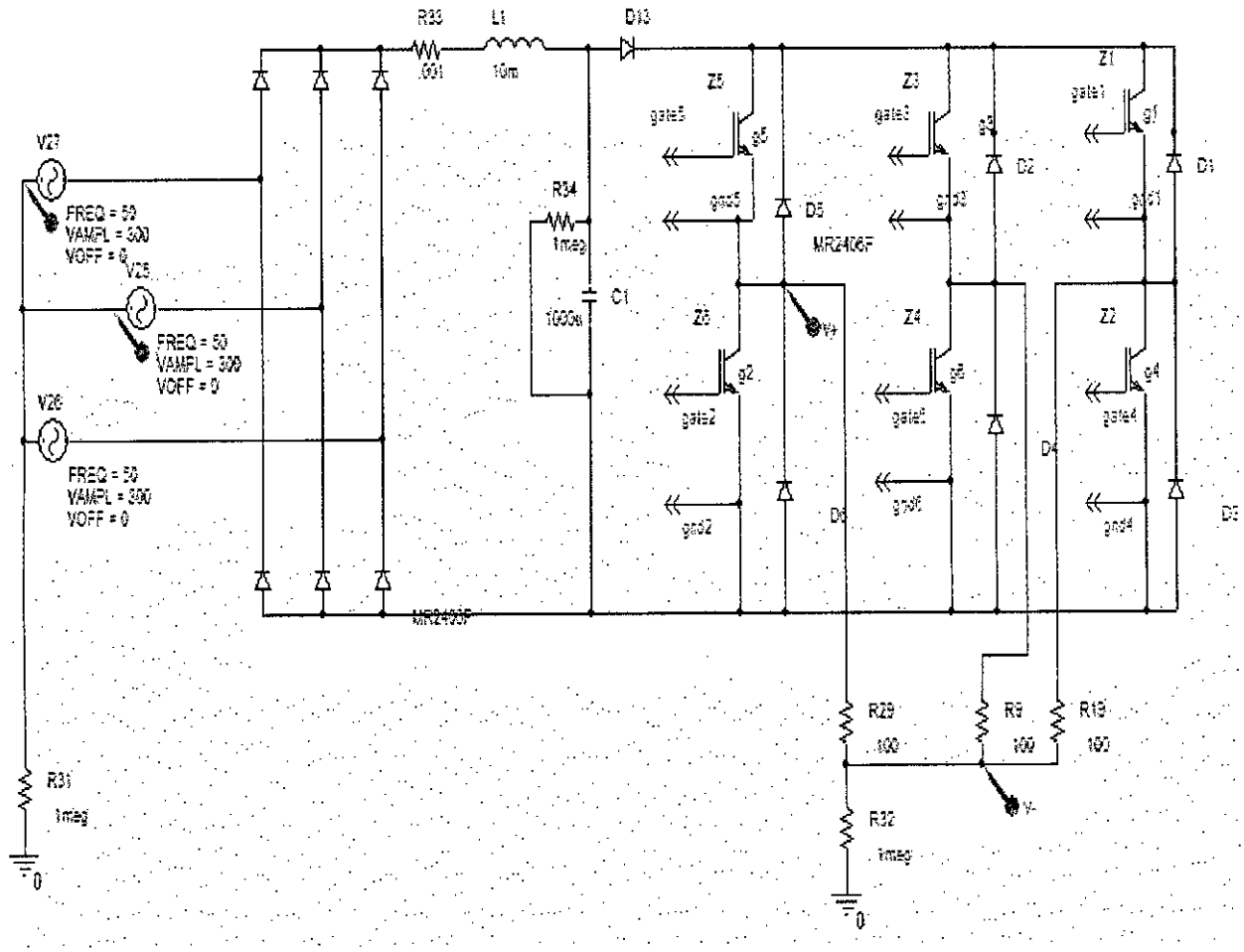
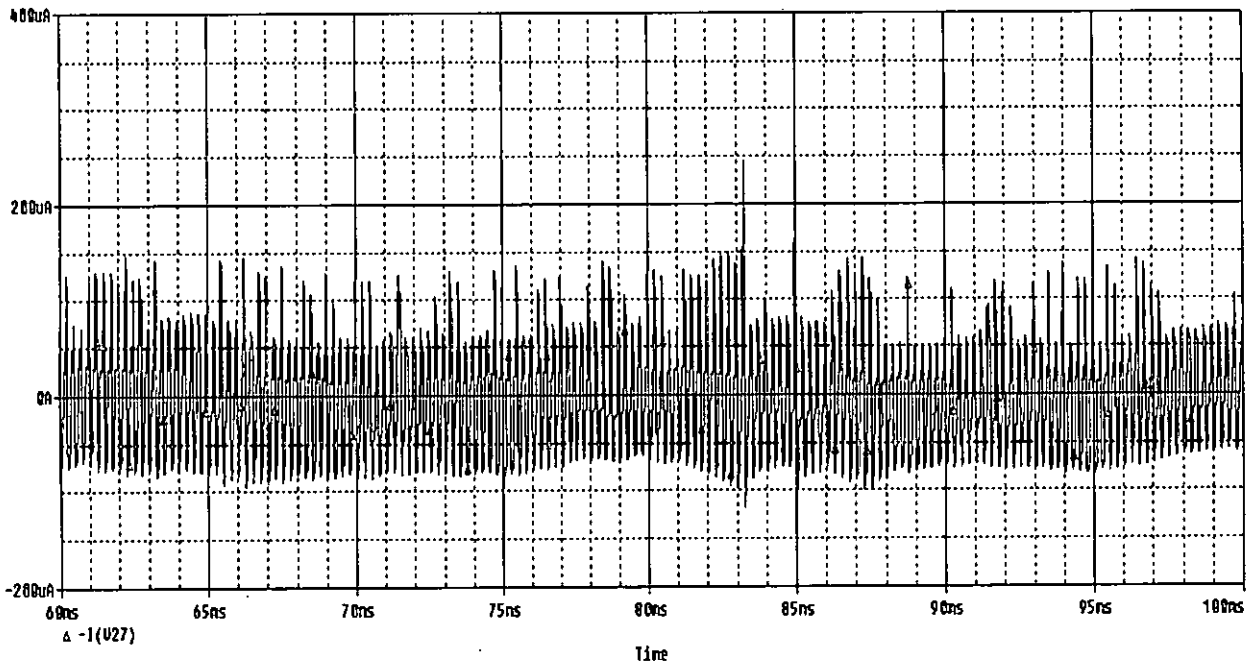
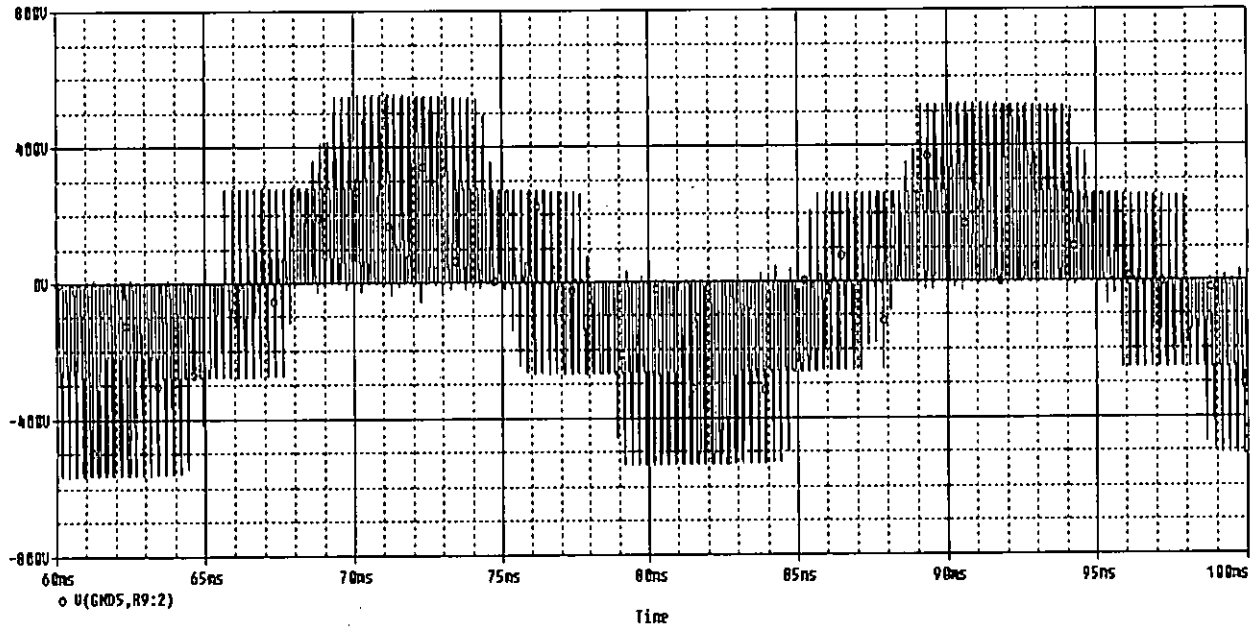


Figure 2.21: Three phase inverter (without input filter) with resistive load. (input source is AC)

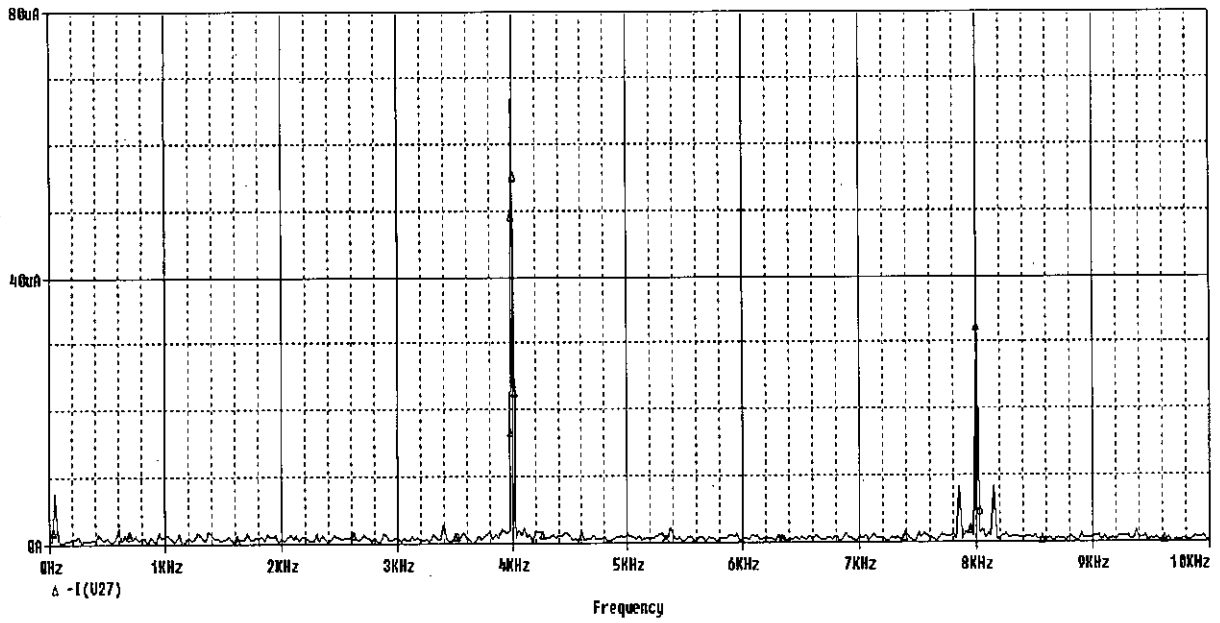


(a) Input Current

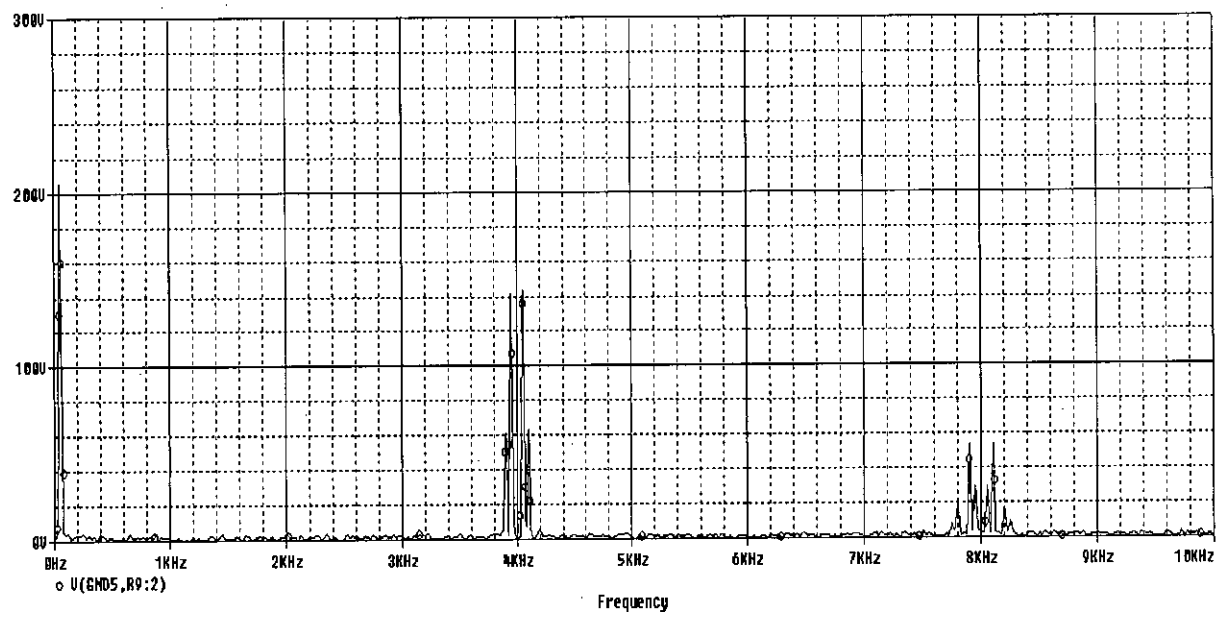


(b) Line to Neutral output voltage

Figure 2.22: Waveforms of a three phase inverter (without input filter), input source is AC.



(c) Spectrum of Input Current



(d) Spectrum of Line to Neutral Voltage

Figure 2.23: Spectrum of waveforms of a three phase inverter (without input filter), input source is AC.

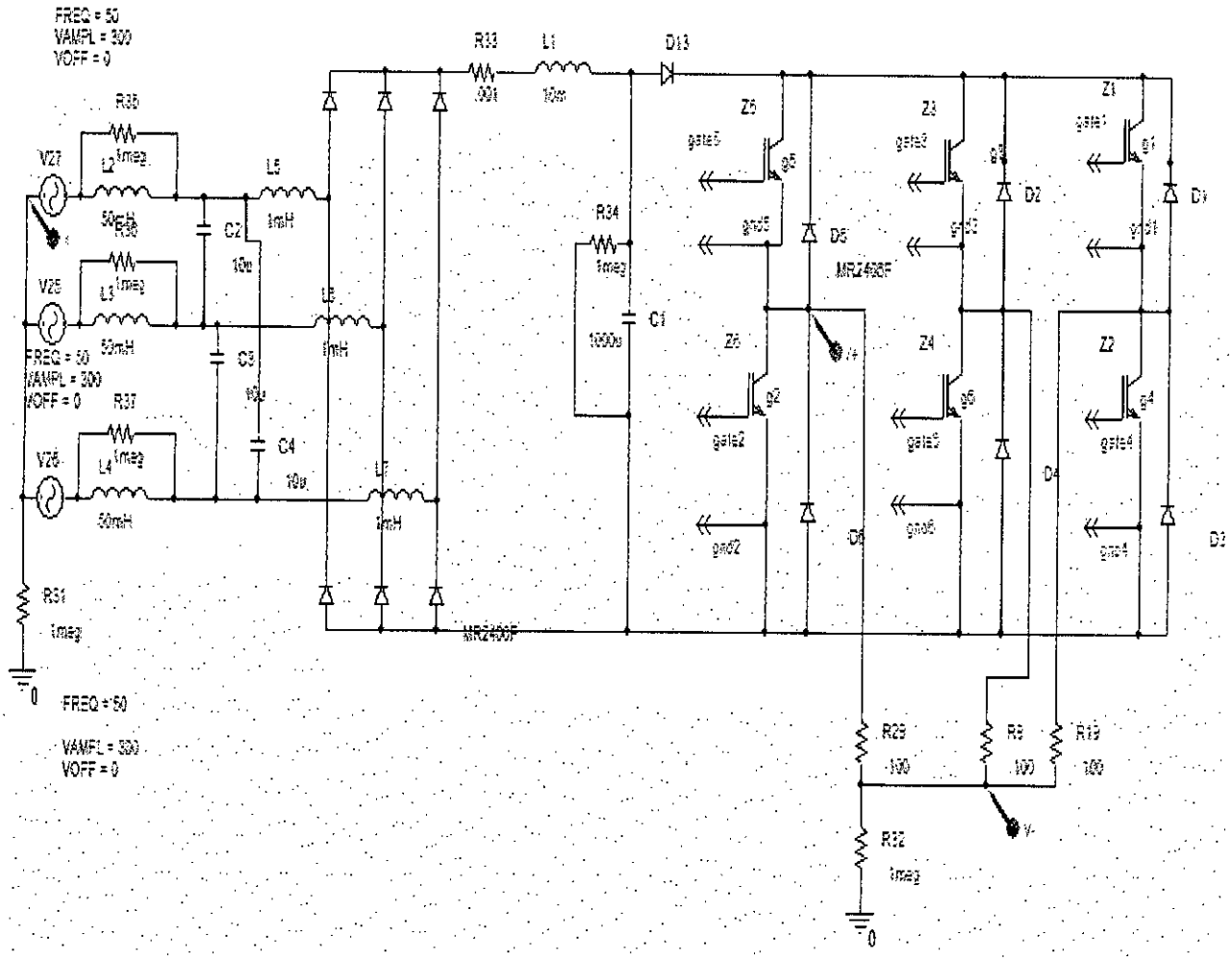


Figure 2.24: Three phase inverter (with input filter) with resistive load. (input source is AC)

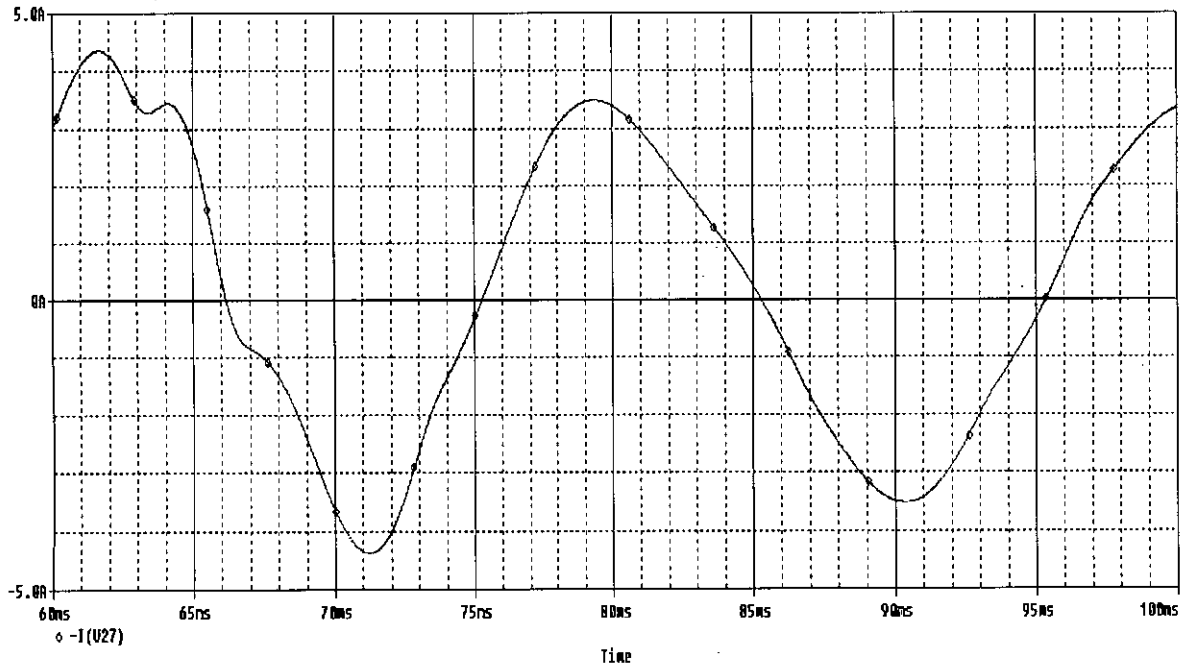


Figure 2.25: Input current wave form of a three phase inverter (with input filter), input source is AC

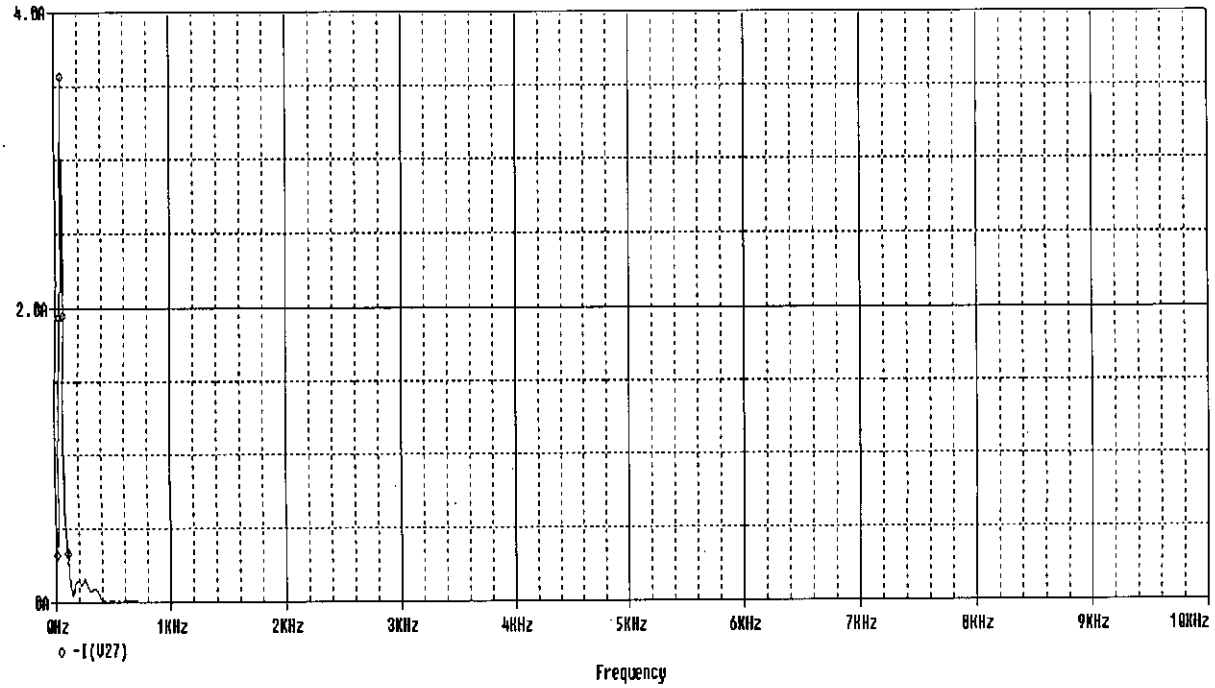


Figure 2.26: Spectrum of input current waveform of a three phase inverter (with input filter), input source is AC

2.5 Input Current Shaping of Three Phase AC-DC-AC Inverter

To reduce the size of the filter an intermediate SMPS circuit was used in Figure 2.27. From the waveshape and the spectrum shown in Figure 2.28 and 2.29 respectively represent that the input current was shaped. The unexpected harmonics were eliminated and the input current becomes sinusoid. It is noticeable that the size of the filter used in this circuit was reduced in a great extent.

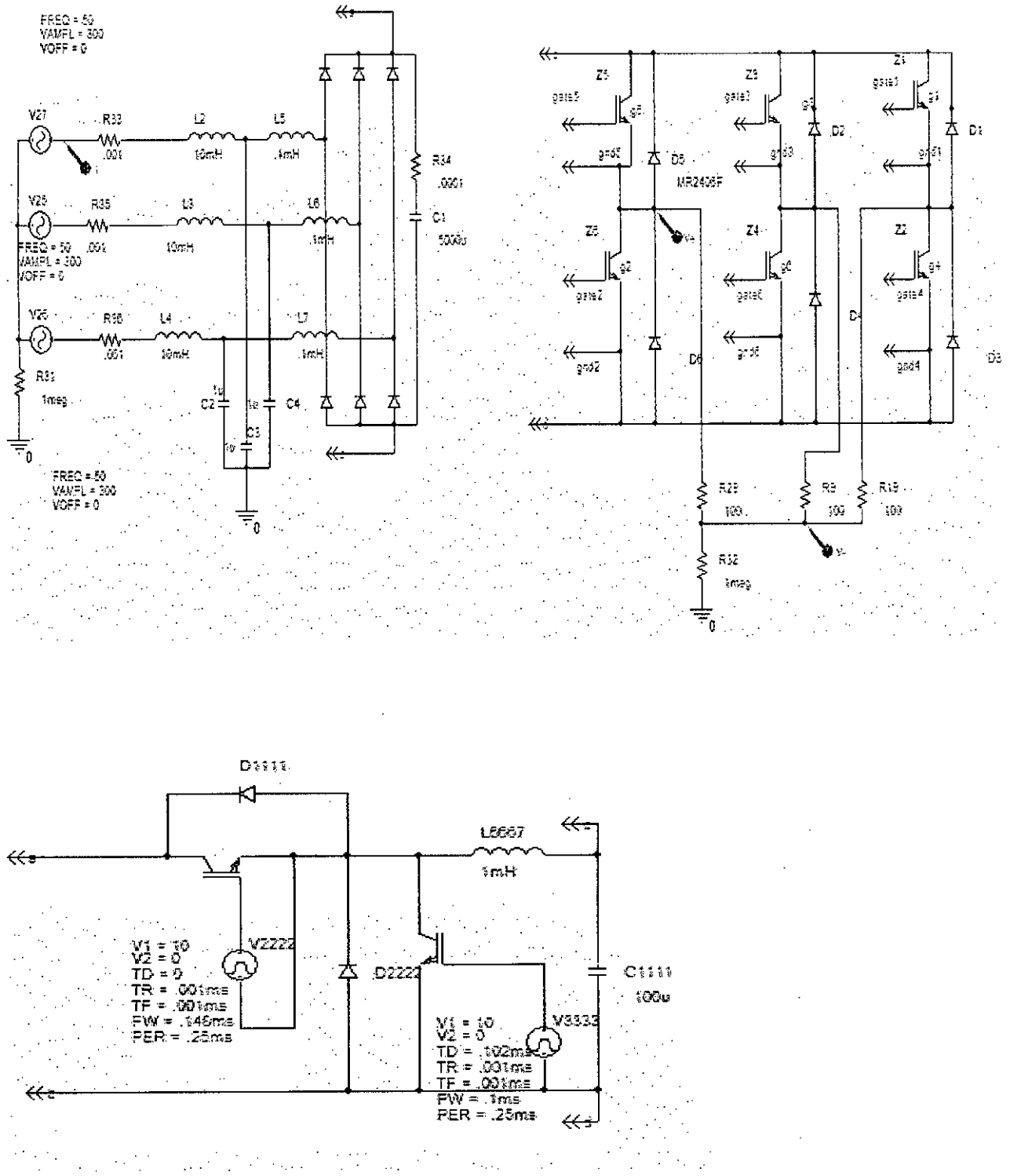


Figure 2.27: Three phase inverter (With input current filter and intermediate SMPS circuit) , input source is AC

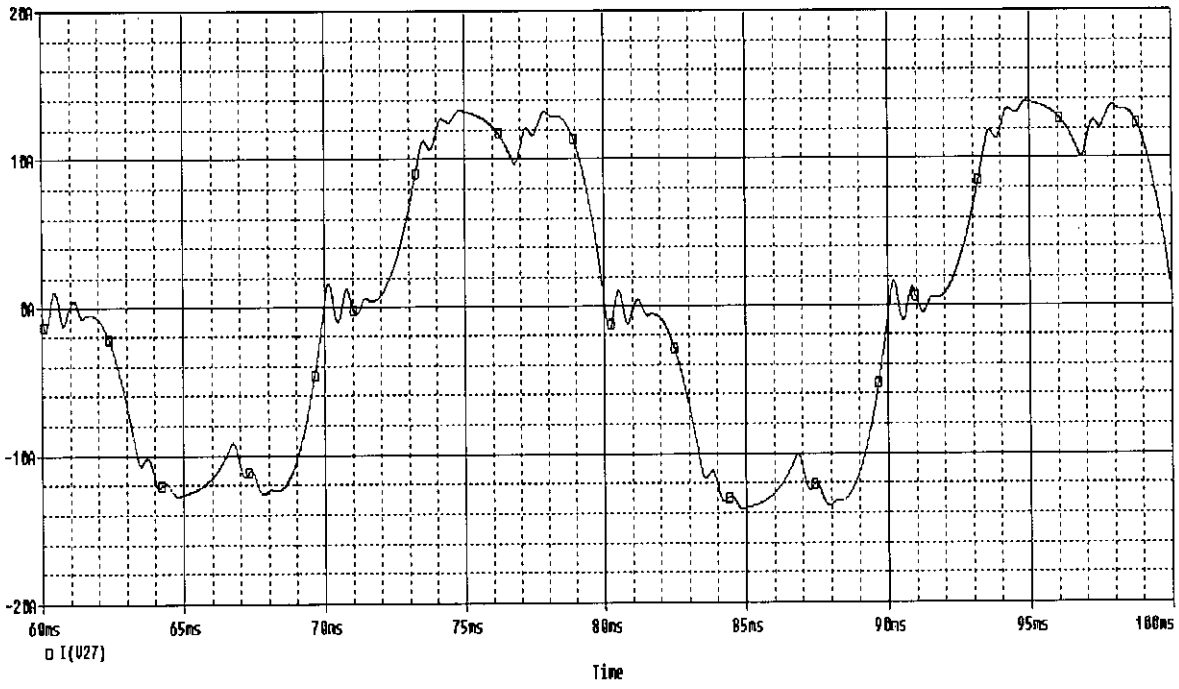


Figure 2.28: Input current waveform of three phase inverter with AC input (Having input current filter and intermediate SMPS circuit)

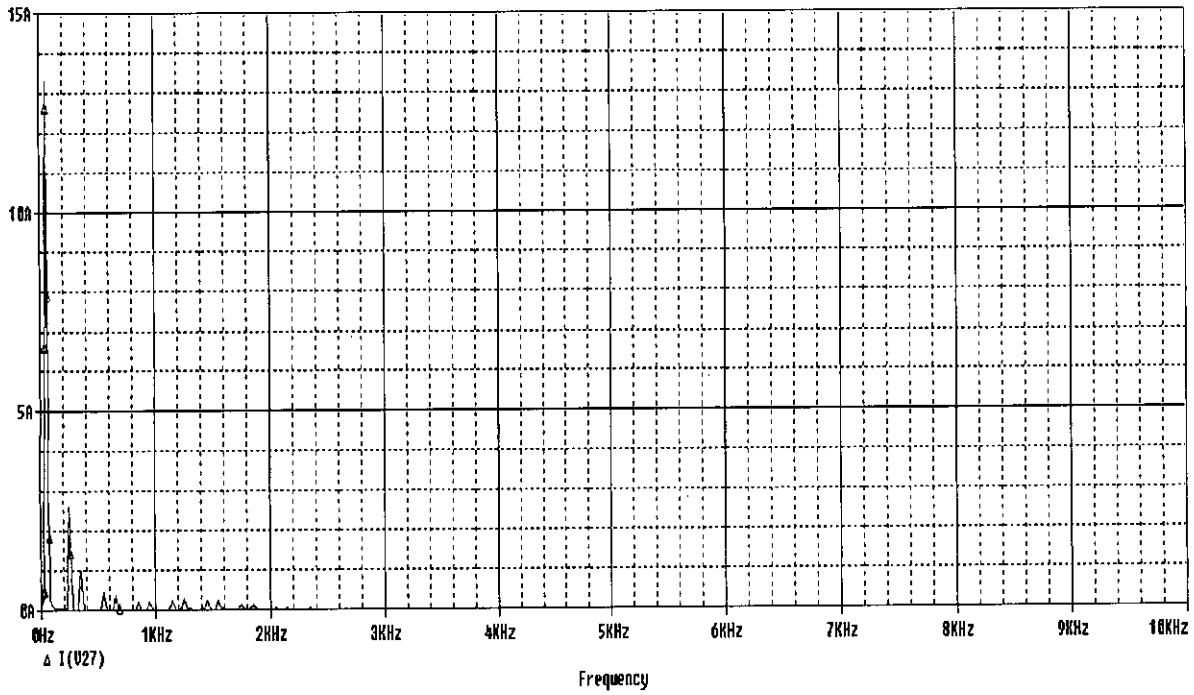


Figure 2.29: Spectrum of input current waveform of three phase inverter with AC input (Having input current filter and intermediate SMPS circuit)

2.6 Input Current Shaping of Three Phase AC-DC-AC PWM Inverter by Active Filtering and Addition of Third Harmonic Filter

Figure 2.28 and 2.29 show that the input current waveform of three phase AC-DC-AC PWM inverter improves significantly by active filtering technique. This requires smaller filters than required for passive filter method only. However, the waveform is still not the desired sine wave and the harmonics spectrum indicates that third harmonic still dominates. To reduce the third harmonic content of the input current and make the shape more sinusoidal, a third harmonic filter is added to the circuit as shown in Figure 2.30. The resultant current waveform is shown in Figure 2.31 together with its spectrum. The current waveform is now near sinusoidal and spectrum has negligible third harmonic component.

Harmonic Filter:

$$f_n = \frac{1}{2\Pi\sqrt{LC}}$$

$$L = \frac{1}{4\Pi^2 f_n^2 C}$$

$$= \frac{1}{4\Pi^2 C^2 (Nf)^2}$$

n is the harmonic

f is the fundamental frequency.

Choice of a practical value of C and L are determined from the above expression.

2.6.1 DC-AC PWM Inverter With Active and Harmonic Filter

In case of dc input, dominant harmonics are 1KHz & 2.5 KHz. Filter for 1 KHz elimination is designed with C=10 μF and L= .253 mH, whereas the filter for 2.5 KHz is designed with C= 10 μF and L= 40 mH. The circuit with harmonic filters is shown in Figure 2.30 and the current waveshape with its spectra is shown in Figure 2.31 (a) & (b). The input current waveshape is improved, however ripples of 500Hz and 4 KHz are present on the waveform. Further filtration will be required to remove these ripples complicating the circuit.

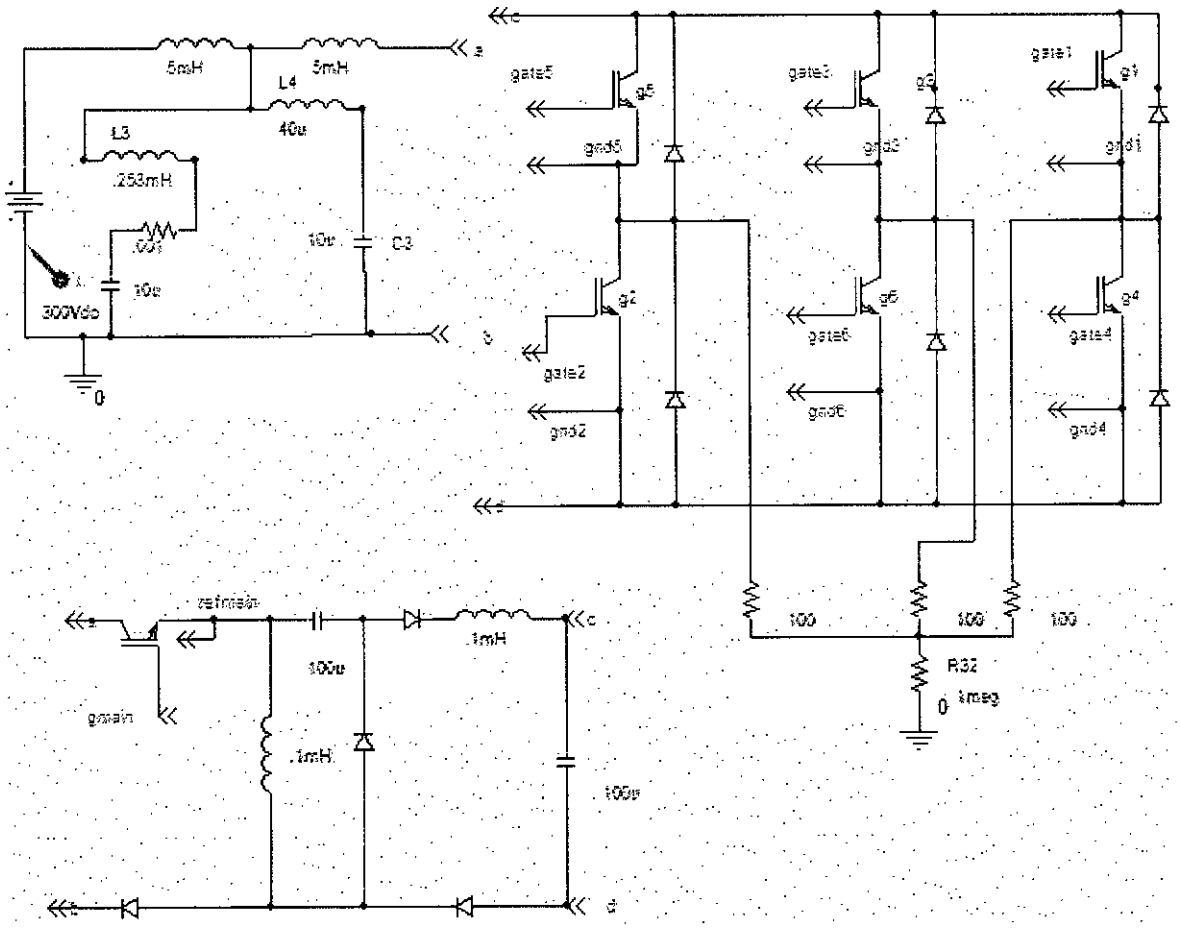
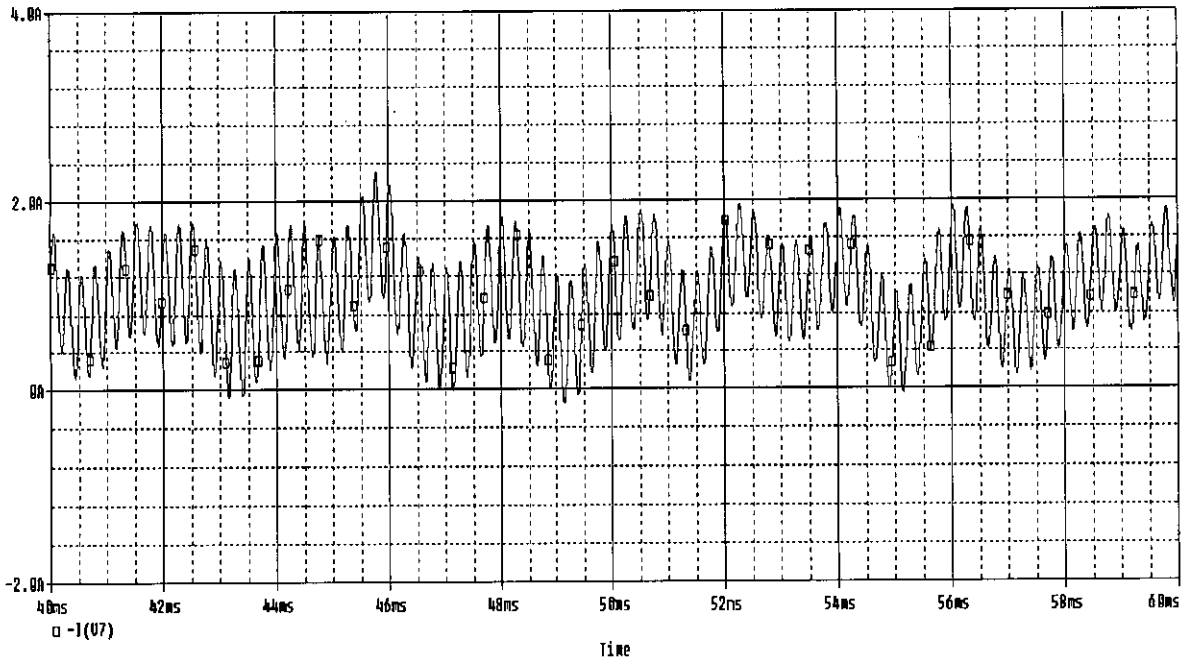
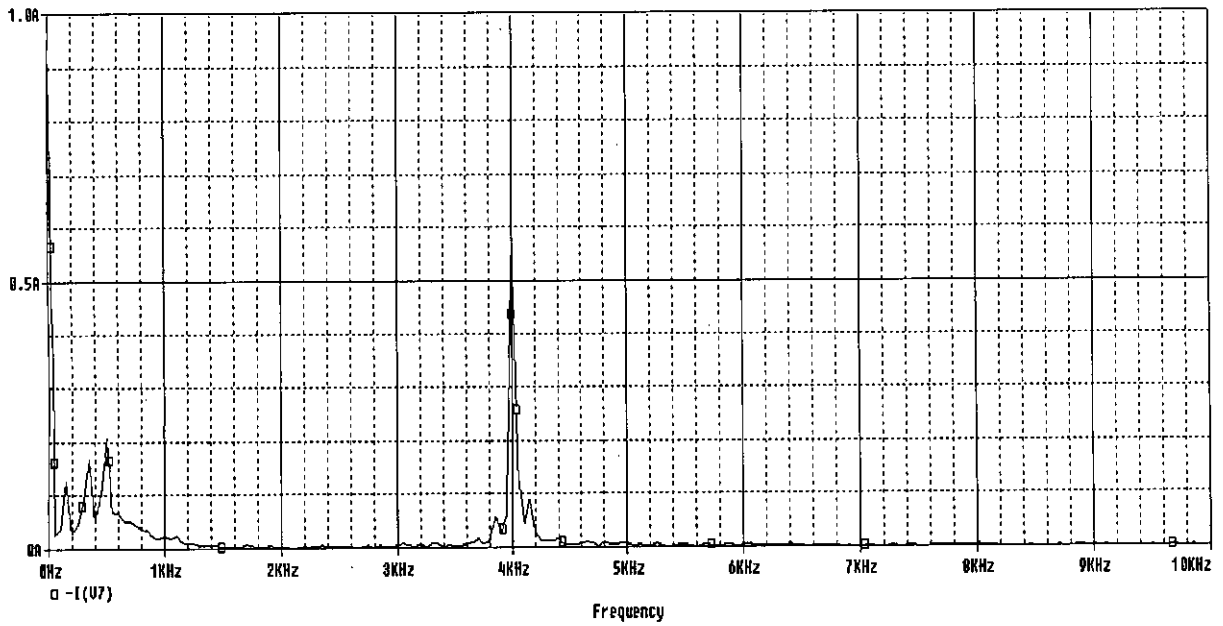


Figure 2.30: Three phase inverter (with input filter, intermediate SMPS circuit and harmonic filter), Input source is DC



(a) Input current waveform



(b) Spectrum of Input Current Waveform

Figure 2.31: Input current waveform and its spectrum of a Three phase inverter (with input filter, intermediate SMPS circuit and harmonic filter), Input source is DC

2.6.2 AC-DC-AC PWM Inverter With Active and Harmonic Filter

In case of inverter with ac input and rectifier lie between supply and inverter it has been observed that 5th harmonic is dominant in the input current wave. Thus a 5th harmonic elimination filter is added choosing C= 20 μF and L=20mH. The circuit with the harmonic filter is shown in Figure 2.32 and the input current and its spectra are shown in Figure 2.33 (a) & (b). The current waveshape is improved further, however it still remains unsinusoidal. However, the distortion is at acceptable range.

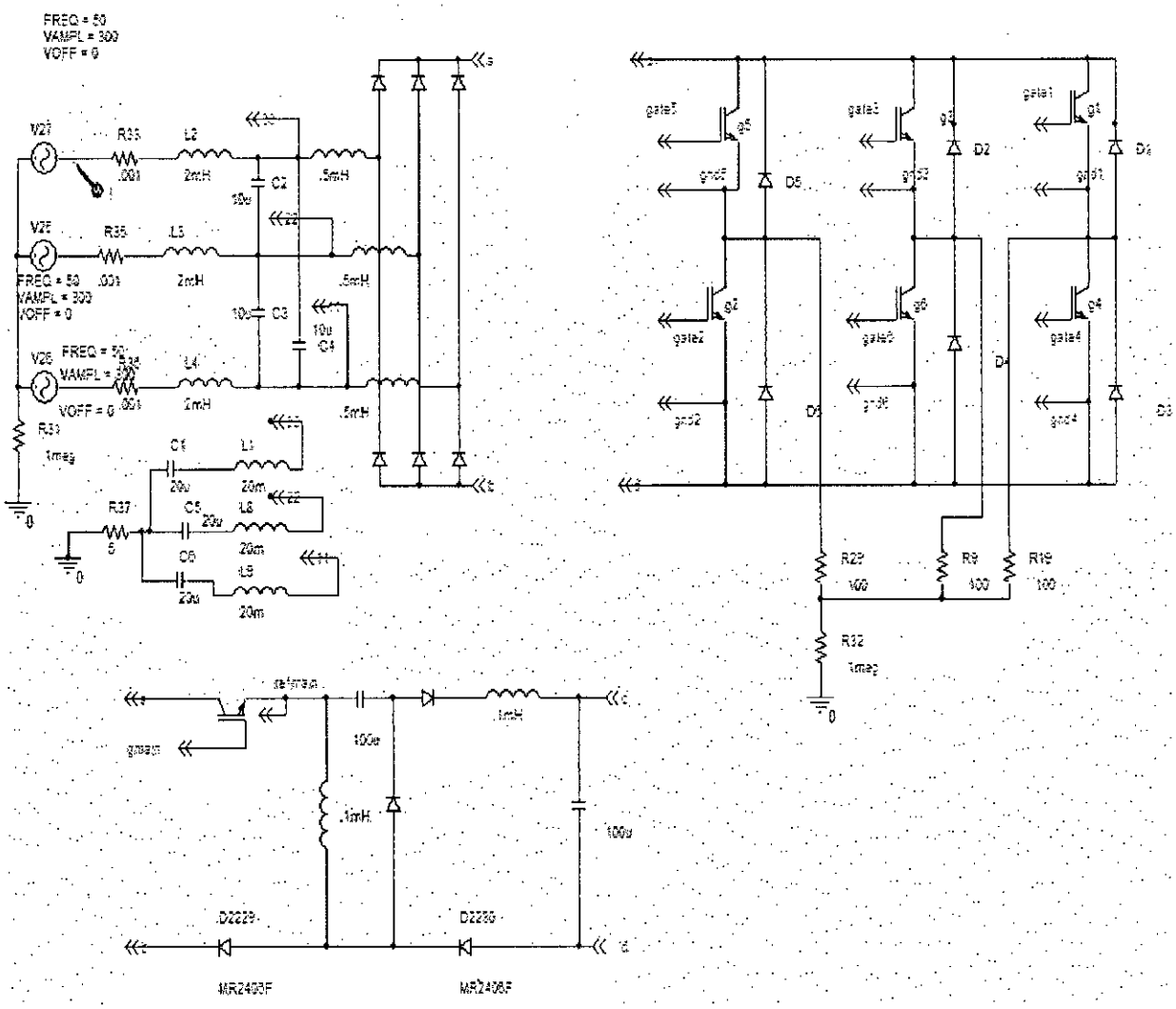
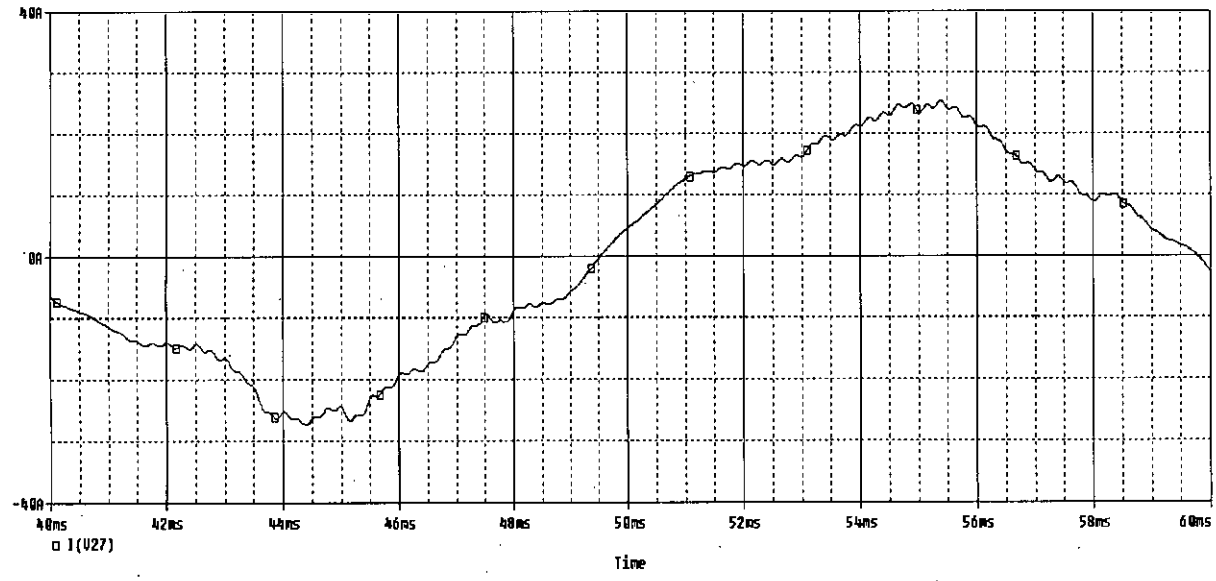
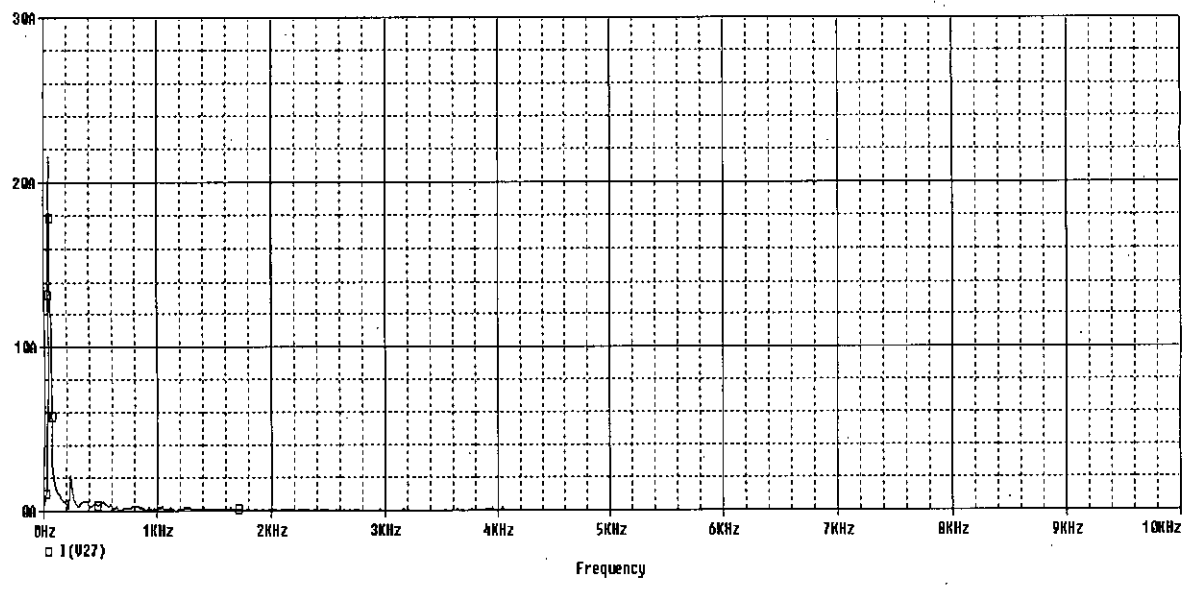


Figure 2.32: Three Phase PWM Inverter With Harmonic Filter (Input source is AC)



(a) Input Current Waveshape



(b) Spectrum of Input Current

Figure 2.33: Input current waveform and its spectrum of a Three phase inverter (with input filter, intermediate SMPS circuit and harmonic filter), Input source is AC

2.7 Total Harmonic Distortion (THD) of AC Component of Input Current

2.7.1 DC-AC PWM inverter

In case of DC-AC PWM inverter (described in 2.2, 2.3 and 2.6.2), input current consists of DC and a ripple AC. The AC component is distorted and its Total Harmonic Distortion (THD) was calculated, which is presented in Table 2.1.

Table 2.1 : Total Harmonic Distortion of AC component of Input Current (DC-AC PWM Inverter)

Type of Inverter	Duty Cycle	DC Component	Total Harmonic Distortion (%)
Three phase DC-AC inverter	--	0	8.85
Three phase inverter (with input filter)	--	0	7.37
DC-AC three phase inverter with active current shaping by SMPS	0.2	0	8.38
	0.3	0	8.4
	0.4	0	8.39
	0.5	0	8.4
	0.6	0	4.39
	0.7	0	8.41
DC-AC PWM inverter with active and harmonic filter	--	0	6.94

2.7.2 Three Phase AC-DC-AC PWM Inverter

In case of AC-DC-AC inverter, input current consists of AC with small amount of DC offset. THD of input current was measured and is presented in Table 2.2.

Table 2.2 : Total Harmonic Distortion of AC component of Input Current (AC-DC-AC PWM Inverter)

Sl.	Type of Inverter	DC Component	Total Harmonic Distortion (%)
1	Three phase AC-DC-AC PWM inverter	0	4.15
2	Three phase AC-DC-AC PWM inverter with input filter	0	4.17
3	Three phase AC-DC-AC PWM inverter with active input current shaping	0	4.56
4	AC-DC-AC PWM inverter with active and harmonic filter	0.0531	1.03

2.8 Observations

In an ideal case for any resistive load the input current must follow the input voltage. But this is not true for any real case. The characteristics of the components used in any practical case cannot be ideal. For this reason harmonics distort the input current from the input voltage.

Without any filter the input current of a three phase PWM is distorted in a great extent from the input voltage. Using conventional filter in the input side of the inverter, the harmonics can be reduced significantly. This situation requires large filters.

Using intermediate SMPS Circuit can reduce filter size. Active filtering method can reduce the harmonics by controlling the control voltage of the SMPS circuit. After a certain level it can work smoothly. Still the input current is not following the input voltage accurately. The input current has some dominant harmonic components. To eliminate the dominant harmonic component we have used harmonic filters and finally have got the input current nearly dc or ac with very small amount of high frequency harmonics.

Chapter-3

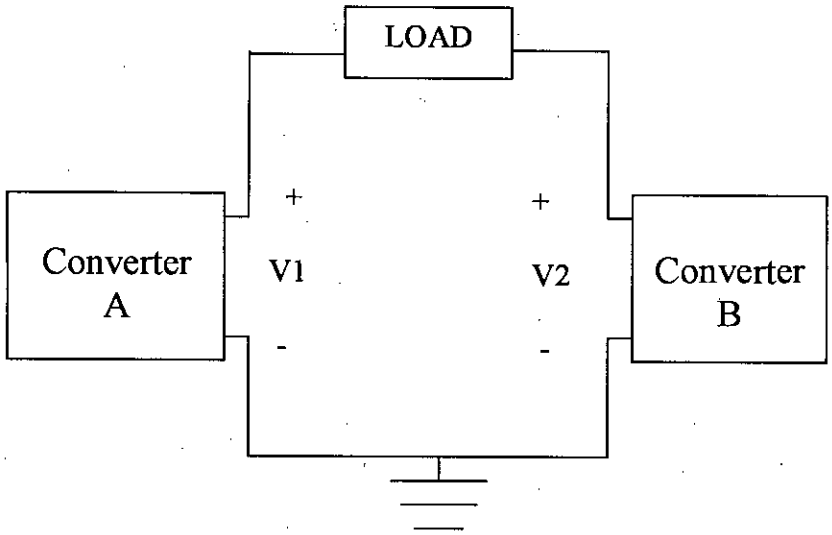
Input Current of New DC-AC Inverters

3.1 Introduction

The conventional voltage source inverter (VSI) referred to as a buck inverter is probably the most important power converter topology. It is used in many distinct industrial and commercial applications. One of the characteristics of the buck inverter is that the instantaneous average output voltage is always lower that the input dc voltage. As a consequence, when an output voltage larger than the input one is needed, a boost dc-dc converter must be used between the dc source and inverter. Depending on the power and voltage levels involved, this solution can result in high volume, weight, cost and reduced efficiency.

3.2 Principle of Operation

New generation of Switch Mode PWM Converter is proposed in [37]. The principle is described in Figure 3.1. The blocks A and B represent dc-dc converters. These converters produce a dc-biased sine wave output, so that each source only produces a unipolar voltage. The modulation of each converter is 180^0 out of phase with the other, which maximizes the voltage excursion across the load. The load is connected differentially across the converters. Thus, whereas a dc bias appears at each end of the load, with respect to ground, the differential dc voltage across the load is zero. The generating bipolar voltage at output is solved by a push-pull arrangement. Thus, the dc-dc converters need to be current bi-directional.



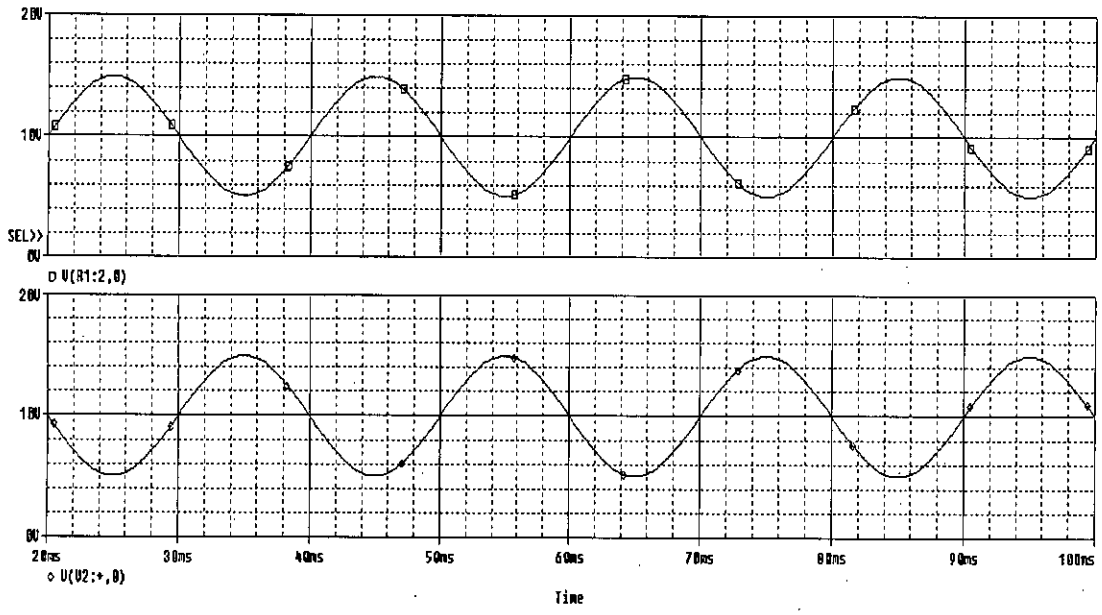


Figure 3.1: A Basic Approach to Achieve DC-AC Conversion, With Boost Characteristics

3.3 Single Phase Boost Inverter

Single phase Boost inverter has been simulated to study its input current. The circuit is given in Figure 3.2. Typical input current and output voltage waveshapes are shown in Figure 3.3. The spectrum of input current is shown in Figure 3.4. Spectrum shows that the input current contains desired dc and harmonics of 100 Hz and 200Hz. Lower frequency harmonics can easily be eliminated with the help of input current filter.

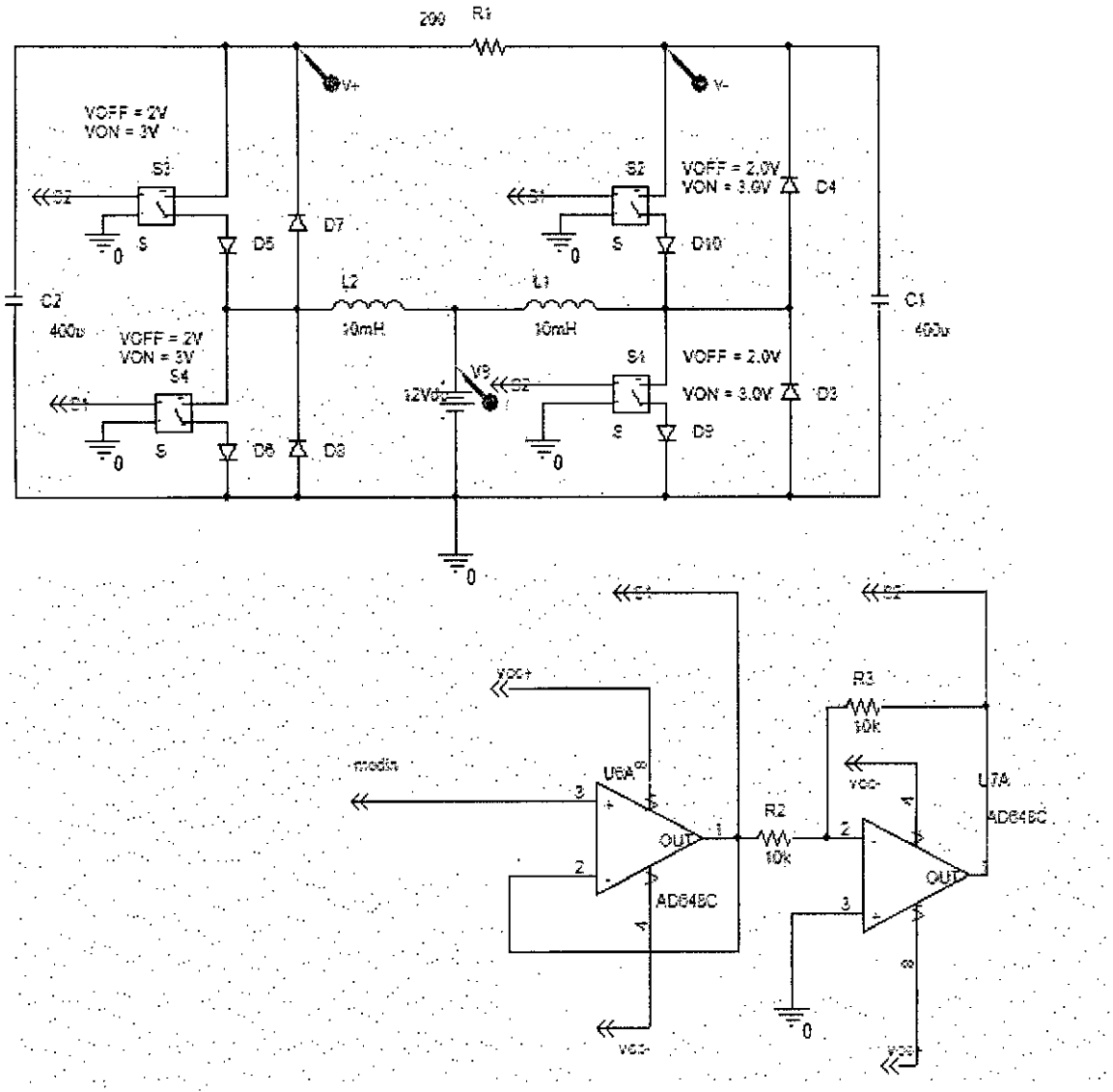
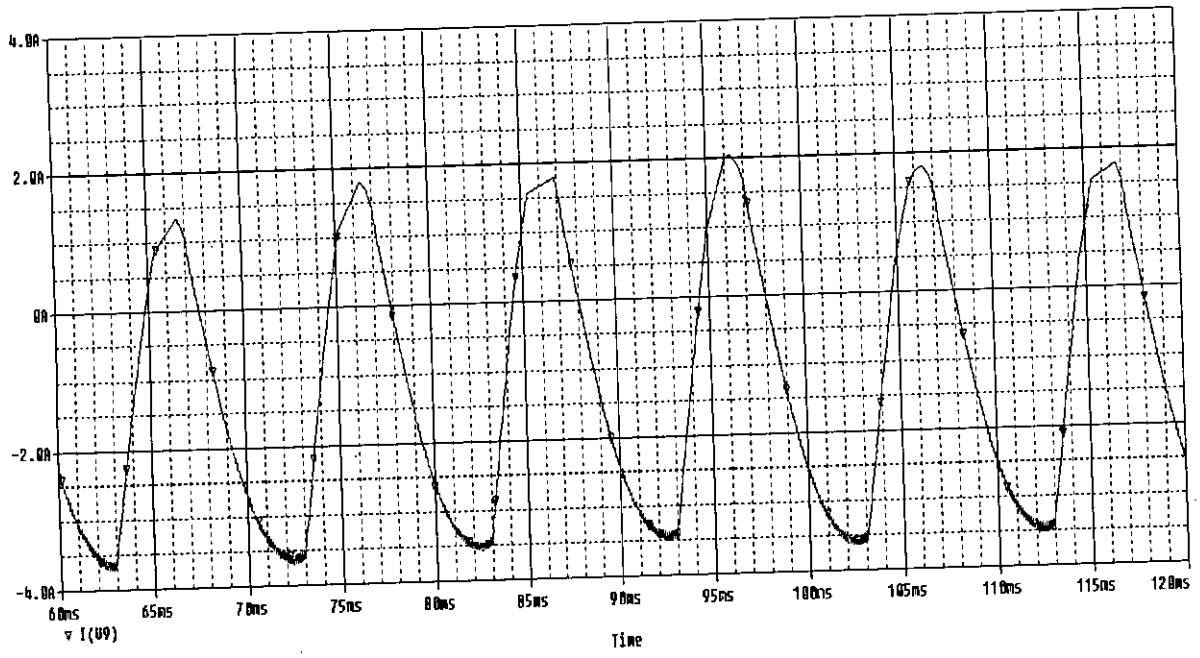
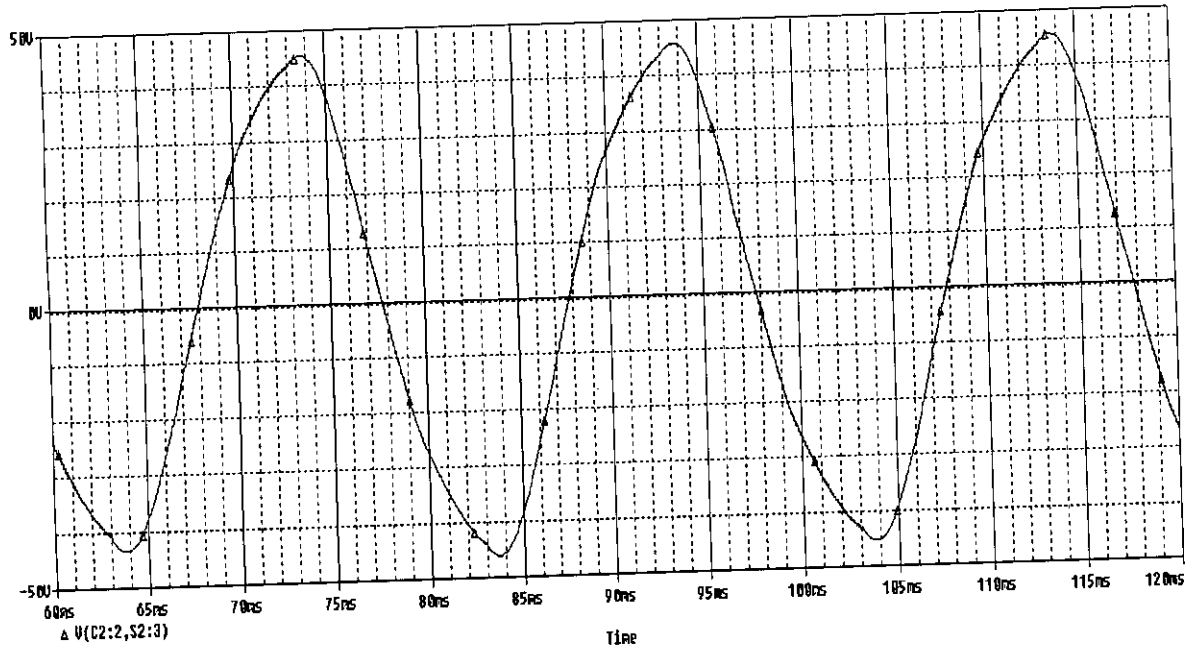


Figure 3.2: Single Phase Boost Inverter

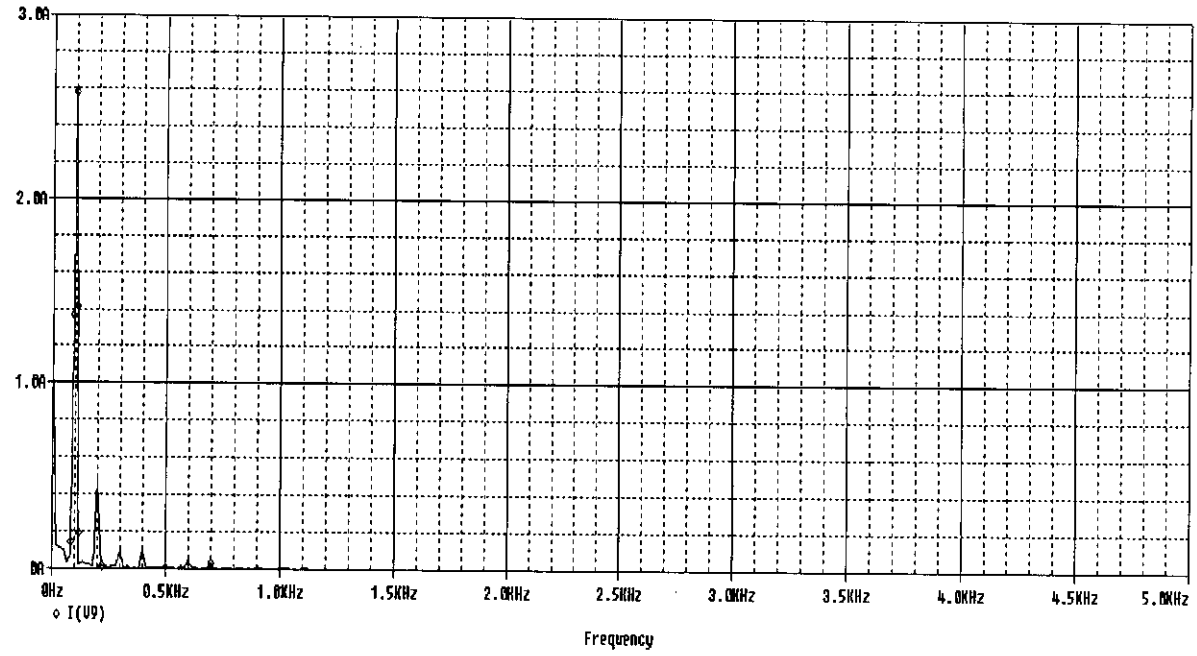


(a) Input Current

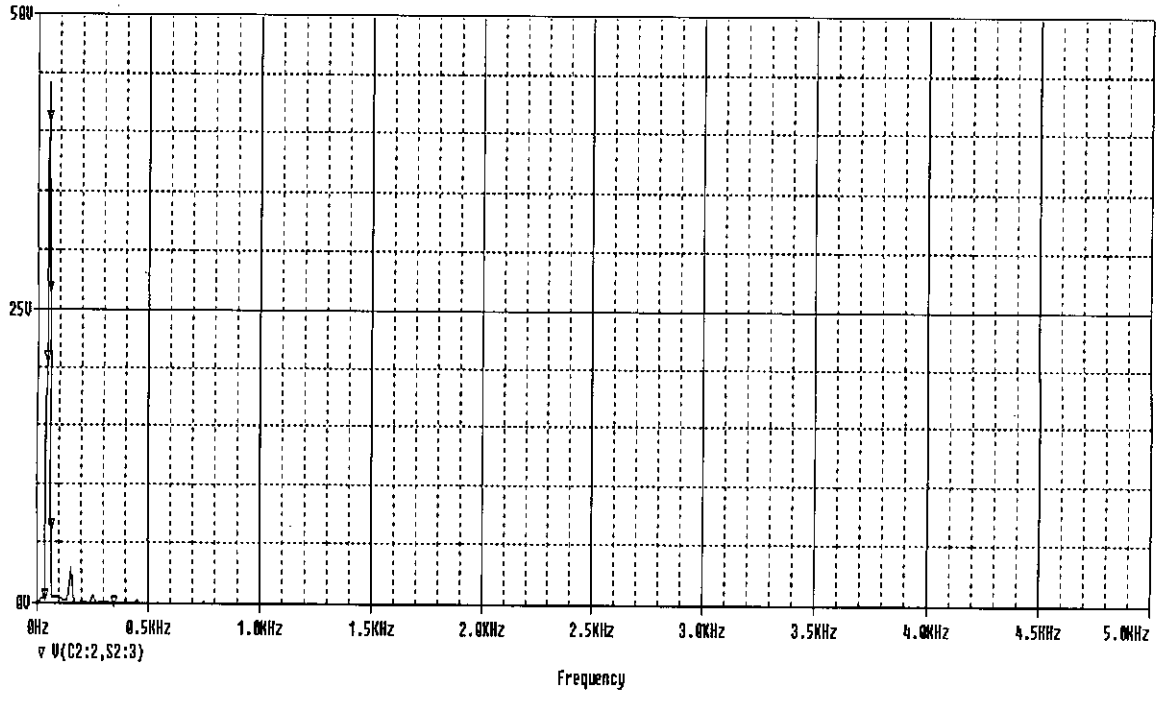


(b) Output Voltage

Figure 3.3: Input Current and Output Voltage of Single Phase Boost Inverter



(a) Spectrum of Input Current



(b) Spectrum of Output Voltage

Figure 3.4: Spectrum of Input Current and Output Voltage of Single Phase Boost Inverter

3.4 Single Phase Boost Inverter With Input Current Shaping

Single phase Boost inverter with input current shaping circuit and filters has been simulated to observe the improvement of input current shape. Figure 3.5 shows the circuit, Figure 3.6 and 3.7 show the waveshape and the spectrum of input current. Spectrum shows input current contains desired dc and 100 Hz harmonic with reduced magnitude. Harmonic of 200 Hz is eliminated. If 100 Hz harmonic has to be eliminated, a harmonic has to be eliminated, a harmonic filter can be used.

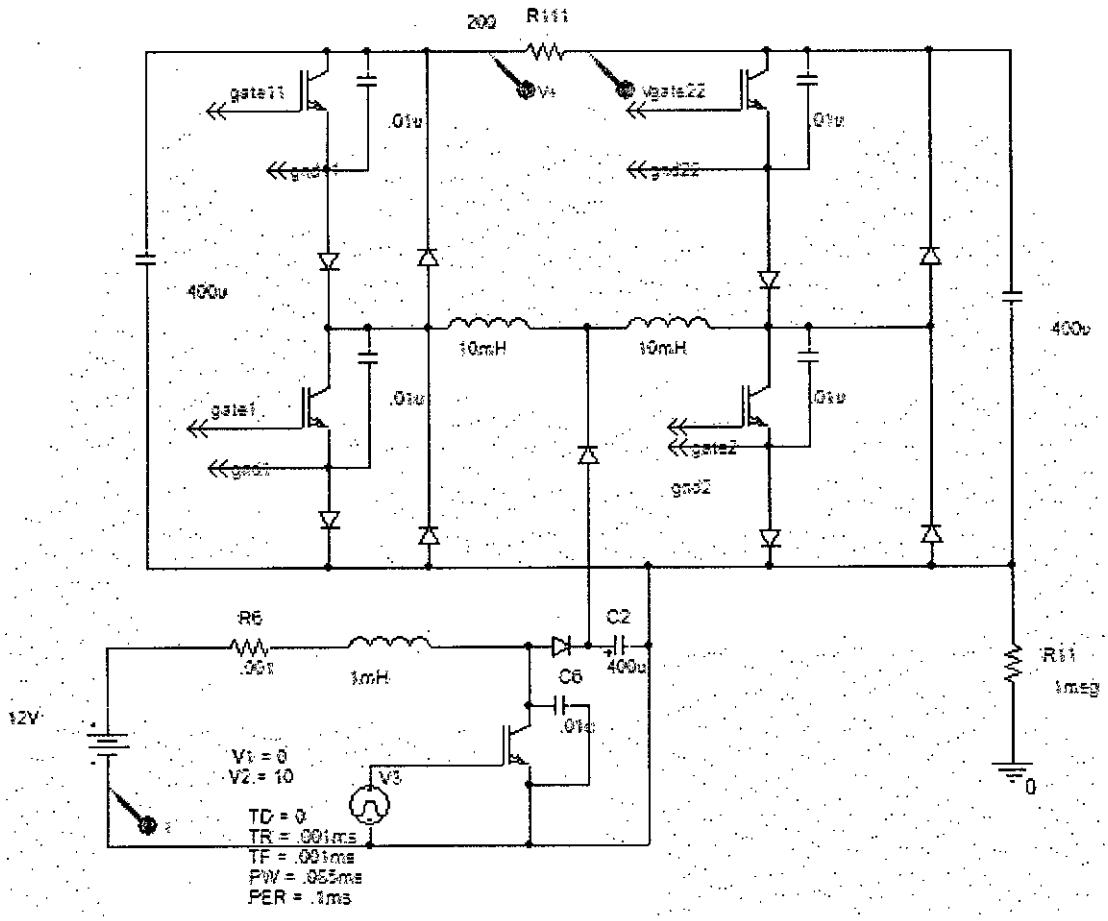
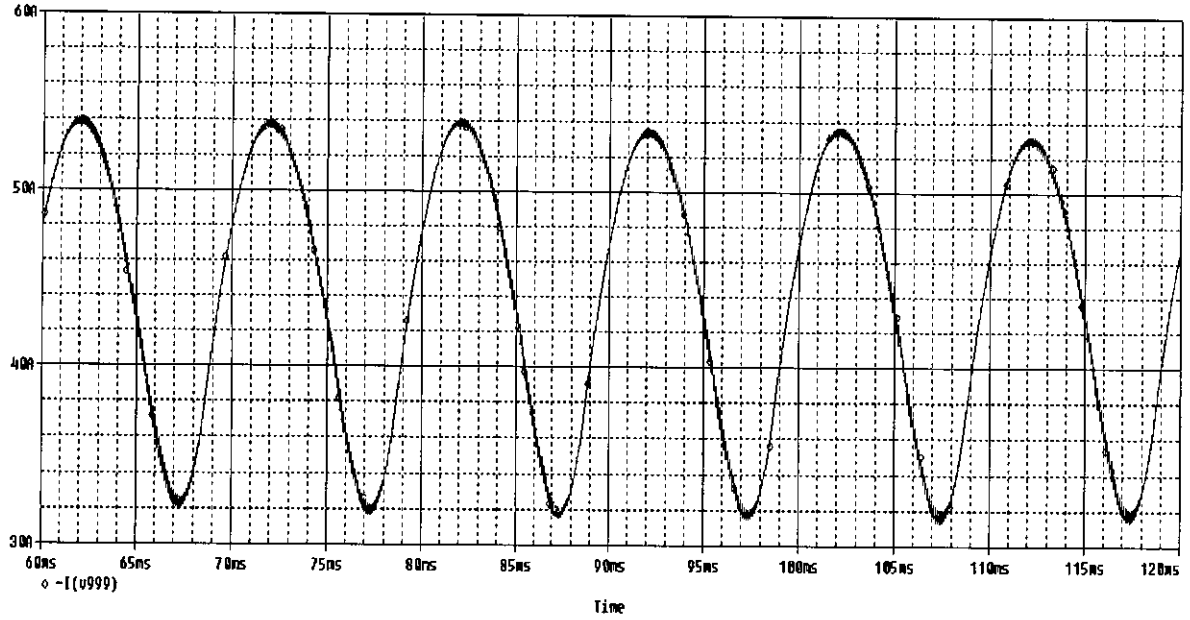
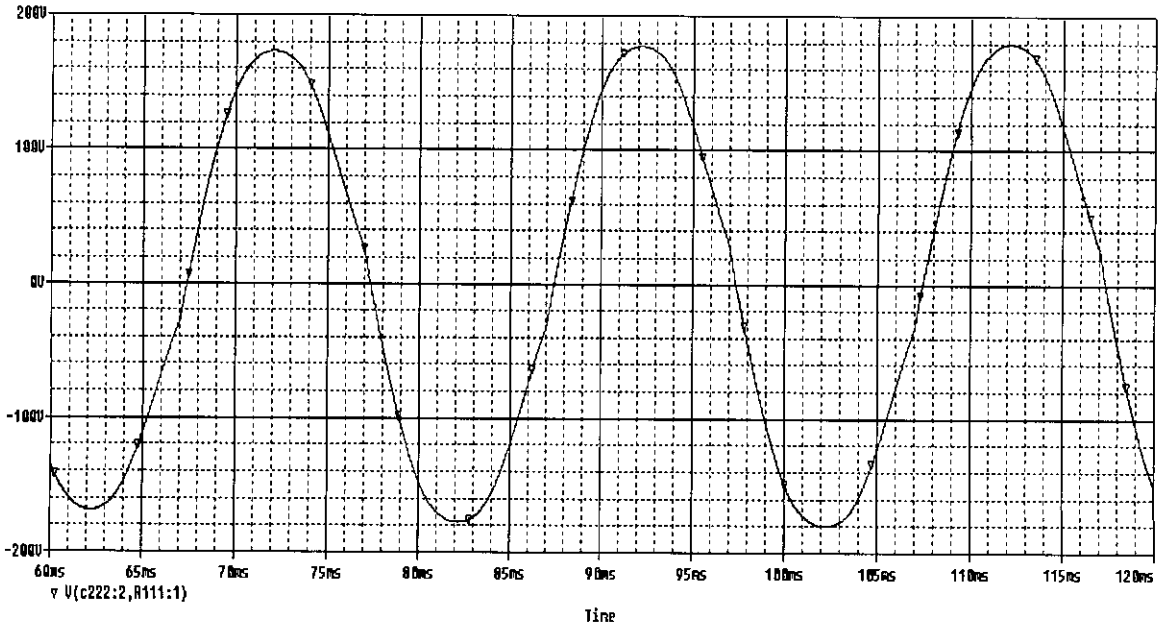


Figure 3.5: Single Phase Boost Inverter (With Active Input Current Shaping)

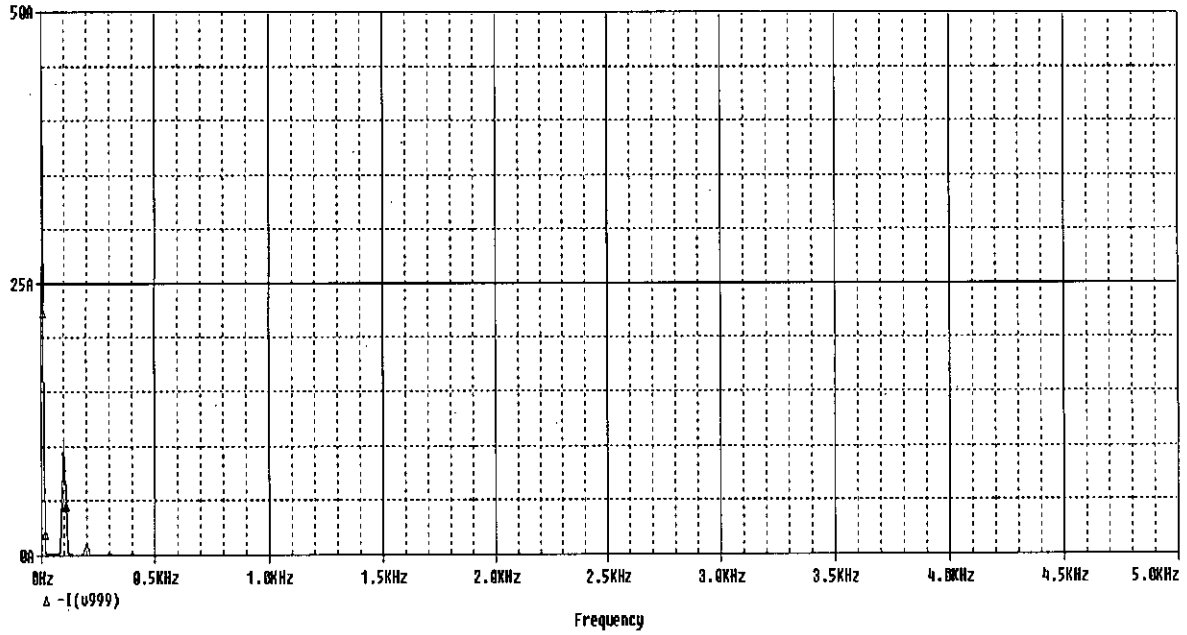


(a) Input Current

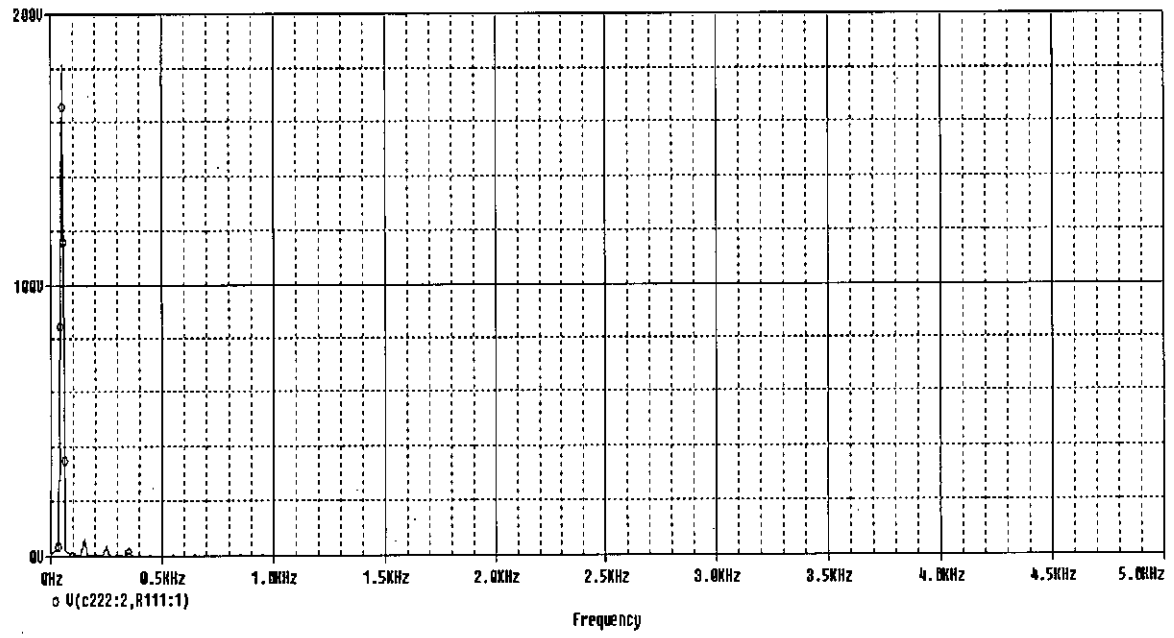


(b) Output Voltage

Figure 3.6: Input Current and Output Voltage of Single Phase Boost Inverter (With Active Input Current Shaping)



(a) Spectrum of Input Current



(b) Spectrum of Output Voltage

Figure 3.7: Spectrum of Input Current and Output Voltage of Single Phase Boost Inverter (With Active Input Current Shaping)

3.5 Three Phase PWM Boost Inverter With DC Input

Three phase PWM boost Inverter has been studied in Figure 3.8, 3.9, 3.10 and 3.11. Figure 3.9 shows the modulator of one phase of the circuit. The wavesahape of input current and its spectrum are shown in Figure 3.10 and 3.11 respectively. Spectrum shows that the input current contains dc and harmonics of 150 Hz. Using harmonic filter this harmonic can be eliminated.

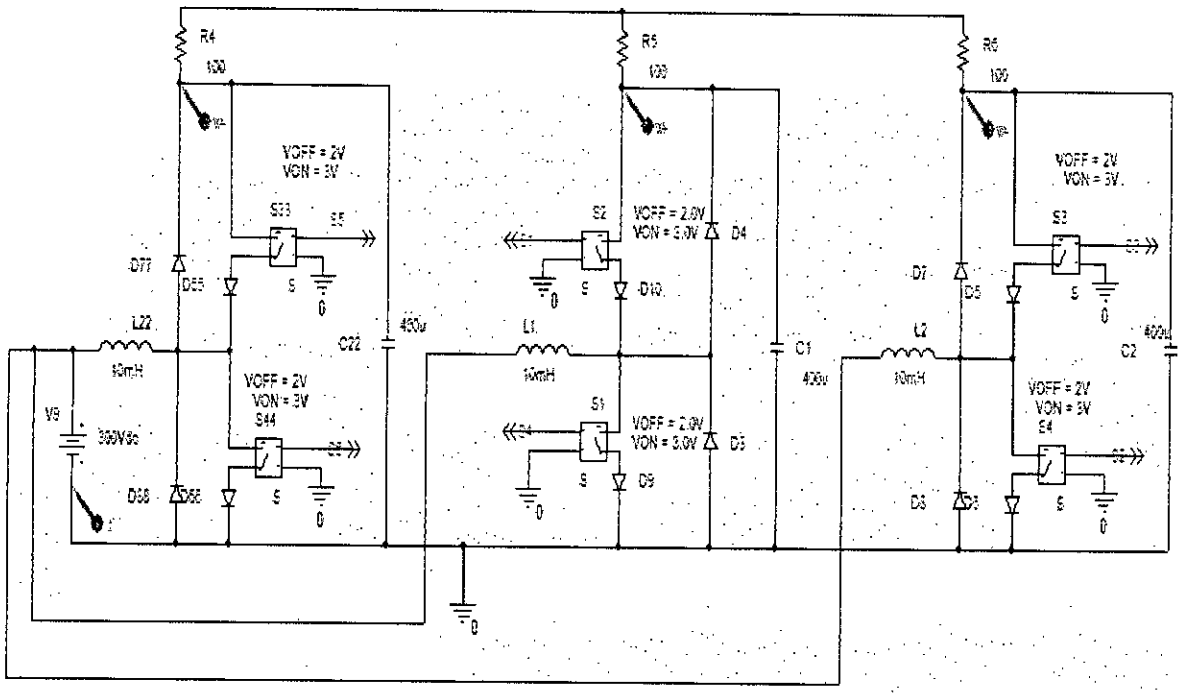


Figure 3.8: Three Phase PWM Boost Inverter Circuit (Without Input Filter)

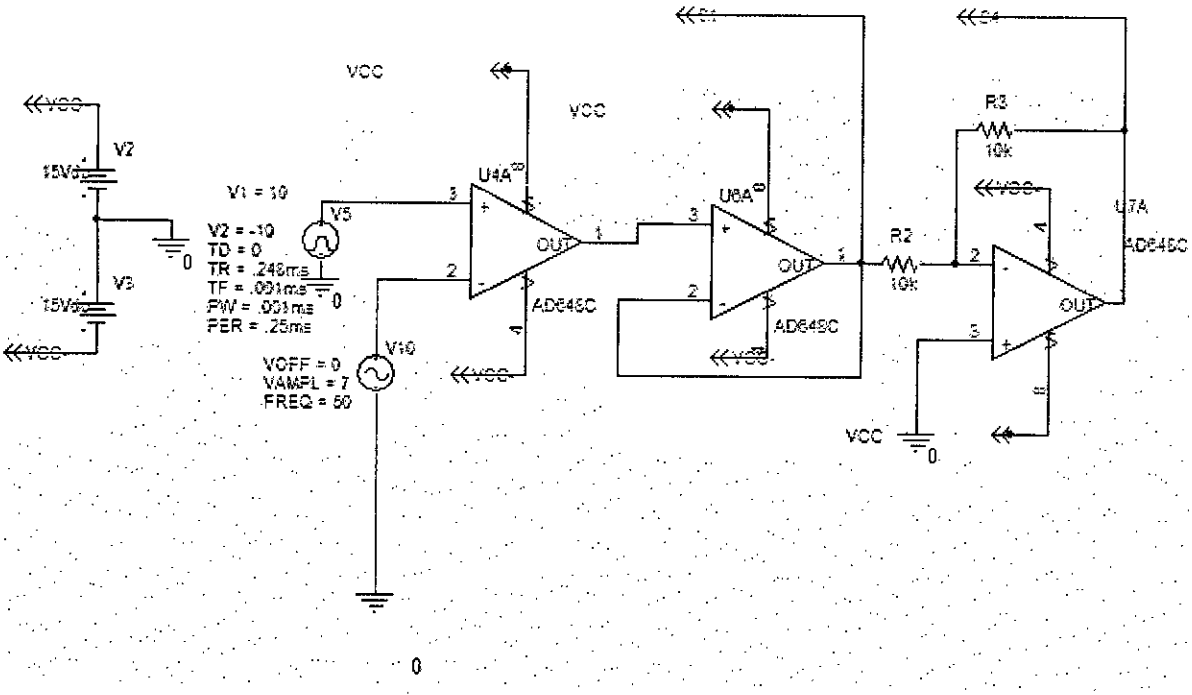
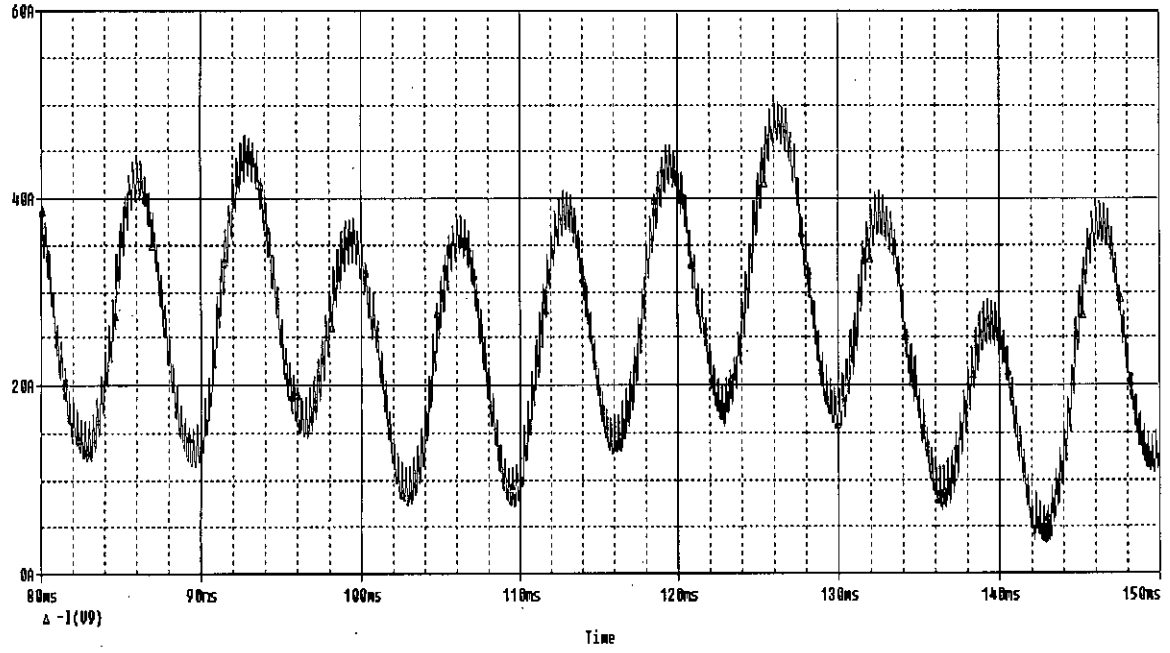
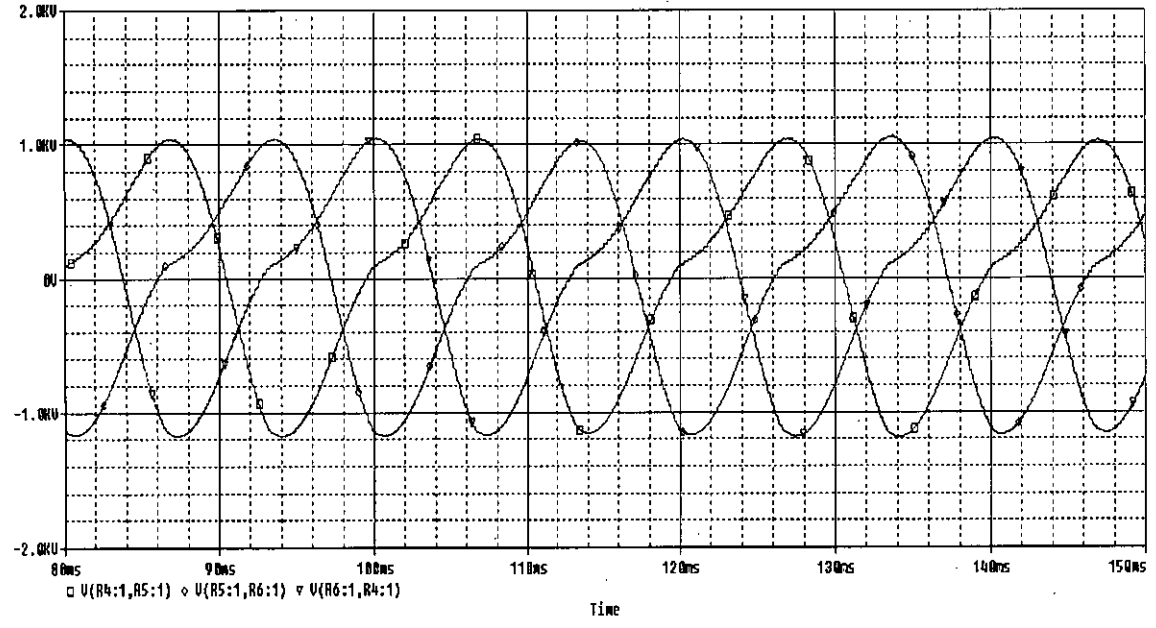


Figure 3.9: Modulator of One Phase of Three Phase PWM Boost Inverter Circuit

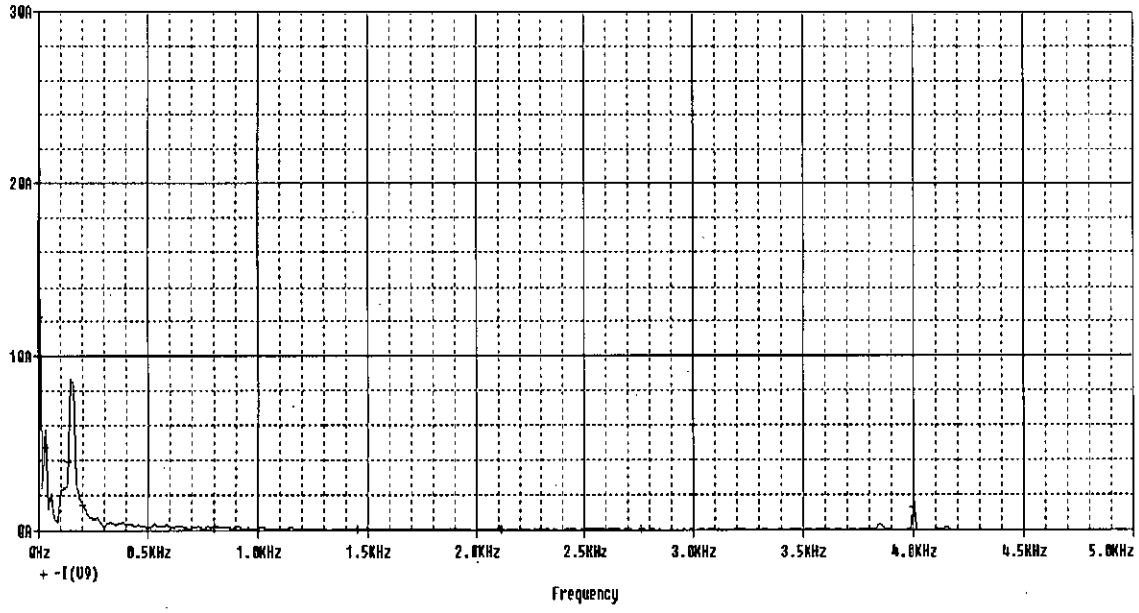


(a) Input Current

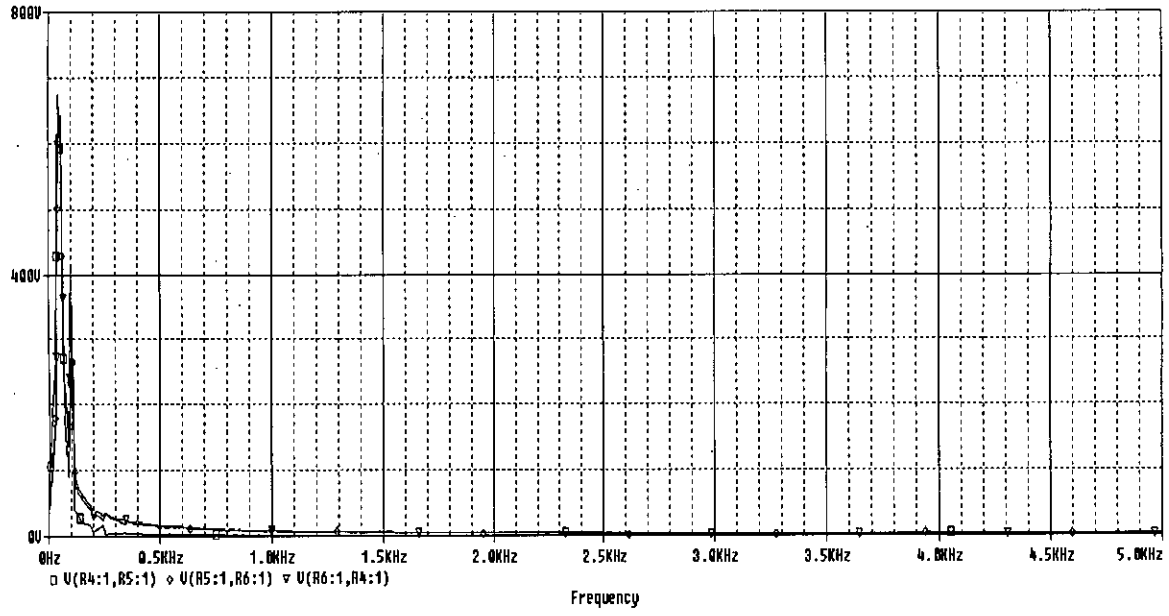


(b) Output Voltage

Figure 3.10: Input Current and Output Voltage Waveforms of Three Phase PWM Boost Inverter Circuit



(a) Spectrum of Input Current



(b) Spectrum of Output Voltage

Figure 3.11: Spectrum of Input Current and Output Voltage Waveforms of Three Phase PWM Boost Inverter Circuit

3.6 Three Phase PWM Boost Inverter with DC Input and Input Filter

Figure 3.12, 3.13 and 3.14 show the improvement of input current of three phase PWM boost inverter with DC input. 3.13 and 3.14 show the waveform and the spectrum of input current respectively. Another high frequency harmonic has been generated. To eliminate the high frequency harmonic, a harmonic filter may be used.

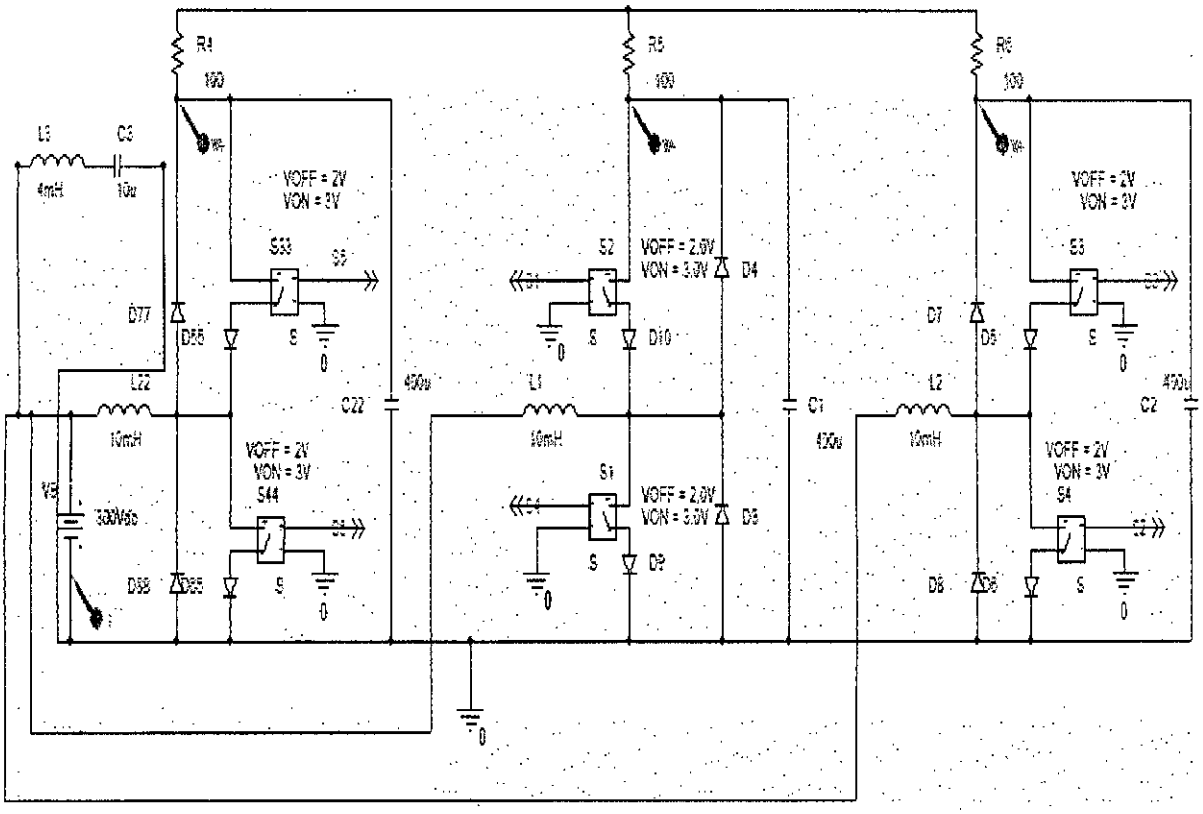
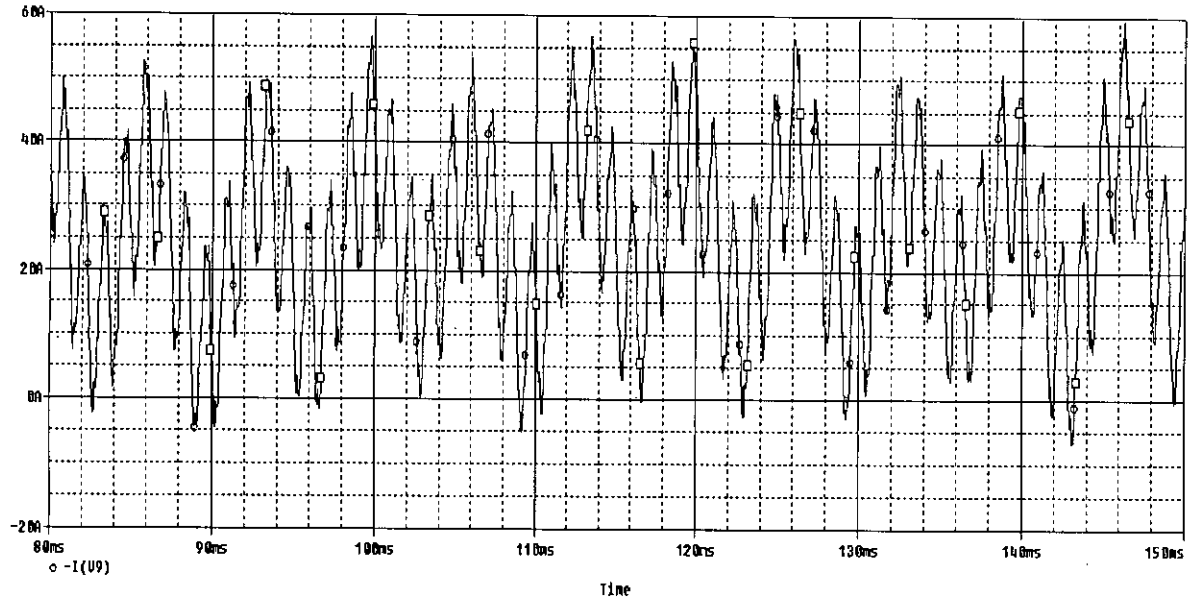
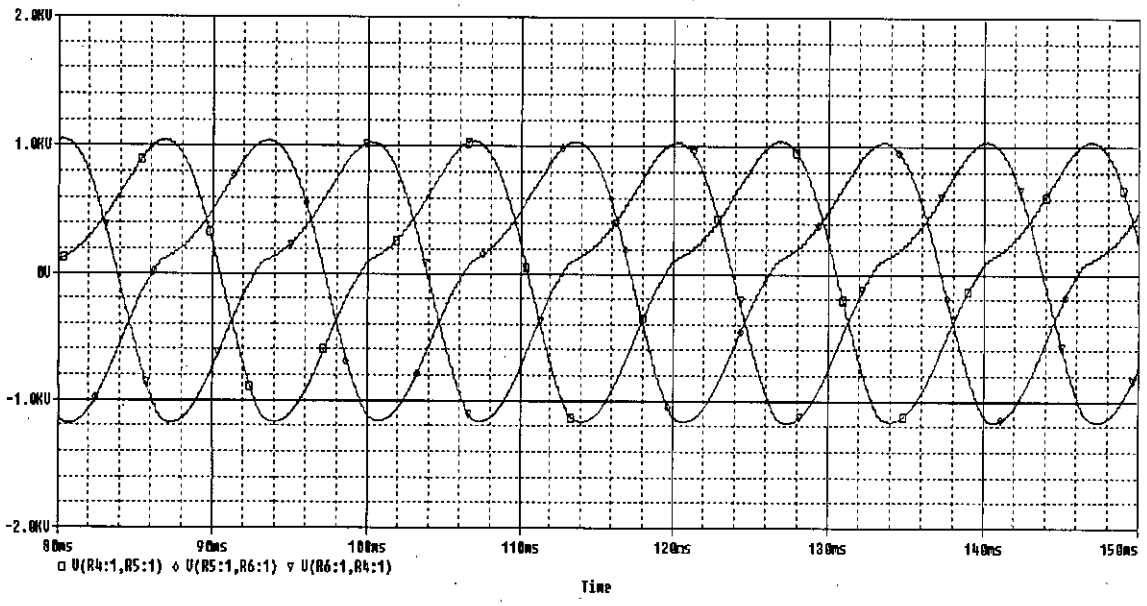


Figure 3.12: Three Phase PWM Boost Inverter With Input Current Filter

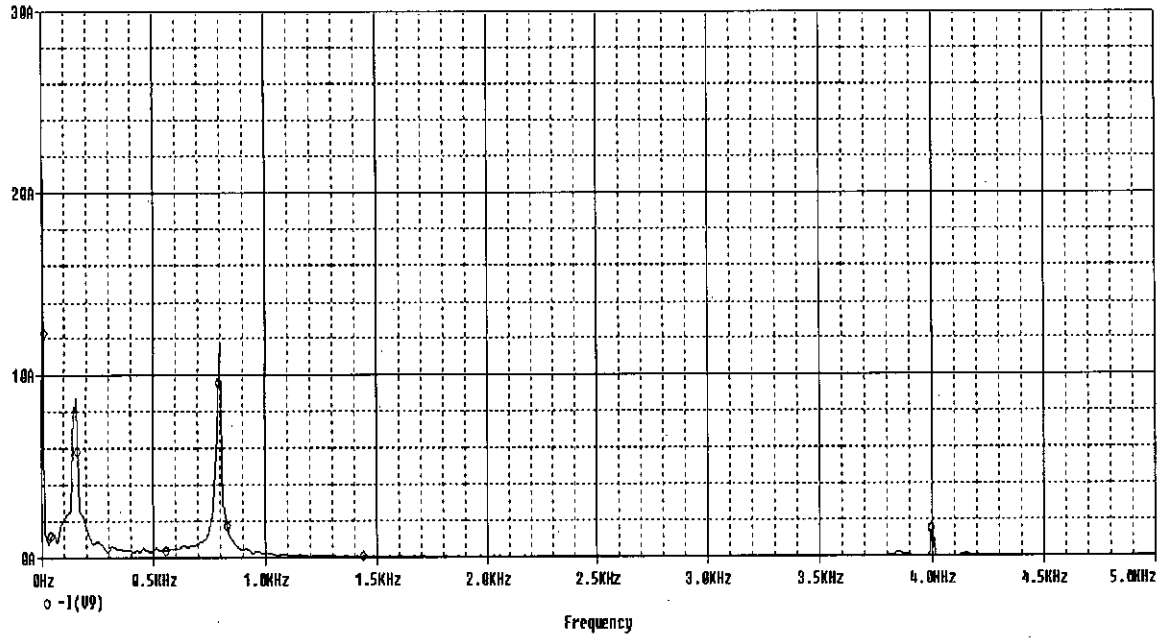


(a) Input Current

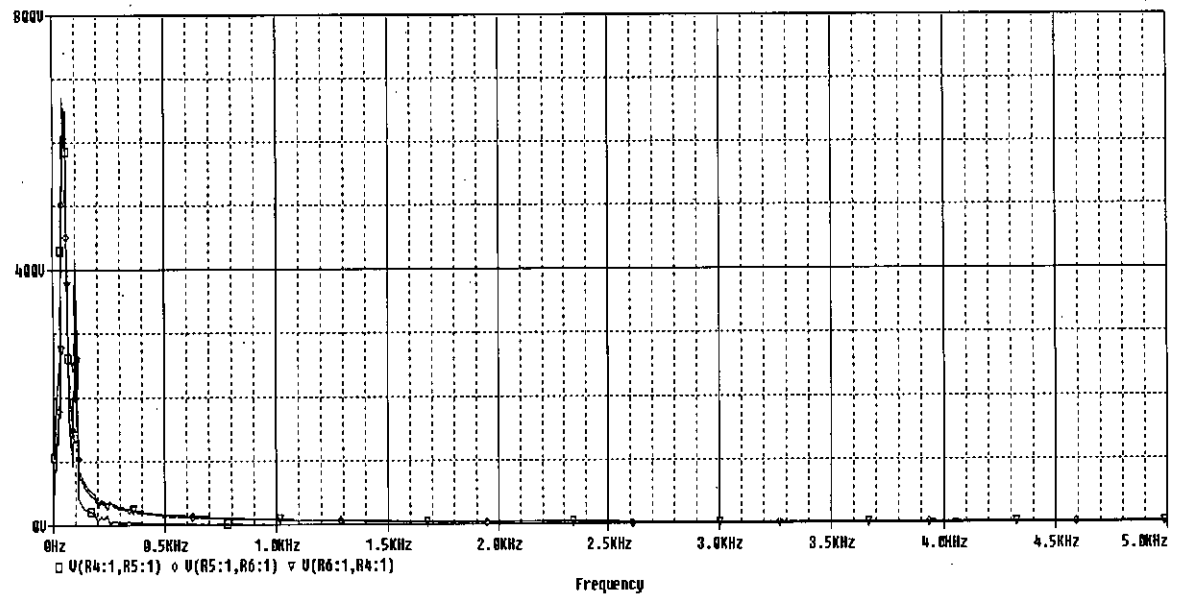


(b) Output Voltage

Figure 3.13: Input Current and Output Voltage Waveforms of Three Phase PWM Boost Inverter (With Input Current Filter)



(a) Spectrum of Input Current



(b) Spectrum of Output Voltage

Figure 3.14: Spectrum of Input Current and Output Voltage Waveforms of Three Phase PWM Boost Inverter (With Input Current Filter)

3.7 THD of AC Component of Input Current

Input current consists of DC and a ripple AC. The Ac component is distorted and its THD was calculated, which is presented in Table 3.1.

Table 3.1 : Total Harmonic Distortion of AC component of Input Current (DC-AC Boost Inverter)

Sl.	Type of Inverter	DC Component	Total Harmonic Distortion (%)
1	Single phase Boost inverter	-0.116	1.62
2	Single Phase Boost Inverter With Input Current Shaping	-3.97	1.68
3	Three Phase PWM Boost Inverter With DC Input	-2.32	1.48
4	Three Phase PWM Boost Inverter with DC Input and Input Filter	-2.80	9.73

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3.8 Three Phase PWM Boost Inverter with Rectifier Input

Practically the input of a three phase boost inverter is from the rectifier output. The three phase PWM boost Inverter with rectifier is shown in Figure 3.15. The input current waveshape and its spectrum are also shown in Figure 3.16 and 3.17 respsctively. Input current of the inverter follows the rectifier current. The current has significant numbers of harmonics.

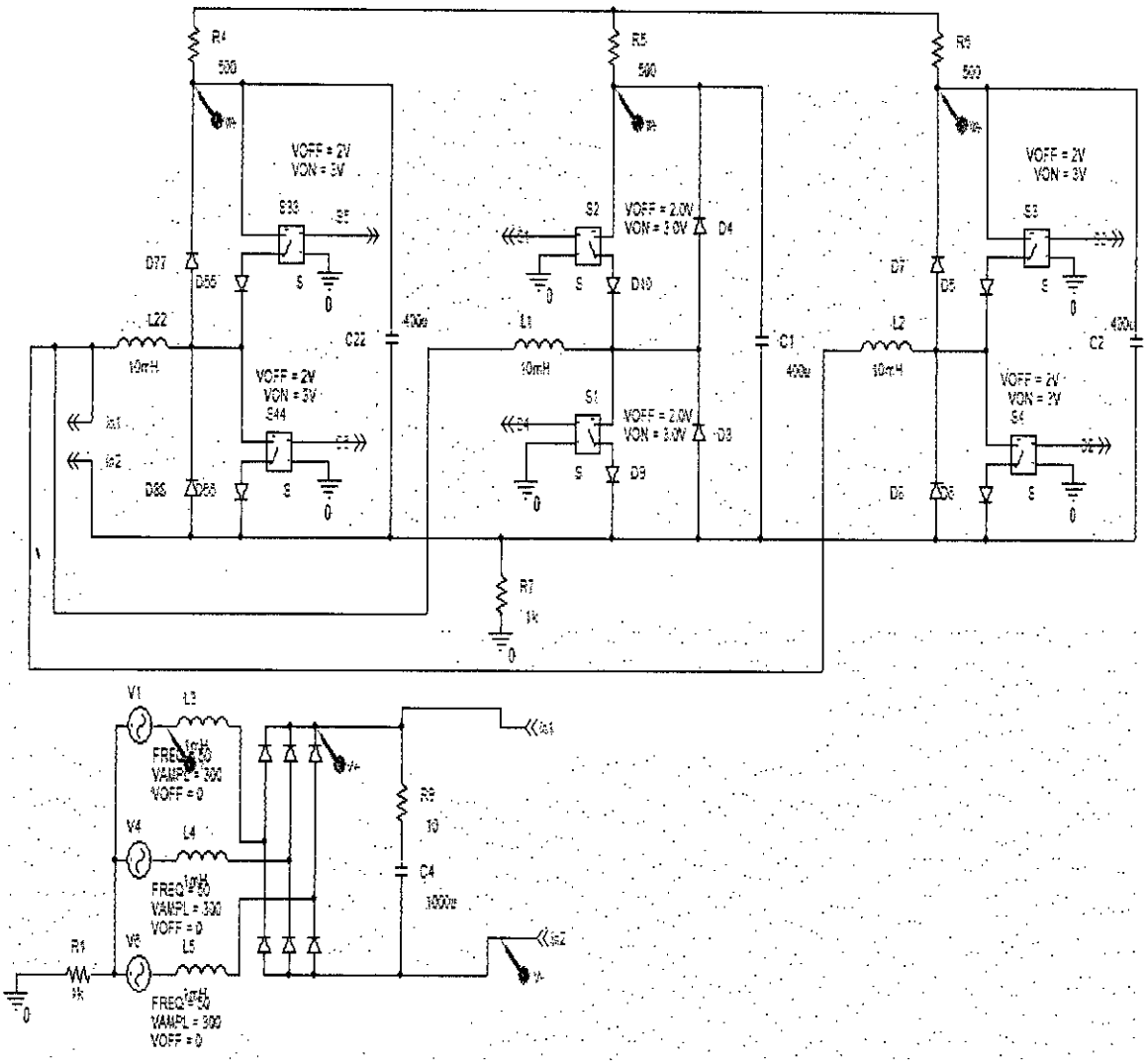
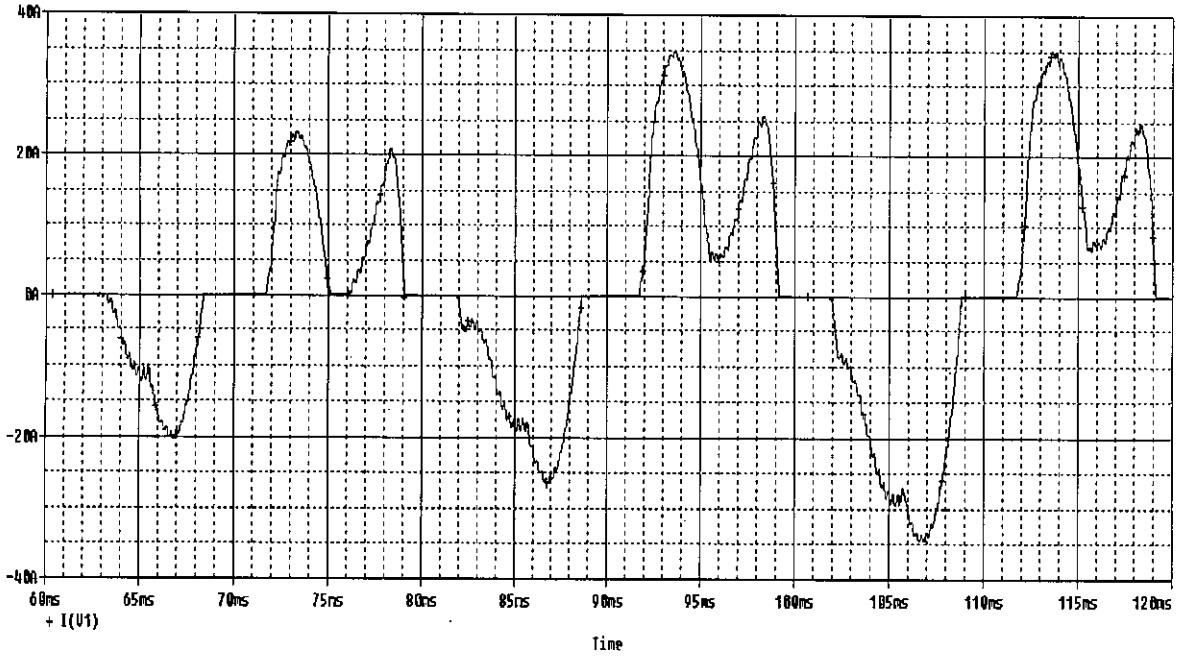
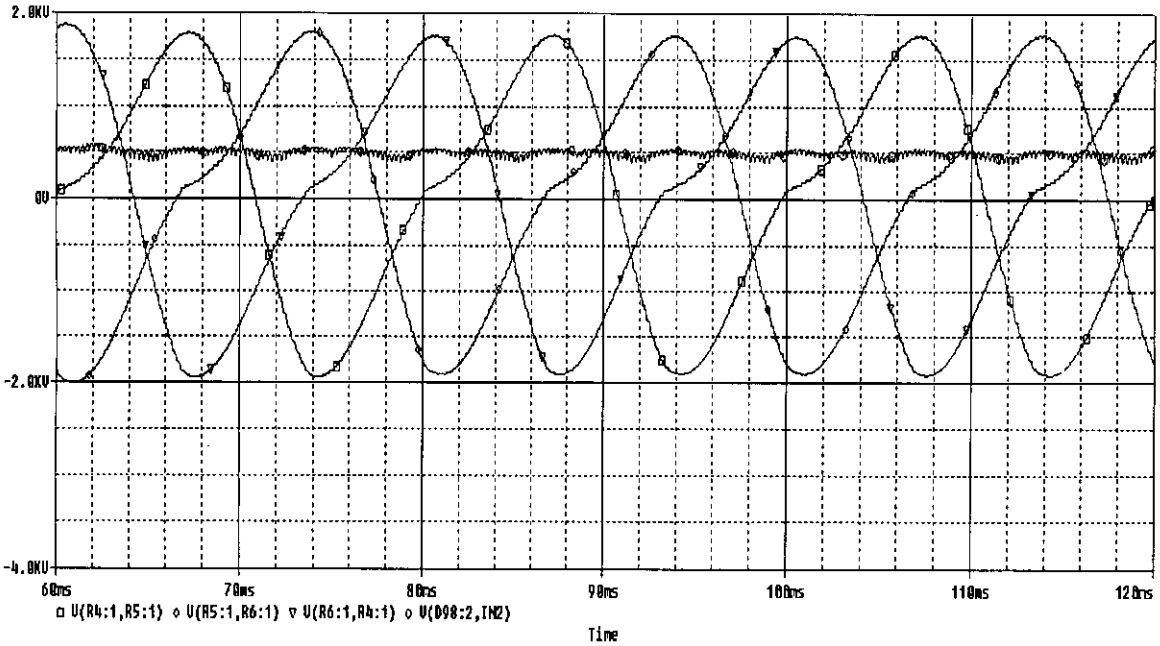


Figure 3.15: Three Phase Boost Inverter With Rectifier Input

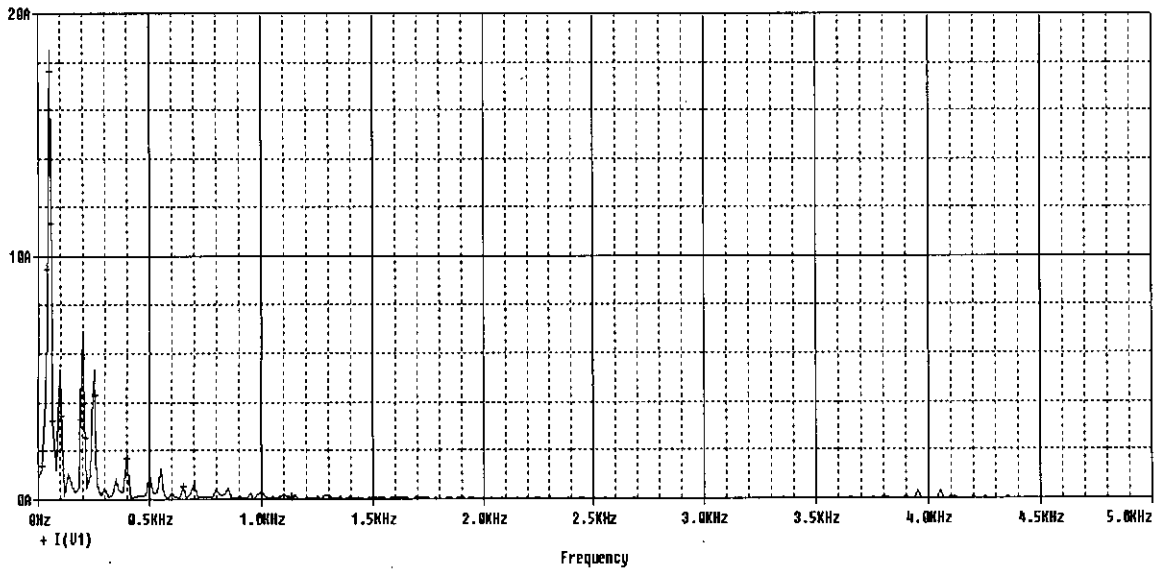


(a) Input Current

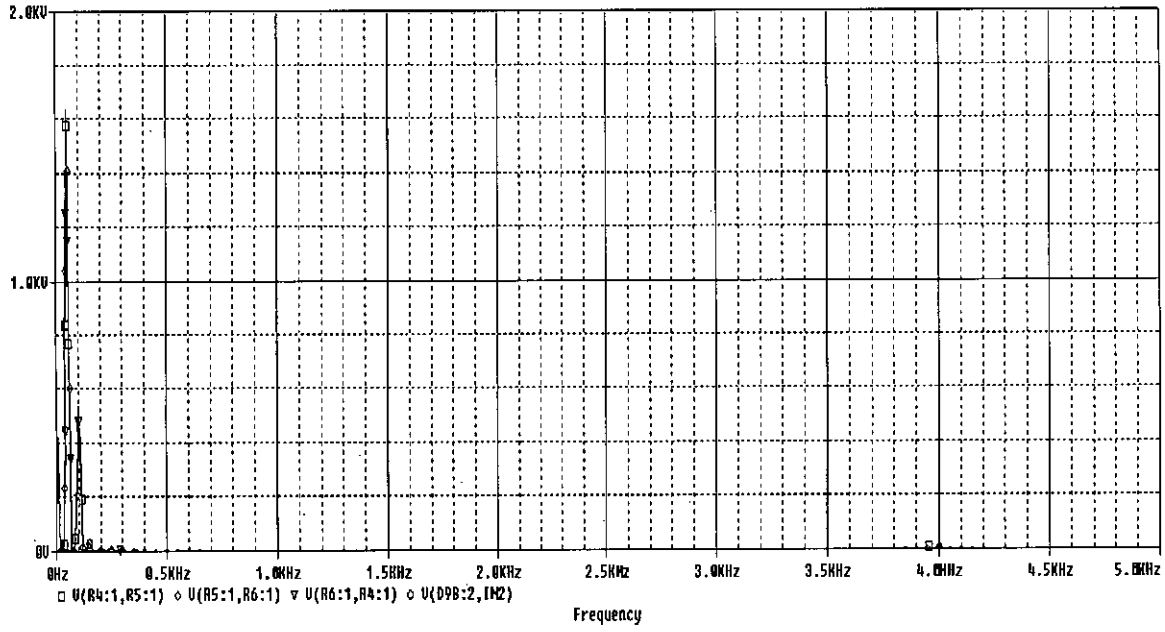


(b) Output Voltage Waveforms

Figure 3.16: Input Current and Output Voltage Waveforms of Three Phase Boost Inverter With Rectifier Input



(a) Spectrum of Input Current



(b) Spectrum of Output Voltages

Figure 3.17: Spectrum of Input Current and Output Voltage Waveforms of Three Phase Boost Inverter With Rectifier Input

3.9 Total Harmonic Distortion (THD) of AC Component of Input Current

Input current consists of AC with DC offset. THD of input current was measured and presented in Table 3.2.

Table 3.2 : Total Harmonic Distortion of AC component of Input Current (AC-DC-AC Boost Inverter)

Sl.	Type of Inverter	DC Component	Total Harmonic Distortion (%)
1	Three Phase PWM Boost Inverter with Rectifier Input	-0.34	4.82
2	Three Phase PWM Boost Inverter with Rectifier Input & Input Filter	-2.53	1.19

Chapter-4

Conclusion and Recommendation

4.1 Conclusion

The advances in the power semiconductor devices have led to the increase in the use of power electronic converters in various applications. It is very common to get AC supplies by inverting the output of a rectifier. Inverters are nonlinear blocks and hence generate harmonics, which are harmful to the appliances. As a result, development of dc to ac converters/inverters with improved waveforms has gained importance due to stringent power quality regulation and strict limit on total harmonic distortion (THD).

Pulse-width modulation (PWM) is often used to control the supply of electrical power. PWM of a signal or power source involves the modulation of duty cycle, to control the amount of power sent to a load. In this thesis we have used three phase PWM inverter, and also Active filtering method to eliminate the dominant harmonics present in the input current of an inverter.

The input current of an inverter is distorted in a great extent. Using passive filters on the input side, the harmonics or the ripple can be eliminated, but a large size of filter is needed. To reduce the size of the filter active filtering method with intermediate SMPS circuits can be used. Further harmonic filter can be used to eliminate the harmonics still exist in the input current.

Boost configuration or methodology is very helpful to reduce the harmonics of the input current. Boost configuration of PWM inverter has less harmonic distortion. It requires small filters to reduce the total harmonic distortion.

4.2 Recommendation

1. From the conclusion it is clear that the boost configuration of three phase PWM inverter is effective to eliminate the ripples of input current.

2. Further study is required to reduce THD of ac component of input current.

3. This thesis was based on the simulation software. Practical experiment was absent here because of the time constraint. The results should be verified through practical experiment.

4. Only the linear resistance was used as load. Nonlinear load must be used for proper results.

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