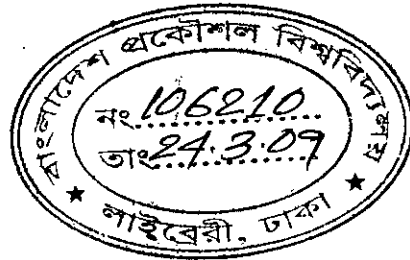
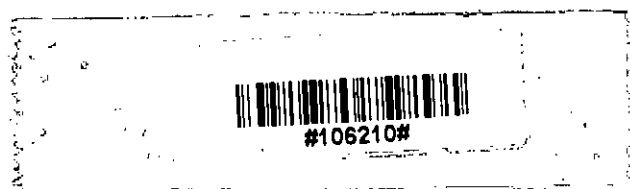


Analysis of a Cascaded Cuk Converters And A PWM Inverter For Use in A PV System



by
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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING OF
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
MARCH, 2009



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A thesis Submitted to the Department of Electrical and Electronic
Engineering of Bangladesh University of Engineering and Technology in
partial fulfillment of the Requirement for the degree of

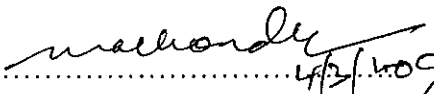
MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

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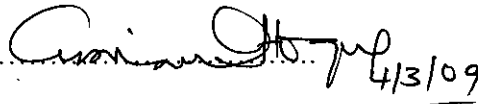
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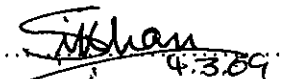
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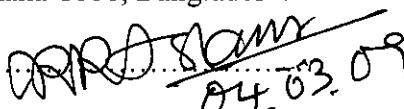
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Signature of the candidate



.....
(S. M. Shamsul Farhan)

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ABSTRACT

Conventional Photovoltaic system use low voltage appliances of 12 or 24 volt rating. Normally available 230VAC, 50Hz lamps, fans and electronics goods cannot be used in these system. In this thesis, attempt to made to design and analyze a dc-dc-ac converter to provide a 230VAC at 50 Hz from PV modules and energy storage batteries used in PV systems. DC converters are used as DC transformers to step up or step down DC voltages. Harmonics are generated at the input and load side of the converter, and these harmonics can be reduced by input and output filter. A Cuk converter increases and decreases the output voltage. In this thesis work a 12V DC to 300V boost is required. A two stages or cascaded Cuk converter is step up the DC voltage to 340V from 12V battery. Cascaded Cuk converter is used for stepping battery voltage up, which can then be converted to AC by a PWM inverter and filtered to have sinusoidal 230VAC at 50Hz. The output AC thus obtained can be regulated precisely, either by controlling the duty cycle of the cascaded Cuk converter or by controlling modulation index of the PWM inverter. The required 230VAC, 50Hz is obtained by a conventional single phase PWM inverter followed by low pass LC filter. The complete circuit has been studied by simulation in this work so as to obtain the design procedures of an integrated switch mode DC-DC-AC power converter. The study provides an integrated switching mode conversion of 12VDC to 230VAC at 50 Hz which will allow conventional appliances of 50 Hz, 230VAC to be used in domestic photovoltaic system.

LIST OF ABBREVIATION

SMPS = Switch Mode Power Supply

MOSFET = Metal Oxide Semiconductor

IGBT = Insulated Gate Bipolar Transistor

PWM = Pulse Width Modulation

OPAMP = Operational Amplifier

RMS = Root Mean Square

PV = Photovoltaic

W = Watt

D = Duty cycle

T = Period

P_0 = Output power

M_v = Voltage gain

f = frequency

V_0 = Output Voltage

V_d = Input dc voltage

V_c = Capacitor voltage

V_L = Inductive voltage

I_L = Inductive current

I_c = Capacitor current

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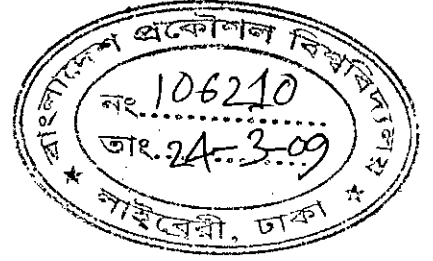
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CHAPTER – 1

INTRODUCTION



1.1 INTRODUCTION

Photovoltaic systems (PV) convert light energy to electrical energy in dc form. In many PV systems, this direct current electrical energy is used for lighting, remote area communication equipment supply or other uses. However, if the converted energy is to be used with conventional 120VAC or 230VAC having 50 or 60 Hz, it is necessary that DC output obtained be used for supply energy storage and conversion of the same to higher voltage dc and its conversion to ac of desired magnitude and frequency. This may be achieved in many ways. Common methods are dc-ac conversion at low voltage at desired frequency and conversion of ac voltage by step up transformer, or DC-DC conversion to have high voltage DC and then DC-AC conversion by inverter. The second methods provide a lighter and efficient solution as it requires no transformer. But most of the time conversion of dc-dc from very low voltage to moderate voltage requires DC-DC conversions' to operate at high duty cycle. But at high duty cycles DC-DC converter are inefficient. In this research cascaded DC-DC converter, particularly the cascaded Cuk converter and its modified version has been proposed and investigated as an alternative to presently used techniques in this area.

1.2 LITERATURE REVIEW

In this section a literature review, on the basic operation of the solar home system, DC-DC converter, PWM inverter and the control techniques commonly used are provided.

1.2.1 PHOTOVOLTAIC SYSTEM AND SOLAR HOME SYSTEM

Semi conductors that convert solar energy directly into electricity are called photovoltaic (PV) devices or solar cells. Although there are about 30 different types of PV devices under development, there main technologies in commercial production are monocrystalline cells, polycrystalline cells and thin-film cells [1].

Monocrystalline-or single crystal solar cells are generally the most efficient at converting solar energy into electricity.. There are two types of Monocrystalline, they are LGBG (laser grooved buried grid) and screen- printed Monocrystalline dark gray cells. In LGBG dark blue cell, narrow grooves are formed in the top wafer surface using a laser and plated with copper to form a conductive grid. The shadowing of the top surface is less than with screen- printed contacts allowing more of the incident light to be collected. Improved light collection is also achieved through the inclusion of antireflection coating and selective phosphorus doping of the silicon in the groove minimizing resistive losses. This results in a 20% increase in output power for a given cell area. This kind of cells efficiency levels is 17% and module power (w/m^2) at STC (standard test conditions) is 150 w/m^2 . In screen printed cells solar cells are made form p-type silicon wafers. The top surface of the wafer is doped with phosphorus creating a P/N junction, which attracts free electrons liberated when light is absorbed by the silicon. Metallic silver contacts are screen printed to the top and bottom surfaces of the wafer to enable connection to external electrical circuit. Commercial screen- printed solar cell typically convert 12-14% of the incident solar energy to electrical energy and module power (w/m^2) at STC (standard test conditions) is 130 w/m^2 .

Polycrystalline solar cells are cut form a block of lower quality multi-crystalline silicon and are less efficient but less expensive to produce. The screen-printed multycrystalline dark blue cells efficiency is 13% having module power (w/m^2) at STC (standard test conditions) 120 w/m^2 . [1]

Thin solar cell is manufactured in a process that is similar to tinting glass. These solar cells are made of semiconductor material deposited as a thin-film on substrate such as glass or aluminum. Thin-film solar cells are generally less than half as efficient as mono and polycrystalline cells but much less expensive to produce. They are widely used for powering a wide range of consumer devices. Thin film black – with no transmission cell efficiency is 7% and module power (w/m^2) at STC is 67 w/m^2 . Thin-film with 10% light transmission's cell efficiency is and module power (w/m^2) at STC is 63 w/m^2 .

Solar cells are encapsulated into modules, several of which are combined into an array. There is however, a growing market of “building-integrated” modules PV devices that are manufactured part of as system may also include energy storage devices (usually batteries), support frames, and electronic controllers. These are collectively referred to as the balance-of-system [BOS].

The amount of power from a PV array is directly proportional to the intensity of light hitting the array. Photovoltaic array produces direct current (DC) electricity. They can be configured to produce any required combination of voltage and converted to conventional residential alternating current (AC) voltages.

There are currently about 400,000 photovoltaic systems [1] in operation worldwide. Applications range from consumer products and small scale stand –alone units for rural use (e.g. solar home system) to grid- connected roof top systems and large central grid power stations.

Typical system size varies from 50W to 1KW for stand –alone systems with battery storage. From 10 kW to megawatts for grid-connected ground-based systems and larger building-integrated systems also exist.

As solid state devices have no moving parts, photovoltaic modules have a demonstrated record of durability and reliability. PV modules will operate for 30 years and are sold with 10-20 year manufacturer warranties. Although PV modules themselves require little

maintenance, other BOS components may require more maintenance-particularly batteries.

In the case of stand-alone systems, the value of electricity is of the value of the service that is providing by the PV system. This value is determined by the cost of providing the service by an equivalent alternative.

For such systems comparisons between PV and other energy supply options should be done on the basis of 'running cost' (fuels, O&M, depreciation interest, etc) because PV system generally have a low running cost (as the 'fuels' is solar energy) but a high capital costs.

A Solar Home System (SHS) consists of: [Fig 1.1]

- Solar module or solar panel,
- Charge control unit,
- Storage battery,
- Cables,
- Electric load and
- Support structure.

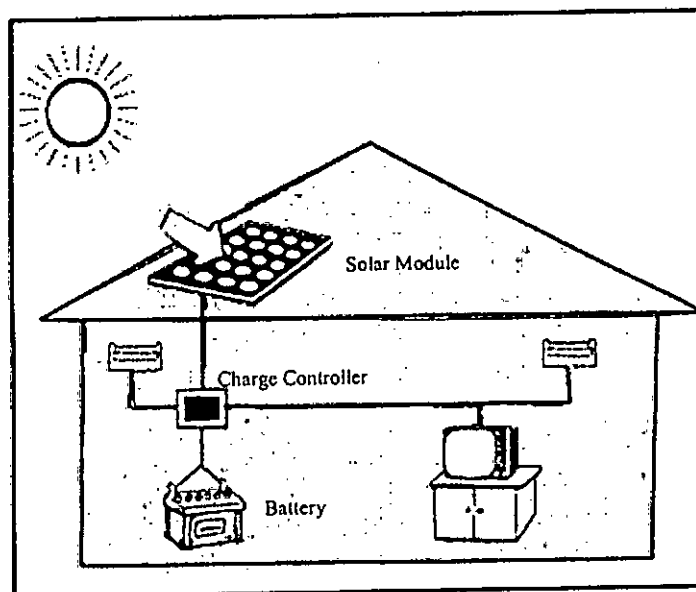


Fig. 1.1 Components of a Solar PV Home System

1.2.1.1 SOLAR SYSTEM

Solar cells

Solar cells receive the Sun's energy and convert it to electricity. The electricity that is produced by the light of the Sun is called solar electricity. The light of the Sun falls on a large thing like a binding picture directly; its name is solar panel. If the light of the sun falls on it, the voltage is created like a battery and the connected cable finds the electricity, to a storage battery. The produced electricity is supplied to the equipments (ie. TV, light fan etc) from this battery.

Solar Panel:

The main part of solar electricity production is the solar panel. A solar cell is made of silicon. When many solar cells are arranged side-by-side and coated within a clear glass frame, then it is called a solar panel. Solar panels arranged side-by-side are called a solar array.

Setting of panel:

Panel setting is dependent on geographical location. In our country it should be on the roof, on poles or on ground where no shadow occurs. The panel is set south facing at a 24° – 34° angle. The more sunlight falls on it the more electricity one will get. The panel setting angle must be accurate. In our country the panel setting must be south facing.

Battery:

Batteries are needed for storage of the solar electricity for use when sunlight is not available. It is a sensitive part in a solar electricity system. If proper care is not taken then it can be damaged easily. The battery bank consists of one or more solar deep-cycle batteries.

Charge controller:

Charge controller is the part that would protect the battery from excessive charging and also from control the charging of battery as prescribed. When the battery discharging then the charge controller also control lower cut off voltage or protect the battery from deep discharged. The charge controller has some indicator to indicate to know the condition of the battery during the charge and discharge.

Wiring and Load

Selecting the correct size and type of wire will enhance the performance and reliability of these systems. The size of the wire must be large enough to carry the maximum current expected without undue voltage loss.

The appliances and devices (such as light, TV's, computer etc.) that consume electrical power are called loads.

1.2.2 REVIEW OF CONVENTIONAL DC - DC CONVERTER

The DC-DC converters are widely used in industrial applications and computer hardware circuits, and the DC-DC conversion technique has been developed very quickly. Since the 1950s there has been five generation of DC-DC converters developed. They are the first-generation (classical) converters, second-generation (multi-quadrant) converters, third - generation (soft - switching) converters, and fifth- generation (synchronous rectifier) converters [2-11]. According the circuit topologies DC voltage can be converted by the following converter configurations:

- a. Buck ,
- b. Boost ,
- c. Buck- Boost,
- d. Cûk and
- e. Luo converter

1.2.2.1 BUCK CONVERTER

A **buck converter** [11] is a step-down DC to DC converter. Its design is similar to the step-up boost converter, and like the boost converter it is a switch-mode power supply that uses two switches (a transistor and a diode) and an inductor and a capacitor.

The simplest way to reduce a DC voltage is to use a voltage divider circuit, but voltage dividers waste energy, since they operate by bleeding off excess voltage as heat; also, output voltage isn't regulated. A buck converter, on the other hand, can be remarkably efficient (easily up to 95% for integrated circuits) and self-regulating, making it useful for tasks such as converting the 12-24V typical battery voltage in a laptop down to the several volts needed by the processor.

1.2.2.2. BOOST CONVERTER

Boost converter (step-up converter) [11] is a power converter with an output dc voltage greater than its input dc voltage. It is a class of switching-mode power supply (SMPS) containing at least two semiconductor switches (a diode and a transistor) and at least one energy storage element. Filters made of inductor and capacitor combinations are often added to a converter's output to improve waveforms.

1.2.2.3 BUCK- BOOST CONVERTER

The **Buck-Boost Converter** [11] is a type of DC-DC converter that has an output voltage magnitude that is either greater or less than the input voltage. It is a switch mode power supply with a similar circuit topology to the boost converter and the buck converter. The output voltage is adjustable based on the duty cycle of the switching transistor. One possible drawback of this converter is that the switch does not have a terminal at ground; this complicates the driving circuitry. Also, the polarity of the output voltage is opposite of that of the input voltage. Neither drawback is of any consequence if the power source is isolated from the load circuit (if, for example, the source is a battery) as the source and diode can simply be reversed and the switch moved to the ground side.

1.2.2.4 CŪK CONVERTER

The CŪk converter [11] [16-20] is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude, with an opposite polarity. It uses a capacitor as its main energy-storage component, unlike most other types of converter which use an inductor.

1.2.2.5 LUO CONVERTER

Luo converters [2] are developed by Fang Lin Luo. He has created nine series converters, and they are as follows,

- (a) Positive output Luo-converter,
- (b) Negative output Luo-converter,
- (c) Double output Luo-converter,
- (d) Multiple-quadrant Luo-converter,
- (e) Switched capacitor multiquadrant Luo-converter,
- (f) Switched inductor multiquadrant Luo-converter,
- (g) Multiquadrant ZCS quasi-resonant Luo-converter,
- (h) Multiquadrant ZVS quasi-resonant Luo-converter and
- (i) Synchronous rectifier dc/dc Luo-converter.

1.2.3. Pulse Width Modulation (PWM) Basics

There are many forms of modulation [3], [21-30] used for communicating information. When a high frequency signal has amplitude varied in response to a lower frequency signal we have AM (amplitude modulation). When the signal frequency is varied in response to the modulating signal we have FM (frequency modulation) . These signals are used for radio modulation because the high frequency carrier signal is needed for efficient radiation of the signal. When communication by pulses was introduced, the amplitude, frequency and pulse width become possible modulation options. In many power electronic converters where the output voltage can be one of two values the only option is modulation of average conduction time.

In power conversion by static converters, following modulation techniques are usually used,

Linear Modulation: The Simplest modulation is where the average ON time of the pulses are varied proportionally with the modulating signal. The advantage of linear processing lies in the ease of de-modulation. The modulating signal can be recovered from the PWM by low pass filtering.

Triangular PWM: The simplest analog form of generating fixed frequency PWM is by comparison with a linear slope waveform such as a triangular wave with the modulating wave. Here the output signal goes high when the modulating (sine) wave is higher than the triangular wave. This is implemented using a comparator whose output voltage goes to a logic HIGH when the input is greater than the other.

Regular Sample PWM : The triangular carrier PWM generates a switching edge at the instant of crossing of the sine wave and the triangle. This is an easy scheme to implement using analog electronics but suffer the imprecision and drifts inherent in all analog computation, as well as, having possibility of generating multiple edges when the signal has even a small added noise. Many modulators are now implemented digitally but there is difficulty in computing the precise intercept of the modulating wave and the carrier. Regular sampled PWM makes the width of the pulse proportional to the value of the modulating signal at the beginning of the carrier period.

There are many ways to generate a Pulse Width modulated signal other than fixed frequency sine saw tooth. For three phase systems the modulation of a Voltage Source Inverter can generate a PWM signal for each phase leg by comparison of the desired output voltage waveform for each phase with the same triangular wave. One alternative which is easier to implement in a computer and gives a larger modulation depth is using space vector modulation.

1.3 OBJECTIVE OF THE THESIS

The objective of the thesis is to investigate the possibility of making an integrated switch mode DC-DC-AC power control. Common domestic photovoltaic systems are used to power lights, fan, TVs at low voltages. Standard solar panels are used to charge 12 volts batteries. As a result, the common appliance of 230VAC of 50 Hz rating cannot be used. Our objective is to modify dc-dc converter to make it possible to have converted to supplies of 230VAC, 50 Hz. One of the dc-dc conversion having both step up/ step down capability is the Cûk conversion. The proposed circuit consists cascaded Cûk converter used for battery voltage step up, which can be converted to ac by a PWM inverter and filtered to have sinusoidal 230VAC at 50 Hz.

In this thesis attempt has been to make to design and analyze a dc-dc-ac converter to provide a 230VAC at 50 Hz from PV modules and energy storage batteries used in PV systems. A two stage Cûk converter is used to obtain a 300VDC from 12V batteries. Two stage of Cûk converter has been used to keep the conversion efficiency of this stage high. The efficiency of DC-DC converters depend on the duty cycle (D). In one stage conversion duty cycle requirement is such that the efficiency is very low.

After DC-DC conversion, required 230VAC, 50 Hz has been obtained by a conventional single phase PWM inverter followed by low pass LC filter. The design and implementation of the system is carried out using commercially available electronics circuit simulation software. All control circuit component has been chosen from available commercial SMPS ICs.

1.4 OUTLINE OF THE THESIS

This thesis consists of three chapters. Chapter 1 deals with description of Solar home system, PWM inverter, various types of DC-DC converter and objective of the thesis and the outline of the thesis.

Chapter 2 includes detailed study of proposed high efficiency Cûk converter and PWM inverter. Automatic control circuit, design of filters and typical performance of proposed Cûk converter is presented in this chapter. Problem face with the dc voltage increased, free wheeling path and possible remedy of increase of dc voltage. Block diagrams are also include in chapter 2.

Chapter 3 concludes the thesis with summary, achievements and suggestion for future works.

CHAPTER – 2

CŪK CONVERTER AND PWM INVERTER

2.1 INTRODUCTION

Modern electronic systems require high-quality, small, light-weight, reliable and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient. This is because they are limited to output voltages smaller than input voltage, and also their power density is low because they require low frequency line transformer and filters. Electronic devices in linear regulators operate in their active modes, but at higher power levels switching regulator are used. Switching regulators use power electronic semiconductor switches in on and off states. Because there is a small power loss in these states, switching regulators can achieve high energy conversion efficiencies. In this chapter we will describe principle of CŪk converter and a PWM inverter, and its filter, power circuit design etc.

2.2 CŪK CONVERTER

The CŪk converter is a type of DC-DC converter that has an output voltage magnitude that is either greater than or less than the input voltage magnitude, with an opposite polarity. It uses a capacitor as its main energy transfer element, unlike other types of converter that use an inductor. The circuit of the CŪk converter is shown in Fig.2.1. It consists of dc input voltage source V_s , input inductor L_1 , controllable switch S , energy transfer capacitor C_1 , diode D , filter inductor L_2 , filter capacitor C , and load resistance R . An important advantage of this topology a continuous current at both the input and the output of the converter. There are a high number of reactive components and high current stresses on the switch, the diode, and the capacitor C_1 . The main waveforms in the converter are presented in Fig. b. When the switch is on, the diode is off and the capacitor C_1 is discharged by the inductor L_2 currents of the inductors L_1 and L_2 , whereas capacitor C_1 is charged by the inductor L_1 current.

To obtain the ideal dc voltage transfer function of the converter, we use the principle that the average current through a capacitor is zero for steady-state operation. Let us assume that inductors L_1 and L_2 are large enough that their ripple current can be neglected. Capacitor C_1 is in steady state if

$$I_{12}DT = I_{L1}(1 - D)T \quad (2.1)$$

For a lossless converter

$$P = V_s I_{L1} = -V_o I_{12} = P_o \quad (2.2)$$

Combining these two equations, the dc voltage transfer function of the Cùk converter is

$$M_v = \frac{V_o}{V_s} = \frac{D}{1-D} \quad (2.3)$$

This voltage transfer function is the same as that for the buck-boost converter.

The boundaries between the CCM (Continuous Current Mode) and DCM (Discontinuous Current Mode) are determined by

$$L_{Bi} = \frac{(1-D)R}{2Df} \quad (2.4)$$

for L_1 and

$$L_{b2} = \frac{(1-D)R}{2f} \quad (2.5)$$

for L_2 .

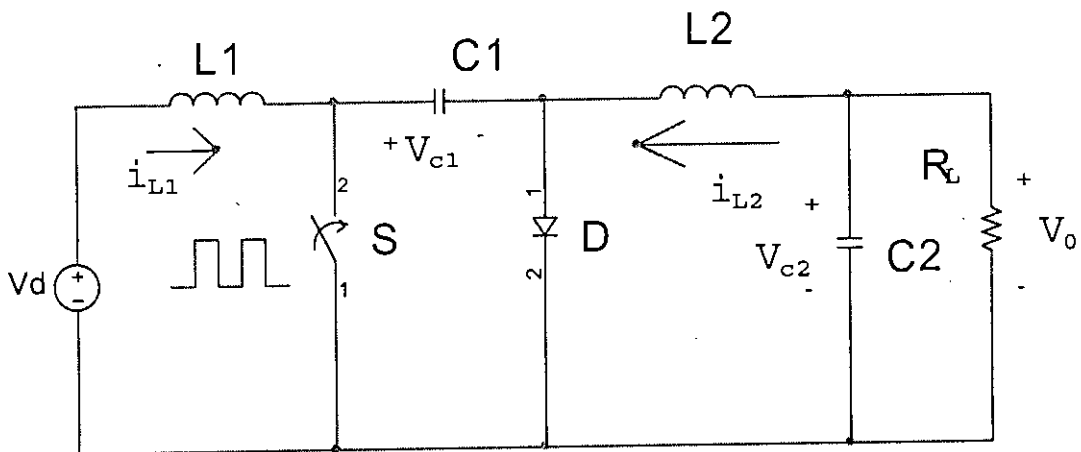
The output part of the Cùk converter is similar to that of the buck converter. Hence, the expression for the filter capacitor C is [3]

$$C_{min} = \frac{(1-D)R}{8V_r L_2 f^2} \quad (2.6)$$

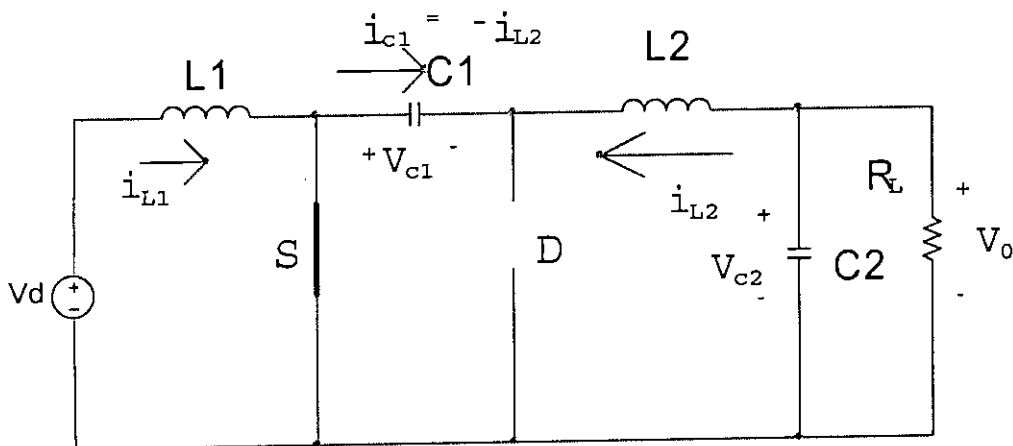
The peak-to-peak ripple voltage in the capacitor C_1 can be estimated as [3]

$$V_{r1} = \frac{DV_0}{C_1 R_f} \quad (2.7)$$

A transformer (isolated) version of the Cuk converter can be obtained by splitting capacitor C_1 and inserting a high frequency transformer between the split capacitors.



(a) Circuit of Cuk converter



(b) Circuit when switch is closed

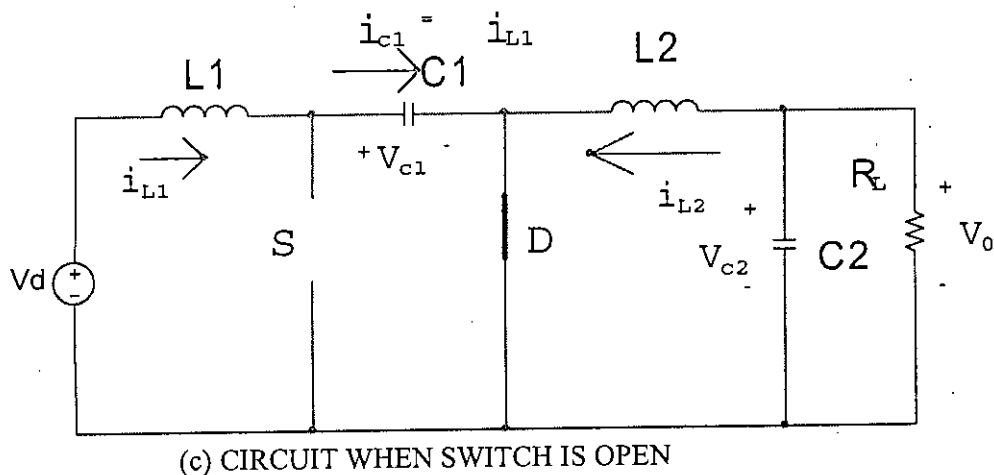


Fig.2.1 Cuk converter and its operation
 (a) The power circuit,
 (b) Circuit when switch is closed and
 (c) Circuit when switch is open.

2.3 CUK ANALYSIS OF CUK converter [3]

2.3.1 FROM CAPACITOR CURRENT POINT OF VIEW [3]

The voltage gain expression of the Cuk converter can be obtained either by analysis of capacitor or by analysis of current through the inductors. Following capacitor current analysis the ideal voltage gain expression can be obtained as follows,

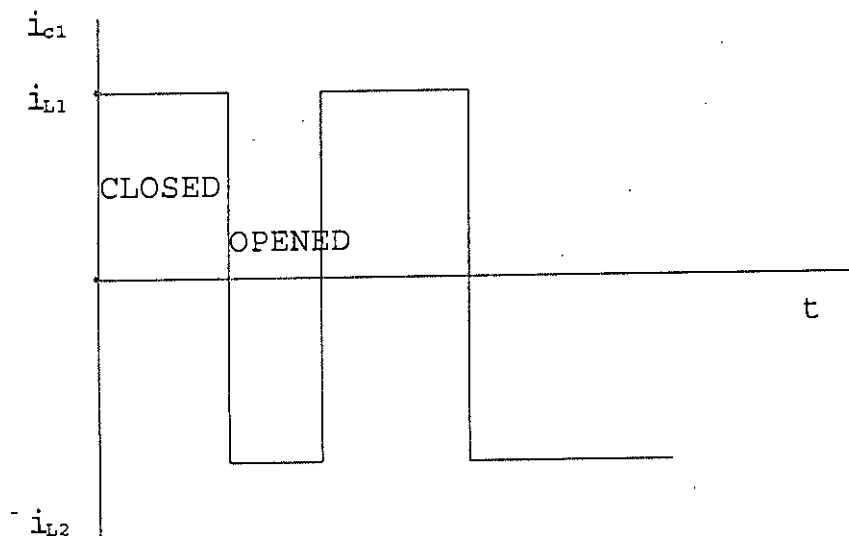


Fig.2.2 Typical waveform of current of capacitor

The average voltage across C_1 computed KVL,

$$V_{C1} = V_d - V_0 \quad (2.8)$$

When the switch is closed, diode is off and the current in C_1 is:

$$(i_{C1})_{close} = -i_{L2} \quad (2.9)$$

When the switch is opened, the current in L_1 and L_2 force the diode on. The current in C_1 is:

$$(i_{C1})_{open} = -i_{L1} \quad (2.10)$$

The power absorbed by the load is equal to the power supplied by the source, i.e.

$$-V_0 I_{L2} = V_s I_{L1} \quad (2.11)$$

For periodic operation, the average current is zero,

$$[(i_{C1})_{close}]DT + [(i_{C1})_{open}](1 - D)T = 0 \quad (2.12)$$

Substituting,

$$-I_{L2}DT + I_{L1}(1 - D)T = 0 \quad (2.13)$$

$$\frac{I_{L1}}{I_{L2}} = \frac{D}{1-D} \quad (2.14)$$

The power absorbed by the load is equal to the power supplied by the source, i.e.

$$-V_0 I_{L2} = V_s I_{L1} \quad (2.15)$$

$$\frac{I_{L1}}{I_{L2}} = \frac{-V_0}{(1-D)} \quad (2.16)$$

Combining, output voltage can be written as:

$$\frac{V_0}{V_s} = - \left[\frac{D}{1-D} \right] \quad (2.17)$$

Note that the output stage (L_2 , C_2 and R) are in the same configuration as the buck converter. Hence,

$$\frac{\Delta V_0}{V_0} = \frac{1-D}{8L_2C_2f^2} \quad (2.18)$$

In time interval DT when switch is closed,

$$V_{L1} = V_d = L_1 \frac{di_{L1}}{dt} \quad (2.19)$$

$$\Rightarrow \frac{\Delta i_{L1}}{DT} = \frac{-V_0}{L_1} \quad (2.20)$$

Or,

$$\Delta i_{L1} = \frac{V_d DT}{L_1} = \frac{V_d D}{L_1 f} \quad (2.21)$$

Cûk design parameters

For L_2 , in time interval DT when switch is closed,

$$0 = +V_{c1} - V_{L2} + V_0 \quad (2.22)$$

$$V_{L2} = V_{c1} + V_0 = (V_d - V_0) + V_0 = V_d \quad (2.23)$$

$$V_{L2} = L_2 \frac{di_{L2}}{dt} \quad (2.24)$$

Or,

$$\Delta i_{L2} = \frac{V_d DT}{L_2} = \frac{V_d D}{L_2 f} \quad (2.25)$$

For continuous current operation,

$$L_{1,min} = \frac{(1-D)^2 R}{2Df} \quad (2.26)$$

$$L_{2,min} = \frac{(1-D)R}{2f} \quad (2.27)$$

2.3.2 FROM INDUCTOR CURRENT POINT OF VIEW [3]

The same expression can be obtained by inductors current analysis as follows,

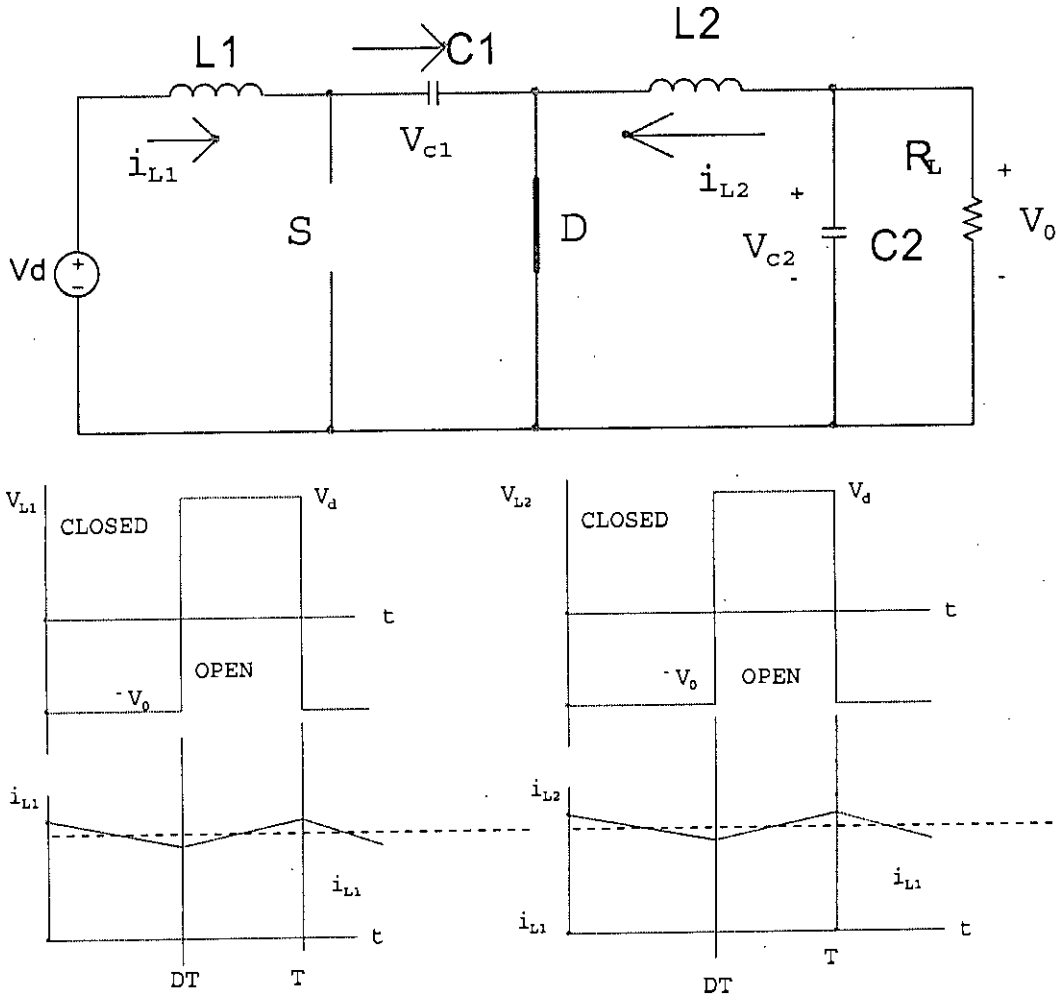


Fig.2.3 Voltage and current waveform circuit when switch is open

In steady state, it can be assumed that V_{L1} and V_{L2} are zero.

$$V_{C1} = V_d + V_o \quad (2.28)$$

It also can be seen that V_{C1} is larger than V_d and V_o

When the switch is off, i_{L1} and i_{L2} flow through the diode. Capacitor C_1 is charged through the diode by energy from V_d and L_1 . The inductor voltage can be written as:

$$V_{L1} = V_d + V_{C1} \quad (2.29)$$

Which is negative since V_{C1} is larger than V_d .

This causes i_{L1} to decrease.

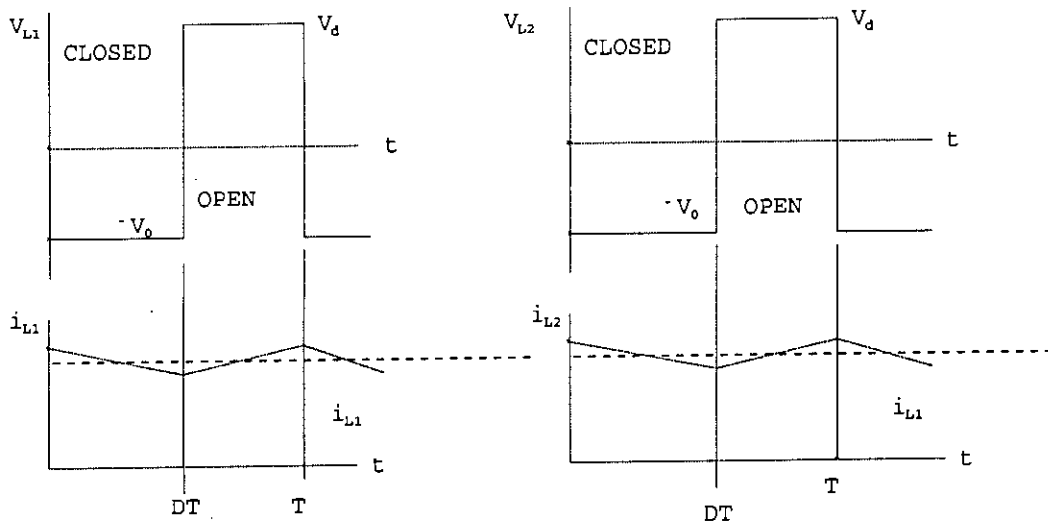
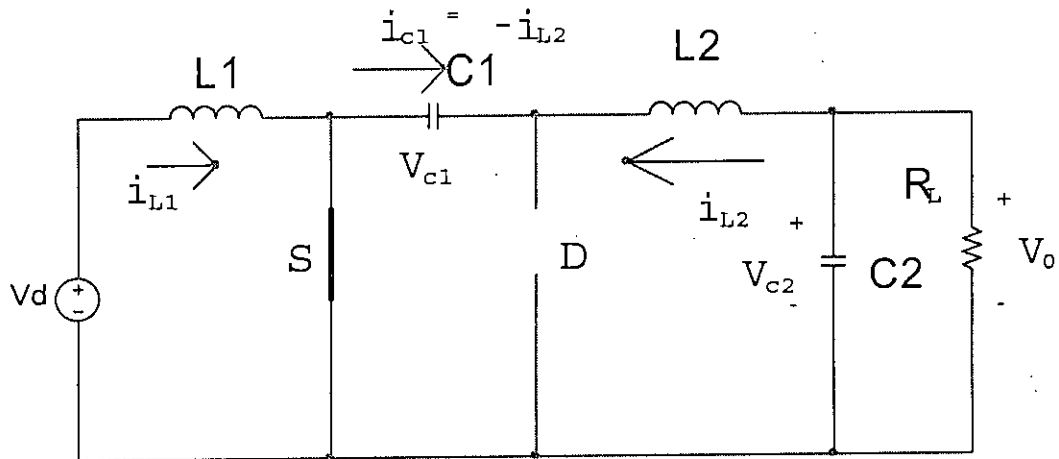


Fig. 2.4 Voltage and current waveform circuit when switch is closed

Similarly on the output side,

$$V_0 = -V_d \quad (2.30)$$

This causes i_{L1} to decrease.

When the switch is on, V_{C1} reverse – biased the diode. The inductor current i_{L1} and i_{L2} flow through the switch.

Since $V_{C1} > V_0$ capacitor C_1 discharged through the switch, transferring energy to the output L_2 . Therefore i_{L2} increases.

The input feeds energy to L_1 , causing to i_{L1} increase.

Equating the integral of the voltages across L_1 and L_2 ,

$$L1 \Rightarrow -V_d DT + (V_d - V_{C1})(1 - D) = 0 \quad (2.31)$$

$$\Rightarrow V_{C1} = \frac{1}{1-D} V_d \quad (2.32)$$

$$L2 \Rightarrow (V_{C1} - V_0)DT + (1 - D)T = 0 \quad (2.33)$$

$$\Rightarrow V_{C1} = \frac{1}{D} V_0 \quad (2.34)$$

Combining:

$$\frac{V_0}{V_d} = \frac{D}{1-D} \quad (2.35)$$

2.4 CASCADED CUK CONVERTER [20]

There is a limitation of single stage cùk converter. It is not possible to increase voltage to desired level without abrupt loss of efficiency. If it use more than single stage than it can get require voltage. If it change duty cycle then the output voltage also change. It's used IC SG1524B for switching. In stage 1 output is reverse of the input. The output stage 1 is the input to the stage 2 (another cùk converter). By second reversed, positive output obtained.

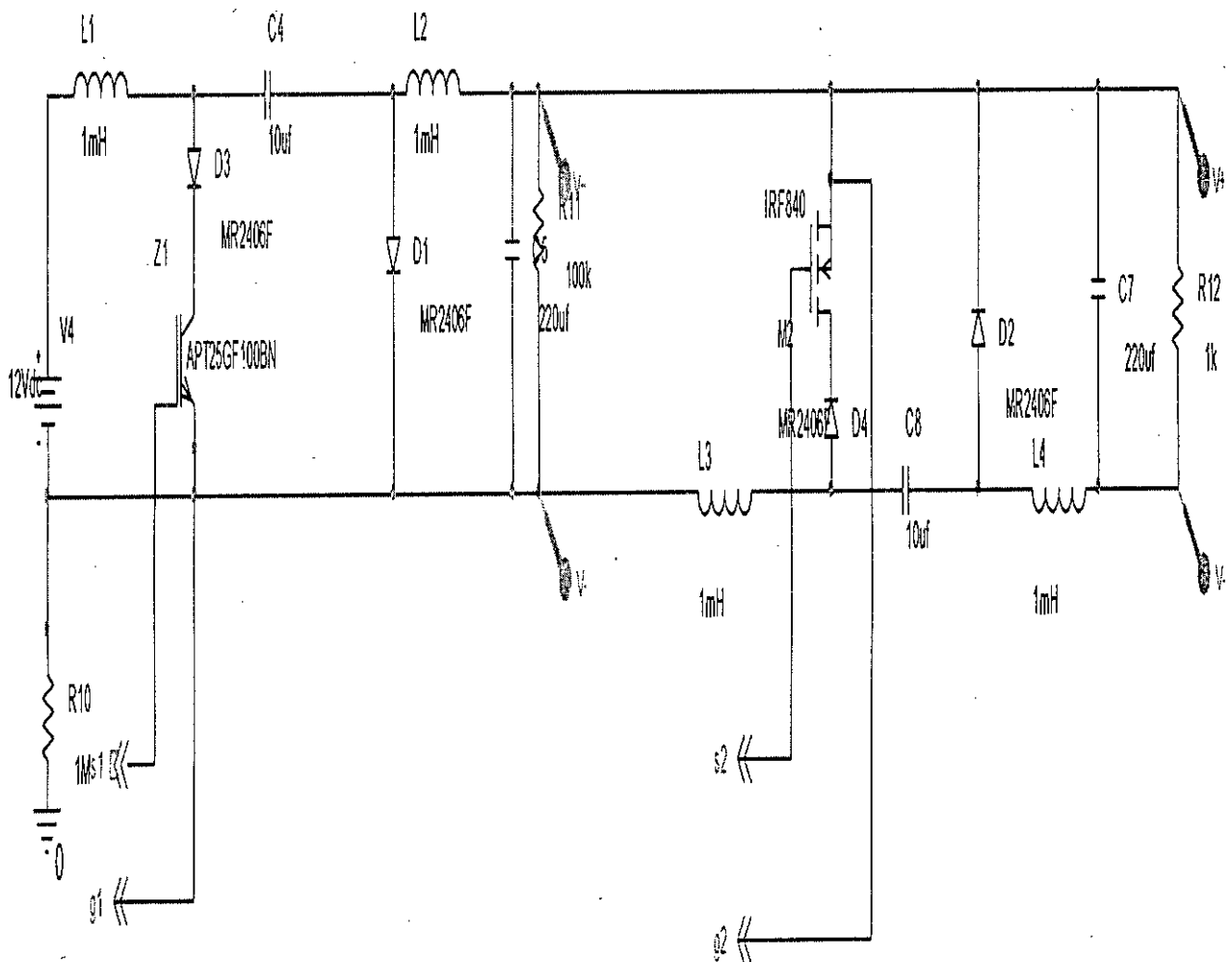


Fig. 2.5(a) Cascaded Cùk converter

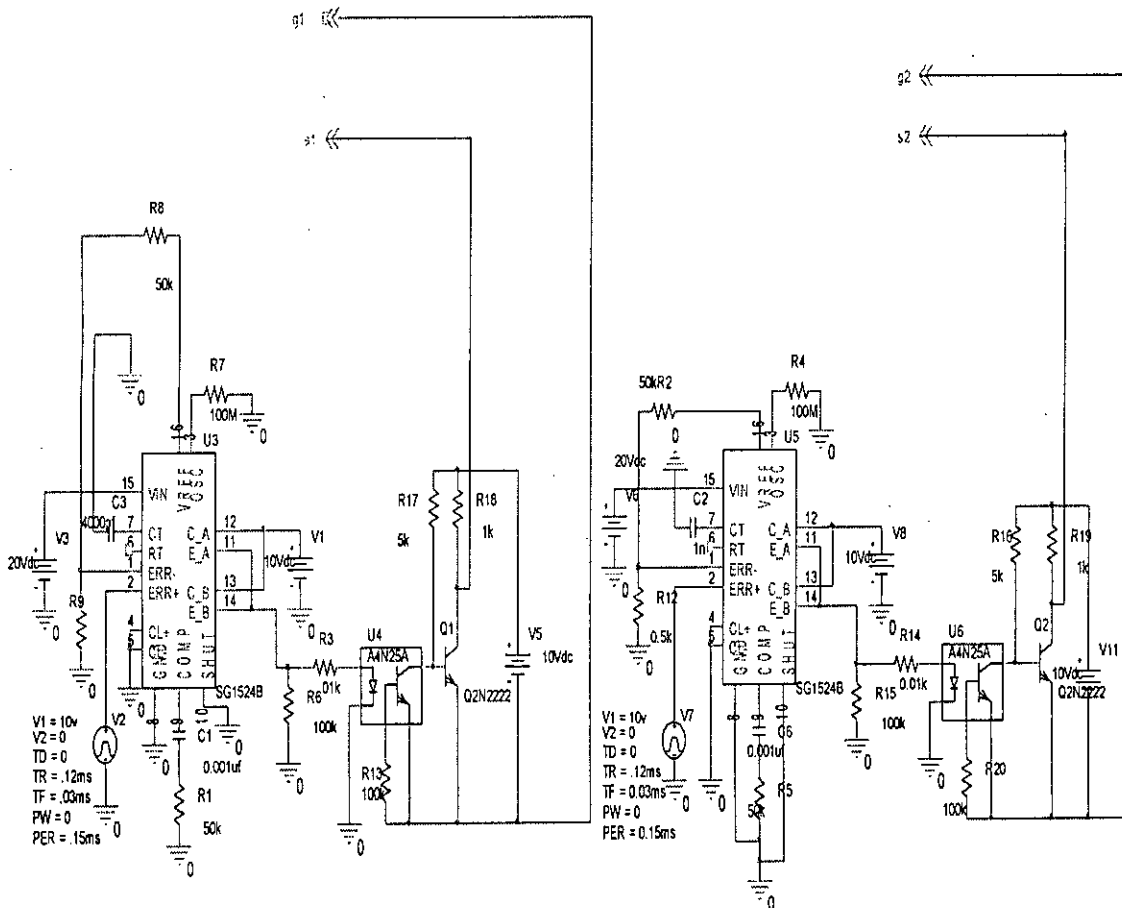


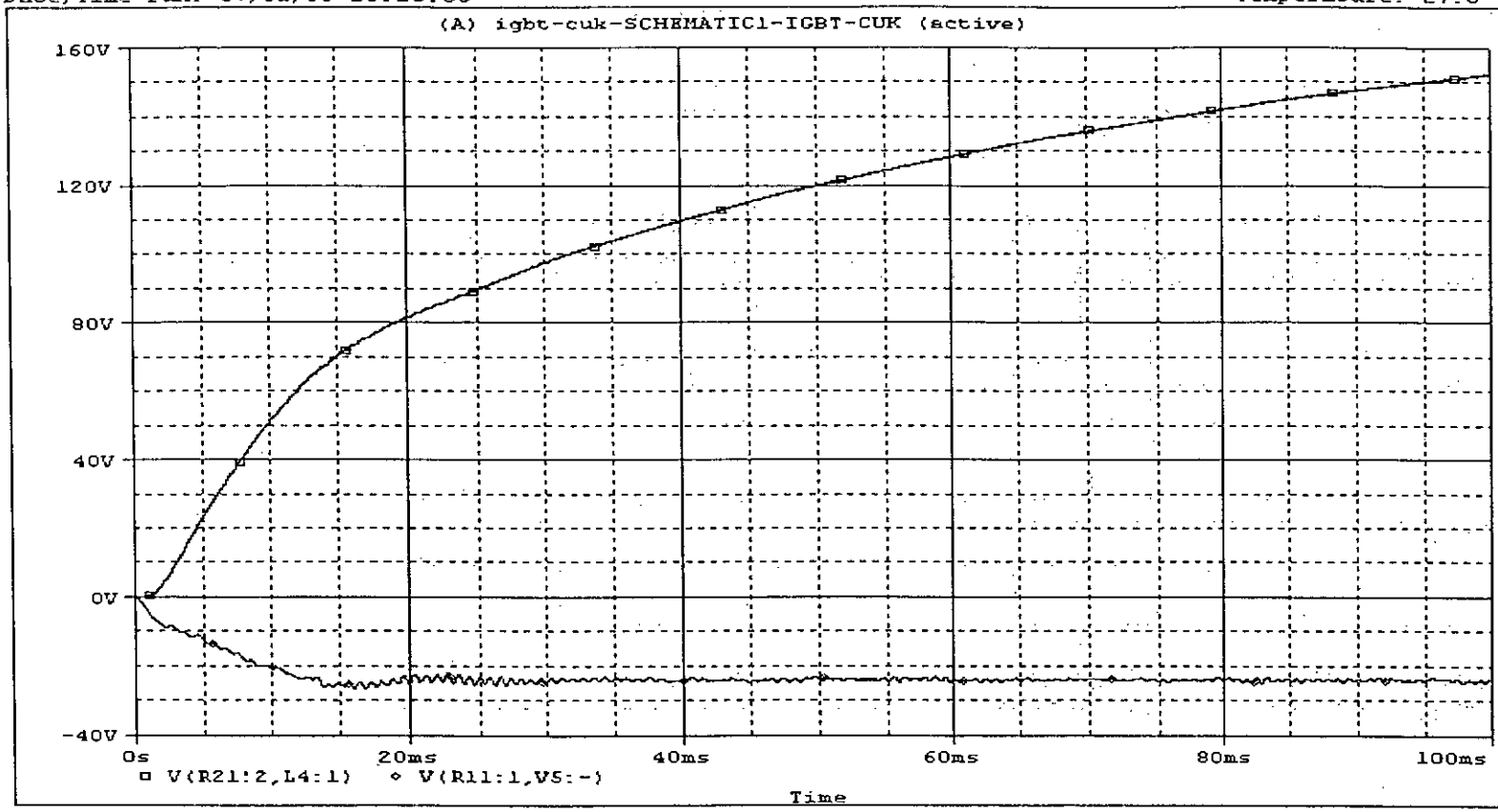
Fig.2.5 (b) The control circuit of the cascaded Cûk converter

Fig.2.5 Cascaded Cûk converter and its control circuit

Fig.- 2.5(a) Cascaded Cûk converter

Fig.-2.5 (b) The control circuit of the cascaded Cûk converter

** circuit file for profile: IGBT-CUK
Date/Time run: 07/31/08 13:10:50 Temperature: 27.0



Date: July 31, 2008

Page 1

Time: 13:15:44

Fig.2.6 Output waveform of cascaded Cuk converter

High power darlington transistor is used in the first stage, where MOSFET is used as switching transistor in the second stage. For simulation purpose pulse source is used, which in practical case can be SMPS switching IC. The circuit is shown in Fig. 2.7 (a) and its output is shown in Fig. 2.7(b) for stage 1 and stage 2.

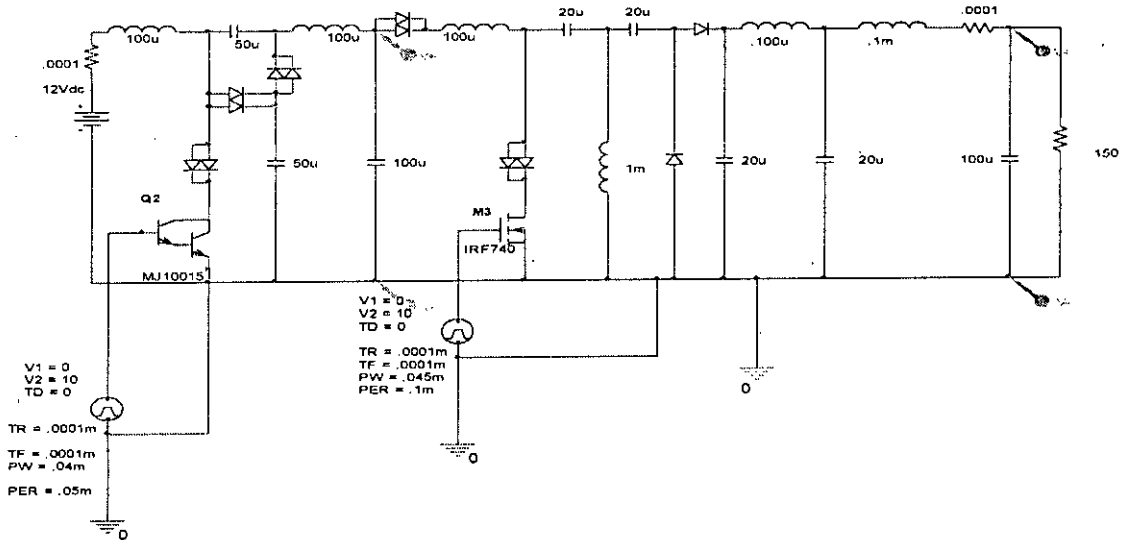


Fig. 2.7(a) Modified cascaded Cuk converter circuit

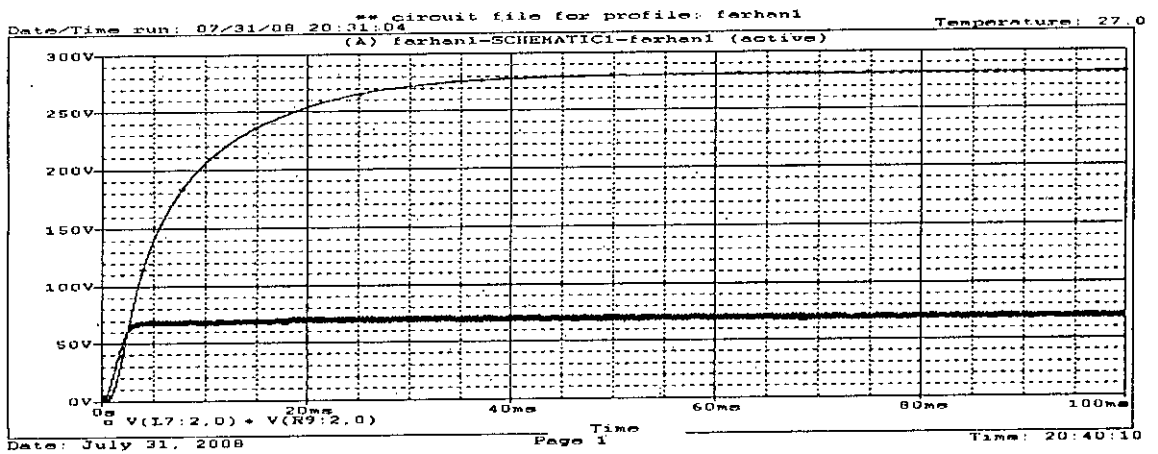


Fig.2.6(b) Output Voltage after stage 1 and stage 2

Fig.2.7 Modified Cascaded Cuk converter and output voltage

(a) Modified cascaded Cuk converter circuit

(b) Output Voltage after stage 1 and stage 2

2.5 VOLTAGE SOURCE PWM INVERTER

Dc- to- Ac converters are known as inverters. The function of an inverter is to change a dc-input voltage to a symmetric ac out put voltage of desired magnitude and frequency. The output voltage could be fixed or variable at a fixed or variable frequency. A variable output voltage can be obtained by varying the input dc voltage and maintaining the gain of the inverter constant. On the other hand, if the dc input voltage is fixed and it is not controllable, a variable output voltage can be obtained by varying the gain of the inverter, which is normally accomplished by the pulse- width- modulation (PWM) within the inverter. The inverter gain may be defined as the ratio of the ac output voltage to dc input voltage.

The output voltage waveforms of ideal inverters should be sinusoidal. However, the waveforms of practical inverters are non sinusoidal and contain harmonics. For low- and medium – power applications, square- wave or quasi-square- wave voltages may be acceptable; and for high-power application, low distortion sinusoidal wave- forms are required. With the availability of high-speed power semiconductor devices, the harmonic contents of output voltage can be minimized or reduced significantly by switching techniques and use of small sized filters.

2.5.1 PWM INVERTER

PWM inverter control circuit consists of switching circuit composed of OP-Amp comparator that compares a triangular carrier wave with reference sine wave (of 50 Hz for this thesis purpose) followed by opto coupler isolation circuit. The switching pulse generating circuit is shown in Fig 2.8 (a) and the opto coupler isolation circuit is shown in Fig 2.8 (b). The isolated switching pulses turn ON/OFF the switching transistor of main power circuit of the inverter that converts DC power to AC. The inverter power circuit is shown in Fig. 2.8 (c). The output voltage of the inverter is non sinusoidal. To obtain sinusoidal voltage across load, filter is used to reduce the harmonics to acceptable magnitude. The output voltage across the load obtained is shown in Fig. 2.9. The voltage regulation of the overall circuit consisting modified cuk converter and inverter can be achieved by either converter. If the duty cycle of the cuk converter is changed, the output voltage will change. Also, if the modulation index of the inverter is changed, the output voltage will change. The effect of duty cycle change of modified cuk converter (which keeping modulation index of converter kept constant) is shown in Fig. 2.10(a) to (e).

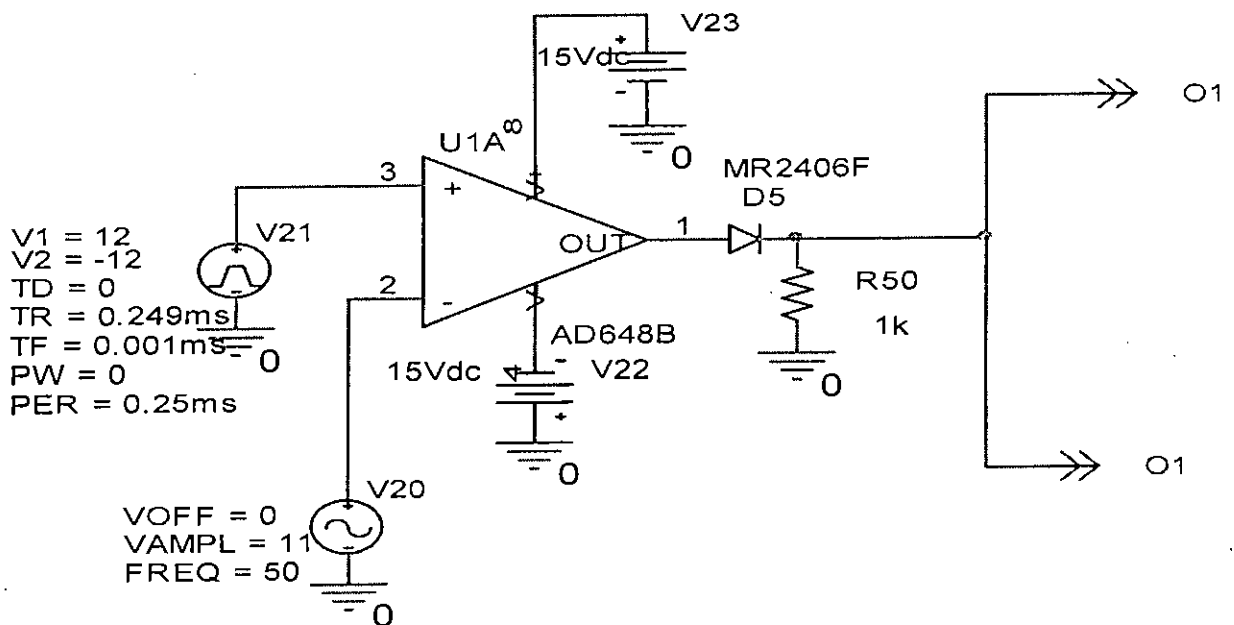


Fig. 2.8 (a) PWM switching signal generator

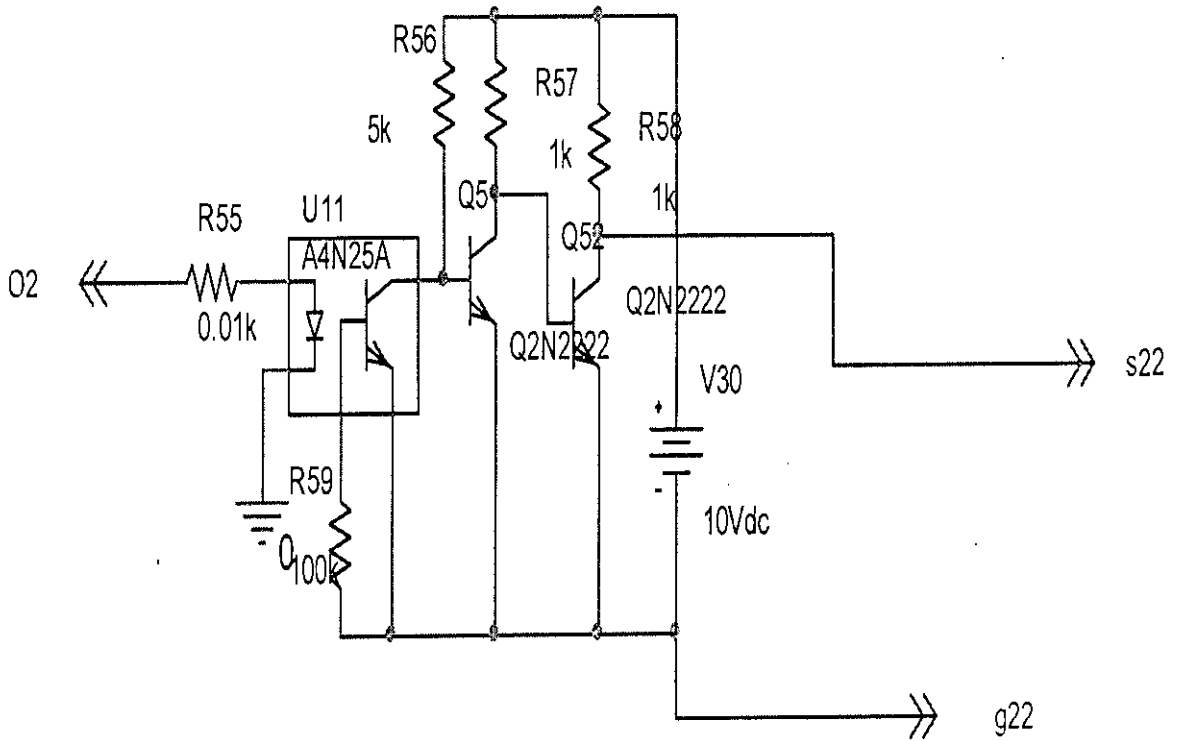
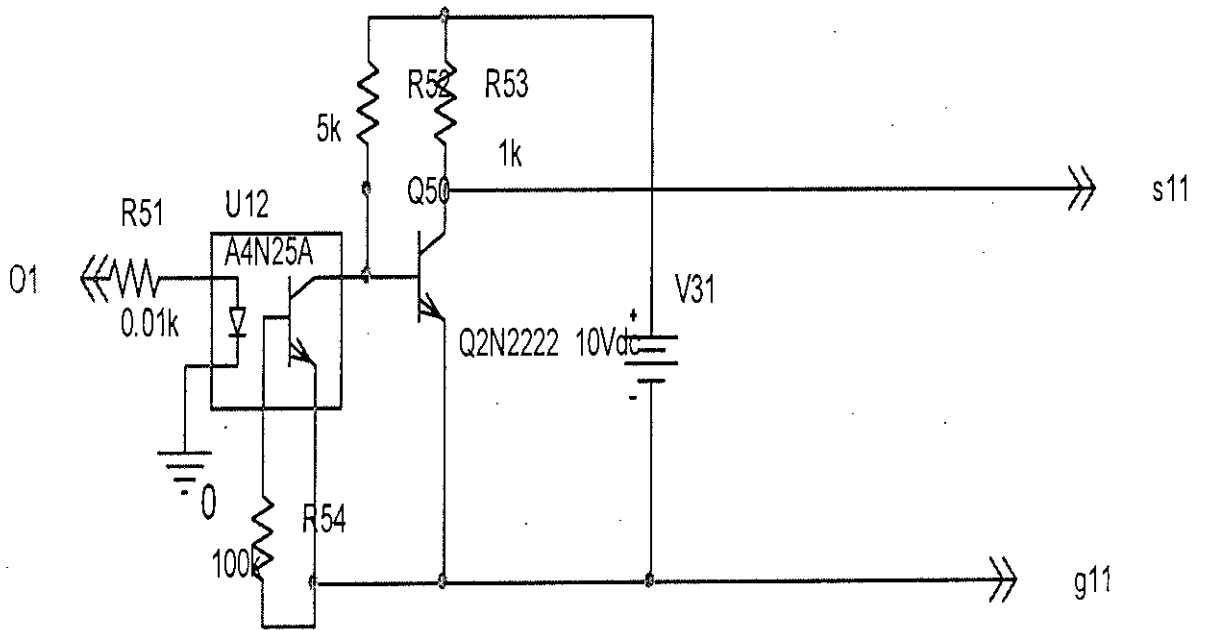


Fig. 2.8 (b) Opto coupler circuits

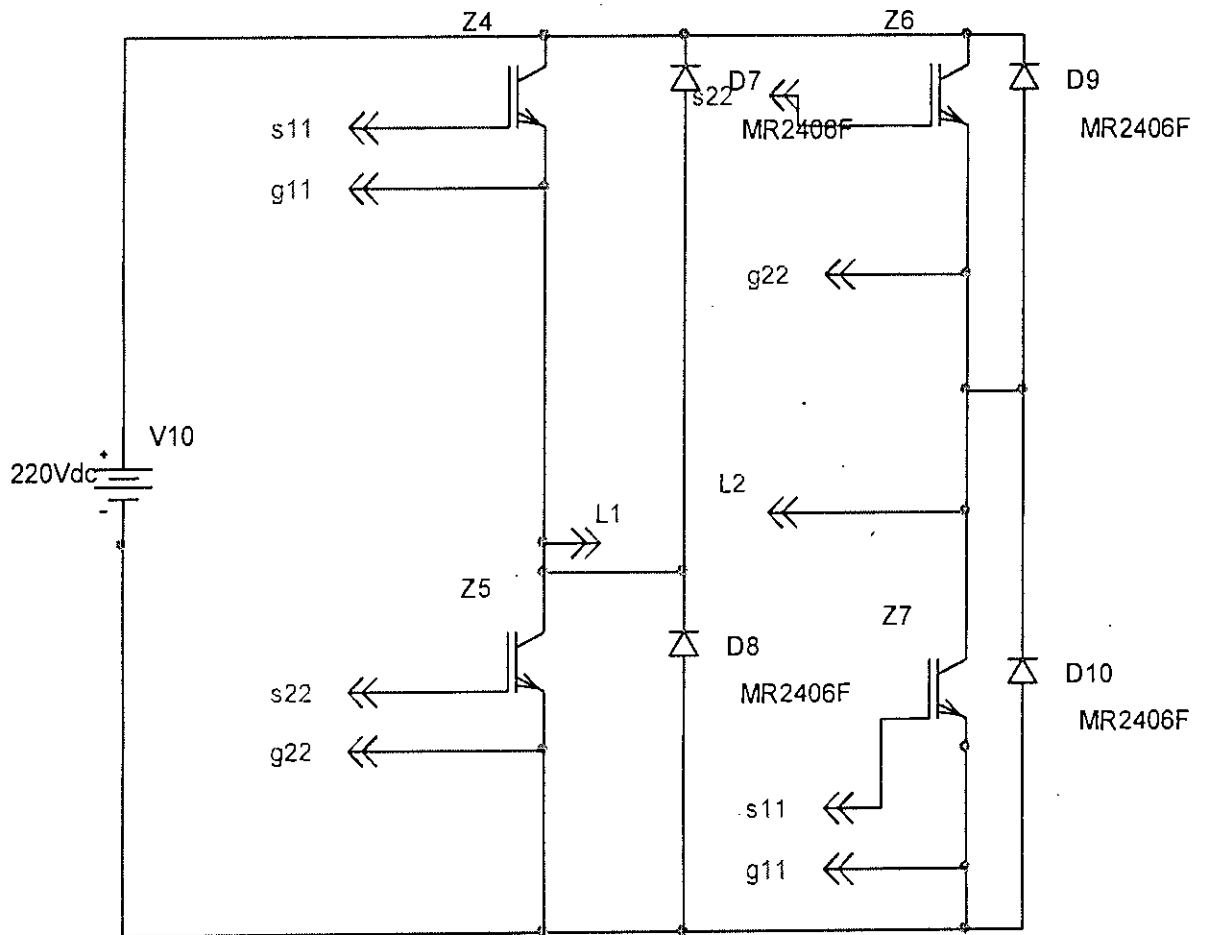


Fig. 2.8 (c) Inverter circuit with filter and load

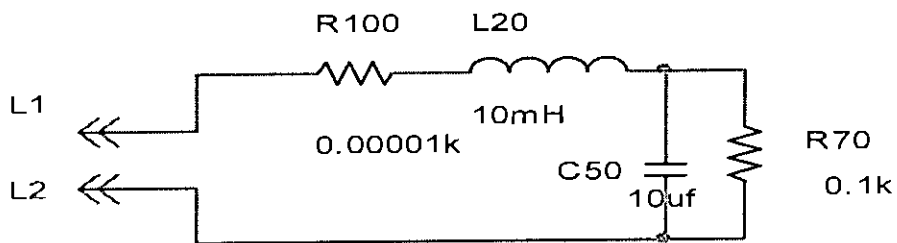


Fig. -2.8 (d) Filter circuit

Fig.2.8 Single phase PWM inverter circuit

- (a) PWM switching signal generator
- (b) Opto coupler circuit
- (c) Inverter circuit with filter and load
- (d) Filter circuit

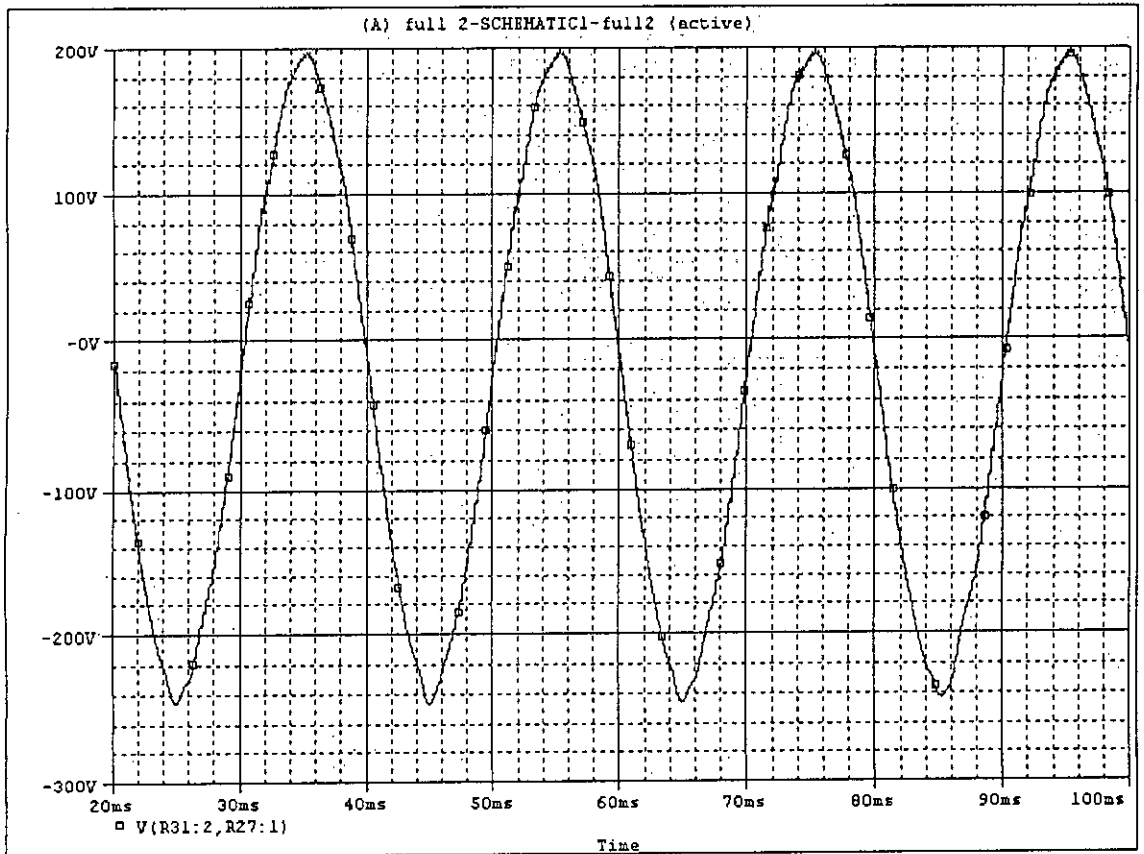


Fig. 2.9 Typical output waveform across load

The maximum output voltage was obtained when the duty cycle was maximum. If the duty cycle is less than 0.5 than negative voltage is obtained. Typical waveforms for duty cycle 0.7, 0.8, 0.9, 0.95 and 0.996 are shown in figure 2.10 (a),(b), (c), (d) and (e) It is observed that output voltage vary with duty cycle. The results of variation of duty cycle from 0.7 to 0.996 given in a table 2.1.

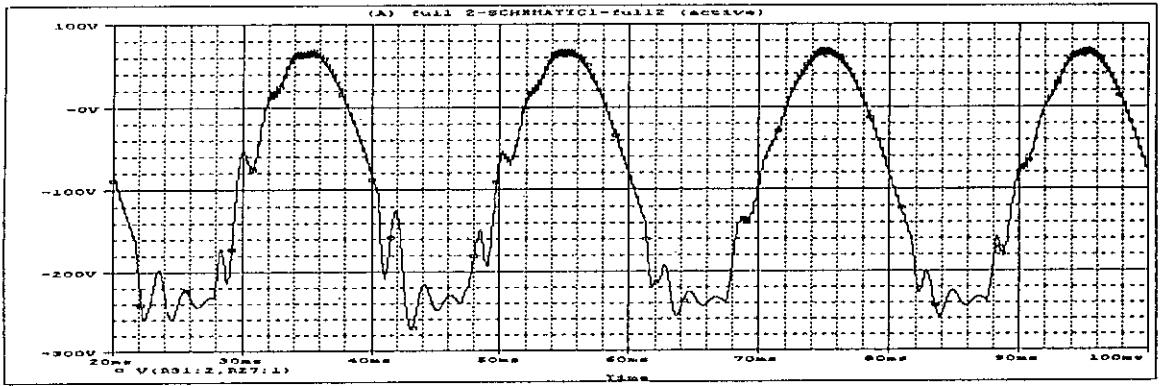


Fig. 2.10(a) Output voltage waveform for duty cycle = 0.7

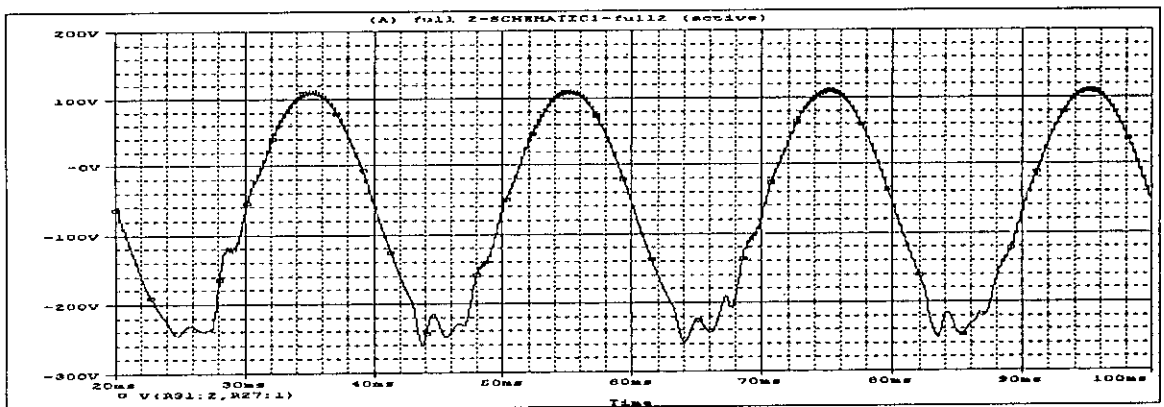


Fig. 2.10(b) Output voltage waveform for duty cycle = 0.8

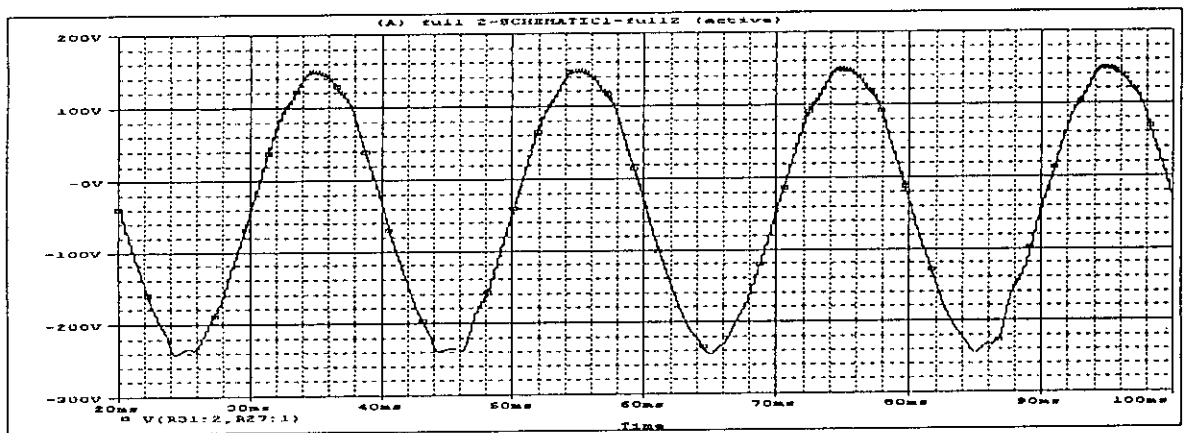


Fig. 2.10(c) Output voltage waveform for duty cycle = 0.9

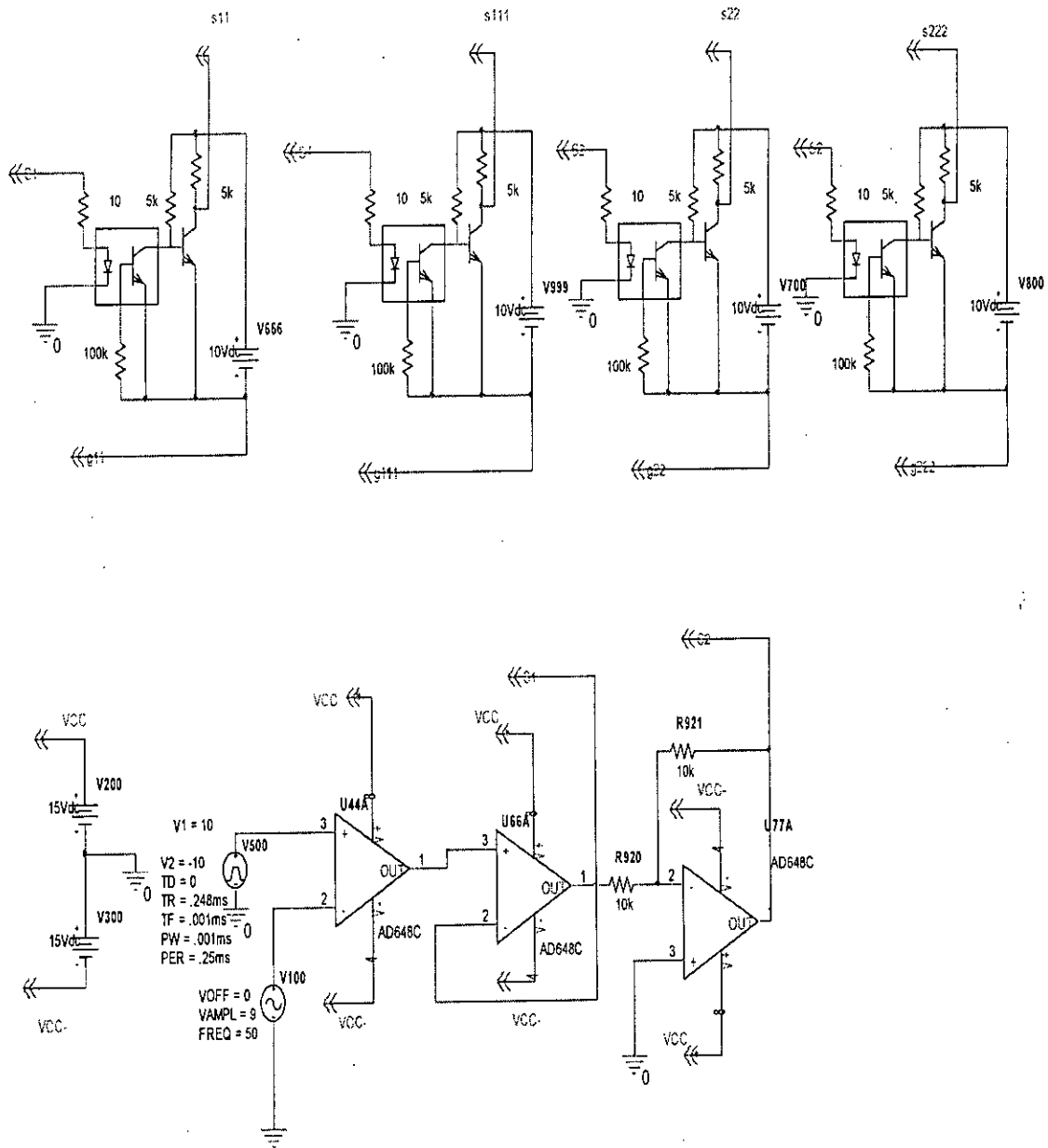


Fig.2.17(c) Switching circuit

Fig.2.17 Proposed cascaded Cuk converter and PWM inverter using practical switch.

- (a) Cascaded Cuk converter
- (b) PWM inverter
- (c) Switching circuit

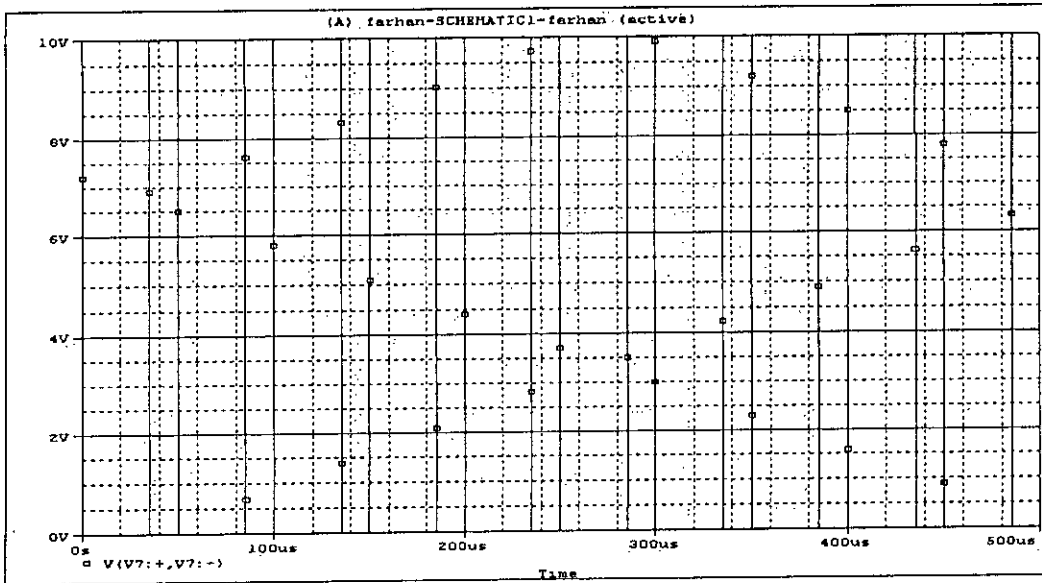


Fig. 2.18(a) Switching signal of transistor of stage 1

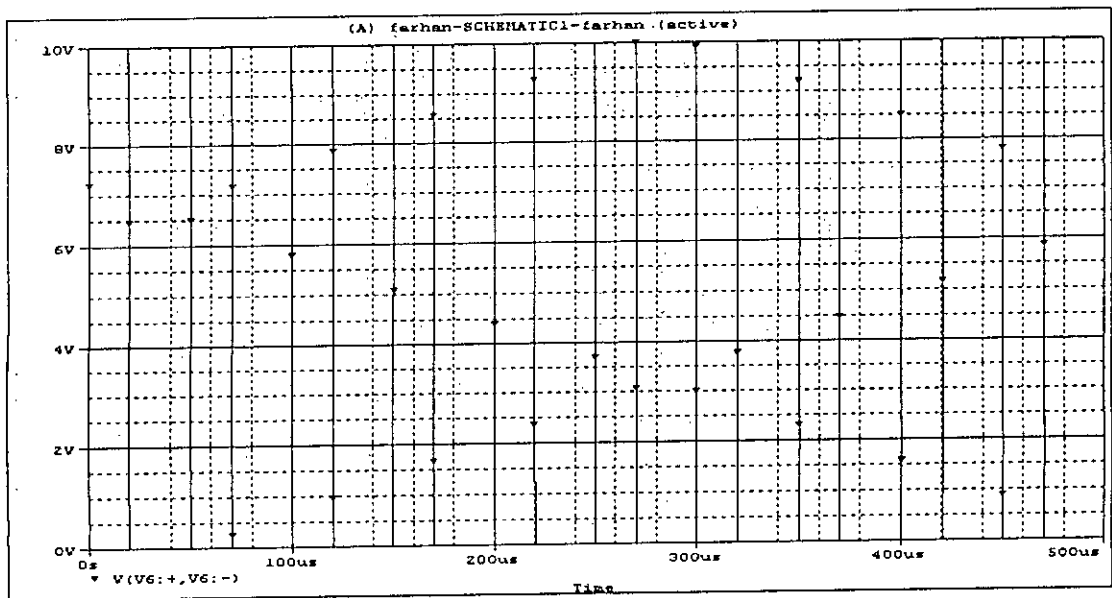


Fig. 2.18(b) Switching signal of MOFET of stage 2

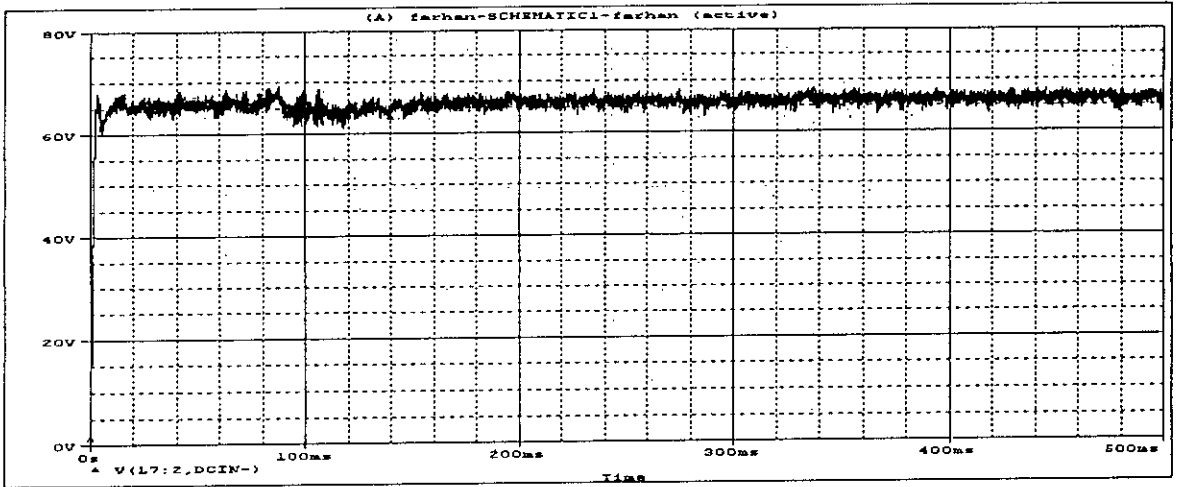
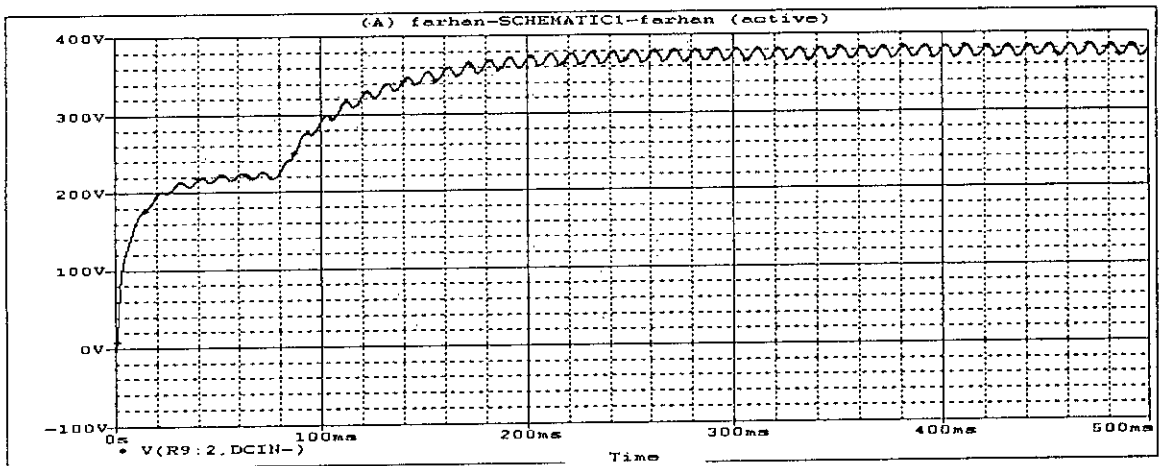


Fig. 2.18 (c) Output of cascaded Cuk converter in 1st stage



2.18 (d) Output of cascaded Cuk converter in 2nd stage

Fig. 2.18 Voltage waveform two stage Cuk converter circuit for simulation

- (a) Switching signal of transistor of stage 1
- (b) Switching signal of MOFET of stage 2
- (c) Output of cascaded Cuk converter in 1st stage
- (d) Output of cascaded Cuk converter in 2nd stage

Output of cascade converter is the input of the PWM inverter. The practical circuit of single – phase bridge voltage source inverter is shown in Fig. 2.17 (b). It consist of four IGB T's.

The waveform for the output voltage is shown in Fig2.19. That is square waveform. When the waveform is filtered by the low pass filter almost sine wave is obtain as shown in Fig. 2.20 and 2.21. The complete circuit diagram of the proposed Cûk converter fed PWM inverter is shown in Fig. 2.17. The variation of output voltage, current and power with load variation is given in table 2.2. Voltage regulation at fixed duty cycle of cascaded cûk converter and fixed modulation index of the inverter is shown in Fig. 2.23 and 2.24. As defined in Figures 2.25 to 2.32 the output voltage waveforms across various resistive loads and the corrects though the load sections same in shape expect change in magnitude.

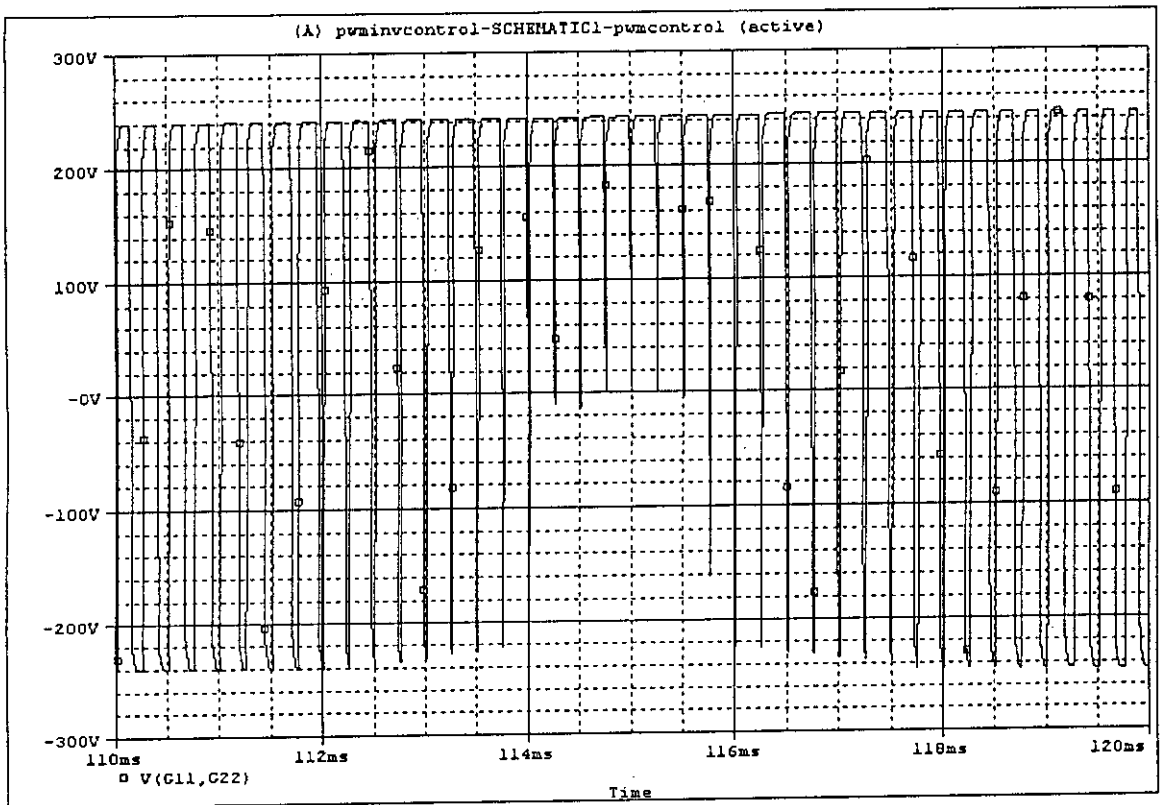


Fig. 2.19 Output Voltage waveform of PWM inverter (Before pass filter)

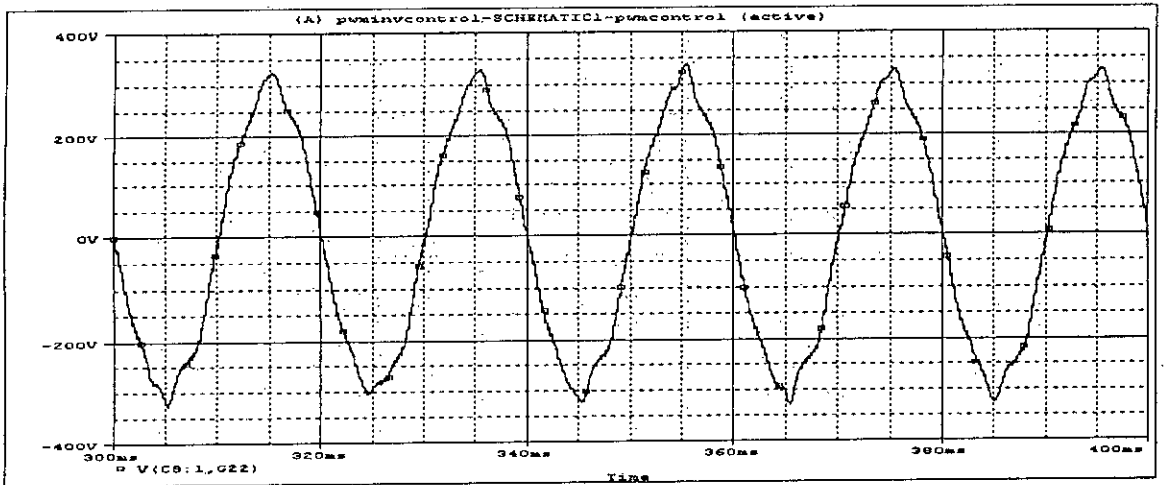


Fig. 2.20 Output Voltage waveform of PWM inverter (After a low pass filter)

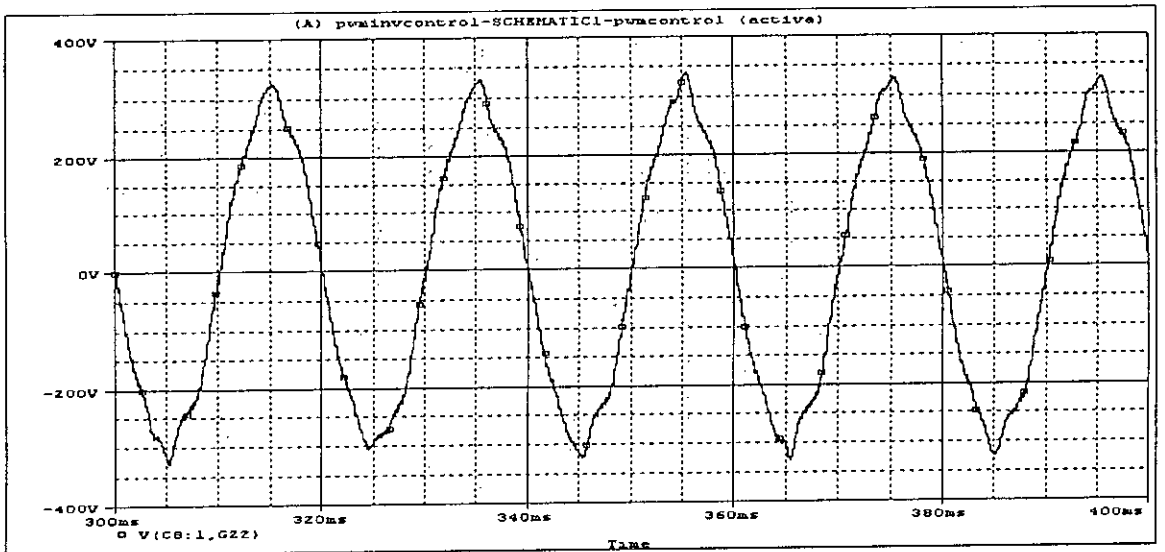


Fig.2.21 Output waveform of PWM inverter after a low pass filter, $R_{load} = 250$ ohm

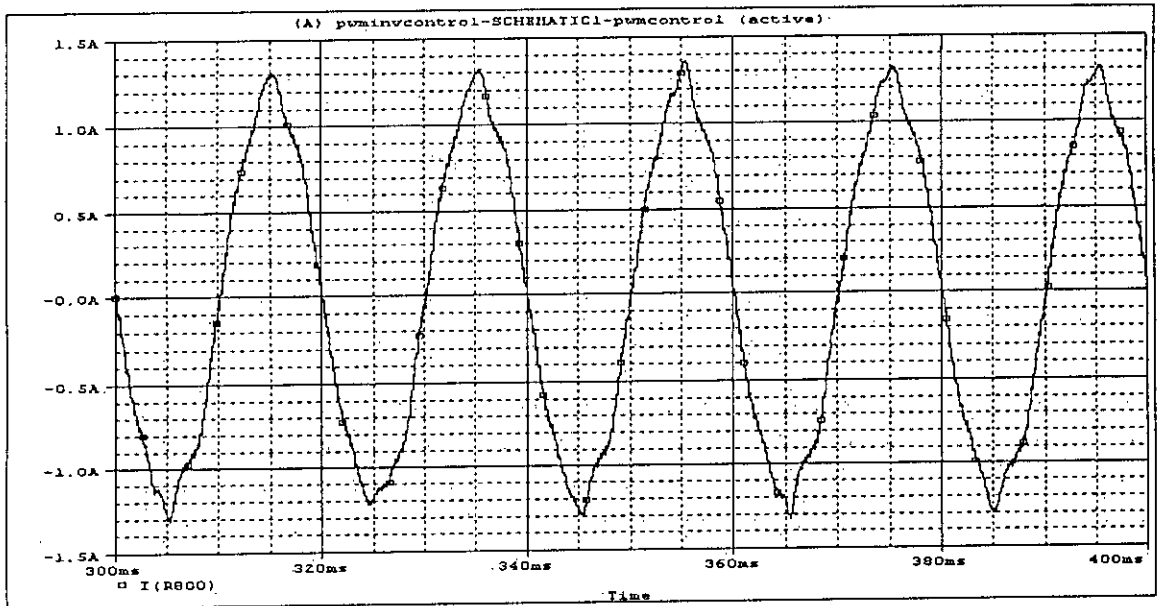


Fig.2.22 Output Current of PWM inverter after a low pass filter, $R_{load} = 250 \text{ ohm}$

Table: 2.2 Output power at various loads

Rload (ohm)	Vout (volt)	Iout (Amps)	Pout (watt)
100	220	3.2	704
150	260	1.8	468
200	300	1.45	435
250	340	1.3	416
500	440	0.85	374

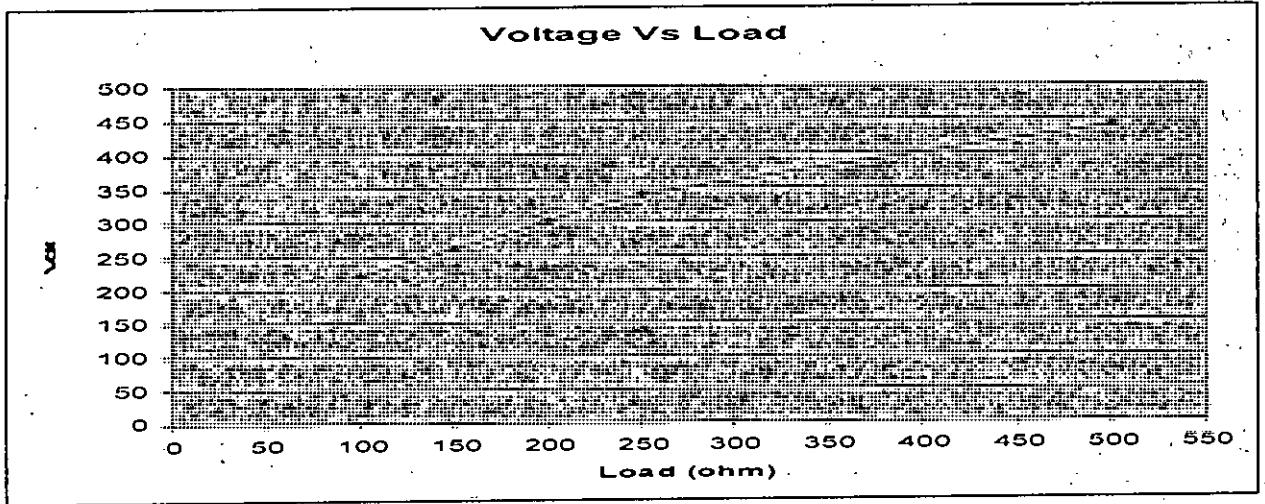


Fig.2.23 Output voltages at various load

Table: 2.3 Voltage gain at various loads

Rload (ohm)	Vin	Vout	Voltage gain
100	12	220	18.33
150	12	260	21.66
200	12	300	25
250	12	340	28.33
500	12	440	36.66

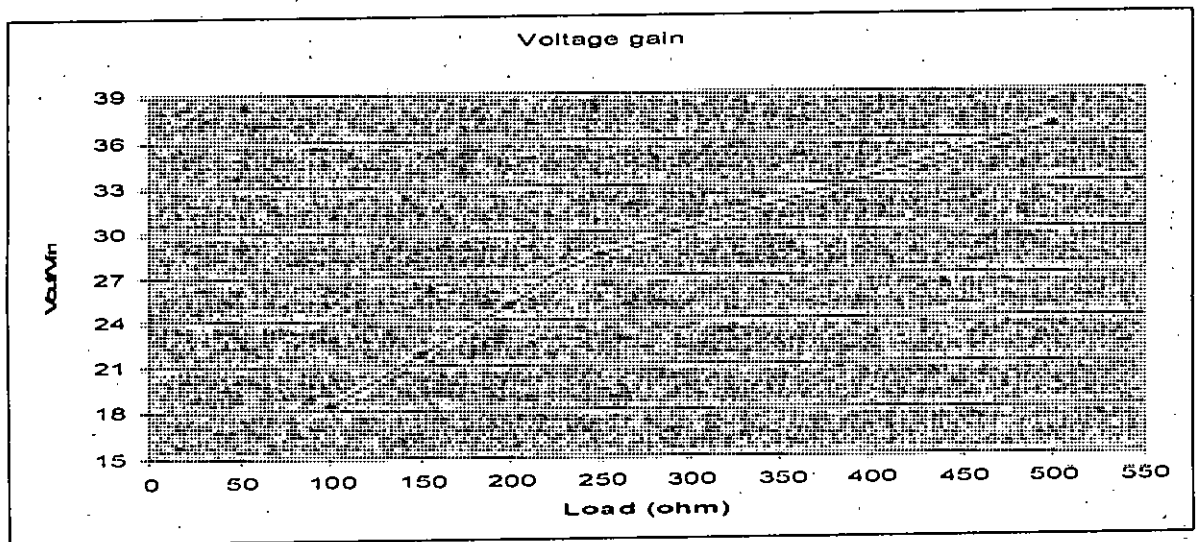


Fig.2.24 Voltage gain at various loads

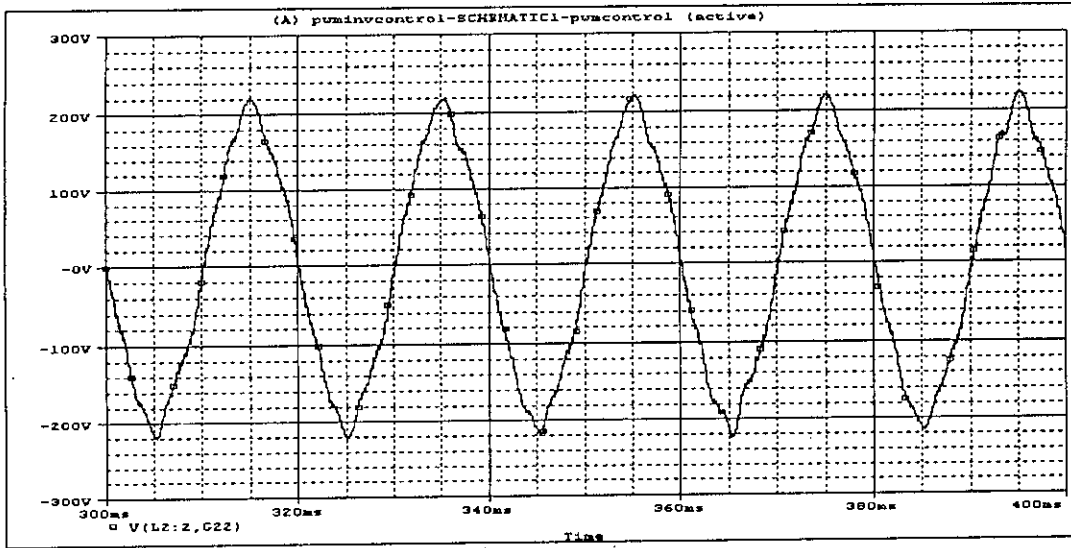


Fig.2.25 Output waveform of PWM inverter after a low pass filter, $R_{load} = 100 \text{ ohm}$

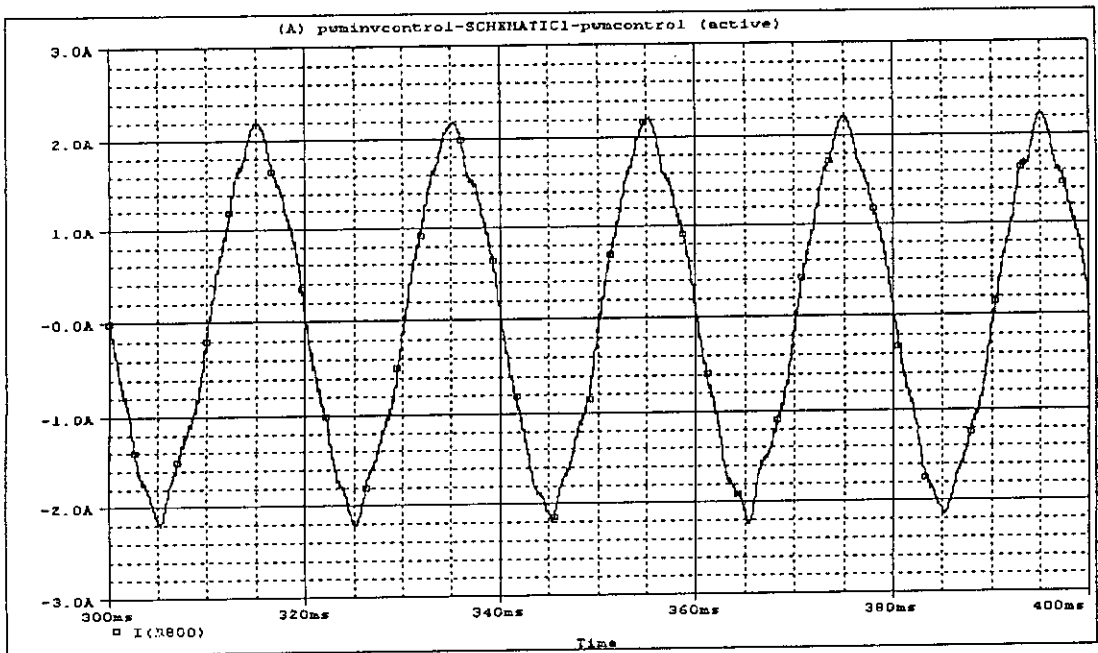


Fig.2.26 Output Current of PWM inverter after a low pass filter, $R_{load} = 100 \text{ ohm}$

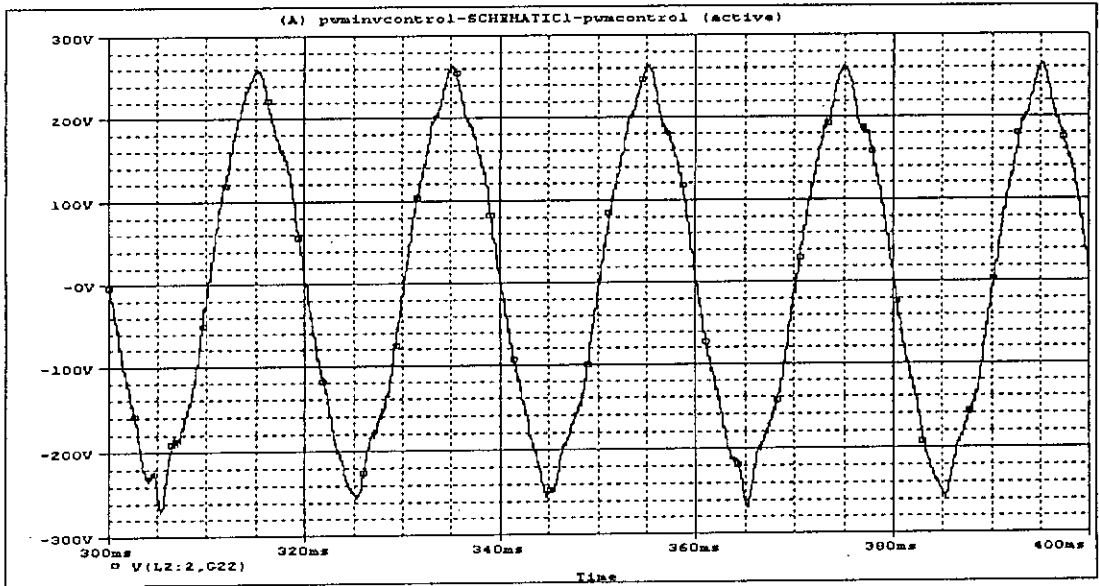


Fig.2.27 Output waveform of PWM inverter after a low pass filter, $R_{load} = 150 \text{ ohm}$

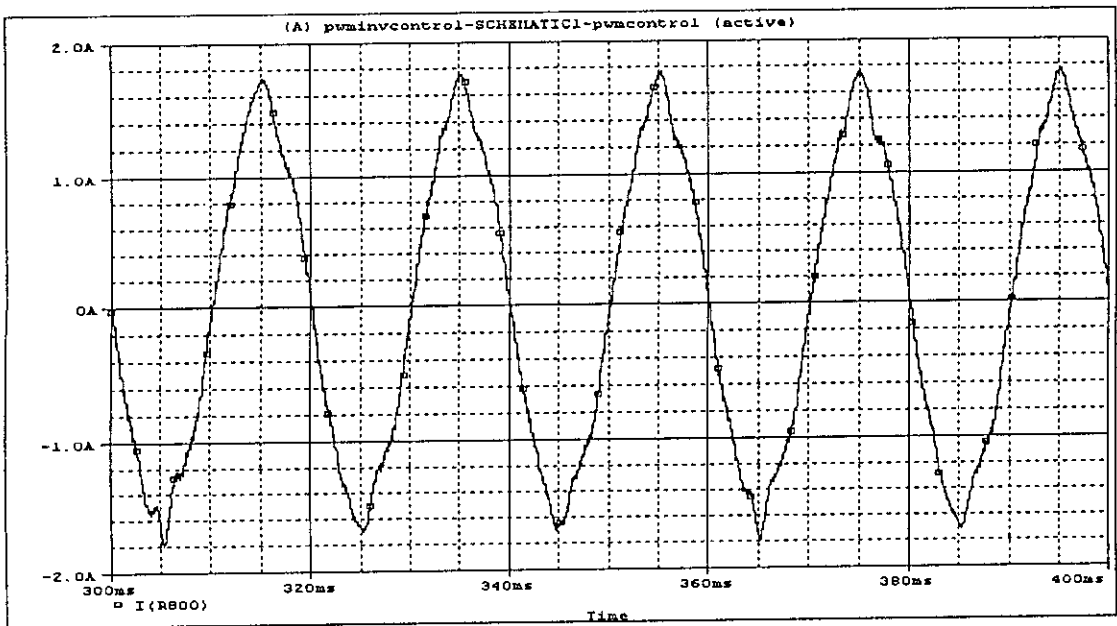


Fig.2.28 Output Current of PWM inverter after a low pass filter, $R_{load} = 150 \text{ ohm}$

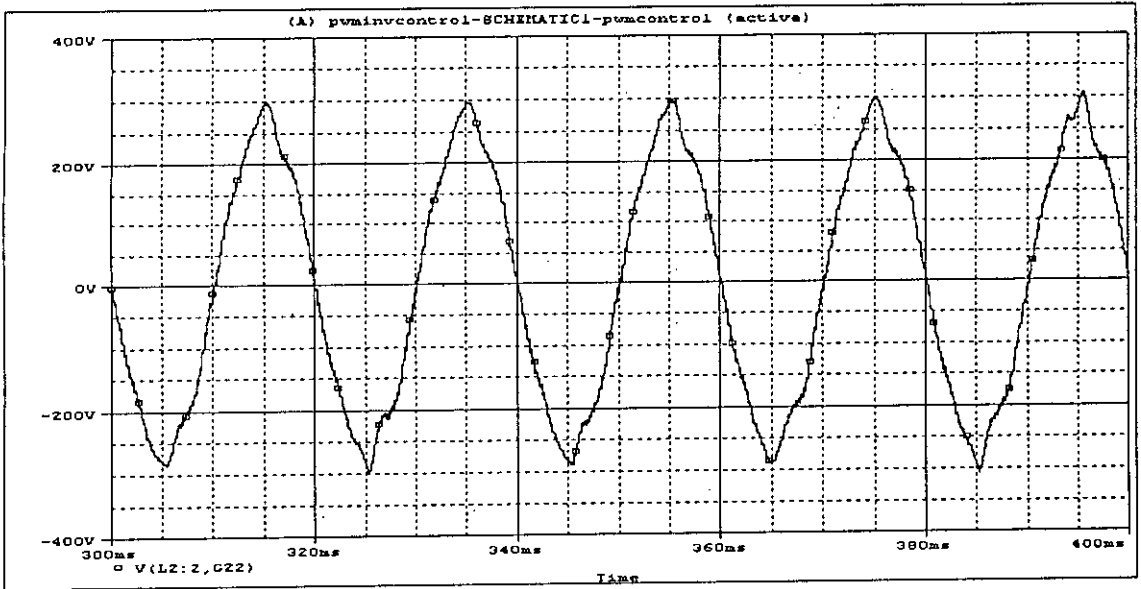


Fig.2.29 Output waveform of PWM inverter after a low pass filter, $R_{load} = 200 \text{ ohm}$

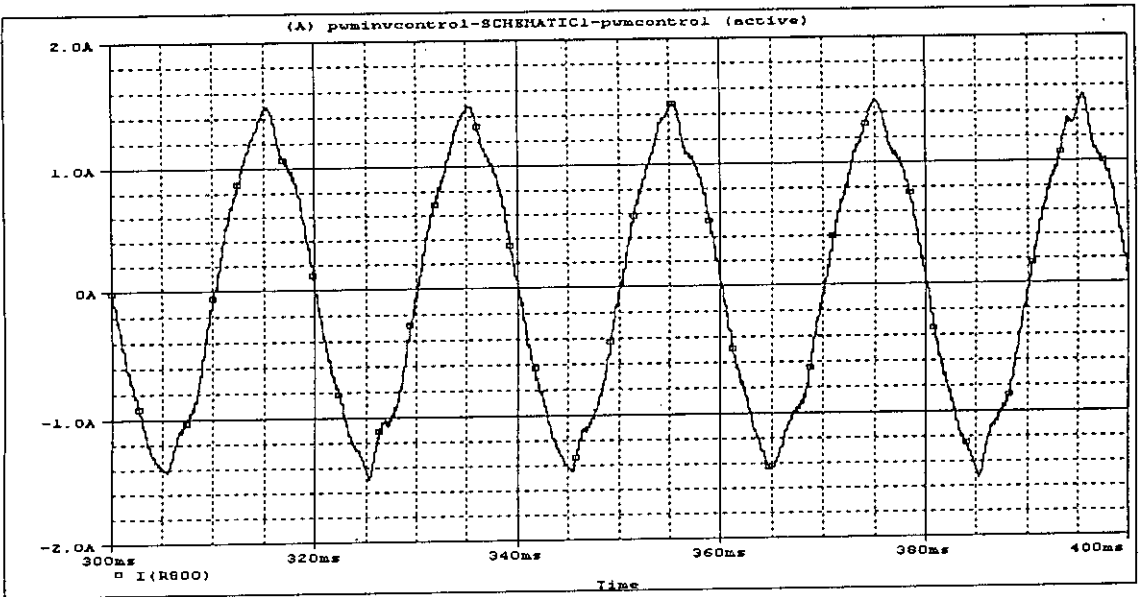


Fig.2.30 Output Current of PWM inverter after a low pass filter, $R_{load} = 200 \text{ ohm}$

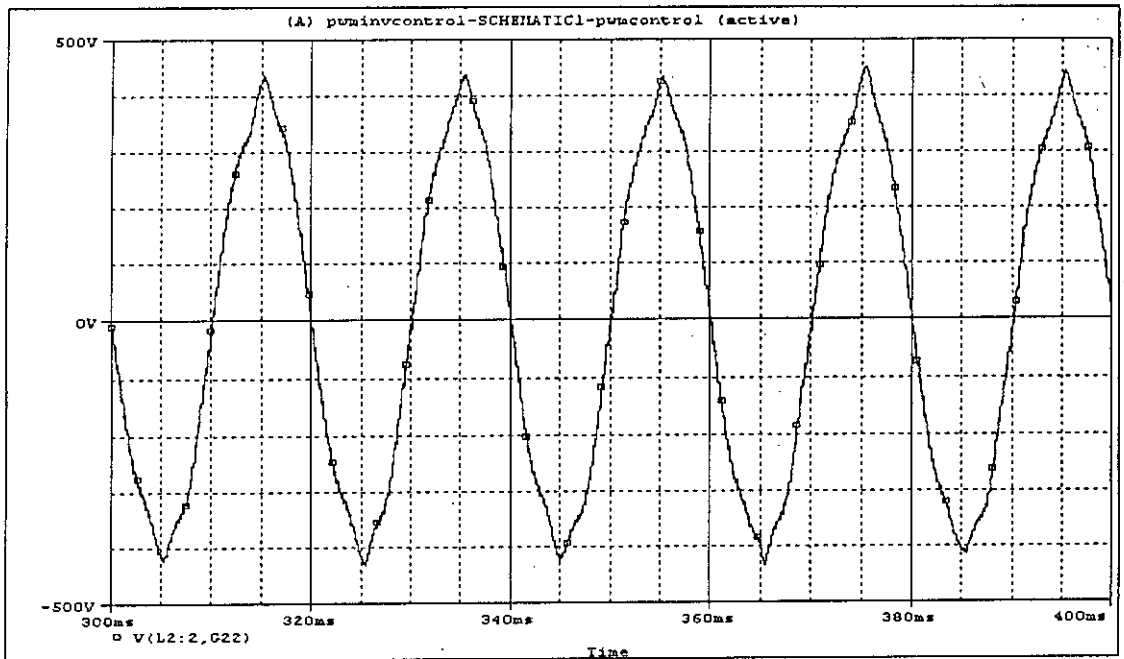


Fig.2.31 Output waveform of PWM inverter after a low pass filter, $R_{load} = 500 \text{ ohm}$

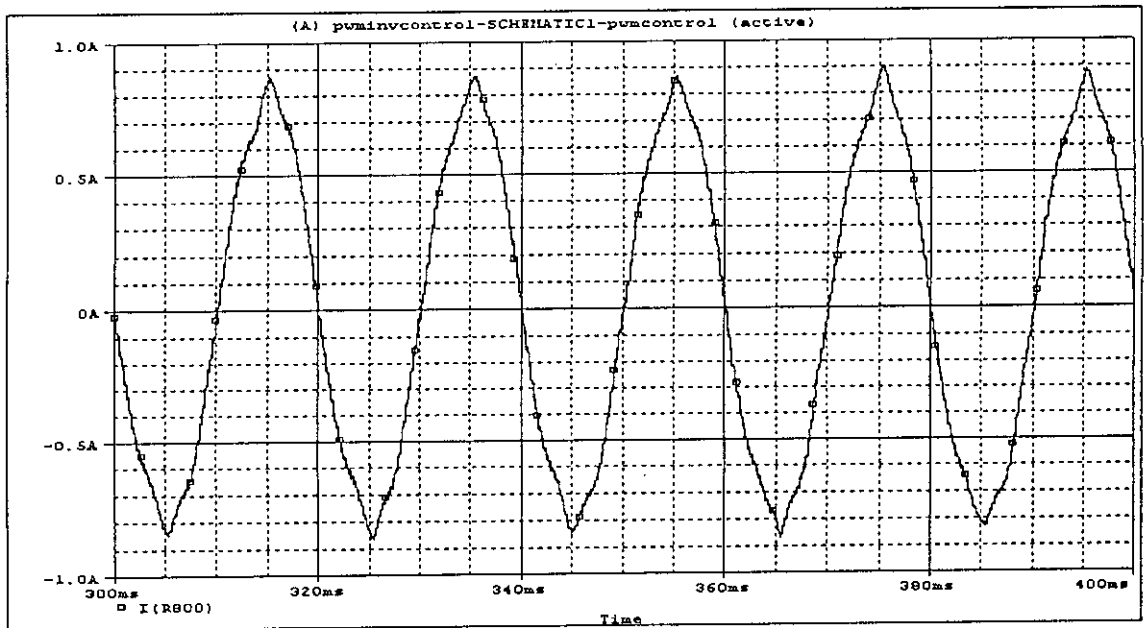


Fig.2.32 Output Current of PWM inverter after a low pass filter, $R_{load} = 500 \text{ ohm}$

2.9.1 Variation of output

It is evident that voltage regulation takes place when load is applied. In the proposed system, the voltage across the load may be maintained nearly constant either by changing the duty cycle of the two stage of C_uk converter or by changing the modulation index of the PWM inverter or by changing them both simultaneously. For this a control strategy is necessary which requires feedback of load voltage to the control circuits. This was not implemented in this work, however typical individual voltage control has been studied for both the cases. Table 2.4 to 2.5 and Figure 2.33 to 2.34 shows the voltage gain variation with the change of duty cycle of C_uk converter stages when modulation index of the inverter stage kept constant. Table 2.6 and Figure 2.35 shows the output (across load) voltage gain variation with the change of duty cycle of C_uk converter stages when modulation index of the inverter stages kept fixed. Table 2.7 and Figure 2.37 shows the total harmonics distortion (THD) values variation with the change of duty cycle of C_uk converter stages when modulation index of the inverter stages kept fixed. Table 2.8 and Fig. 2.38 to 2.39 shows modulation index change of inverter stage which keeping the duty cycle of the C_uk converter stages fixed. Same is shown in Table 2.10 and Fig. 2.41 for frequency change of inverter stage which keeping the duty cycle of the C_uk converter stages fixed. Table 2.9 and Figure 2.40 and Table 2.11 and Figure 2.42 shows the total harmonics distortion (THD) variation for modulation index and frequency change of inverter stage which keeping the duty cycle of the C_uk converter stages fixed. Typical waveforms for Table 2.6 to 2.11 are shown in Fig. 2.43 to 2.68 which indicates that out voltage waveforms across the load remain nearly sinusoidal.

Table: 2.4 Variation of cascaded Cuk output voltage with duty cycle variation (after stage 1)

PW	Duty cycle	Vout (Volt) -1st stage	Vin (Volt) -1st stage	Vout/Vin
0.005	0.10	26	12	2.16
0.010	0.20	28	12	2.33
0.015	0.30	32	12	2.67
0.02	0.40	35	12	2.91
0.025	0.50	41	12	3.41
0.030	0.60	51	12	4.25
0.035	0.70	62	12	5.16
0.040	0.80	87	12	7.25
0.0425	0.85	102	12	8.50
0.0450	0.90	100	12	8.33
0.0475	0.95	90	12	7.50
0.49	0.98	38	12	3.16

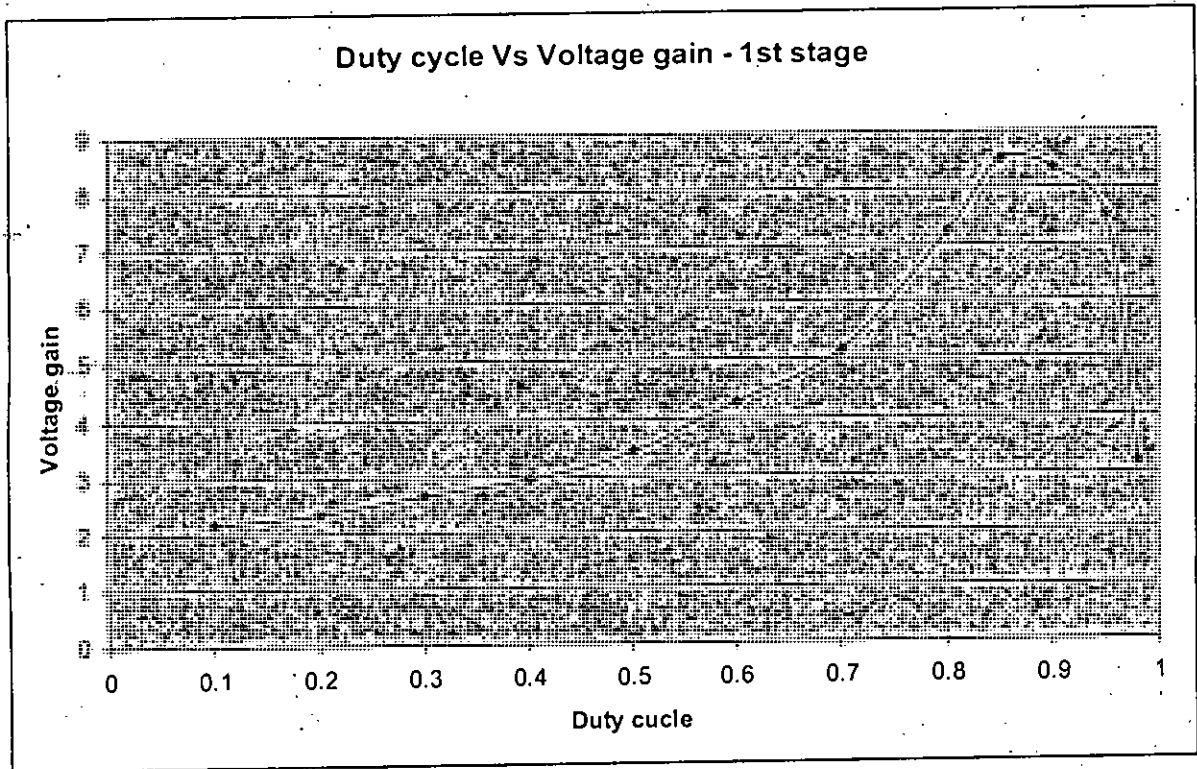


Fig.2.33 Variation of cascaded Cuk converters voltage gain with duty cycle (after stage 1)

Table: 2.5 Variation of cascaded Cûk output voltage with duty cycle variation (after stage 2)

PW	Duty cycle	Vout (Volt) -2nd stage	Vin (Volt) -2nd stage	Vout/Vin
0.005	0.10	142	26	5.46
0.010	0.20	155	28	5.53
0.015	0.30	182	32	5.68
0.02	0.40	204	35	5.82
0.025	0.50	240	41	5.85
0.030	0.60	310	51	6.07
0.035	0.70	382	62	6.16
0.040	0.80	540	87	6.20
0.0425	0.85	640	102	6.27
0.0450	0.90	620	100	6.20
0.0475	0.95	525	90	5.83
0.49	0.98	212	38	5.57

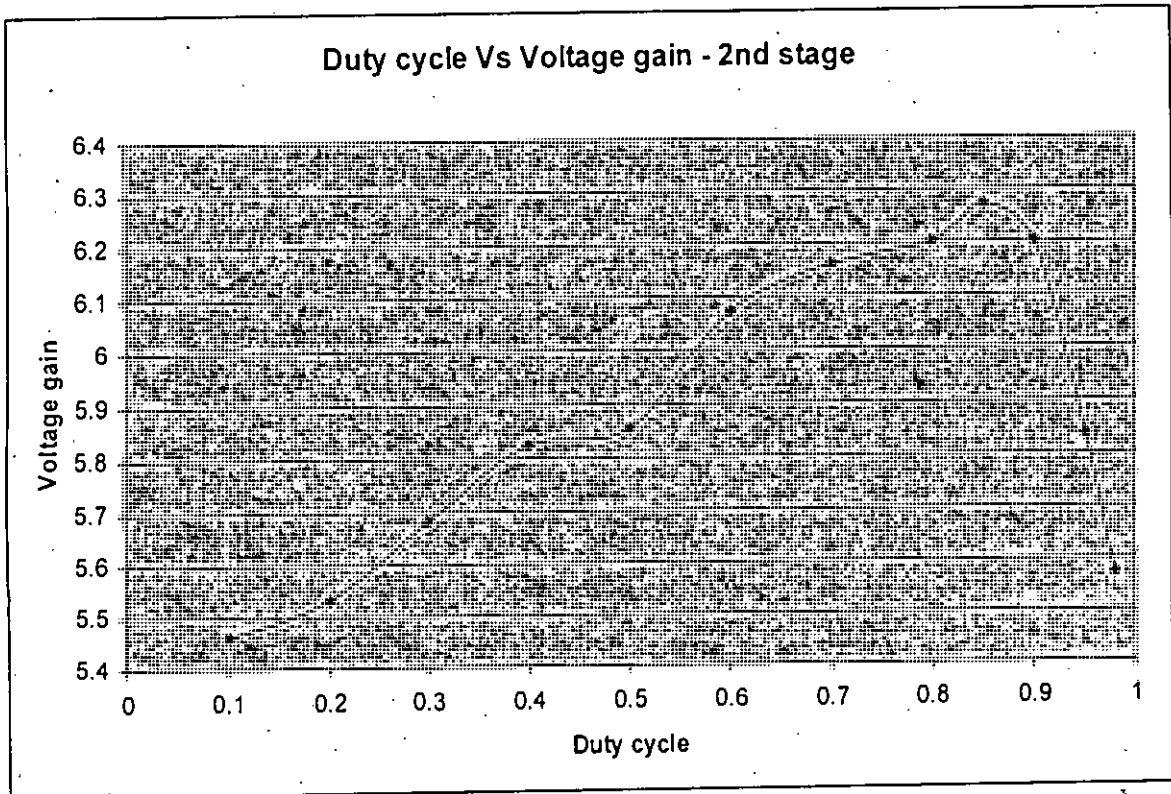


Fig.2.34 Variation of cascaded Cûk converter output power with duty cycle (after stage 2)

Table: 2.6 Variation of output (across load) with duty cycle variation where $M = 0.90$

PW	Duty cycle	Vout (Volt)	Iout (Amps)	Vin (Volt)	Pout	Vout/Vin
0.005	0.10	122	0.50	12	61	10.16
0.010	0.20	135	0.55	12	74.25	11.25
0.015	0.30	162	0.65	12	105.3	13.5
0.02	0.40	180	0.70	12	126	15
0.025	0.50	210	0.85	12	178.5	17.5
0.030	0.60	260	1.00	12	260	21.66
0.035	0.70	340	1.30	12	420	28.33
0.040	0.80	470	1.80	12	846	39.16
0.0425	0.85	500	2.00	12	1000	41.66
0.0450	0.90	480	2.10	12	864	40.00
0.0475	0.95	450	1.60	12	720	37.50
0.49	0.98	180	0.7	12	126	15

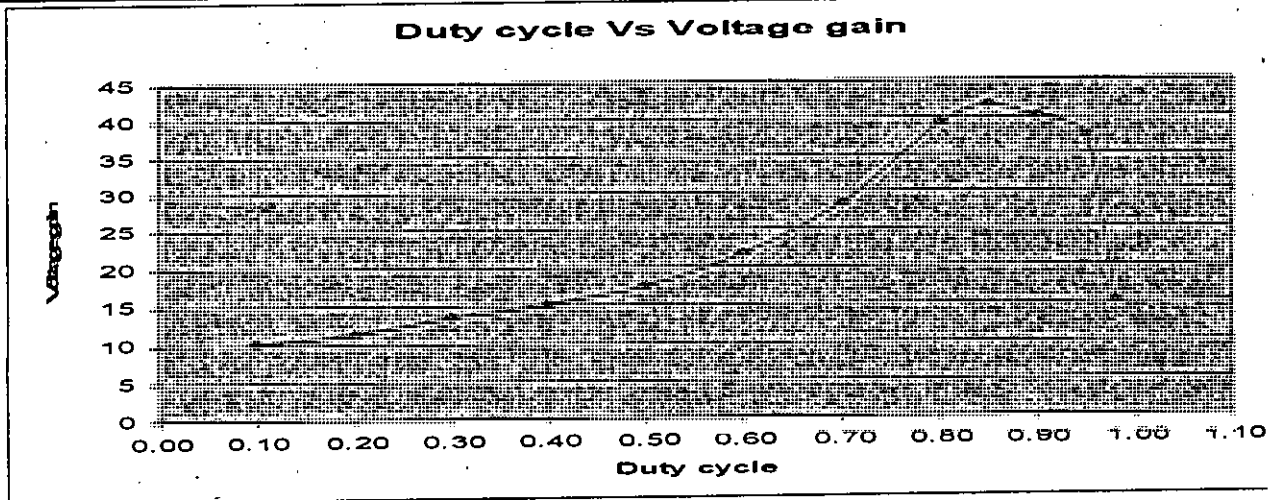


Fig.2.35 Variation of output (across load) voltage gain with duty cycle where $M = 0.90$

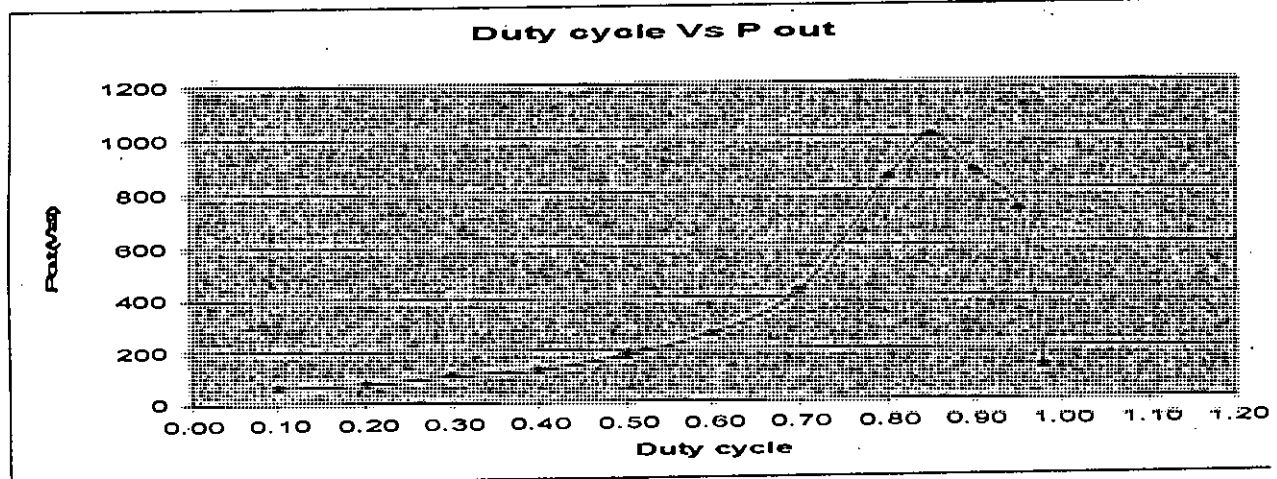


Fig.2.36 Variation of output (across load) power with duty cycle where $M = 0.90$

Table: 2.7 THD (%) output voltages with Variation of duty cycle variation

Duty cycle	Vout (Volt)	(%)THD
0.10	122	4.57
0.20	135	4.90
0.30	162	5.65
0.40	180	5.64
0.50	210	5.78
0.60	260	5.43
0.70	340	5.23
0.80	470	6.44
0.85	500	5.84
0.90	480	7.68
0.95	450	7.26
0.98	180	5.45

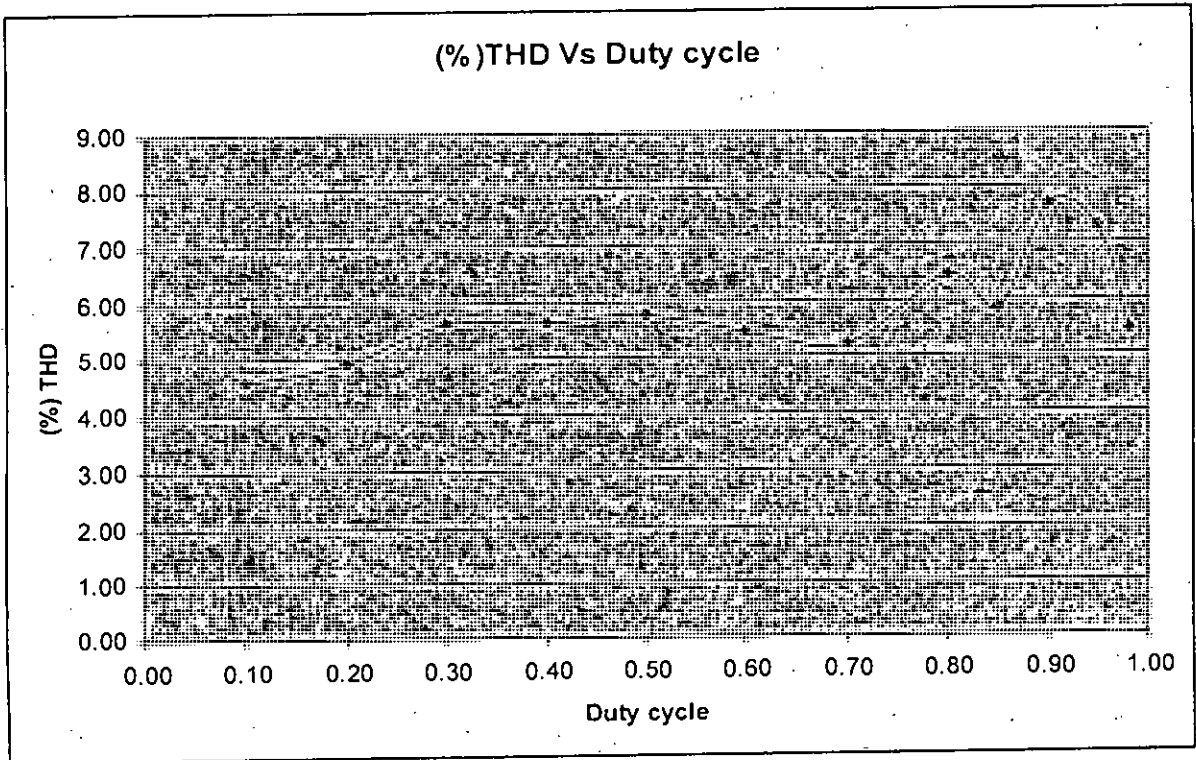


Fig.2.37 THD(%) output voltage with Variation of duty cycle variation

Table: 2.8 Variation of PWM inverter output with modulation index variation (after stage 2) where Duty cycle, $D = 0.70$

Sing_Ampl	M	Vout (Volt)	Vin (volt)	Vout/Vin
2.00	0.20	130	12	10.83
3.00	0.30	185	12	15.41
4.00	0.40	210	12	17.50
5.00	0.50	240	12	20.00
6.00	0.60	260	12	21.66
7.00	0.70	265	12	22.08
8.00	0.80	280	12	23.33
9.00	0.90	340	12	28.33
10.00	1.00	350	12	29.16
11.00	1.10	350	12	29.58

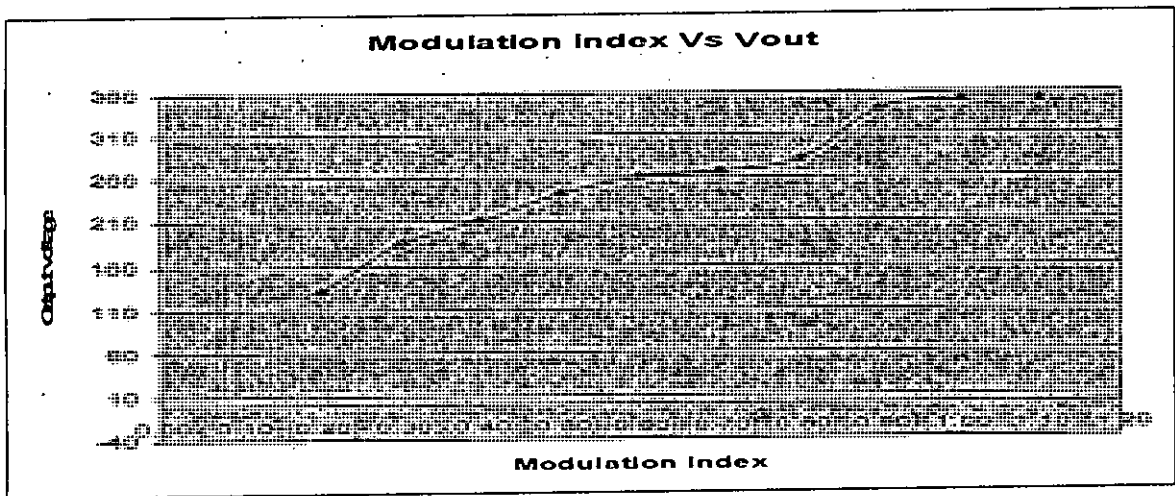


Fig.2.38 Variation of output voltage with modulation index where Duty cycle, $D = 0.70$

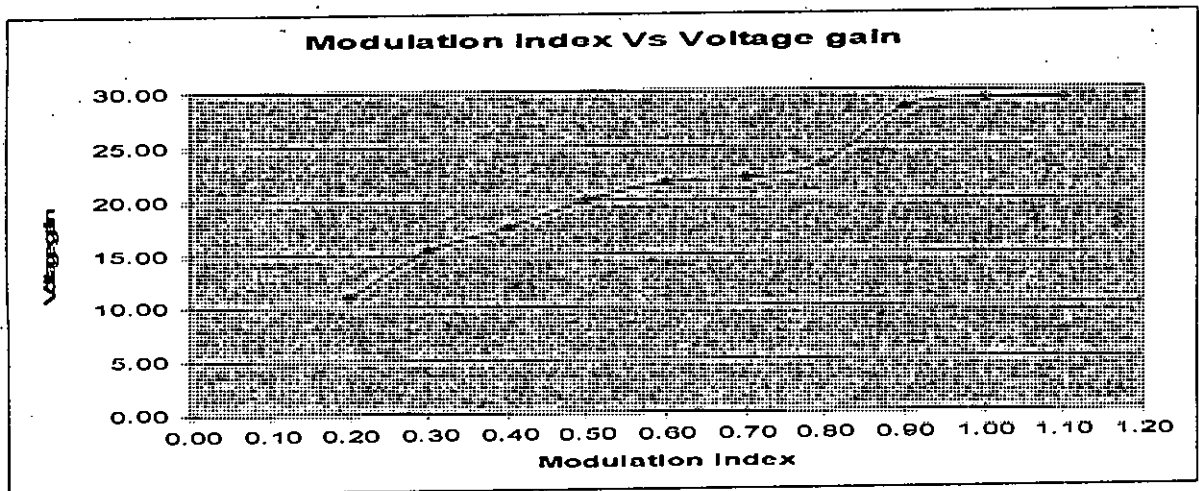


Fig.2.39 Variation of voltage gain with modulation index where Duty cycle, $D = 0.70$

Table: 2.9 THD of output voltage with Variation of modulation index

Sing_Ampl	M	Vout (Volt)	(%)THD
2.00	0.20	130	5.95
3.00	0.30	185	5.23
4.00	0.40	210	3.09
5.00	0.50	240	3.12
6.00	0.60	260	2.91
7.00	0.70	265	5.22
8.00	0.80	280	5.46
9.00	0.90	340	5.23
10.00	1.00	350	9.12
11.00	1.10	350	9.07

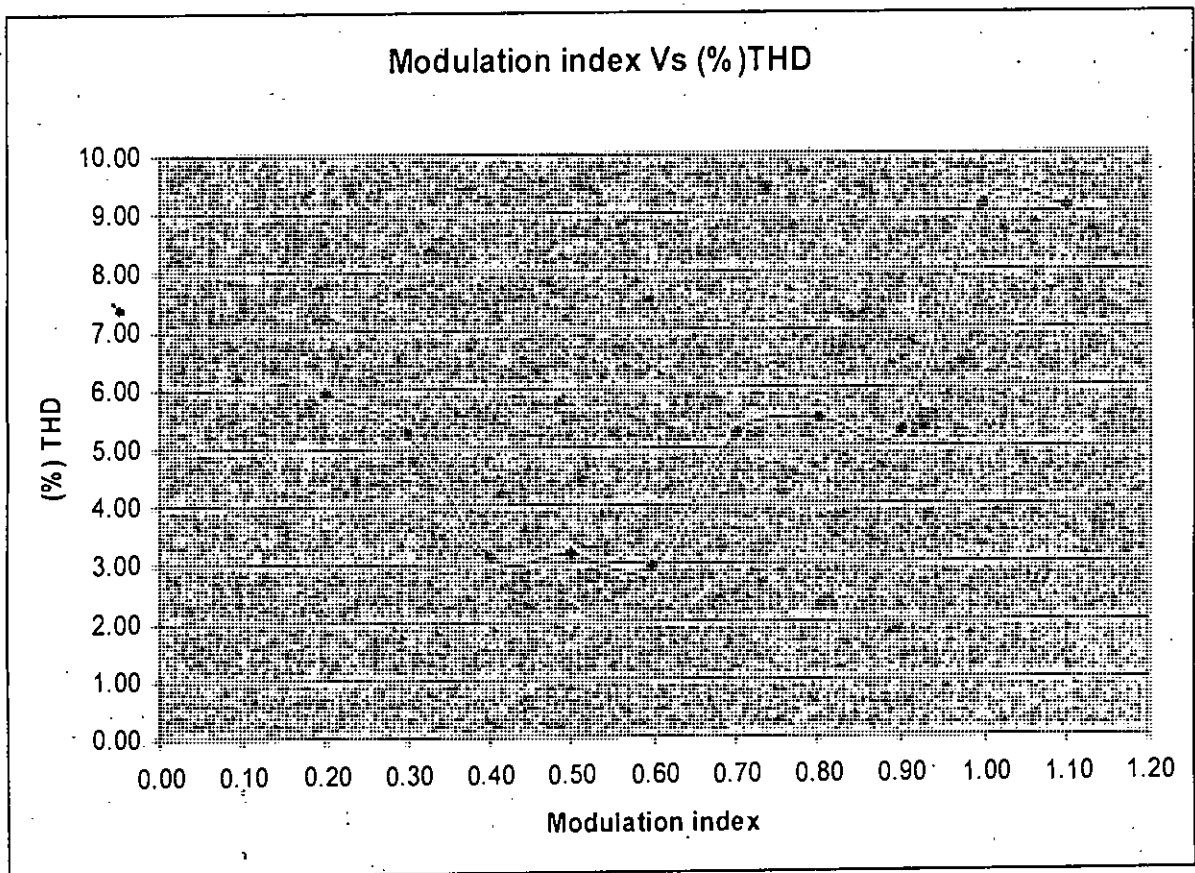


Fig.2.40 THD of output voltage with Variation of modulation index

Table: 2.10 Variation of output Voltage with input frequency variation

Fin (Hz)	Vout (volt)	Vin (volt)	Vout/Vin
50	340	12	28.33
60	320	12	26.67
70	310	12	25.83
80	300	12	25

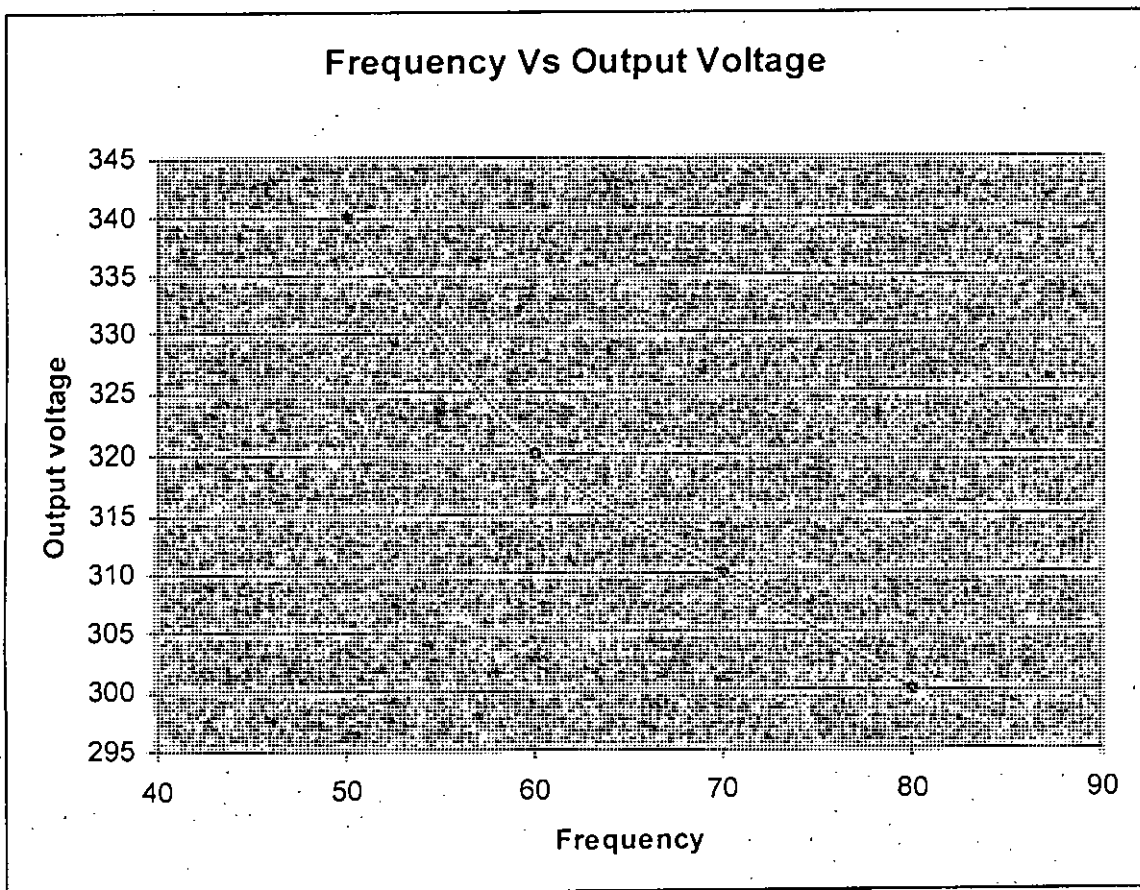


Fig.2.41 Variation of output voltage with input frequency

Table: 2.11 Output voltage THD variations with variation of input frequency

Fin (Hz)	Vout (volt)	(%)THD
50	340	5.23
60	320	5.03
70	310	5.19
80	300	4.13

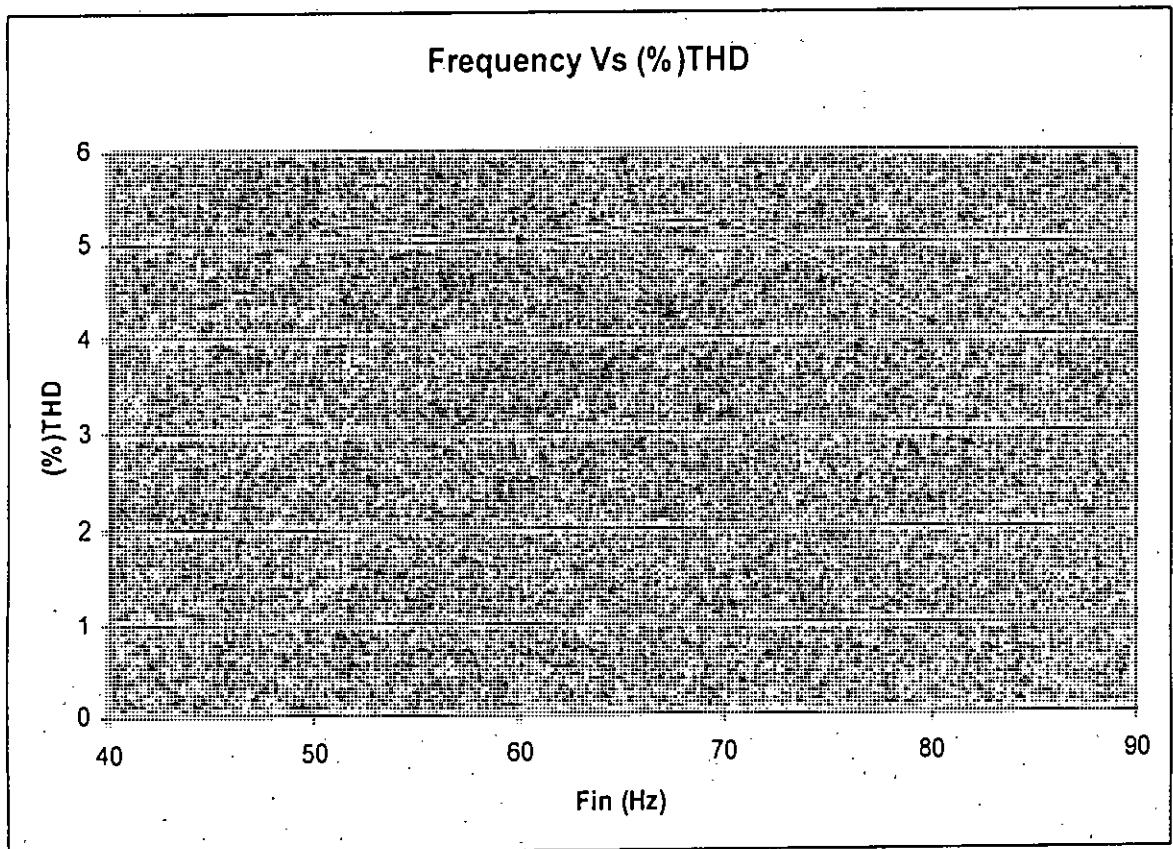


Fig.2.42 Output voltage THD variations with variation of input frequency

2.9.2. Variation in graphical form

In graphical form we shown the variation of output voltage wave form with duty cycle, modulation index and input frequency.

2.9.2.1. Variation by duty cycle in cascade Cûk converter

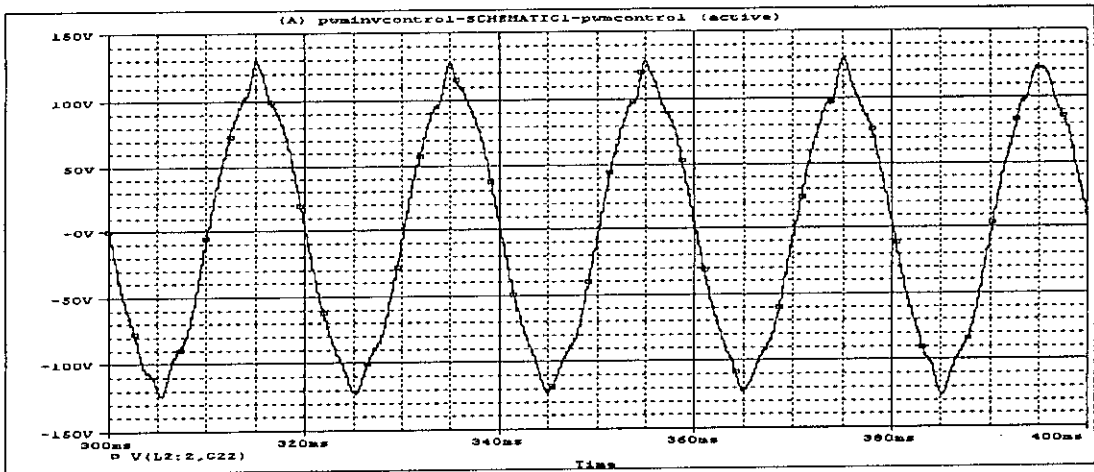


Fig.2.43 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.10

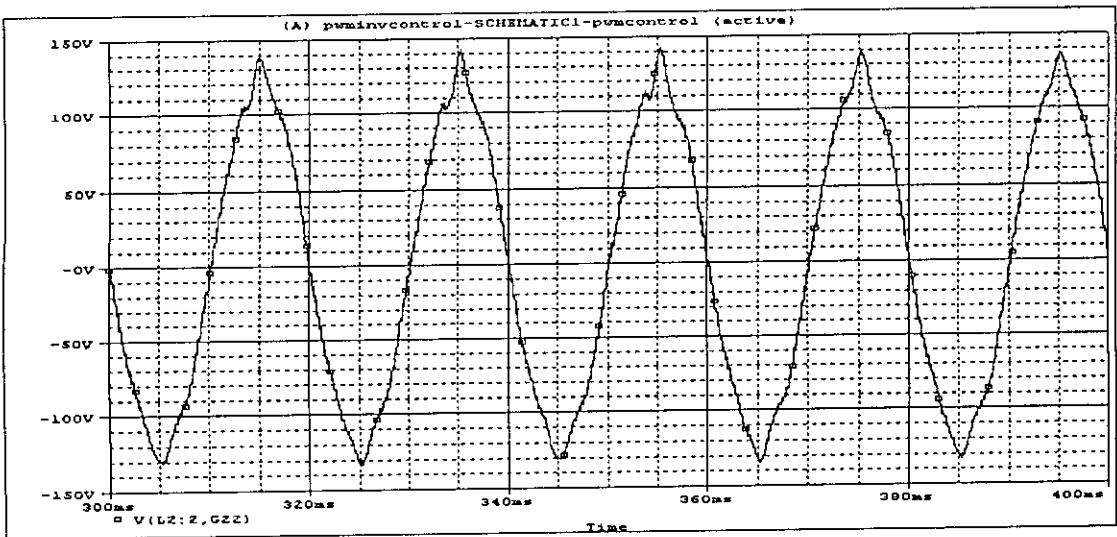


Fig.2.44 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.20

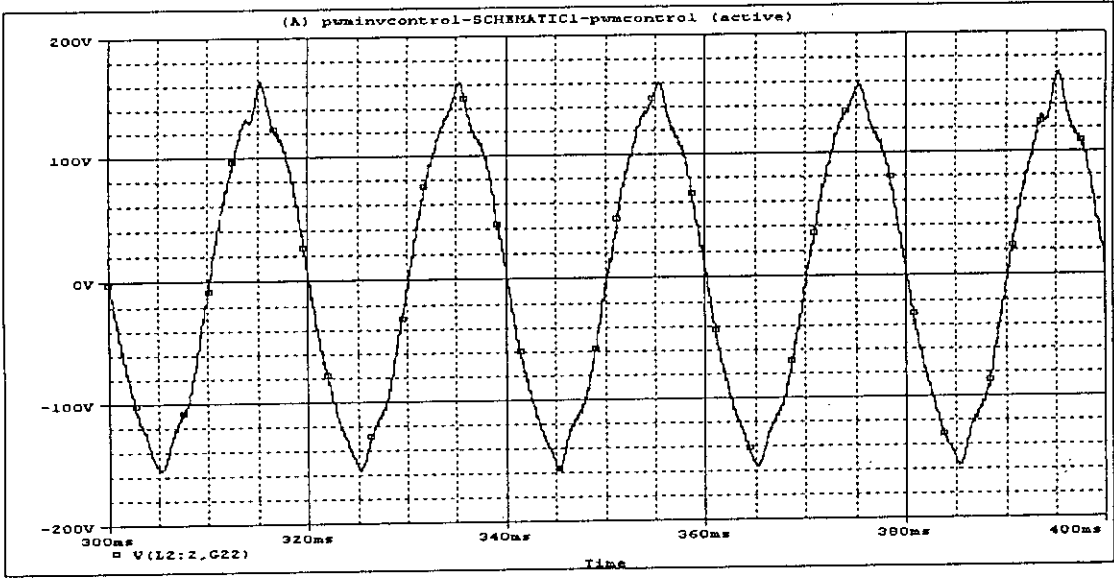


Fig.2.45 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.30

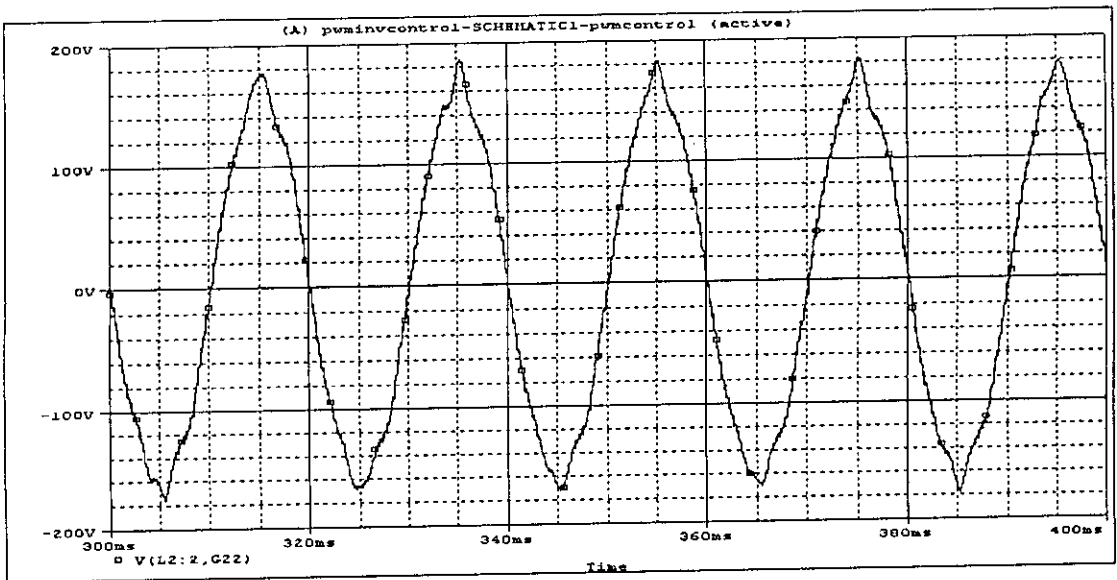


Fig.2.46 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.40

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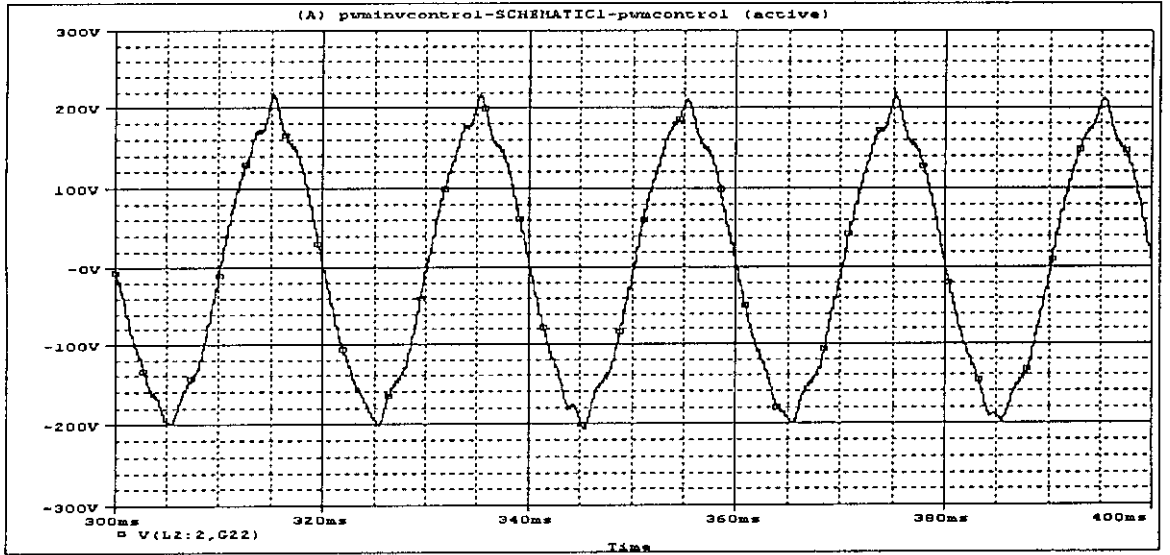


Fig.2.47 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.50

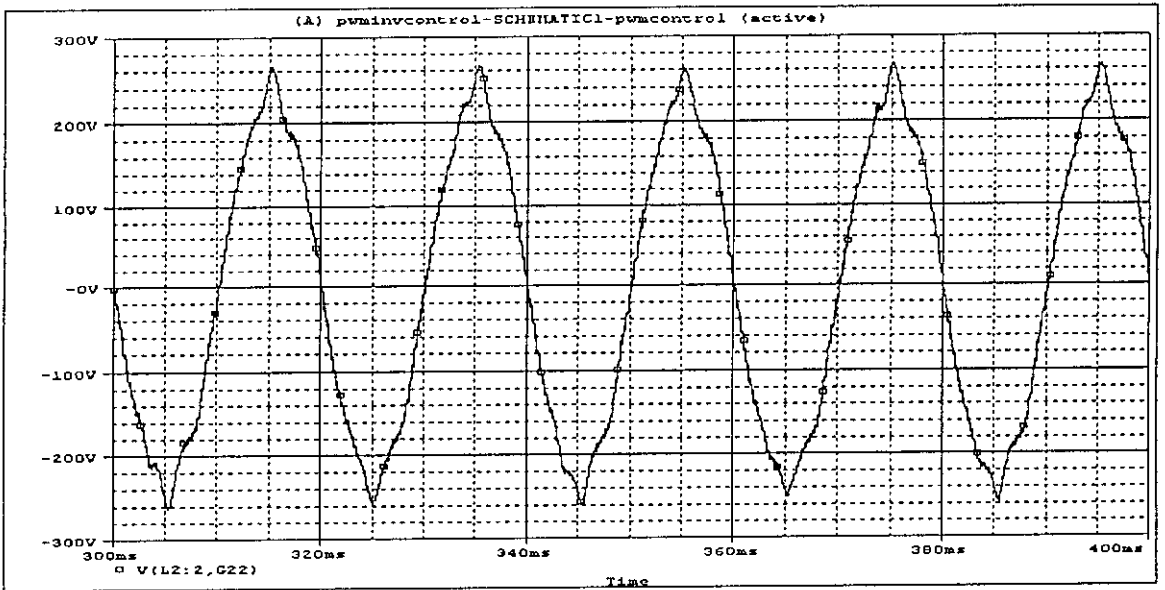


Fig.2.48 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.60

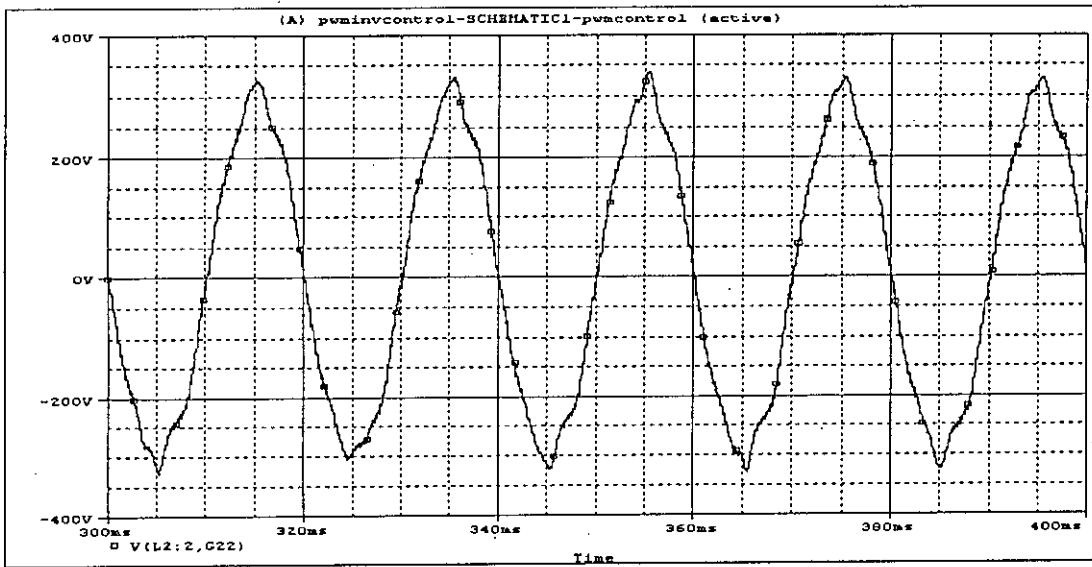


Fig.2.49 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.70

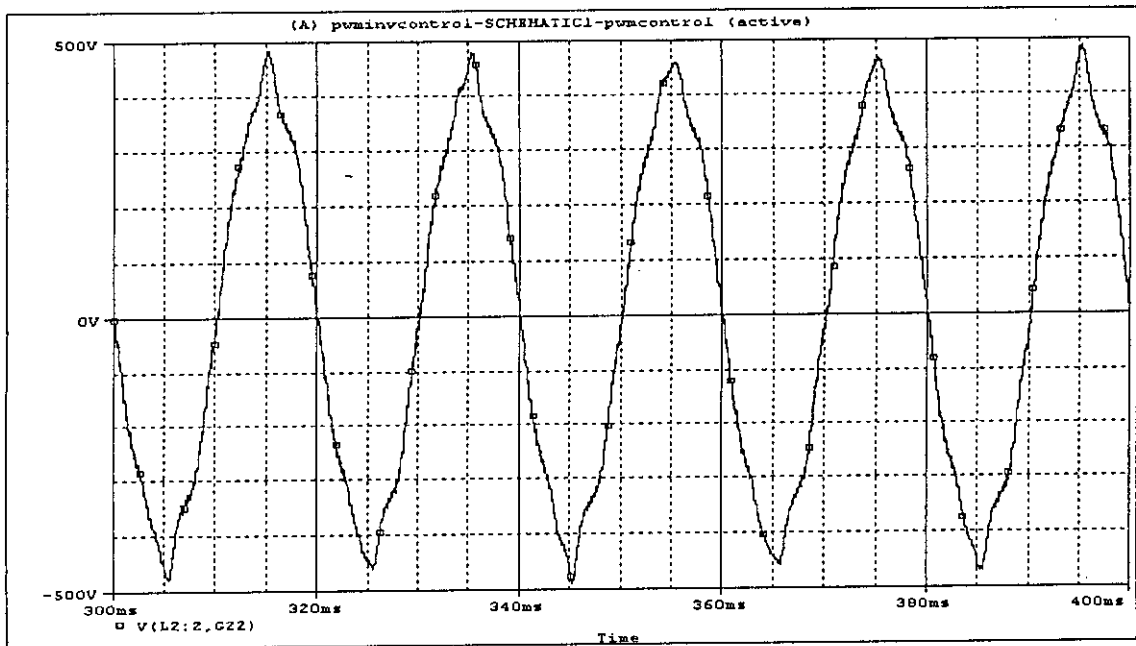


Fig.2.50 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.80

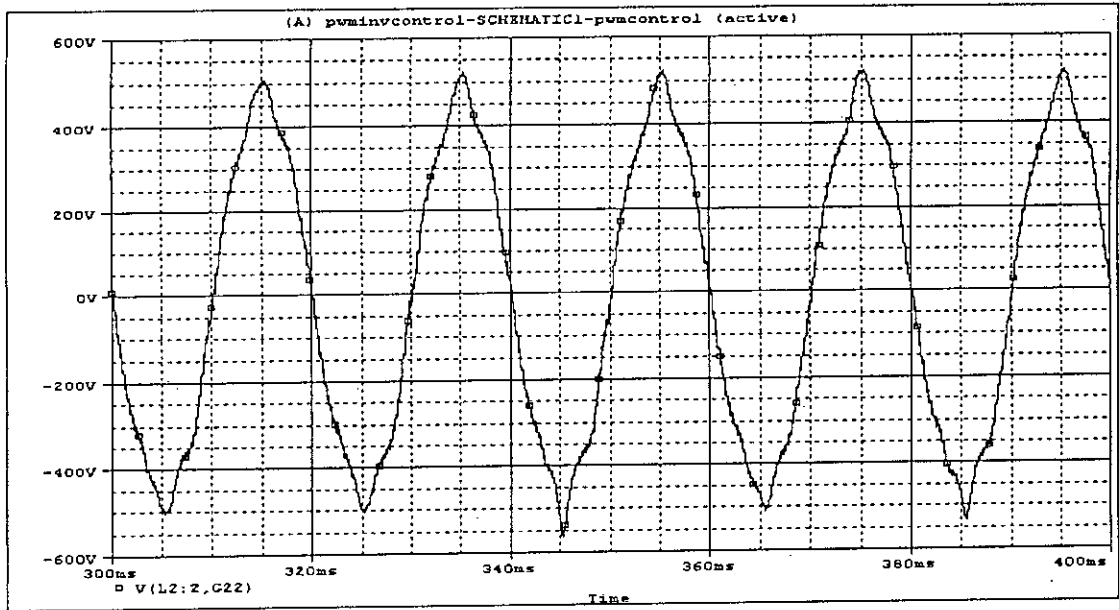


Fig.2.51 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.85

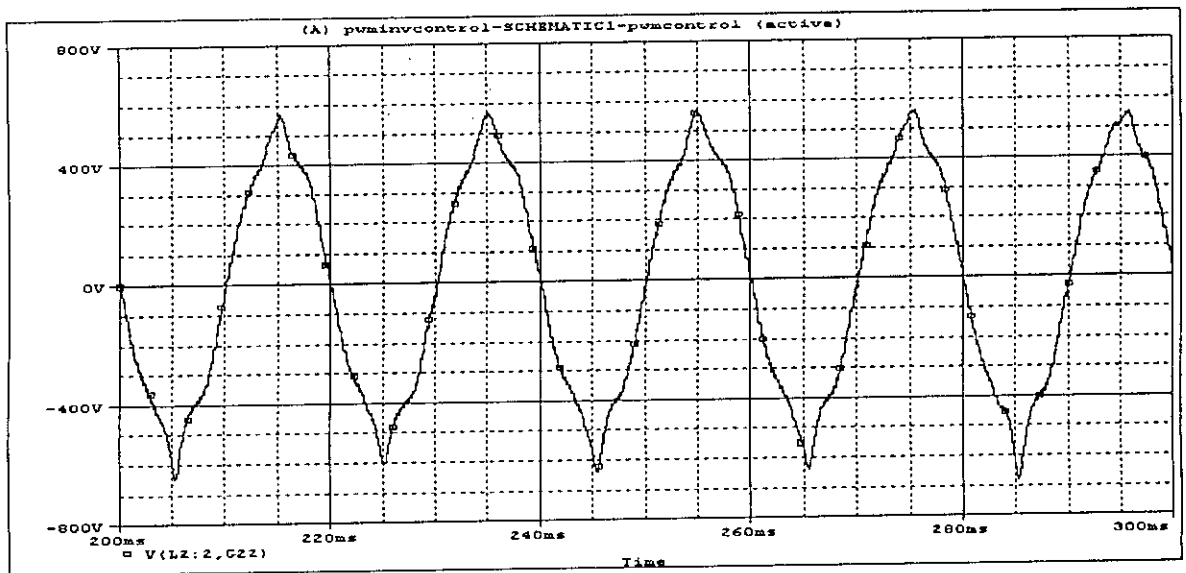


Fig.2.52 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.90

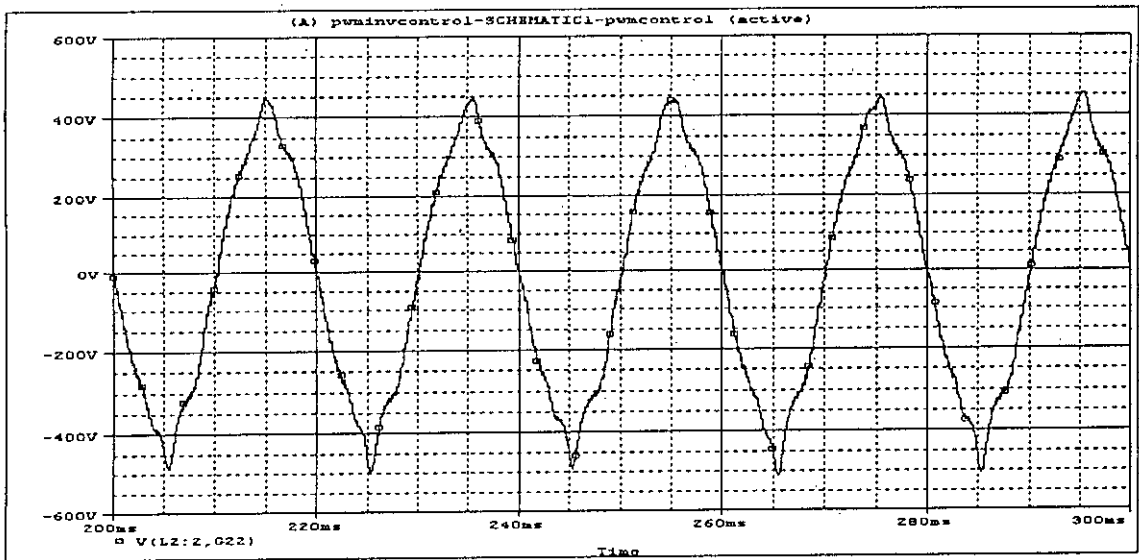


Fig.2.53 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.95

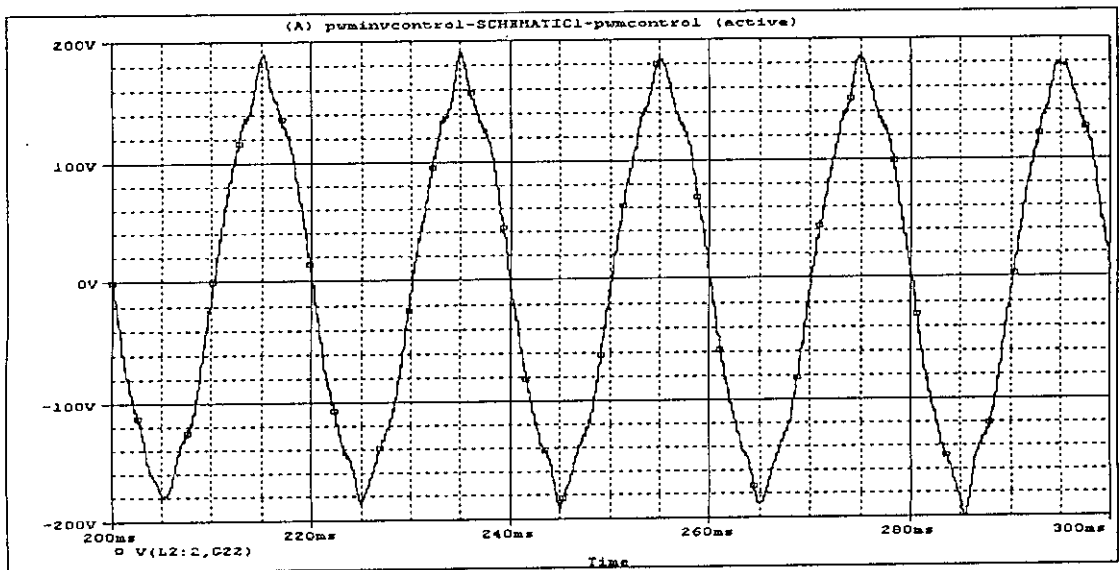


Fig.2.54 Variation of output voltage (across load) by Cûk stage, duty cycle = 0.98

2.9.2.2. Variation by modulation index

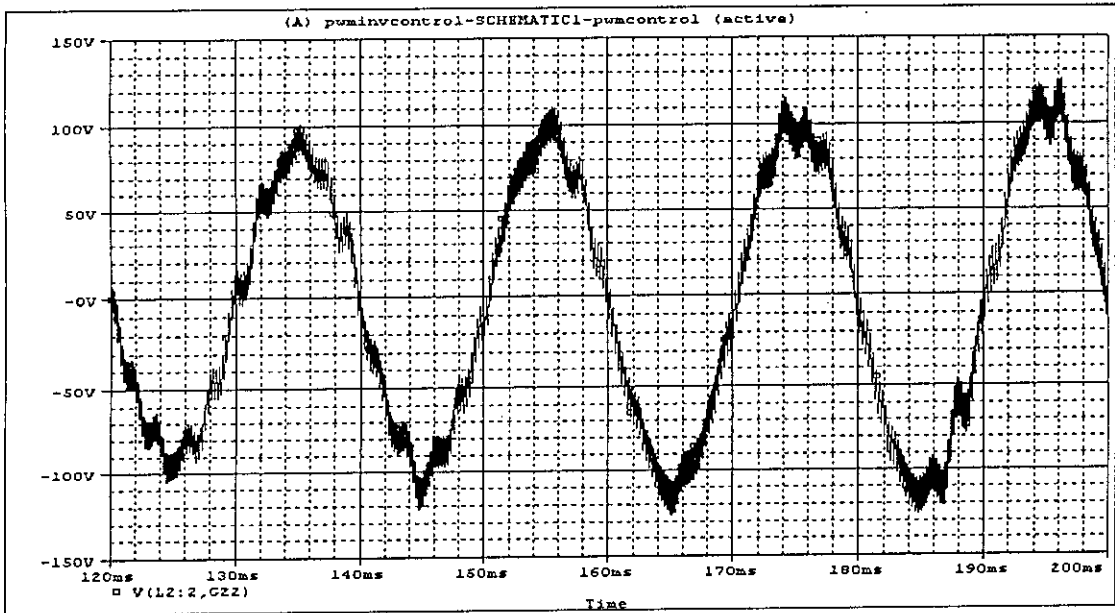


Fig.2.55 Variation of output voltage (across load) by modulation index for $m = 0.20$

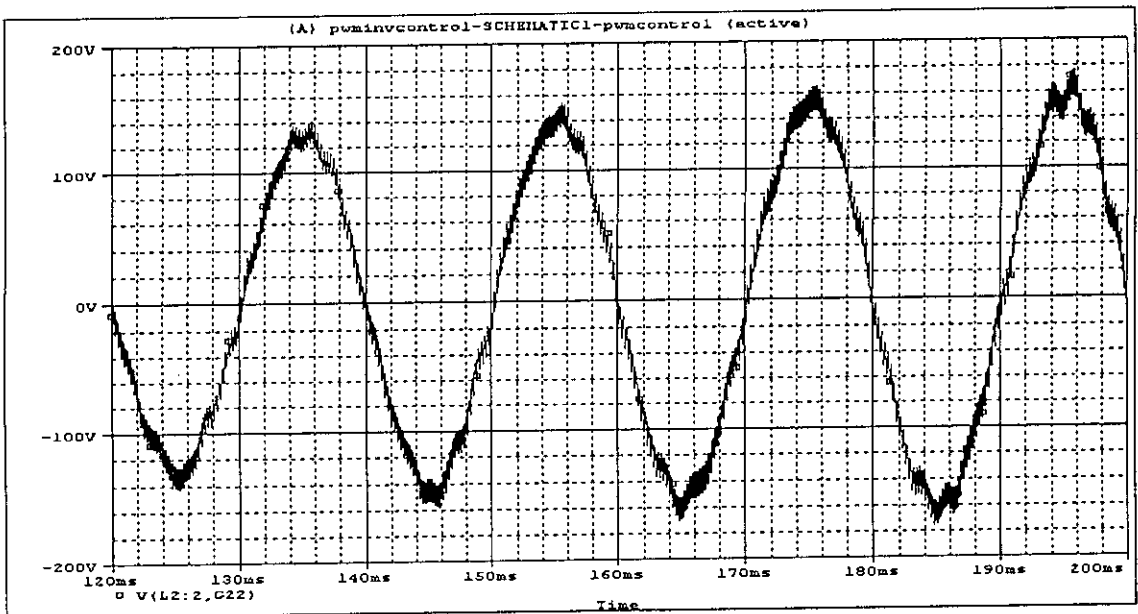


Fig.2.56 Variation of output voltage (across load) by modulation index for $m = 0.30$

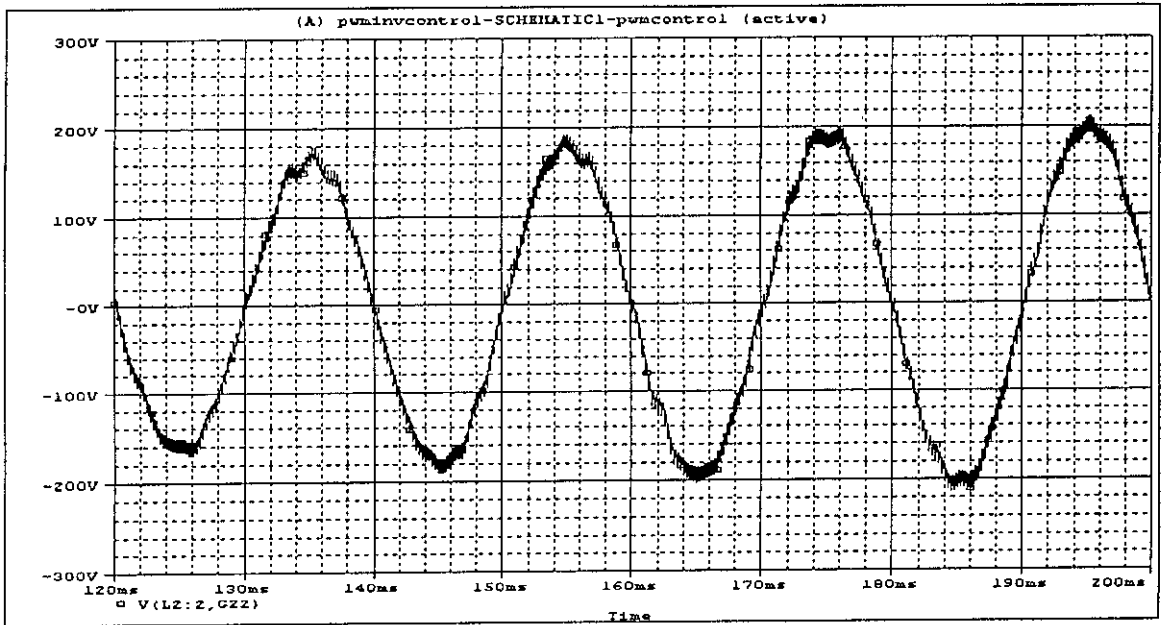


Fig.2.57 Variation of output voltage (across load) by modulation index for $m = 0.40$

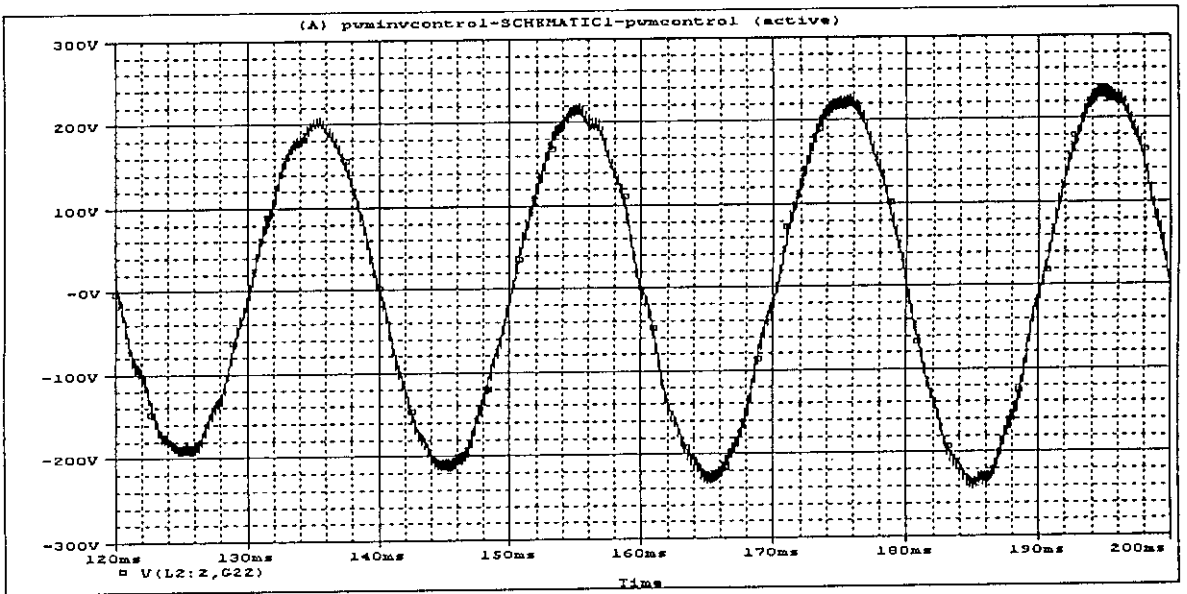


Fig.2.58 Variation of output voltage (across load) by modulation index for $m = 0.50$

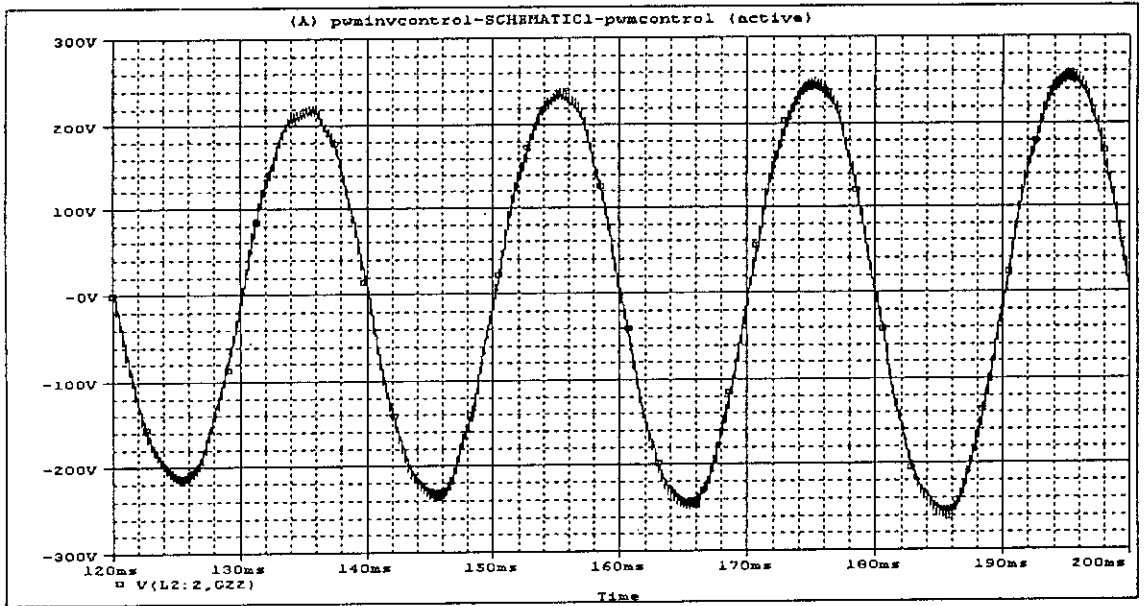


Fig.2.59 Variation of output voltage (across load) by modulation index for $m = 0.60$

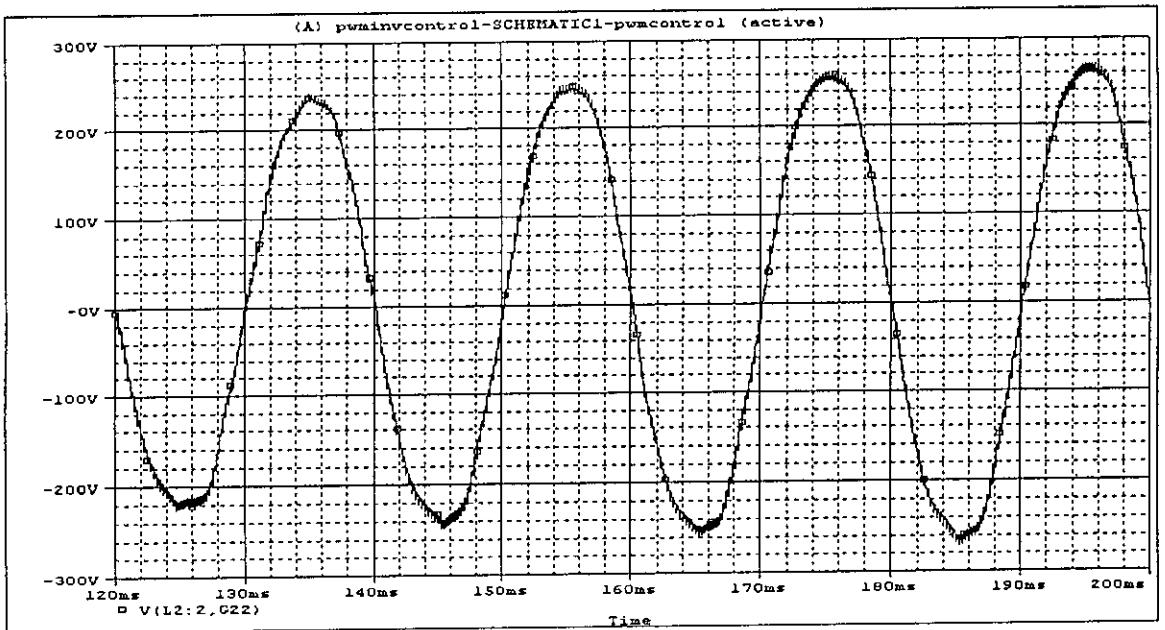


Fig.2.60 Variation of output voltage (across load) by modulation index for $m = 0.70$

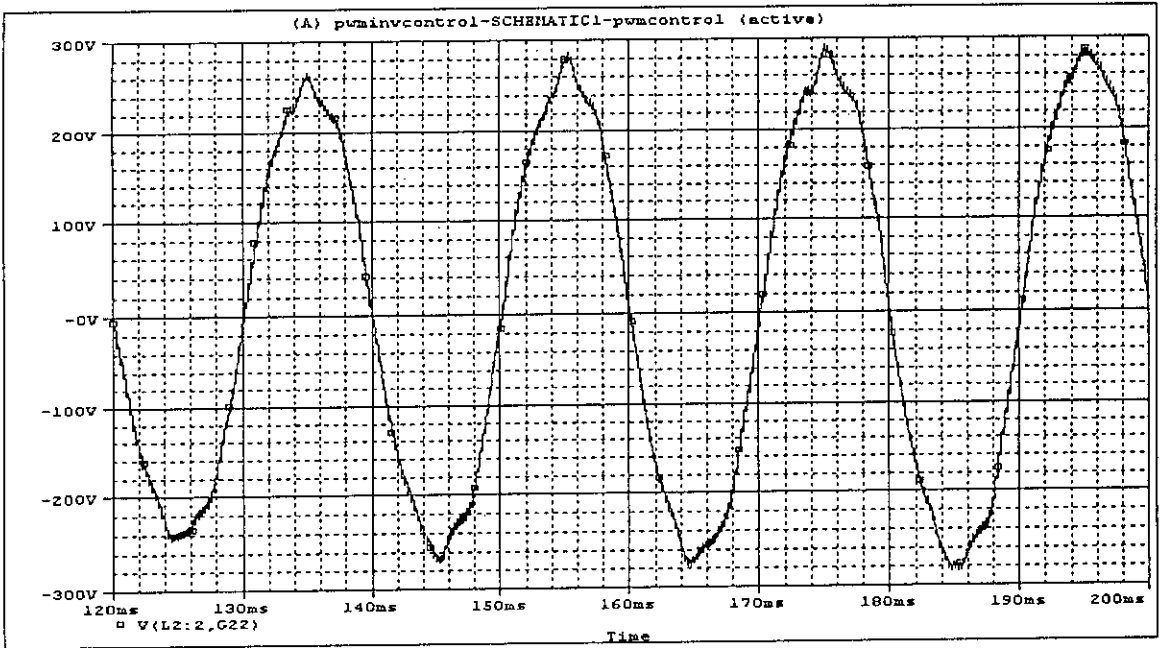


Fig.2.61 Variation of output voltage (across load) by modulation index for $m = 0.80$

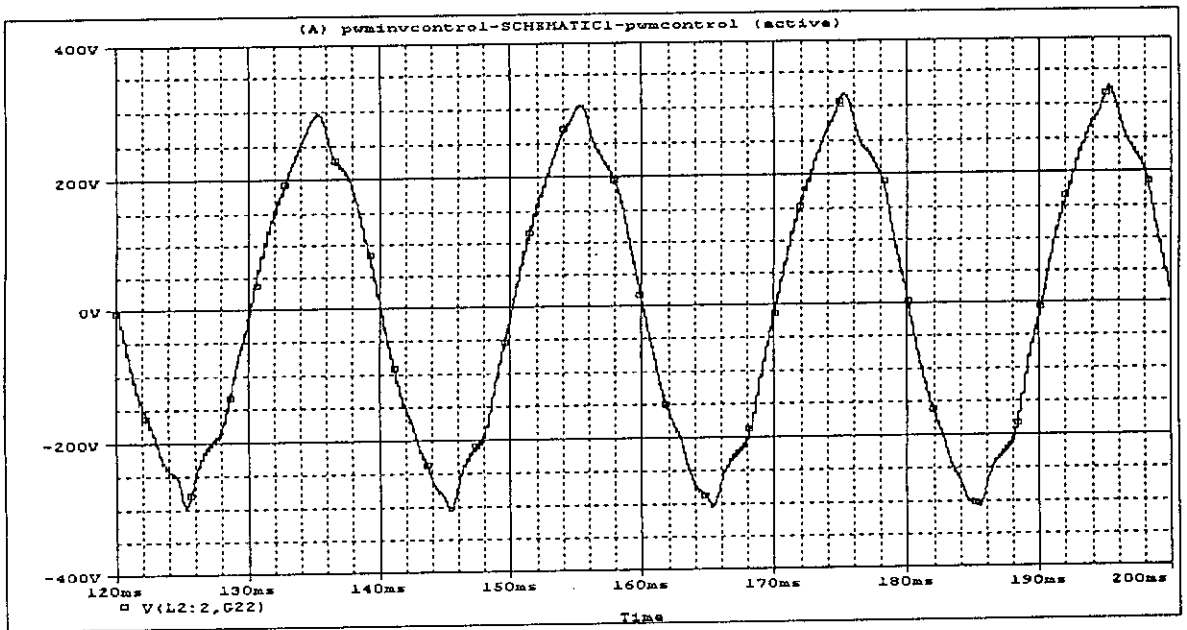


Fig.2.62 Variation of output voltage (across load) by modulation index for $m = 0.90$

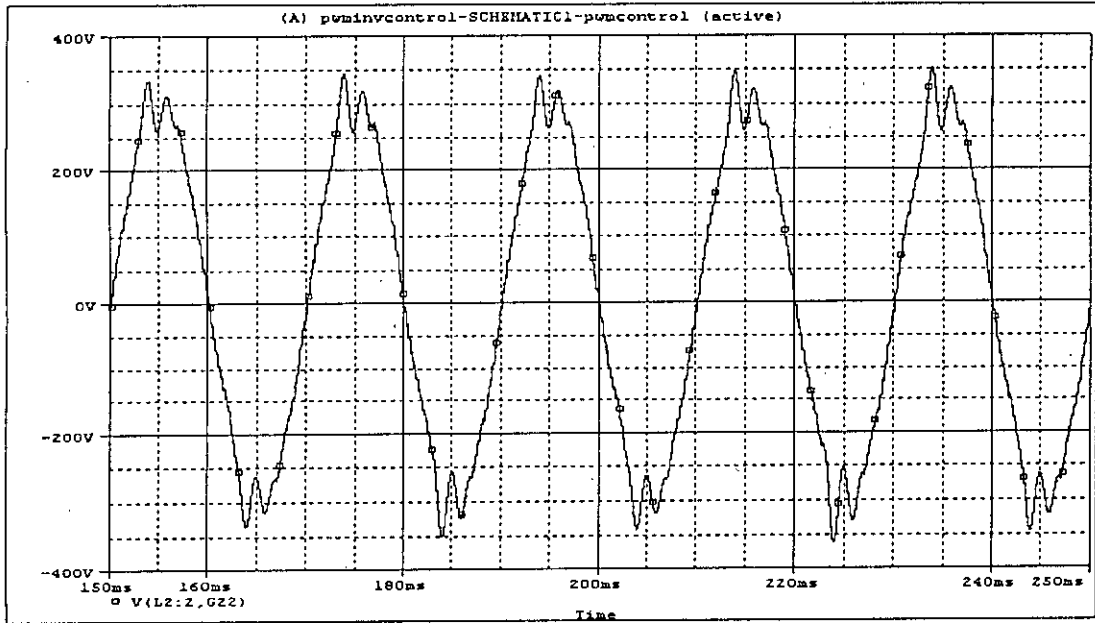


Fig.2.63 Variation of output voltage (across load) by modulation index for $m = 1.00$

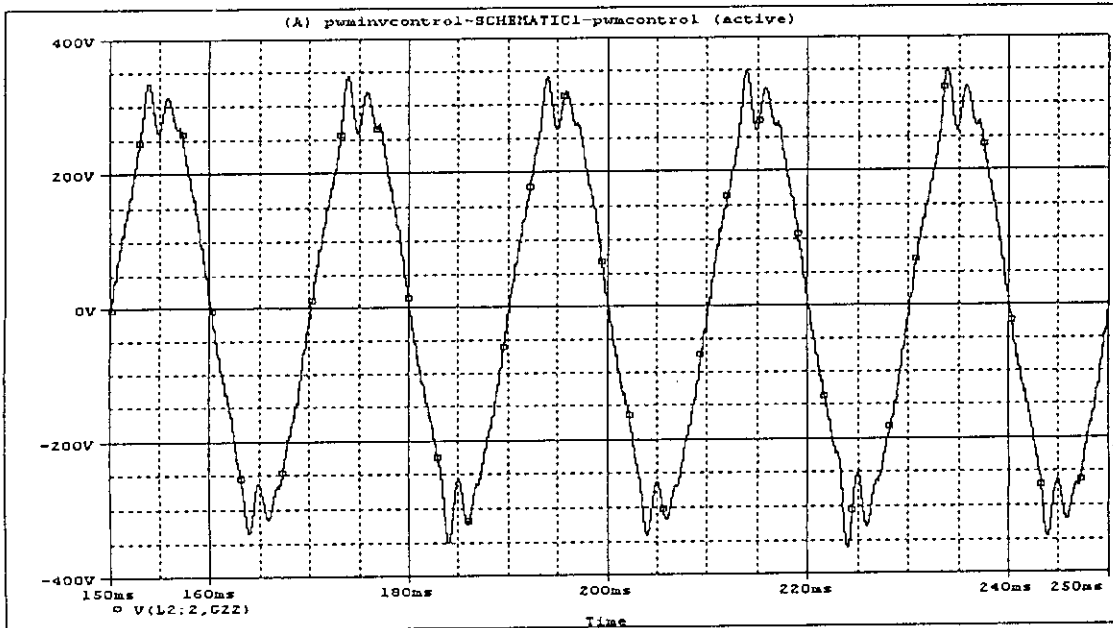


Fig.2.64 Variation of output voltage (across load) by modulation index for $m = 1.10$

2.9.2.3. Variation by modulation frequency

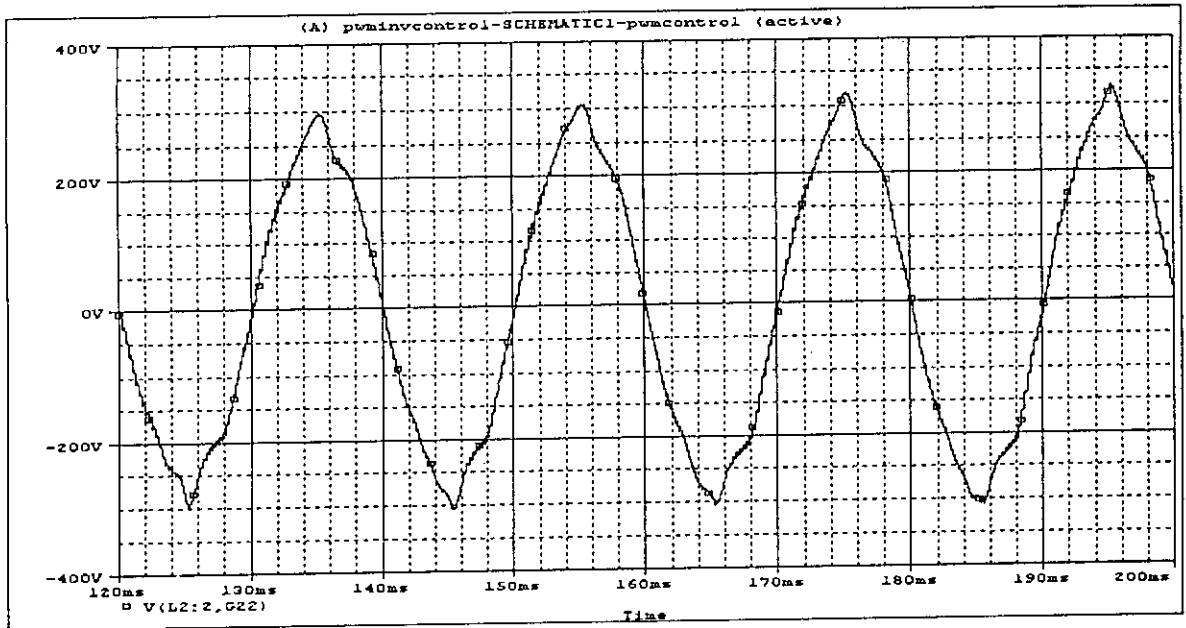


Fig.2.65 Variation of output frequency (across load) by modulation frequency, $f = 50$

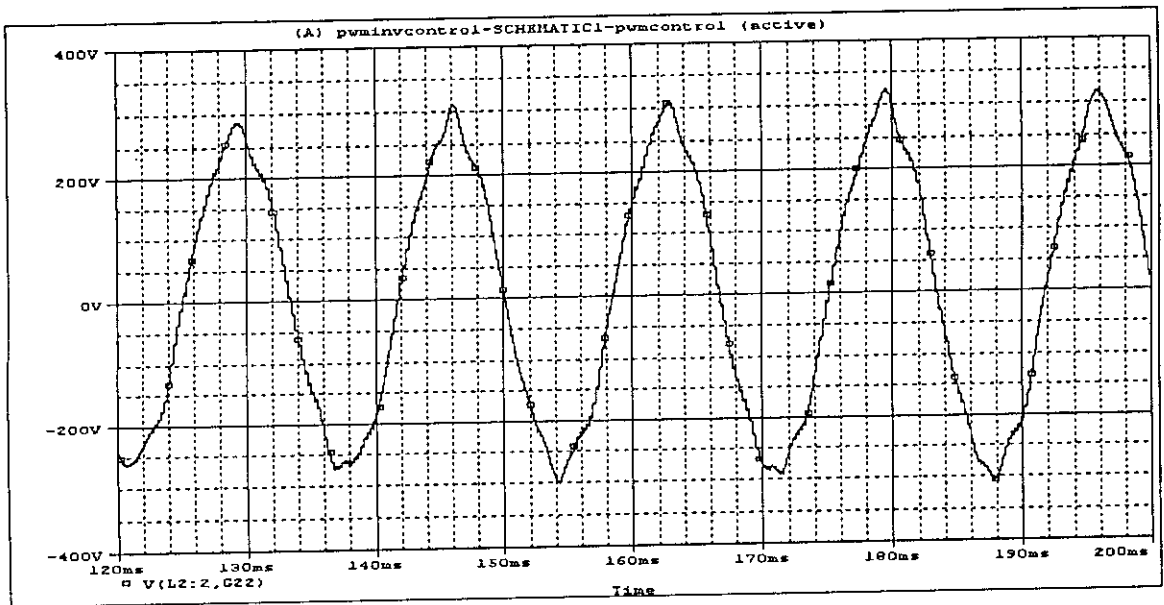


Fig.2.66 Variation of output frequency (across load) by modulation frequency, $f = 60$

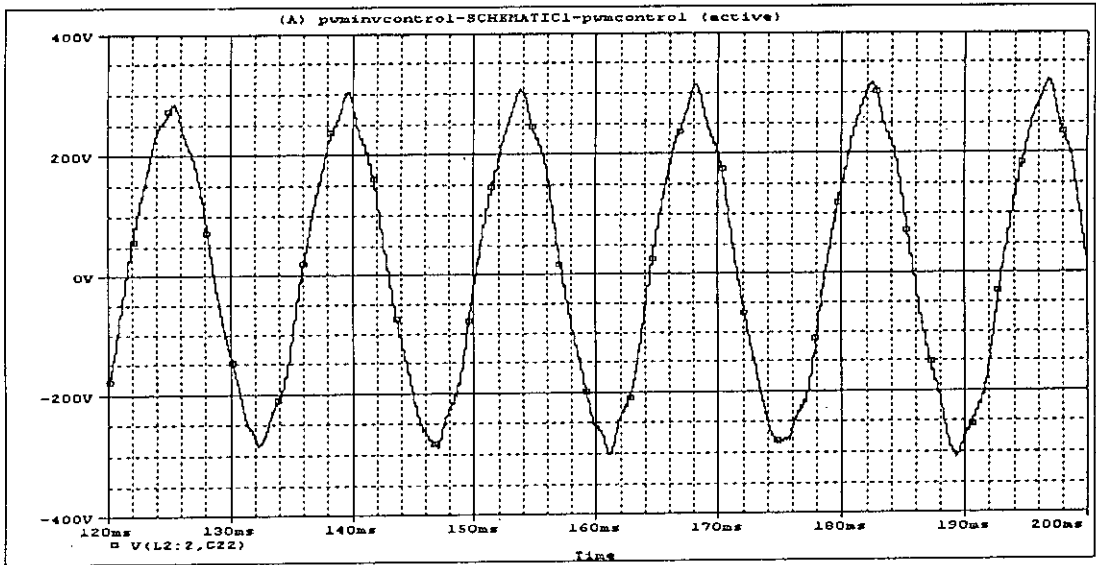


Fig.2.67 Variation of output frequency (across load) by modulation frequency, $f = 70$

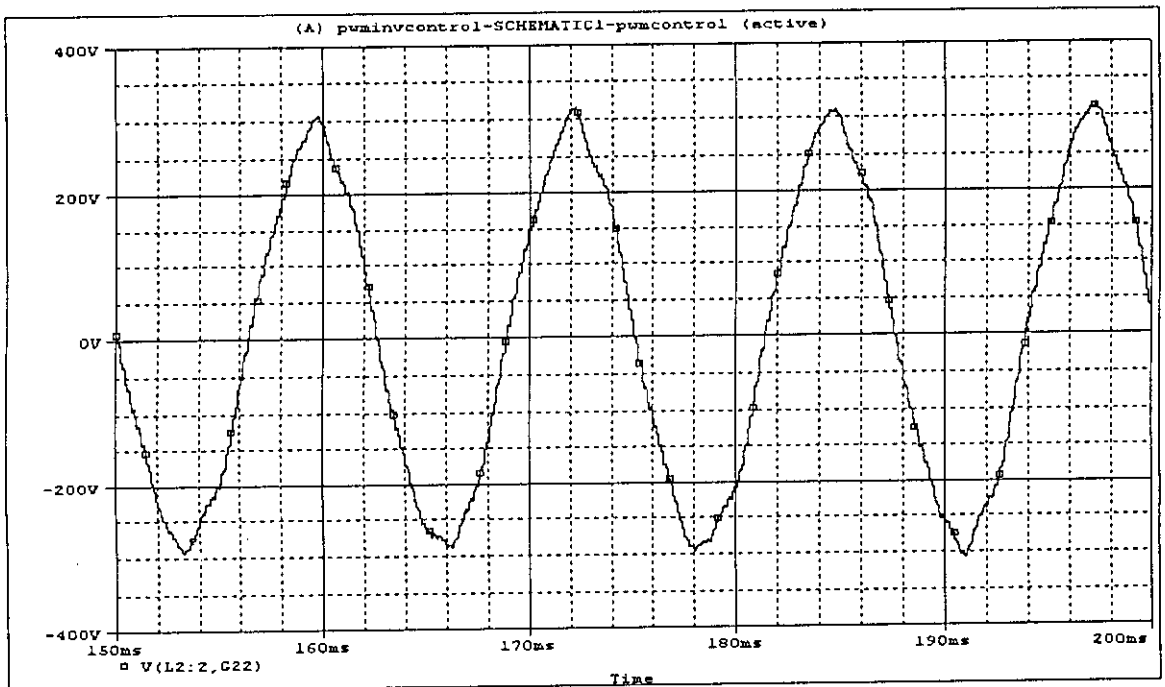


Fig.2.68 Variation of output frequency (across load) by modulation frequency, $f = 80$

2.10. OBSERVATION

Both circuit (with ideal and practical) switches have demonstrated voltage control. The main attribute of the new topology is the fact that it generates an ac output voltage larger than the dc input one, depending on the duty cycle and modulation index. The output voltage can be controlled to a fixed voltage by automatic feedback from the output and comparison of this with a reference voltage. The difference in the two will result an error that would increase or decrease the pulse widths to bring the voltage to a desired level. Such feedback can be achieved with commercially available ICs.

CHAPTER – 3

CONCLUSION AND RECOMMENDATION

3.1 CONCLUSION

This thesis has proposed a cascaded Cuk converter fed PWM inverter for use in photovoltaic system. Common domestic photovoltaic systems are used to power lights, fans, TVs at low voltage. Standard solar panels use 40W modules of solar cells to charge 12V battery. As a result, the common appliances of 230VAC of 50 Hz cannot be used. The proposed Cuk converter fed PW inverter can make it possible to have supplies of 230VAC, 50Hz converted from 12 VDC. Cascaded Cuk regulator is used for stepping battery voltage up, which is then converted to ac by a PWM inverter and filtered to have sinusoidal 230VAC at 50 Hz. The output AC thus obtained can be regulated precisely, either by controlling the duty cycle of the cascaded Cuk converter or by controlling the modulation index of the PWM inverter. The Cuk regulators are studied with practical switch having ground isolation. It has been observed that in the proposed DC-DC converter when input voltage is 12VDC, the output voltage is always maintained at above 340V corresponding to output voltage 230V_{rms}. To maintain constant voltage across the load PWM control is used in the inverter section. Filter circuit is used to get pure sinusoidal the output voltage. In the proposed model, output power can be varied from 400W to 700W, depending on the load.

In renewable energy use, operating cost is low and longevity is long. In homes the first step is to make sure that we have the most energy efficient appliances available. Most of residential and smaller offices consume 1 KW to 3 KW load. For small homes easily can install 250W or 600W systems can be installed and with the Cuk converter fed inverter as proposed in this thesis conventional appliances (light, fan, TV etc) can be used with a changeover switch with commercial electricity supply available.

3.2 RECOMMENDATION FOR FUTURE WORK

In the proposed system output voltage varies with load. This is not desirable, it needs feedback from output to be sensed and then a switching circuit be implemented which will control the cascaded C_uk converter, to vary the duty cycle. This will increase or decrease the duty cycle to obtain constant output voltage. The proposed DC-DC converter circuit will act as an excellent voltage regulator if changing duty cycle with any change of load or input voltage variation is incorporated. For generation of switching voltage commercially available IC can be used. The same chip will be utilized to regulate the output voltage by varying the gate signal of the switches if any changes occur in output voltage.

In future research can be undertaken to implement the followings,

1. Output voltage feedback to switching circuit to control cascaded C_uk converters duty cycle to obtain constant output voltage
2. Design can be done so that Output power can be increased up to 3 KW
3. The proposed system may be fabricated and tested for commercial use.

REFERENCES

- [1] Photovoltaic System & photovoltaic modules,
www.cwanswers.com/8921/photovoltaic_array-87k, December, 2000
- [2] M.H .Rashid, "POWER ELECTRONICS - HANDBOOK", Academic press series in Engineering
- [3] M.H. Rashid, "POWER ELECTRONICS", Prentice Hall of India, 2004, 3rd Edition
- [4] R. D.Middlebrook and S. M.,Ćuk, "A General Unified Approach to Modelling Switching Converter Power Stages", Proc. IEEE Power Electronics Specialists Conference, 1976
- [5] **Ćuk converter** example 2.5. Estimating the output voltage ripple in converters containing two-pole low-pass filters 2.6. Summary of key points
<http://www.colorado.edu/~pwrelect/book/contents/TOC.html>, 1992
- [6] A modified **Ćuk converter**, in the DCM, uses a coupled inductor to transfer ripple from the input to the output, thus reducing switching harmonics in the line
www.ieee.org/organizations/pubs/newsletters/emcs/spring00/emcabs.htm, 1997
- [7] Review of the '**Ćuk Converter** and Its Operation; Bifurcation Behavior for Fixed-Frequency Operation; Bifurcation Behavior for Free-Running Operation ...
www.engnetbase.com/ejournals/books/book_summary/toc.asp?id=1075, 2203
- [8] Steady-state and dynamic analyses of **Ćuk converter** in continuous and discontinuous conduction modes Trans. IEICE of Japan, vol.
www.tc.knct.ac.jp/~oota-i/papers-e.html, 1992
- [9] M. H.Rashid, Pspice Application in Power Electronics, Book 13. Slobodan **Cuk**,
Ćuk Converter, One Cycle Control .
encon.fke.utm.my/nikd/dcconverter.htm, 2004

[10] The high efficiency **Cûk converter** has been selected as the most appropriate topology to supply the various distributed loads. To achieve the best compromise csdl.computer.org/comp/proceedings/delta/2002/1453/00/14530257abs.htm, 2003

[11] Response topic, DC - to - DC **Converter**. Message, How much power do you need? The full bridge is not an easy design if you're in a hurry. The **Cûk converter** www.gotopower.net/disc_viewt.asp?mid=264, 1992

[12] M.Brkovic, and S. **Cûk**, (1992) "Input current shaper using Cûk Converter", Proceedings of 14th International telecommunications Energy Conference, INTELE'92, Washington, D.C, pp.532-539, 4-8 October 1992.

[13] J. C.Salmon, "Techniques for Minimizing the Input current Distortion of current controlled single-phase Boost Rectifier", IEEE Transactions on Power Electronics, Vol-8, no.4, pp.509-520, October 1993.

[14] Q.Huang, and F. C.Lee, "Harmonic Reduction In A Single-Switch, Three- Phase Boost Rectifier With High Order Harmonic Injection PWM ", Conference Record IEEE PESC, pp. 1266-1271, 1996

[15] OrCAD software, Releases 9: OrCAD, Inc., U.S.A, 1985 – 1999

[16] Cuk-Based Converter Concepts: Part 1. Basic Converter Configurations with Ripple -Current Steering by Dennis L Feucht. http://www.en-genius.net/site/zones/technoteZONE/technical_notes/col_050508, 1995

[17] Isolated **Cûk converter**, Chapter 1 Introduction, Low Voltage High Current Power Conversion with Integrated . <http://www.pdf-search-engine.com/isolated-cuk-converter--pdf.html>, 1994

[18] **Cûk** DC-to-DC switching converter with input current shaping for power factor operation <http://www.patentstorm.us/patents/5442539/claims.html>, 1996

- [19] Cûk converter with inductors and capacitors on both power lines
<http://www.wipo.int/pctdb/en/wo.jsp?wo=2004068685>, 1994
- [20] G. R. Walker, P. C. Sernia, "Cascaded DC-DC converter connection of photovoltaic modules". Ieee Transactions On Power Electronics, volume – 19. 1990
- [21] *Pulse Width Modulated Inverter Model*, Fig. PWM-1 to 6.
<http://www.ewh.ieee.org/soc/es/Nov1998/08/PWMINV.HTM>, 1986
- [22] C. Rivas, A. Rufer . P.W.M. Current converter for electric energy production Systems from fuel- cells, EPF 2000.
- [23] New technique of PWM boost inverter for solar home application
dSPACE.bracu.ac.bd/bitstream/123456789/71/1/Rafia%20Akhter.pdf, 1999
- [24] N. Mohan, T.M. Undeland, W.P . Robbins. Power electronics: Converters, applications and design, John Wiley & Sons, US- New York, 1995 .
- [25] Vazquez N, Almazan J, Alvarez J , Aguilar C, Arau J. Analysis and experimental study of the PWM inverters (J). Power Electronics, 2:801 – 806 , 1999.
- [26] F. Barzegar and S. Cuk , "Solid state drives for induction motors : Early technology to current research," in Proc. IEEE Region 6 Conf., Anaheim, CA, Feb. 15-18 , 1982 .
- [27] G. Grandi, D. Casadei, "Analysis of Common- and Differential-Mode HF Current Components in PWM Inverter"
<http://portal.acm.org/citation.cfm?id=1348052>, 1988
- [28] V. VorpCrián, " Simplified Analysis of PWM converters Using the Model of the PWM Switch part I: Continuous Conduction," Proceeding of the VPEC seminar. Blackburg, VA, pp 1-9, 1989.

[29] R. Tymerski, V. Vorperian, F.C. Lee and W . Baumann 'Nonlinear Modeling of the PWM Swith " IEE Power Electronics Specialists Conference, pp 968-976 1988.

[30] Analysis of a PWM Boost Inverter for Solar Home Application

www.waset.org/pwaset/v17/v17-40.pdf, 1992

