Analysis of A PWM Boost Inverter for Solar Home Application.

By
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Declaration

It is hereby declared that this thesis or any part of it has nor been submitted elsewhere for the award of any degree or diploma.

Rafia

(Rafia Akhter)

Dedication

To my beloved parents, husband and only one son.

The thesis entitled **"Analysis of A PWM Boost Inverter for Solar Home Application.** " Submitted by Rafia Akhter , Roll No. 040306106P, Session April 2003 has been accepted as satisfactory in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONICS ENGINEERING

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Abstract

This thesis analyzes the procedural approach and benefits of applying optimization techniques to the design of a boost dc-ac converter with solar cell as an input. The analysis is performed based on the particular 12V DC to 230 V AC conversion for home applications. A traditional design methodology is the use of buck inverter. One of the characteristics of the most classical inverter is that it produces an AC output instantaneous voltage always lower than the DC input voltage. Thus, if an output voltage higher than the input one is needed, a boost dc-dc converter must be used between the DC source and the inverter. It is less complex, lower cost and provides higher power conversion efficiencies. This technique allows the P.W.M. voltage source inverter to become a new feasible solution for solar home application.

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Introduction

1.1. Introduction

Photovoltaic cells produce DC power over a wide voltage range depending on the amount of sunlight and ambient temperature. A minimum DC voltage is required to directly convert this DC voltage to a standard 230 Volts AC and to do so without the use of any transformer. An addition of a transformer decreases power conversion efficiency and adds to the weight and overall inverter or system costs. In our thesis, our requirement is 230 V for residential use i.e. for Solar Home Application(SHS). For this, in this thesis we proposed a new voltage source inverter which is less complexive, lower cost and has higher power conversion efficiencies.

1.2. Literature Review

In this section a literature review, on the basic operation of the solar cells, converters and the control techniques most commonly used is provided.

1.2.1 Stand-alone solar electricity or Solar Home Systems

A means to supply remote areas with electrical energy are Solar Home Systems (SHS). Apart from its ecological advantages in many cases this option is also the most economic way to electrify rural areas, especially when consumption is low and grid extension would be long. But even this most economic way has often a price that is too high for allowing wide spread of SHS [1].

Stand-alone solar electricity systems or solar home systems are used when no grid electricity is available. A battery is needed to ensure the availability of electricity at night or at periods with little bright sunlight. Solar Home Systems are often used to cover the electricity needs of a household. Small systems (commercially available as a SHS kit) cover the most basic needs (lighting and sometimes TV or radio), larger systems can also power a water pump, wireless phone, refrigerator, electric tools (drill, sewing machine, etc) and a VCR [2-5].

The system consists of :

- a solar panel,
- a control unit,
- battery storage,
- cables,
- the electric load and
- a support structure.

1.2.2. Solar System

Solar Cells

Solar cells receive the sun's energy and change it to electricity. Inside a solar panel, each cell contains silicon, an element found in sand that absorbs sunlight. The energy in this absorbed light produces a small electrical current. Metal grids around the solar cells direct the currents into wires that lead to the power controls.

Solar Panels

The solar array is comprised of one or more solar PV modules (solar panels) which convert sunlight into clean solar electricity. PV is short for Photo voltaics which means electricity from light. The solar modules need to be mounted facing the sun and avoiding shade for best results.

Charge Controller

The main function of a charge controller is to prevent over charging the batteries, as well as keeping electrical storage in the batteries from discharging to the solar modules at night.

Batteries

The batteries store the solar power generated and delivers the power as needed. The battery bank consists of one or more solar deep-cycle type batteries. Depending on the current and voltages for certain applications, the batteries are wired in series and/or parallel.

Inverter

The Inverter changes the DC current stored in the batteries into usable AC current which is the most common type used by most household appliances and lighting.

Wiring

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

Loads

The appliances and devices (such as TV's, computers, lights, water pumps etc.) that consume electrical power are called loads.

1.2.3. Pulse Width Modulation (PWM) Basics

There are many forms of modulation 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 [6].

Linear Modulation: The simplest modulation to interpret is where the average ON time of the pulses varies proportionally with the modulating signal. The advantage of linear processing for this application 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. Here the output signal goes high when the 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 [7-9].

Regular Sampled 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 suffers the imprecision and drifts of all analog computation, as well as, having difficulties 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 (see page 31).

1.3. The Modern Switched-Mode Power Supply Topologies and Trends

1.3.1. The Switching Regulator Family

A DC-to-DC converter is a device that accepts a DC input voltage and produces a DC output voltage. Typically the output produced is at a different voltage level than the input. In addition, DC-to-DC converters are used to provide noise isolation, power bus regulation, etc [10-11].

DC-DC power converters are employed in a variety of applications, including power supplies for personal computers, office equipment, spacecraft power systems, laptop computers, and telecommunications equipment, as well as DC motor drives. The input to a DC-DC converter is an unregulated dc voltage. The converter produces regulated output voltage ,having a magnitude (and possibly polarity) that differs from the input. For example, in a computer off-line power supply, the 120 V or 240 V ac utility voltage is rectified, producing a DC voltage of approximately 170 V or 340 V, respectively. A dc-dc converter then reduces the voltage to the regulated 5 V 3.3 V required by the processor ICs. High efficiency is invariably required, since cooling of inefficient power converters is difficult and expensive. The ideal DC-DC converter exhibits 100% efficiency; in practice, efficiencies of 70% to 95% are typically obtained. This is achieved using switched-mode, or chopper, circuits whose elements dissipate negligible power. Pulse-width modulation (PWM) allows control and regulation of the output voltage. This approach is also employed in applications involving alternating current, including high-efficiency DC-AC power converters (inverters and power amplifiers), AC-AC power converters, and some AC-AC power converters (low-harmonic rectifiers).

1.3.2. Analysis of Converter Waveforms

Under steady-state conditions, the voltage and current waveforms of a DC-DC converter can be found by uses of two basic circuit analysis principles. The principle of inductor volt-second balance states that the average value, or DC component, of voltage applied across an ideal inductor winding must be zero. This principle also applies to each winding of a transformer or other multiple winding magnetic devices. Its dual, the principle of capacitor amp-second or charge balance, states that the average current that flows through an ideal capacitor must be zero. Hence, to determine the voltages and currents of DC-DC converters operating in periodic steady state, one averages the inductor current and capacitor voltage waveforms over one switching period, and equates the results to zero. The inductor currents and capacitor voltages contain dc components, plus switching ripple at the switching frequency and its harmonics. In most well designed converters, the switching ripple is small in magnitude compared to the DC components. For inductor currents, a typical value of switching ripple at maximum load is 10% to 20% of the DC component of current. For an output capacitor voltage, the switching ripple is typically required to be much less than 1% of the DC output voltage. In both cases, the ripple magnitude is small compared with the dc component, and can be ignored.

Some of the popular DC-to-DC converter topologies are :

1. Buck Converter/ Step down converter.
2. Boost Converter/ Step up converter.
3. Buck-Boost Converter/ Step up-down converter.
4. Cuk Converter

Buck Converter/ Step down converter- The buck converter, also known as the step-down converter, is a switching converter that has the five basic components, namely a power semiconductor switch, a diode, an inductor, a capacitor and a PWM controller . This converter produces an output voltage LOWER than the source. Here,

$$\frac{Vo}{Vin} = \frac{t_{on}}{T}$$

and defining "duty ratio" as

$$D = \frac{t_{on}}{T}$$

the voltage relationship becomes Vo=D V_{in} . Since the circuit is lossless and the input and output powers must match on the average V_o* I_o = V_{in}* I_{in}. Thus the average input and output current must satisfy I_{in} =D I_o These relations are based on the assumption that the inductor current does not reach zero (continuous conduction mode).

Boost Converter/ Step up converter- The boost converter, also known as the step-up converter, is another switching converter that has the same components as the buck converter, but this converter produces an output voltage greater than the source. The ideal boost converter has the five basic components, namely a power semiconductor switch, a diode, an inductor, a capacitor and a PWM controller. The placement of the inductor, the switch and the diode in the boost converter is different from that of the buck converter. Here,

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1-D)}$$

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude.

Buck-Boost Converter/ Step up-down converter- Here the output voltage may be higher or lower than the source depending to the value of D. The circuit components are same. Here,

$$\frac{Vo}{Vin} = -\frac{D}{(1 - D)}$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

Cuk Converter- The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The CUK converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. Here,

$$\frac{Vo}{Vin} = -\frac{D}{(1 - D)}$$

Thus the voltage ratio is the same as the buck-boost converter.

1.4. Motivation and Objective

The design of a power electronics system involves a large number of design variables and the application of knowledge from several different engineering fields (electrical, magnetic, thermal, solar and mechanical). In order to simplify the design problem, traditional design procedures fix a subset of the design variables and introduce assumptions (simplifications) based on the designer's understanding of the problem. These simplifications allow an initial design to be obtained in a reasonable amount of time, but further iterations through hardware prototype testing are usually required. The ability and expertise of the designer usually leads to good and optimum design.

The aim of this work is to design and propose a new voltage source inverter (VSI) referred to as a boost inverter or boost dc–ac converter. The main attribute of the new inverter topology is the fact that it generates an ac output voltage larger than the dc input one, depending on the instantaneous duty cycle. This property is not found in the classical VSI, which produces an ac output instantaneous voltage always lower than the dc input one. The new inverter is intended to be used whenever an ac voltage larger than the dc link voltage is needed, with no need of a second power conversion stage. Here as input , PV cell is used.

1.5. Outline

The proposed VSI consist of a boost-regulator, four switches with eight diodes; dc filter capacitor and a load. These converters will produce a DC - biased sine wave output, so that each source only produces a unipolar voltage. The modulation of each converter will be 180 degrees out of phase with the other, which maximizes the voltage excursion across the load. The load will be connected differentially across the converters. The values of series inductor and capacitor will be so chosen as to resonate at supply frequency. A proper switching scheme will be developed and the duty cycle of the switching pulse will be modulated over the period of main supply voltage. The proposed inverter circuit will be modeled mathematically and simulation will be carried out to reveal the influence of input resonating series inductor–capacitor and switching frequency on input. The information thus obtained will be used for design and finally comparison will be made with the voltage source inverter generally used at present.

Chapter 2

Conversion of Electric Energy by the new PWM Boost Inverter

2.1. Introduction

The electricity produced by solar cells is direct current (DC), so it cannot be used in the home as it is. For this reason, an inverter is installed in the solar system to carry out the conversion of the generated direct current to alternating current (AC) for use in the home.

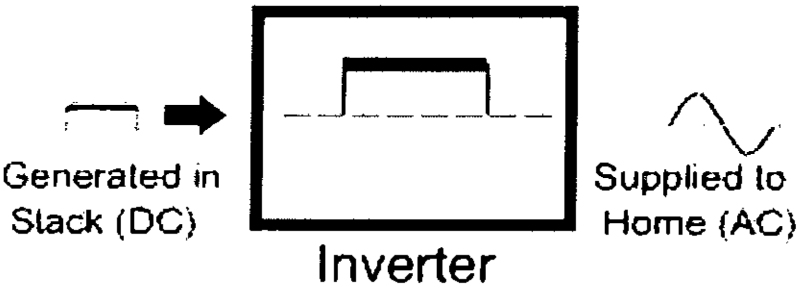


Figure. 2.1: Conversion of dc to ac

In the inverter, the direct current generated in the stack is converted as follows: square wave → step-up → modulation/rectification → corrugation and is finally synchronized with the alternating current used in the household, before being supplied to the home.

2.2. Solar Cells

Solar cells receive the sun's energy and change it to electricity. Inside a solar panel, each cell contains silicon, an element found in sand that absorbs sunlight. The energy in this absorbed light produces a small electrical current. Metal grids around the solar cells direct the currents into wires that lead to the power controls.

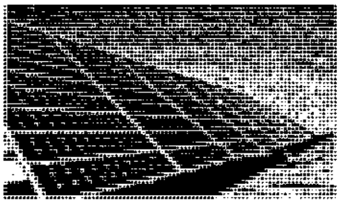


Figure. 2.2 Solar Panel

2.2.1. Solar Electric Systems :

Solar energy systems consist of five major parts. These are,

1. **The sun:** Sunny days and cloudy days will produce power in a solar electric system. Light rays from the sun - visible light and invisible rays, both help to produce electricity in the panels.

2. **The power producing mechanism:** This consists of the solar electric panels. These panels are assembled from solar cells. Each cell will produce electric power when exposed to sunlight. These cells are manufactured in a high-tech process similar to that which is used to make computer chips. Solar electricity was developed in the 1950's and has been perfected since then. Present solar panels have no moving parts, are very reliable, and have a long life.

3. **The roof mounting structure:** This consists of aluminum and stainless steel units which are used to mount the system on the roof of home.

4. **The inverter:** Solar cells produce DC (direct current), which is similar to that produced by a car battery or flashlight battery. The electrical inverter, through electronic circuits, produces the AC (alternating current) power which is used by appliances and lighting fixtures. The inverter makes the power useful by producing AC power to the standards of our local power.

5. **The wiring:** This will be connected to the load center (circuit breaker box or electrical panel) of home. The solar electric system, when installed this way, can be thought of as a home appliance which produces power, rather that one which uses power.

2.2.2. PV Cell interconnection and Module Design

Solar cells are rarely used individually. Rather, cells with similar characteristics are connected and encapsulated to form modules (arrays) which, in turn, are the basic building blocks of solar arrays.

As maximum voltage from a single silicon cell is only about 600 mV, cells are connected in series to obtain the desired voltage. Usually about 36 cells are used for a nominal 12 V charging system.

Under peak sunlight (1 W/m^2) the maximum current delivered by a cell is approximately 30 mA/cm^2. Cells are therefore paralleled to obtain the desired current.

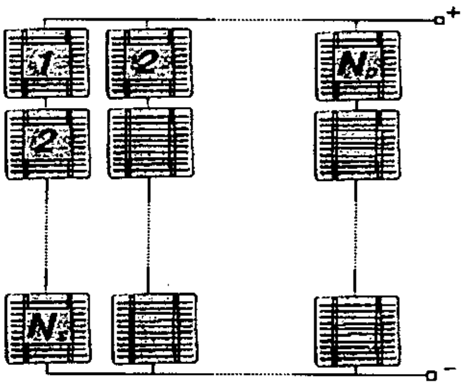


Figure. 2.3: Cells in series and in parallel.

A typical 36 cell module based on screen printed silicon cell technology has the cells series connected to suit the charging of 12 volt battery [12].

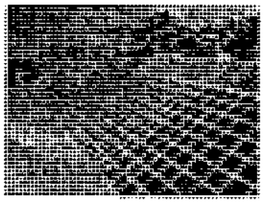
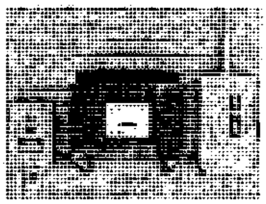
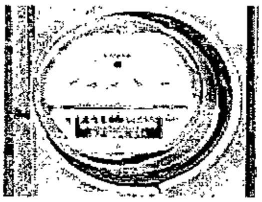
The typical characteristics for each cell would be:
Voc = 600 mV (25^{O} C)
Isc = 3.0 Amps
Vmp = 500 mV (25^{O} C)
Area = 100 cm^2

Therefore 36 cells in series give:
Voc = 21.6 Volts (25^{O} C)
Isc = 3.0 Amps
Vmp = 18 Volts (25^{O} C)
Imp = 2.7 Amps

2.3. Stand Alone Solar Electric Systems

Stand-Alone solar electric systems operate on the same basic principles as grid-tied with battery back-up systems, however, instead of tying into the local utility they function independently from the grid. They are used for properties where utility power is not available, or very costly. A stand-alone system utilizes a battery bank to store the energy produced by the modules, allowing one to draw electricity even when the modules are not receiving energy from the sun. After being stored in the batteries, the DC power flows to the inverter where it is converted to AC electricity for use in home [4].

Table: 2.1 **How a Standard Grid-Tied Solar System Works:**

PHASE 1 **ABSORB**	The solar photovoltaic modules absorb the energy from sunlight and generate direct current (DC) power.	
PHASE 2 **CONVERT**	The Inverter converts this power into high quality AC electricity for connection to the utility.	
PHASE 3 **PROFIT**	Net-Metering allows meter to spin backwards and "bank" excess energy for later use.	
PHASE 4 **ENJOY**	Living independently solar powered by the sun!	

2.4. Voltage Source Inverter with Pulse Width Modulation

2.4.1. Voltage Source Inverter

The amplitude of the harmonics can be reduced by using the *pulse width modulation* (PWM) technique [13-14]. The basic concept of the PWM method is the division of the on-time into several on and off periods with varying duration. The rms value of the ac voltage is controlled by the on-time of the switches. The most frequently used PWM technique is *sinusoidal pulse width modulation.* This approach requires a bridge converter with IGBT or MOSFET switches shunted by an anti-parallel connected diode.

The diode allows current flow in the opposite direction when the switch is open. These freewheeling diodes prevent inductive current interruption

This provides protection against transient over voltage, which may cause reverse breakdown of the IGBT and MOSFET switches. The typical circuit diagram is shown in Figure. 2.4.

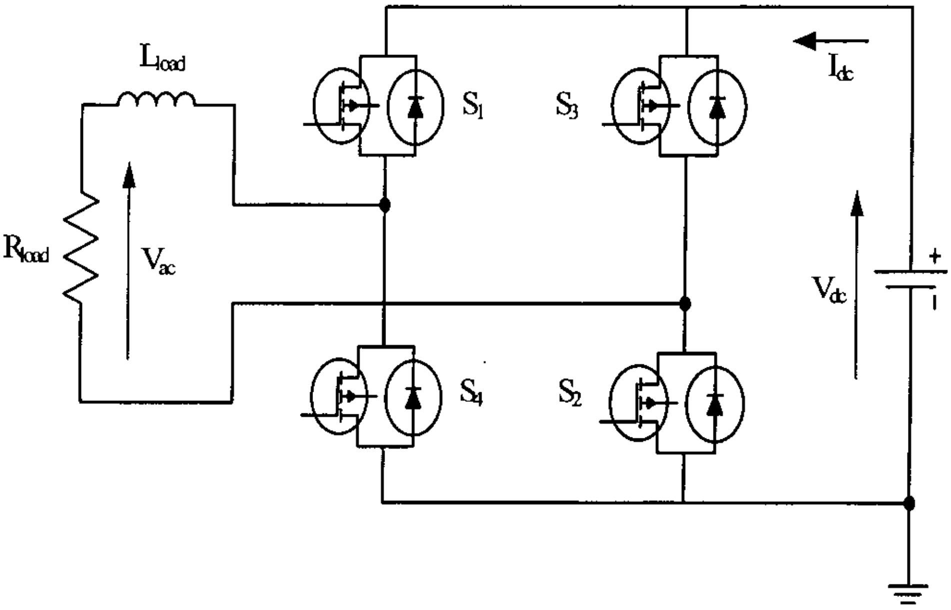


Figure. 2.4. Single-phase voltage source converter

During the positive cycle, S1 and S2 are switched by the high frequency pulse train shown in Figure 2.5.During the negative cycle, the pulse train switches S3 and S4.

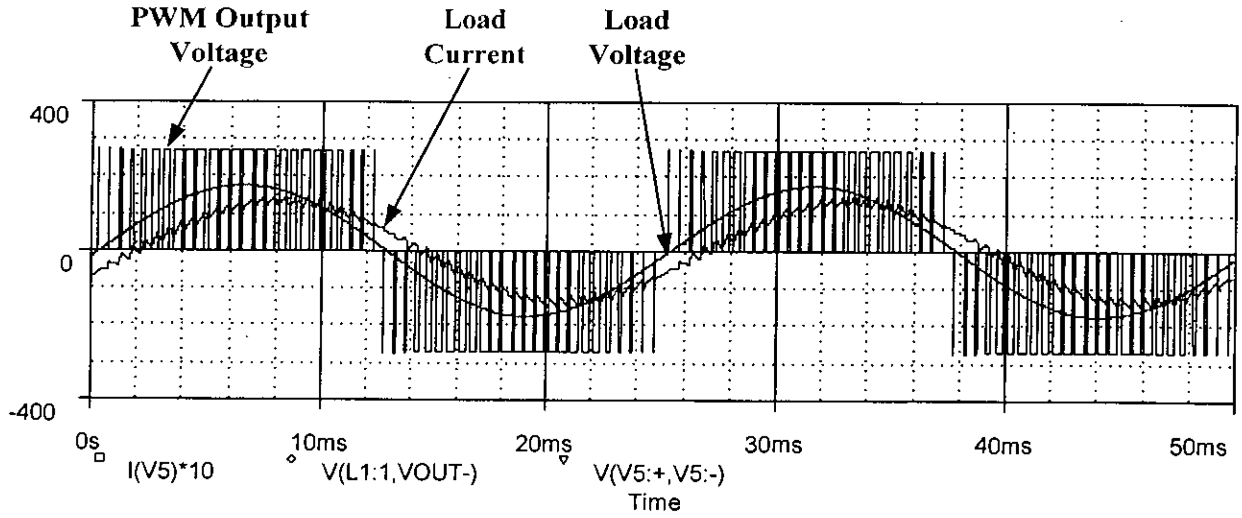


Figure 2.5: Gate pulse input signal, and ac voltage and current outputs of a pulse width modulation (PWM) converter.

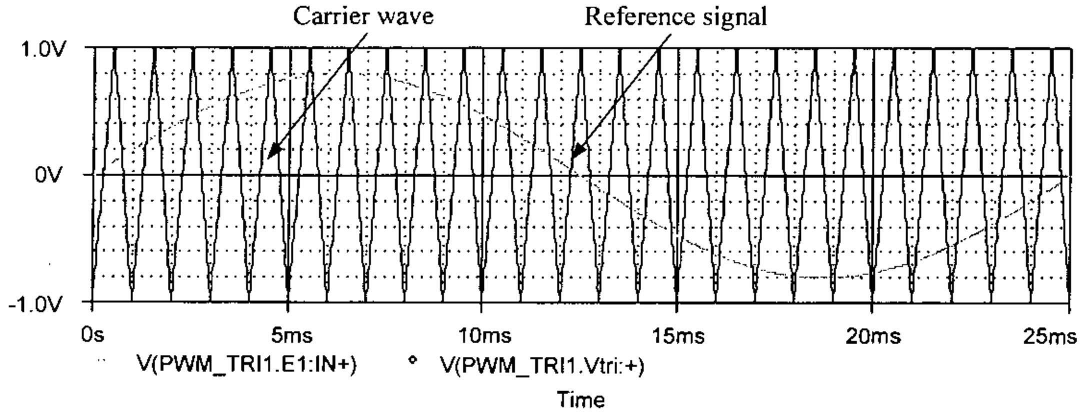
The load inductance integrates the generated pulse train and produces a sinusoidal voltage (Vac) and current wave, as shown in Figure 2.5.The width of each pulse is varied in proportion to the amplitude of a sine wave. A typical PWM waveform is also shown in Figure 2.5.The switches in this converter are controlled by gate pulses.

The gate signal contains several pulses distributed along the half-cycle. The control circuit produces the gate pulse train by generation of a triangular carrier wave and a sinusoidal reference signal. The two signals are compared, and when the carrier wave is larger than the reference signal, the gate signal is positive. When the carrier wave is smaller than the reference signal, the gate signal is zero. This results in a gate pulse with variable width.

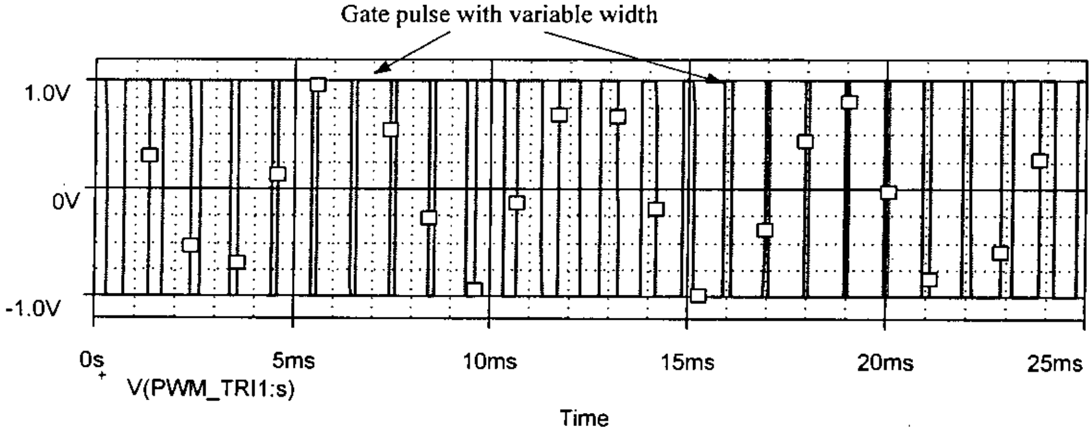
On the next page, in Figure 2.6, it

(a) shows the carrier wave and reference sine wave;

(b) depicts the resulting gate signal with variable width pulses. It has to be noted that several other methods are used for generation of PWM signals



(a) Triangular carrier wave and sinusoidal reference signal



(b)Variable-width gate pulse signal

Figure 2.6: Pulse width modulation (PWM) signals.

The frequency of the reference sine wave determines the frequency of the generated ac voltage. The amplitude of the ac voltage can be regulated by the variation of the reference signal amplitude. The amplitude of the fundamental component of the ac voltage is:

$$V_{ac} = \frac{V_{control}}{V_{carrier}} V_{dc} = m\, V_{dc}$$

The *modulation index, m* is the ratio of the peak-to-peak ac voltage ($2Vac$) to the dc voltage.

2.4.2. Freewheeling diode

The inverter interrupts the current several times each cycle. The interruption of an inductive current would generate unacceptably high over voltage. This overvoltage generation is eliminated by providing *freewheeling diodes* connected in parallel with the switches. When the switches open, the current, if inductive, is diverted to the diodes, as shown in Figure 2.7.

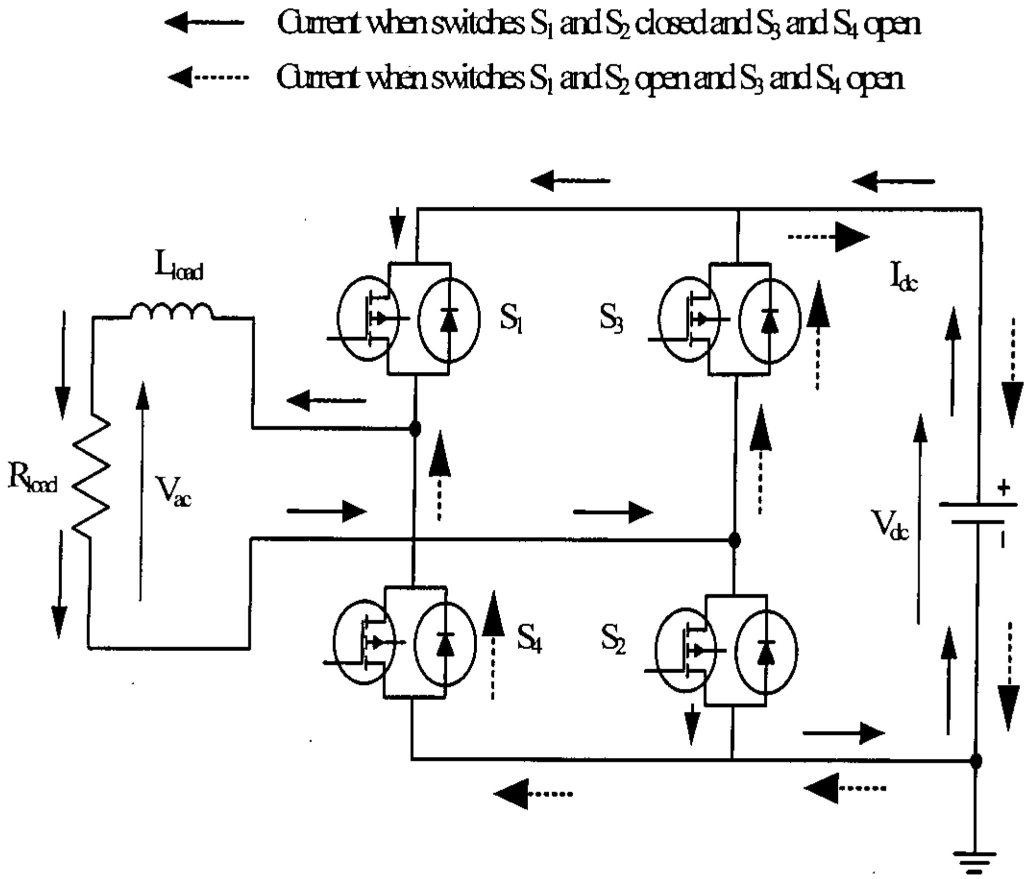


Figure 2.7: Freewheeling diode operation.

The diagram shows the current path when switches S1 and S2 are closed, and switches S3 and S4 are open. When switches S1 and S2 open (now all switches are open), the current diverts through the diodes of switches S3 and S4. This current diversion prevents the interruption of inductive current.

2.5. Switching Mode Regulator

Dc converter can be used as a switching-mode regulator to convert a dc voltage, normally unregulated, to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is normally BJT, MOSFET or IGBT. There are four basic topologies of switching regulator [15-21]:

i. Buck regulator
ii. Boost regulator
iii. Buck-boost regulator
iv. Cuk regulator

2.5.1. Buck regulator

The buck converter is also known as the step-down converter. Here the average output voltage is less than the input voltage.

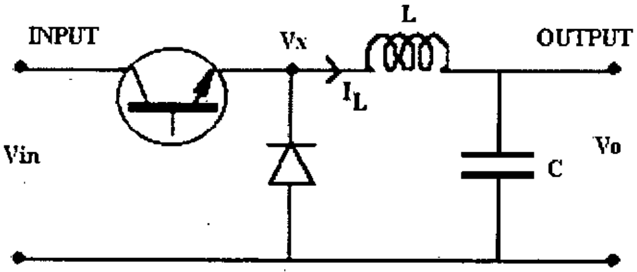


Figure. 2.8: Buck Converter

In this circuit the transistor turning ON will put voltage Vin on one end of the inductor. This voltage will tend to cause the inductor current to rise. When the transistor is OFF, the current will continue flowing through the inductor but now flowing through the diode.

It is initially assumed that the current through the inductor does not reach zero, thus the voltage at Vx will now be only the voltage across the conducting diode during the full OFF time. The average voltage at Vx will depend on the average ON time of the transistor provided the inductor current is continuous.

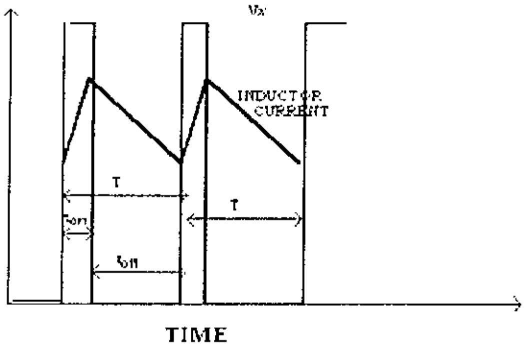


Figure. 2.9: Voltage and current changes

To analyze the voltages of this circuit let consider the changes in the inductor current over one cycle. From the relation

$$V_x - V_o = L\frac{di}{dt}$$

the change of current satisfies

$$di = \int_{ON}(V_x - V_o)dt + \int_{OFF}(V_x - V_o)dt$$

For steady state operation the current at the start and end of a period T will not change. To get a simple relation between voltages ,it is assumed that no voltage drop across transistor or diode while ON and a perfect switch change. Thus during the ON time V_x=V_{in} and in the OFF V_x=0.

Thus

$$0 = di = \int_0^{t_{on}}(Vin - Vo)dt + \int_{t_{on}}^{t_{on}+t_{off}}(-Vo)dt$$

which simplifies to

$$(Vin - Vo)t_{on} - Vo\, t_{off} = 0$$

which gives,

$$\frac{Vo}{Vin} = \frac{t_{on}}{T}$$

and defining "duty ratio" as

$$D = \frac{t_{on}}{T}$$

the voltage relationship becomes Vo=D* Vin. Since the circuit is lossless and the input and output powers must match on the average $V_o * I_o = V_{in} * I_{in}$. Thus the average input and output current must satisfy $I_{in} = D\, I_o$ These relations are based on the assumption that the inductor current does not reach zero.

2.5.2. Boost regulator

The buck converter is also known as the step-down converter. Here the average output voltage is more than the input voltage.

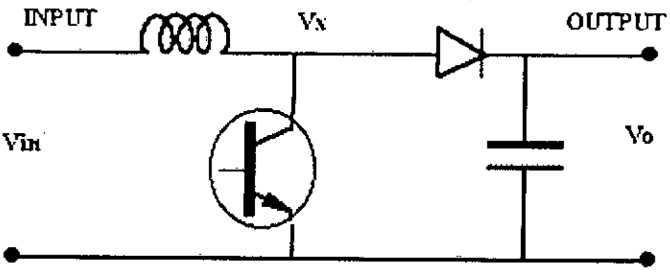


Figure. 2.10: Boost Converter Circuit

While the transistor is ON $V_x = V_{in}$, and the OFF state the inductor current flows through the diode giving $V_x = V_o$. For this analysis it is assumed that the inductor current always remains flowing (continuous conduction). The voltage across the inductor is shown in Figure. 2.11 and the average must be zero for the average current to remain in steady state

$$Vin\, t_{on} + (Vin - Vo)t_{off} = 0$$

This can be rearranged as

$$\frac{Vo}{Vin} = \frac{T}{t_{off}} = \frac{1}{(1 - D)}$$

and for a lossless circuit the power balance ensures

$$\frac{Io}{Iin} = (1 - D)$$

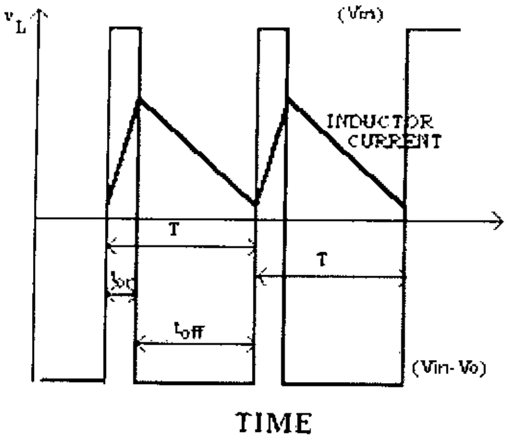


Figure. 2.11: Voltage and current waveforms (Boost Converter)

Since the duty ratio "D" is between 0 and 1 the output voltage must always be higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

2.5.3. Buck-Boost regulator

Here the average output voltage may be more or less than the input voltage depending on the duty cycle.

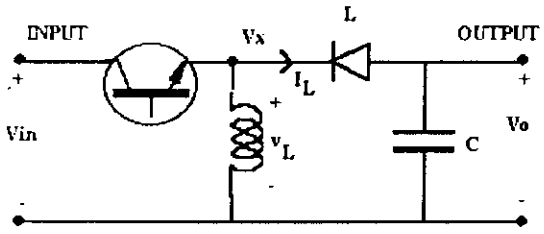


Figure. 2.12: schematic for buck-boost converter

With continuous conduction for the Buck-Boost converter $V_x = V_{in}$ when the transistor is ON and $V_x = V_o$ when the transistor is OFF. For zero net current change over a period the average voltage across the inductor is zero

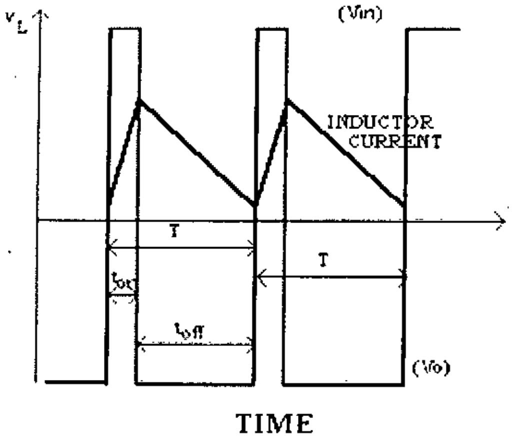


Figure. 2.13: Waveforms for buck-boost converter

$$V_{in} t_{ON} + V_o t_{OFF} = 0$$

which gives the voltage ratio

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)}$$

and the corresponding current

$$\frac{Io}{Iin} = -\frac{(1-D)}{D}$$

Since the duty ratio "D" is between 0 and 1 the output voltage can vary between lower or higher than the input voltage in magnitude. The negative sign indicates a reversal of sense of the output voltage.

2.5.4. Cuk Regulator

The buck, boost and buck-boost converters all transferred energy between input and output using the inductor, analysis is based of voltage balance across the inductor. The CUK converter uses capacitive energy transfer and analysis is based on current balance of the capacitor. The circuit in Figure. 2.14 is derived from DUALITY principle on the buck-boost converter.

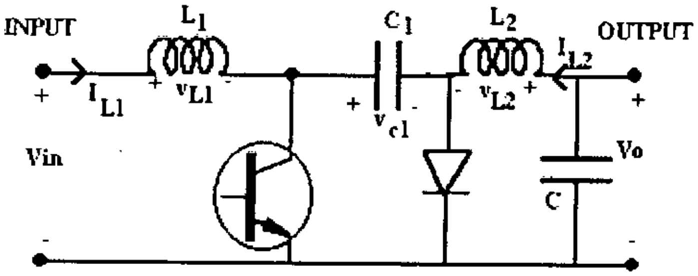


Figure. 2.14: CUK Converter

It is assumed that the current through the inductors is essentially ripple free andcan examine the charge balance for the capacitor C1. For the transistor ON the circuit becomes

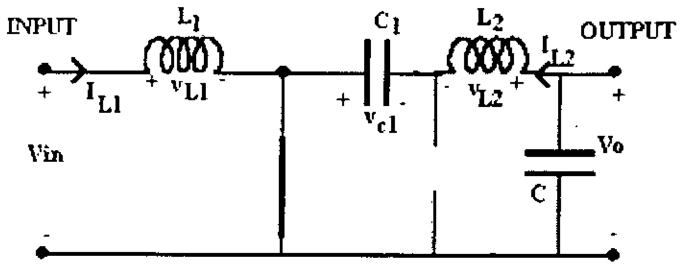


Figure. 2.15: CUK "ON-STATE"

and the current in C1 is I_{L1}. When the transistor is OFF, the diode conducts and the current in C1 becomes I_{L2}.

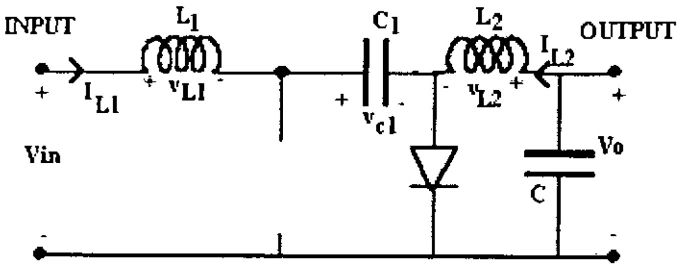


Figure. 2.16: CUK "OFF-STATE"

Since the steady state assumes no net capacitor voltage rise ,the net current is zero

$$I_{L1} t_{ON} + (-I_{L2}) t_{OFF} = 0$$

which implies

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

The inductor currents match the input and output currents, thus using the power conservation rule

$$\frac{Vo}{Vin} = -\frac{D}{(1-D)}$$

Thus the voltage ratio is the same as the buck-boost converter. The advantage of the CUK converter is that the input and output inductors create a smooth current at both sides of the converter while the buck, boost and buck-boost have at least one side with pulsed current.

2.5.5. Converter Comparison

The voltage ratios achievable by the DC-DC converters is summarized in Figure. 2.17. Notice that only the buck converter shows a linear relationship between the control (duty ratio) and output voltage. The buck-boost can reduce or increase the voltage ratio with unit gain for a duty ratio of 50%.

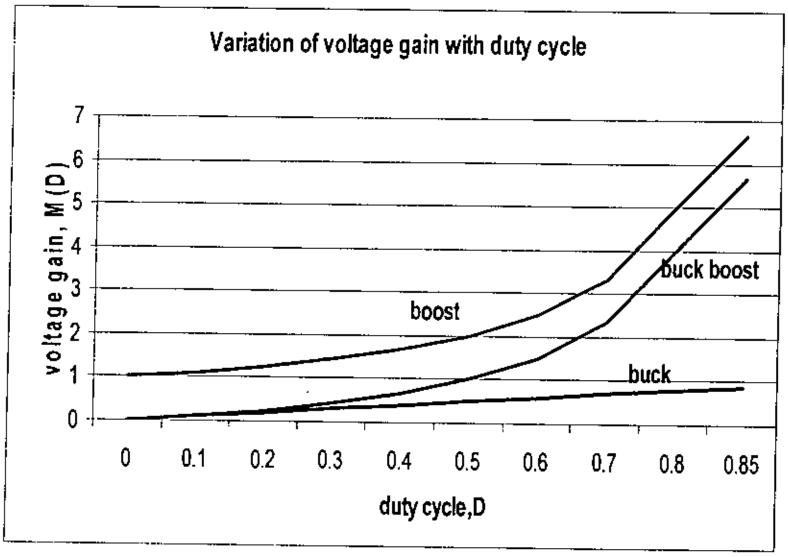


Figure. 2.17: Comparison of voltage ratio with duty cycle

2.6. Converter Interface of PV Panels

In grid-connected inverters for PV applications, a number of different approaches have been developed and used over the last 20 years. An excellent review of such systems available in Europe is given in [22]. Only the two more common approaches used in smaller residential scale installations (1–3 kW) are compared here (Figure. 2.18).

2.6.1. Single DC String, Single DC–AC Inverter

In a residential system of say 2 kW or less, all the PV panels on the rooftop can be connected electrically in series, to create high voltage low current dc source. This source is connected a single dc–ac inverter within the roof or house. The ac then runs to the residential switchboard [23].

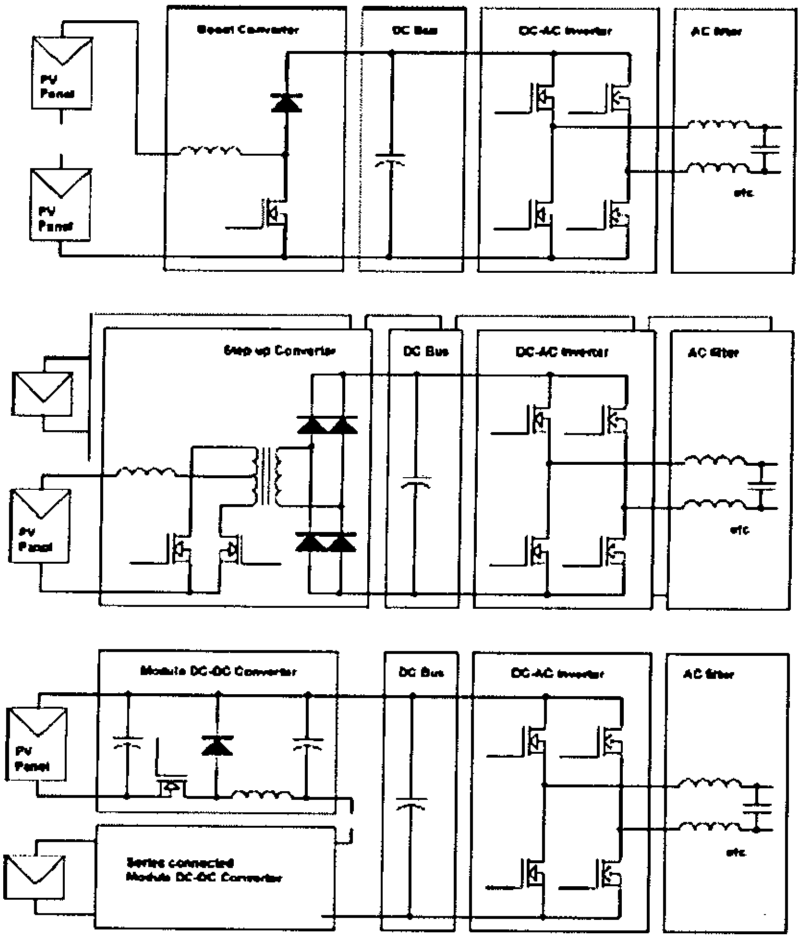


Figure. 2.18: Comparison of three grid connected PV inverter topologies.

a) a single dc–ac inverter connected to a single dc PV string,

b) integrated dc–ac inverter for every PV panel and

c) the proposed series connected panel integrated DC-DC converters connected to a centralized dc–ac inverter.

2.6.2. Individual DC–AC Inverters per Panel (Module Integrated Converters)

In this more recent approach, each PV panel has its own dc–ac inverter, mounted at the panel on the rooftop. A 220-V ac connection from the switchboard runs to the rooftop, and loops from inverter to inverter, panel to panel. Each panel is now effectively placed in parallel, via its own dedicated inverter. To be small, light and low cost, module-integrated converters generally use high frequency switch mode techniques. To efficiently convert the panel's low dc voltage to the 220-V ac grid voltage they invariably require a transformer isolated converter. Most approaches rectify to a high voltage dc bus which is followed by an ac inversion stage and line side filtering.

2.6.3. Multi-Converter Strings—Panel Integrated DC-DC, string DC-DC

The approach proposed in this thesis combines aspects of this two approaches. Every panel has its own converter, but these converters are DC-DC converters, and the panels with their associated converters are still placed in series to form a dc string. A single dc–ac inverter is then required to connect to the grid. This intermediate solution is argued to combine the best features of the two existing approaches presented.

2.7. Batteries Used in Some PV Systems

Batteries are often used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply it to electrical loads as needed (during the night and periods of cloudy weather). Other reasons batteries are used in PV systems are to operate the PV array near its maximum power point, to power electrical loads at stable voltages, and to supply surge currents to electrical loads and inverters. In most cases, a battery charge controller is used in these systems to protect the battery from overcharge and over discharge.

2.8. PWM Control

A pulse-width modulated signal is a square wave whose duty cycle is proportional to the instantaneous value of some continuous source signal. The PWM signal effectively applies discrete "on" and "off" signals for varying amounts of time. Below, there is a 1Hz sine wave modulated with a 10Hz square wave.

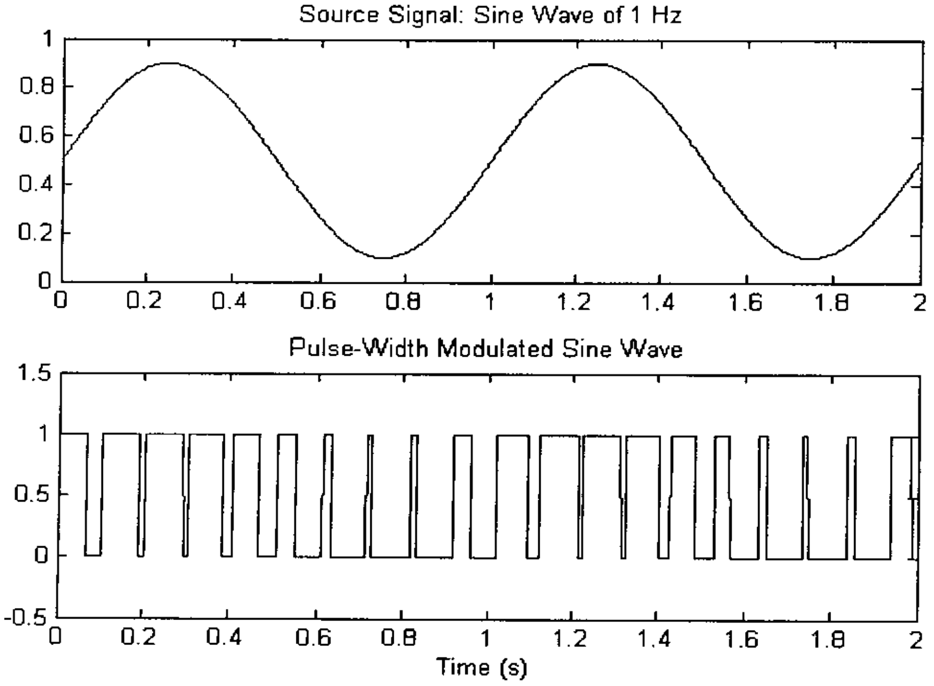


Figure.2.19: Pulse width modulation

is driven by a constant value of 1 and the 50% duty cycle square wave.

2.8.1 Principle

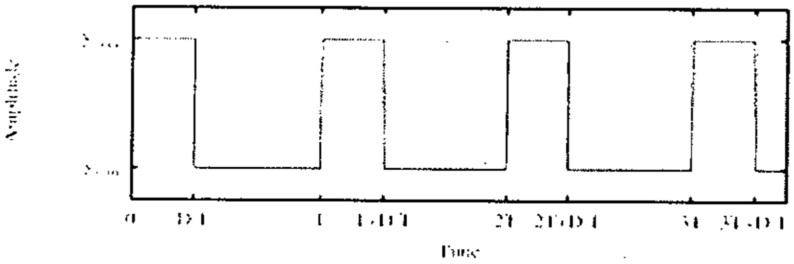


Figure.2.20 :Square wave, showing the definitions of y_{min}, y_{max}

Pulse-width modulation uses a square wave whose duty cycle is modulated resulting in the variation of the average value of the waveform. If we consider a square waveform $f(t)$ with a low value y_{min}, a high value y_{max} and a duty cycle D ,the average value of the waveform is given by:

$$\bar{y} = \frac{1}{T}\int_0^T f(t)\,dt$$

As $f(t)$ is a square wave, its value is y_{max} for $0 < t < D \cdot T$

and y_{min} for $D \cdot T < t < T$. The above expression then becomes:

$$\begin{aligned}\bar{y} &= \tfrac{1}{T}\left(\int_0^{DT} y_{max}\,dt + \int_{DT}^{T} y_{min}\,dt\right)\\ &= \frac{D\cdot T\cdot y_{max} + T(1-D)\,y_{min}}{T}\\ &= D\cdot y_{max} + (1-D)\,y_{min}\end{aligned}$$

This latter expression can be fairly simplified in many cases where $y_{min} = 0$ as $\bar{y} = D \cdot y_{max}$. From this, it is obvious that the average value of the signal ($\bar{y}$) is directly dependent on the duty cycle D.

2.8.2. Generation

2.8.2.1 Intersective

The simplest way to generate a PWM signal is the intersective method, which requires only a sawtooth or a triangle waveform (easily generated using a simple oscillator) and a comparator. When the value of the reference signal (the green sine wave in figure 2.21) is more than the modulation waveform , the PWM signal is in the high state, otherwise it is in the low state.

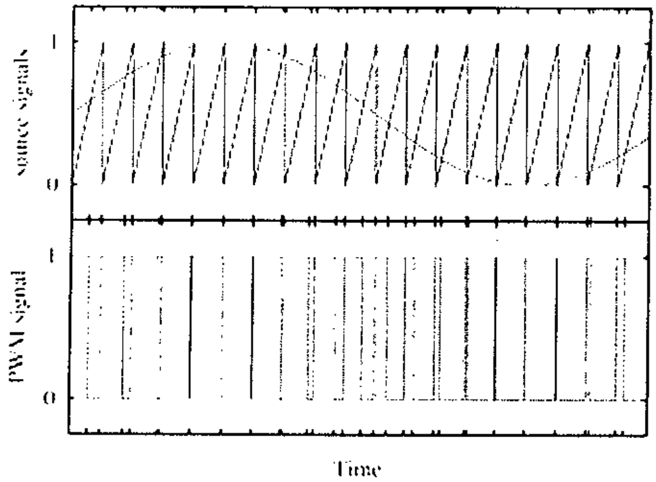


Figure.2.21: A simple method to generate the PWM pulse train corresponding to a given signal is the intersective PWM: the signal (here the sinewave) is compared with a sawtooth waveform When the latter is less than the former, the PWM signal is in high state (1). Otherwise it is in the low state (0).

2.8.3. PWM Methods

Various PWM techniques, include:

1. **Sinusoidal PWM (most common)**

The most common PWM approach is sinusoidal PWM. In this method a triangular wave is compared to a sinusoidal wave of the desired frequency and the relative levels of the two waves is used to control the switching of devices in each phase leg of the inverter.

2. **Space-Vector PWM**

Space vector PWM is an advanced, computationally intensive technique that offers superior performance in variable-speed drives. This technique has the advantage of taking account of interaction among the phases when the load neutral is isolated from the center tap of the dc supply. Space vector PWM can be used to minimize harmonic content of the three-phase isolated neutral load.

3. Sigma-Delta Modulation

Sigma-delta modulation is a useful technique for high frequency link converter systems - uses integral half-cycle pulses to generate variable freq., variable voltage sinusoidal waves.

2.8.4. Objective of PWM

- Control of inverter output voltage
- Reduction of harmonics

2.8.5. Disadvantages of PWM

- Increase of switching losses due to high PWM frequency
- Reduction of available voltage
- EMI problems due to high-order harmonics

In our circuit , sinusoidal pulse width modulation is used for switching. The description is given to the next page [24-26].

2.9. The Conventional VSI

The single phase VSI in Figure. 2.22 uses the topology which has the characteristic that the average output voltage is always lower than the input dc voltage. Thus if an output voltage higher than the input one is needed, a boost DC-DC converter must be used between the dc source and the inverter, shown in Figure. 2.23. [27-35].

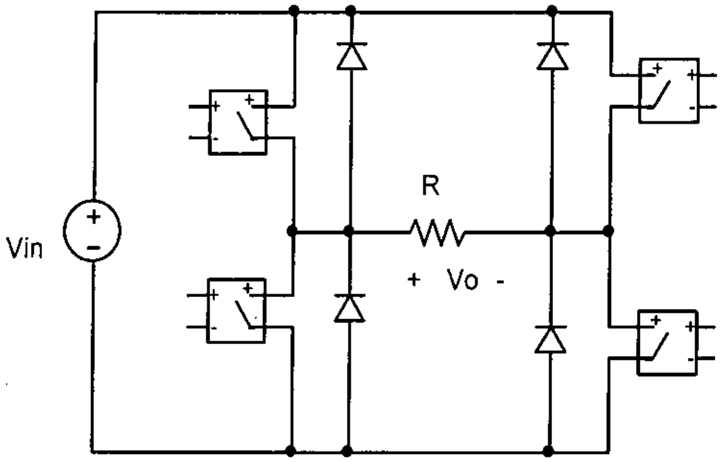


Figure. 2.22: The conventional voltage source inverter or buck inverter

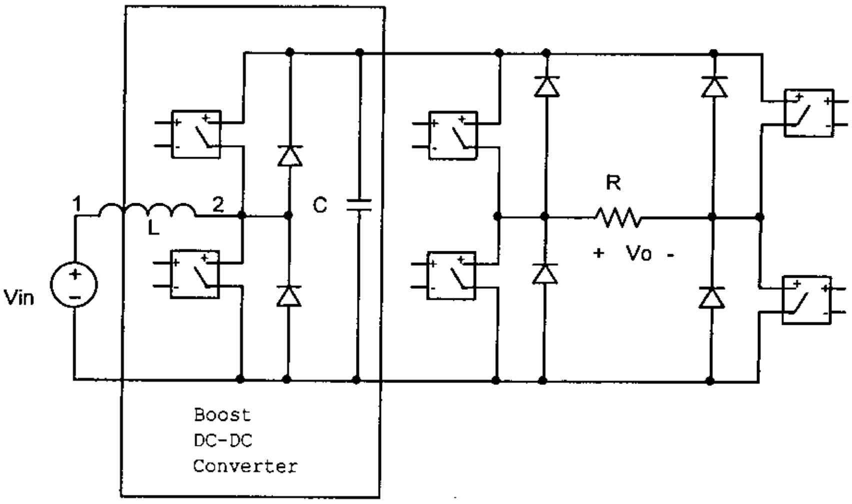


Figure. 2.23: Circuit used to generate an AC voltage larger than DC input voltage

2.9.1. Proposed Boost Inverter

In this thesis, a new VSI is proposed, referred to as boost inverter, which naturally generates an output ac voltage lower or larger than the input dc voltage depending on the duty cycle .

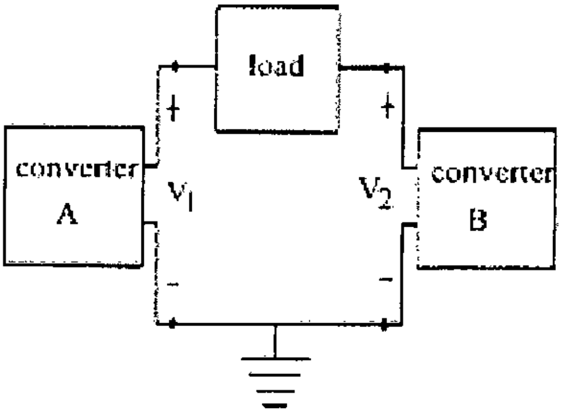
2.9.1.1. The New Inverter and Principle of Operation

Let us consider two DC-DC converters feeding a resistive load R as shown in Figure. 2.24a.The two converters produces a dc-biased sine wave output such that each source only produces a unipolar voltage as shown in Figure. 2.24b. The modulation of each converter is 180 degrees out of phase with the other so that the voltage excursion across the load is maximized. Thus, the output voltage of the converters are described by

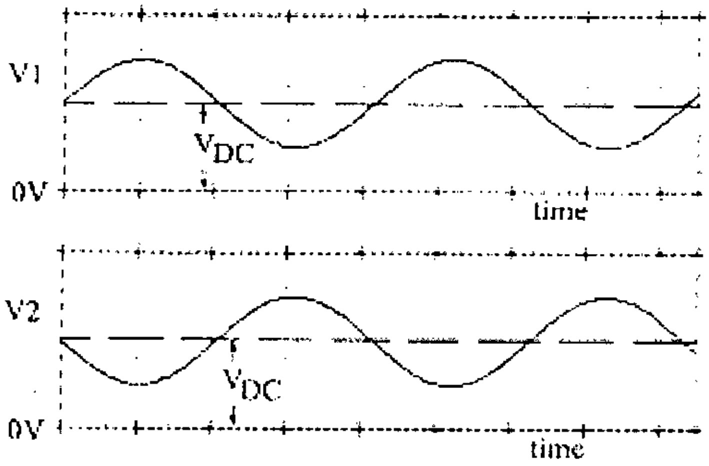
$$v_1 = V_{dc} + V_m \sin wt \cdots\cdots\cdots\cdots (i)$$
$$v_2 = V_{dc} - V_m \sin wt \cdots\cdots\cdots\cdots (ii)$$

Thus, the output voltage is sinusoidal as given by

$$v_o = v_1 - v_2 = 2V_m \sin wt \cdots\cdots\cdots (iii)$$



(a) Two DC-DC converter



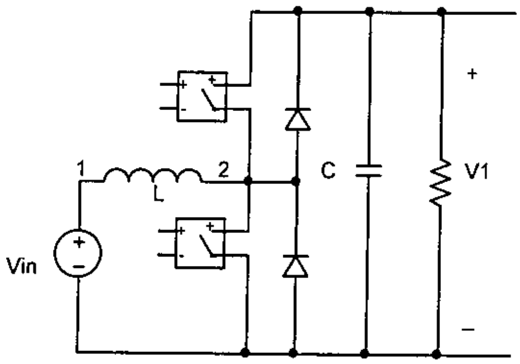
(b) Output voltage

Figure. 2.24: Principle of boost inverter

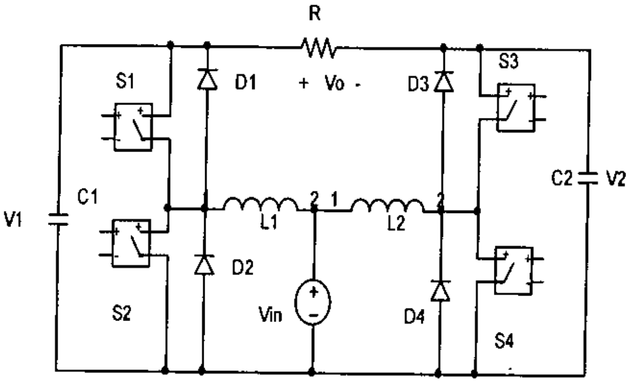
Thus, a dc bias voltage appears at each end of the load with respect to ground, but the differential dc voltage across the load is zero.

2.10. Boost Inverter Circuit:

Each converter is a current bidirectional boost converter as shown in Figure. 2.25a. The boost inverter consists of two boost converters as shown in Figure. 2.25b. The output of the inverter can be controlled by one of the two methods: (1) use a duty cycle D for converter A and a duty cycle of (1- D) for converter B or (2) use a differential duty cycle for each converter such that each converter produces a dc-biased sine wave output. The second method is preferred and it uses controllers A and B to make the capacitor voltage v_1 and v_2 follow a sinusoidal reference voltage.



(a) The current bi-directional boost converter



(b) The proposed DC-AC boost converter

Figure. 2.25: The proposed Boost Inverter

2.10.1. Circuit Operation:

The operation of the Inverter can be explained by considering one converter A only as shown in Figure. 2.26. There are two modes of operation: mode 1 and mode 2.

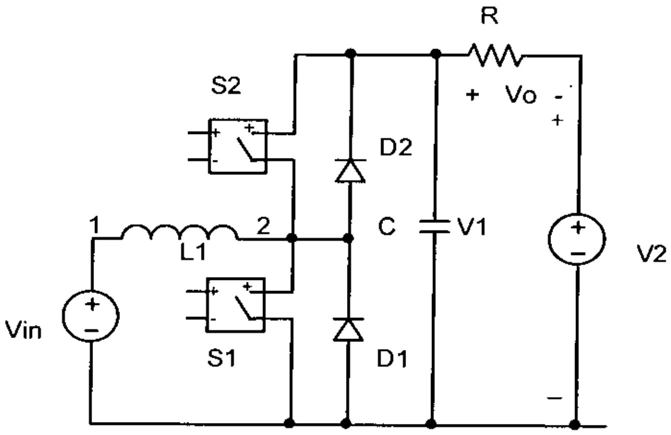


Figure. 2.26: Equivalent circuit for the boost inverter

Mode 1: When the switch S_1 is closed and S_2 is open as shown in Figure. 2.27a,current i_{L1} rises quite linearly, diode D_2 is reverse polarized, capacitor C_1 supplies energy to the output stage, and voltage V_1 decreases.

Mode 2: When switch S_1 is open and S_2 is closed ,as shown in Figure. 2.27b,current i_{L1} flows through capacitor and the output stage. The current i_{L1} decreases while capacitor C_1 is recharged.

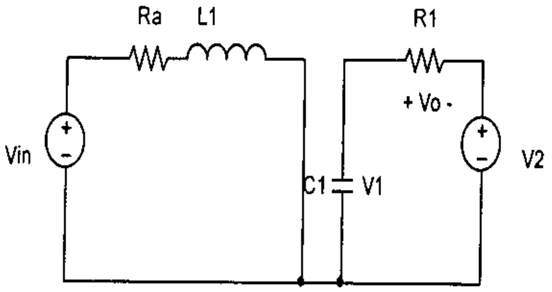


Figure. 2.27a: Mode 1: S_1 is closed and S_2 is open

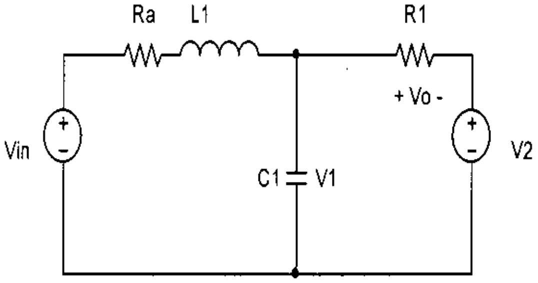


Figure. 2.27b : Mode 2: S_1 is open and S_2 is closed

The average output of converter A, which operates under the boost mode, can be found from

At mode 1: $V_{La} = V_{in}$

At mode 2: $V_{La} = V_{in} - V_o$

From the above two equations,

$$\Rightarrow V_{La}T_{ON} + V_{L1}T_{OFF} = 0$$
$$\Rightarrow V_{in}T_{ON} + (V_{in} - V_o)T_{OFF} = 0$$
$$\Rightarrow V_{in}T_{ON} + V_{in}T_{OFF} = V_oT_{OFF}$$
$$\Rightarrow V_{in}T = V_O(T - T_{ON})$$
$$\Rightarrow \frac{V_O}{V_{in}} = \frac{T}{T - T_{ON}}$$
$$\Rightarrow \frac{V_O}{V_{in}} = \frac{D}{1 - D}$$

So,

$$\frac{V_1}{V_{in}} = \frac{1}{1-D} \cdots\cdots\cdots\cdots (iv)$$

The average output of converter B , assuming which operates 180 degree out of phase, can be found from

$$\frac{V_2}{V_{in}} = \frac{1}{D} \cdots\cdots\cdots\cdots\cdots (v)$$

Therefore, the average output voltage is given by

$$V_o = V_1 - V_2 = \frac{V_{in}}{1-D} - \frac{V_{in}}{D} \cdots\cdots (vi)$$

This gives the dc gain of the boost inverter as

$$G_{dc} = \frac{V_o}{V_{in}} = \frac{2D-1}{D(1-D)} \cdots\cdots (vii)$$

where D is the duty cycle. It should be noted that V_0 becomes zero at D=0.5. If the duty cycle D is varied around the quiescent point of 50% duty cycle, there is an ac voltage across the load. Because the output voltage in equation in (iii) is twice the sinusoidal component of converter A, the peak output voltage equals to

$$V_{o(pk)} = 2V_m = 2V_1 - 2V_{dc} \cdots\cdots\cdots (\text{viii})$$

Because a boost converter cannot produce an output voltage lower than the input voltage, the dc component must satisfy the condition

$$V_{dc} \geq (V_m + V_{in})$$

Which implies there are many possible values of V_{dc}. However, the equal term produces the least stress on the devices. From the equation (iv), (vii) and (viii), we get

$$V_{o(pk)} = \frac{2V_{in}}{1-D} - 2(\frac{V_{o(pk)}}{2} + V_{in})$$

Which gives the ac voltage gain is

$$G_{ac} = \frac{V_{o(pk)}}{V_{in}} = \frac{D}{1-D}$$

Thus , $V_{o(pk)}$ becomes V_{in} at D=0.5.

Chapter 3

Simulation and Experimental results

3.1. System Description

New residential scale photovoltaic (PV) arrays are commonly connected to the grid by a single dc–ac inverter connected to a series string of pv panels, or many small dc–ac inverters which connect one or two panels directly to the ac grid.

Buck, boost, buck-boost, and Cúk converters are considered as possible dc–dc converters that can be cascaded. ORCAD Capture 9.1 simulations are used here for conversion.

The conversion structure from solar sell to home is shown in the Figure. 3.1. It consists of the cascade connection of two stages. The first stage is a boost-regulator and the second stage is the boost inverter. A solar cell can charge a battery up to 12 V dc. Using boost regulator is the first stage where output dc voltage is almost 50 V dc. This output is the input of the second stage of the boost inverter. Here, the output is 230 V ac , pure sinusoidal. Then this voltage is applied to home.

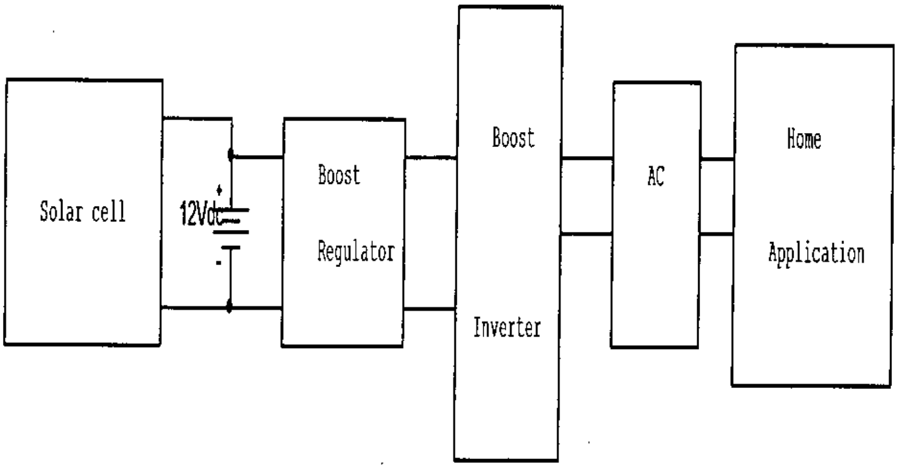


Figure. 3.1: Conversion of solar cell to home application

Here, a solar cell charges a battery up to 12 V dc. Then a boost regulator is used. It boost up the 12 V to 48 V. This is the input of the boost inverter. Its output across resistive load is 230 V ac. This is then applied to home.

3.2. The Circuit Description For The Proposed Boost Inverter

The boost dc–ac converter is shown in Figure.3.2. It includes dc supply voltage V_{in}, input inductors L_1, L_2 and L_3, power switches S_1 – S_5, transfer capacitors C_1 – C3, free-wheeling diodes D_1-D_5 and load resistance R .The principal purpose of the controllers A and B is to make the capacitor voltages V_1 and V_2 follow as faithfully as possible a sinusoidal reference. The operation of the boost inverter is better understood through the current bidirectional boost dc–dc converter shown in Figure. 2.8. In the description of the converter operation, we assume that all the components are ideal and that the converter operates in a continuous conduction mode. Figure. 2.9 shows two topological modes for a period of operation.

3.2.1. Control Design Methodology

In the design of the converter, the following are assumed:

- ideal power switches;
- power supply free of sinusoidal ripple;
- converter operating at high-switching frequency.

3.2.2. Selection of Control Parameters

Once the boost inverter parameters are selected, inductances L_1, L_2 and L_3 are designed from specified input and output current ripples, capacitors C_1 – C_3 are designed so as to limit the output voltage ripple in the case of fast and large load variations, and maximum switching frequency is selected from the converter ratings and switch type.

3.3 Simulation and Experiment

3.3.1. The simulation and Experimental results

Frequency, f=50Hz.

R= 250 ohm

V_{in} = 12 V_{dc}

V_{out} = 226 V_{ac}

$S_1 - S_5$: switches ;

D_1-D_5 : D1N1190(diodes);

C_1 -C_2- C_3 : 400uF

L_1. L_2-L_3 : 10 mH

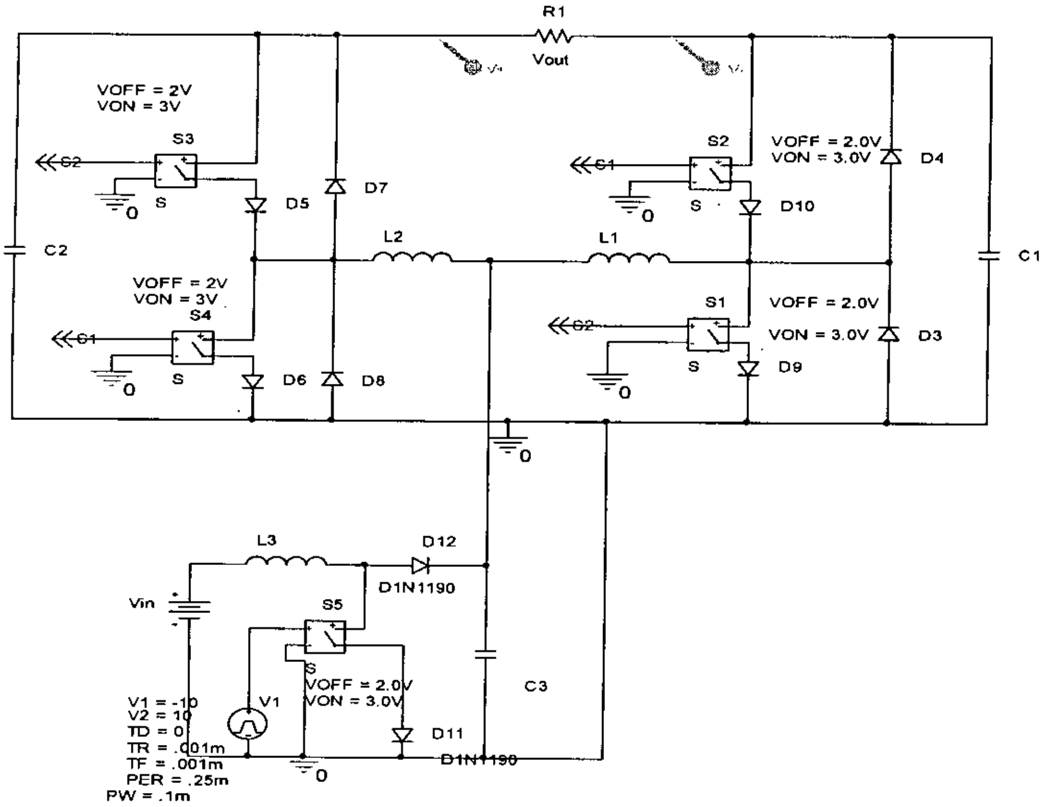


Figure. 3.2: Boost Inverter with ideal switches

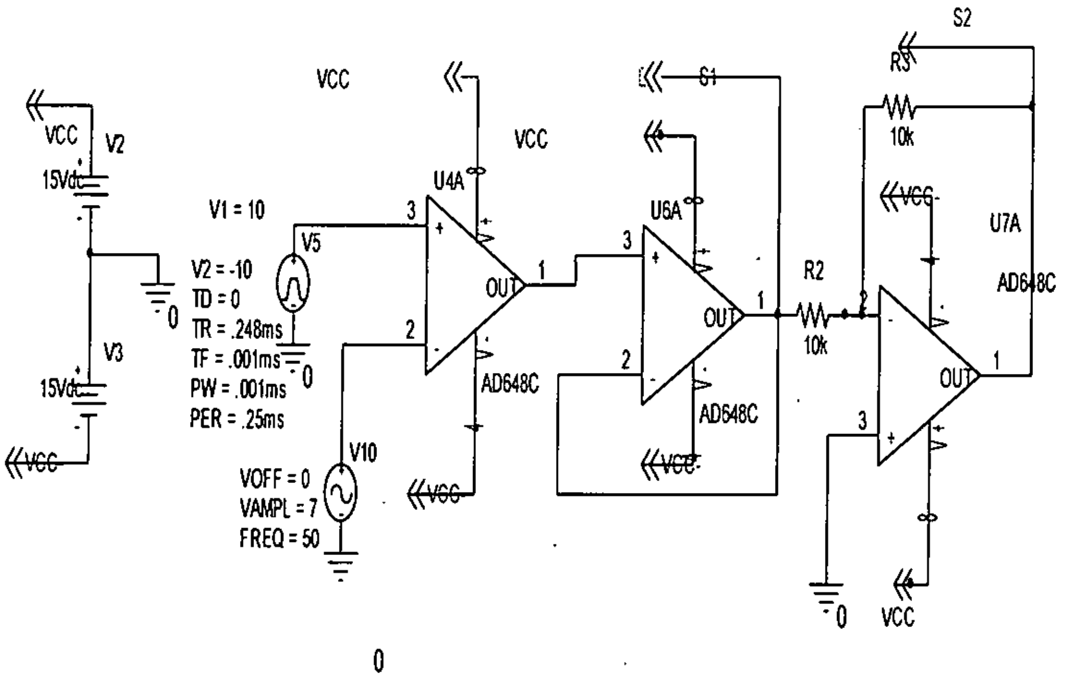


Figure. 3.3: Control circuit

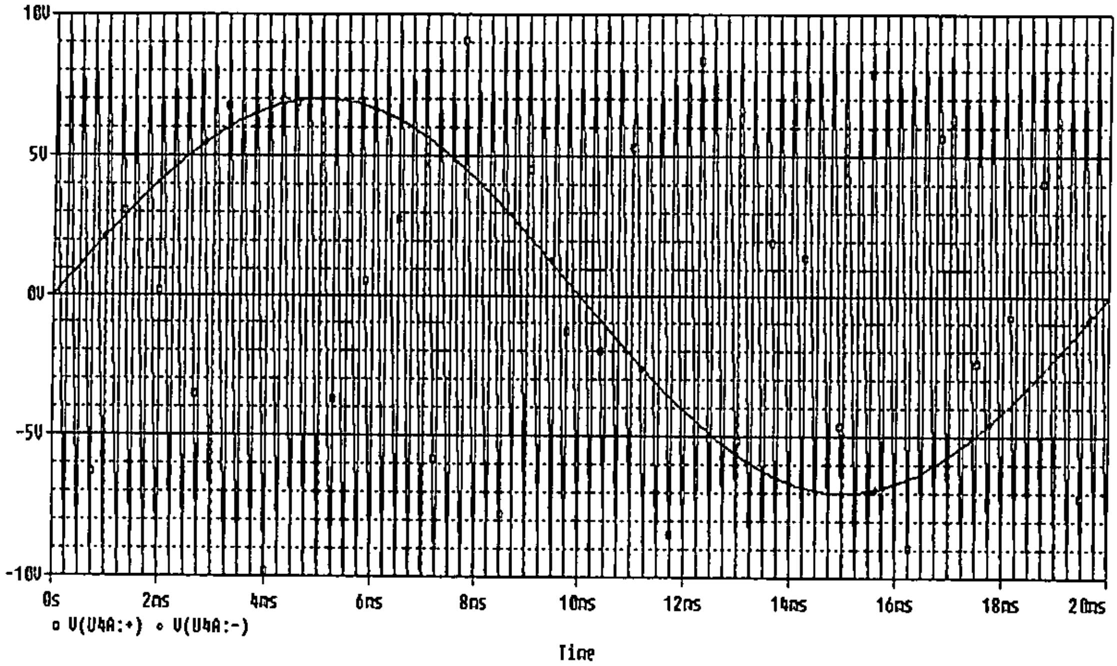


Figure. 3.4a: Pulse Width Modulation signal

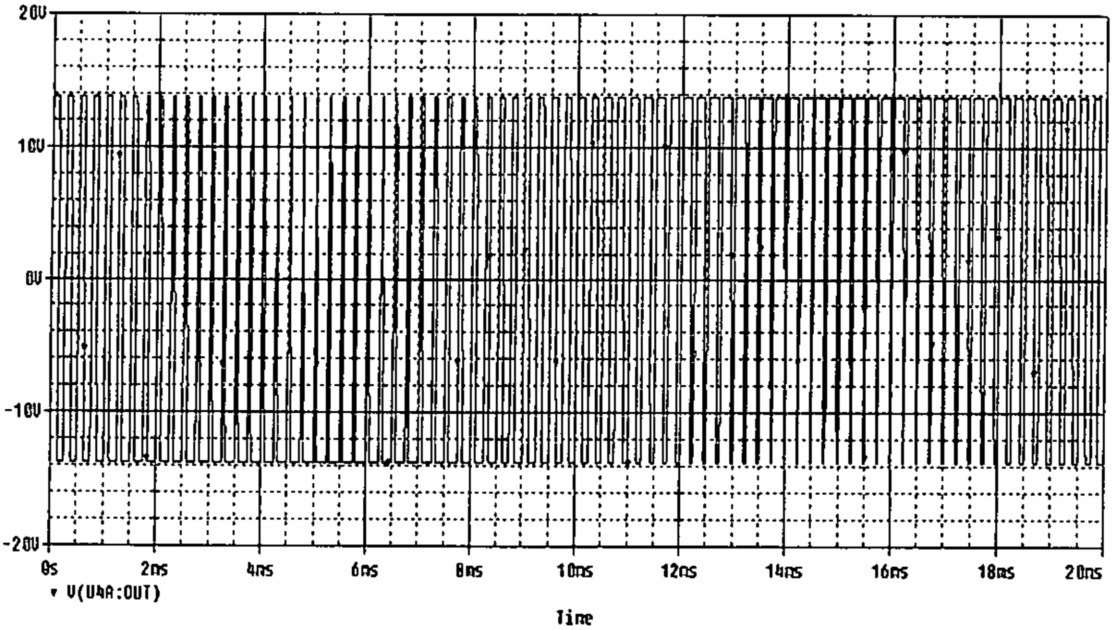


Figure. 3.4b: Pulse width modulated signal

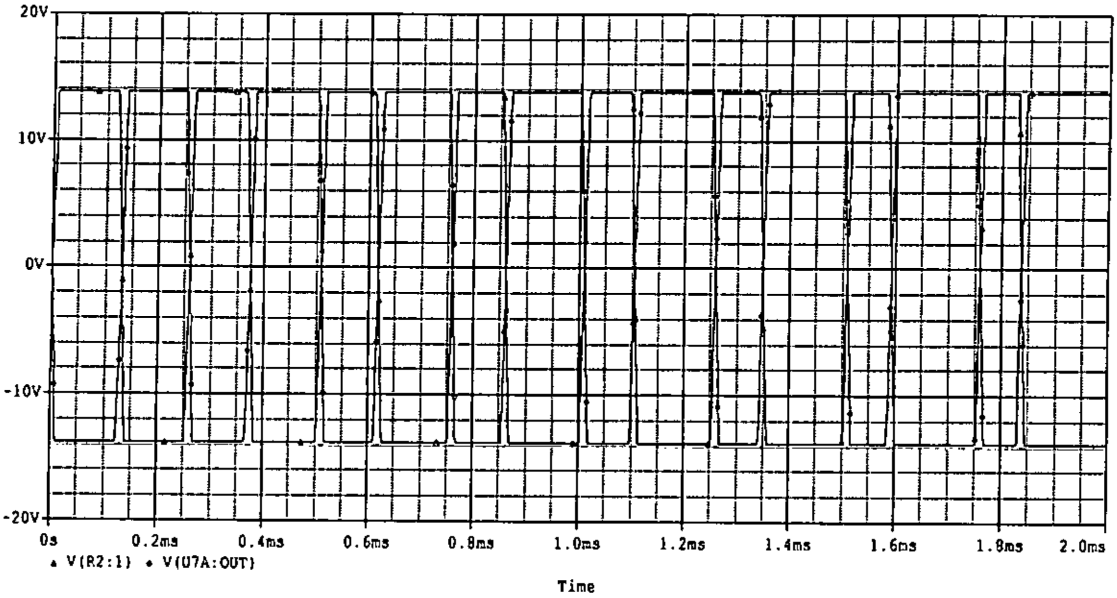


Figure. 3.5: Output wave shapes of S1 and S2

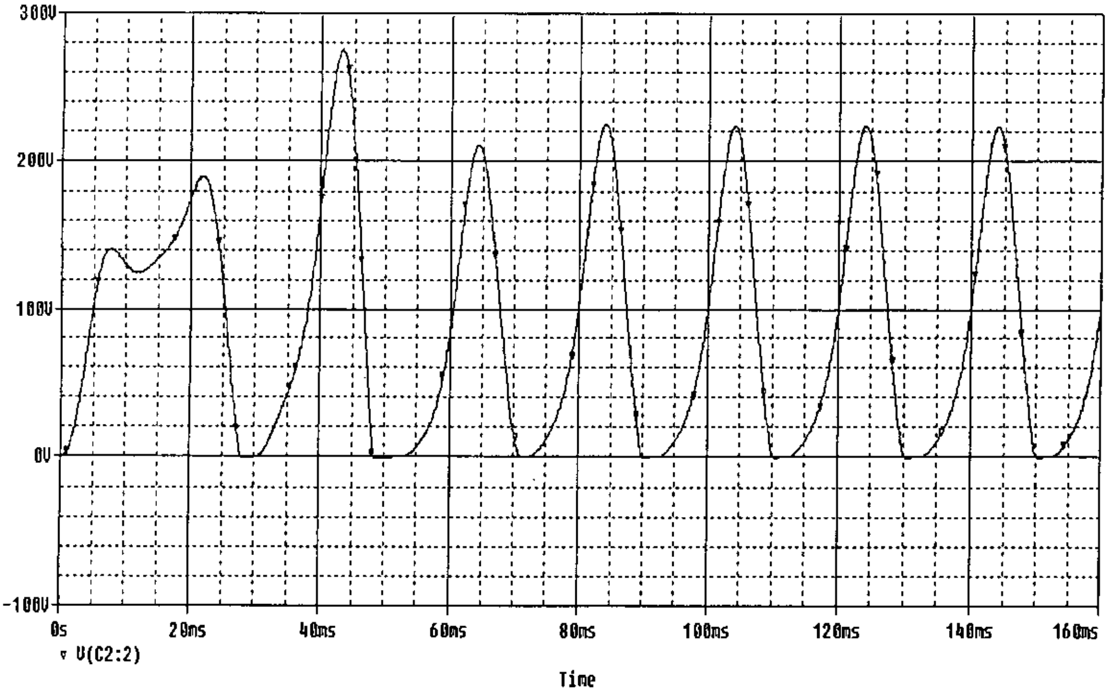


Figure. 3.6: Output voltage across C2

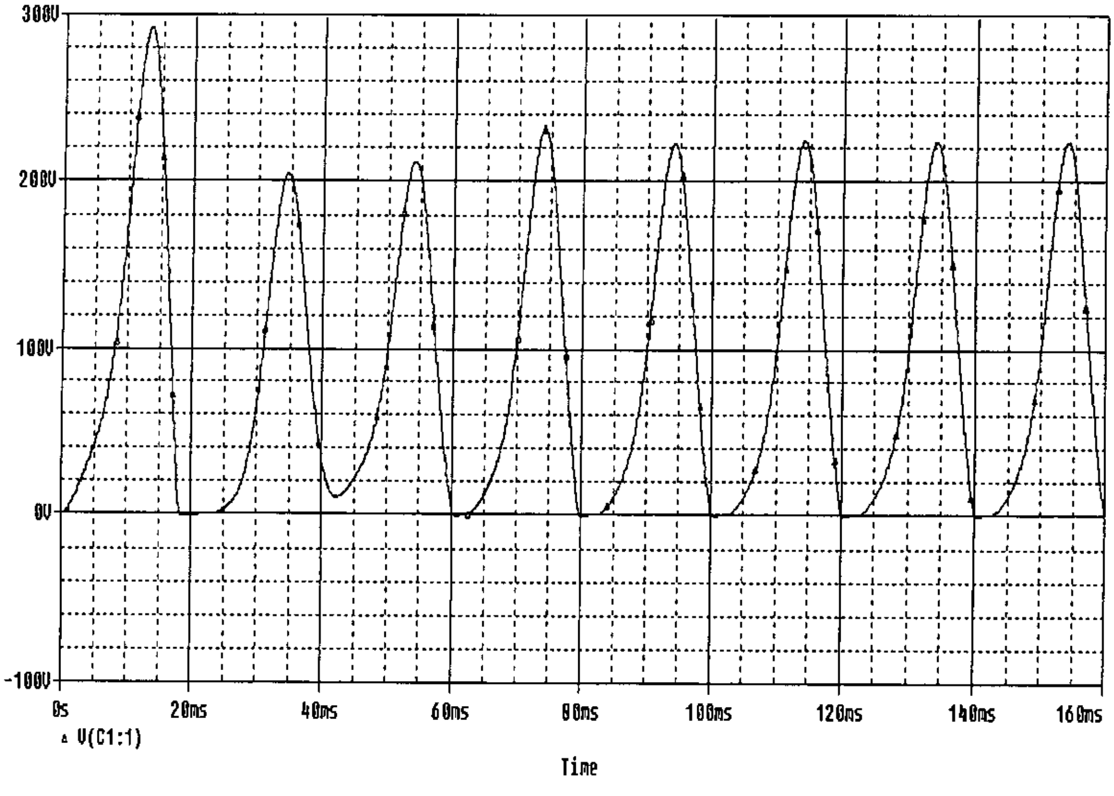


Figure. 3.7: Output voltage across C1

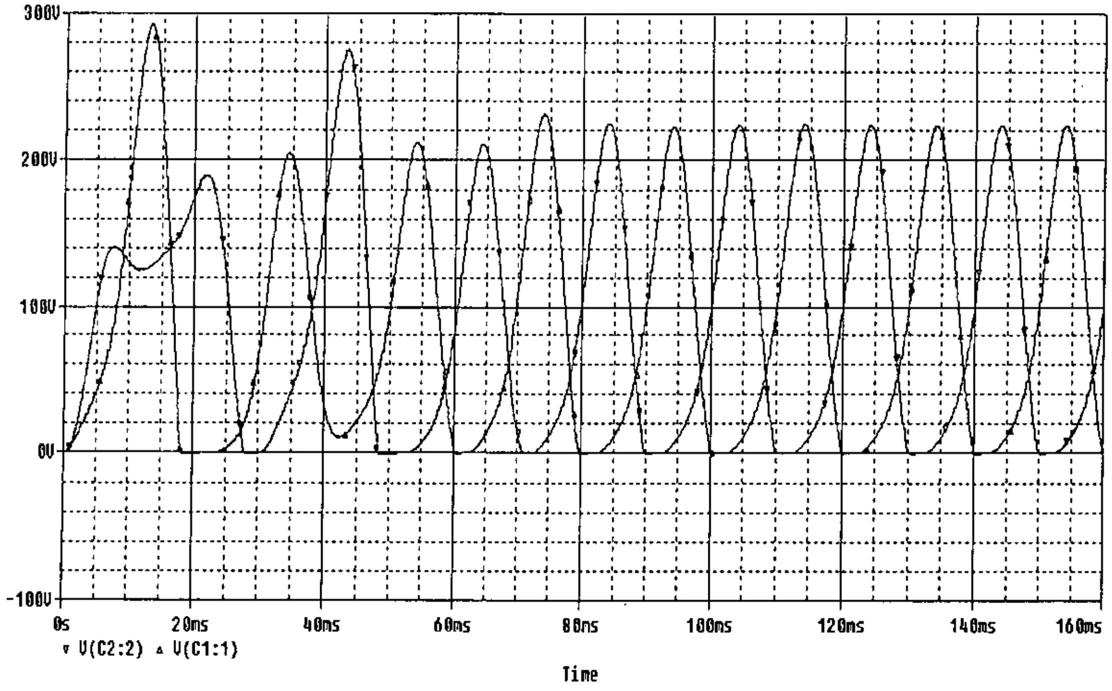


Figure. 3.8: Output voltage across both c1 and c2

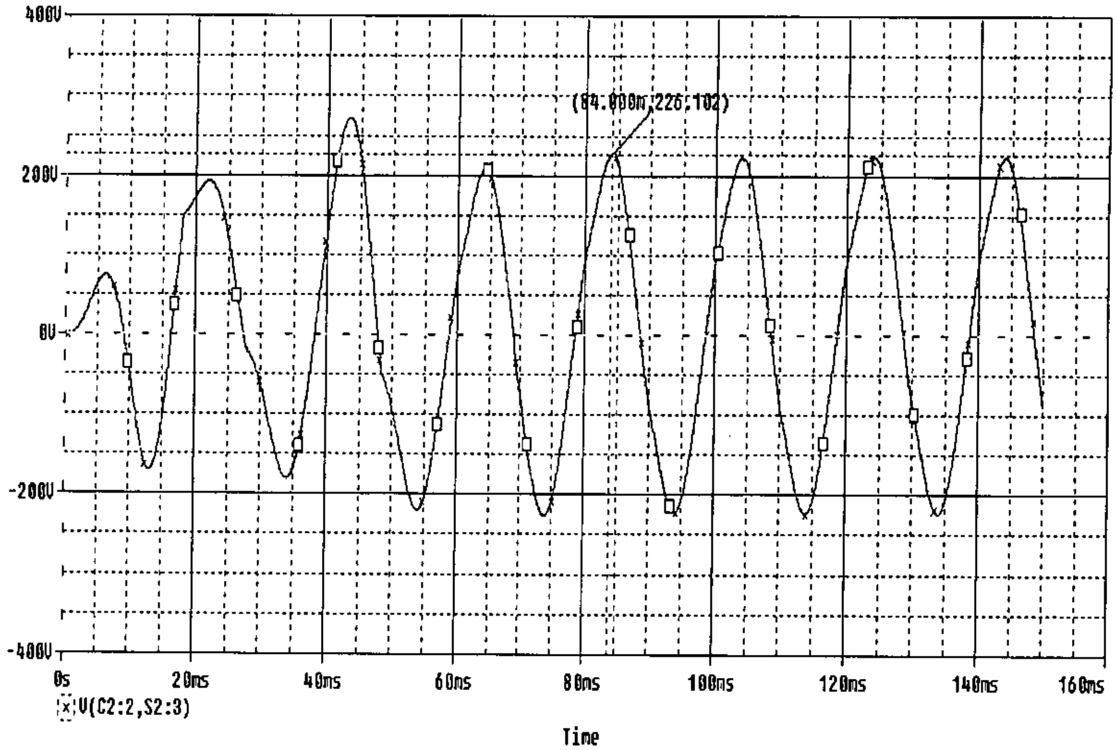


Figure. 3.9: Output voltage at load 250 Ohm, time t=84.1 ms, Vout= 226 Vac

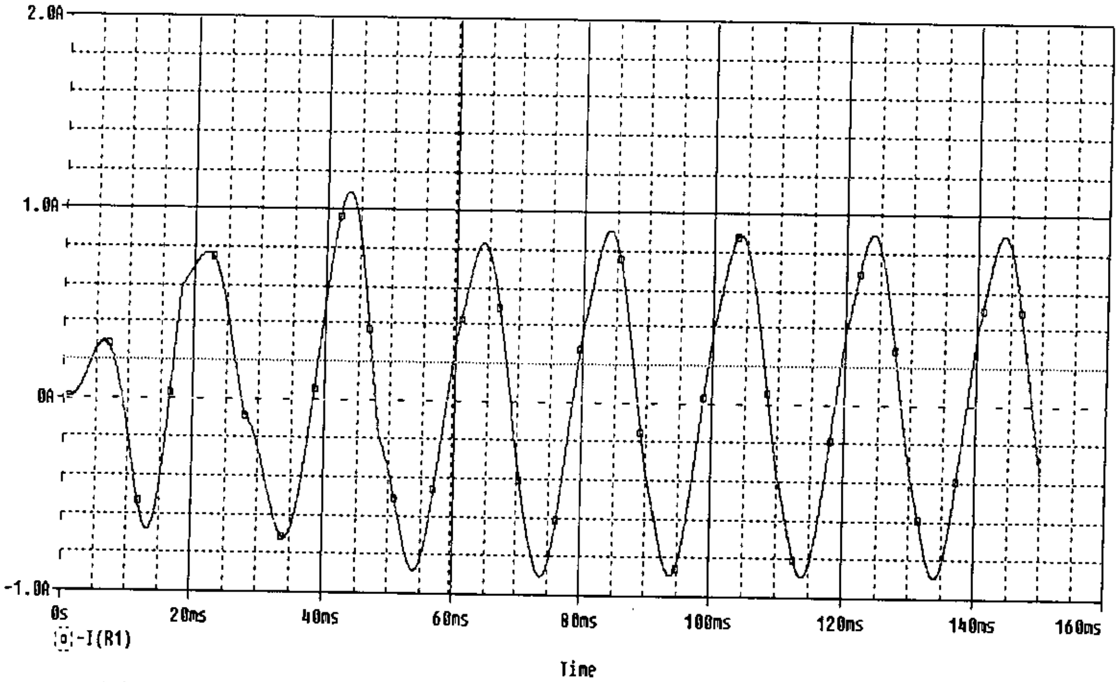


Figure. 3.10: Current for Rload= 250 Ohm, At time t= 83.67m, 0.9 A

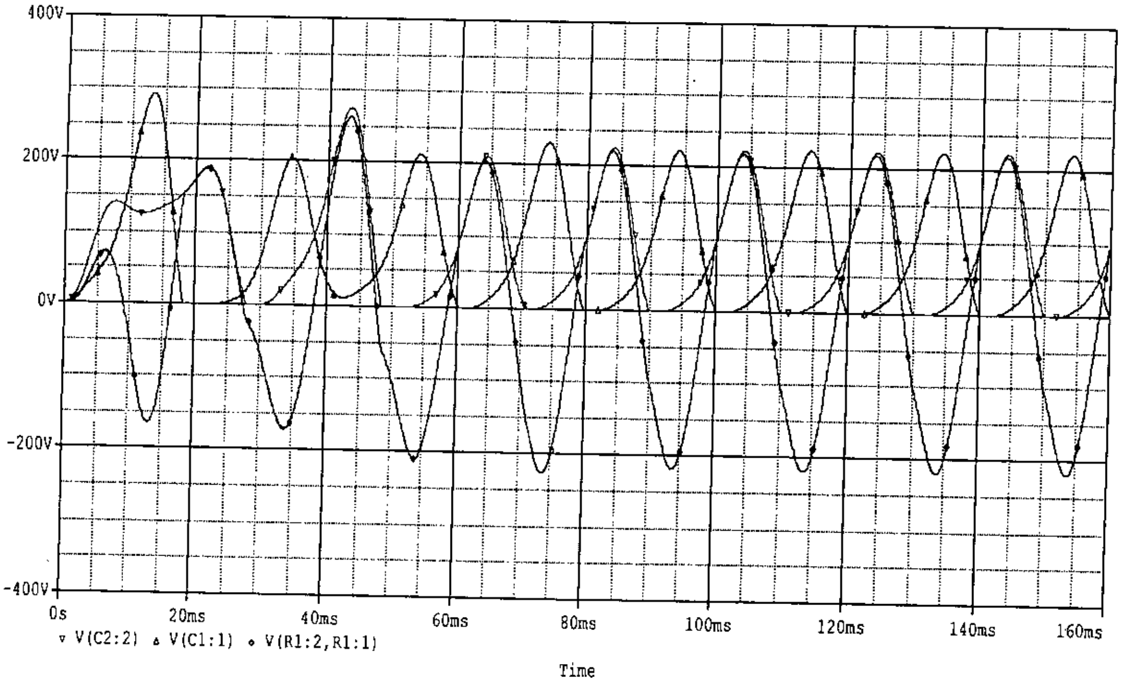


Figure. 3.11: Combined output voltage across C2,C1 and for load 250 Ohm

3.3.1.1. Variation of output with load 150 and 500 ohm:

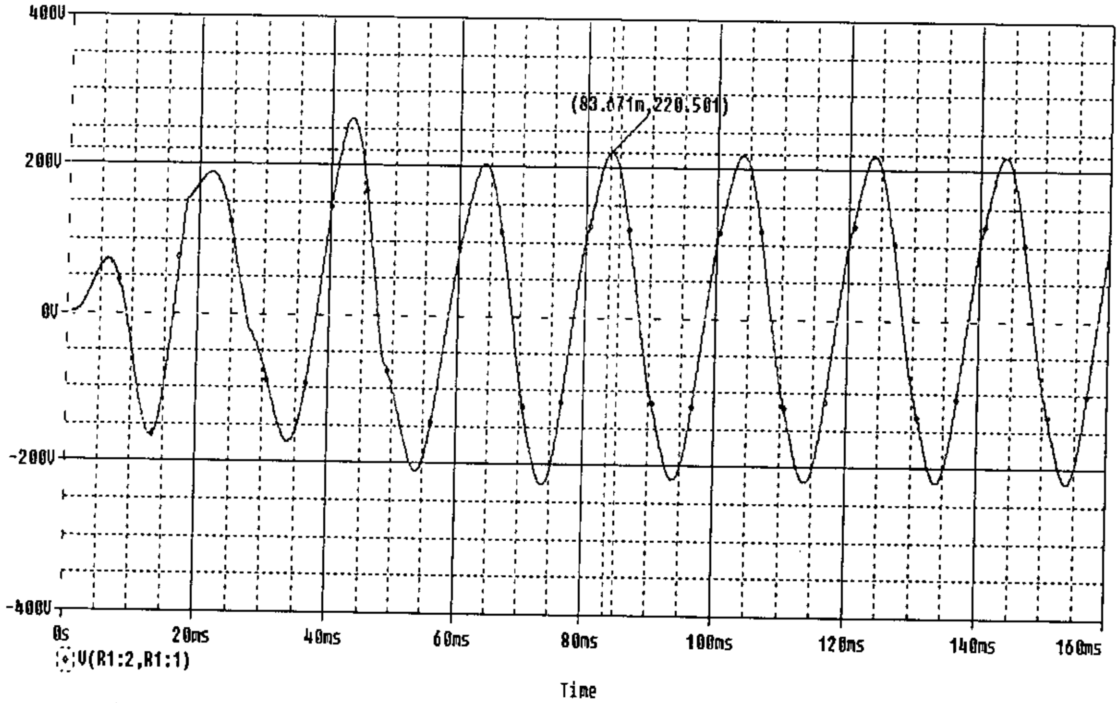


Figure. 3.12: Vout = 220.51 V ac at time, t=83.67 ms, Rload=150 ohm

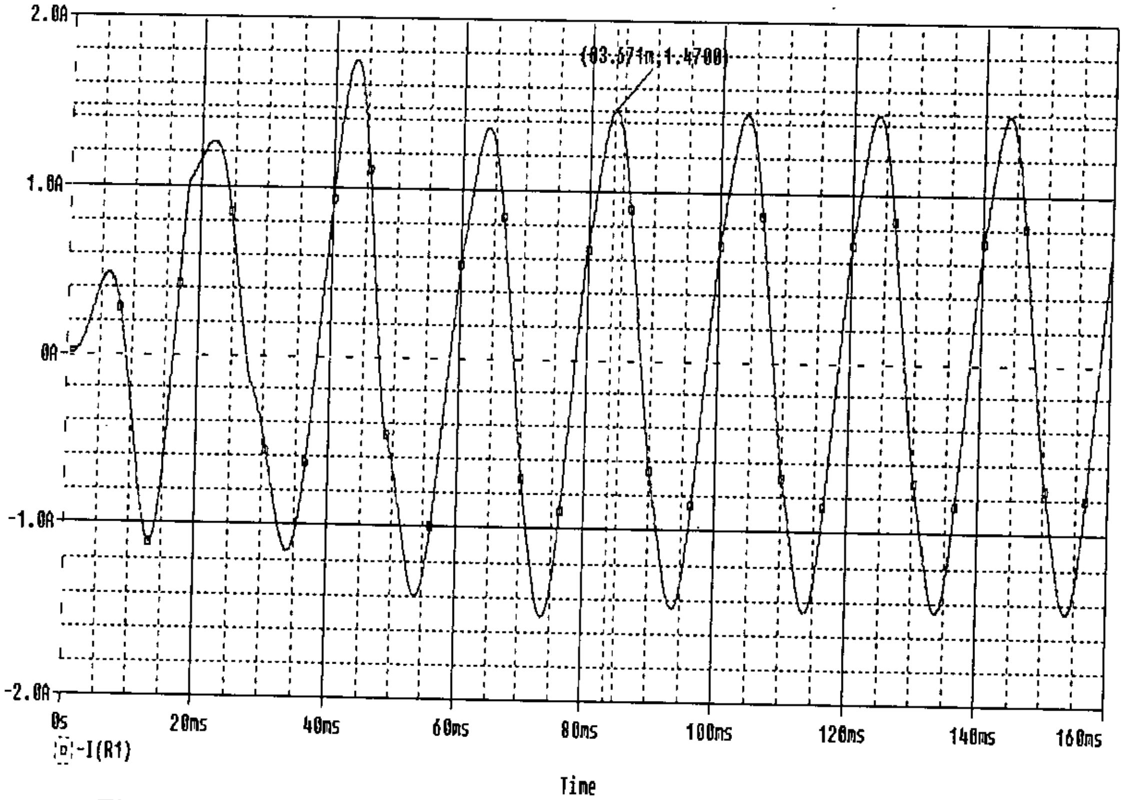


Figure. 3.13: Current for Rload= 150 Ohm, at time t= 83.67m, 1.47 A

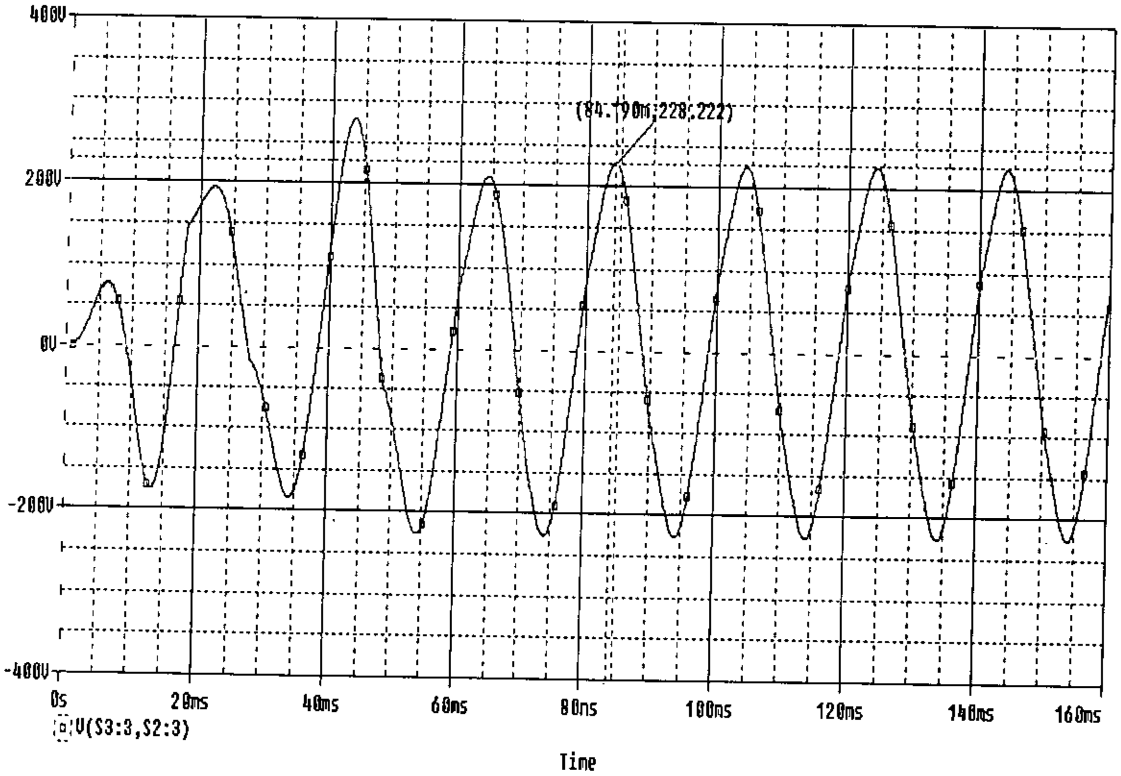


Figure. 3.14: Vout = 228 V ac at time, t=84 ms, Rload=500 ohm

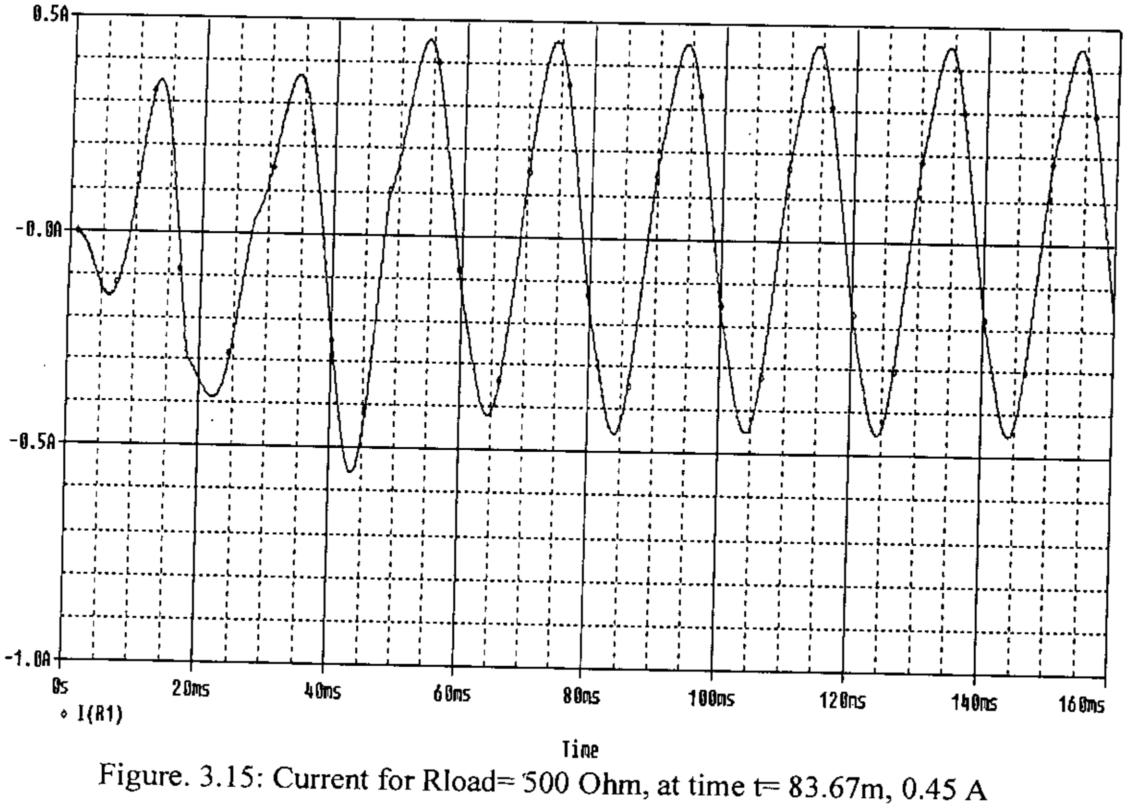
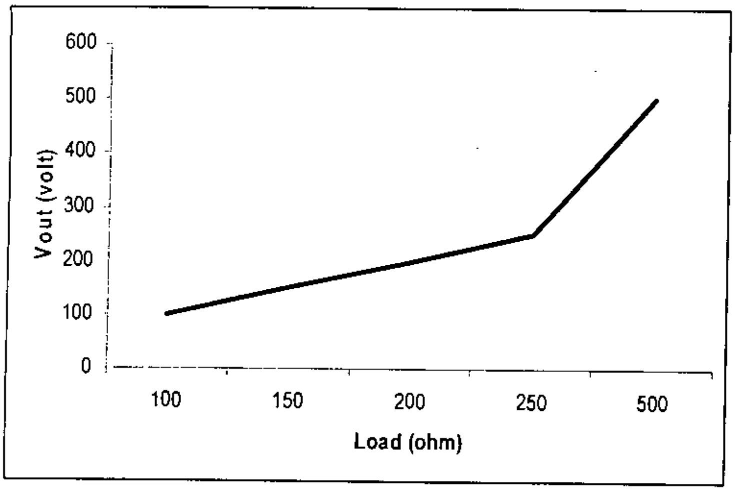


Figure. 3.15: Current for Rload= 500 Ohm, at time t= 83.67m, 0.45 A

Table: 3.1 Output Power at various load

Rload (ohm)	Vout (volt)	Pout (watt)
100	216	471
150	220.51	324.15
200	226	258
250	228	210
500	230	102.6



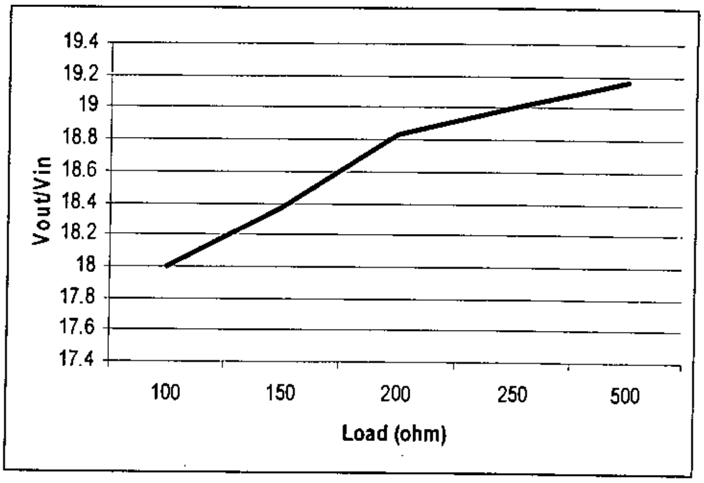


Figure. 3.16: Output voltage at various load, Figure.3.17 : voltage gain at various load

3.3.2. Efficiency of conversion

It is the ratio of ac output power to the dc input power.

$$Efficiency = \frac{P_{out}}{P_{in}} * 100\%$$

3.3.3. Simulation results with practical switches

3.3.3.1.The simulation and experimental results

Frequency, f=50Hz.

R : 300 ohm

V_{in} : 12 V_{dc}

V_{out} : 228 V_{ac}

$S_1 - S_5$: APT45G100BN ,practical switches (igbt) ;

D_1-D_5 : D1N1190(diodes);

C_1 -C_2 : 265 uF

C_3 : 280uF

L_1. L_2 : 10 mH

L_3 : 1 mH

Pout : 173 Watt

Pin : 178 Watt

Efficiency: 97.19 %

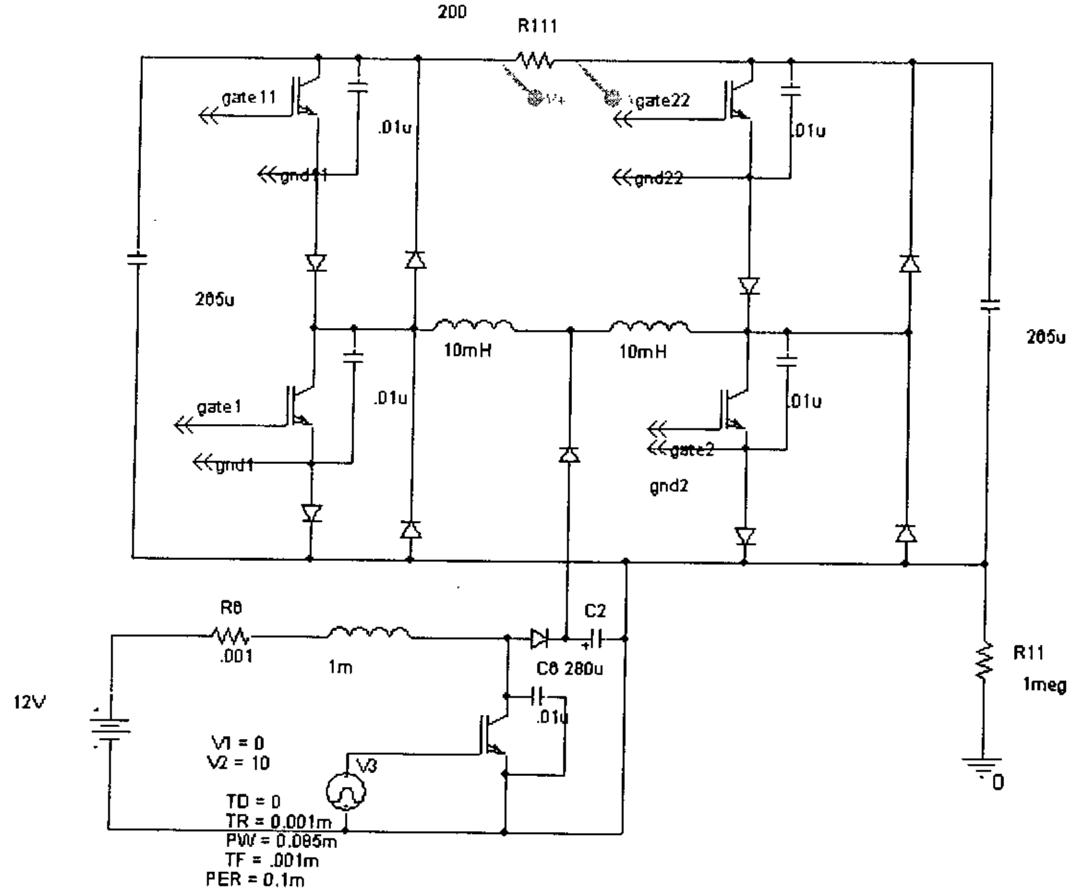


Figure. 3.18: Boost Inverter using practical switches

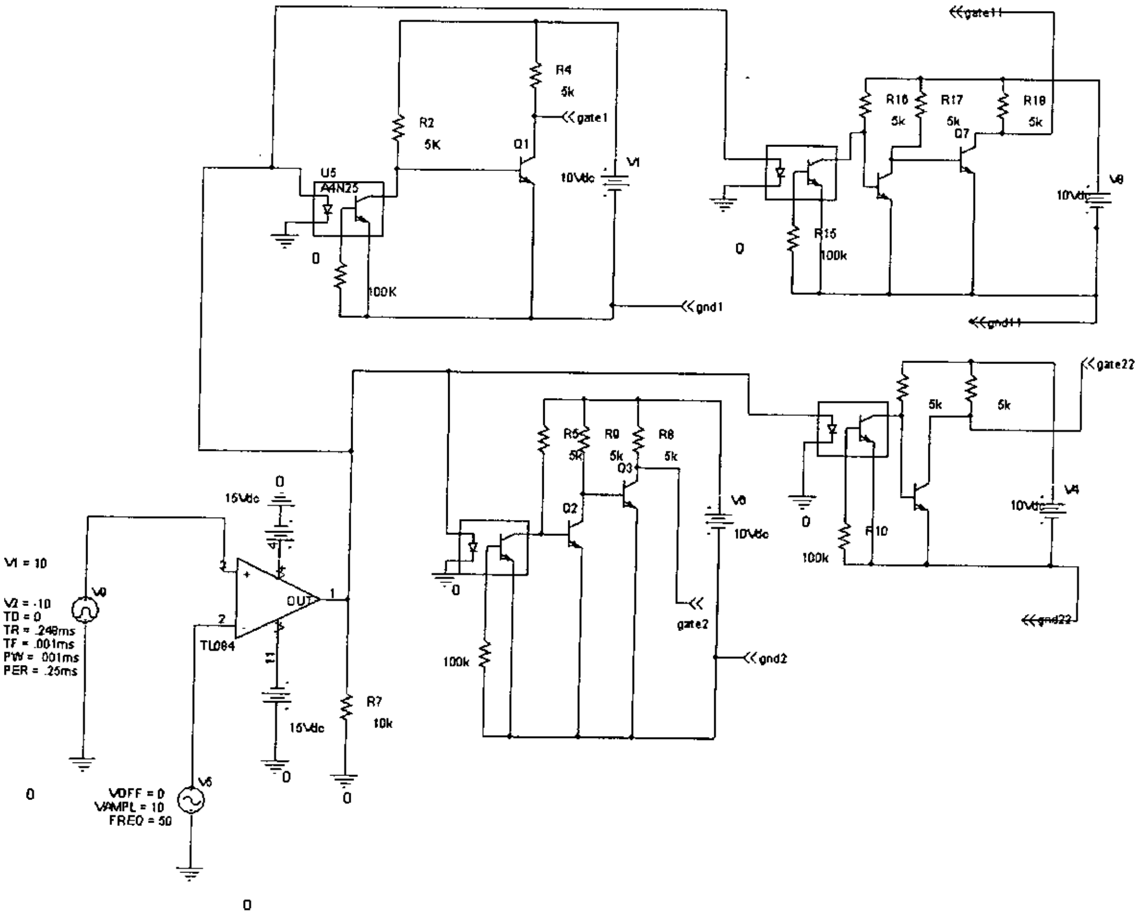


Figure. 3.19: Control circuit

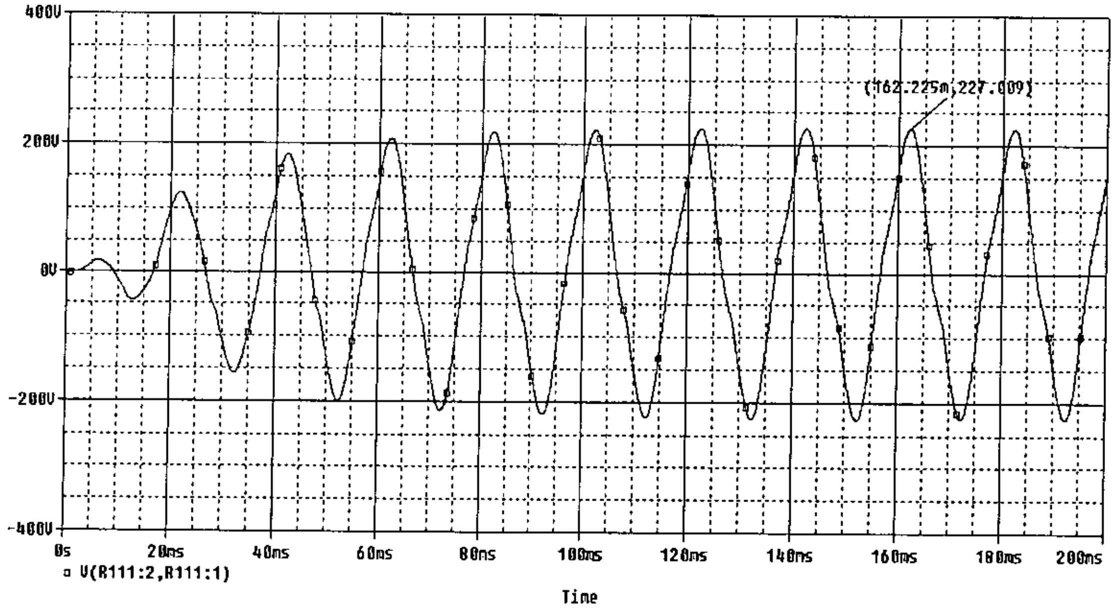


Figure. 3.20: Vout = 228 V ac at Rload=300 ohm

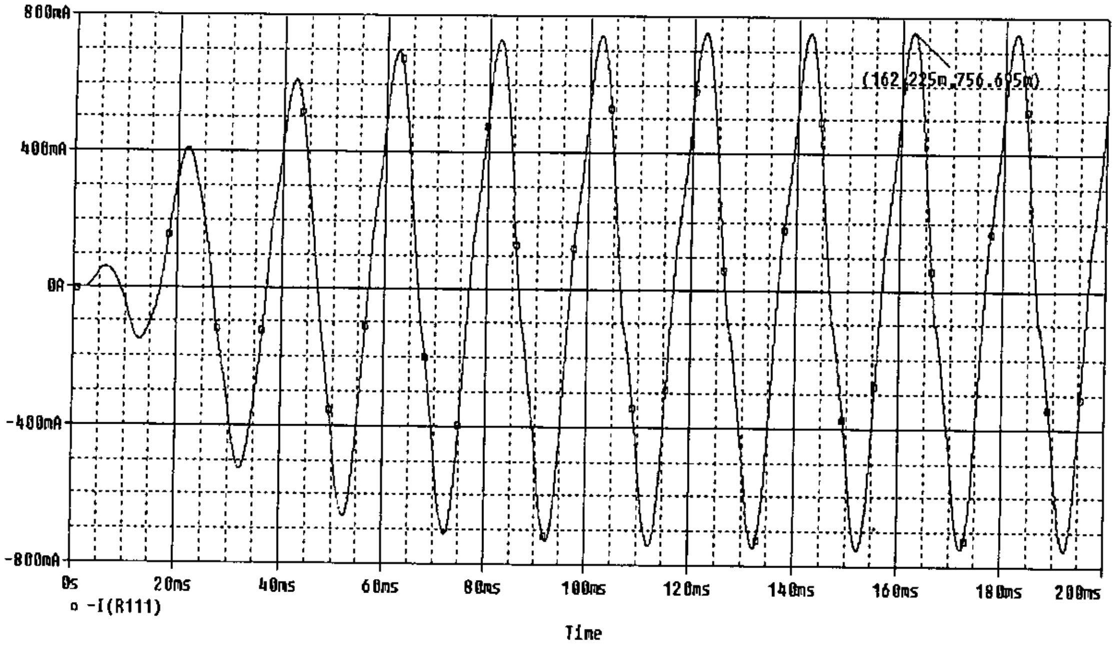


Figure. 3.21: Iout = 0.76A ac at Rload=300 ohm

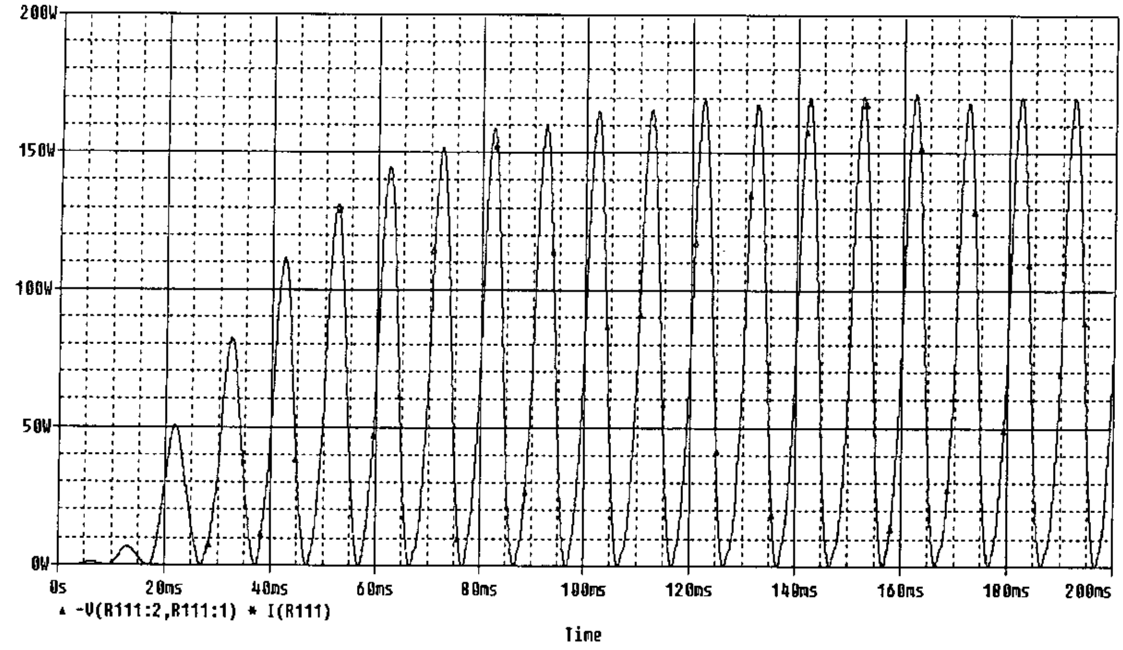


Figure. 3.22: Pout = 173.28 Watt

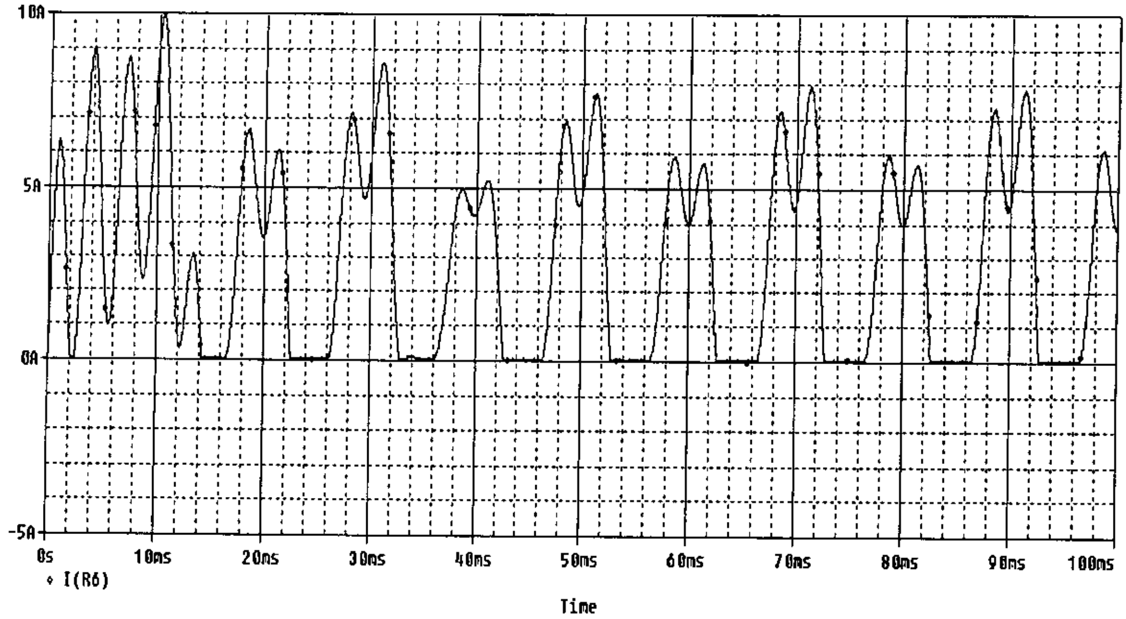


Figure. 3.23:Iin = 10A

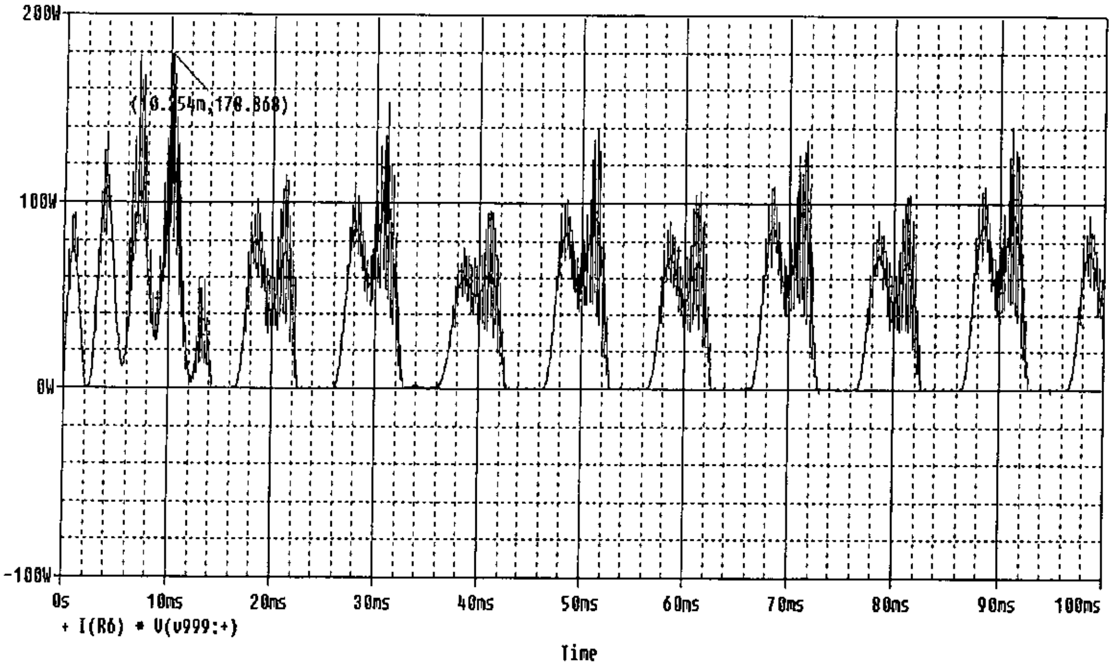


Figure. 3.24 : Pin = 178. 86Watt

$$Efficiency = \frac{P_{out}}{P_{in}} * 100\%$$

$$= \frac{173.28}{178.86} * 100\%$$

$$= 97\%$$

3.4. Variation of output

(a) in Tabular form
(b) by graphical form

3.4.1. Variation in Tabular form:

The variables are

(i) Boost stage (i.e. duty cycle)
(ii) Modulation Index
(iii) Input frequency to the gate pulse

Table: 3.2 Variation of Boost stage

pw	Duty Cycle	Vout(volt)	Vin	Vout/Vin
.098	.98	77	12	6.41
.095	.95	134	12	11.16
.087	.87	221	12	18.41
.086	.86	226	12	18.83
.085	.85	227	12	18.91
.084	.84	224	12	18.67
.075	.75	166.16	12	13.84
.065	.65	133	12	11.08
.055	.55	117.3	12	9.77
.045	.45	102.5	12	8.54
.035	.35	95.882	12	7.99
.025	.25	87.112	12	7.26
.015	.15	76.6	12	6.38
.005	.05	60.275	12	5.02

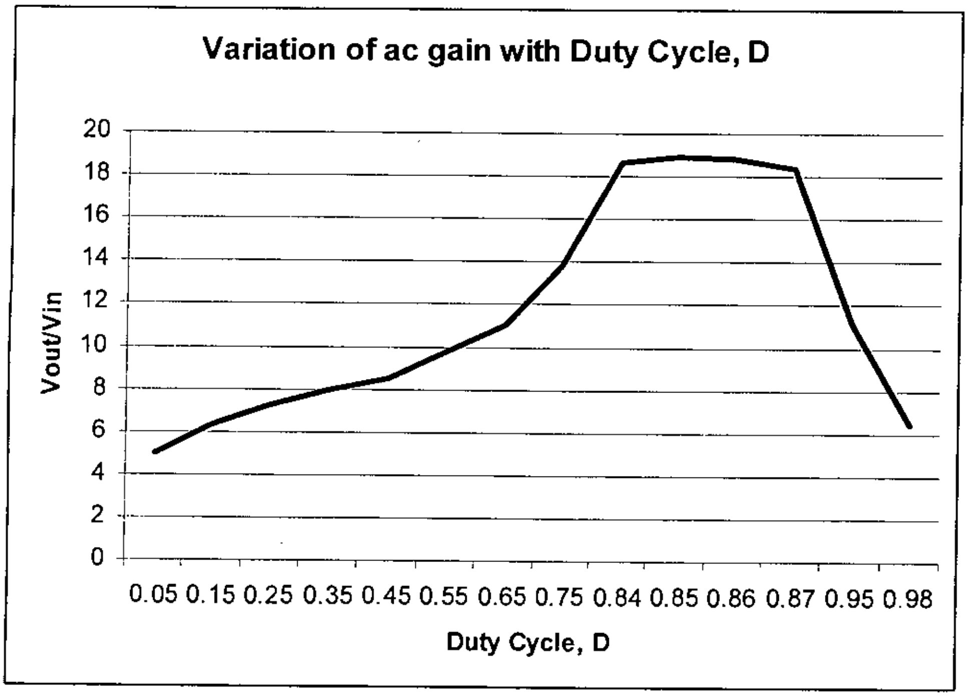


Figure. 3.25: Variation of voltage gain with duty cycle

Table: 3.3 Variation of modulation index

Sin_ampl	M	Vout(volt)	Vin
11	1.1	233	12
10	1.0	227	
9	0.9	215	
8	0.8	214	
7	0.7	212	
6	0.6	210	
5	0.5	209	
4	0.4	205	
3	0.3	202	
2	0.2	119	

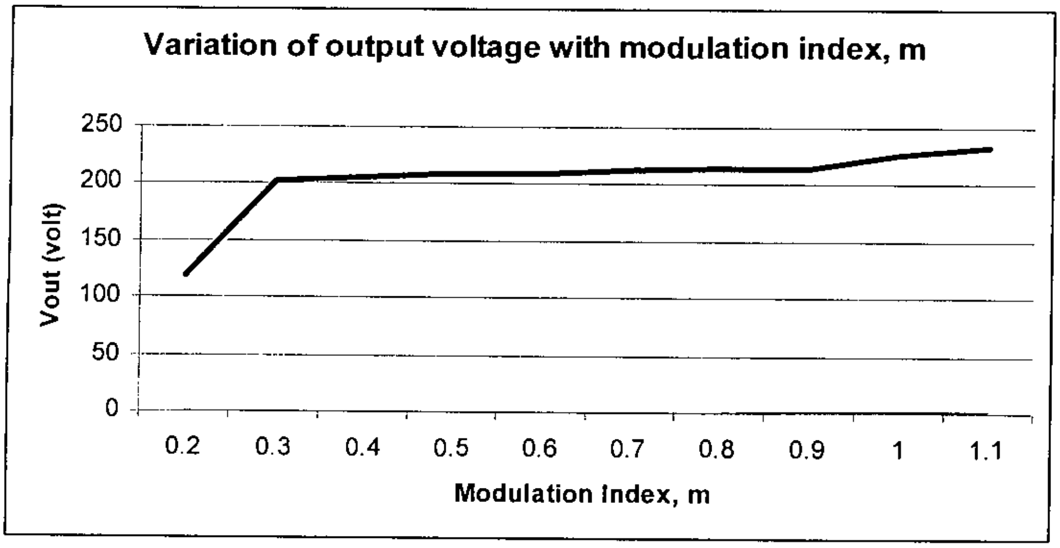


Figure. 3.26: Variation of output voltage with modulation index

- ❖ From the graph, it is shown that, the amplitude of the ac voltage can be regulated by the variation of the reference signal amplitude.

Table: 3.4 Variation of input freq

Fin(Hz)	Fout(Hz)
20	20
30	30
40	40.03
50	50.01
60	60.06
70	70.4
80	80
90	90
100	100.01
110	110

- ❖ It is shown that, the frequency of the reference sine wave determines the frequency of the generated ac voltage.

3.4.2. Variation by graphical form

3.4.2.1. Variation by modulation index

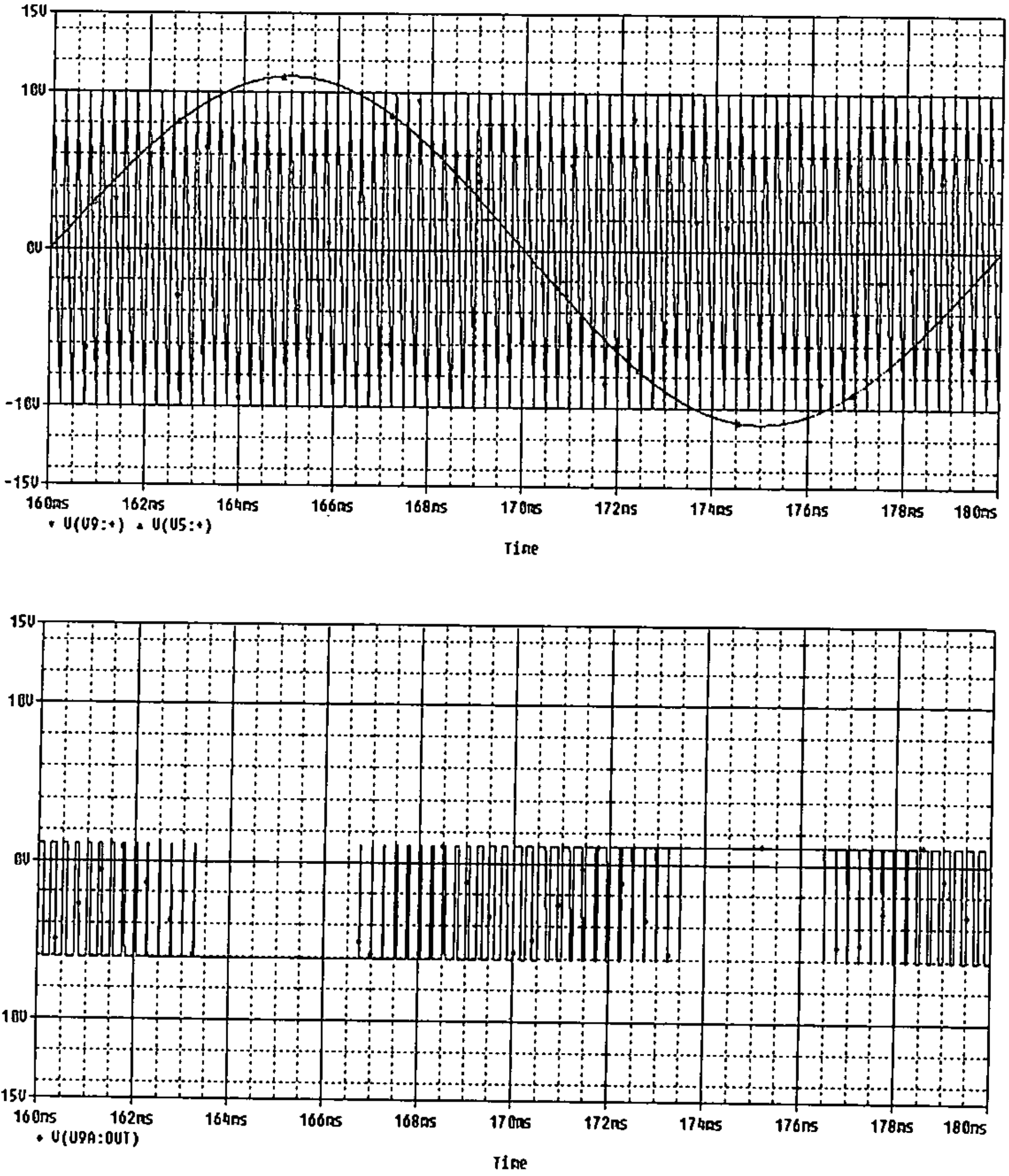


Figure. 3.27: Pulse width modulated signal for m=11

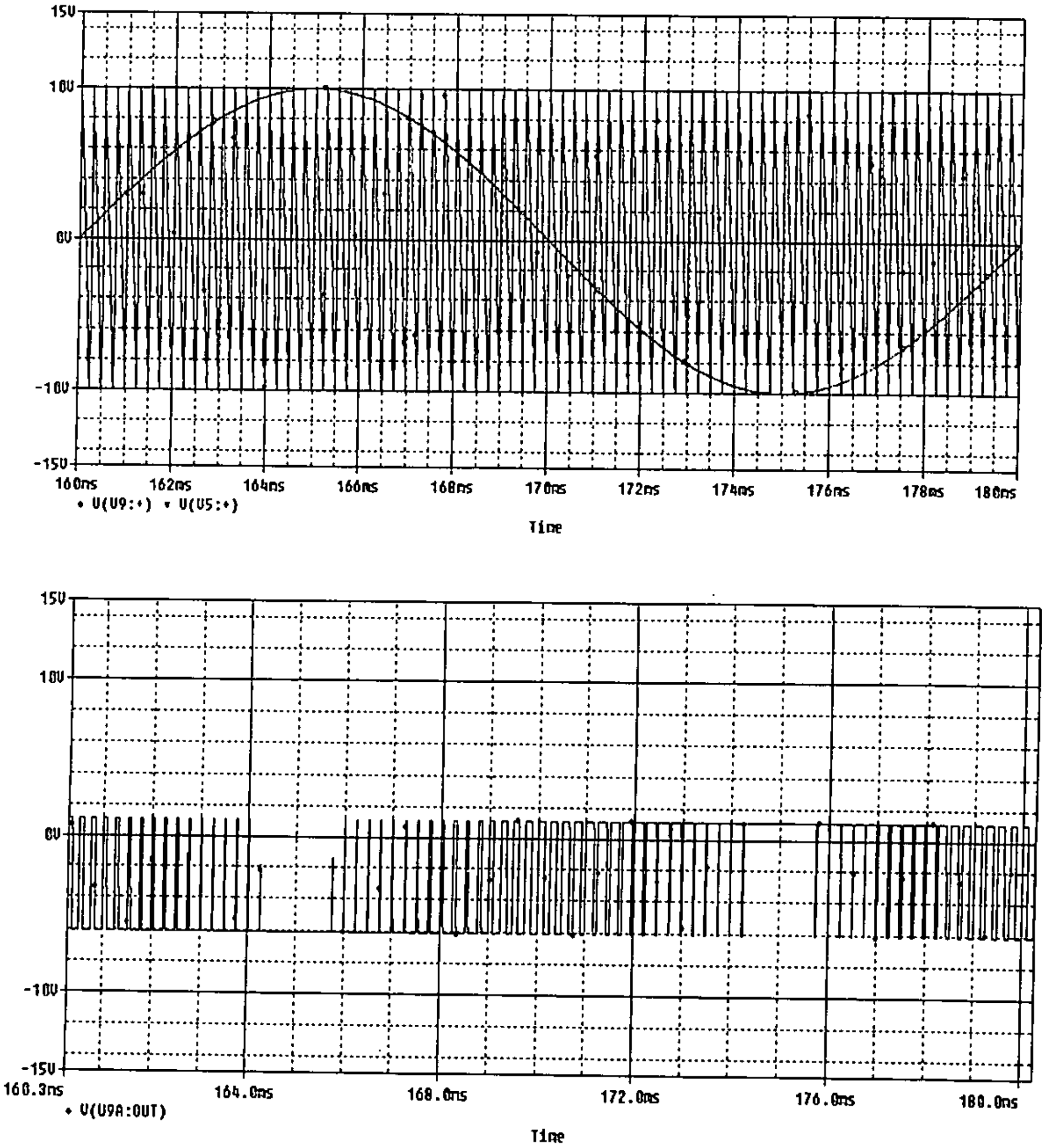


Figure. 3.28: Pulse width modulated signal for m=10

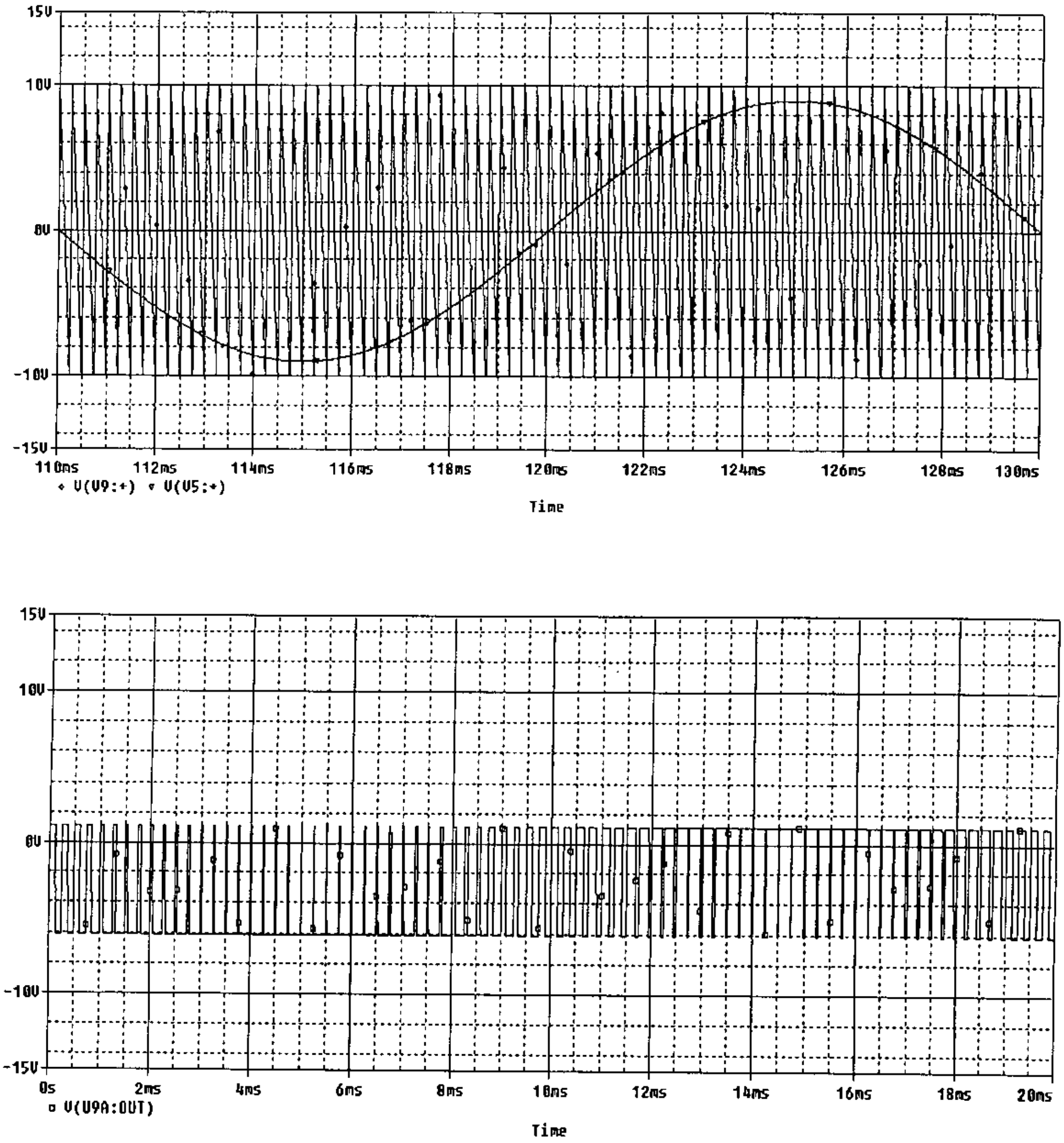


Figure. 3.29: Pulse width modulated signal for m=9

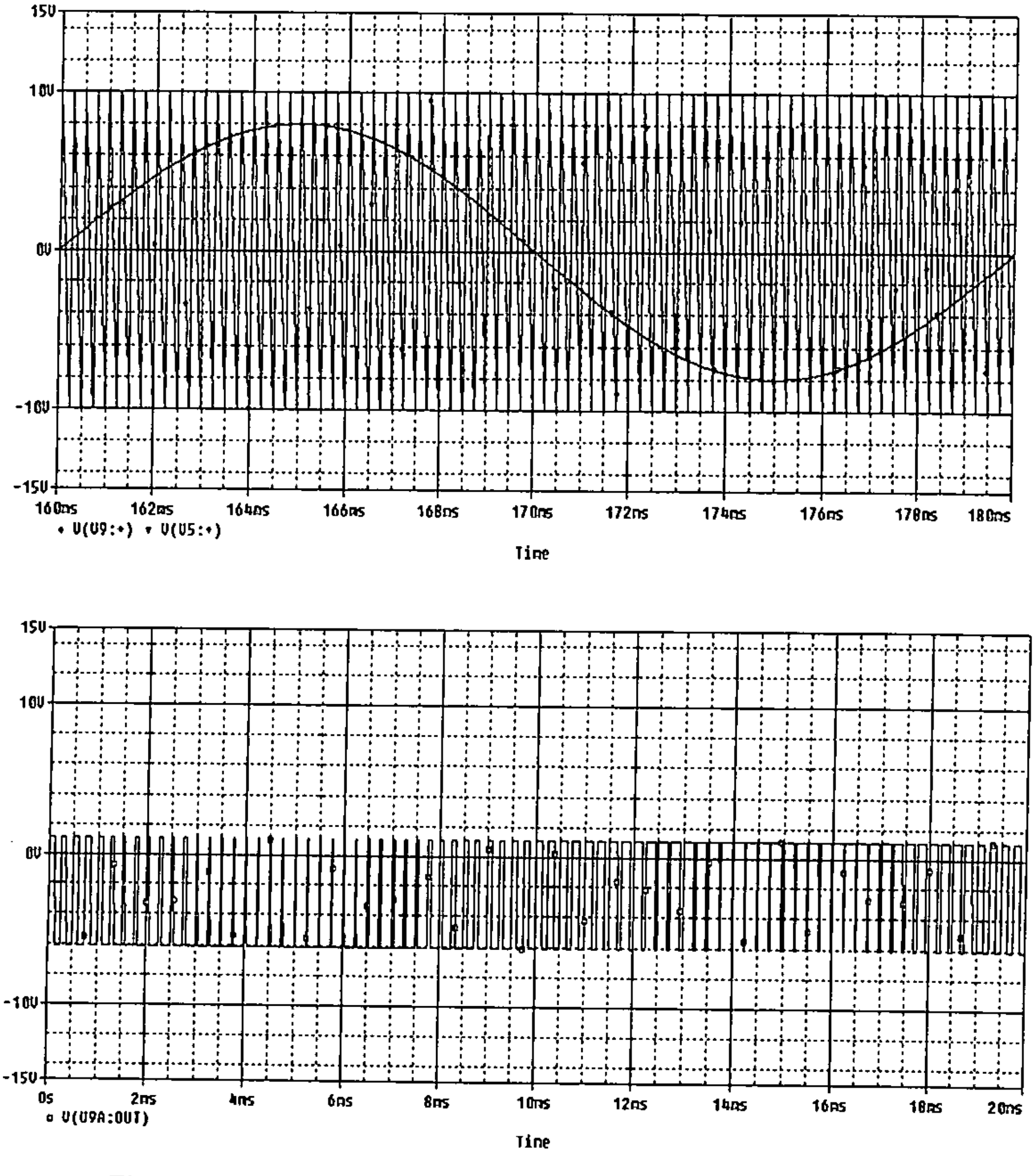


Figure. 3.30: Pulse width modulated signal for m=8

3.4.2.2.Variation by modulating frequency

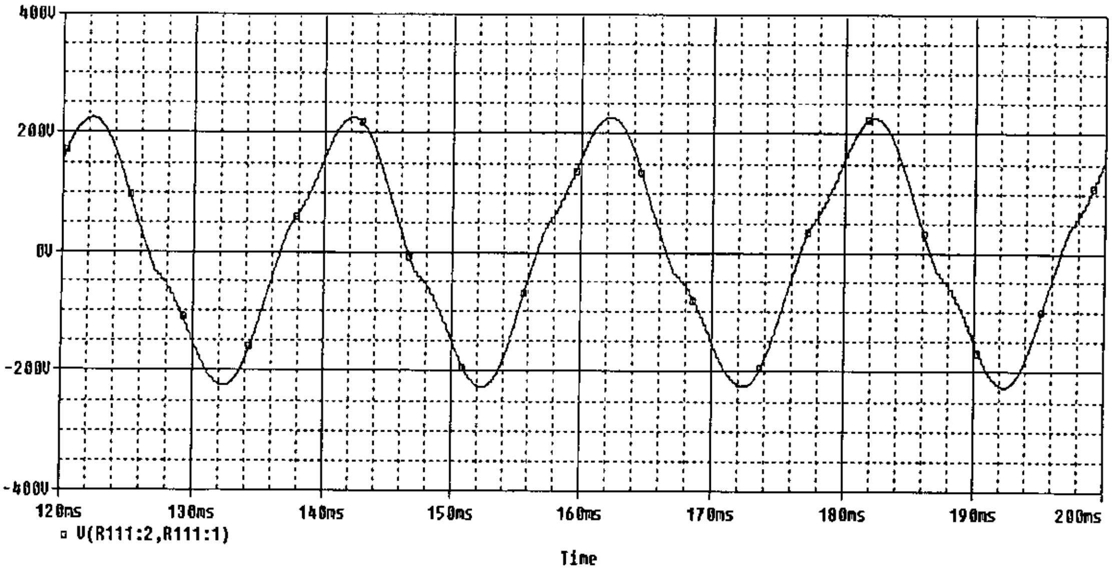


Figure. 3.31: Variation of output modulating frequency, f= 50 Hz

Here, T=(156.3-136.3)m=20m, f=1/20m=50Hz

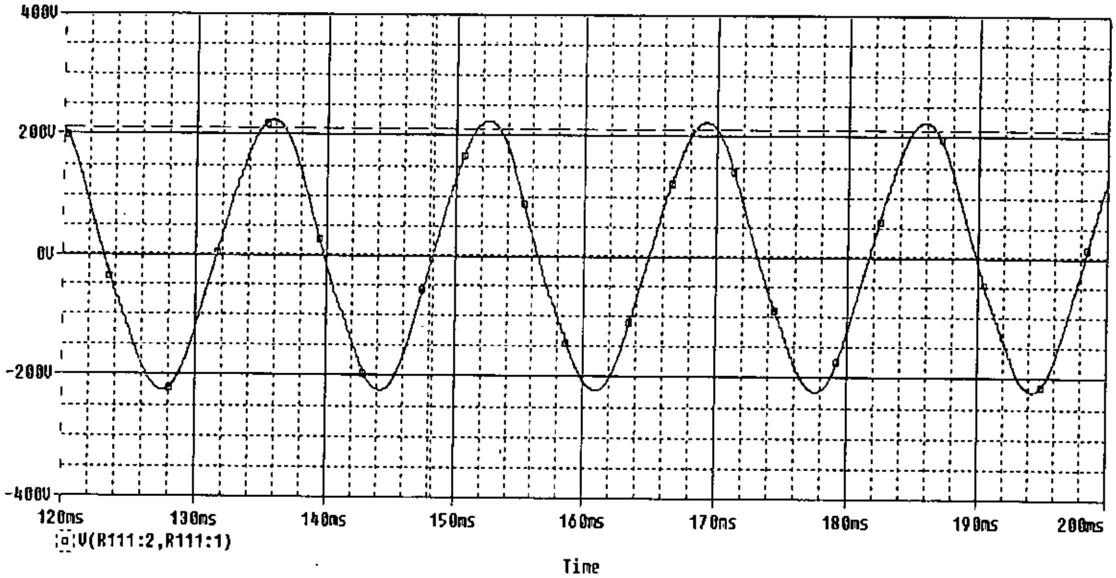


Figure. 3.32: Variation of output modulating frequency, f= 60 Hz

T=(148.273-131.623) m==16.65 m , f=1/T = 60.06Hz

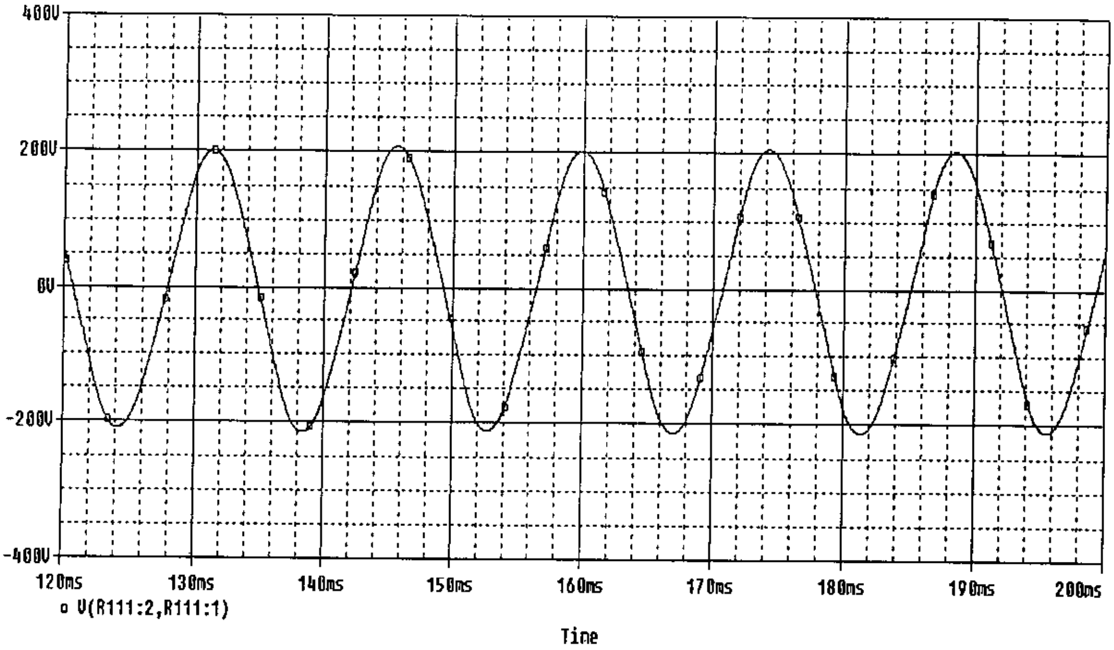


Figure. 3.33: Variation of output modulating frequency, f= 70 Hz

T=(156.2-142)m=14.2m, f=70.4 hz

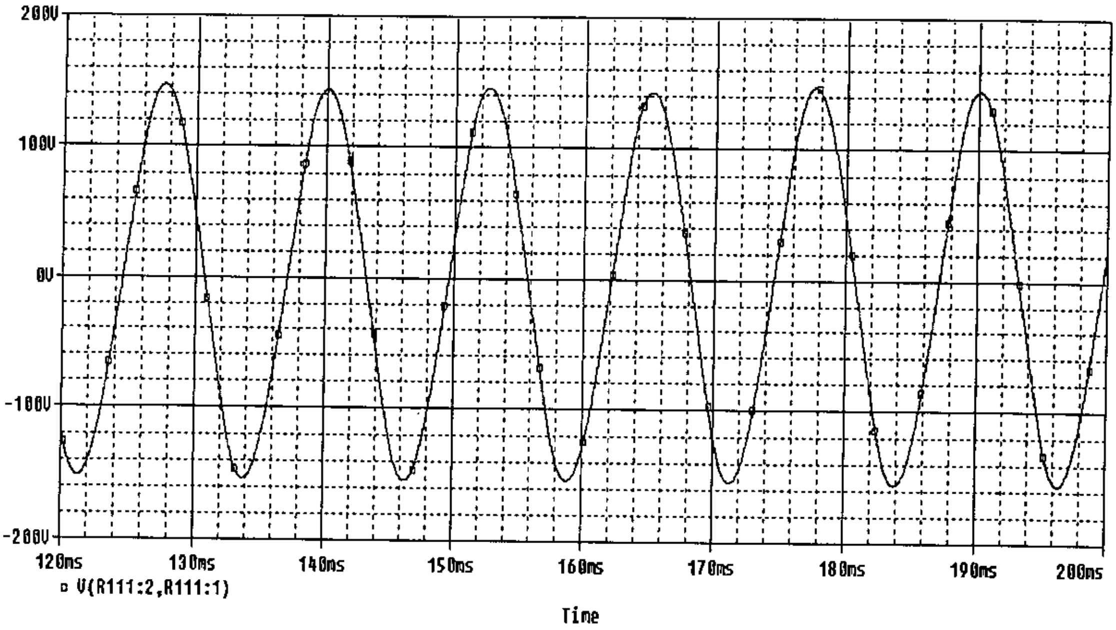


Figure. 3.34: Variation of output modulating frequency, f= 80 Hz

T= (187.09-174.55)m, f = 79.8h

3.4.2.3.Variation by Boost stage

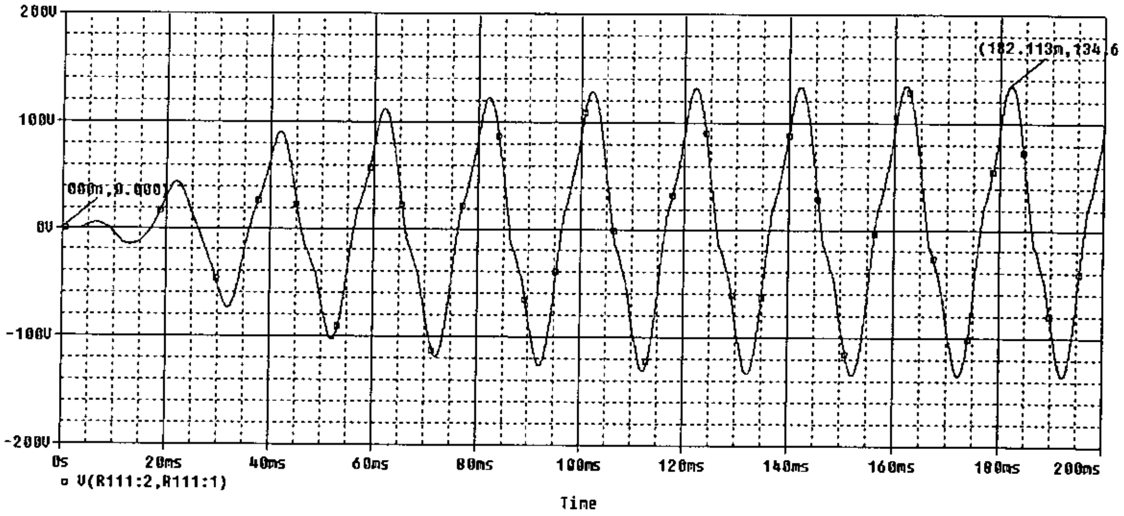


Figure. 3.35: Variation of output by Boost stage, duty cycle =0.95

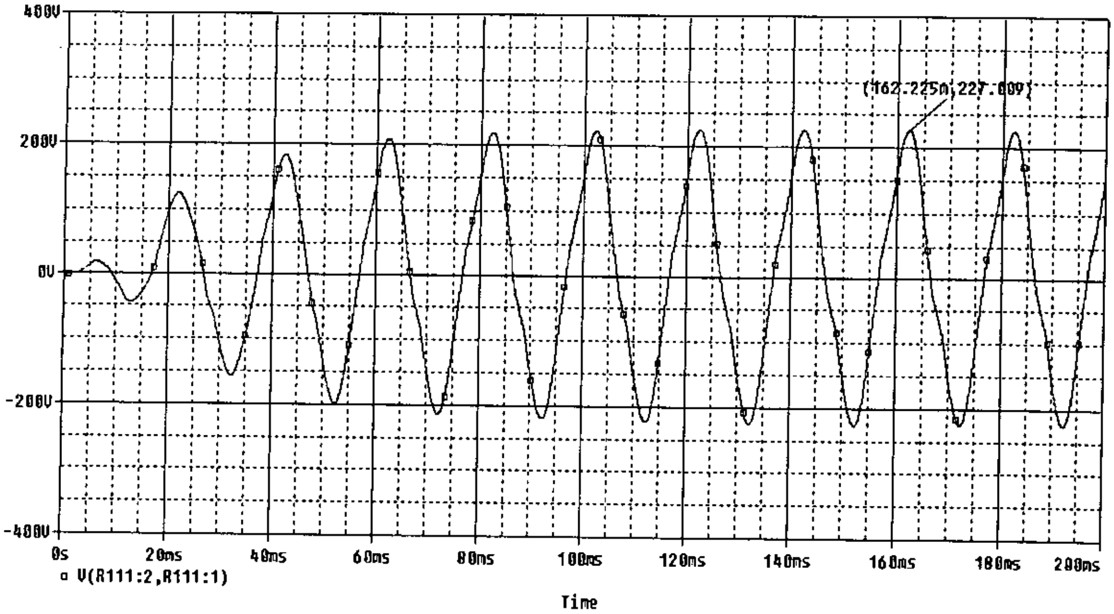


Figure. 3.36: Variation of output by Boost stage, duty cycle =0.85

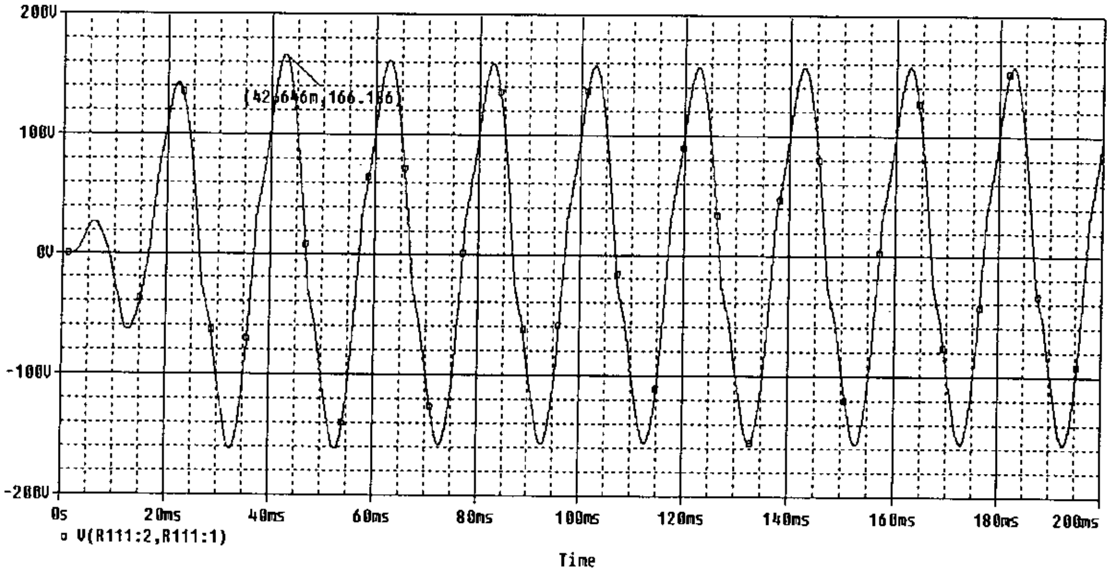


Figure. 3.37: Variation of output by Boost stage, duty cycle =0.75

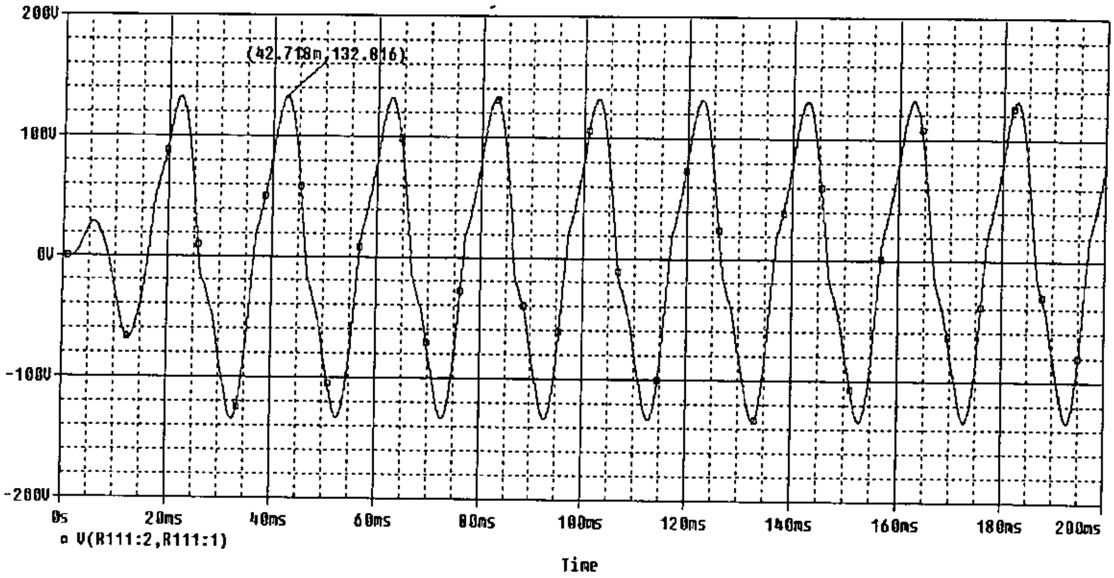


Figure. 3.38: Variation of output by Boost stage, duty cycle =0.65

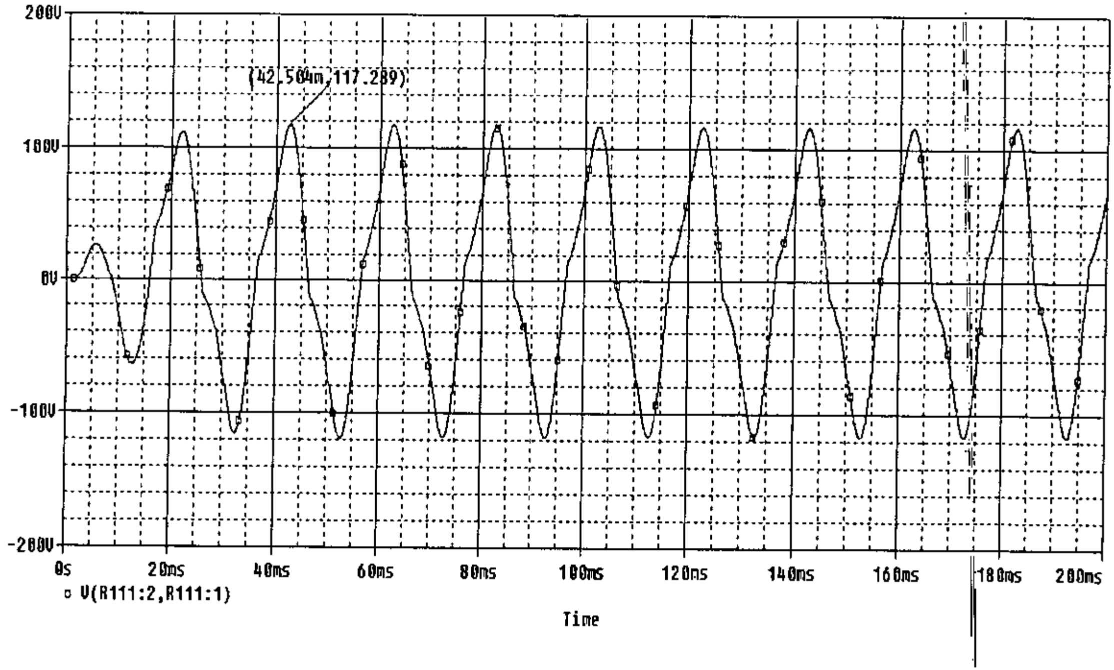


Figure. 3.39: Variation of output by Boost stage, duty cycle =0.55

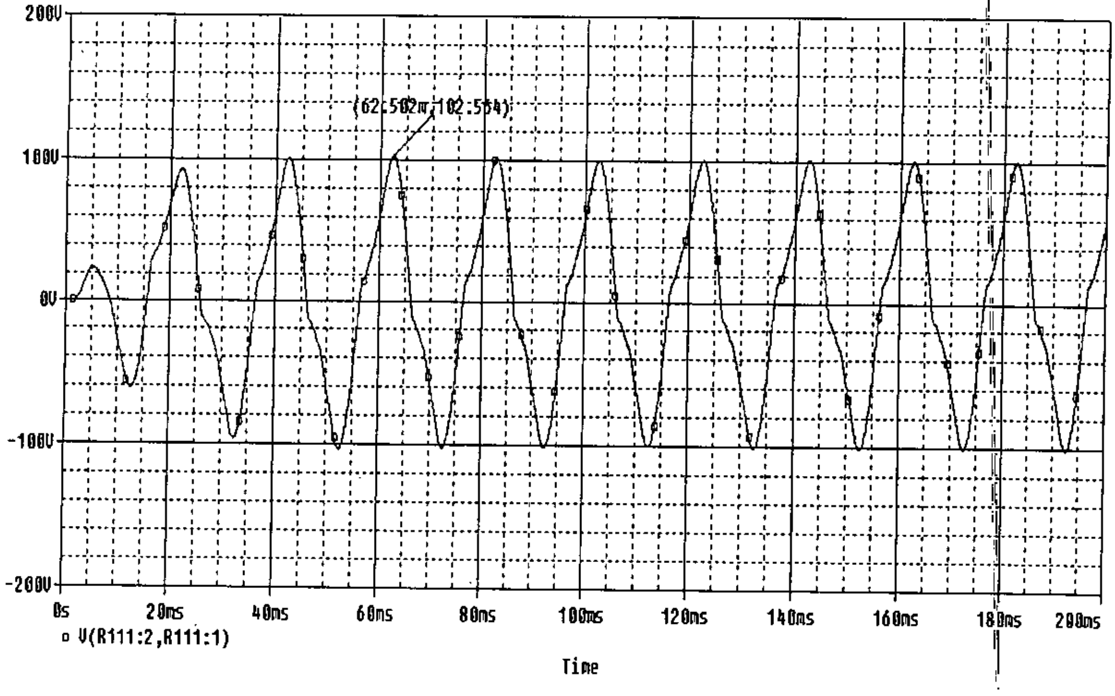


Figure. 3.40: Variation of output by Boost stage, duty cycle =0.45

Chapter 4

Conclusion

4.1. GENERAL

DC to AC power conversion is essential if the supply voltage is a battery or solar cell or a fuel cell. Use of inverter for the conversion is essential in power lines of all capacities. Our proposed circuit is an attempt to propose a new voltage source inverter (VSI) referred to as a boost inverter or boost dc–ac converter.

The main attribute of the new inverter topology is the fact that it generates an ac output voltage larger than the dc input one, depending on the instantaneous duty cycle. This property is not found in the classical VSI, which produces an ac output instantaneous voltage always lower than the dc input one. The DC and small-signal performance of a boost DC to AC converter is determined simply by substituting the circuit's models (point by point) by the PWM switch, and analyzing the resulting linear circuits.

Renewable energy can be cost effective right now in the right application. For cabins and homes the first step is to make sure that we have the most energy efficient appliances available. This will lower our cost of the renewable energy system and give a quicker payback. Efficient appliances would include fluorescent lighting (about 4 times as efficient as incandescent), efficient appliances such as a refrigerator/freezer and clothes washer, efficient water pump, and so on. The use of propane or natural gas appliances will also have to be considered for heating, cooking, air conditioning, and other high power consuming duties. Although, these could also be done with high efficiency wood burning appliances, solar heating, floor radiant heating, geothermal heat pump, or other renewable means.

Photovoltaic can power just about any electrical load. However, air conditioning and electric heating elements (cook stove, water heater or furnace) use large amounts of electricity which drives the system cost beyond the average homeowner's means.

For most residential and small offices, a 1 kilowatt to 3 kw system should add some real value. For smaller homes and limited roof space, a 250 or 600 watt system can be installed. A rough calculation is that 100 watts of AC peak power require 12 square feet of roof space - or 1 kw requires 120 square feet.

In our thesis, we found 228 Vac for modulation index=1.0, Sin_ampl =10, input frequency=50Hz and duty cycle= 0.85. The output power can be varied from 100 W to 480 W, depending on the load.

So, it may be concluded that the thesis work is successful to achieve the goal for running a small house by solar power.

4.2. FUTURE WORKS

Reviewing the proposal and contributions made in this thesis, we can suggest some future works to be done to achieve the same or related goals.

Research can be done

- on minimizing the time to achieve the desired sinusoidal vales.
- on minimizing the Capacitor current spikes in the inverter circuit.
- the boost – regulator can be minimized and circuit may more simple.
- the output power can be increased .
- the initial input current is very high (almost 10 A). So it can be minimized.

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Glossary

Alternating current (ac) — Electric current that regularly alternates direction. This kind of electricity is delivered from an inverter and used by buildings and homes.

Annual solar savings — The amount of energy saved by the power generated by a solar electric system.

Cell — A (solar) cell or photovoltaic cell is a device that converts light energy into electrical energy.

Cell efficiency — The percentage of electrical energy that a solar cell produces compared to the total amount of energy from the sun falling on the cell under standard testing conditions.

Current — The flow of electricity between two points. Measured in amps.

Direct current (dc) — Electrical current that flows only in one direction. This kind of electricity is generated by a solar system and is converted into AC power by the inverter. It is the most common form of electricity used in boats and RVs.

Efficiency — The ratio of output energy to input energy.

Electric circuit — The path followed by electricity, beginning from the generating source, continuing through the devices that use the electricity, and then traveling back to the source.

Electricity — The controlled flow of electrons through a conductor.

Energy — Usable power. It is measured in kilowatt-hours.

Energy audit — A process that determines how much energy you use in your home.

Grid — A distribution network, including towers, poles, and wires that a utility uses to deliver electricity.

Grid-connected PV system — A solar electric system that is tied in to the utility's network. When a solar system generates more power than a building needs at that time, solar power is lent to the utility grid and retrieved later when it is needed.

Inverter — A device that converts the electricity generated from a solar electric system from direct current (DC) to alternating current (AC) for use in the home.

Irradiance — The amount of solar energy that strikes a surface during a specific time period. Measured in kilowatts (kW).

Junction box — The point on a solar panel where it connects, or is strung, to other solar modules.

Kilowatt (kW) — A unit of electrical power, one thousand watts.

Kilowatt-hour (kWh) — A unit of electric energy, or one thousand watts acting over a period of one hour. The consumption of electrical energy by homes is typically measured in kilowatt-hours.

Load — Anything that is connected to an electrical circuit and draws power from that circuit.

Megawatt (mW) — One million watts, or one thousand kilowatts.

Module — Synonym for solar panel, or an assembly of solar cells used to generate electricity.

Monocrystalline solar cell — A solar cell made from a thin slice of a single large crystal of silicon.

Multicrystalline — A solar cell composed of many small crystals (crystallites). Because of the numerous grain boundaries, solar cells that employ this crystal structure will operate with lower efficiency than monocrystalline solar cells.

Panel — Synonym for solar module, or an assembly of solar cells used to generate electricity.

Passive solar home — A house that uses part of the building as a solar collector, in contrast to active solar generation as with a solar power system.

Peak load — This is the largest amount of electricity being used at any one point in time during the day.

Photovoltaic (PV) — This is the conversion of visible light into electricity. Photo means "light", voltaic means "electric."

Photovoltaic array — Synonym for a solar system. A solar array is an interconnected assembly of solar panels that functions as a single electricity-producing unit.

Photovoltaic cell — Synonym for solar cell; A solar cell or photovoltaic cell is a device that converts light energy into electrical energy.

Photovoltaic module — The layers of glass, plastic, and silicon cells framed in metal, which collect the sun's energy.

Semiconductor — A solid material such as silicon or germanium that has an electrical conductivity between that of a conductor and an insulator. Typical semiconductors for

PV cells include silicon, gallium arsenide, copper indium diselenide, and cadmium telluride.

Silicon (Si) — A chemical element that is the most common semiconductor material used in making PV cells.

Single-crystal silicon — Silicon material with a single crystal structure. A common material for the construction of solar PV cells.

Solar cell — A solar cell or photovoltaic cell is a device that converts light energy into electrical energy.

Solar energy — Energy from the sun.

Solar module — see photovoltaic module.

Solar panel — see photovoltaic module.

Solar power — Electricity generated from sunlight.

Voltage (or electric potential) — The electric force that causes electric current to flow (analogous to pressure which can cause a water current to flow in a pipe) measured in volts (V).

Watt (W) — The unit of electric power, which is the rate of energy production, or the amount of energy consumed at a point in time. One ampere of current flowing at a potential of one volt produces one watt of power.

Watt-hour (Wh) — A unit of energy equal to one watt of power being used for one hour.