Power Line Voltage Regulation by PWM AC Buck-Boost Voltage Controller

Palash Kumar Banerjee

DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGINEERING
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by

Palash Kumar Banerjee

A thesis submitted to the Department of Electrical and Electronic Engineering of Bangladesh University of Engineering and Technology (BUET) in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING

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Signature of the supervisor

....

(Dr. Mohammad Ali Choudhury)
Professor
Department of Electrical and Electronic Engineering
BUET, Dhaka-1000, Bangladesh.

Signature of the candidate

....

(Palash Kumar Banerjee)

Dedication

To my parents

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Abstract

High frequency switching power supplies have become a part of electronic equipments to provide regulated dc of desired voltages at a low cost and high efficiency. These power supplies have several advantages over their counterpart the linear power supplies. Main advantages are smaller compact size due to elimination of step down transformer and small filters due to high frequency operation. These power supplies have high efficiency because the regulating device(s) in them works as switches ensuring low device loss. Their output voltage can be controlled for a wide range of input voltage fluctuation by ON/OFF ratio (duty cycle) control.

Four common types of switch mode converters are used in dc to dc conversion. They are BUCK (step down), BOOST (step up), BUCK-BOOST (step up/down) and Cûk converters. At present these converters use high frequency multiple pulse switching to generate the controlling signal(s) of power devices.

Utility AC voltage fluctuation both momentary and prolonged, affects adversely the domestic, industrial and commercial customers. In this research, an electronic AC Buck –Boost regulator has been proposed for maintaining constant voltage across the output of the load during any change in load or input voltage variation. AC Buck-Boost regulator made of ideal switches and practical IGBT switches have been investigated. Control circuit is proposed for generating pulses (PWM) for maintaining constant output voltage. The PWM controls the ON/OFF time (Duty cycle) of switching devices (IGBTs) of the proposed regulator. By regulating duty cycle of the control signal, output voltage can be maintained almost constant for wide range of input voltage and load variation. Freewheeling path and surge voltage across switches create problem in the proposed regulator. Snubbers are used for suppressing surge voltage across switches. Input current of the proposed regulator is excessively high and needs to be reduced by further research to make the regulator technically viable. In this thesis input filter requirement is also calculated to determine the proper LC values so that the current ripple of input/output currents are within prescribed limit.

List of Abbreviation

EMI	=	Electromagnetic Interference.
SMPS	=	Switch Mode Power Supply.
BJT	=	Bipolar Junction Transistor.
MOSFET	=	Metal Oxide Semiconductor Field Effect Transistor.
IGBT	=	Insulated Gate Bipolar Transistor.
PWM	=	Pulse Width Modulation.
OPAMP	=	Operational Amplifier.
SCR	=	Silicon Controlled Rectifier.
GTO	=	Gate Turn OFF SCR

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CHAPTER – 1

INTRODUCTION

1.1 INTRODUCTION

Normal power lines experience voltage sags due to switching lines/loads and faults somewhere in the system. Short time voltage sags may also occur because of nearby momentary aperiodic loads like welding and operation of building construction equipment. Voltage sags are much more common since they can be associated with faults remote from the customer. In Bangladesh continuous voltage sags are also prevalent in many areas due to inadequate supply and demand situation. Both momentary and continuous voltage sags are undesirable in complex process controls and household appliances as they use precision electronic and computerized control. Major problems associated with the unregulated long term voltage sags include equipment failure, overheating and complete shutdown. Tap changing transformers with SCR switching are usually used as a solution to continuous voltage sags [1]. They require large transformer with many SCRs to control the voltage at the load which lacks the facility of adjusting to momentary changes. Some solutions have been suggested in the past to encounter problems of voltage sag [2,3,4]. But the proposals have not been transferred to practical developments to replace the tap changing transformers. Advances in power semiconductor devices are making it possible for utilities to use a variety of power control equipment to raise power quality levels to meet the requirements [3]. Manual and auto ac voltage regulators are also used for low, medium and high power applications in domestic, commercial and industrial use. The area of power line conditioning for sensitive loads is important in power electronics. A wide class of equipment is available including transient suppressors, line voltage regulators, standby power supplies as well as off-line and online uninterruptible power supplies. Given the proliferation of personal computer loads, the need for economical power conditioners is growing rapidly. The use of isolation is not vitally important in many applications, as the input power supply normally contains a high frequency transformer. However, most techniques presently used incorporate a low frequency transformer to realize the Buck-Boost function needed for ac line voltage regulation [7]

1.2 REVIEW OF SWITCH MODE DC- DC CONVERTER

A switch mode DC-DC power supply (SMPS) is switched at very high frequency. Conversion of both step down and step up dc with insignificant filter size having facility of feed back regulation by ON/OFF high frequency switching is possible in an SMPS. Usually SMPSs are used in dc-dc conversion for their light weight, high efficiency and isolated multiple outputs with and without voltage regulation. Uses of SMPSs are now universal in space power applications, computers, TV and industrial units. SMPSs have advantages of being low cost, compact, self regulating and self protected. Diverse types of SMPS are investigated to meet user requirements and research is still continuing to find newer ways of switching, increase in switching frequencies, modified topologies and enhanced performance of filters to reduce ripples and EMI.

A simple DC-DC SMPS consists of a rectifier fed directly from line voltage, a filter and a static switch (BJT, MOSFET, IGBT etc). The SMPS is switched by control circuitry at a very high frequency to step down or step up dc voltage by ON/OFF ratio (duty cycle) control. The filter and the feedback circuit are the other components of a DC-DC SMPS. Fig.-1 shows the block diagram of a DC-DC SMPS.

Main components of a dc-dc SMPS are:

1. Power circuit
2. Control circuit
3. Magnetic circuit.

The control circuit of an SMPS basically generates high frequency gating pulses for the switching device to control the dc. Switching is performed in multiple pulse width modulation (PWM) fashion according to feedback error signal from the load to serve two purposes,

a) Produce high frequency switching signal

b) Control ON / OFF period of switching signal to maintain constant voltage across load.

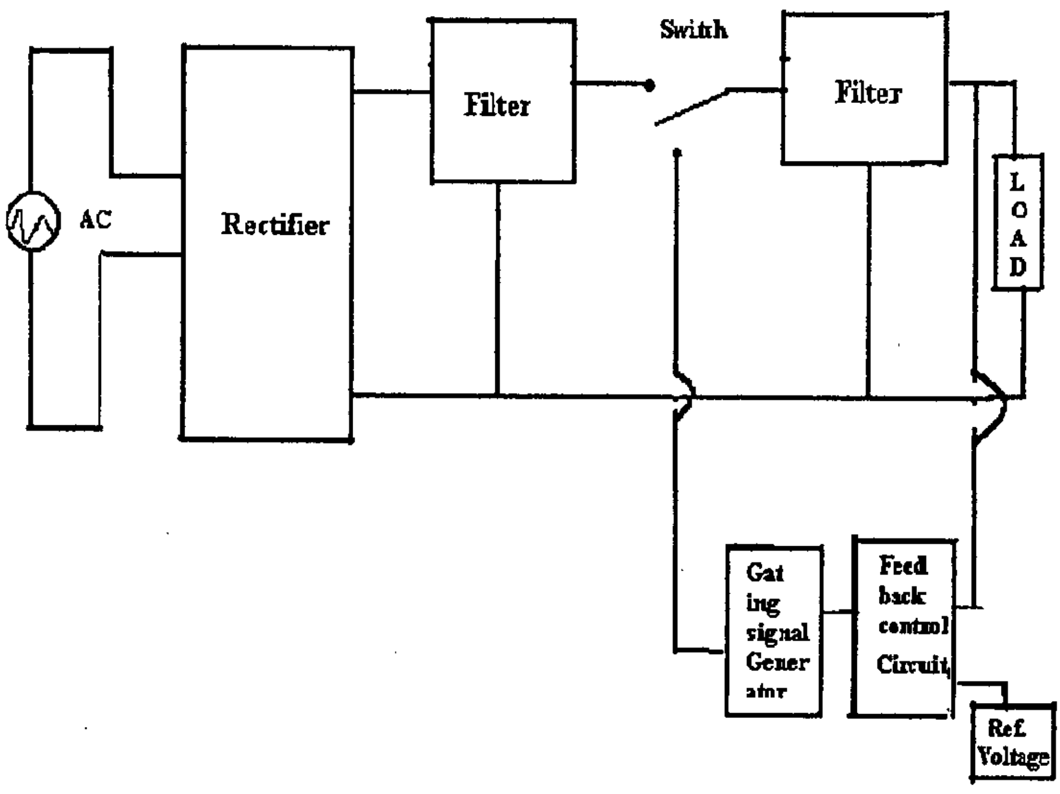


Fig 1: Block diagram of an SMPS

High frequency switching reduces filter requirements at the INPUT/OUTPUT sides of the converter. Simplest pwm control uses multiple pulse modulations generated by comparing a dc with a high frequency carrier triangular wave.

1.2.1 PRINCIPLE OF OPERATION [9]

Fig.-2 illustrates the circuit of a classical linear power conversion. Here power is controlled by a series linear element; either a resister or a transistor is used in the linear mode. The total load current passes through the series linear element. In this circuit greater the difference between the input and the output voltage, more is the power lost in the controlling device. Linear power conversion is dissipative and hence is inefficient. The efficiency range is typically 30 to 60% for linear regulators.

The circuit of Fig.-3 illustrates basic principle of a dc-dc switch mode power conversion. The controlling device is a switch. By controlling the ratio of the time intervals spent in ON and OFF positions (defined as duty ratio), the power flow to the load can be controlled in a very efficient way. Ideally this method is 100% efficient. In practice, the efficiency is reduced as the switch is non-ideal and losses occur in power circuits.

The semiconductor devices can be used as a switch in an efficient way. The dc load to the voltage can be controlled by controlling the duty cycle of the rectangular waveform supplied to the base or gate of the switching device. When the switch is fully ON, it has only a small saturation voltage drop across it. In the OFF condition the current through the device is zero.

The output of the switch mode power conversion control (Fig.-3) is not pure dc. This type of output is applicable in some cases such as oven heating without proper filtration. If constant dc is required, then output of SMPS has to be smoothed out by the addition of a low-pass LC filter. Switches are required as basic components for efficient electric power conversion and control. Ideally lossless storage components, inductors and capacitors are required to generate dc output voltage. Inductors and capacitors are used to smooth the pulsating dc originating from the switching action.

Although the conversion would be 100% efficient in the ideal case of lossless components (Fig.-4), in practice all components are lossy. Thus, efficiency is reduced.

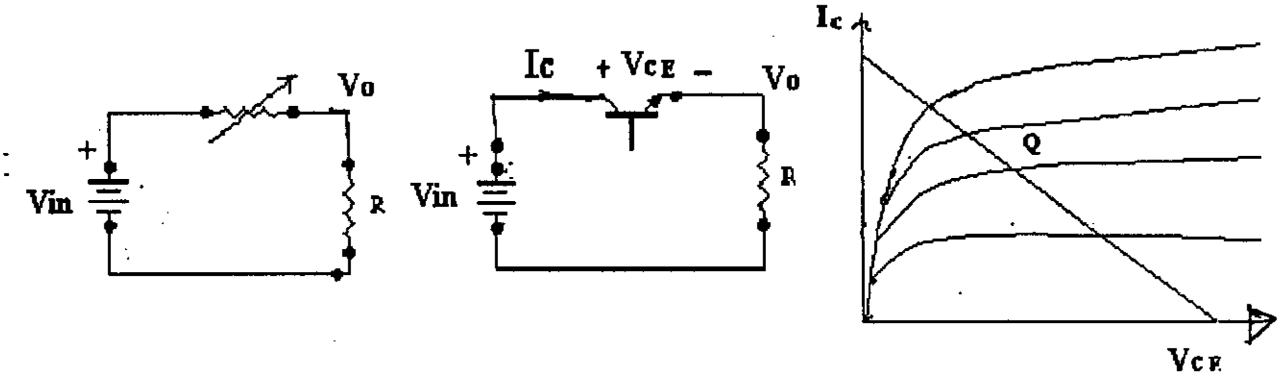


Fig:2 Linear (dissipative) power conversion circuit.

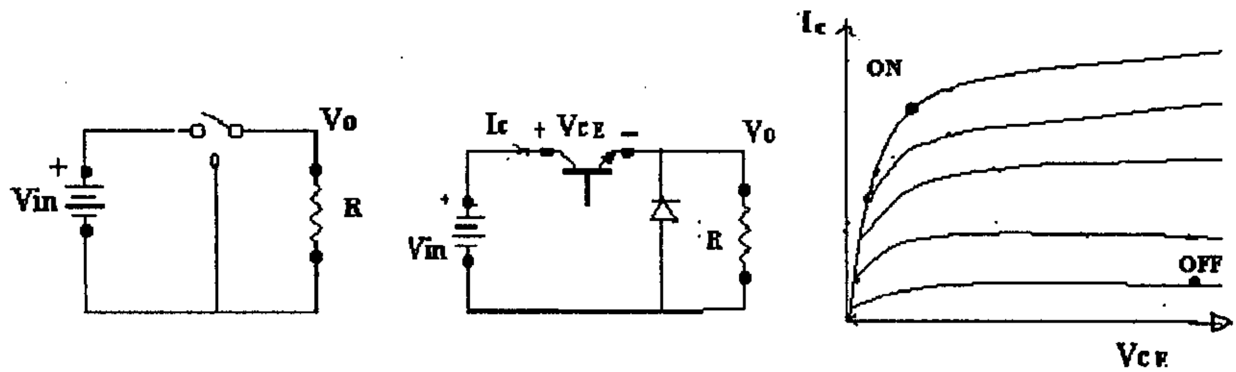


Fig:3 Switchmode (nondissipative) power conversion circuit

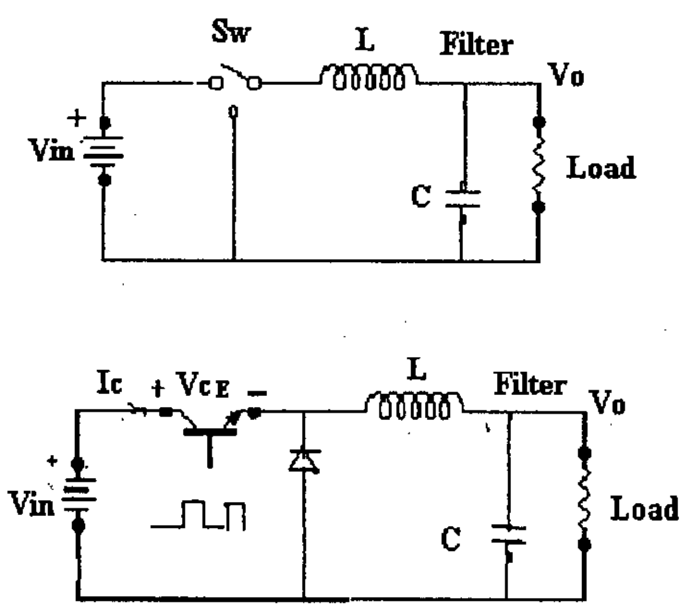


Fig:4 Typical Switchmode power conversion.

Hence, one of the prime objectives in switch mode power conversion is to realize conversion with the least number of components having better efficiency and reliability.

1.2.2 TYPES OF DC-DC CONVERTERS

The simplest dc-to-dc SMPS converter topology consists of a single switch (single-pole double throw ideal switch S in Fig.-5), a single inductor and a single capacitor.

By different arrangement of these components, four types of converter have been developed in the past [9, 10, 14, 15], these are,

a. Buck (step down) converter,
b. Boost (step up) converter,
c. Buck-Boost converter and
d. Cûk converter.

1.2.2.1 BUCK CONVERTER [9, 10]

The simplest configuration of Buck converter is shown in Fig.-6. The input dc voltage V_{in} is chopped by the switch S. Hence, this converter is also called as the **Chopper**. Due to the chopping, an intermediate pulsed waveform V_1 is produced. This voltage V_1 is filtered by a low-pass filter.

When the switch is ON ($t = T_{oN}$) input current rises through filter inductor L, capacitor C and load resistor R. As the switch is turned OFF ($t = T_{off}$) the freewheeling diode D_m conducts due to energy stored in the inductor and the inductor current continues to flow through L, C, load and diode D_m. The inductor current falls until the switch is again turned ON in the next cycle. The ideal voltage gain and current gain relationship of this converter are given by [9],

$$\frac{V_o}{V_{in}} = D \qquad \dots \qquad \dots \qquad \dots \qquad (1)$$

$$\frac{I_0}{I_{in}} = \frac{1}{D} \qquad \dots \qquad \dots \qquad \dots \qquad (2)$$

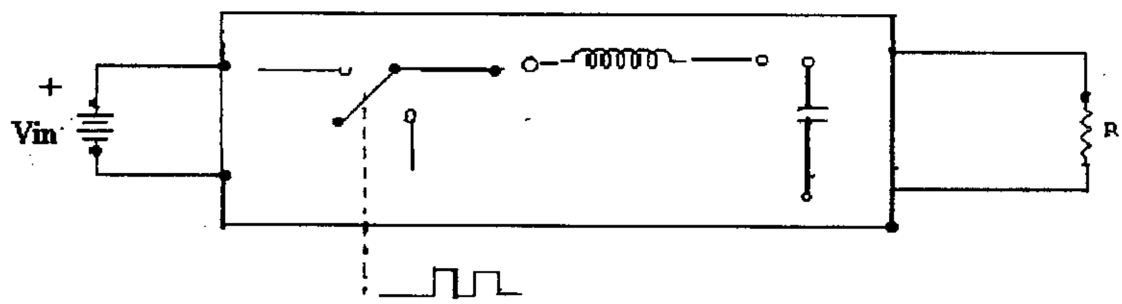


Fig: 5 Simple generalized dc-to-dc converter topology (buck,boost and buck-boost can be realized by rearrangemant of components).

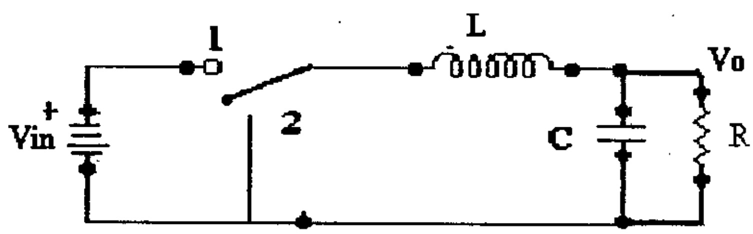


Fig6(a): Buck conversion by SPDT switch

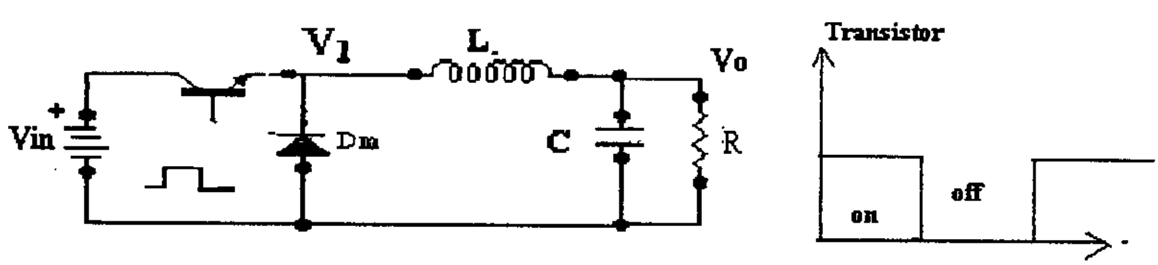


Fig 6(b): SPDT switch realization by a BJT and a diode.

Fig 6: Basic Buck SMPS for DC-DC conversion.

Where, D is the duty cycle of the switching waveform of the SMPS. The efficiency of the converter is ideally 100% if the switch and other components are thought to be lossless. In the real world the voltage gain, current gain and efficiency of buck converter deviates from ideal one due to lossy components, switching and conduction losses of switch and voltage drop across the switch. The voltage gain and current gain relationship may also be different from the one shown in equs. (1) and (2) for discontinuous conduction mode of the inductor current and switching and conduction losses of the switch as well as stray resistances of magnetic circuits and capacitors used in the circuit. Above observations will be valid for the other three topologies of DC-DC SMPS.

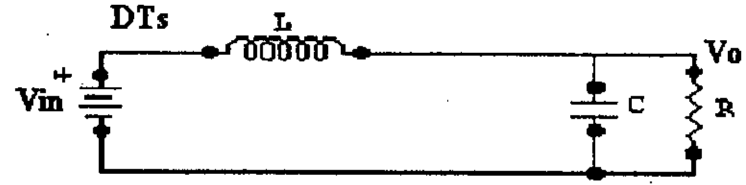
1.2.2.2 SEMICONDUCTOR IMPLEMENTATION OF THE SWITCHING ACTION [9]

To fully gain electronic control of the converter, a semiconductor implementation of the single pole, double- throw switch is desired. Implementation using a diode and a bipolar transistor is shown in Fig.6 (b). The diode works in synchronism with the transistor, which is the only controlled device. When the transistor is turned ON, the input dc voltage reverse biases the diode and turns the diode OFF for the interval DT_s.. When the transistor turns OFF, the inductor voltage reversal forward biases the diode and turns it ON. This semiconductor implementation simulates the original ideal switch only in a limited fashion. Equivalent circuits of the buck SMPS are shown in Fig.-7 for switch ON and OFF position respectively. The buck converter pulsating input current often requires an input filter to smooth out large current variations. Hence the buck converter of Fig.- 8 has an input capacitance to reduce current ripple .

1.2.2.3 BOOST CONVERTER [9, 10,]

An interchange of the source and load of the BUCK converter generates a boost converter from the buck converter as shown in Fig.-9. Operation of boost converter can be explained with the help of Fig.-10. When the switch is ON ($t = T_{on}$) the input current rises through filter inductor L and the switch. When the switch is OFF ($t = T_{off}$) the current that was flowing through the switch would now flow through L,C, load and diode D_m. The inductor current falls until the switch is again turned ON in the next cycle.

at t=Ton



at t=Toff

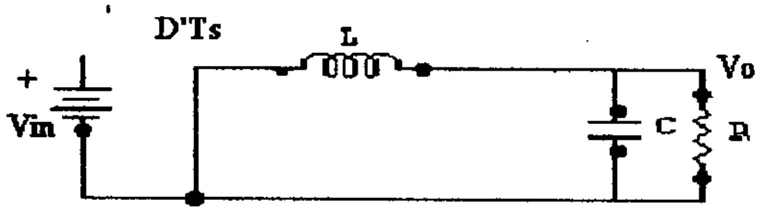


Fig 7: Equivalent circuit of Buck SMPS for ON and OFF time of the switch.

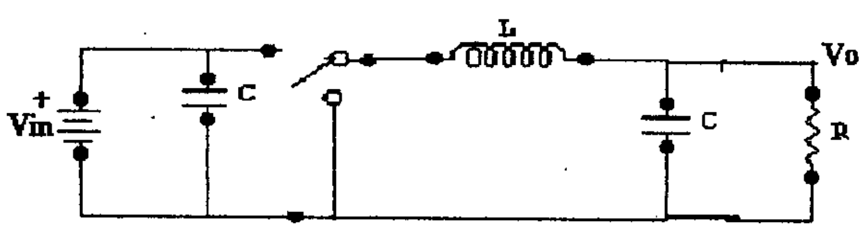


Fig 8: Buck SMPS with input current filter

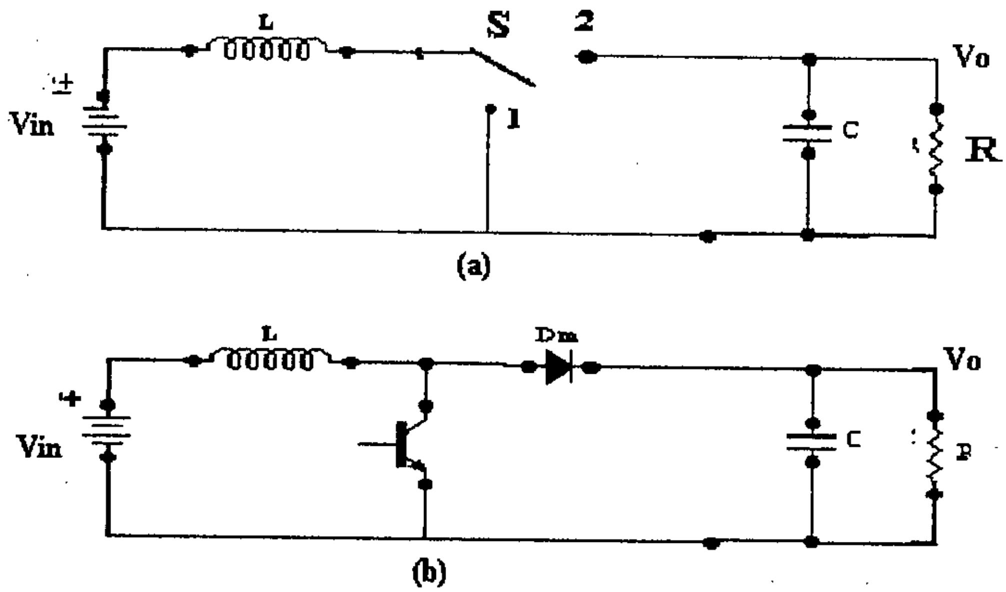


Fig 9: Boost switch mode DC-DC converter
a) Circuit with an SPDT switch .
b) Circuit with BJT and diode realizing the SPDT switch.

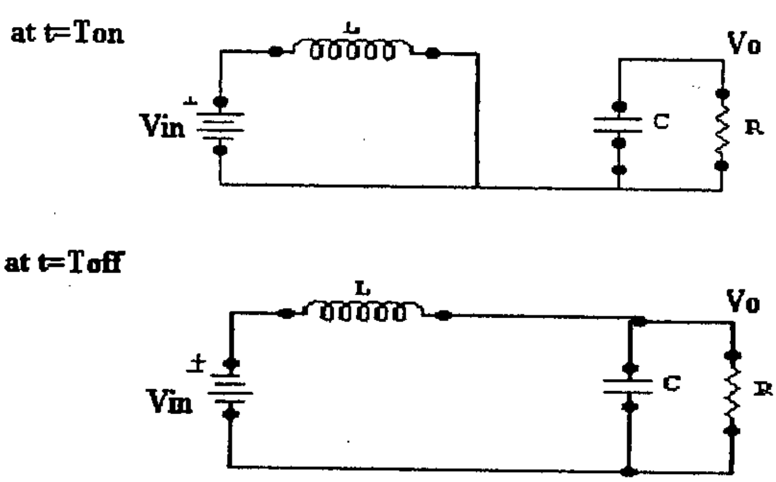


Fig 10: Equivalent circuits of Boost converter for ON and OFF time of the switch.

The dc voltage and current gains of the boost configuration, due to the nature of the source and load interchange are given by [9]

$$\frac{V_0}{V_{in}} = \frac{1}{1-D} \qquad \ldots \quad \ldots \quad \ldots \qquad (3)$$

$$\frac{I_0}{I_{in}} = 1-D \qquad \ldots \quad \ldots \quad \ldots \qquad (4)$$

In the practical implementation of boost converter as shown in Fig.-10, the input capacitance is also omitted as non essential for basic operation of the converter. The conversion is realized by the least number of components: a single switch, an inductor and a capacitor. Equivalent circuits of a Boost SMPS are shown in Fig.-10.

1.2.2.4 **BUCK- BOOST CONVERTER** [9, 10]

Buck converters can step-down and boost converters can step-up dc voltages individually. The Buck-Boost converter in which the inductor is grounded can perform either of these two conversions. The output voltage polarity is opposite to input voltage and as a result the converter is also known as an *inverting* converter.

Operation of the Buck-Boost converter can be explained with the help of Fig.-11. When the switch is turned ON, the diode D_m is reversed biased. The input current rises through inductor L and the switch. When the switch is turned OFF ($t = T_{off}$) the current which was flowing through inductor L would flow through L, C, D_m and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until the switch is again turned ON in the next cycle.

The voltage and current gains of the Buck Boost SMPS are given by,

$$\frac{V_0}{V_{in}} = -\frac{D}{(1-D)} \qquad \ldots \quad \ldots \quad \ldots \qquad (5)$$

$$\frac{I_0}{I_{in}} = -\frac{(1-D)}{D} \qquad \ldots \quad \ldots \quad \ldots \qquad (6)$$

Thus either a step-up ($D > 0.5$) or a step-down ($D < 0.5$) conversion can be achieved with the same converter. For D = 1. 0, the gain becomes infinite, but practically a finite voltage gain results due to the inclusion of inductor's parasitic resistance, switching losses and voltage drops across the switch /diode.

Equivalent circuits of a BUCK-BOOST converter are shown in Fig.-12.

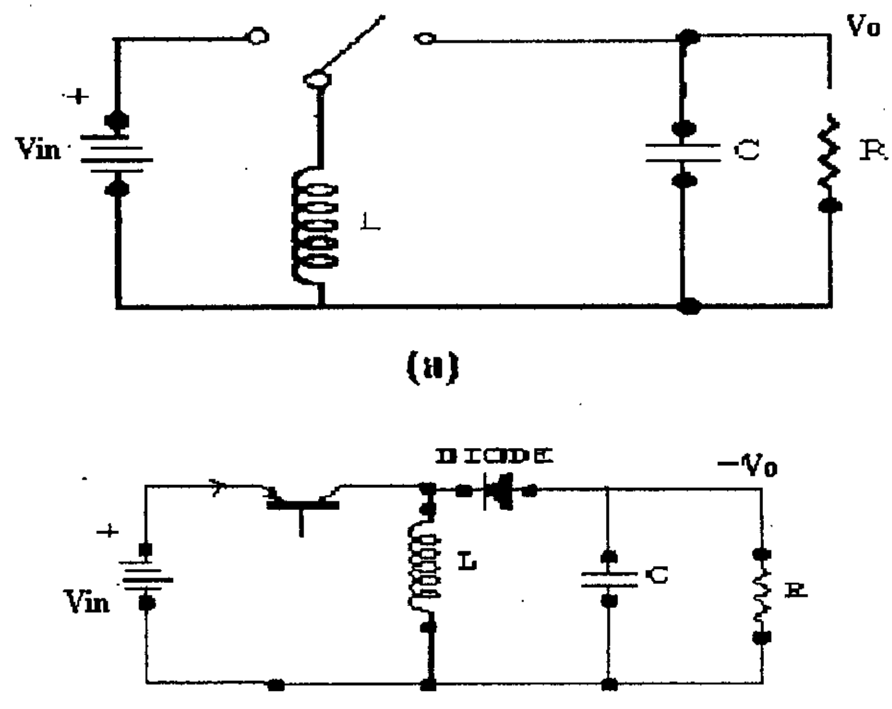


Fig 11: Buck-Boost circuit

a) circuit with an SPDT switch .

b) circuit realization with a BJT and a diode.

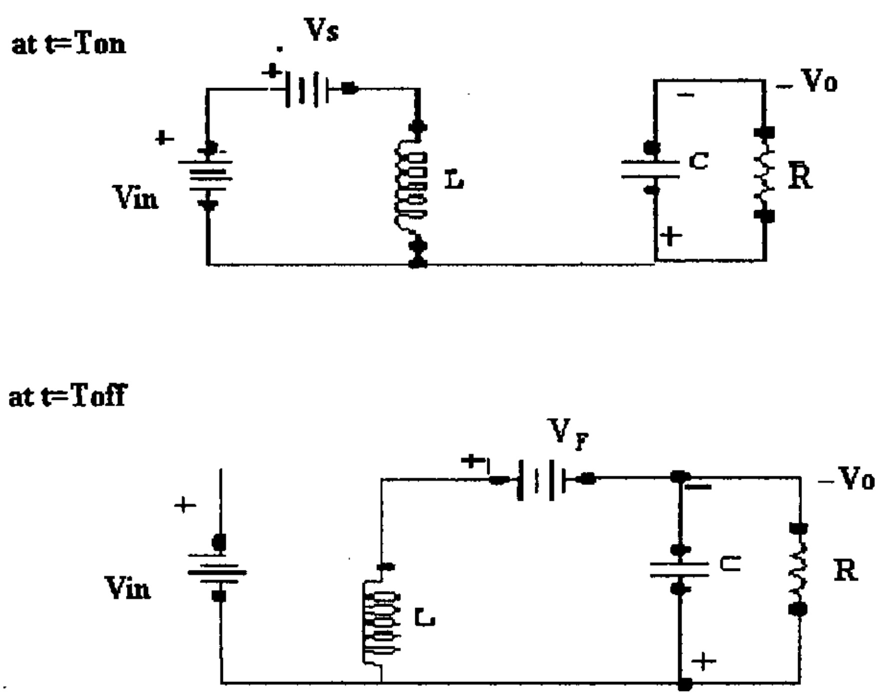


Fig 12: Equivalent circuit of a Buck-Boost converter for switch ON and OFF position.

1.2.2.5 CÛK CONVERTER [9,10]

CÛK converter provides an output voltage which is less than or greater than the input voltage and the output voltage polarity is opposite to that of the input voltage. TheCÛK converter is based on capacitive energy transfer. Dc voltage gain of CÛK converter is given by,

$$\frac{V_0}{Vin} = -\frac{D}{(1-D)} \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

and current gain is given by,

$$\frac{I_0}{I_{in}} = -\frac{(1-D)}{D} \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

Fig.-13 shows the CÛK converter with an SPDT and BJT / Diode as switch. When the switch is turned ON ($t = T_{on}$) current rises through inductor L_1. At the same time voltage of capacitor C_1 reverse biases diode D_m and turns it OFF. Capacitor C_1 discharges to the circuit formed by C_1, C_2, load and L_2. When the switch is turned OFF ($t = T_{off}$) the capacitor C1 is charged from the input supply and the energy stored in the inductor L_2 is transferred to the load. The diode D_m and the switch provides a synchronous switching action. The capacitor C_1 is the medium for transferring energy from the source to the load. The equivalent circuits of a CÛK converter switch ON and OFF period are shown in Fig.-14.

1.2.3 ADVANTAGES OF AN SMPS [9, 10]

Switch mode power supplies have following advantageous features:

* Isolation between the source and the load
* High power density for reduction of size and weight
* Controlled direction of power flow
* High conversion efficiency
* Input and output waveforms with low total harmonic distortion for small filters
* Controlled power factor if the source is an ac voltage

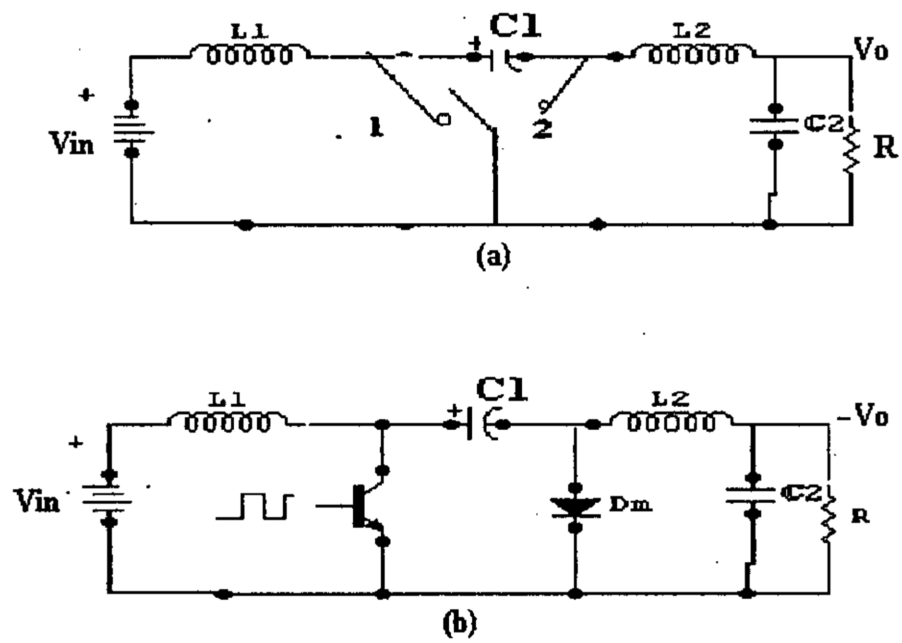


Fig 13: CÛK converter circuit diagram.
a) SPDT as a switch.
b) BJT and diode as a switch.

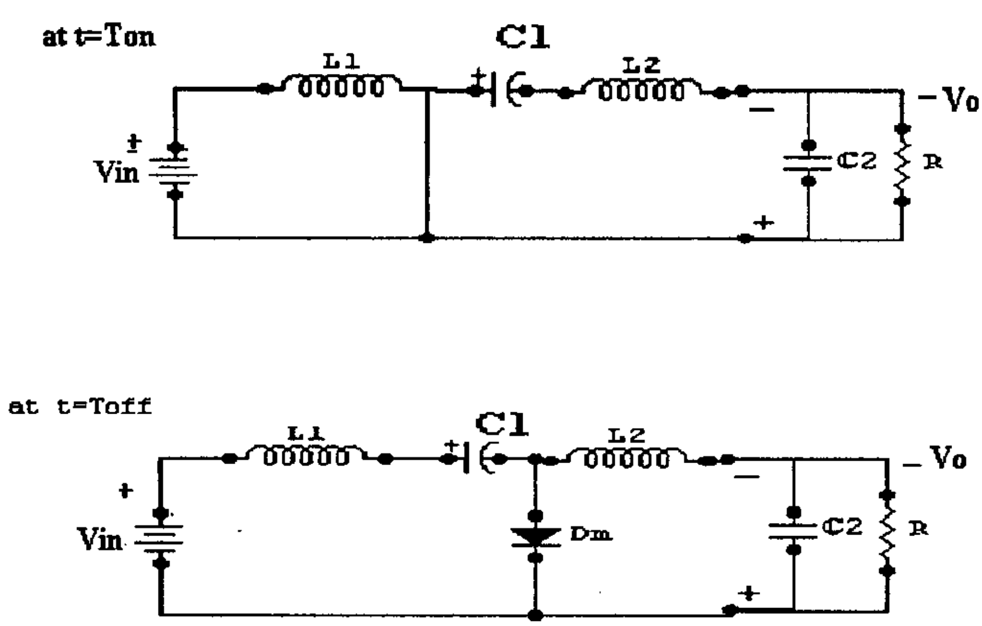


Fig 14: Equivalent circuit of the CÛK converter when the switch is ON and OFF.

1.3 REVIEW OF PWM TECHNIQUES AS USED IN POWER CONVERTERS

In many industrial applications, it is often required to control the output voltage of the converter. The most efficient method of controlling the gain (and output voltage) is to incorporate pulse-width-modulation (pwm) control. Some commonly used techniques are:[10]

1) Single-pulse-width modulation,
2) Multiple pulse-width-modulation,
3) Sinusoidal pulse-width-modulation,
4) Optimized pulse-width-modulation ,
5) Delta pulse-width-modulation,
6) Trapezoidal pulse-width-modulation,
7) Current controlled pulse width modulation,
8) Space vector pulse width modulation and
9) Selected harmonic injected pulse width modulation.

In SMPS control usually the multiple pulse width modulation technique is used.

1.3.1 MULTIPLE-PULSE-WIDTH-MODULATION [10]

In multiple-pulse-width modulation for DC-DC SMPS control pulses are generated comparing a reference signal Ar with a triangular carrier as shown in Fig.-15. In dc to ac conversion same technique may be modified with square wave as reference and triangular wave as carrier.

1.4 REVIEW OF AC VOLTAGE REGULATORS [25, 26]

The AC voltage regulator is a device by which the voltage can be set to a desired value and can be maintained constant all the time. This subject is vast and the field of application extends from very large power systems to small electronic apparatus. Naturally, the types of regulators are also numerous. The design of the regulator system depends mainly on the power requirements and degree of stability.

The voltage regulator may be

(a) Manually controlled or

(b) Automatically controlled.

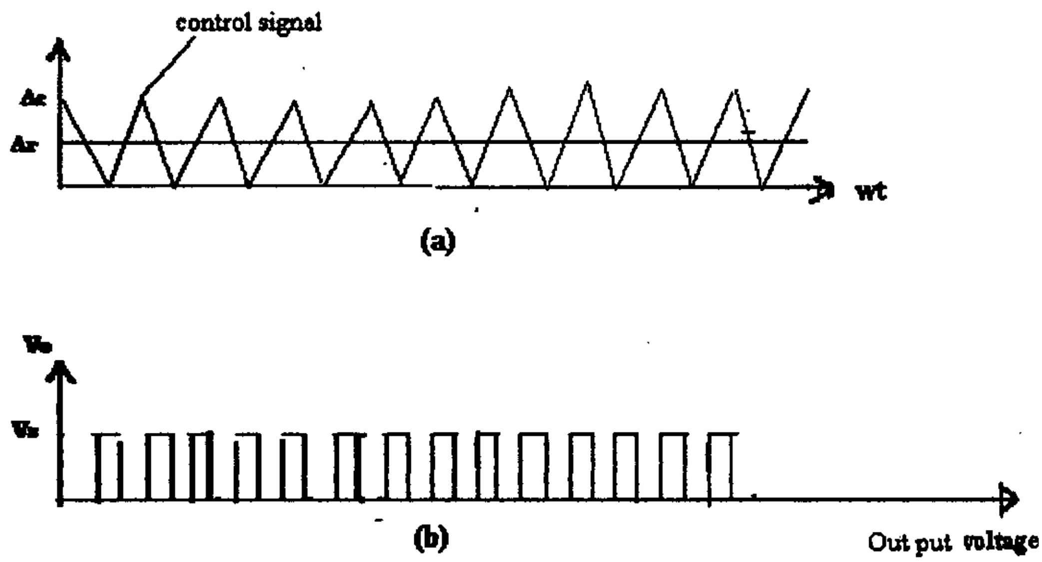


Fig 15: Multiple pulse width modulation

a) Comparison of a triangular wave with a reference DC.

b) Gate pulses generated for switching purpose.

When the stability is not very stringent, manual control is generally preferred from economic considerations. The voltage can be regulated either in steps (discontinuous), or continuously. In the automatic regulator, there is a sensing element, a signal processing unit, and finally the power-control unit. The output voltage is compared with a fixed reference voltage, and the error thus generated is amplified, integrated or differentiated whenever necessary. The processed error voltage is fed to the main controlling unit to have required corrective power. Thus the output voltage is maintained constant.

All regulators take a finite time to effect a change in the supply voltage or load. This time is referred to as the time constant of the regulator, but in most case it is termed as response time. In some cases, the response time is dependent on the magnitude of the change of output voltage, but the rate of change remains constant. The maximum allowable response time depends upon the type of application. It is always desirable to make the response time as small possible to reduce the transients in the output voltage.

1.4.1 MANUALLY CONTROLLED VOLTAGE REGULATOR [25]

The voltage can be regulated manually by:

(a) Tap-changing switches,

(b) A variable auto-transformer (variac) or

(c) An induction regulator.

In some cases, variable resistance and variable inductances are also used.

1.4.1.1 TAP-CHANGING SWITCHES [25]

The voltage regulations by tap-changing switches are used in many industrial applications where, the maintenance of output voltage at a constant value is not very important. In smaller installations, OFF-load tap-changing switches are used, but for large installations, incorporation of ON-load tap-changing switches are necessary. The arrangement of OFF-load tap-charging switch is shown in Fig.-16

The switches are generally incorporated at the secondary of the transformer as shown. When the required number of control steps is large than the number of positions available at the switch, more than one switch is used, but the taps are so arranged that equal voltage steps are available at the output points. In the figure three four-position switches are shown such that the minimum of X volts per step are available at the output. The transformer taps are such that the fine-control coil has four taps having X volts each, whereas, the medium section of the coils should have four taps each having 4 X V, and the coarse control section should have four taps of 16X volts each.

1.4.1.2 STEPLESS CONTROL BY VARIAC [25-28]

The voltage is corrected by tap-charging switches in steps. In many applications, this may be objectionable. Where stepless control is required, variable autotransfromers or variacs are used. The normal variac consists of a toroidal coil wound on a laminated iron ring. The insulation of the wire is removed from one of the end faces and the wire is ground to ensure a smooth path for the carbon brush. Carbon brush is used to limit the circulating current, which flows between the short-circuited turns. An almost stepless control of voltage may be obtained due to gradual change of contact area as the brush moves from one turn to the next. For three-phase operation, three variacs are ganged together. The toroidal structure of variacs is limited to smaller current ratings. For large currents, rectangular cores are used. Stepped core with round coils are used for high power variacs. These variacs are available as single-and three-phase units. The construction is similar to that of ordinary transformers except that coils are wound on a single layer to facilitate 100% variation. The carbon brush slides on the bare surface of the coils. The electrical circuit representation is shown in Fig.-17.The input is connected to a tap on the total winding so as to obtain a greater output than the input. The volts per turn of the variac is made much smaller than that of a transformer of similar rating because its choice is guided by the circulating current due to the interturn voltage through the sliding brush. Generally, 1 V per turn is allowed to limit the circulating current and special high-resistance brush is used for this purpose.

When 100% variation is not required, a Buck-Boost transformer is often used as shown in Fig.-18. The maximum voltage impressed at the primary of the Buck-Boost transformer is $\pm E_1/2$ and that the secondary is $(E_1/2)\ (N_s / N_p)$. The output voltage can therefore be varied steplessly. For three-phase units, a three-phase variac and three Buck-Boost transformers are required.

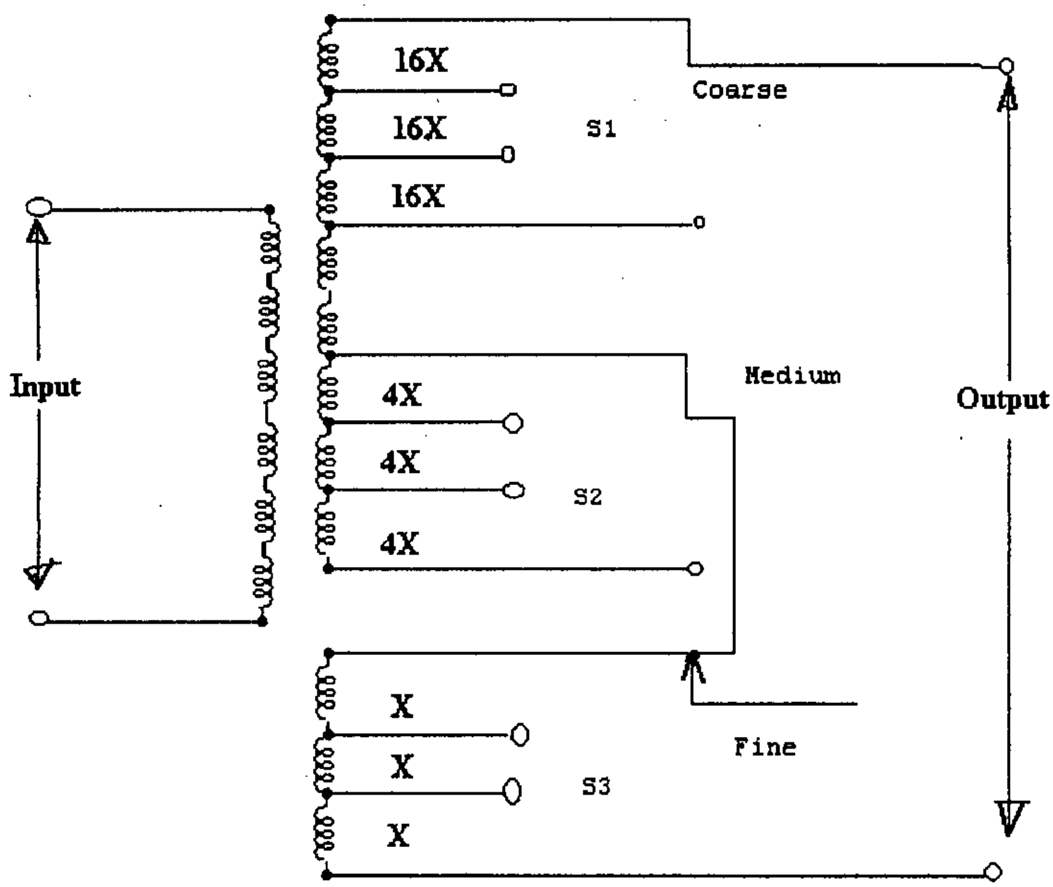


Fig 16: OFF load tap changing switch arrangement.

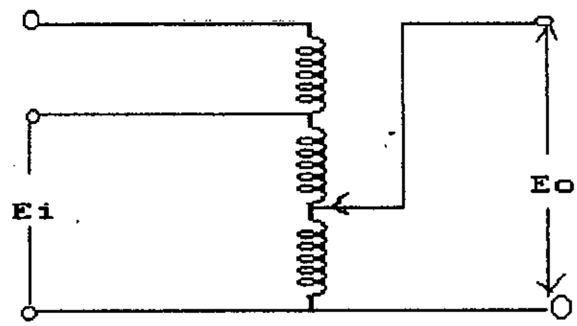


Fig17 : Normal arrangement of a variac

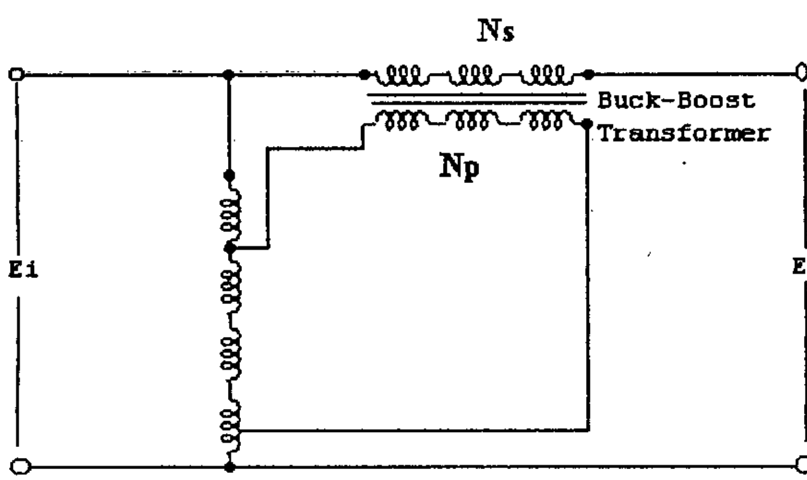


Fig 18: Voltage control by combination of a Buck-Boost transformer and a variac

1.4.2 AUTOMATIC VOLTAGE REGULATORS [25-27]

In manual control, the output voltage is sensed with a voltmeter connected at the output; the decision and correcting operation is made by a human judgment. The manual control may not be feasible always due to various factors. In automatic voltage regulators, all functions are performed by instruction, and give much better performance, so far as stability, speed of correction, consistency, fatigue, etc. are concerned. Moreover, the highly unpredictable personal factor is totally absent.

There are two types of automatic control – discontinuous control and continuous control. It has been already said that the automatic-control system consists of a sensing or measuring unit and a power control or regulating unit. The measuring unit compares the output voltage or the controlled variable with a steady reference and gives an output proportional to their mh difference. The regulating unit is driven by the error signal derived from the measuring unit and gives the correcting power.

In the discontinuous type of control, the measuring unit is such as to produce no signal so long as the voltage is within certain limits. This region where no signal is given is called the `dead zone'. When the voltage goes outside the dead zone, a signal is produced by the measuring unit until the voltage is again brought within this zone. An example of this type of \measuring unit is the voltage-sensitive relay with charge-over contacts. In this type of measuring or sensing unit, the correcting voltage is independent of percentage of error.

In the discontinuous-control system, the regulating or the power-controlling unit also operates in a discontinuous manner. It is activated by a discontinuous measuring unit and selects a fixed and predetermined amount of correction voltage. When the voltage is brought back to the dead zone, the signal from the measuring unit is zero and the regulating unit remains at its new position until another signal is received from the measuring unit.

In continuous control, the measuring unit produces a signal with amplitude proportional to the difference between the fixed reference and the controlled voltage. The output of the measuring unit is zero when the controlled voltage or a fraction of it is equal to the reference voltage. An example of this type of measuring unit is a voltage-sensitive bridge or a comparator. The regulating or the controlling unit, which is associated with the continuous measuring unit, gives a correcting voltage proportional to the output of the measuring unit. This is nothing but a voltage-and-power amplifier. This may be sometimes associated with a phase-sensitive detector and a driving mechanism. The discontinuous control system is simpler than the continuous-control system, but its response time is longer and less accurate. Therefore, it is used, where, the required output stability or the accuracy of control is not more than ± 1%. This is due to the presence of a finite width of dead zone in the measuring unit. The continuous-control type has faster response due to feedback action, and the output can be achieved more than ± 1%, but it is costly. The adjustment to suppress hunting is also critical. An auto transformer type automatic tap changing voltage regulator shown in Fig.19.

1.4.3 AUTOMATIC VOLTAGE REGULATOR USING SERVO SYSTEM [25-29]

Automatic voltage regulators using servo systems are quite common. Both single and three-phase types are available. The rating of this type of regulator is quite high and is more economical for high power rating. This regulator consists normally of a variac driven by a servomotor, a sensing unit and a voltage and power amplifier to drive the motor in a reversible way. Sometimes, limit switches are incorporated in series with the motor to disconnect the motor supply when the variac reaches either the upper or the lower limit of its travel.

Various types of driving motor may be used for regulating the unit, viz. direct current, induction and synchronous motors. However, in all cases, the motor must come to rest rapidly to avoid overrun and hunting. The amount of overrun may be reduced by dynamic braking in the case of a dc motor or by disconnecting the motor from the variac by a clutch as soon as the signal from the measuring unit ceases. This enables the variac to stop more rapidly as its inertia is small, and allows the motor to overrun without causing any difficulty. This overrun is important for faster correcting systems and sets a limit to the speed of connection. When the motor is driven directly by an amplifier, overrun may be prevented by velocity feedback using a tachogenerator coupled to the motor.

The schematic diagram of the auto voltage regulator using servo system is shown in Fig.-20. The output voltage of the regulator is stepped down by transformer T_3 and rectified by the bridge rectifier R_s. The rectified voltage is filtered by capacitor C_1. The measuring circuit is the zener bridge B. The zener bridge is adjusted by P to produce zero voltage at the desired regulator output voltage E_0. When the regulator output voltage deviates from the desired value, the zener bridge produces a voltage whose polarity depends on the value of the regulator output voltage. This error voltage is amplified by an operational amplifier with complementary-symmetry (OP-AMP) which drives a power-amplifier stage. Two dc relays R_{e1} and R_{e2} are put in the collector circuits of the amplifier as loads. The armature of a separately excited dc motor M is connected to a dc source through the contacts of the relays in such a way that it can be driven in both directions. If the regulator output voltage is low, the zener bridge becomes unbalanced in such a direction that the OP-AMP output is negative. Relay R_{e2} is energized and relay R_{e1} is OFF.

The motor rotates in such a direction as to increase the regulator output voltage up to the desired value. At this condition, the zener bridge output is zero, and as a result, both the relays are OFF. The wiper of the variac remains in the new position. Similarly, if the regulator output voltage becomes high, the zener-bridge output voltage changes sign and relay R_{e1} is energized rotating the motor in the other direction so that the output voltage becomes nominal. In this condition, both the relays are again OFF.

The advantage of the above regulating system is that the rating of the power amplifier need not be very large, because the load is only the relay coil. The accuracy of the system is better than ± 1%, and the speed of correction lies between 32 and 70 V per second. The chief disadvantage of this type of regulator is the low life of the contact points of the relays.

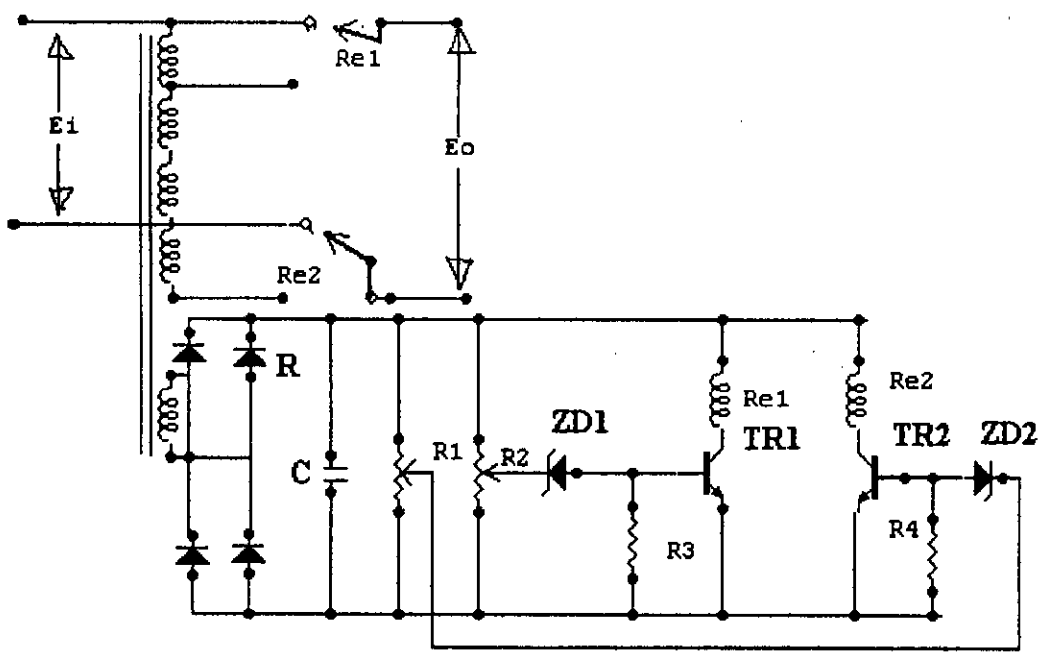


Fig 19: Auto transformer type automatic tap changing voltage regulator using two relays

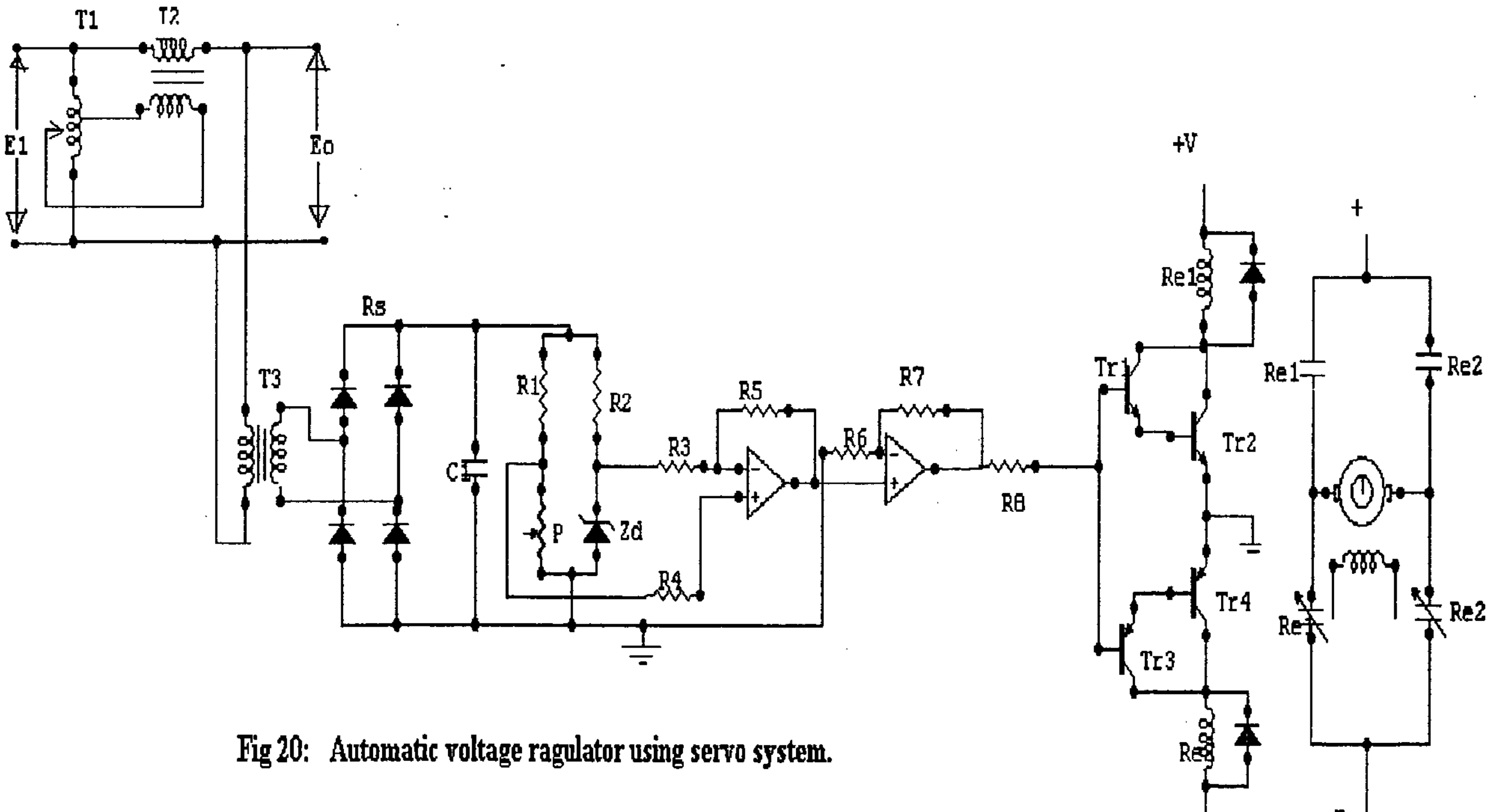


Fig 20: Automatic voltage ragulator using servo system.

1.5 RECENT WORK

A switch mode voltage regulator based on Buck conversion principle with a step up injection transformer at its output has been proposed in the literature [5]. The converter uses ON/ OFF duty cycle PWM control. Enhanced power quality has been reported by PWM control of AC to AC voltage controller. Voltage gain and efficiency of practical buck converter deviates from ideal ones due to lossy passive components and non-ideal switches. The voltage gain and efficiency of this converter decrease with duty cycle of the control signal.

The AC to AC Buck Converter as reported is shown in Fig-21. Normally, when input voltage decreases then the output voltage also decreases. But when the output voltage is less than the desired value, it can be increased to the desired value by adding a suitable voltage which is produced in the transformer secondary with the input voltage. The induced voltage which is added to the input can be varied by PWM technique.

Fig-22 shows the practical implementation of AC to AC buck converter. The input–output waveforms are shown in Fig.23 for input voltage of 250V. It is observed that when input voltage is 250V then output voltage is 300V. The voltage induced in the transformer secondary (E_b) is added with input voltage (V_{in}). The input voltages of OPAMP'S and its output voltage pulse, gate pulses for limit2 and limit1 are shown in Fig.24, 25 and 26 respectively. To maintain output 300V the input DC voltage of OPAMP'S is required to be 8V. If the input voltage is decreased to 225V then output voltage is 300V, which is shown in Fig.27. The input voltages of OPAMP'S and its output voltage pulse, gate pulses for limit2 and limit1 are shown in Fig.28, 29 and 30 respectively. To maintain output 300V the input DC voltage of OPAMP'S is required to be 4V. Pulse width variation controls the duty cycle and output remains constant with the variation of input voltage.

If the input voltage is increased then output is increased. But it is necessary to decrease the output voltage V_0 to the desired value by subtracting the voltage E_b from input voltage V_{in}. But it is not possible by this arrangement. This drawback may be overcome by using Buck-Boost converter configuration.

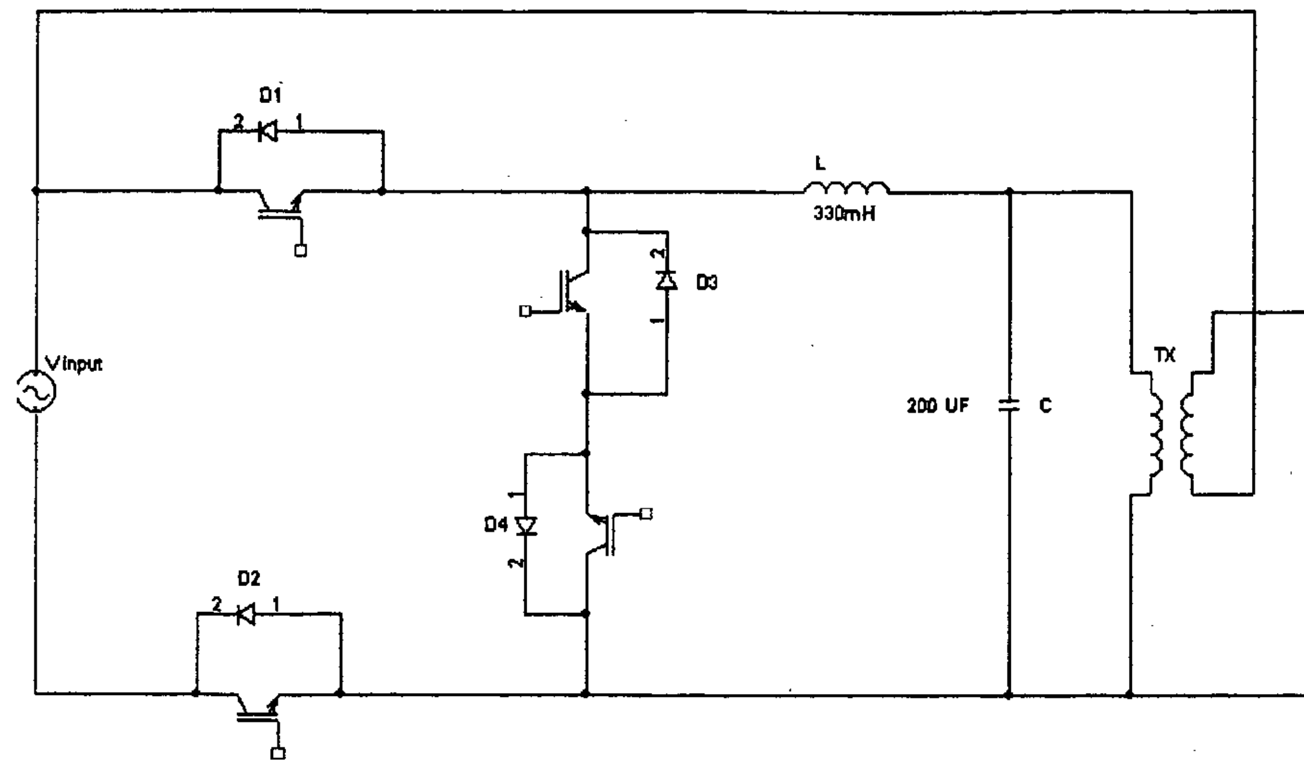
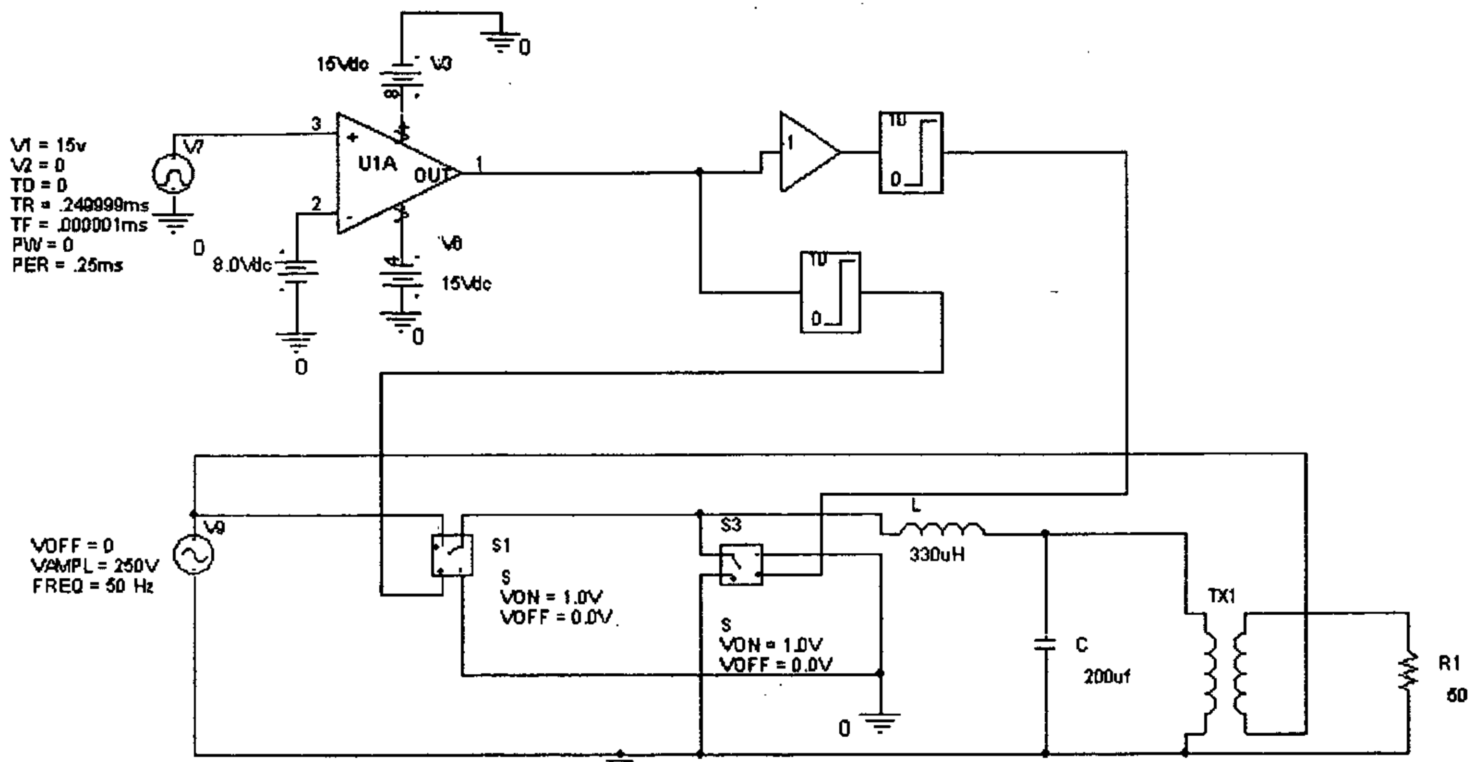


Fig. 21 AC to AC Buck Converter



(a)

Fig. 22 Ac Buck voltage controller with manual control
(a) With ideal switches. (b) With practical IGBT switches.

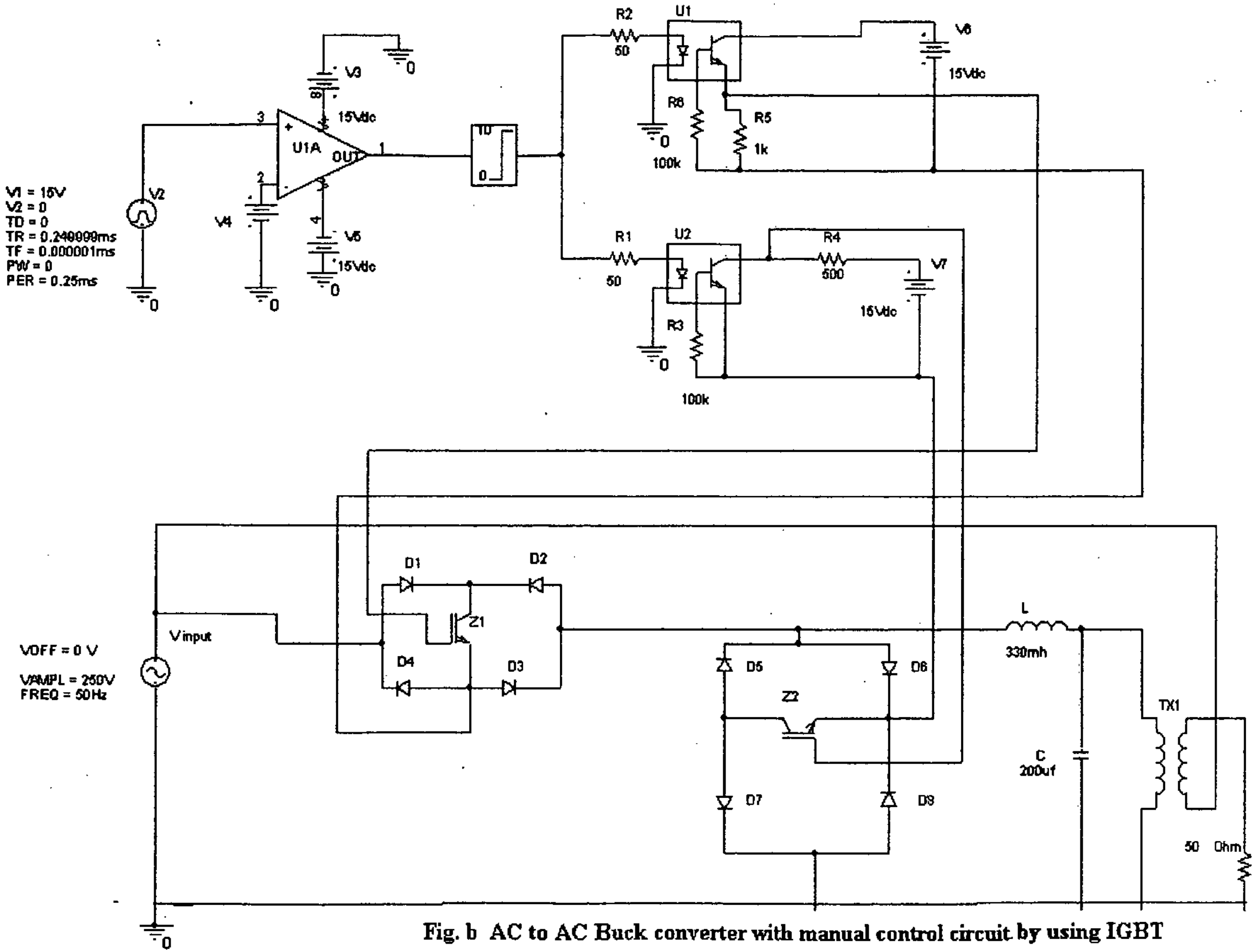


Fig. b AC to AC Buck converter with manual control circuit by using IGBT

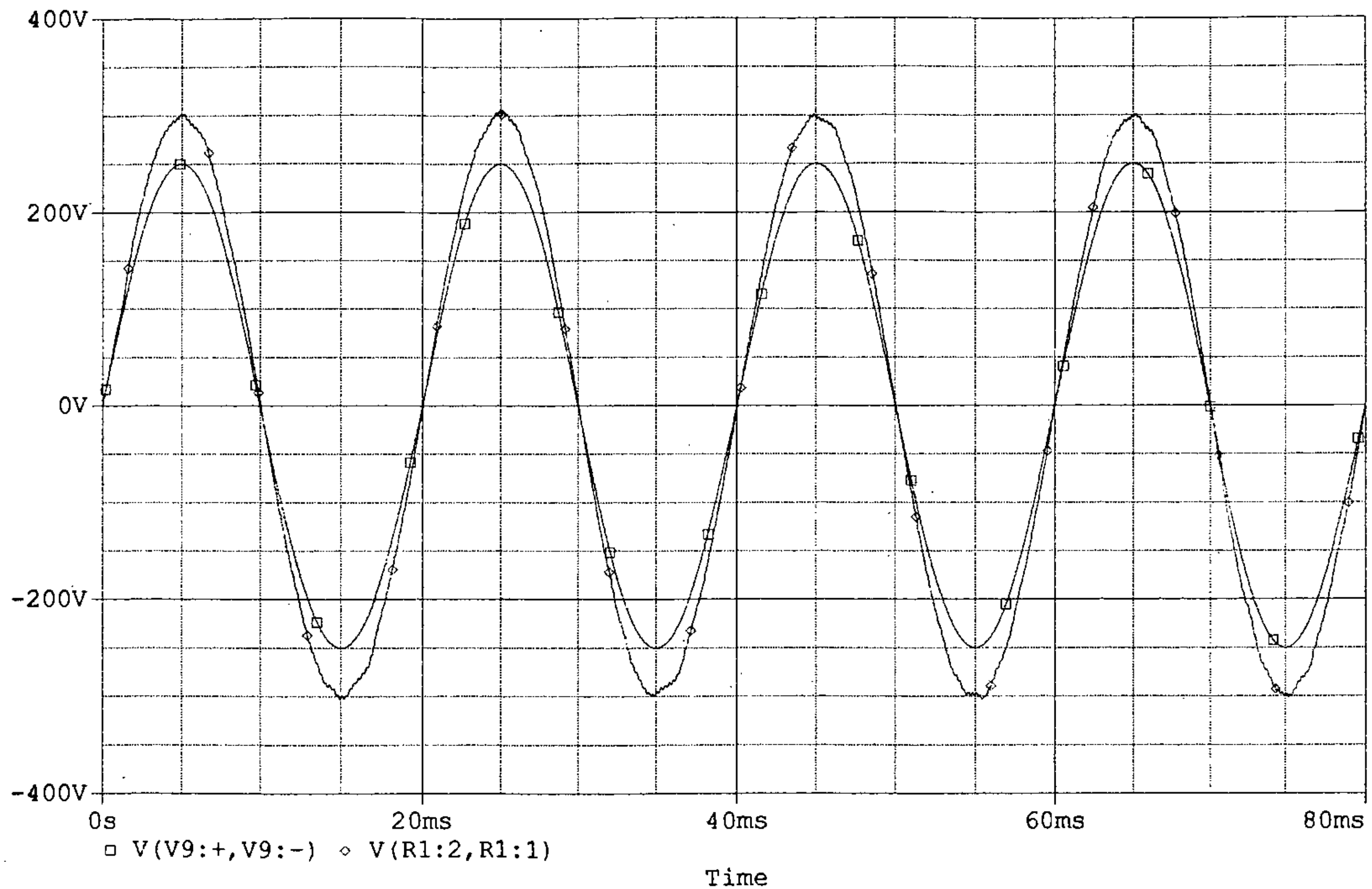


Fig. 23 Input-output voltage waveforms when input voltage =250V and output voltage =300V

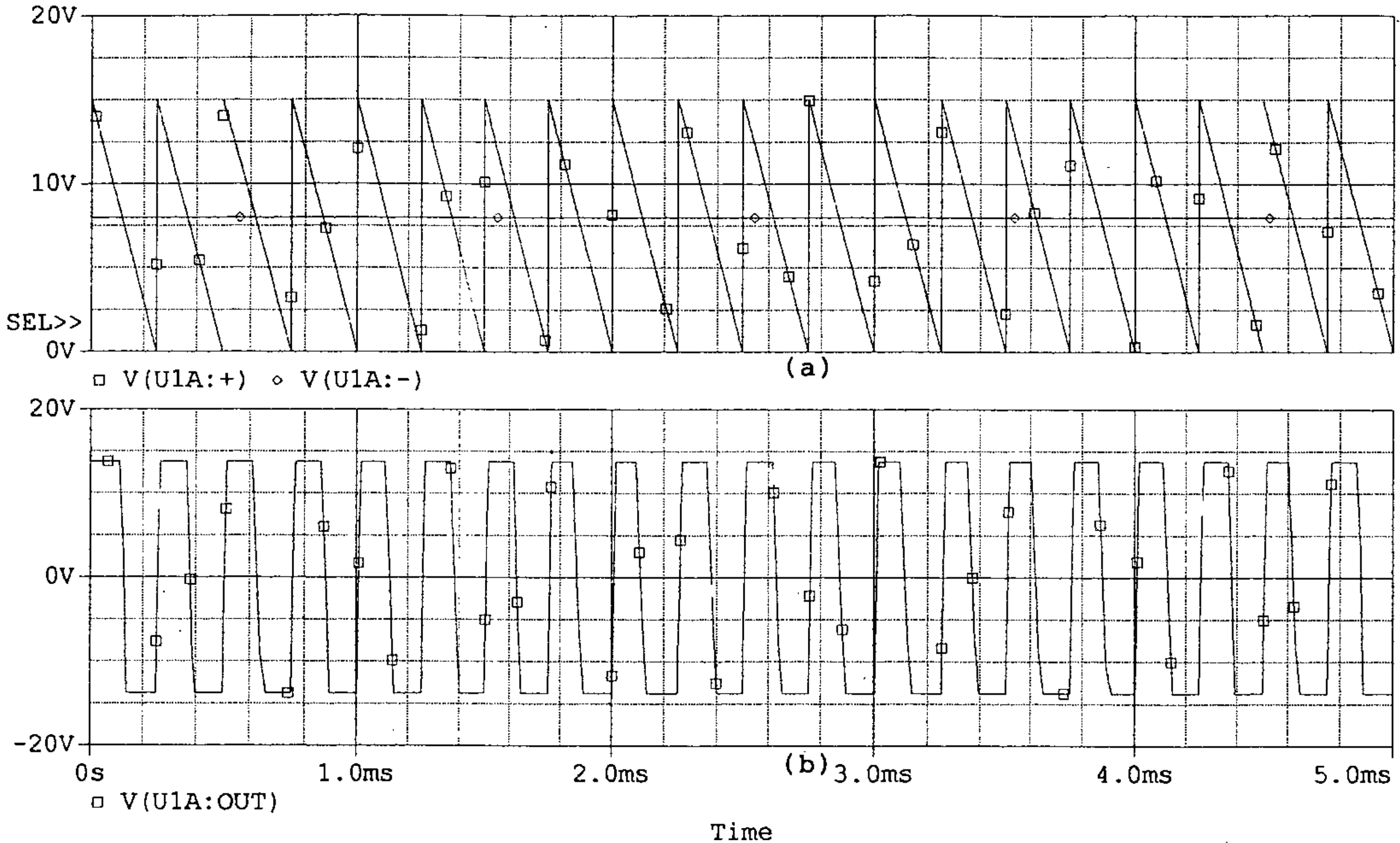


Fig. 24 Waveforms of manual control circuit when Vdc = 8V
(a) Saw-tooth wave and DC comparison
(b) Gating pulses of one switch

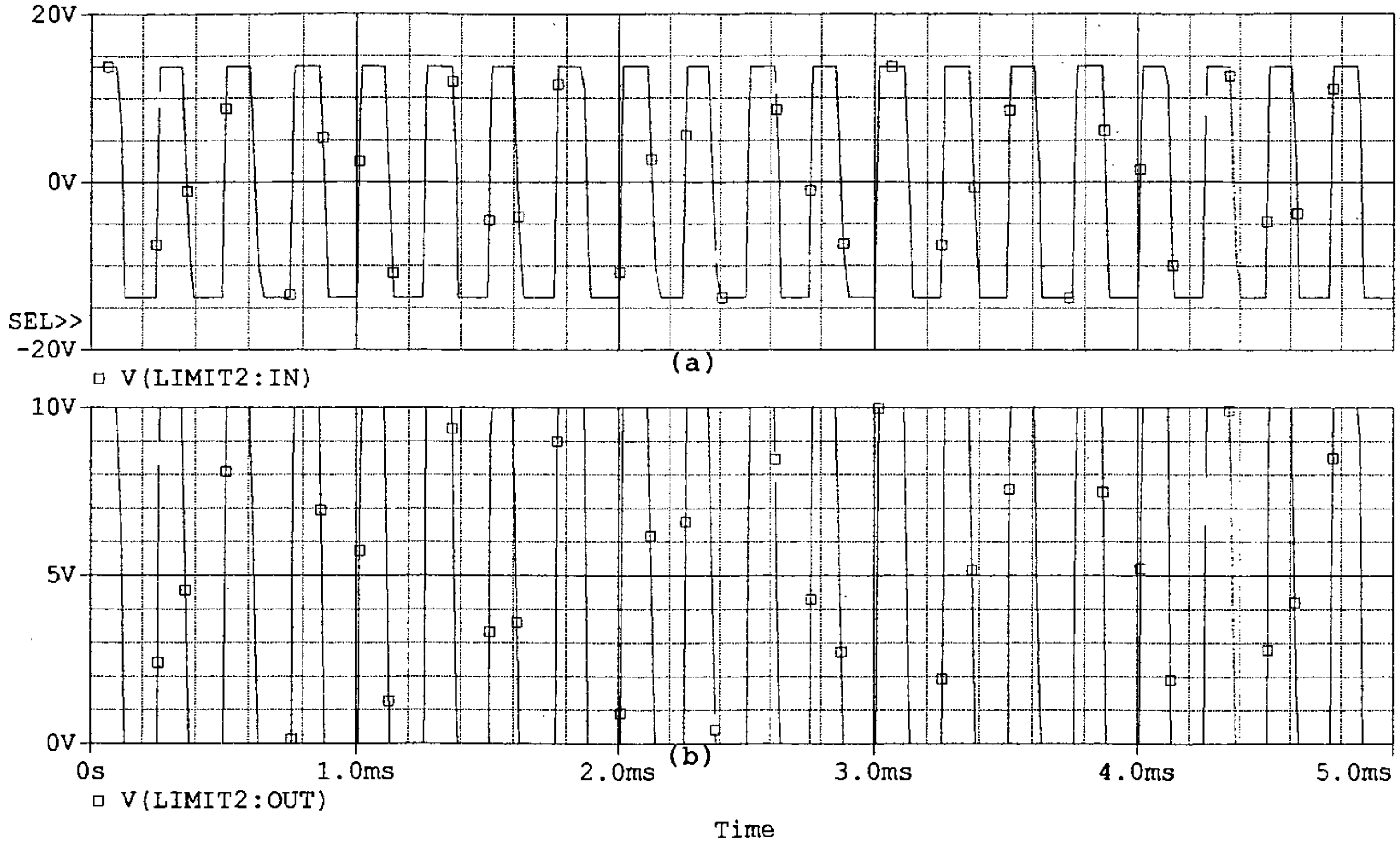


Fig. 25 Gate pulses for DC = 8V
(a) LIMIT2 : IN
(b) LIMIT2 OUT

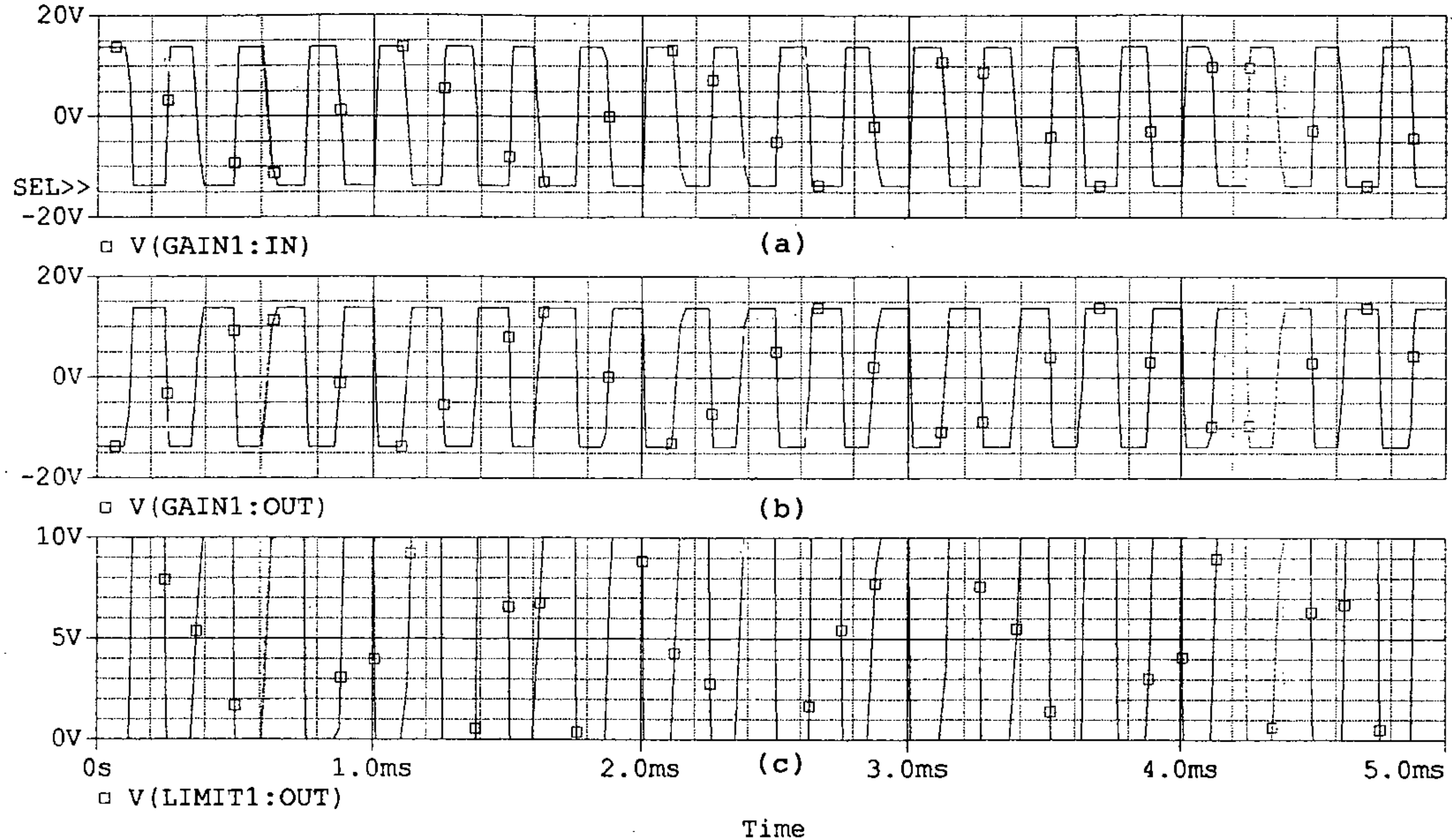


Fig. 26 Gate pulses for DC = 8V
(a) GAIN1 : IN
(b) GAIN1 : OUT
(c) LIMIT1 : OUT

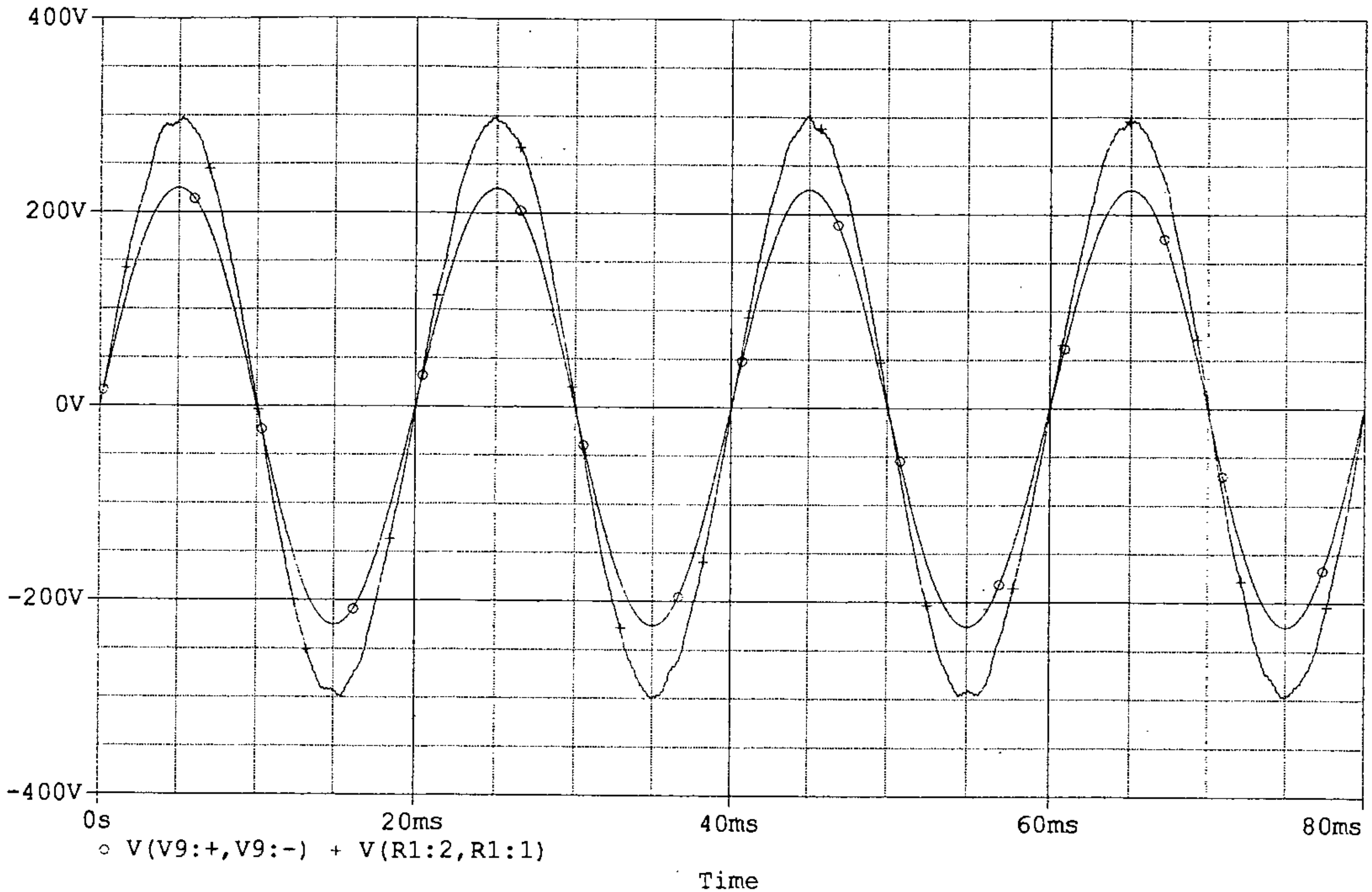


Fig. 27 Input-output voltage waveforms when input voltage = 225V and output voltage =300V

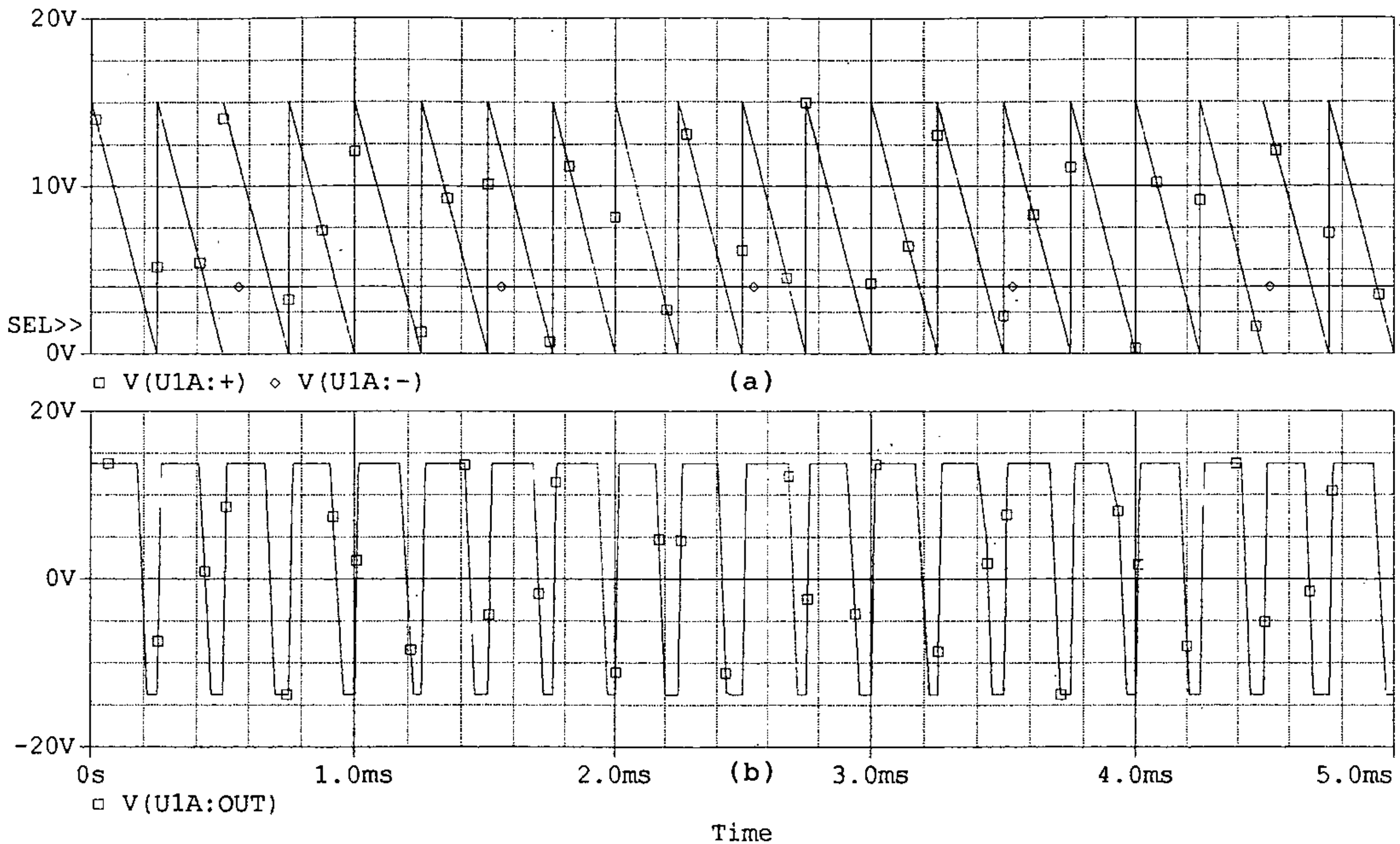


Fig. 28 Waveforms of manual control circuit when Vdc = 4V
(a) Saw-tooth wave and DC comparison
(b) Gating pulses of one switch

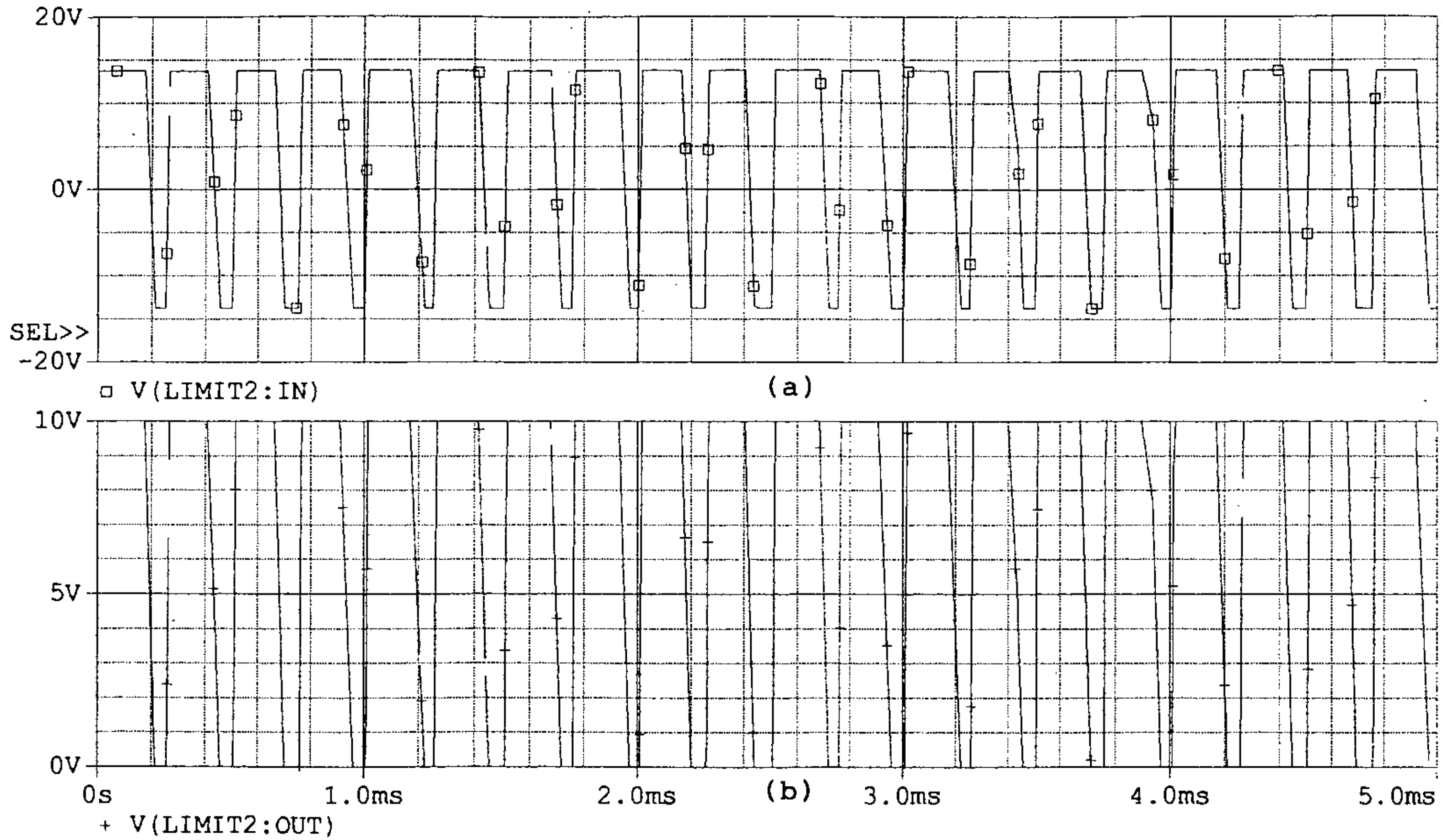


Fig. 29 Gate pulses for Dc = 4V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

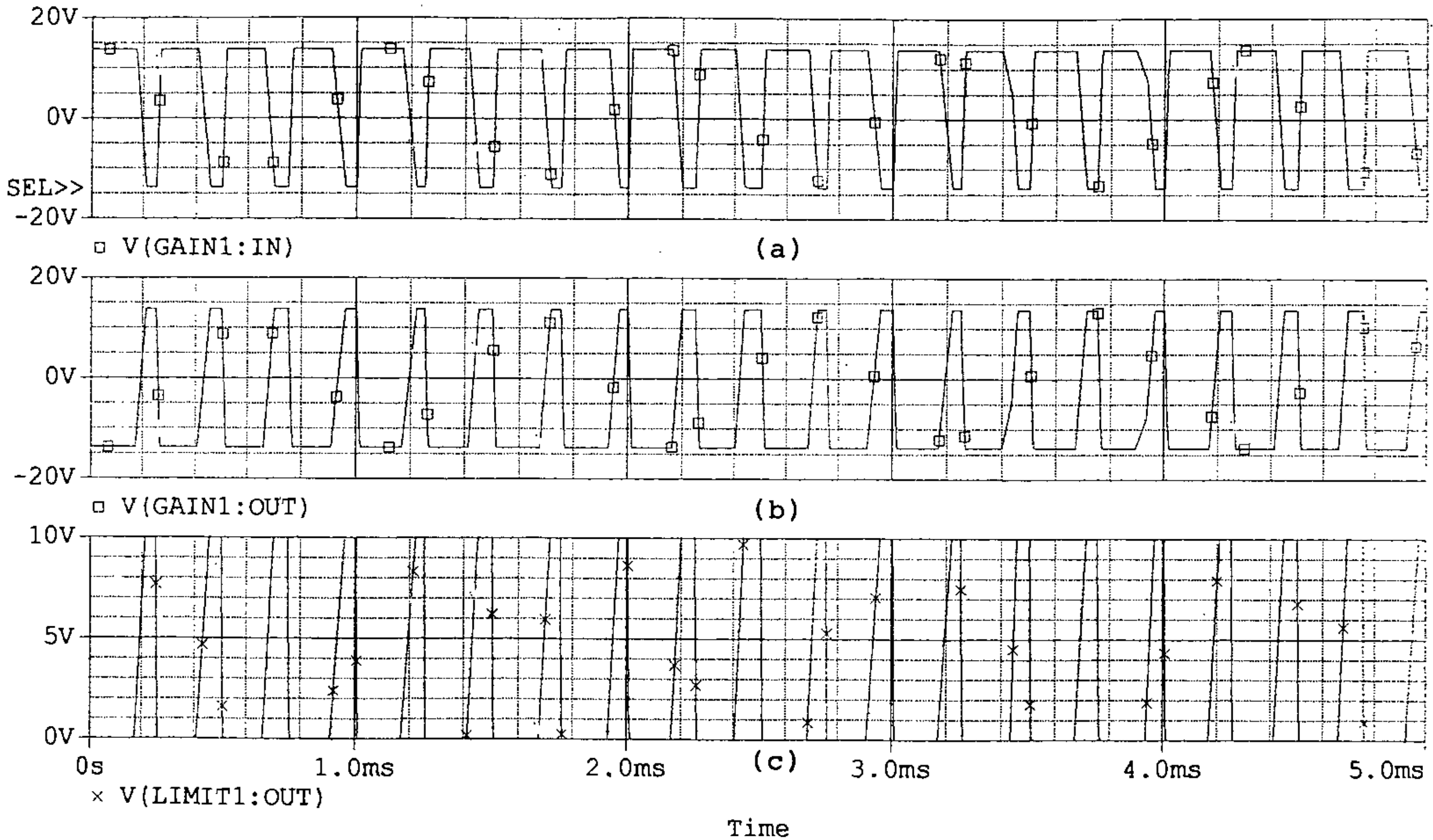


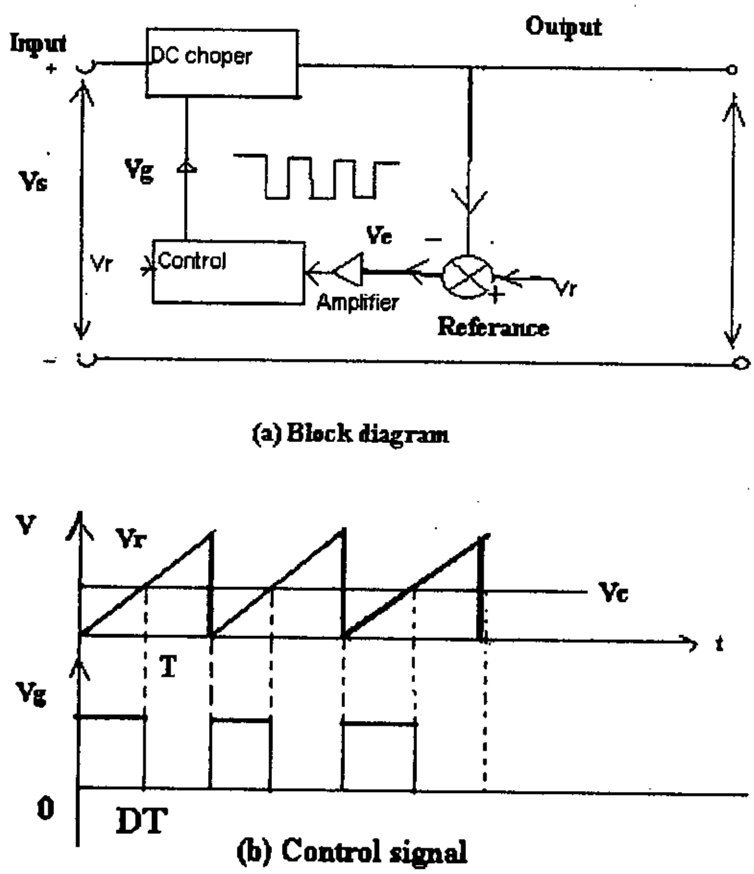
Fig. 30 Gate pulses for Dc = 4V
(a) GAIN1 : IN
(b) GAIN1 : OUT
(c) LIMIT1 : OUT

1.6 OBJECTIVE OF THE THESIS

It is observed that in recent work when input voltage decreases then output voltage can be increased to the desired value by adding a suitable voltage with the input voltage. But if the input voltage increases then output voltage cannot be maintained constant by subtracting certain voltage from the input voltage as it would require polarity reversal of transformer winding. Our objective is to develop an automatic voltage regulator using an AC to AC Buck-Boost voltage controller with PWM control. In this arrangement output voltage will remain constant for either increases or decreases of the input voltage and also for any change in load. The output of the converter will be compared with a reference and proper PWM signal will be generated (by adjusting pulse widths) to compensate the voltage difference. The proposed voltage regulator is expected to provide a practical way of compensation for both short term and long term voltage changes at the load for either input voltage variation or the load variation within specified limit.

1.7 CONTROL FUNDAMENTALS [10, 30, 42]

Semiconductor implementation of the ideal switch allows electronic control of the power processing through variation of the duty cycle of control signals. Electronic control of the conversion ratio allows easy transformation of the converter into a switched mode regulator. In the control circuit the output is compared with a reference voltage and the error signal is amplified to provide the desired control signal. The control signal is compared with a saw tooth voltage to generate the PWM signal for the dc chopper as shown in Fig.-31. Same idea can be intended to the AC-AC SMPS control which has been investigated in thesis for a Buck-Boost Ac voltage regulator.



(a) Block diagram

(b) Control signal

Fig 31 : Elements of switching mode regulators.

1.8 OUTLINE OF THE THESIS

This thesis consists of three chapters. Chapter-1 deals with introduction to SMPS, review of voltage regulators and PWM techniques. It incorporates various advantages and requirements the SMPS. Objective of the research and discussion on expected results are also included in chapter-1.

Chapter-2 includes the detailed study of AC Buck-Boost regulator. AC Buck-Boost regulator with ideal and practical IGBT switch implementation has been proposed and studied. Input /output ideal and non ideal relationship for Buck-Boost SMPS are presented in this chapter. Uncontrolled AC Buck-Boost regulator by ideal switch, gate signal generating circuit and results of the operation of an AC Buck-Boost regulator is included in chapter-2. This chapter also includes proposed controlled AC Buck-Boost regulator implemented by practical IGBT switches. Automatic control circuit and results of AC Buck-Boost regulator is presented in this chapter. Problems faced like freewheeling path, surge voltage across switches and possible remedy of freewheeling path and surge voltage are included in this chapter. Input /output filter requirement is also described in brief in chapter-2.

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

CHAPTER-2

AC BUCK-BOOST VOLTAGE REGULATOR

2.0 INTRODUCTION

A Buck-Boost regulator provides an output voltage which may be less than or greater than the input voltage–for this reason it is called "Buck-Boost". The output voltage polarity is opposite to that of the input voltage and the regulator is therefore known as an inverting regulator. A Buck-Boost converter can be obtained by the cascade connection of the two basic converter: the step down (Buck) converter and the step up (Boost) converter. In steady state, the output to input voltage conversion ratio is the product of the conversion ratios of the two converters in cascade. The main application of a Buck-Boost converter is in regulated power supplies.

2.1 BUCK-BOOST REGULATOR TOPOLGY

The cascade connection of the Buck and Boost converters which can be combined into the single Buck-Boost converter is shown in Fig. 32. The circuit operation can be divided into two modes. During mode 1, transistor Q_1 is turned ON and diode D_m is reversed biased. The input current, which rises, flows through inductor L and transistor Q_1. During mode 2, transistor is switched OFF and the current, which was flowing through inductor L, would flow through L,C, D_m, and the load. The energy stored in inductor L would be transferred to the load and the inductor current would fall until transistor Q_1 is switched on again in the next cycle. The equivalent circuits for the modes are shown in Fig. 33.

2.1.1 IDEAL SWITCH IMPLEMENTATION OF AC BUCK– BOOST REGULATOR

AC Buck-Boost implementation by ideal switch is a very simple arrangement as shown in Fig.34. Fig. 34 shows two S-break switches which are actually bi-directional switch. S-break switches are considered as lossless switch. During positive half cycle of input voltage when switch s_1 is ON (by gate signal) and s_2 is OFF the input provides energy to the inductor. When s_1 is OFF and s_2 is ON (by gate signal) the energy stored in the inductor is transferred to the output through the load. During negative half cycle of input voltage the same operation takes place but direction of energy stored in inductor is opposite.

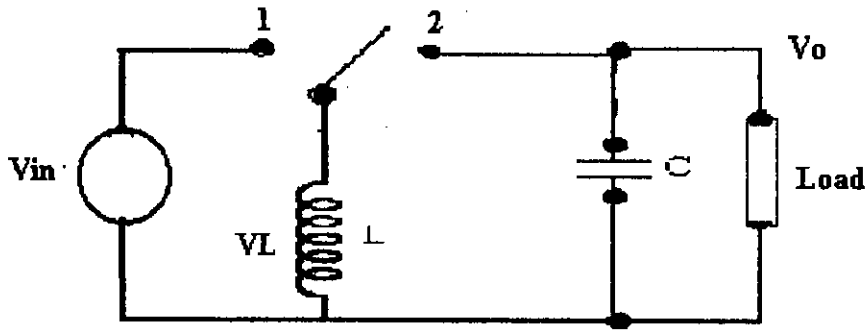
The operation of AC Buck-Boost regulator by ideal switch in positive and negative half cycle of input voltage is shown in Fig.35 (a) and (b) respectively.

2.1.2 PRACTICAL IGBT SWITCH IMPLEMENTATION

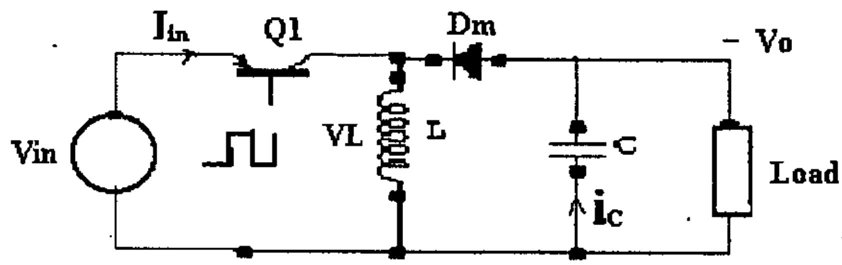
Practically AC Buck-Boost regulator may be implemented by three different topologies as shown in Fig.36, 37 and 38. Fig. 36 shows the AC Buck-Boost regulator implemented by two switches with required gate signals for IGBT-1 and IGBT-2. Fig 37 shows the AC Buck-Boost regulator implemented by three switches together with gate signals for IGBT-1, IGBT-2. and IGBT-3. Fig. 38 shows the AC Buck-Boost regulator implemented by four switches with gate signals for IGBT-1, IGBT-2, IGBT-3 and IGBT-4 respectively. Among the three topologies two switch implementation requires minimum switching devices. So in this thesis we have investigated this configuration only.

The practical AC Buck-Boost regulator of two switch implementation is shown in Fig.36. The ideal S- break switch is replaced by 4 diode bridge and one IGBT which in Fig.36. During positive half cycle of input voltage when IGBT-1 is ON (by gate signal), then current passes through diode D_1, IGBT-1, diode D_2 and inductor L. The energy is stored in the inductor L. When IGBT-1 is OFF and IGBT-2 is ON (by gate signal) the stored energy in the inductor is transferred to the output load by D_5, IGBT-2 and D_6.

During the Negative half cycle of input voltage current passes through inductor L, D_3, IGBT-1 and D_4, when IGBT-1 is ON and IGBT-2 is OFF. The energy is stored in the inductor L. When IGBT -1 is OFF and IGBT-2 is ON, the stored energy in the inductor is transferred to the output load by D_7, IGBT-2 and D8. The operations of positive and negative half cycle of input voltage are shown in Fig. 39(a) and (b) respectively.

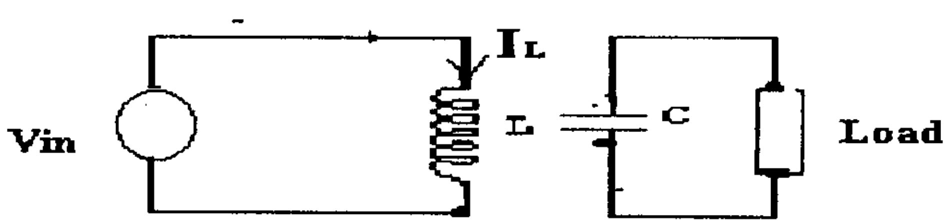


(a)

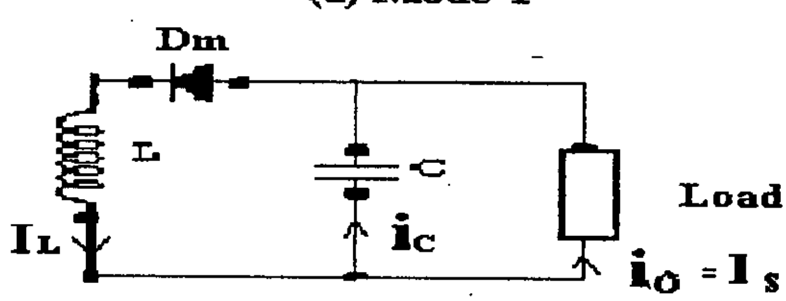


(b)

Fig 32 : Buck-Boost Regulator Topologies
a) circuit with an SPDT switch.
b) circuit realization with a BJT and a diode.



(a) Mode-1



(b) Mode-2

Fig 33 : Equivalent circuit of Buck-Boost regulator for switch ON and OFF position.

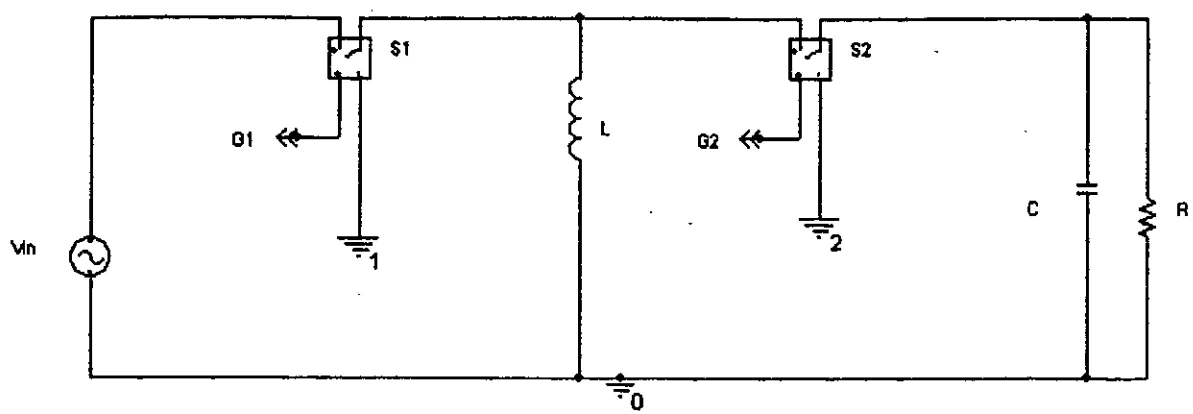


Fig. 34 AC Buck- Boost regulator implementation by ideal switch

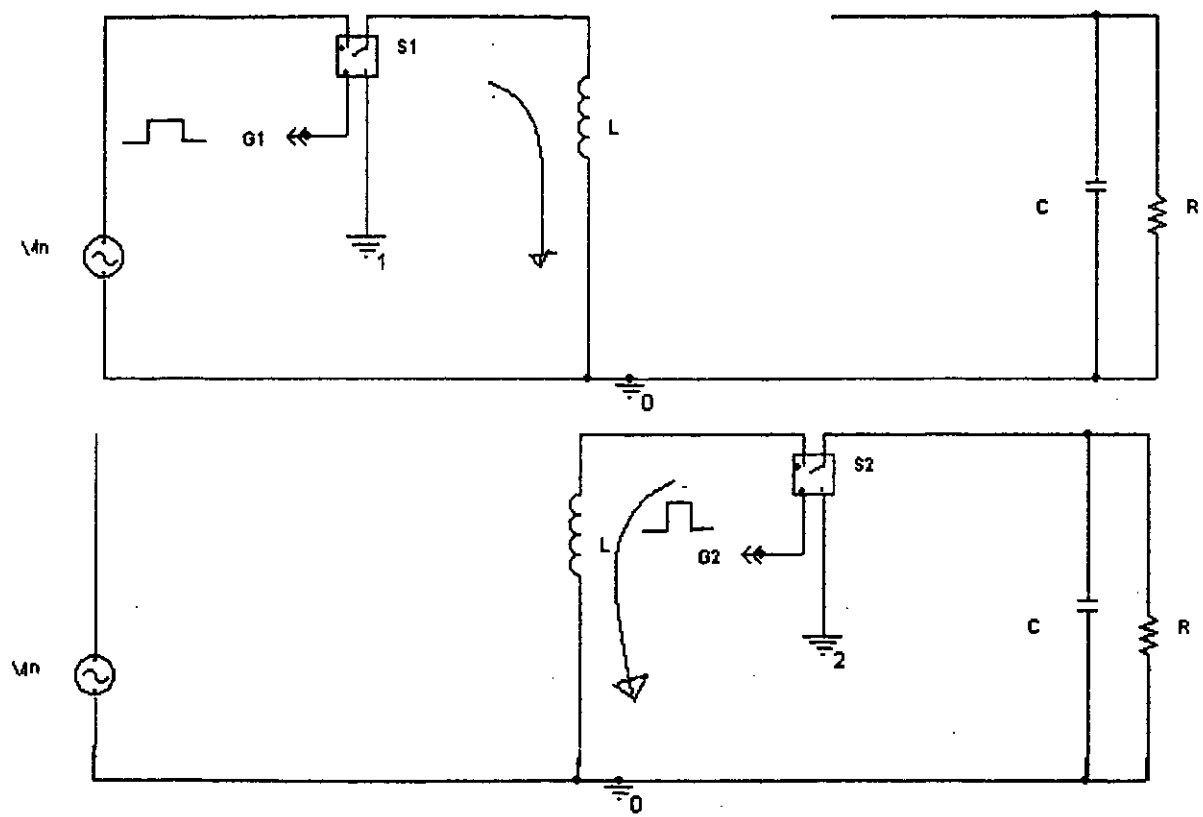


Fig. 35(a) Operation of an Ac Buck- Boost regulator during positive half cycle of input voltage.

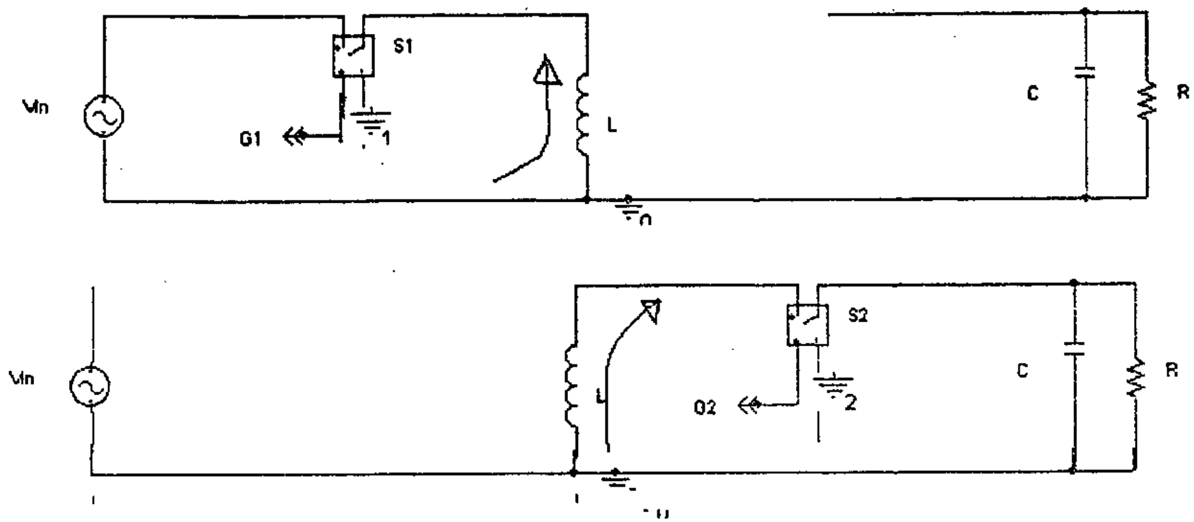


Fig.35(b) Operation of an AC Buck- Boost regulator during negative half cycle of input voltage.

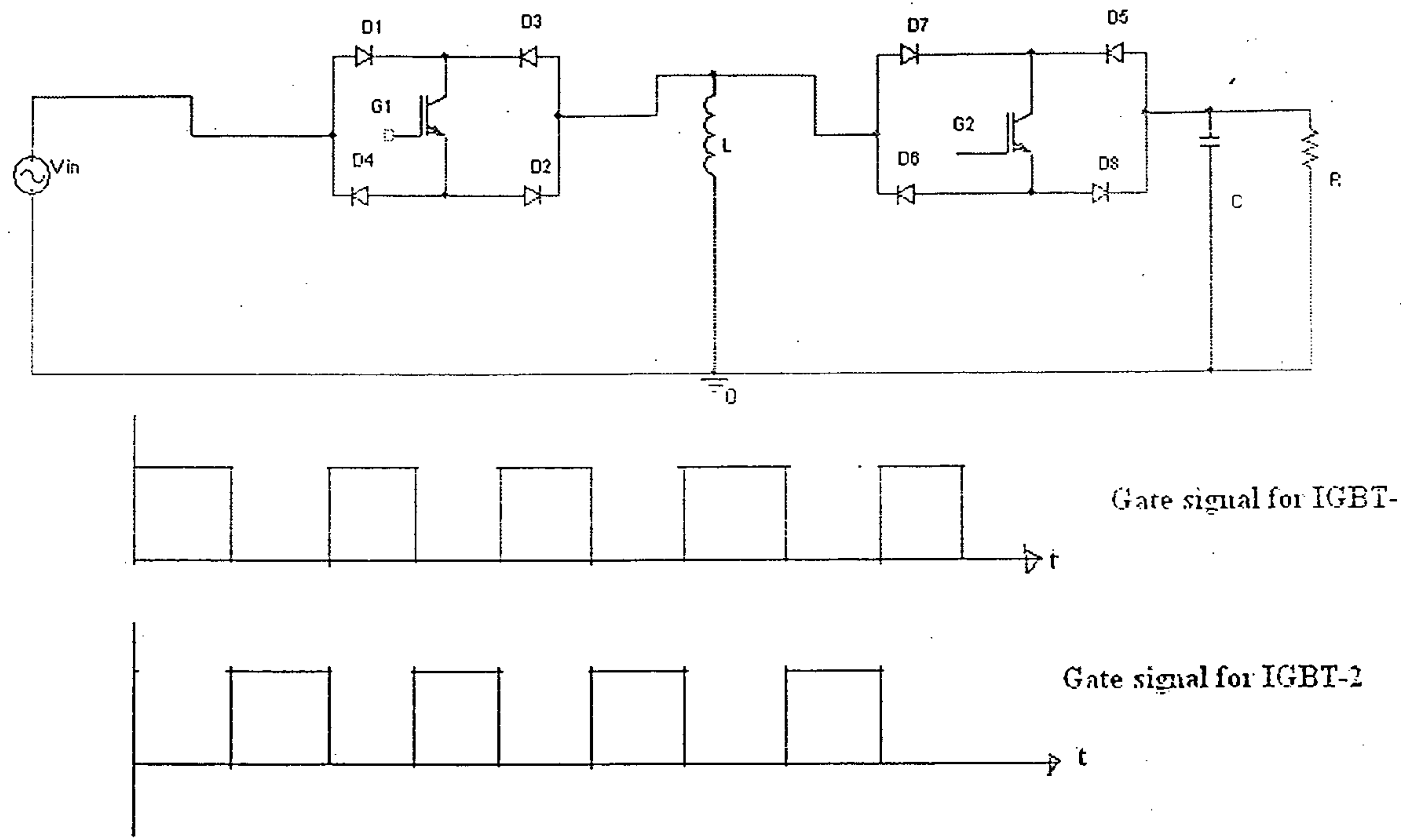


Fig 36: AC Buck-Boost regulator implementation by two IGBT switches and gate signals for IGBT-1 and IGBT-2

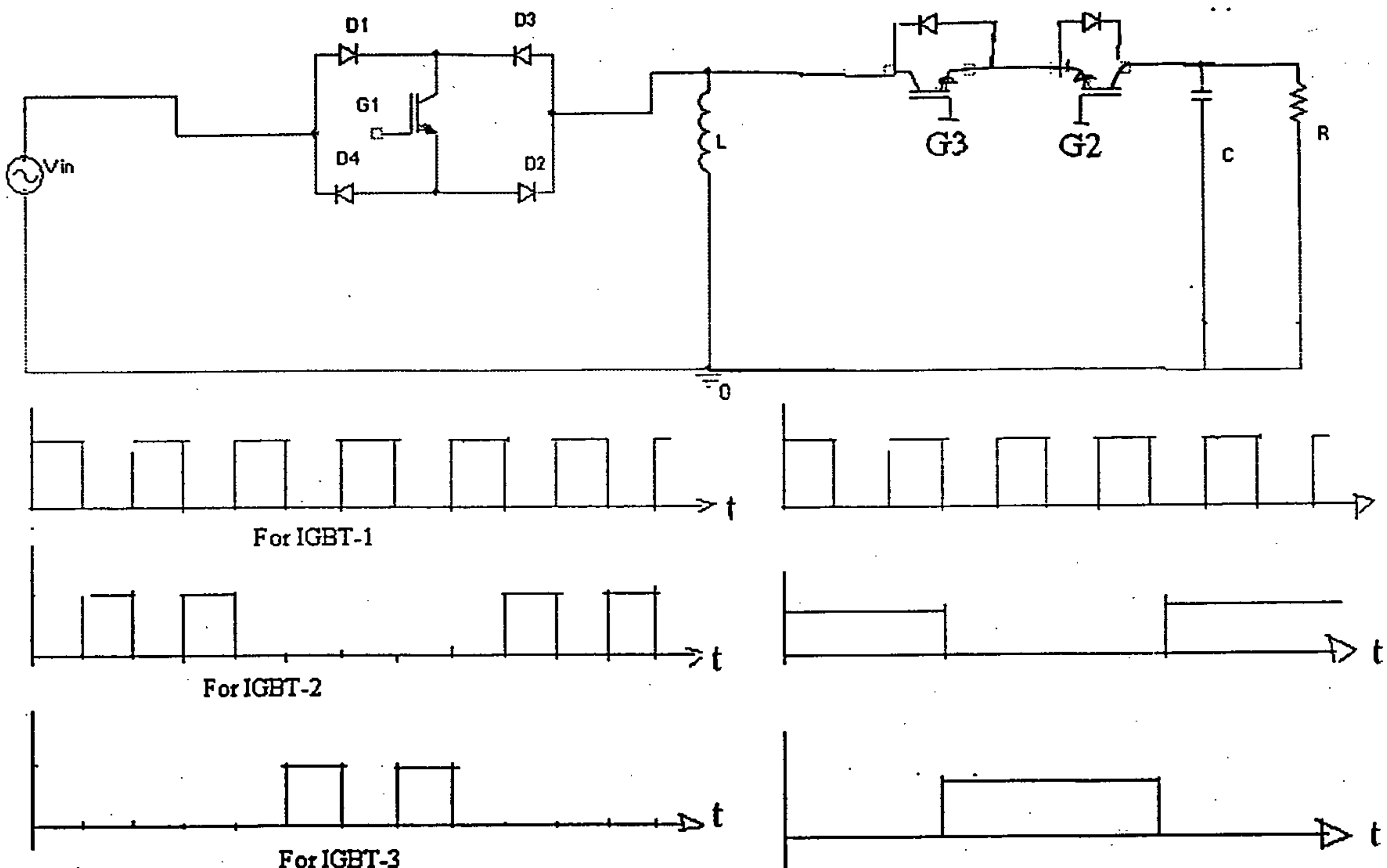


Fig 37: AC Buck-Boost regulator implement by three IGBT switches and gate signals for IGBT-1,2and 3

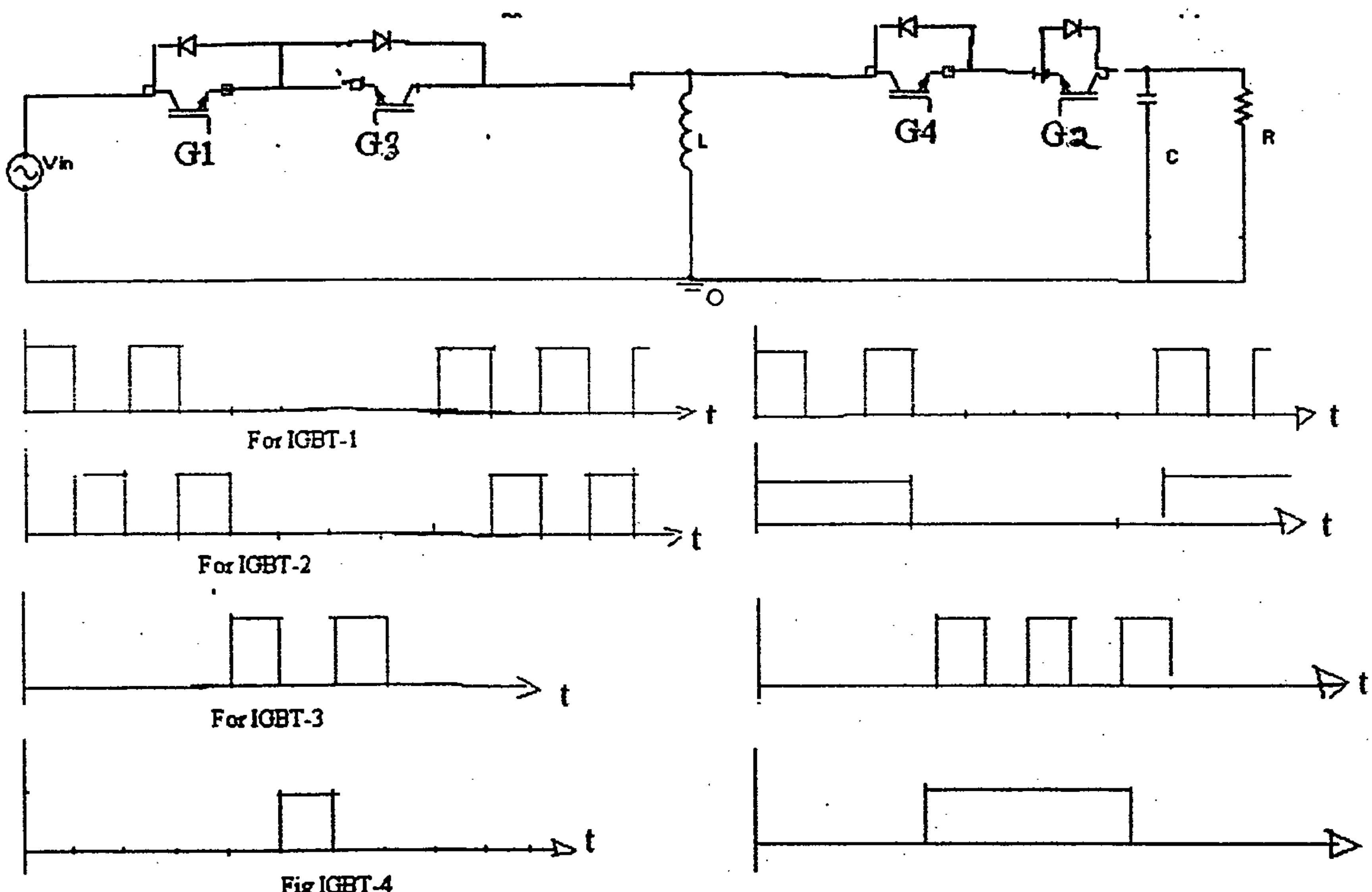


Fig 38: AC Buck-Boost regulator implement by four IGBT switches and gate signals for IGBT-1,2,3 and 4

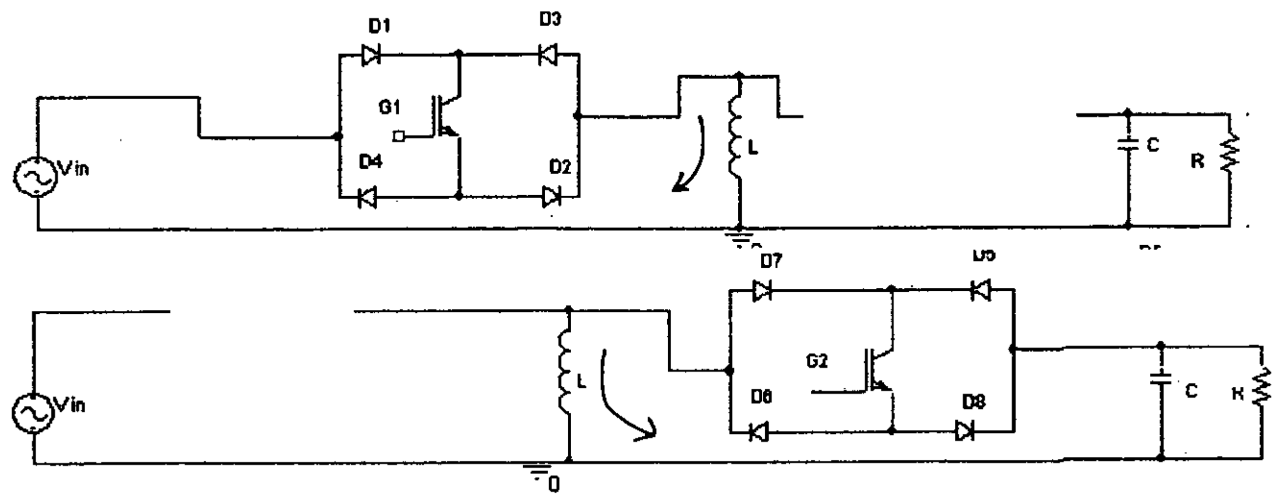


Fig.39(a) Operation of Ac Buck-Boost regulator for the positive half cycle of input voltage

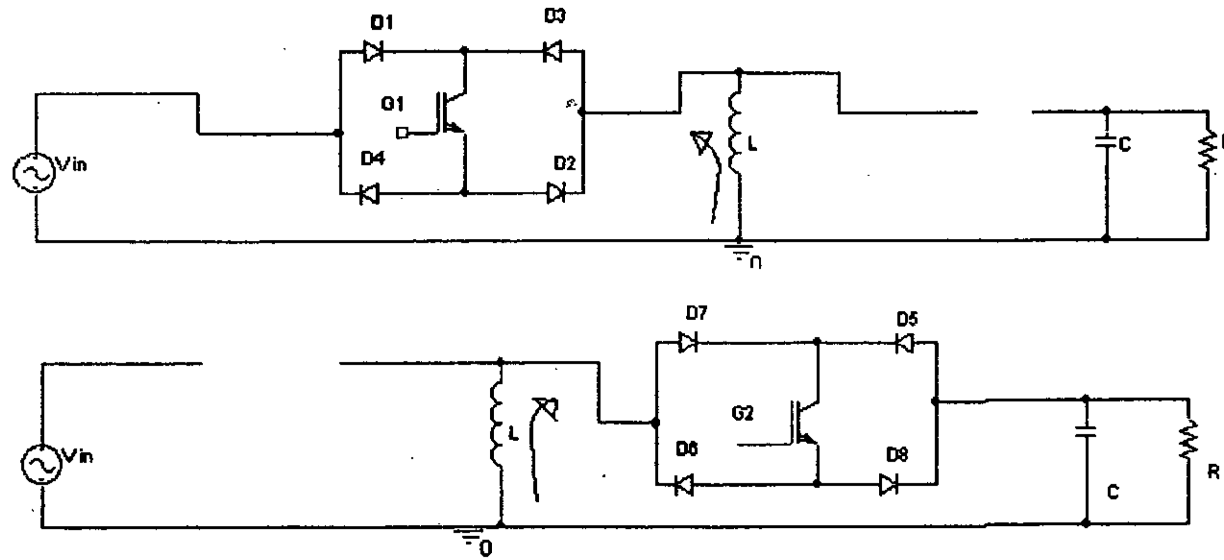


Fig:39(b) Operation of AC Buck-Boost regulator for the negative half cycle of input voltage.

2.2 INPUT /OUTPUT RELATIONSHIP

2.2.1 IDEAL RELATIONSHIP

The Ideal relationship between input and output means the losses associated with the inductor, capacitor, the switch and the diode is not take into account. The relationship is derived for any half cycle of Buck-Boost regulator and assumed to hold for other half cycle of AC Buck-Boost regulator.

From Fig.40(a), we have

When switch is at 1 for T_{ON} time

$v_L = v_{in}$

When switch is at 2 for T_{OFF} time

$v_L = - v_o$

By voltage second balance,

$$\int_0^{T_{ON}} v_{in}\,dt = -\int_{T_{ON}}^{T} v_0\,dt$$

or, $v_{in} T_{ON} = - v_0 (T - T_{ON})$

$$\text{or} \quad -\frac{v_0}{v_{in}} = \frac{T_{ON}}{T - T_{ON}}$$

$$\text{or} \quad -\frac{v_0}{v_{in}} = -\frac{1}{\frac{T}{T_{ON}} - 1} = -\frac{1}{\frac{1}{D} - 1} = -\frac{D}{1-D}$$

$$v_0 = -\frac{D}{1-D} v_{in} \qquad \dots \quad \dots \quad \dots \qquad (9)$$

If $D < .5$ $\quad v_0 < v_{in}$.(step down)

and $D > .5$ $\quad v_0 > v_{in}$. (step up)

For 100% efficient (ideal) converter

$$\frac{i_0}{i_{in}} = -\frac{1-D}{D} \qquad \dots \quad \dots \quad \dots \qquad (10)$$

Equation (9) & (10) show the ideal relationship of input-output voltage and input-output current respectively. Voltage and current quantities are in time varying form.

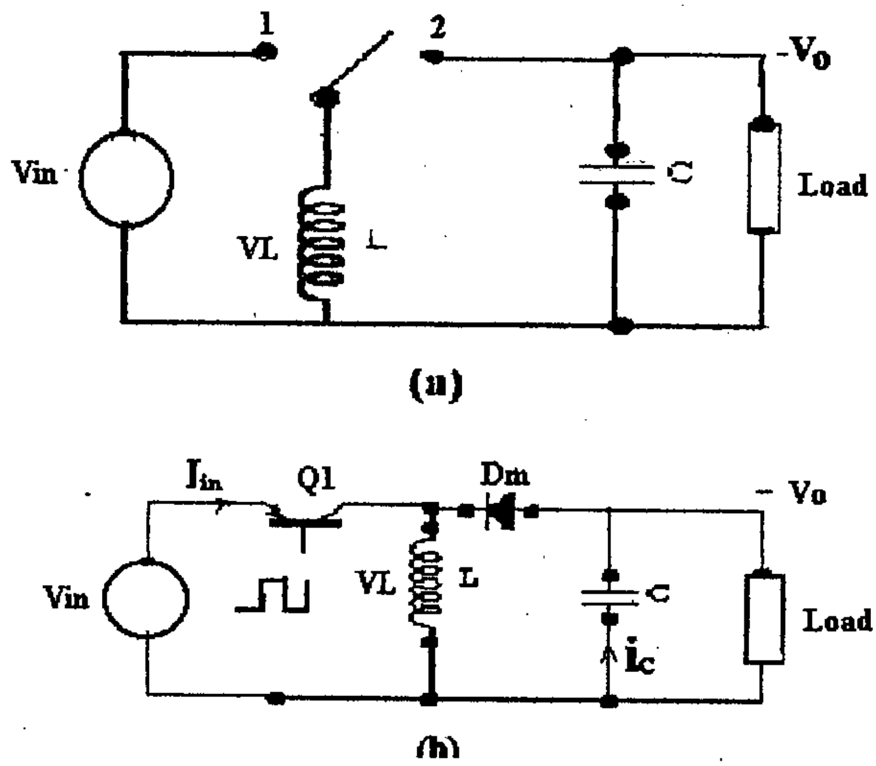


Fig 40 : Buck-Boost Regulator Topologies
a) circuit with an SPDT switch .
b) circuit realization with a BJT and a diode.

The ideal voltage and current gain relationships also hold for rms values as well. That is,

$$V_0 = -\frac{D}{1-D} V_{in}$$

$$I_0 = -\frac{D}{1-D} I_{in}$$

A Buck-Boost regulator of the topology having only one bidirectional switch provides output voltage polarity reversal. Instead if two switches are used cascading individual Buck and Boost regulator, output voltage polarity can be maintained the same.

2.2.2 NON IDEAL RELATIONSHIP

The parasitic in a Buck-Boost regulator are due to nonideal inductor, capacitor, the switch and the diode. The parasitic elements have significant impact on the voltage conversion ratio, efficiency and the stability of the switch mode converters. Fig.41 shows the typical effect of these parasitic elements on voltage gain of an SMPS. The effect of these parasitic elements can be modeled in the circuit simulation programs for designing such converter.

Parasitic Effect on Voltage Gain and Efficiency:

Inclusion of lossy elements in the converter analysis is necessary, since otherwise the results may be qualitatively misleading. The voltage gain of the Buck-Boost converter as obtained in equation (9) becomes infinitely large when the duty ratio D approaches 1, which is not achievable practically. Inclusion of lossy elements in the analysis, such as the parasitic resistance R_l of the inductor, corrects this problem.The efficiency also reduces from the ideal 100 %, because of the loss on the inductor resistance and other components of the regulator. Let the inductor resistance is R_l.

We know,

$$\text{Efficiency} = \frac{P_{out}}{P_{out} + P_{loss}}$$

$$= \frac{I_0^2 R}{I_0^2 + I_l^2 R_l}$$

$$= \frac{1}{1+\left(\frac{I_l}{I_0}\right)^2 \cdot \frac{R_l}{R}} \qquad \text{Let } a = \frac{R_l}{R}$$

For ideally 100% efficient converters, $\frac{I_l}{I_0} = \frac{1}{1-D}$

Therefore efficiency expression becomes

$$\text{efficiency} = \frac{1}{1+a\left(\frac{1}{1-D}\right)^2}$$

$$= \frac{(1-D)^2}{(1-D)^2+a} \qquad \dots \quad \dots \quad \dots \quad (11)$$

We know $\eta = \frac{V_0 I_0}{V_{in} I_{in}}$

or, $\frac{V_0}{V_{in}} = \eta \times I_{in} / I_0$

From equation (10) and (11) we get,

$$\frac{V_0}{Vin} = \frac{(1-D)^2}{(1-D)^2+a} \cdot \frac{D}{(1-D)}$$

$$\frac{V_0}{V_{in}} = \frac{(1-D)D.}{(1-D)^2+a} \qquad \dots \quad \dots \quad \dots \quad (12)$$

The input-output relation which is shown in equation (12) differs from equation (9) due to effect of parasitic elements on the voltage conversion ratio in a Buck-Boost converter.

Effect of Switch Non idealities On Efficiency:

The semiconductor switch may be approximated by two batteries as shown in Fig. 42. One modeling the saturation voltage drop of transistor V_s and the other the forward voltage drop of the diode V_F. Leakage currents in both devices when they are off can safely be neglected. To simplify derivations and observation, we now assume that the inductors are ideal and consider only efficiency loss due to switch non idealities.

From the input and output pulsed current waveforms, the average currents are calculated, and so the efficiency η in

$$\eta = \frac{V_0 D' I_L}{V_{in} D I_L} = \frac{V_0 / V_{in}}{D/D'} = \frac{\text{real voltage gain}}{\text{ideal voltage gain}} \qquad \ldots \quad \ldots \quad \ldots \quad (13)$$

However, in steady-state the voltage-second balance still applies, and results in

$$(V_{in} - V_S)\, DT_S = (V_0 + V_F)\, D'T_S \qquad \ldots \quad \ldots \quad \ldots \quad (14)$$

Substitution of (14) in (13) results,

$$\eta = \frac{Vin - V_S}{Vin} \, \frac{V_0}{V_0 + V_F} \qquad \ldots \quad \ldots \quad \ldots \quad (15)$$

In the special cases of the Buck-Boost converter, this result could have been obtained from consideration of "input" and "output" circuit efficiency η_I and η_0, respectively.

$$\eta_I = \frac{(V_{in} - V_S) I_{in}}{V_{in} I_{in}} = \frac{V_{in} - V_S}{V_{in}}$$

$$\eta_0 = \frac{V_0 I_{out}}{(V_0 + V_F) I_{out}} = \frac{V_0}{V_0 + V_F}$$

$$\eta = \eta_I \, \eta_0$$

The form of the result (15) leads to a general conclusion:
High efficiency is difficult to obtain even with switching converters when either input or output voltages are low and comparable to transistor and diode drops.

2.3 UNCONTROLLED AC BUCK-BOOST REGULATOR - Ideal Switch Implementation

The proposed uncontrolled AC Buck-Boost regulator made of ideal switches and proper circuit elements is shown in Fig.43. In this regulator, output voltage across the load may be kept constant irrespective of increase or decrease in the input voltage and change in load by controlling the duty cycle of gate pulses manually or by control circuits. The constant output is achieved by using PWM technique which is manually controlled initially. Output pulse width of OPAMP is varied by changing DC control voltage to the OPAMP. The variable pulse width controls the switches S_1 and S_2.

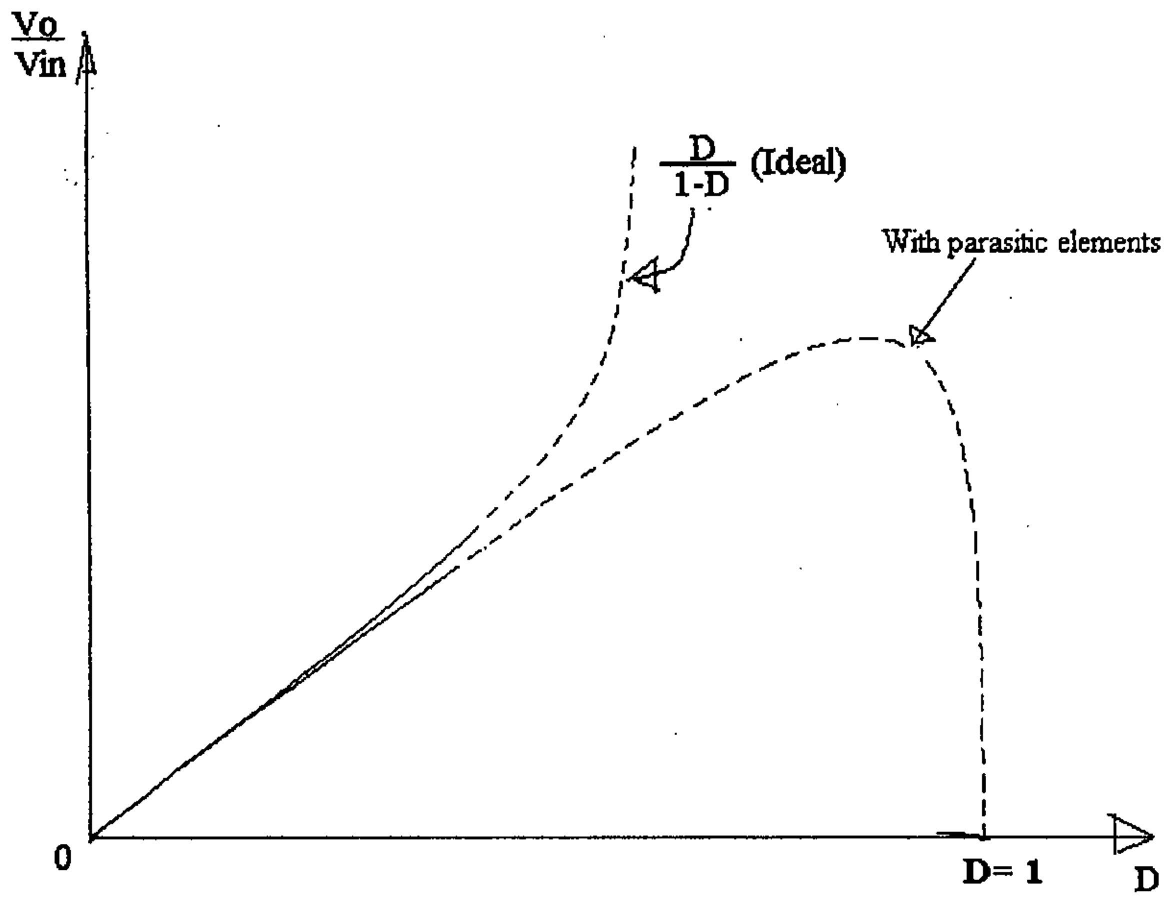


Fig 41 **Effect of parasitic elements on the voltage conversion ratio in Buck-Boost regulator**

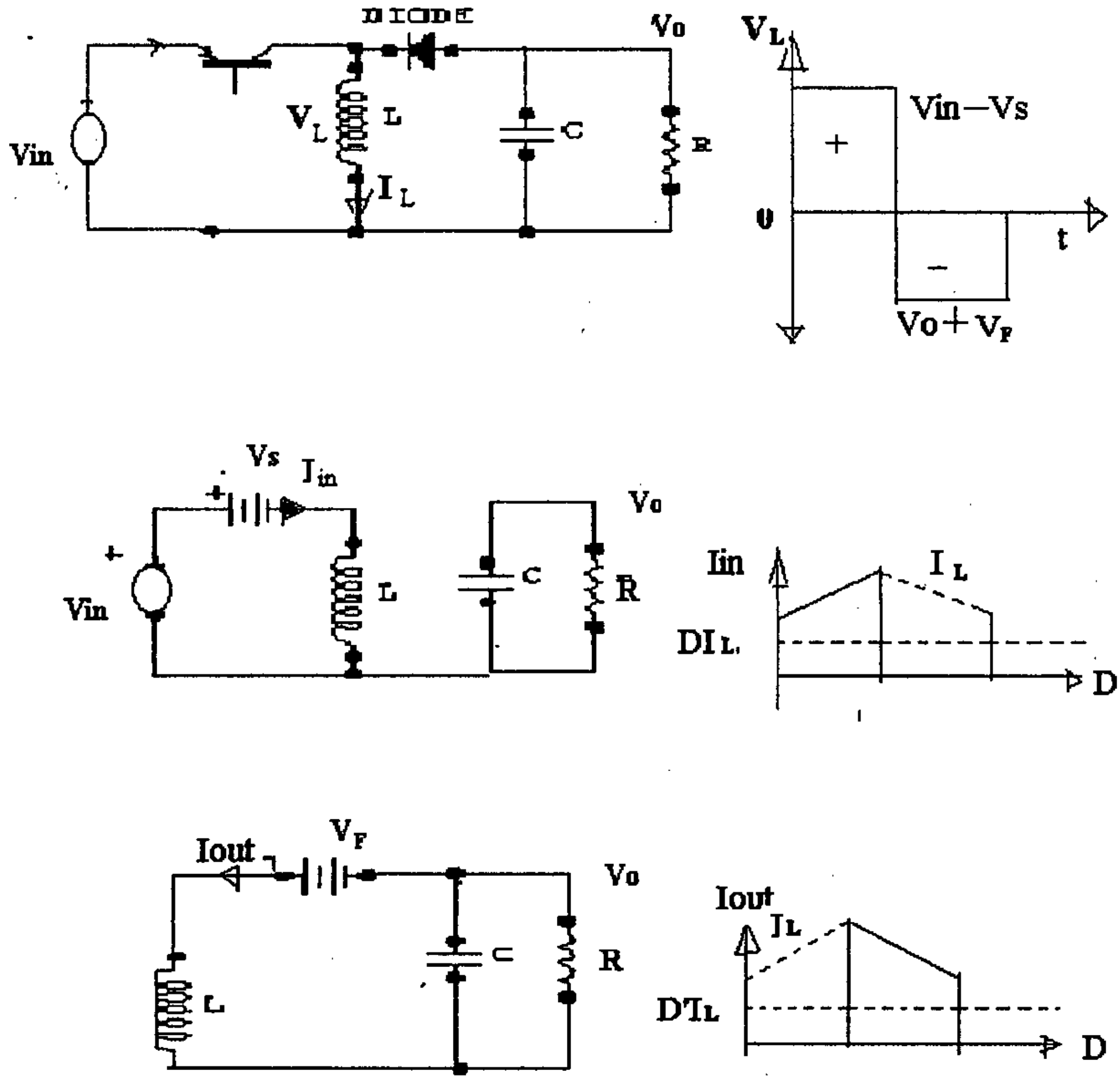


Fig 42 Buck-Boost regulator efficiency in presece of switch non-idealities (non-zero transistor and diode voltage drops).

By changing ON/OFF time of switches S_1 and S_2, output voltage across the load can be maintained constant for any change of input voltage and load. In this work our objective is to keep output voltage always 300V corresponding to 230Vrms. Fig.44 shows that the voltage waveforms when the input voltage is 250V then output voltage is 300V. Fig.45 shows that the voltage waveforms when the input voltage is 300V then output is voltage 300V. Fig.46 shows that the voltage waveforms when the input voltage is 400V then the output voltage are 300V. So both Buck and Boost operation has done the required regulation. Voltage regulation during load change is discussed in section 2.3.2.

2.3.1 GATE SIGNAL GENERATING CIRCUIT FOR UNCONTROLLED AC BUCK-BOOST REGULATOR

The gate signal generating circuit for uncontrolled AC Buck-Boost regulator is shown in Fig.47. The control circuit shows an OPAMP whose inputs are a saw-tooth wave and a DC voltage. OPAMP acts as comparator. Output of the OPAMP depends on the difference of two inputs. Viz. $(V_+ - V_-)$. In this circuit positive input (saw-tooth wave) is kept fixed and negative input (DC voltage) is varied. So, output pulse width depends on DC input voltage of OPAMP. Fig.48 shows the input voltage waveforms and output gate signal of OPAMP when input DC voltage is 8V. Fig.49 shows the input voltage waveforms and output gate signal of the OPAMP when the input DC voltage is 4V. Comparing Figs.48 and 49 it is clear that the output pulse widths of OPAMP are smaller than when the input DC is less. Variation of pulse width controls the duty cycle. Output signal of OPAMP is passed through two limiters. One directly inputs the limit2. The function of limit2 is to limits the magnitude of signal from 0v-10v without change of the shape or pulse width of signal. The output of limit2 is the gate signal for switch S_1. When switch S_1 is ON then switch S_2 is OFF. So the gate signal generating circuit is arranged in such a way that when gate signal for switch S_1 is ON then gate signal for switch S_2 is OFF and vise versa. For this reason output of OPAMP is multiplied by (-1) using a gain unit. Output of the gain passes through the limit1. The output gate pulses of limit1 are of magnitude 0-10 V which is the gate signal for switch S_2.

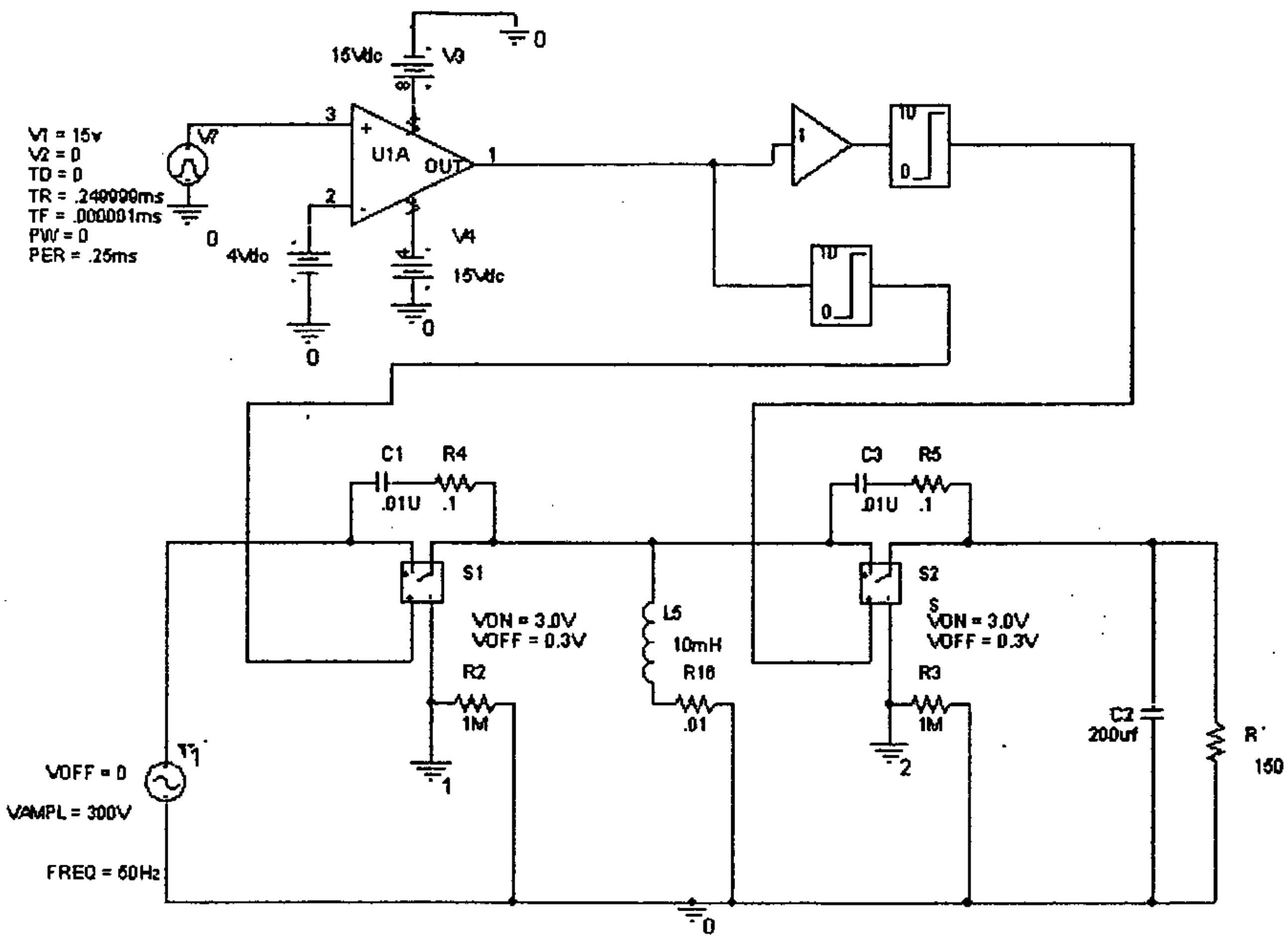


Fig 43: Uncontrolled Ac Buck- Boost regulator implemented by ideal switch

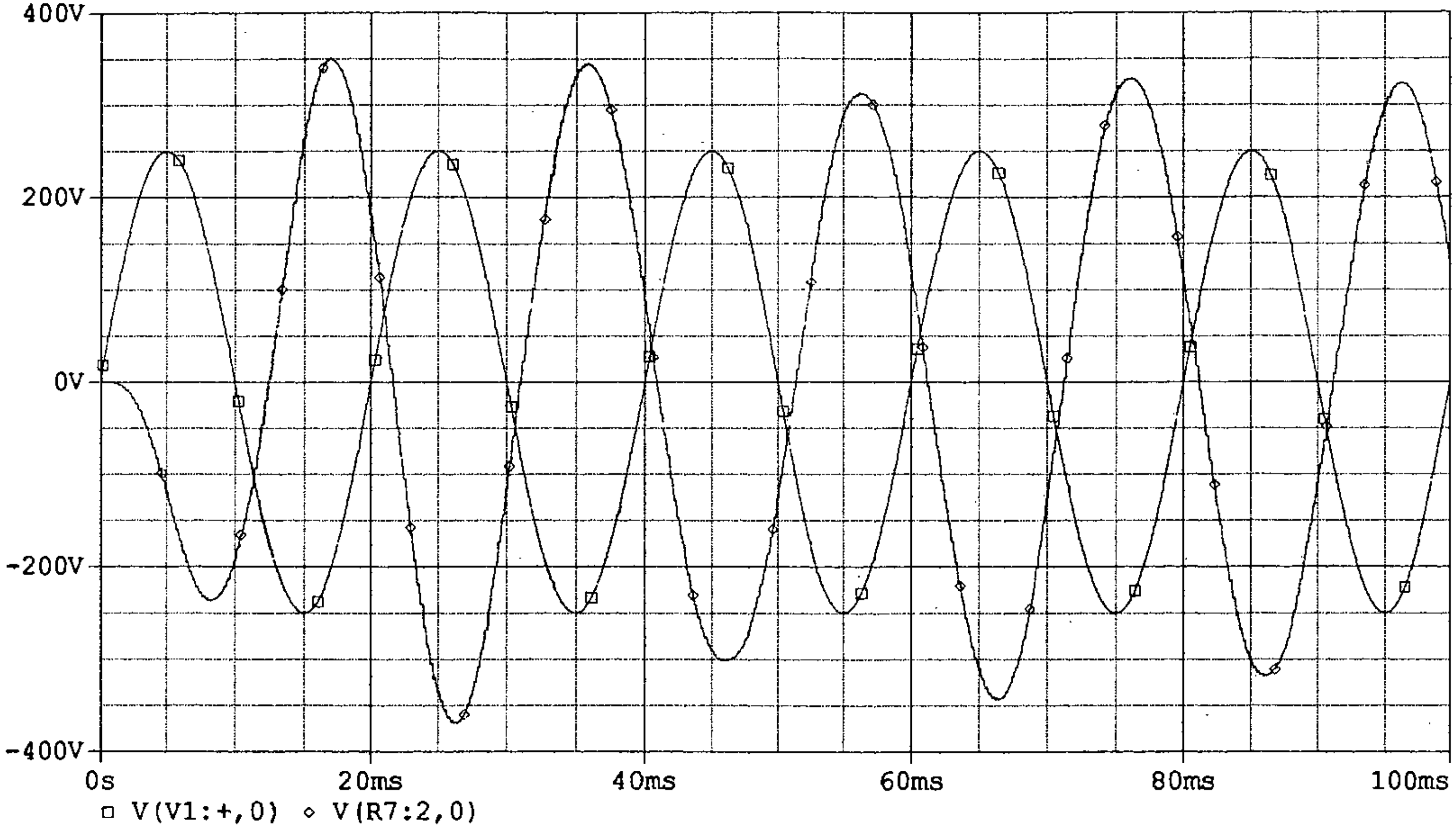


Fig. 44 Input- output voltage waveforms when input voltage=250 and load =100 Ohm and output voltage =300V

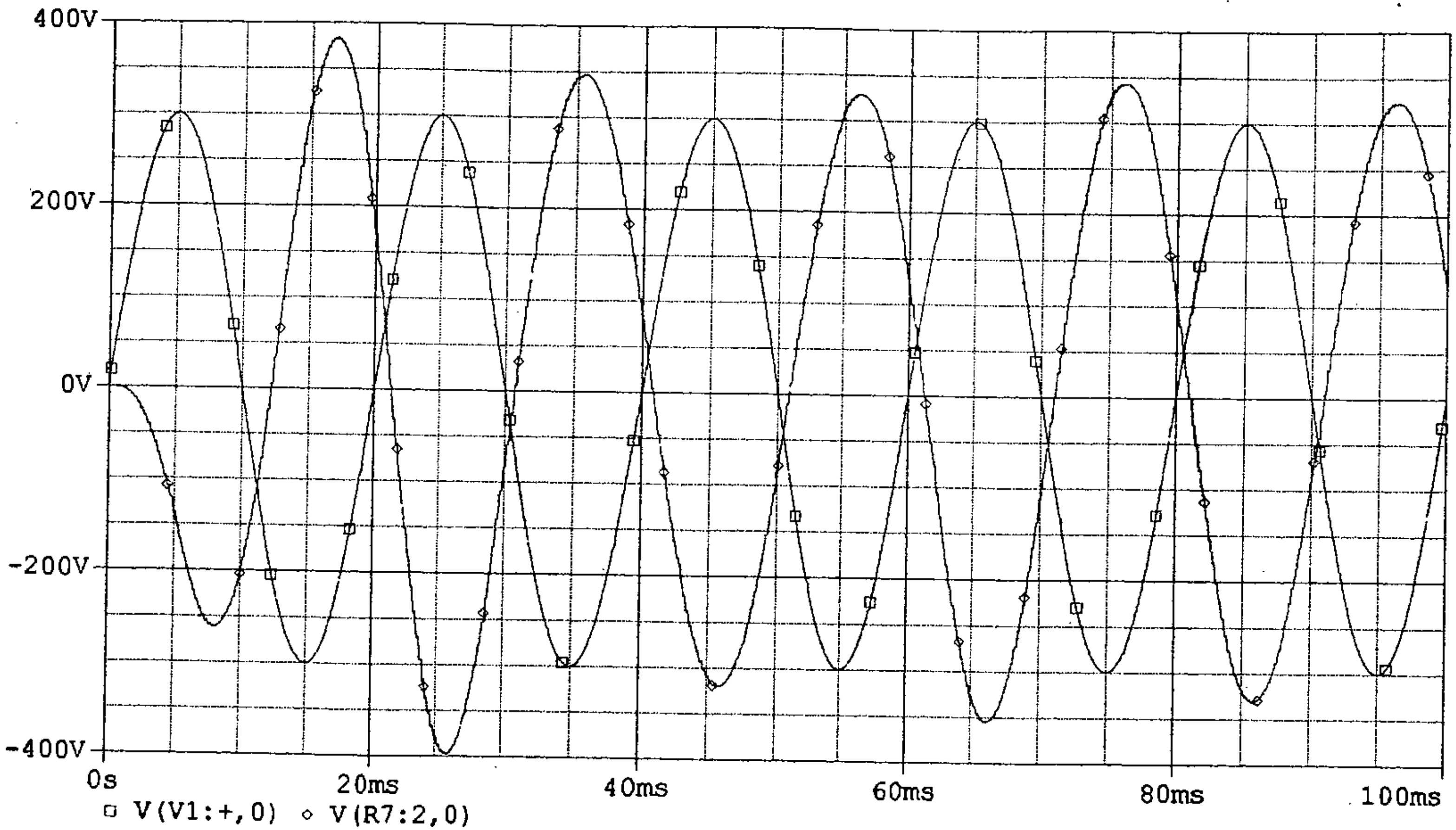


Fig. 45 Input- output voltage waveforms when input voltage=300V and load =100 Ohm and output voltage =300V

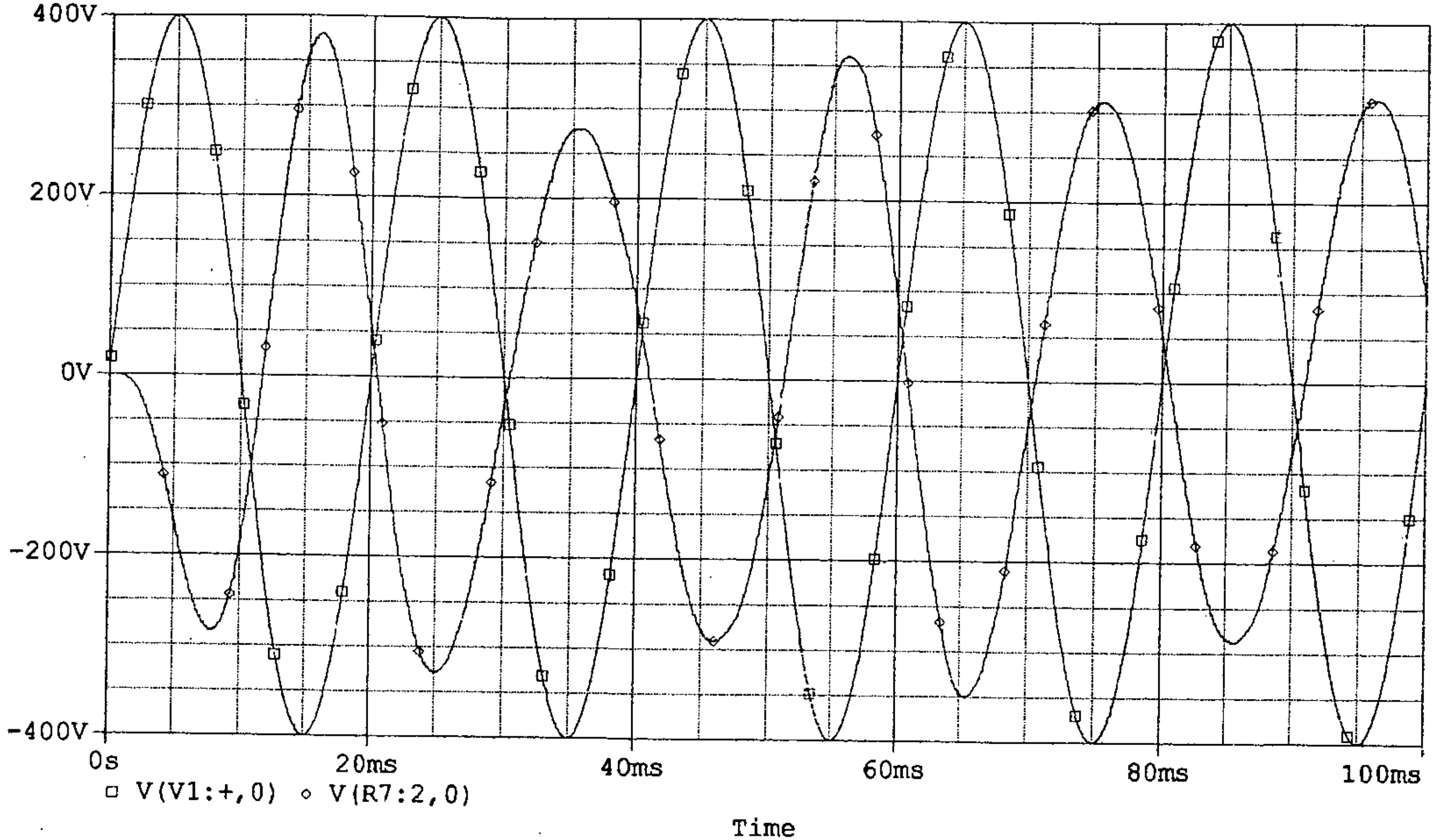


Fig. 46 Input- output voltage waveforms when input voltage=400V and load =100 Ohm and output voltage =300V

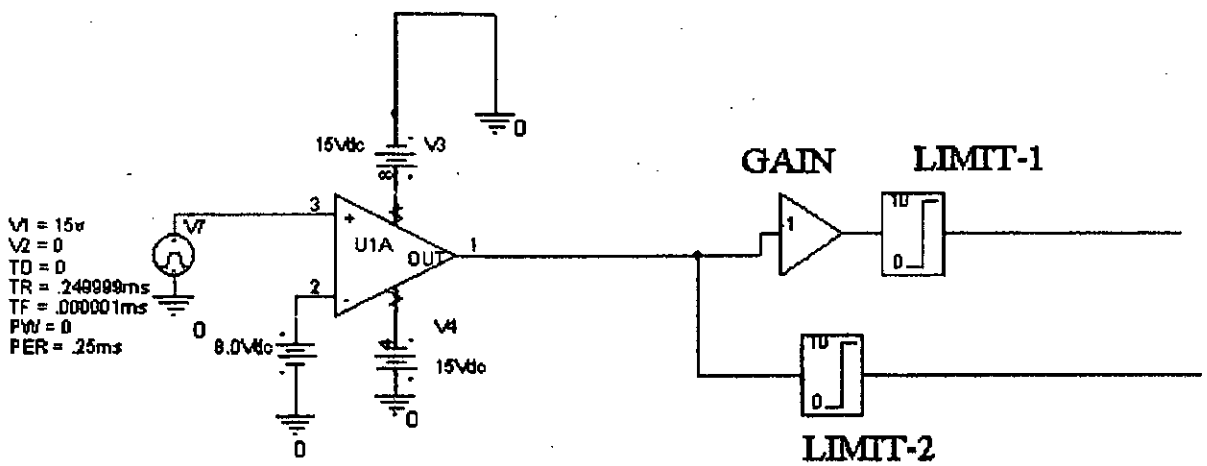


Fig.47 Gate signal generating circuit for uncontrolled AC Buck-Boost regulator.

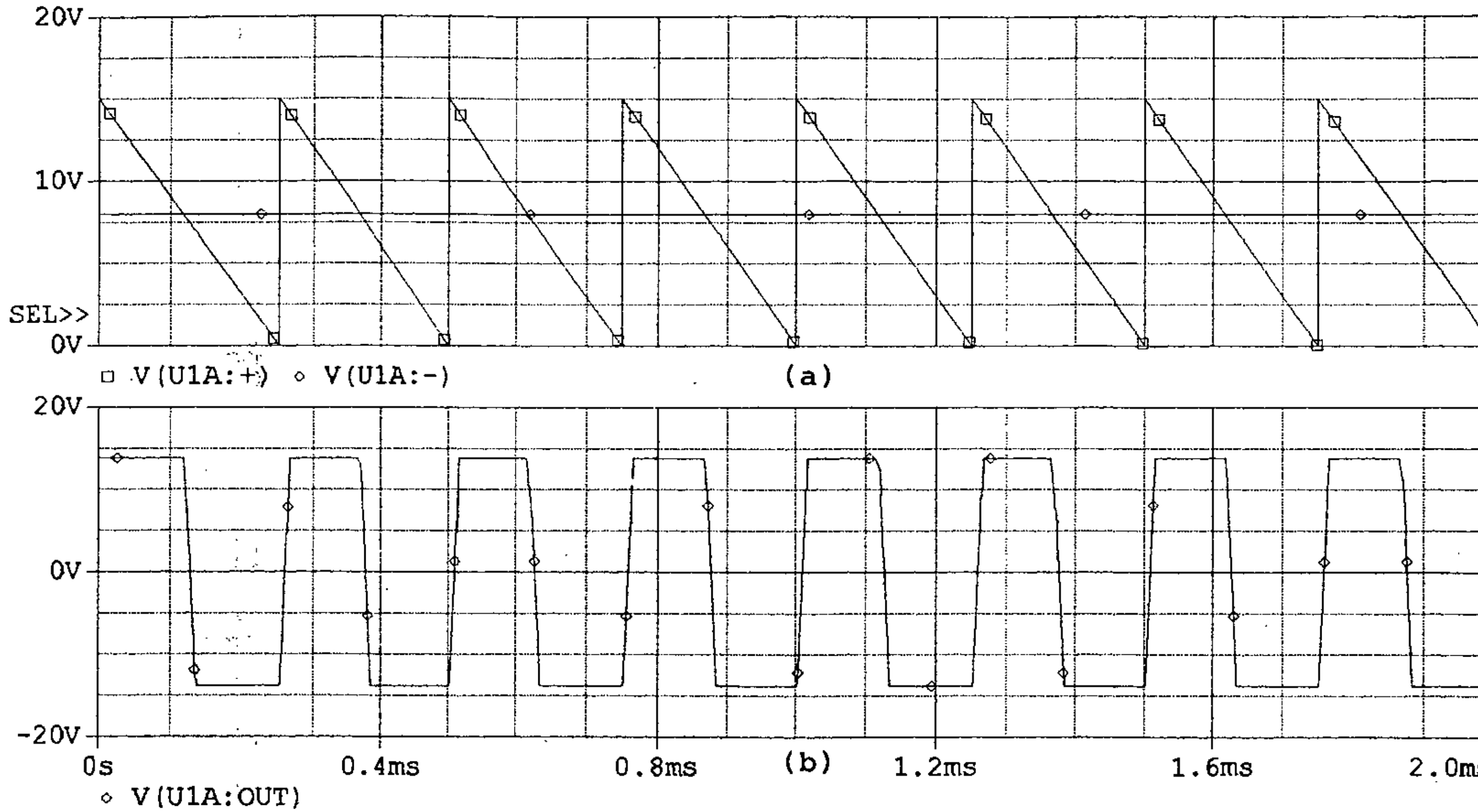


Fig. 48 Waveforms of manual control circuit when DC = 8V
(a) Saw-tooth wave and Dc waves
(b) Gating pulses of one switch

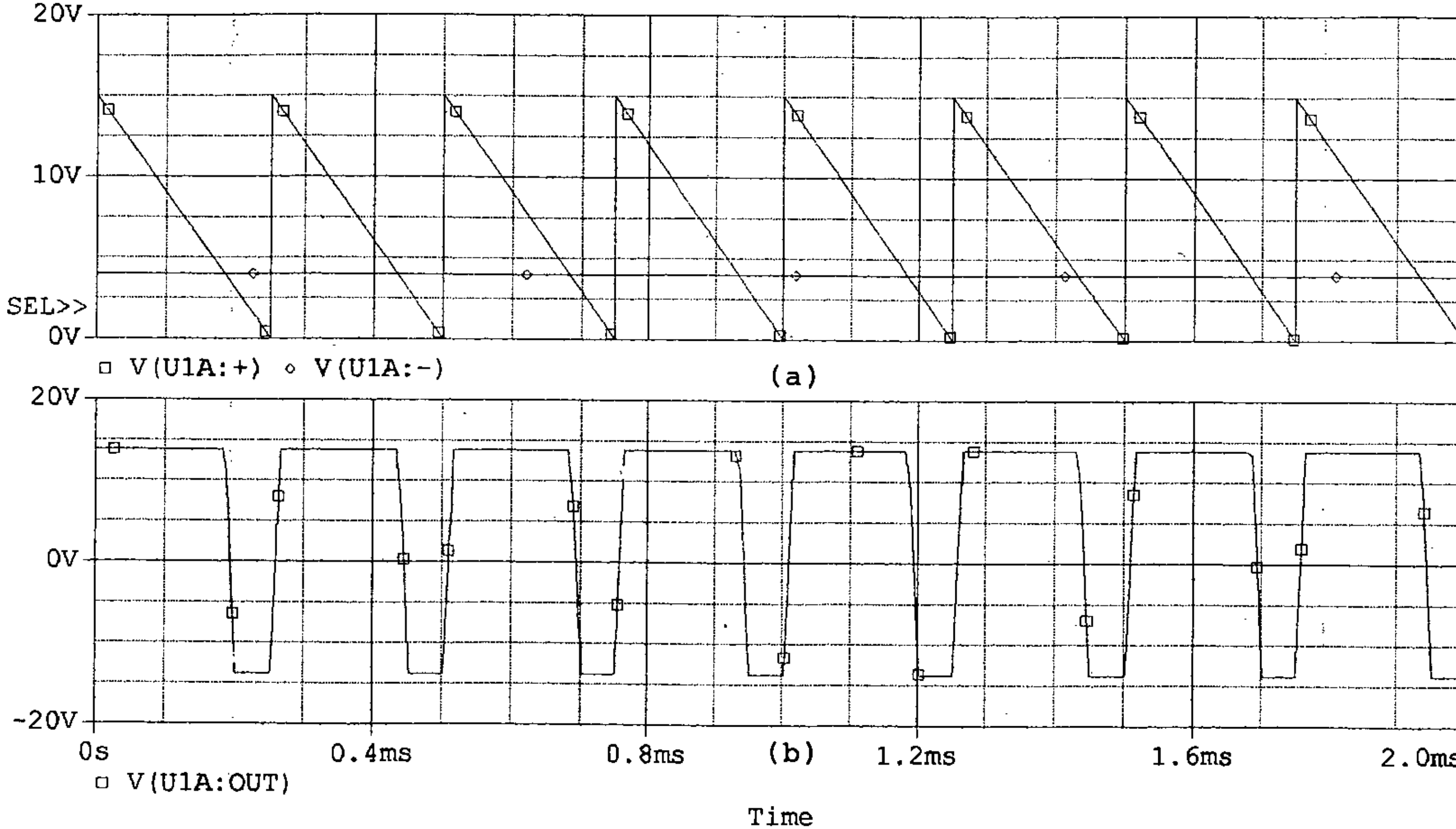


Fig. 49 Waveforms of manual control circuit when DC = 4V
(a) Saw-tooth wave and Dc waves
(b) Gating pulses of one switch

For DC 8V the output pulses of OPAMP (input of limit2) and output of limit2 are shown in Fig.50. The input of the gain, output of the gain and output pulse of limit1 are shown in Fig.51. For DC 4V the output pulses of OPAMP (input of limit2) and output of limit2 are shown in Fig.52. The input of the gain, output of the gain and output pulse of limit1 are shown in Fig.53. The OPAMP input, output and gate pulses at limit1 and limit2 for input voltage 250V, 300V and 400V to keep output voltage 300V are shown in Figs.54, 55, 56(for input 250V), Figs.57, 58, 59(for input 300V), and Figs.60, 61, 62(for input 400V) respectively.

2.3.2 RESULTS OF UNCONTROLLED AC BUCK-BOOST REGULATOR (Ideal Switch Implementation)

When input voltage is 250V and load is varied 50 Ohm to150 Ohm, it is seen that output is 300Vas shown in Fig.63 and Fig. 64 respectively. When input voltage is 300V and load is varied from 50 Ohm to 150 Ohm, it is seen that the output is 300 V as shown in Fig.65 and Fig 66 respectively. When input voltage is 400V and load is varied 50 Ohm to 150 Ohm, it is seen that output is 300 V as shown in Fig.67 and Fig. 68 respectively. When input varies as 250 V, 300V and 400V and load is 100 Ohm, then output remains constant at 300 V as already been shown Figs. 44, 45 and 46 respectively. From the results it is seen that due to input voltage change or load change output voltage across the load can be maintained constant by changing the pulse width of gate signals of switches S_1 and S_2.

2.4 CONTROLLED AC BUCK-BOOST REGULATOR (Practical Switch Implementation)

Controlled AC Buck-Boost regulator implemented with IGBTs as Switches is shown in Fig 69. Comparing AC Buck-Boost regulator implemented with ideal switch which is shown in Fig. 43 and practical AC Buck-Boost regulator as shown in Fig 69 (a) and (b), it can be observed that the ideal S-break switch is replaced by 4 diode bridge and 1one IGBT switch. Limits are replaced by a diode and a resistance. Since it is desired that when gate signals for IGBT-1 is ON when gate signal for IGBT-2 should be OFF, two optocouplers are used. Connection of optocouplers with IGBT switches are such that when gate signal of IGBT-1 is ON then gate signal of IGBT-2 is OFF and vice-

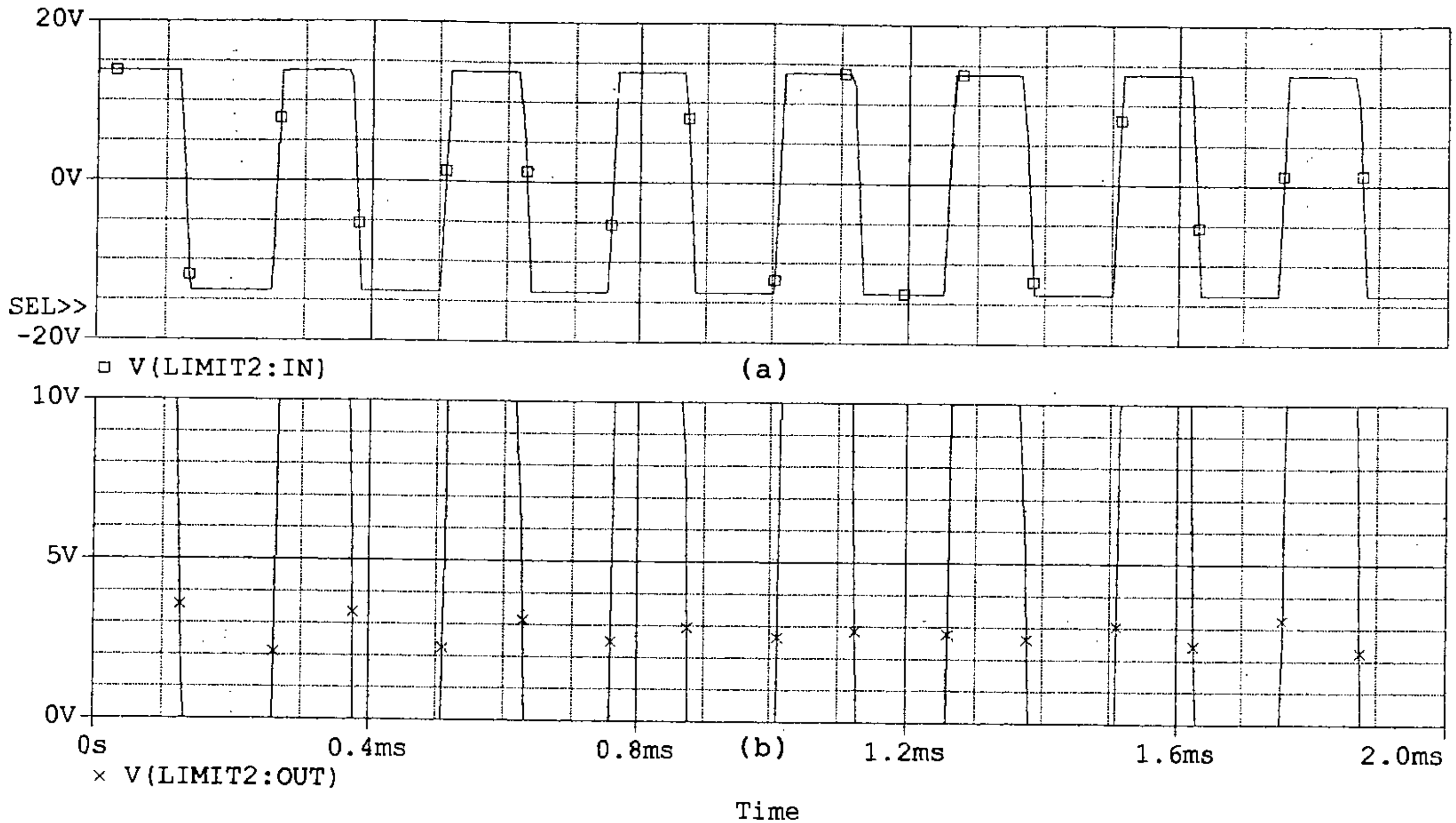


Fig.50 Gate pulses for DC = 8V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

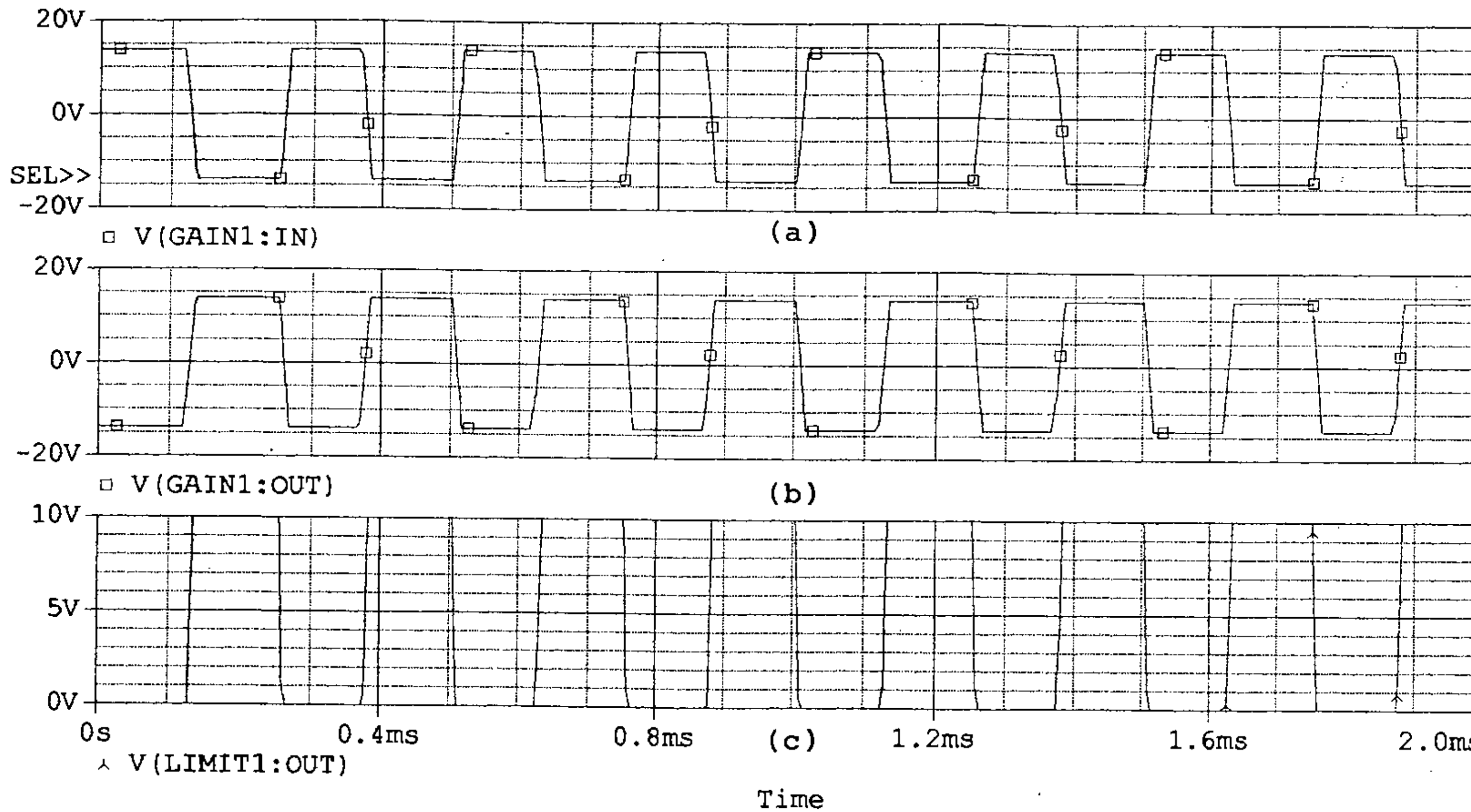


Fig.51 Gate pulses for DC = 8V
(a) GAIN1 : IN
(b) GAIN1 : OUT
(c) LIMIT1 : OUT

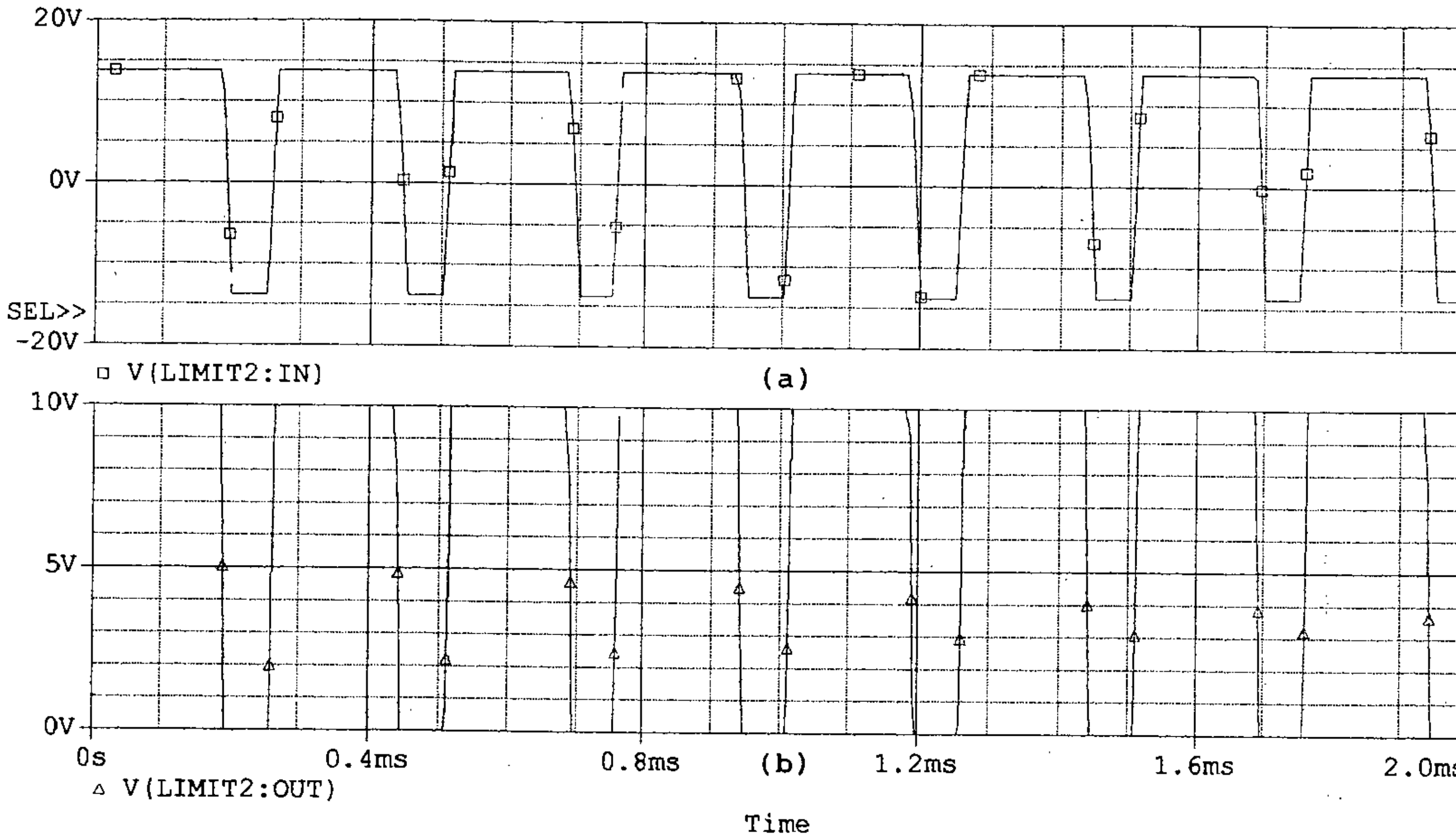


Fig.52 Gate pulses for Dc = 4V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

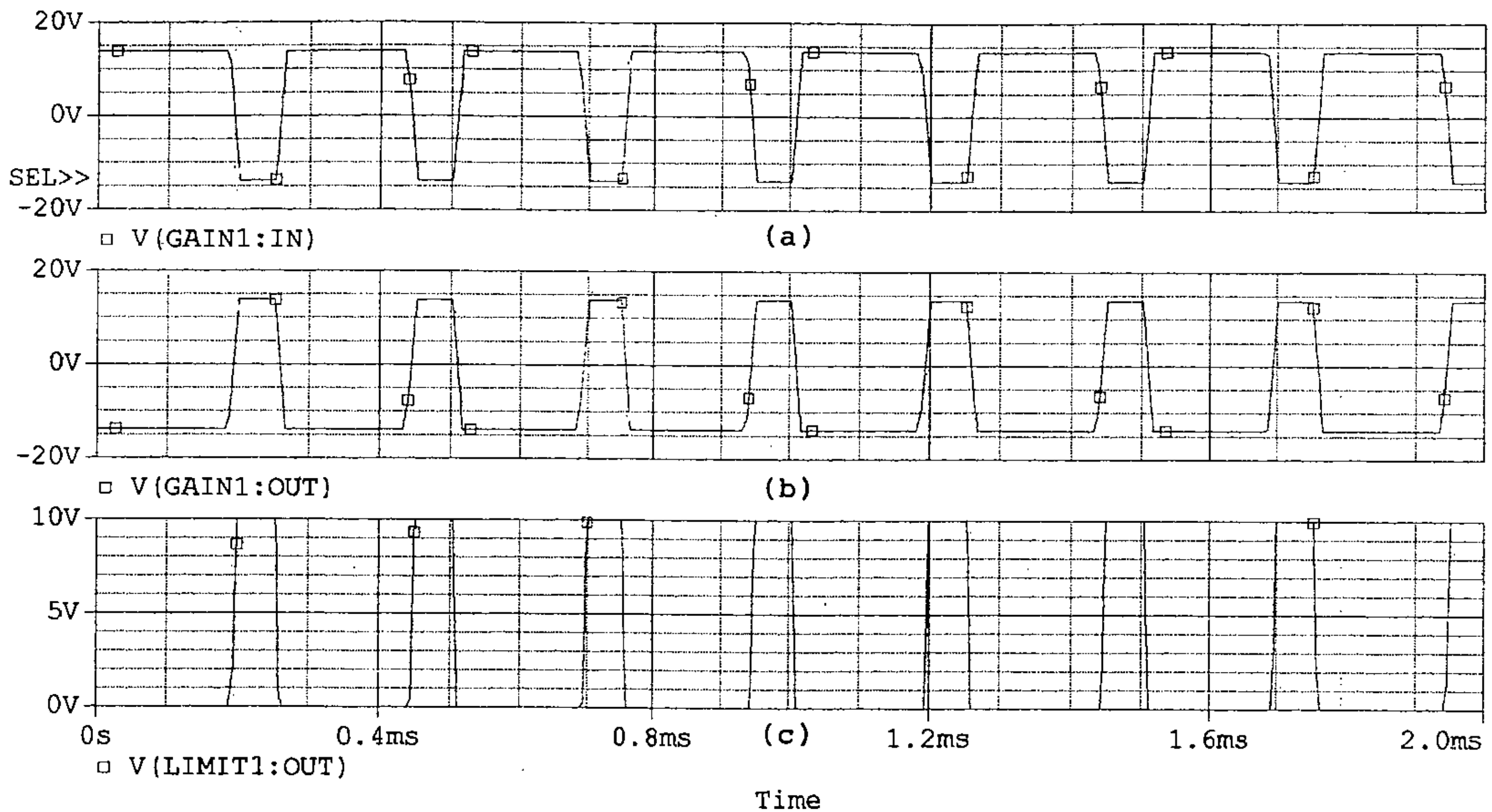


Fig.53 Gate pulses for DC = 4V

(a) GAIN1 : IN

(b) GAIN1 : OUT

(c) LIMIT1 : OUT

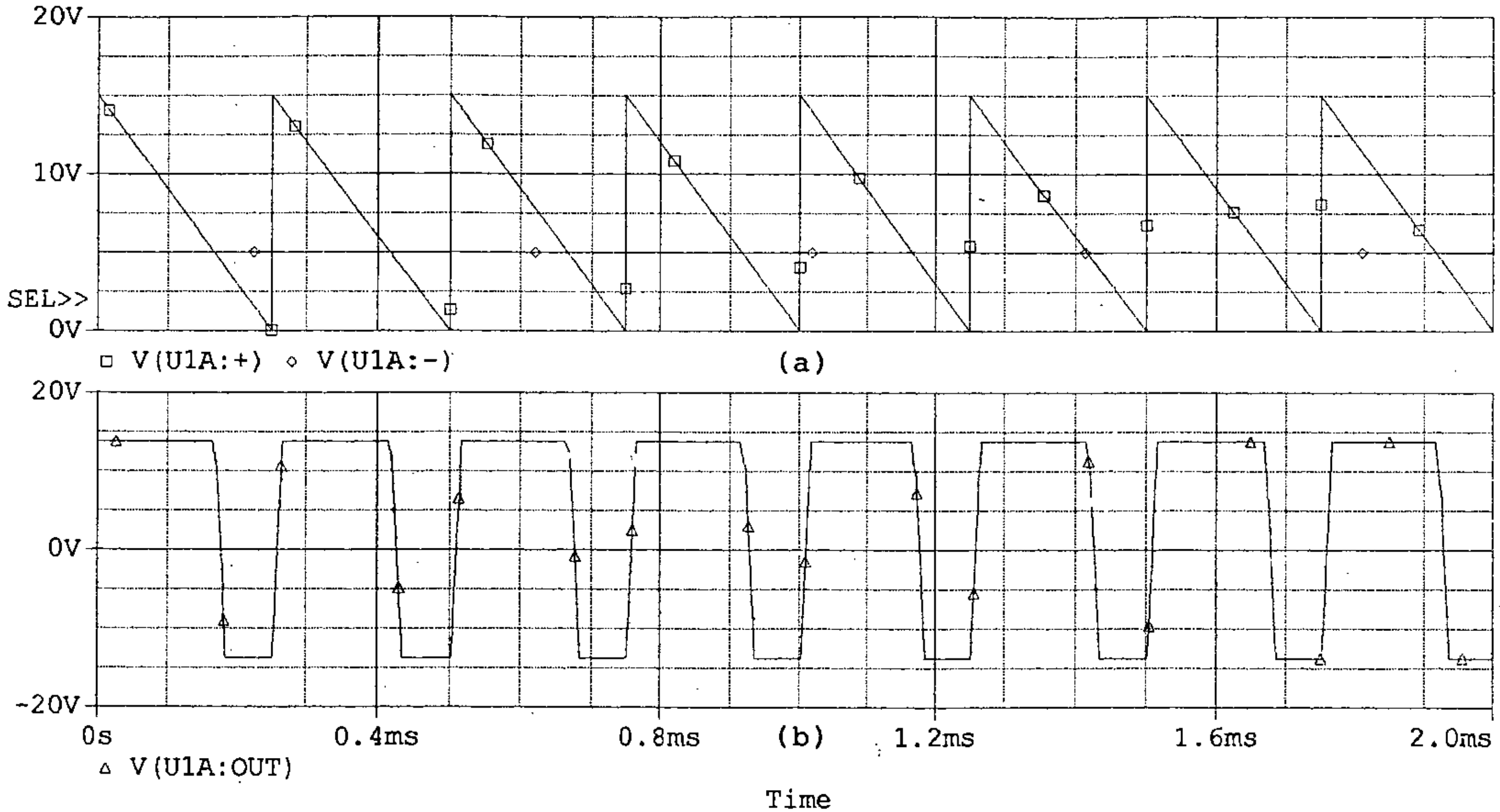


Fig.54 Gate pulses for input voltage = 250V and output voltage = 300V
(a) Saw-tooth and DC waves
(b) Gating pulses of one switch

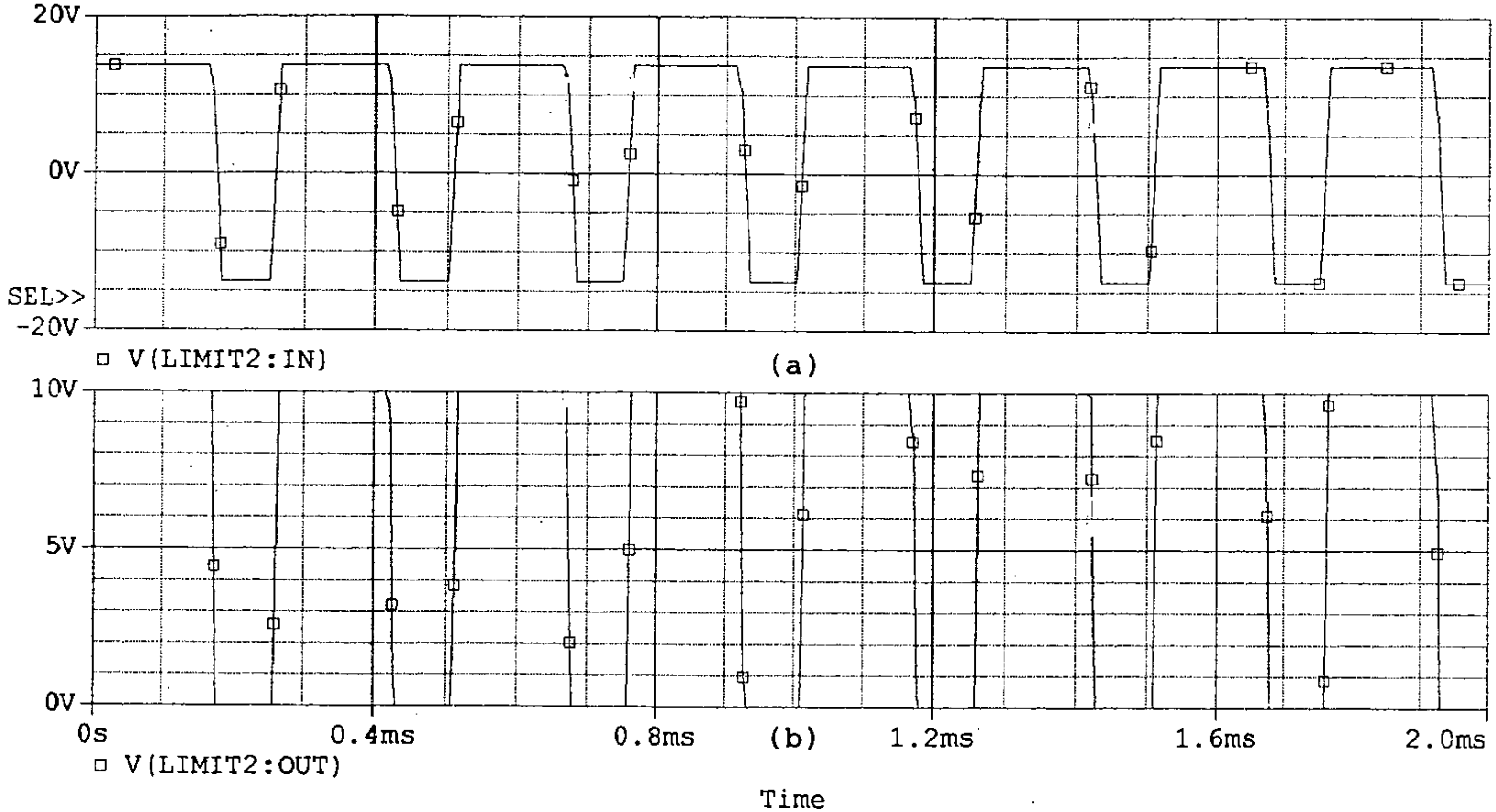


Fig.55 Gate pulses for input voltage = 250V and output voltage = 300V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

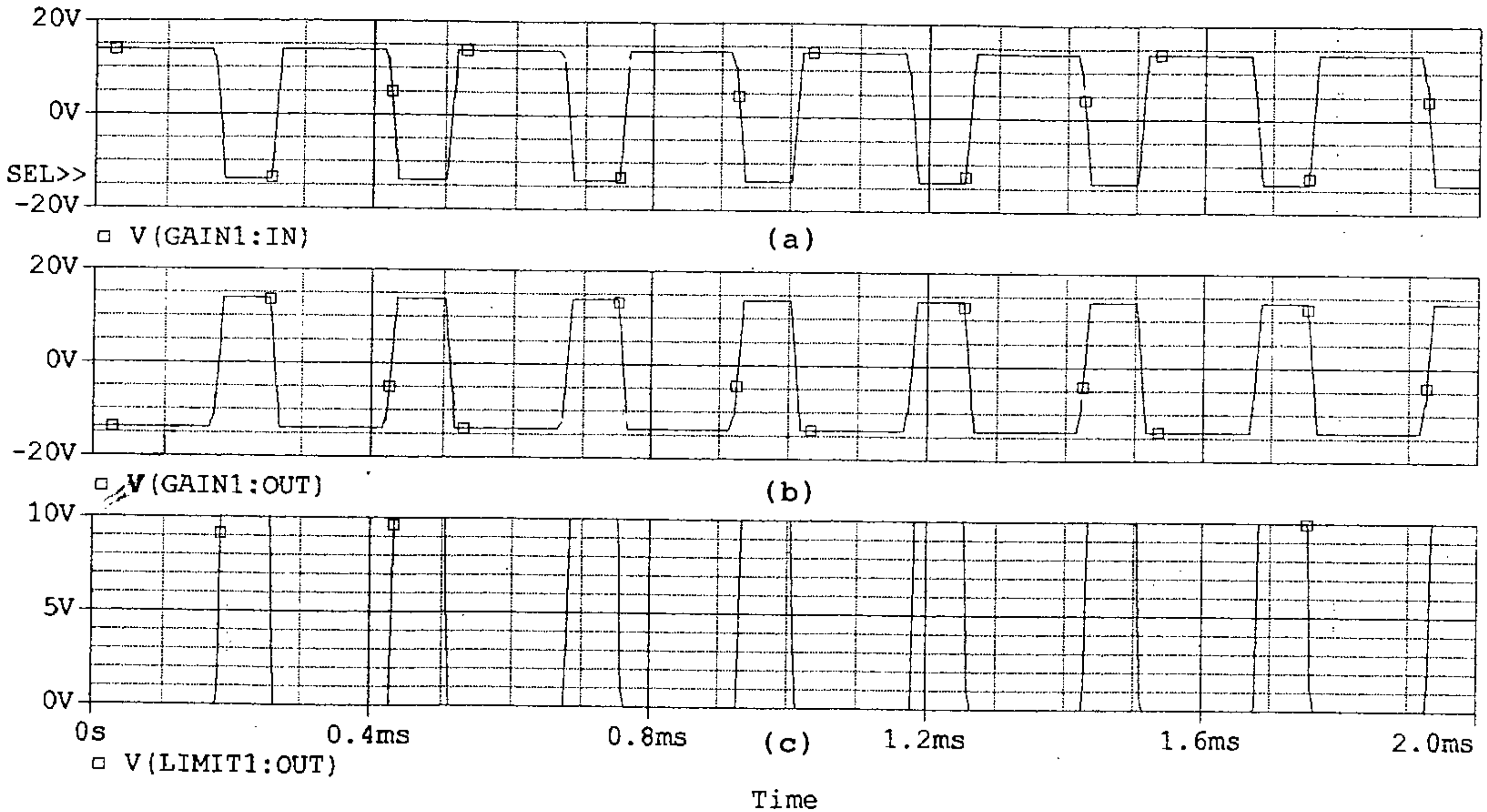


Fig.56 Gate pulses for input voltage = 250V and output voltage = 300V
(a) GAIN1 : IN
(b) GAIN1 : OUT
(c) LIMIT1 : OUT

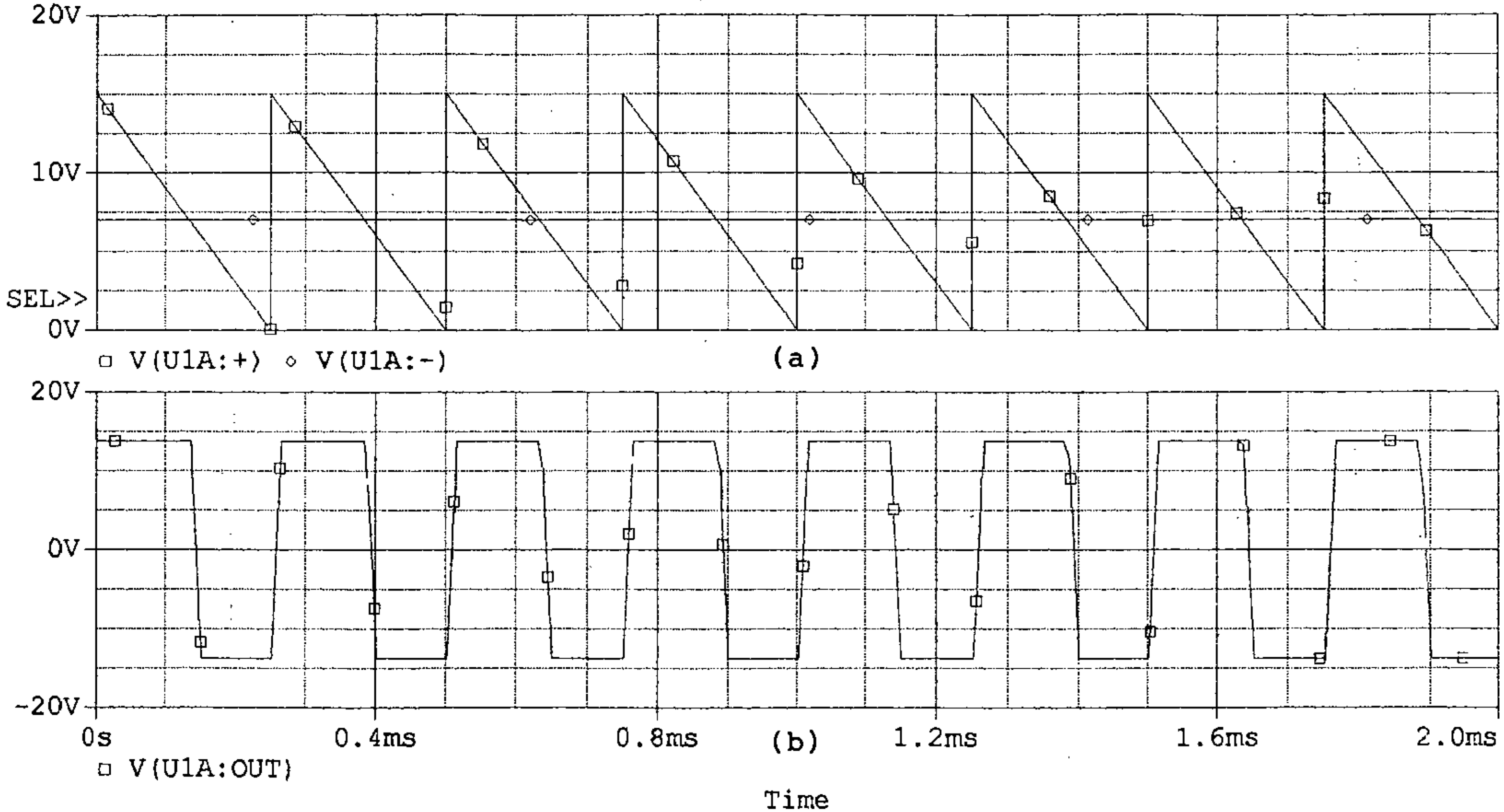


Fig.57 Gate pulses for input voltage = 300V and output voltage = 300V
(a) Saw-tooth and DC waves
(b) Gating pulses of one switch

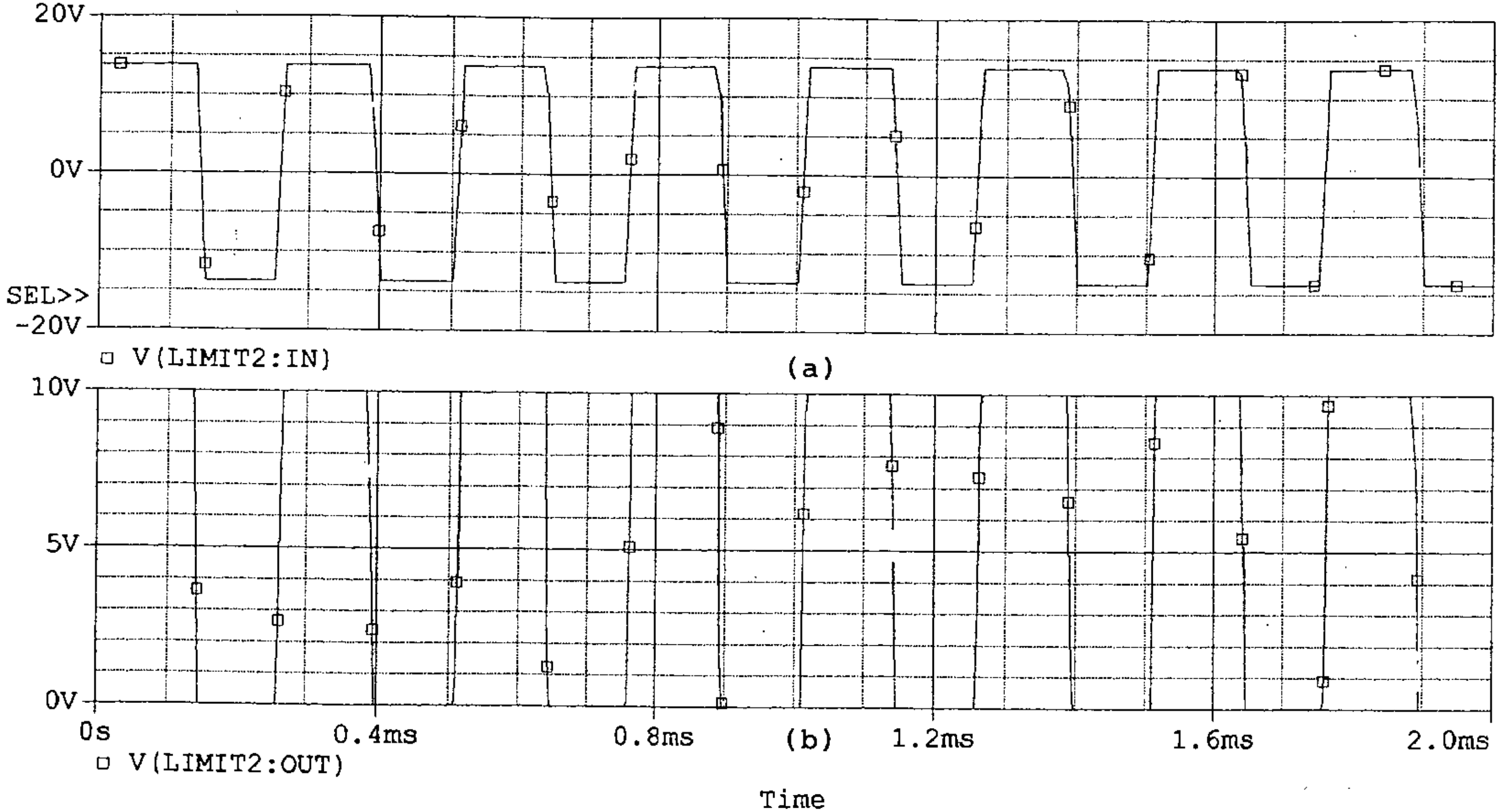


Fig.58 Gate pulses for input voltage = 300V and output voltage = 300V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

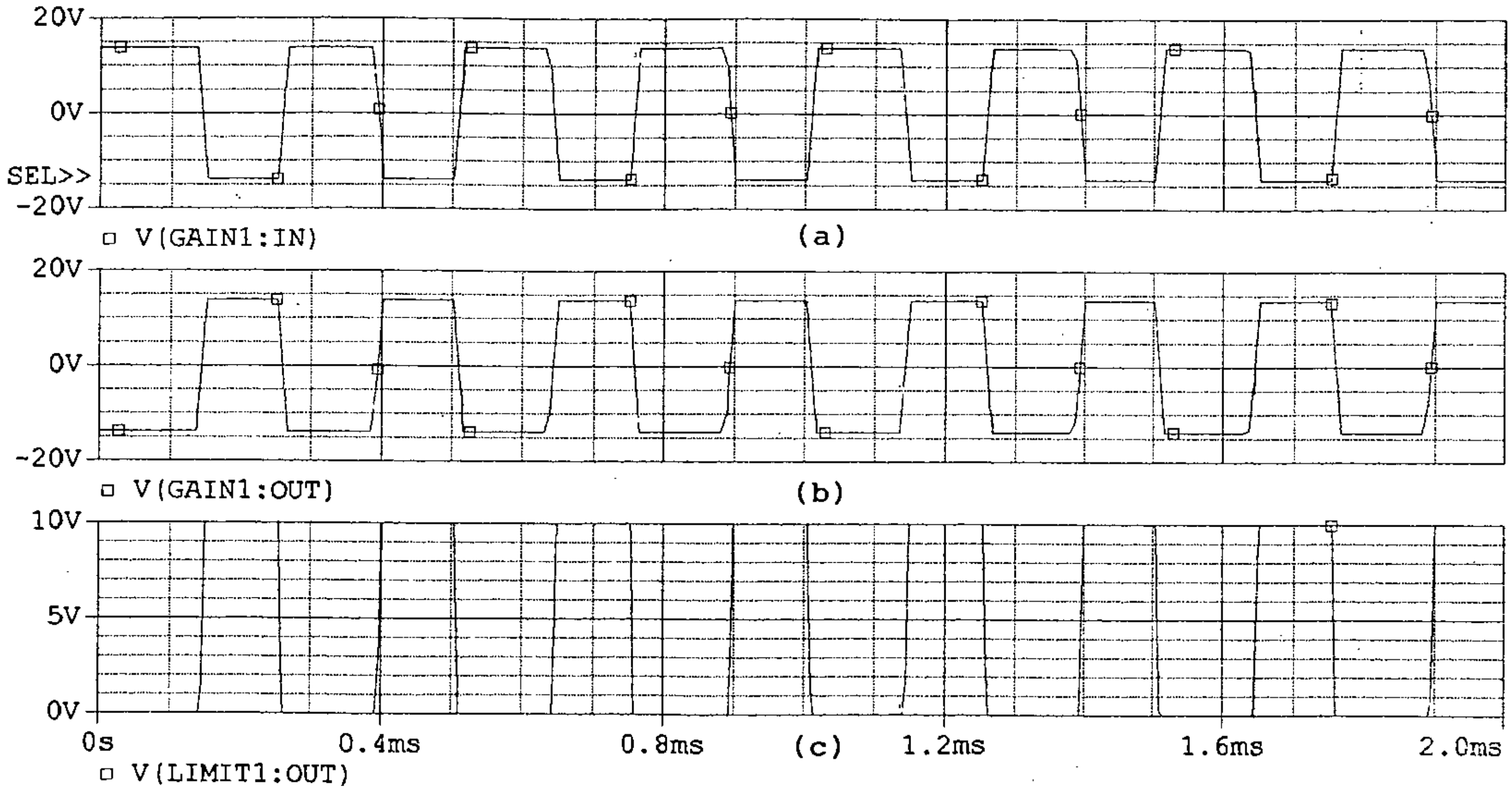


Fig.59 Gate pulses for input voltage = 300V and output voltage = 300V

(a) GAIN1 : IN

(b) GAIN1 : OUT

(c) LIMIT1 : OUT

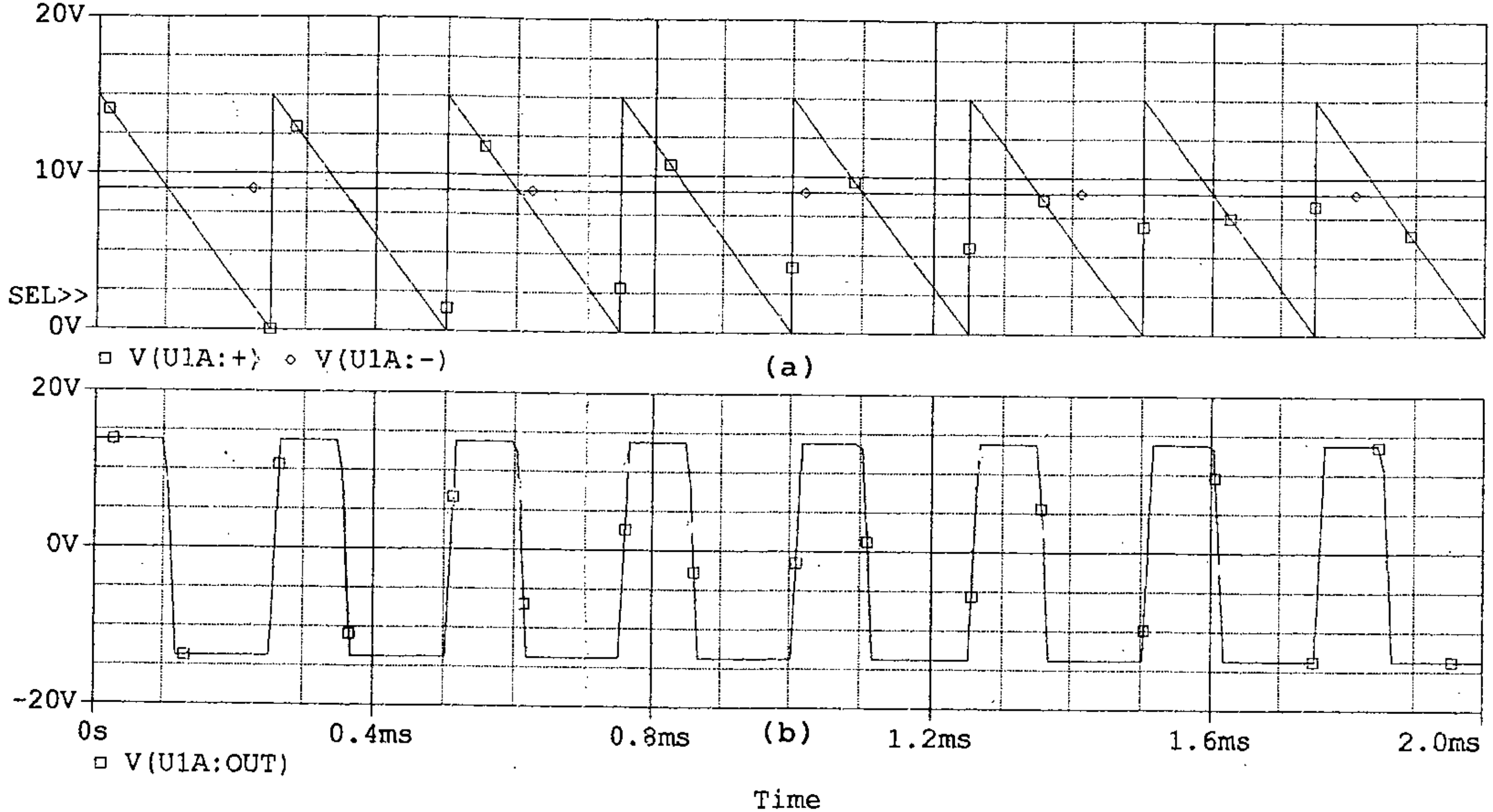


Fig.60 Gate pulses for input voltage = 400V and output voltage = 300V
(a) Saw-tooth and DC waves
(b) Gating pulses of one switch

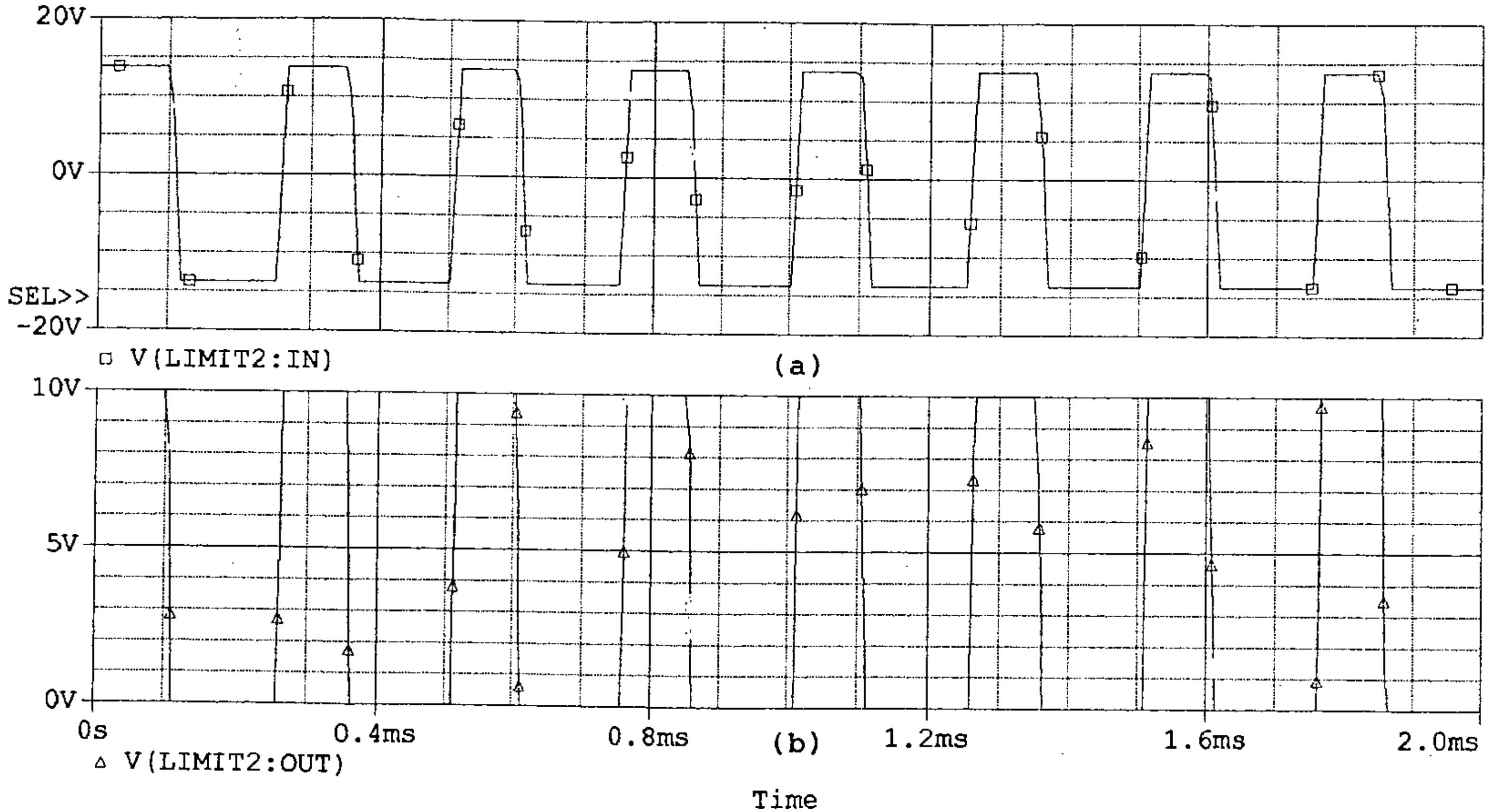


Fig.61 Gate pulses for input voltage = 400V and output voltage = 300V
(a) LIMIT2 : IN
(b) LIMIT2 : OUT

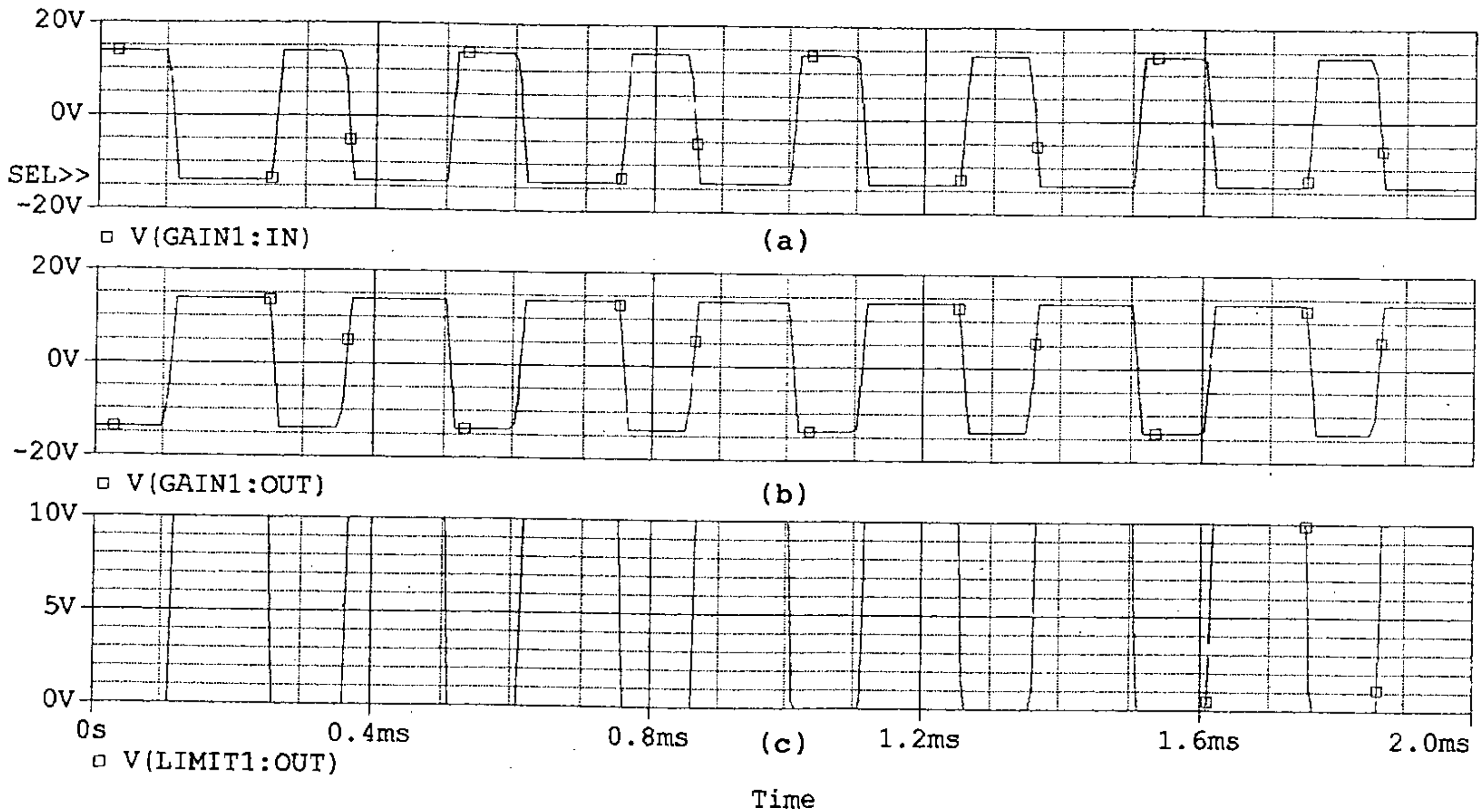


Fig.62 Gate pulses for input voltage = 400V and output voltage = 300V
(a) GAIN1 : IN
(b) GAIN1 : OUT
(c) LIMIT1 : OUT

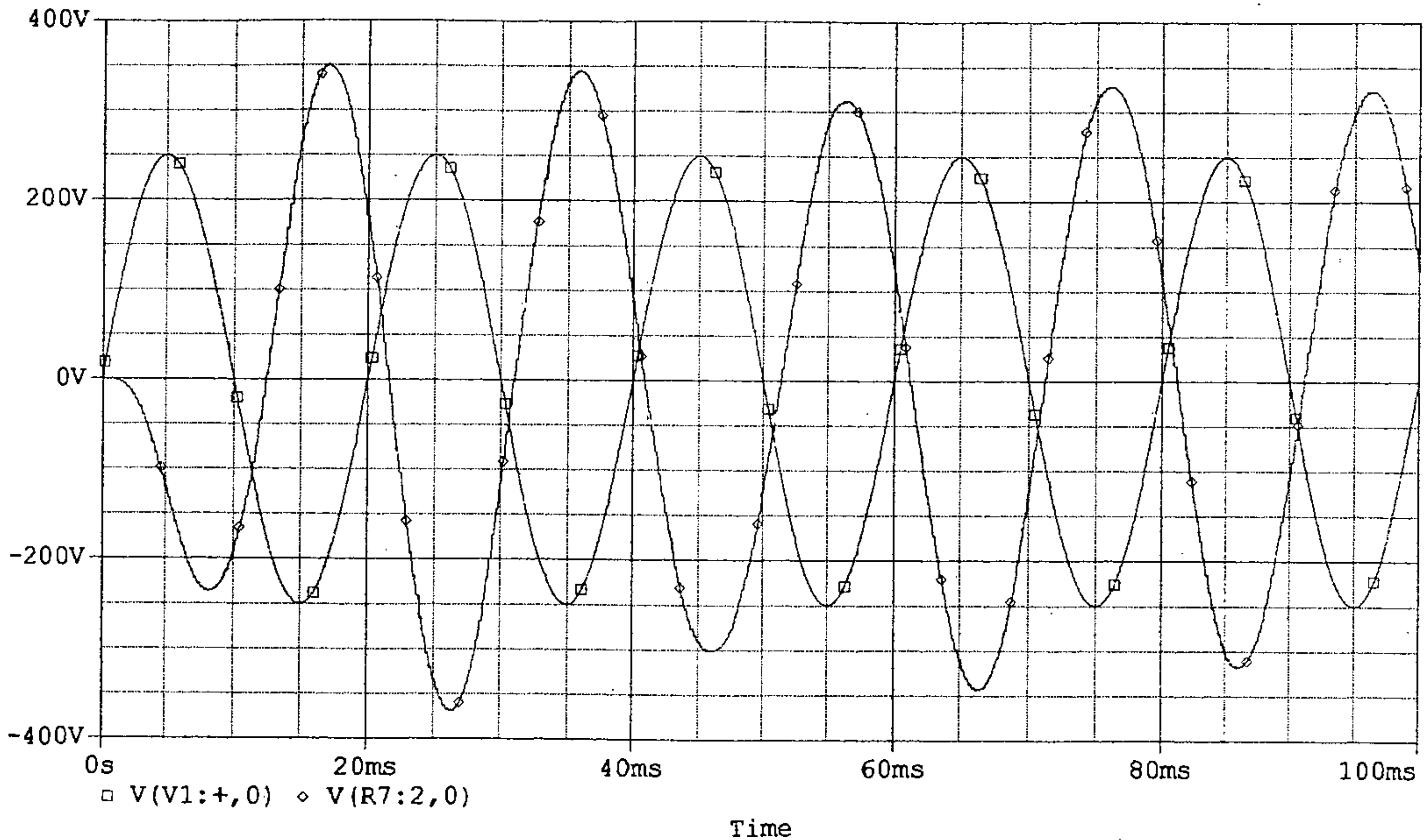


Fig. 63 Input- output voltage waveforms when input voltage=250 and load =50 Ohm and output voltage =300V

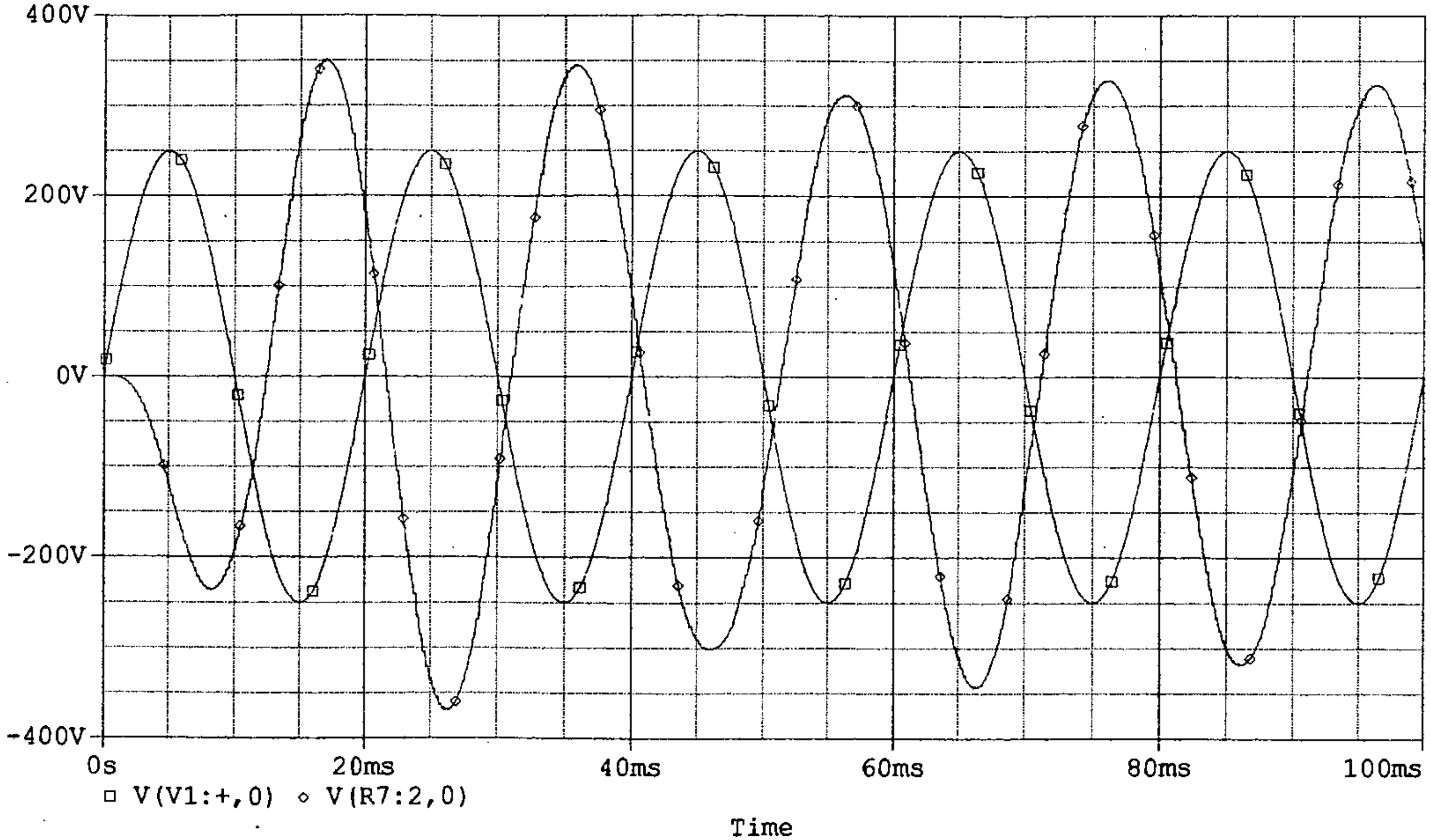


Fig. 64 Input- output voltage waveforms when input voltage=250 and load =150 Ohm and output voltage =300V

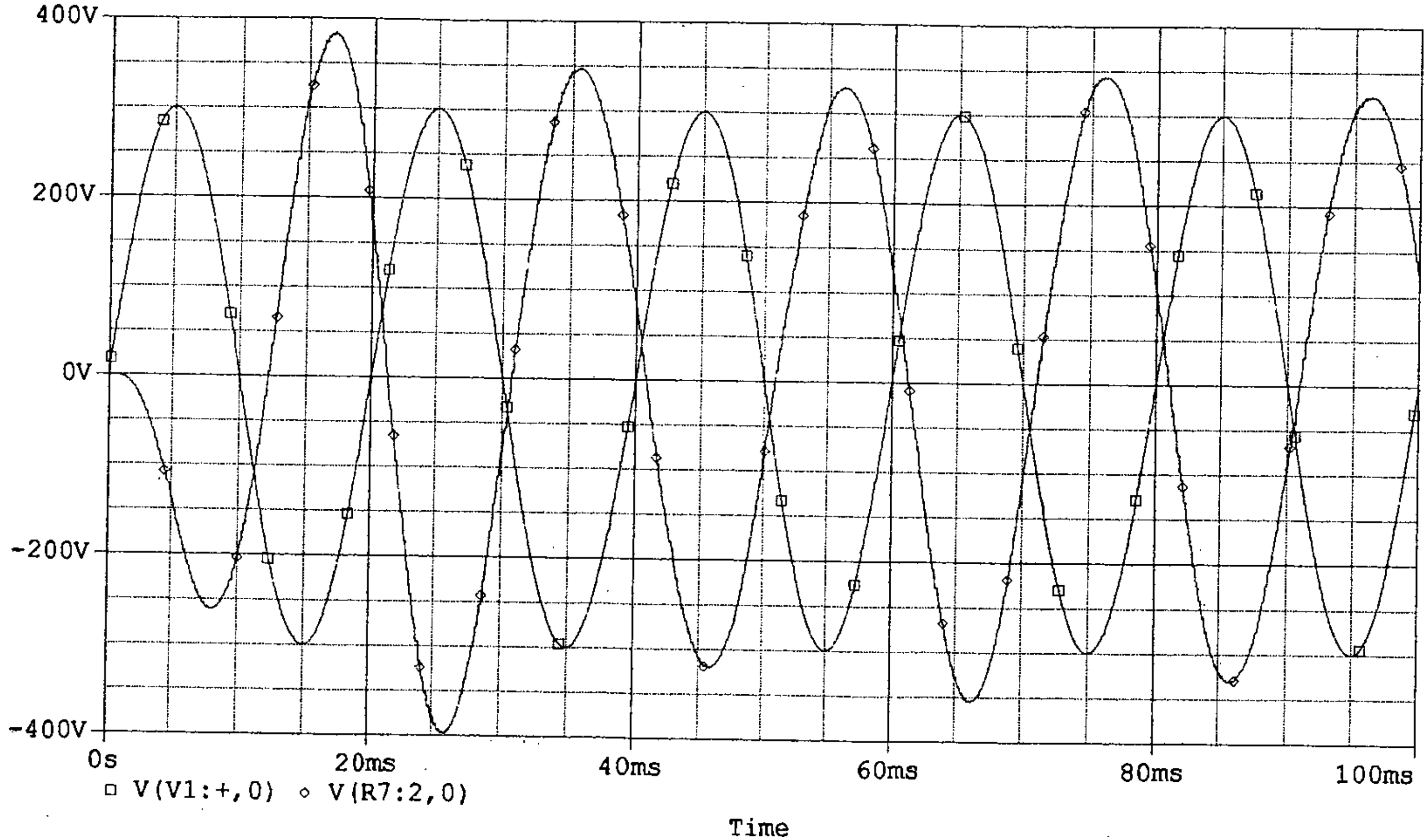


Fig. 65 Input- output voltage waveforms when input voltage=300V and load =50 Ohm and output voltage =300V

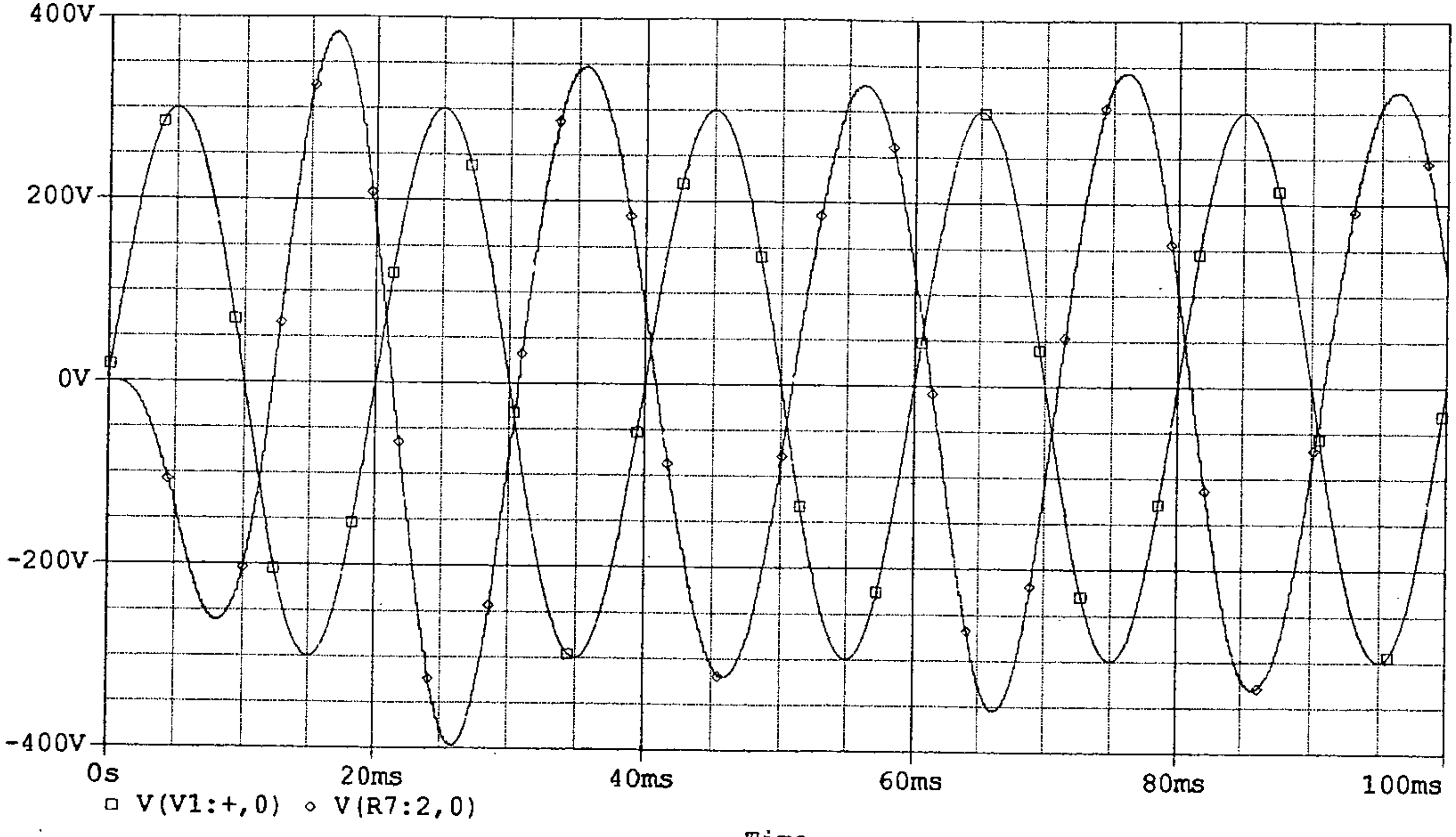


Fig. 66 Input- output voltage waveforms when input voltage=300V and load =150 Ohm and output voltage =300V

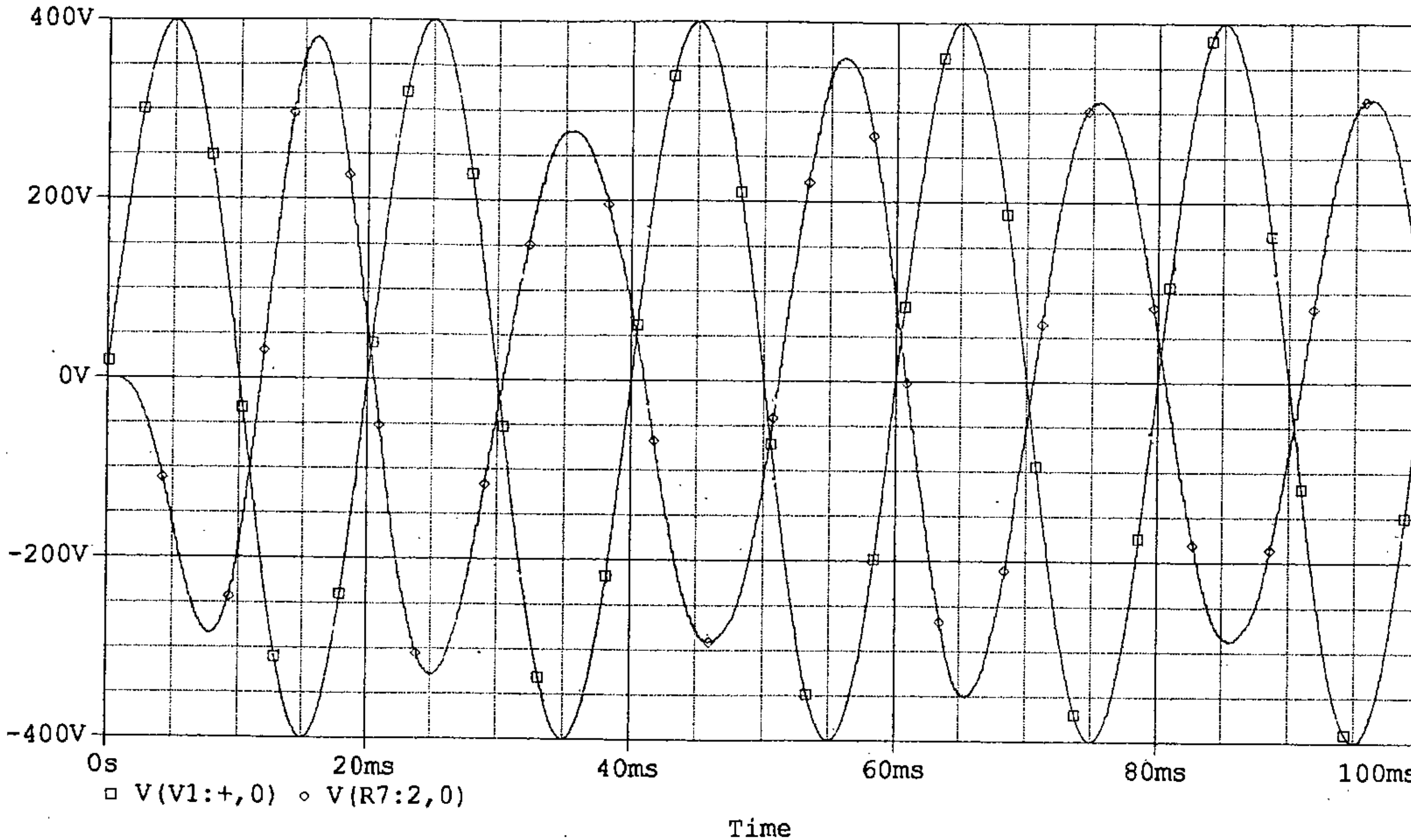


Fig. 67 Input- output voltage waveforms when input voltage=400V and load =50 Ohm and output voltage =300V

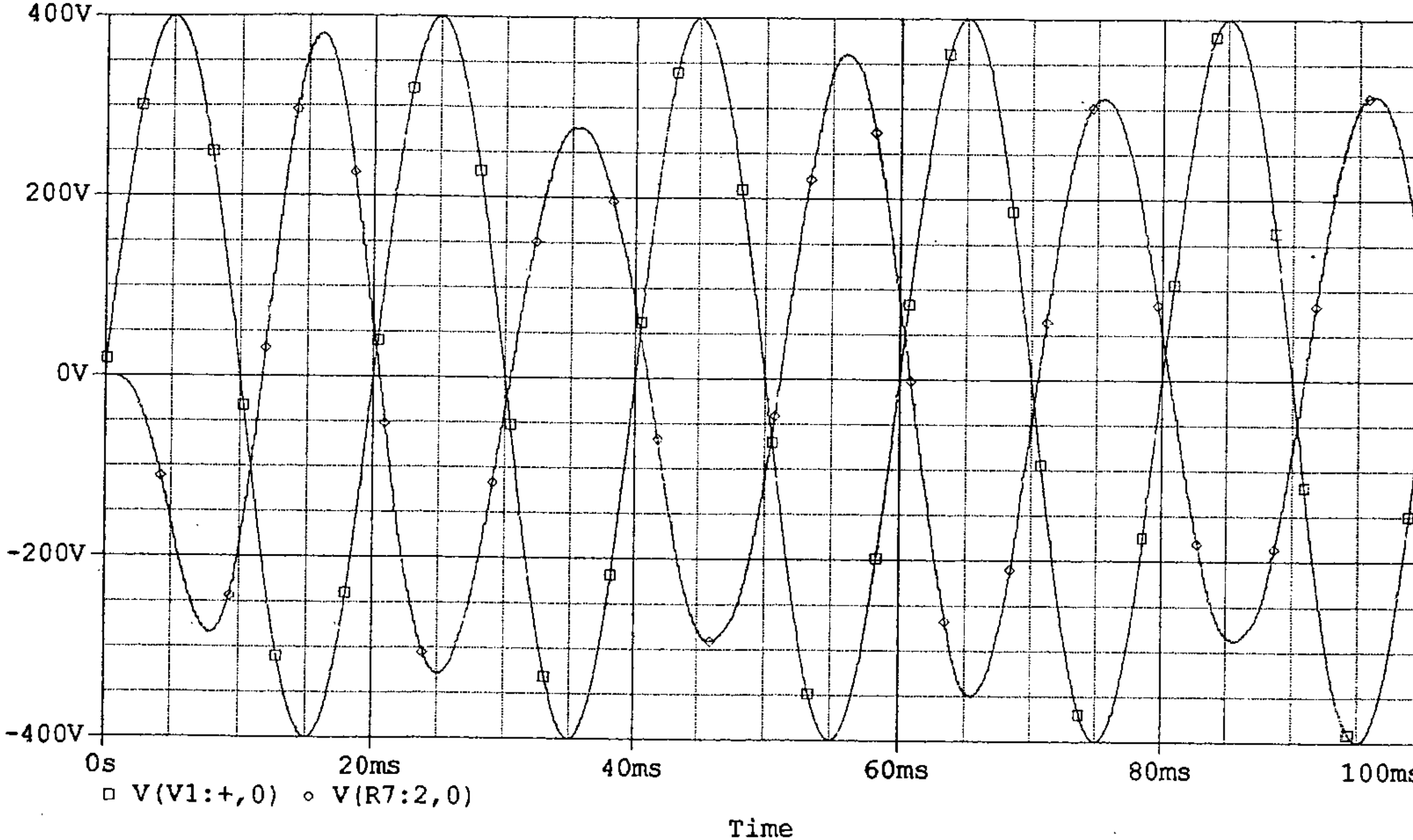


Fig. 68 Input- output voltage waveforms when input voltage=400V and load =150 Ohm and output voltage =300V

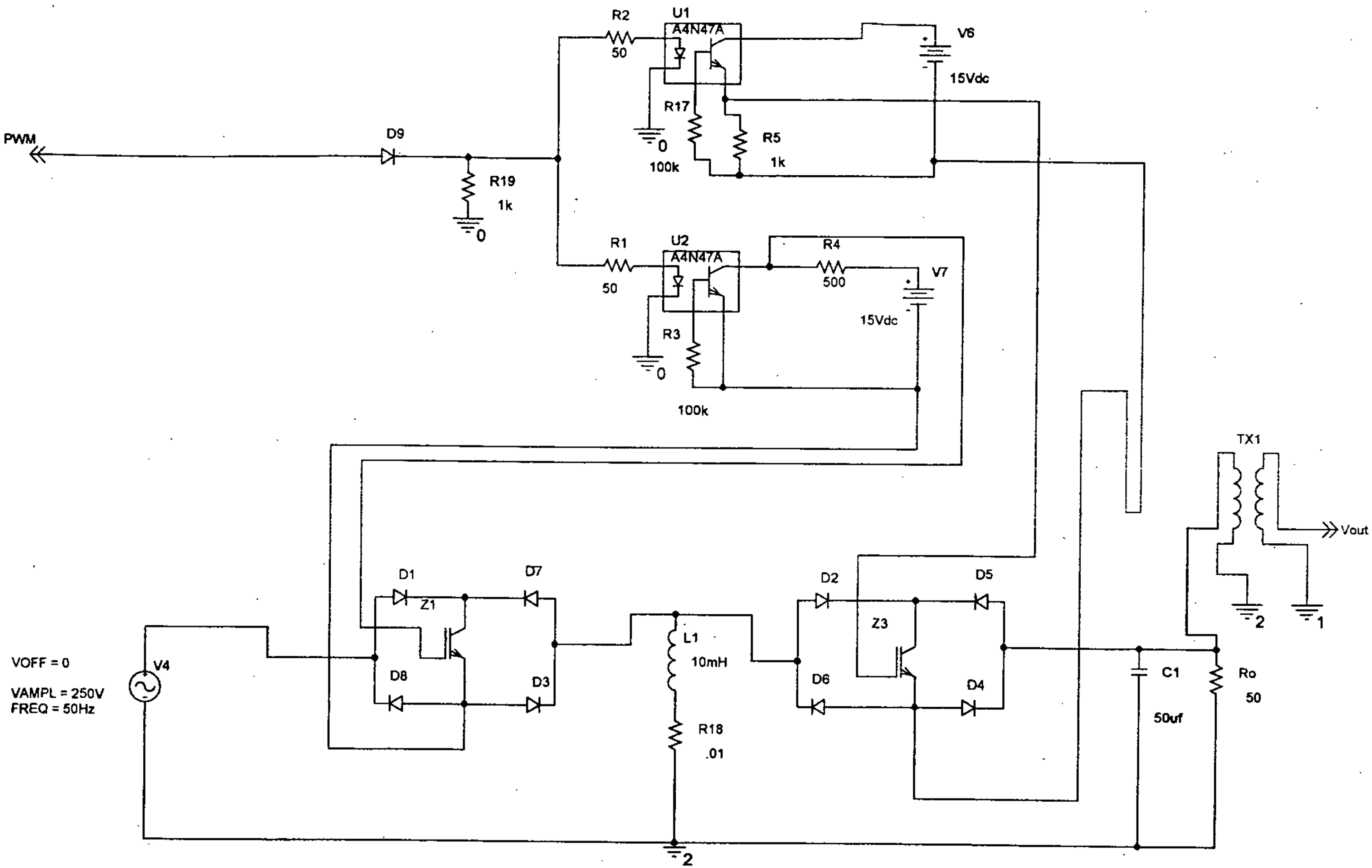
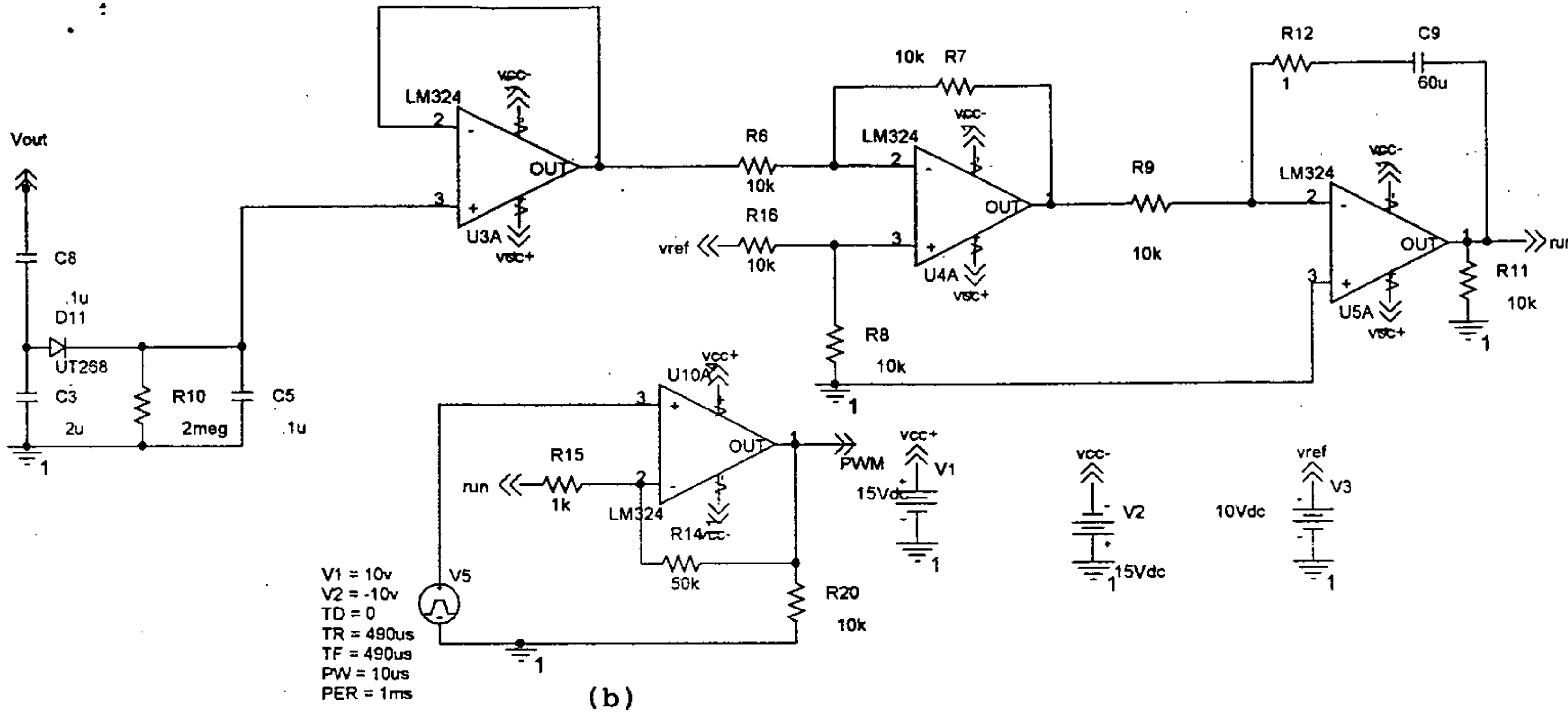


Fig.69(a) AC Buck-Boost regulator.



(b)

Fig.69 Controlled AC Buck-Boost regulator.
(a) AC Buck-Boost regulator.
(b) Control circuit.

versa. Optocouplers connections are shown in Fig 69(a). Fig 69(b) is an automatic controlled circuit. Ground isolation of power and control circuit is achieved by using a single transformer having ratio 1:1. Automatic control circuit controls the PWM. PWM controls ON and OFF time of IGBT -1 and IGBT-2 and maintains output voltages across the load constant for any change in either input voltage or load.

2.4.1 CONTROL AND GATE SIGNALGENERATING CIRCUIT FOR CONTROLLED AC BUCK-BOOST REGULATOR

Fig. 70 shows the automatic control and gate signal generating circuit for AC Buck-Boost regulator. Let the input voltage is 250V AC. The input AC voltage is converted to pulsating DC by using a diode. Output of the diode circuit is passed through an OPAMP buffer (U3A :+). Buffer (U3A) is used to remove the loading effect. Output of the buffer is same as its input. The input AC voltage, output of the diode circuit, input of the buffer and output of the buffer are shown in the Fig. 71(a), (b), (c) and (d) respectively. Output of the buffer is the input to the difference circuit (U4A :-). Another input (positive input) of the difference circuit is V_{ref}. V_{ref} is the reference voltage by which we get the desired output. The function of the difference circuit is to give output of the difference of two signals. The input of the difference circuit (U4A :-), V_{ref} voltage and output of the difference circuit are shown in Fig. 72(a), (b) and (c) respectively. Output of the difference circuit is the input of the integrator circuit (U5A :-).

The input of the integrator circuit and its output voltage are shown in Fig 73 (a) and (b) respectively. Output of the integrator circuit is the input to the (U10A :-). Another input of (U10A) is a triangular wave. Output of (U10A) is the PWM signal required for the control. The inputs of (U10A) and output of (U10A) are shown in Fig. 74(a), (b) and (c) respectively. The inputs of (U10A) and its output PWM signal are shown in Fig. 75 (a), (b) and (c) respectively for input to the controller at 300V AC. The inputs of (U10A) and its output PWM signal are shown in Fig. 76 (a), (b) and (c) respectively for the input voltage of 400V AC. Comparing Fig. 74(a) and 75(a) it is seen that for input voltage 250 V the negative input signal of (U10A) is more deviated from the X-axis than that for the input voltage of 300V. Also comparing Fig.74 (d) and Fig.75 (d) it is seen that for input voltage 250 V the width of PWM signal (output

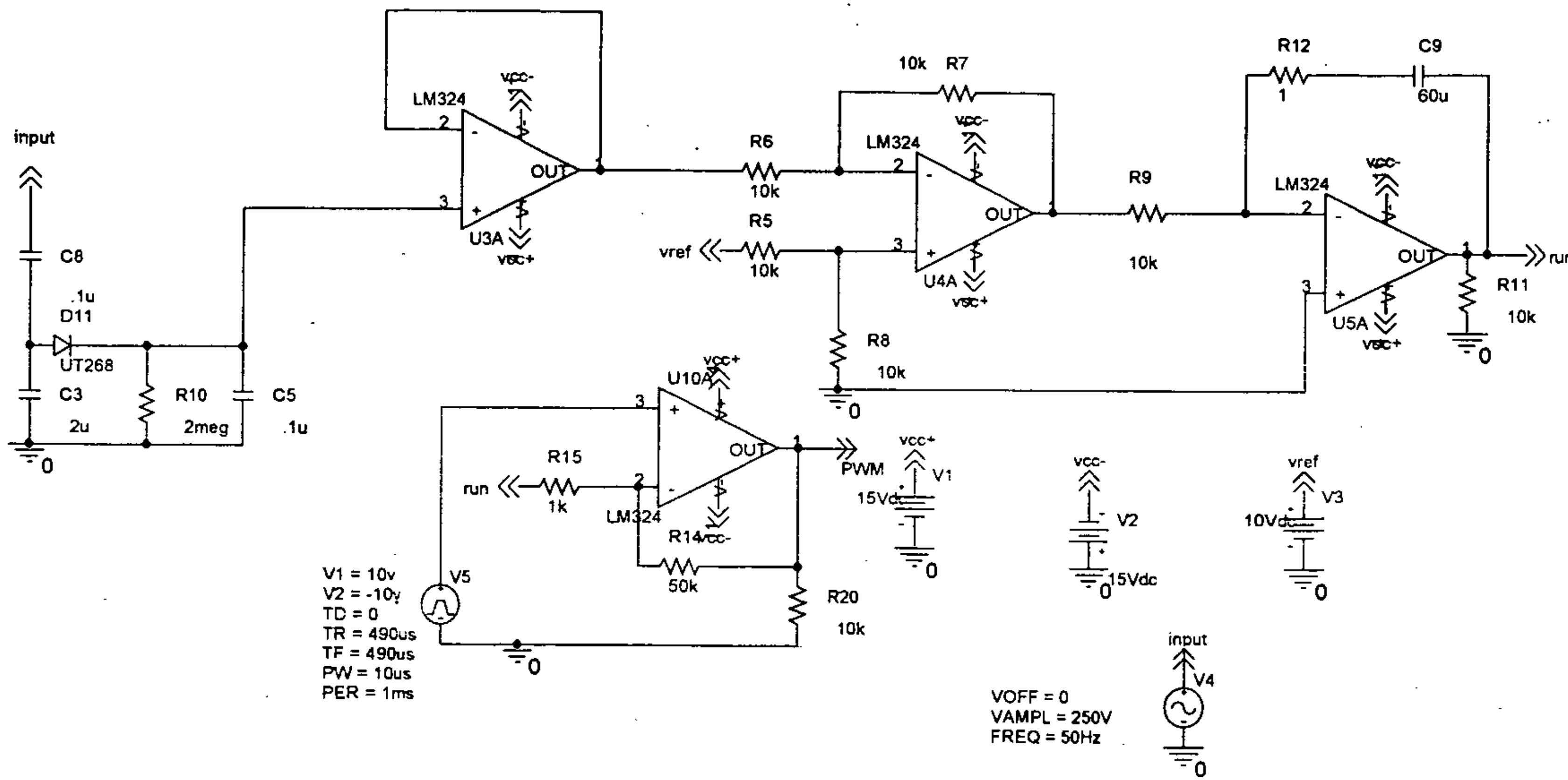


Fig.70 Control and gate signal generating circuit.

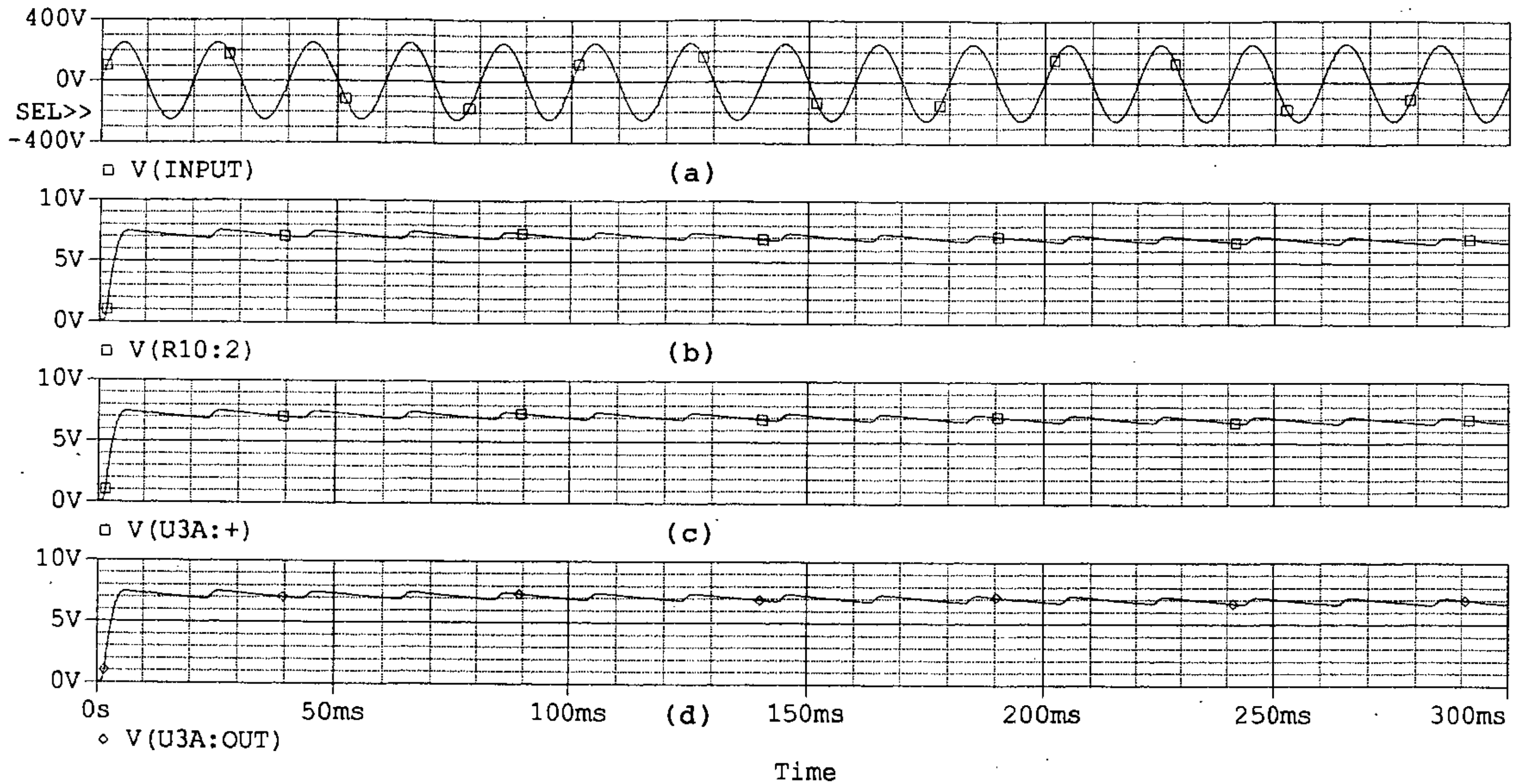


Fig. 71 Waveforms at various points of automatic control circuit when input voltage =250V
(a) Input voltage waveform
(b) Voltage waveform of the output at diode
(c) Voltage waveform of the input of Buffer circuit
(d) Output of Buffer circuit

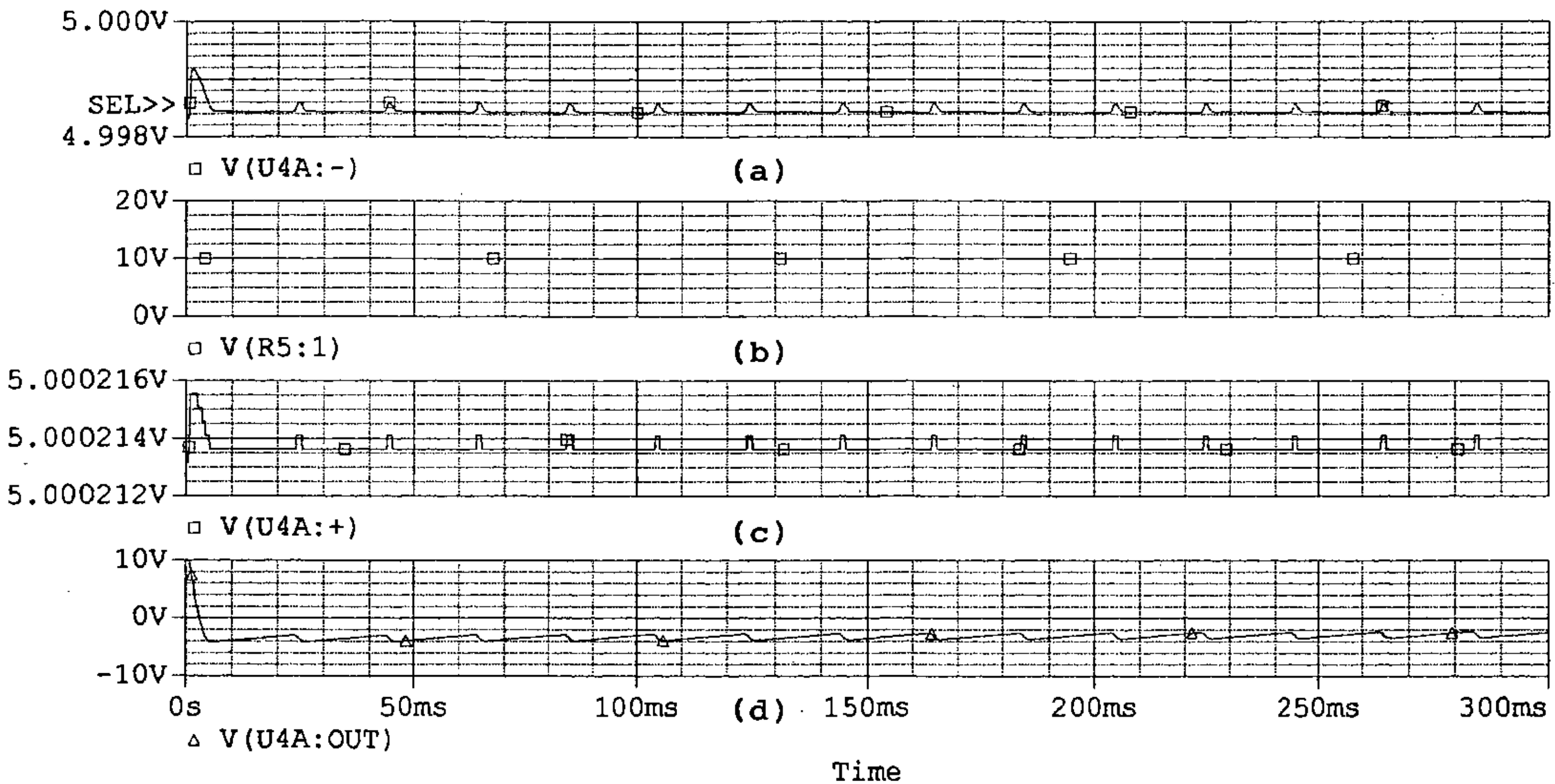


FIg. 72 Waveforms at various points of automatic control circuit when input voltage = 250V
(a) Input voltage waveform of U4A : -
(b) Voltage waveform of the Vref
(c) Voltage waveform of the input at U4a : +
(d) Voltage waveform of the output at U4A

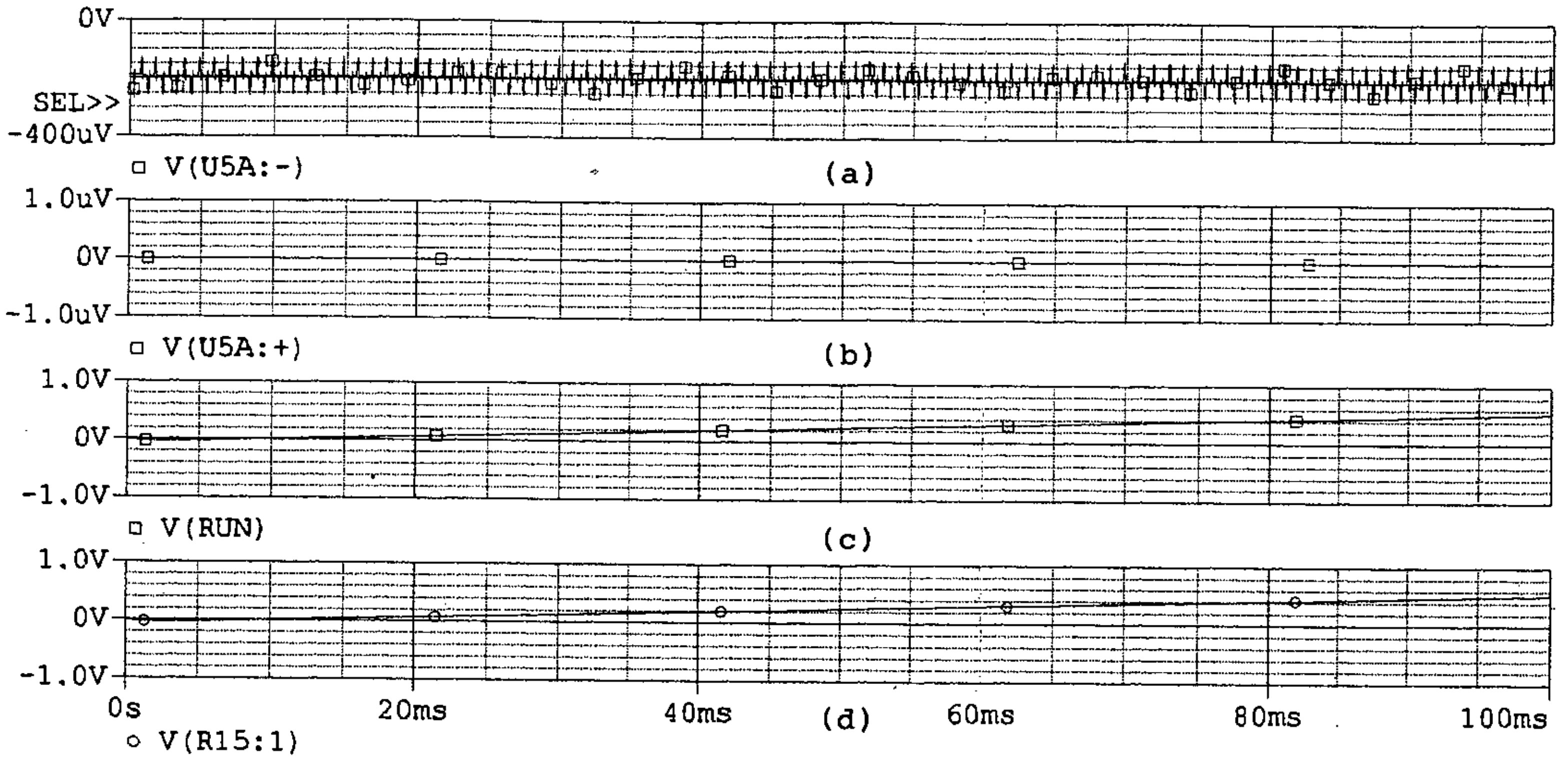


FIg. 73 Waveforms at various points of automatic control circuit when input voltage = 250V
(a) Input voltage waveform of U5A : -
(b) Input voltage waveform of U5A : +
(c) waveform at the U5A : OUT (RUN)
(d) Waveform at R15

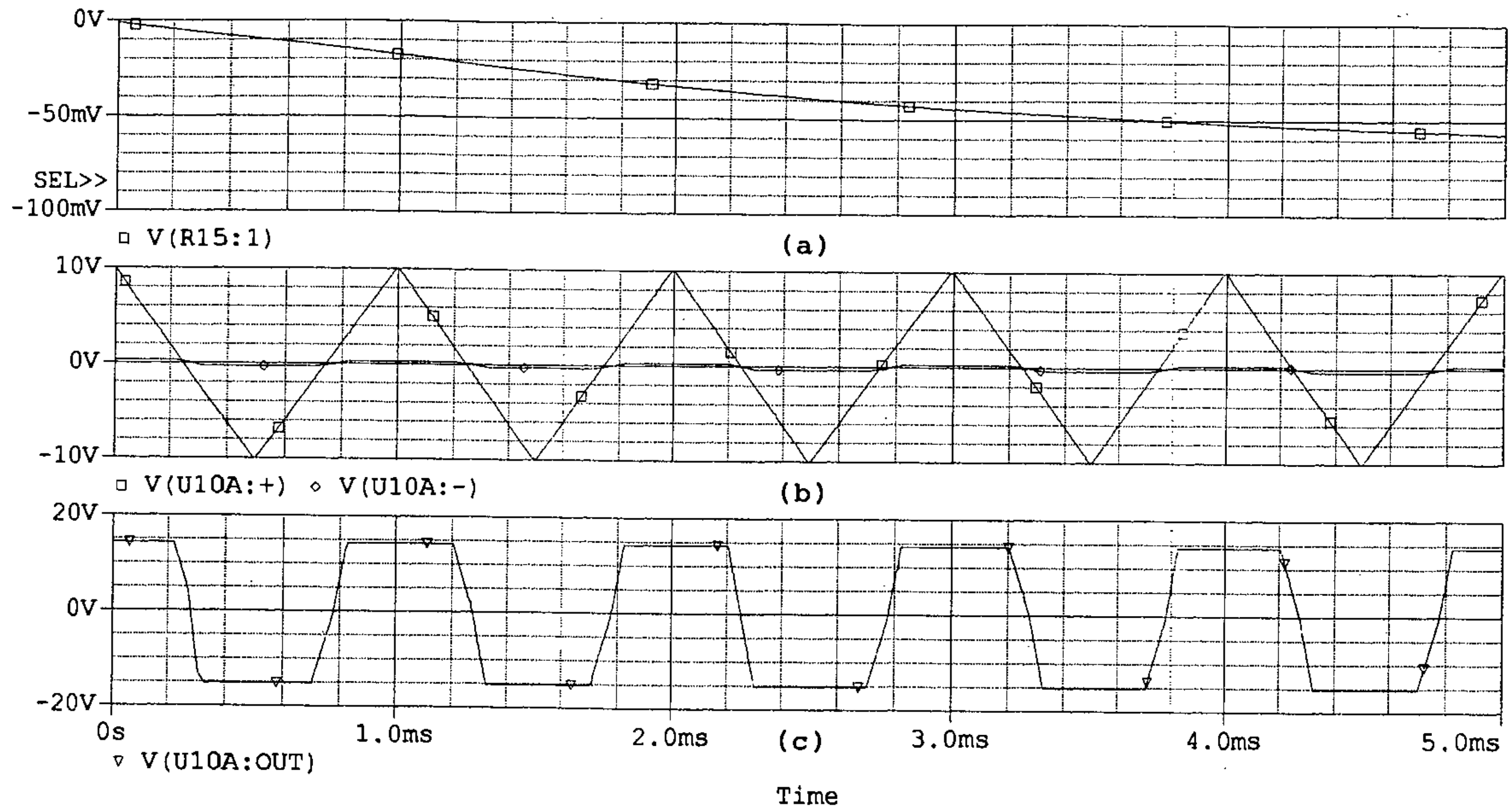


Fig. 74 Waveforms at various points of automatic control circuit when input voltage =250V
(a) Input voltage waveform at R15
(b) Comparison of two inputs at U10A
(c) Output waveform at U10A : OUT

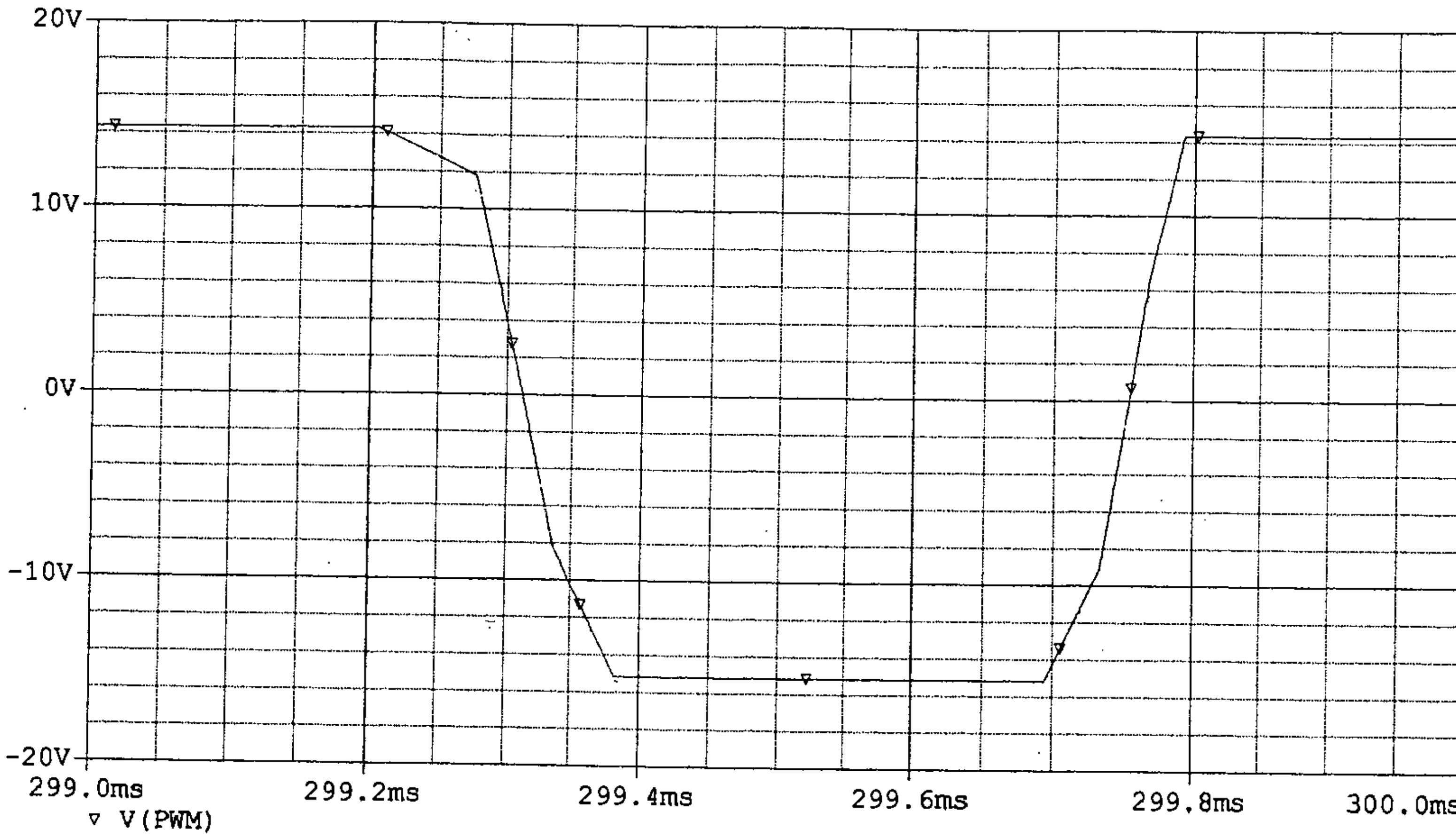


Fig.74(d) Expanded view of PWM signal for input voltage = 250V

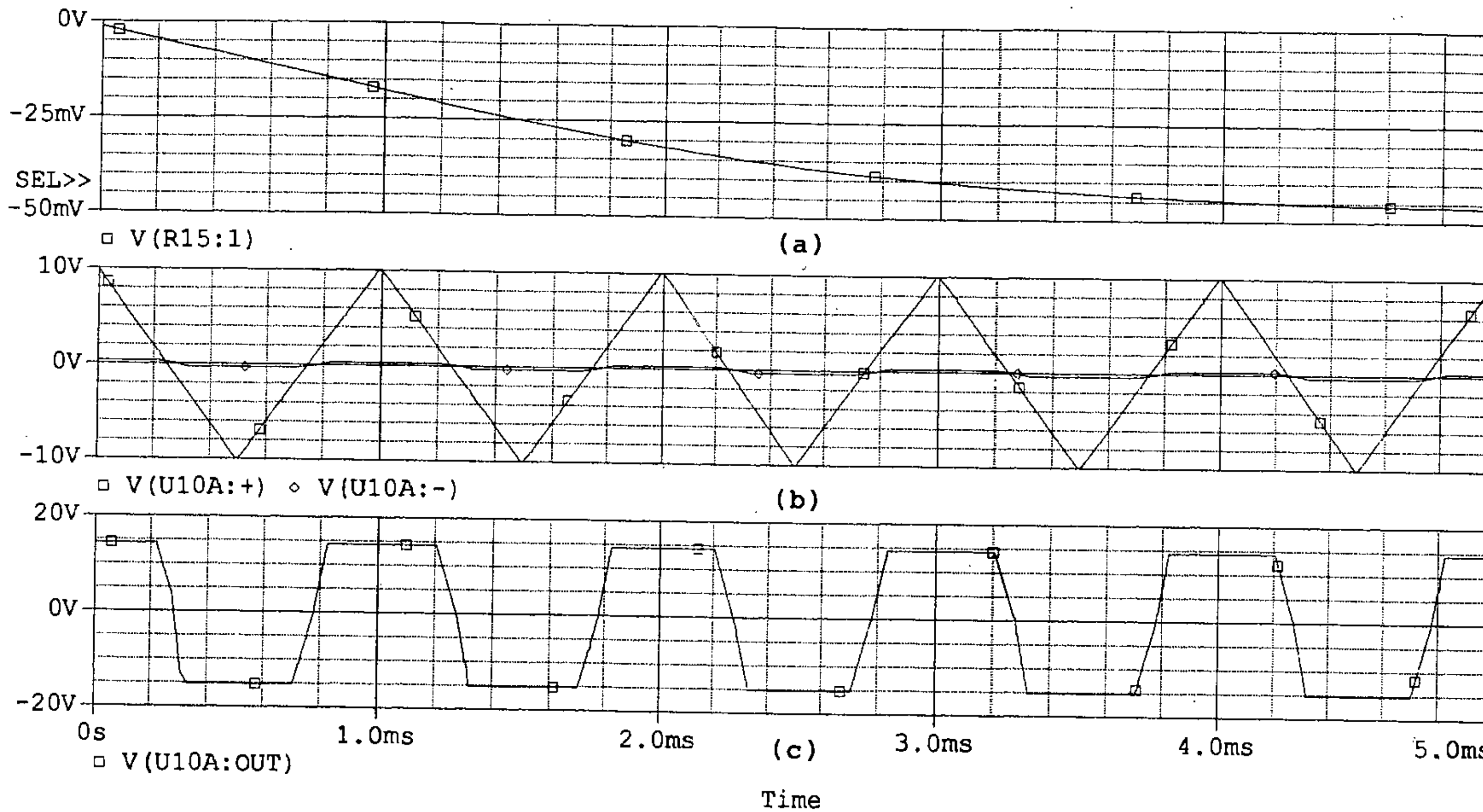


Fig. 75 Waveforms at various points of automatic control circuit when input voltage = 300V
(a) Input voltage waveform at R15
(b) Comparison of two inputs at U10A
(c) utput waveforms at U10A : OUT

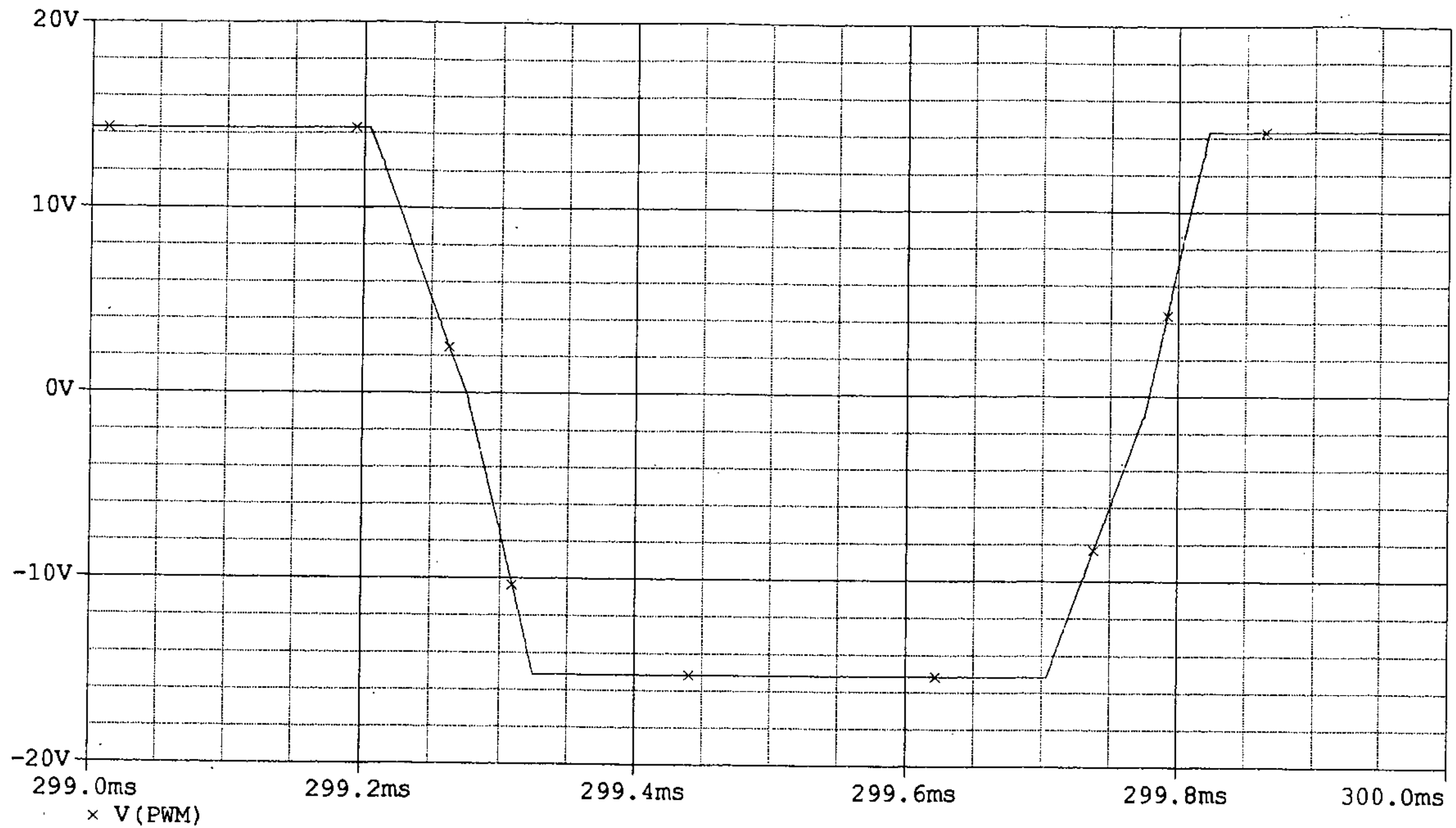


Fig. 75(d) Expanded view of PWM signal for input voltage = 300V

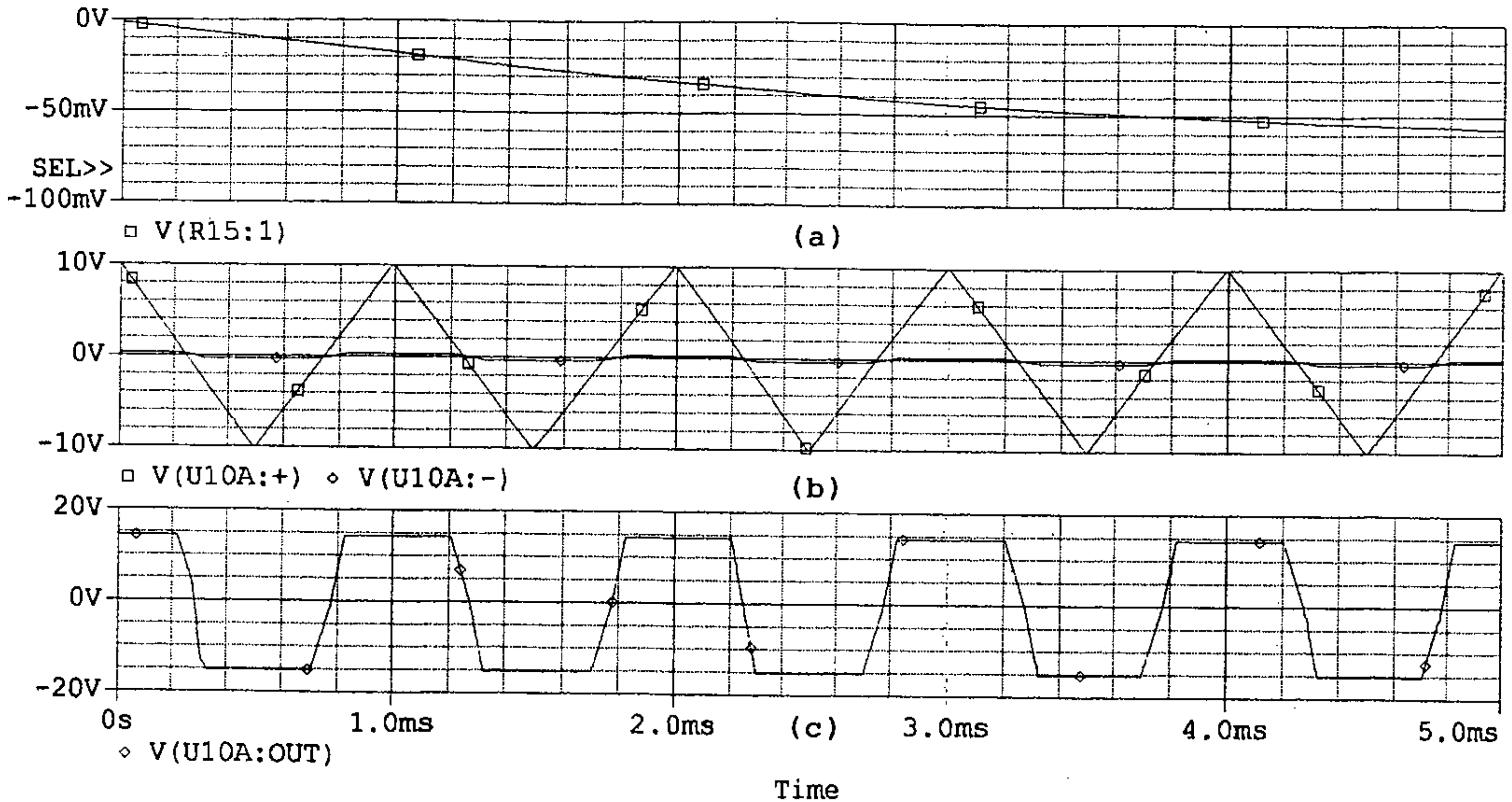


Fig.76 Waveforms at various points of automatic control circuit when input voltage = 400V
(a) Input voltage waveform of U10A : -
(b) Comparison of two inputs at U10A
(c) Output waveform at U10A : OUT

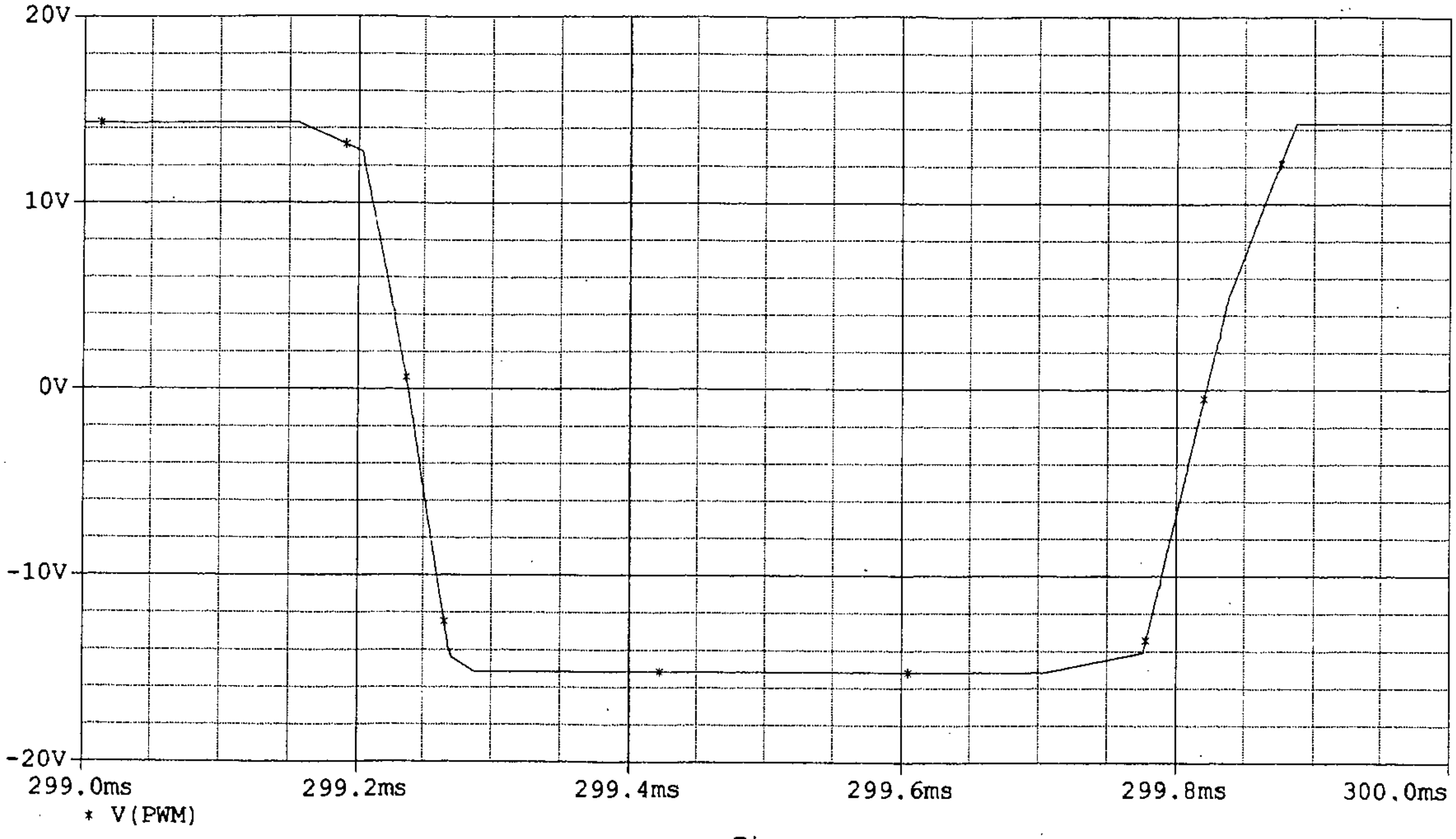


Fig. 76(d) Expanded view of PWM signal for input voltage = 400V of U10A) is wider than that for the input voltage of 300V. Comparing Fig.75 (a) and 76(a) it is seen that for input voltage 300 V the negative input signal of (U10A) is more deviated from the X-axis than that for the input voltage of 400V. Also comparing Fig.75 (d) and Fig.76 (d) it is seen that for input voltage 300 V the width of PWM signal (output of U10A) is wider than that for the input voltage of 400V. The negative input signal of (U10A) varies the PWM signal (output of U10A). By this change in PWM signal output remains constant (300V) for any input voltage.

2.4.2 RESULTS OF CONTROLLED AC BUCK-BOOST REGULATOR (IGBT Switch Implementation)

When input voltage is 250V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is 300 V as shown in Fig.77, Fig.78 and Fig 79 respectively. When input voltage is 300V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is 300 V as shown in Fig.80, Fig.81 and Fig 82 respectively. When input voltage is 350V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is 300 V as shown in Fig.83, Fig.84 and Fig.85 respectively. When input voltage is 400V and load is varied from 50 Ohms to 150 Ohms, it is seen that output is maintained at 300 V as shown in Fig.86, Fig.87 and Fig.88 respectively. From these results we can infer that the Buck-Boost ac voltage regulator with automatic control can maintain output voltage at load constant in both cases of input voltage variation and change in load.

2.5 DRAWBACKS OF AC BUCK-BOOST REGULATOR

Switching losses:

Efficiency of an AC Buck-Boost regulator is ideally 100%. But due to non-ideal elements (stray resistances in inductances and capacitor) and switching of devices, losses take place in Buck-Boost regulator. Losses due to non-ideal elements account negligible towards total loss. However, the losses associated with switching device are substantial and may change with regulation and switching. Switching device losses are of two types.

1. Product of device drop (0.3 to 0.7 V) and current through the device during ON time
2. Product of voltage and current in the device during turn ON or OFF period.

Usually no loss occurs during OFF period. The secondly loss depends largely on the frequency of switching and time required to turn ON and OFF the switches. ON /OFF switching per second gives rise to losses in SMPS and is dissipated as heat.

During ON/OFF period of switching, spike voltage is created across the switching device. The second drawback of AC Buck-Boost regulator is a high input current. The input current of AC Buck-Boost regulator is shown in Fig. 89 without input filter. The input current of AC Buck-Boost regulator is shown in Fig. 90 with input filter circuit. By comparing Fig. 89 and 90 it is seen that the current wave shape smooth up as input filter is used.

2.5.1 FREE WHEELING PATH AND SURGE VOLTAGES ACROSS SWITCHING DEVICE

Current does not change in an inductance circuit instantaneously. When inductive circuits are switched ON and OFF, abrupt change of current causes high $\frac{di}{dt}$ resulting high voltages. These voltages appear across the switches as surge. Usually such occurrence is restricted by providing freewheeling path made of diodes in power circuits.

Surge Voltage:

In the proposed circuit the two switches serve as the freewheeling path for each other. However, for very short period when one switch is turned OFF and other is turned ON, an interval elapses due to delay in the switching time. As a result, freewheeling during this interval is disrupted in the proposed circuit. If the current in any circuit is abruptly disrupted, a high $L\frac{di}{dt}$ across the switch appears due to absence of freewheeling path. High spiky surge voltage appears across during these short intervals. This is shown in Fig.91 (a) & (b) for switches S_1 and S_2 of Buck-Boost AC regulator. These spiky voltages across the switches may be excessively high and destroy switches during operation of the circuit. Remedial measures should be taken to prevent this phenomenon to make the circuit commercially viable. In this thesis another method of suppressing surge voltages across switches is used by R-C snubbers across the switches. Typical waveforms across switches with and without snubber circuits are shown in Figs.91 (a), (b) and 92(a), (b) respectively. However, in practical circuit with IGBT switches this problem does not exist as shown in Fig 92(c) and (d) which may not be so always. Use of snubber reduced the spike voltages across the switches but further reduction of spike voltages to a tolerable limit of switches is desired with proper snubber design and application.

2.5.2 POSSIBLE REMEDY OF FREEWHEELING PATH AND SURGE VOLTAGE ACROSS SWITCHES

Fig.93 and 94 shows the possible ways of remedy of freewheeling path and surges voltage. Fig.93 shows the three switch implementation and Fig.94 shows the four switch implementation of AC Buck-Boost regulator to provide proper freewheeling path. In these spike is created but only one spike created during half cycle of AC wave which is shown in Fig.95. If we use a current sensing element at the place marked I in the 93 and 94 in both circuits then there would be no spike in current waves.

2.5.3 HIGH INPUT CURRENT

The main disadvantage of AC Buck-Boost regulator is it has high input current. The input current of AC Buck-Boost regulator is shown in Fig.96 without filter. The input current of AC Buck-Boost regulator shown in Fig.97 with and without input filter circuit. Output current of AC Buck-Boost regulator shown in Fig.98 with input filter circuit. By comparing Fig.96 and Fig.97 it is seen that input current is decreases and smooth shape is obtained when input filter is connected. By comparing Fig.98 (a) and Fig.98 (b) it is seen that output current decreases and smooth shape is obtained when input filter is used. Fig.99 shows the AC Buck-Boost regulator with input filter circuit. The elements of filter circuit (L, C) values are calculated later in section 2.6.

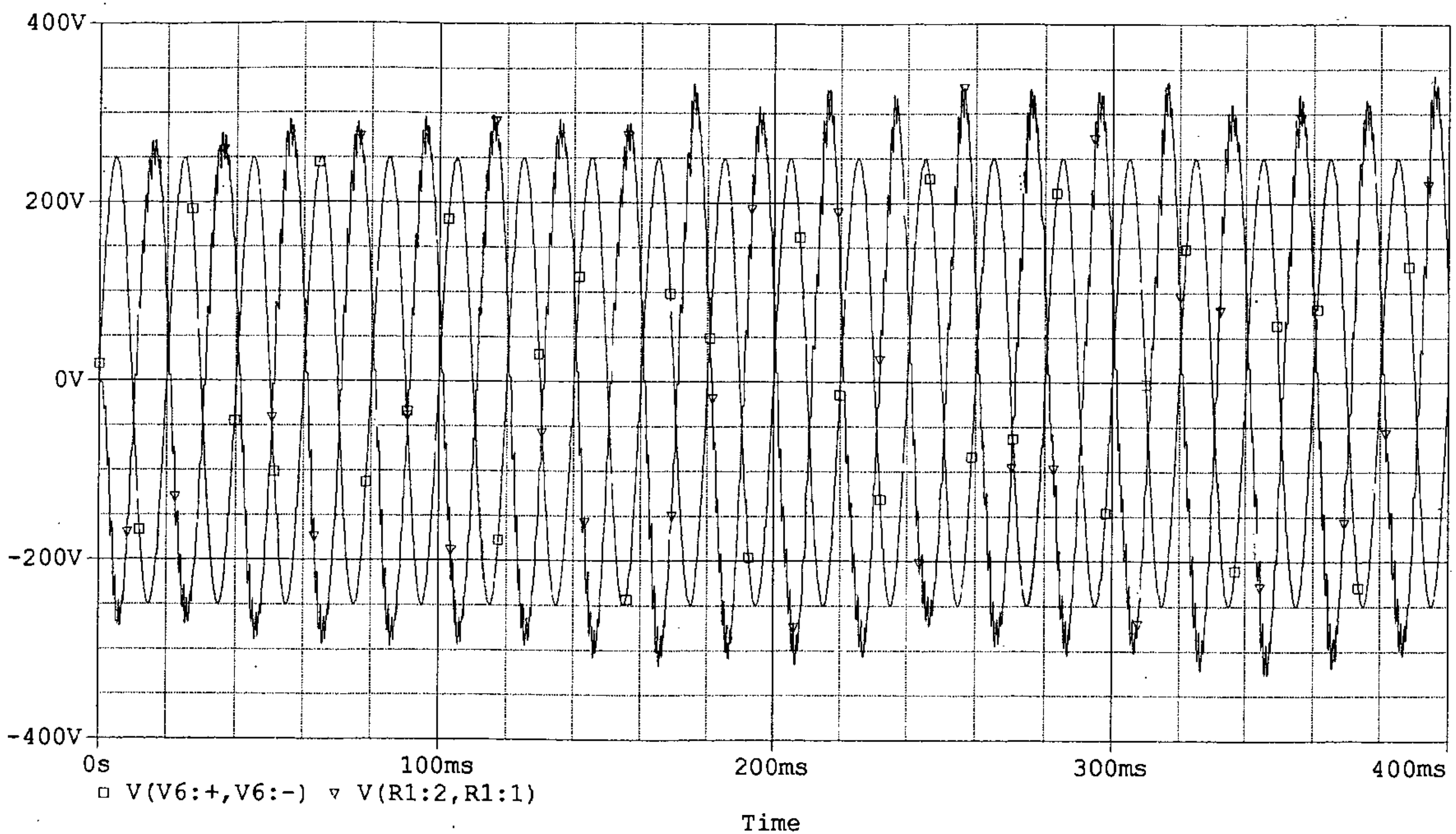


Fig. 77 Input- output voltage waveforms when input voltage= 250V and load =50 Ohm and output voltage = 300V

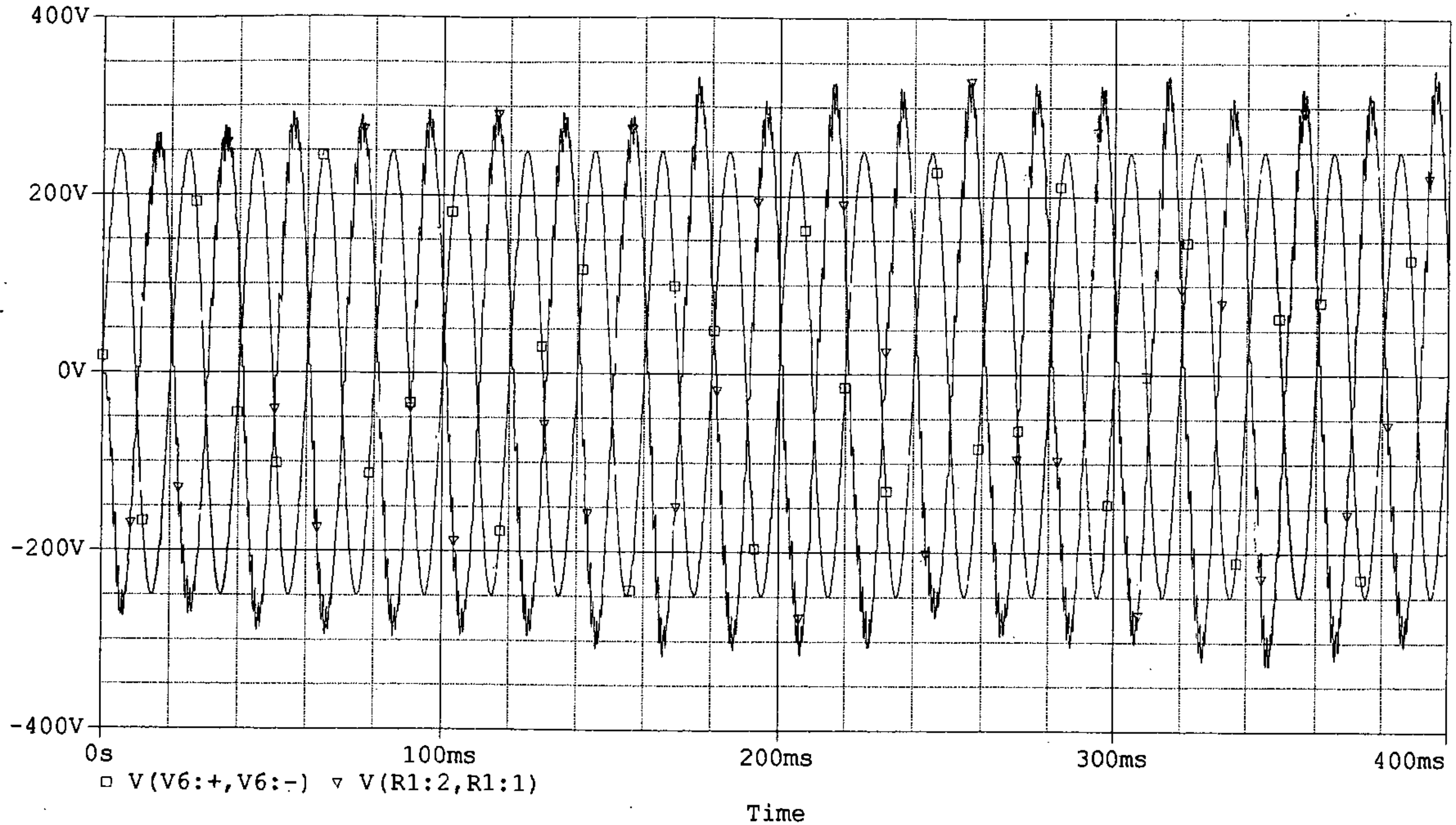


Fig. 78 Input- output voltage waveforms when input voltage= 250V and load =100 Ohm and output voltage = 300V

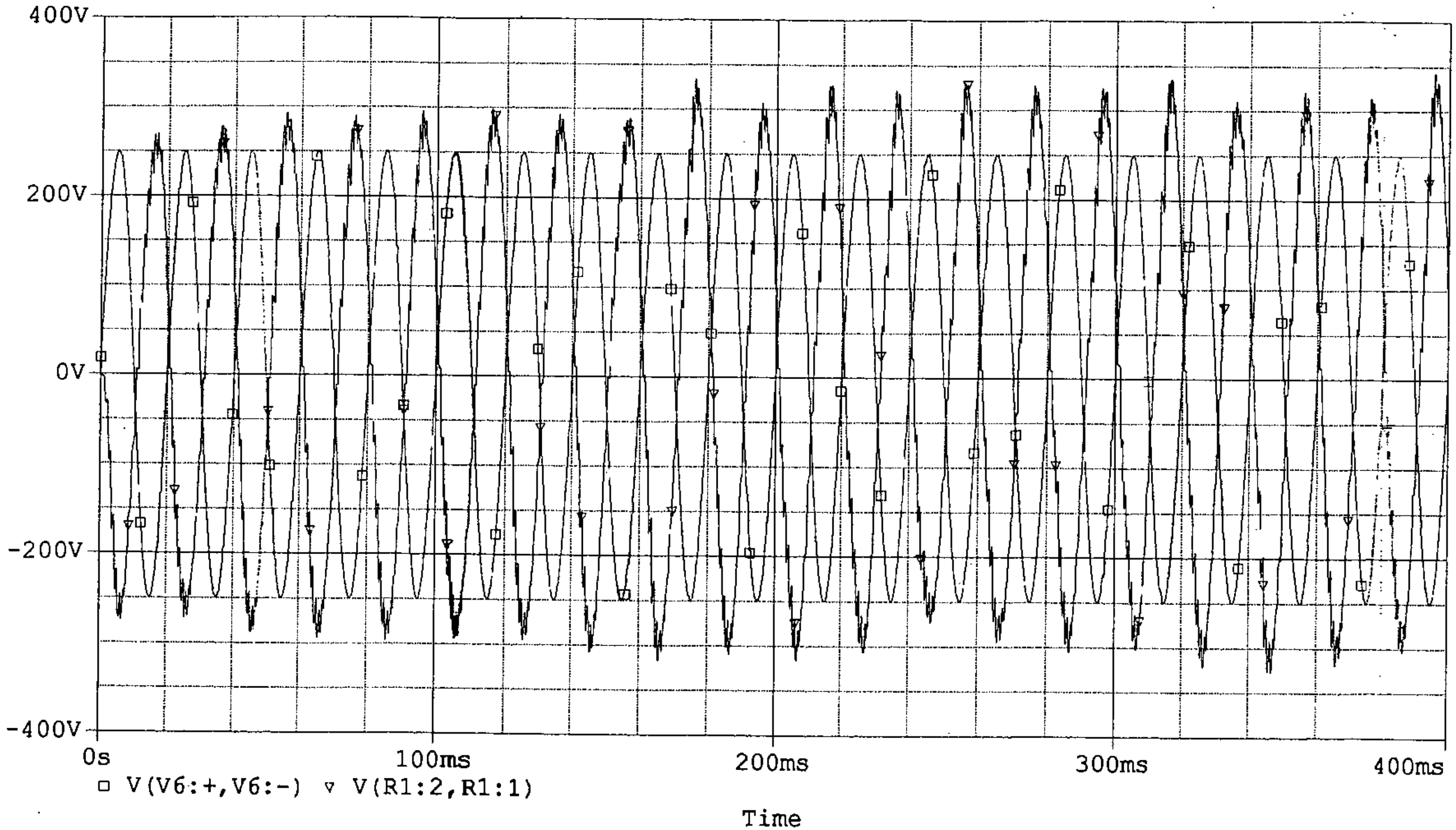


Fig. 79 Input- output voltage waveforms when input voltage= 250V and load =150 Ohm and output voltage = 300V

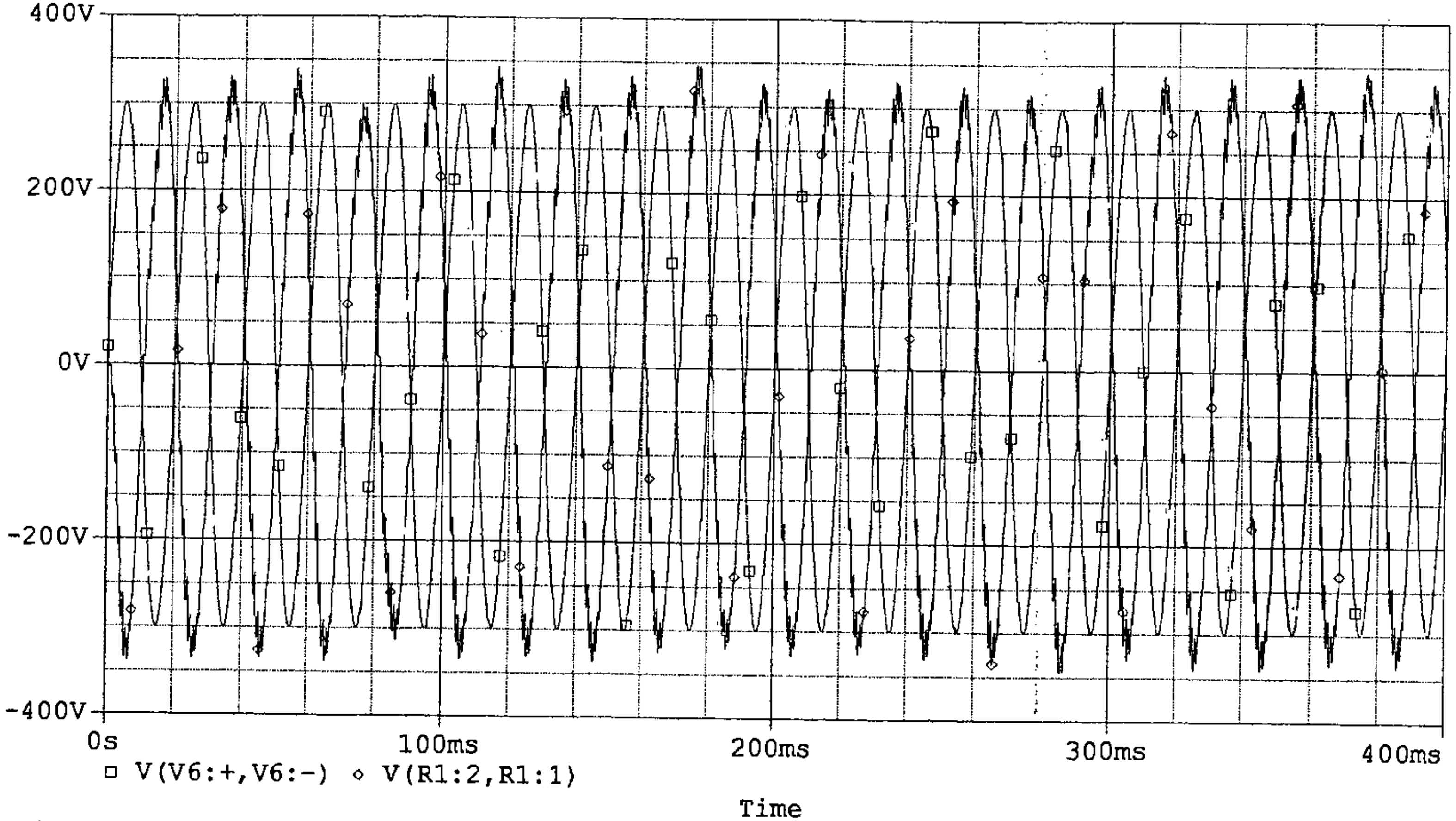


Fig.80 Input-output voltage waveforms when input voltage = 300V and load = 50 Ohm and output voltage = 300V

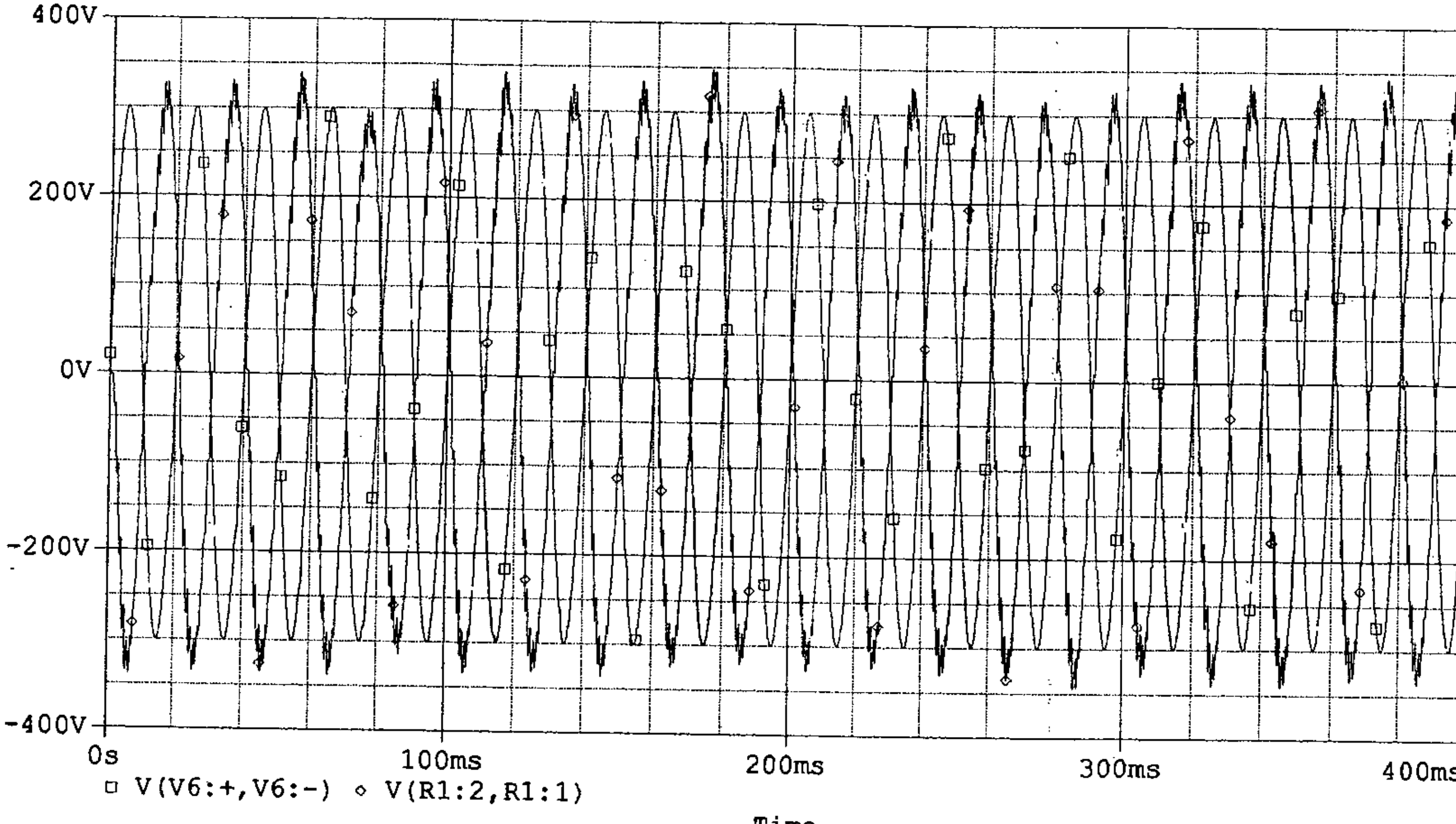


Fig.81 Input-output voltage waveforms when input voltage = 300V and load = 100 Ohm and output voltage = 300V

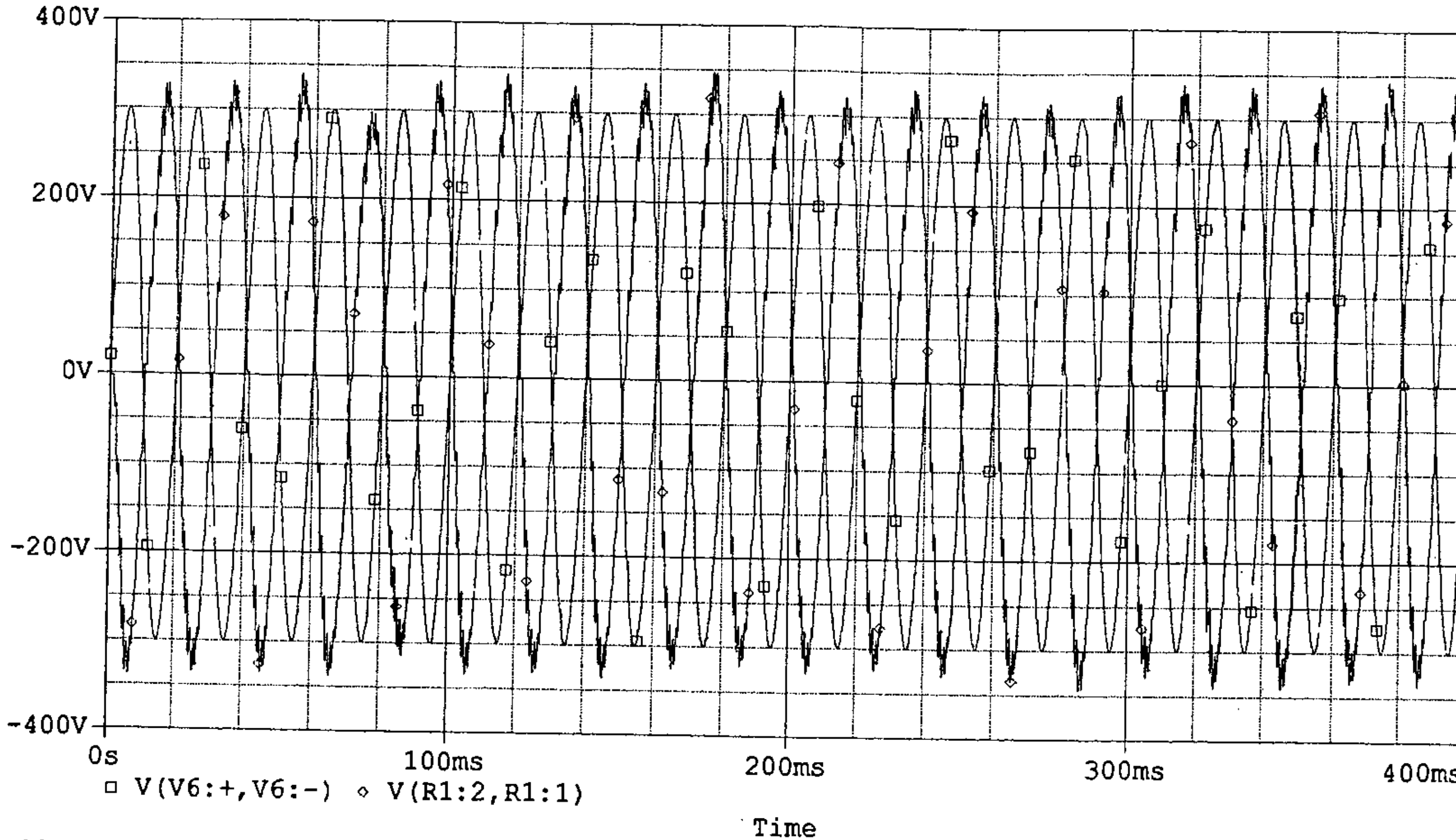


Fig.82 Input-output voltage waveforms when input voltage = 300V and load = 150 Ohm and output voltage = 300V

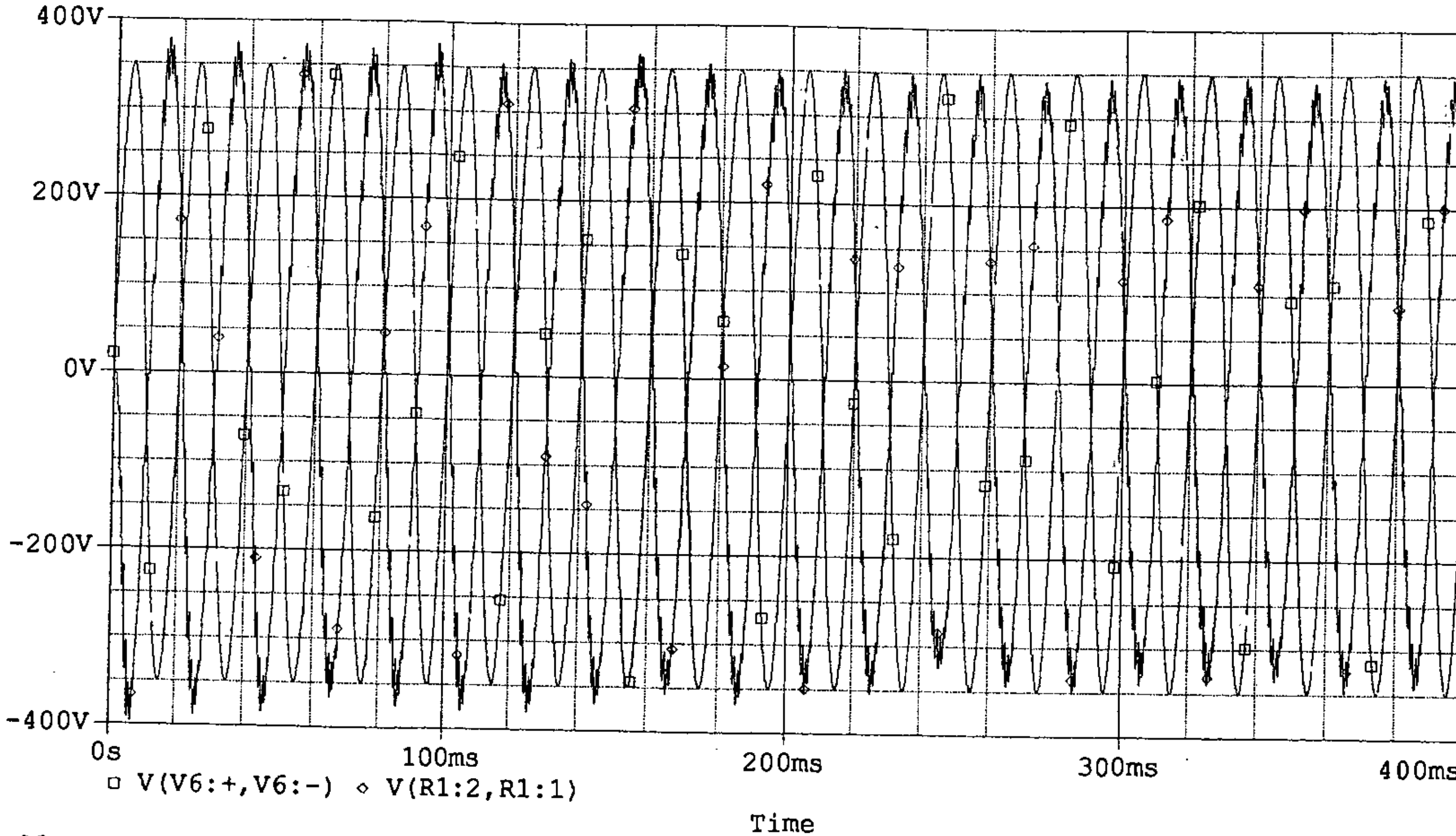


Fig.83 Input-output voltage waveforms when input voltage = 350V and load = 50 Ohm and output voltage = 300V

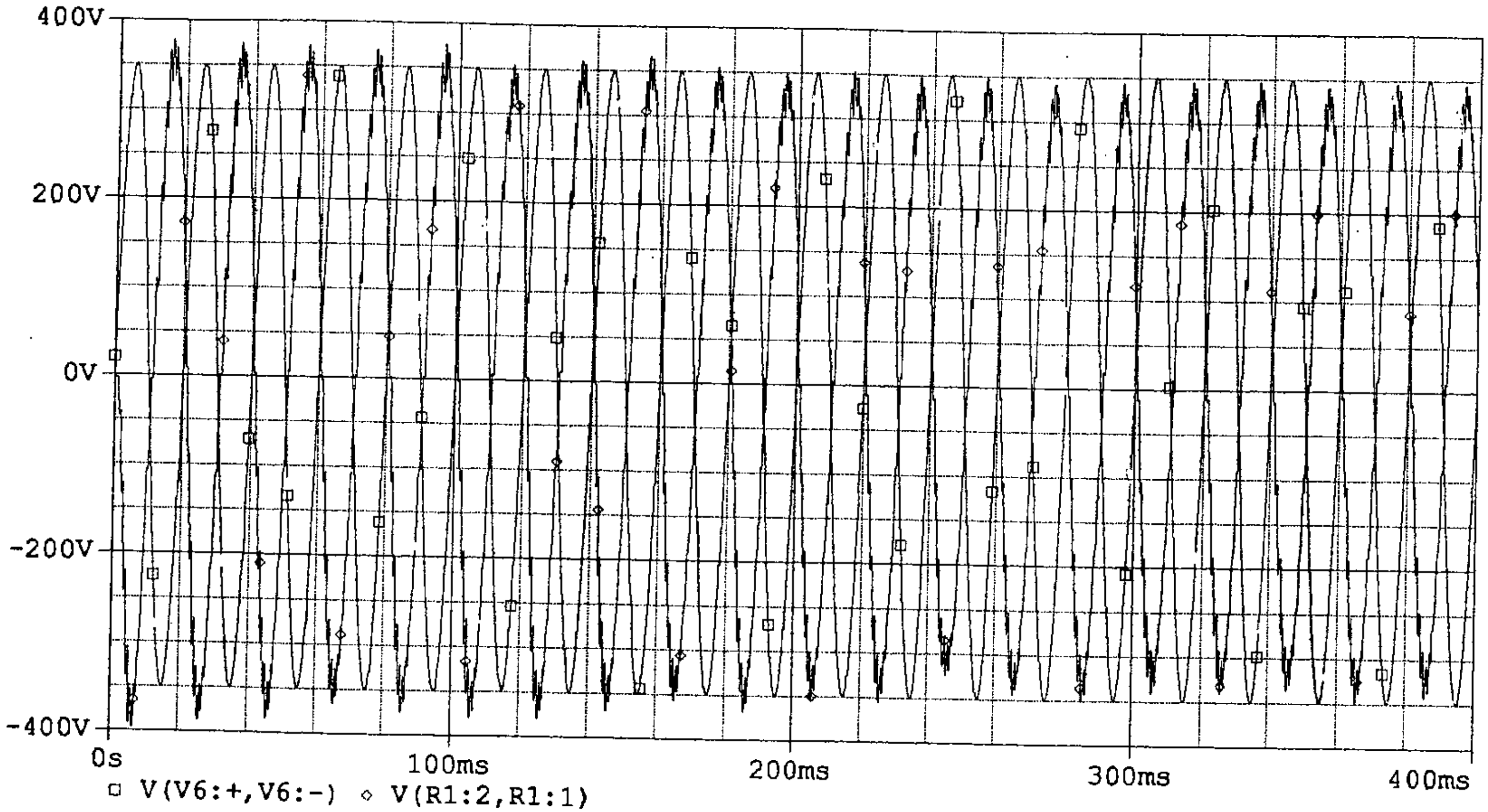


Fig.84 Input-output voltage waveforms when input voltage = 350V and load = 100 Ohm and output voltage = 300V

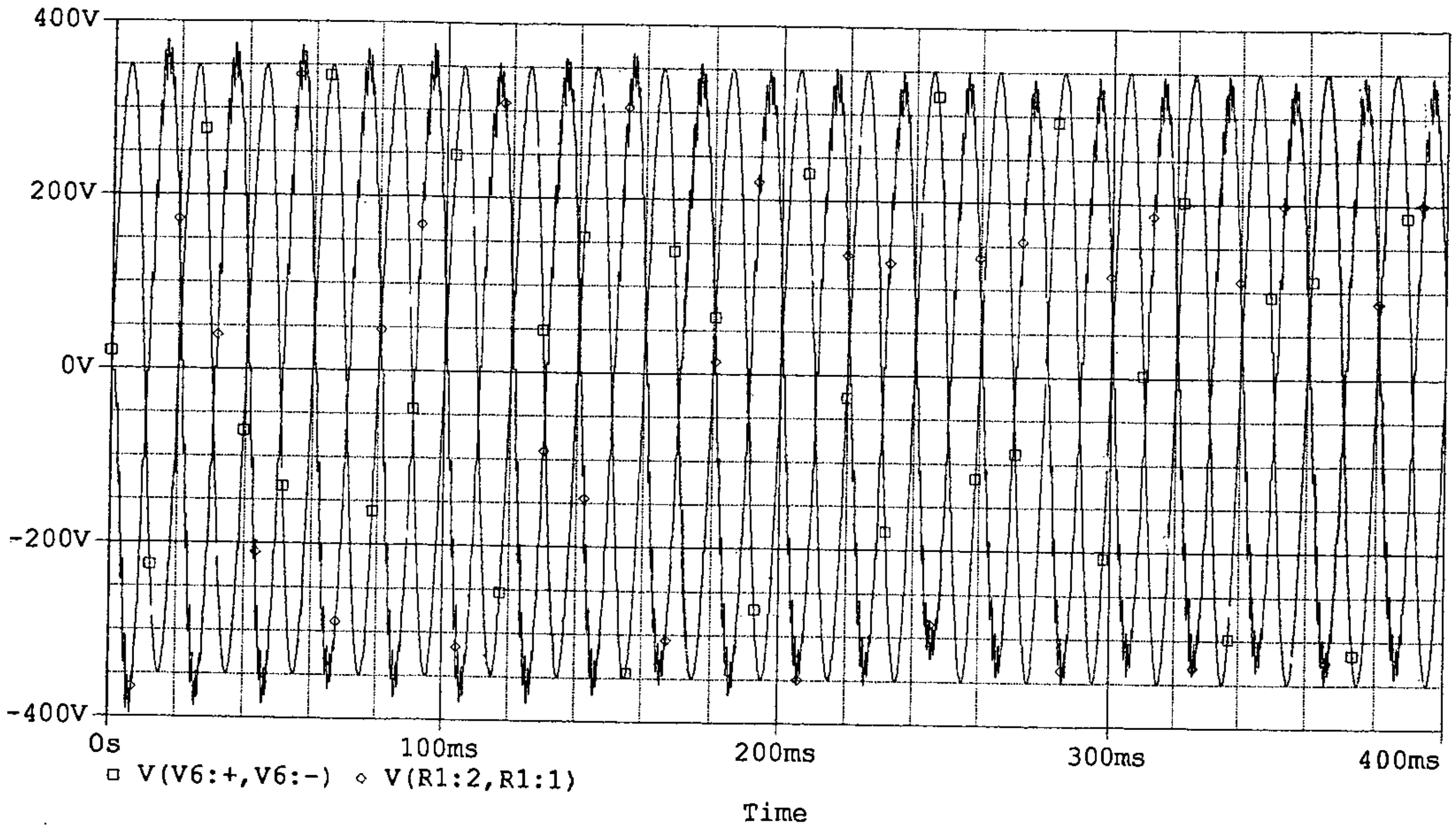


Fig.85 Input-output voltage waveforms when input voltage = 350V and load = 150 Ohm and output voltage = 300V

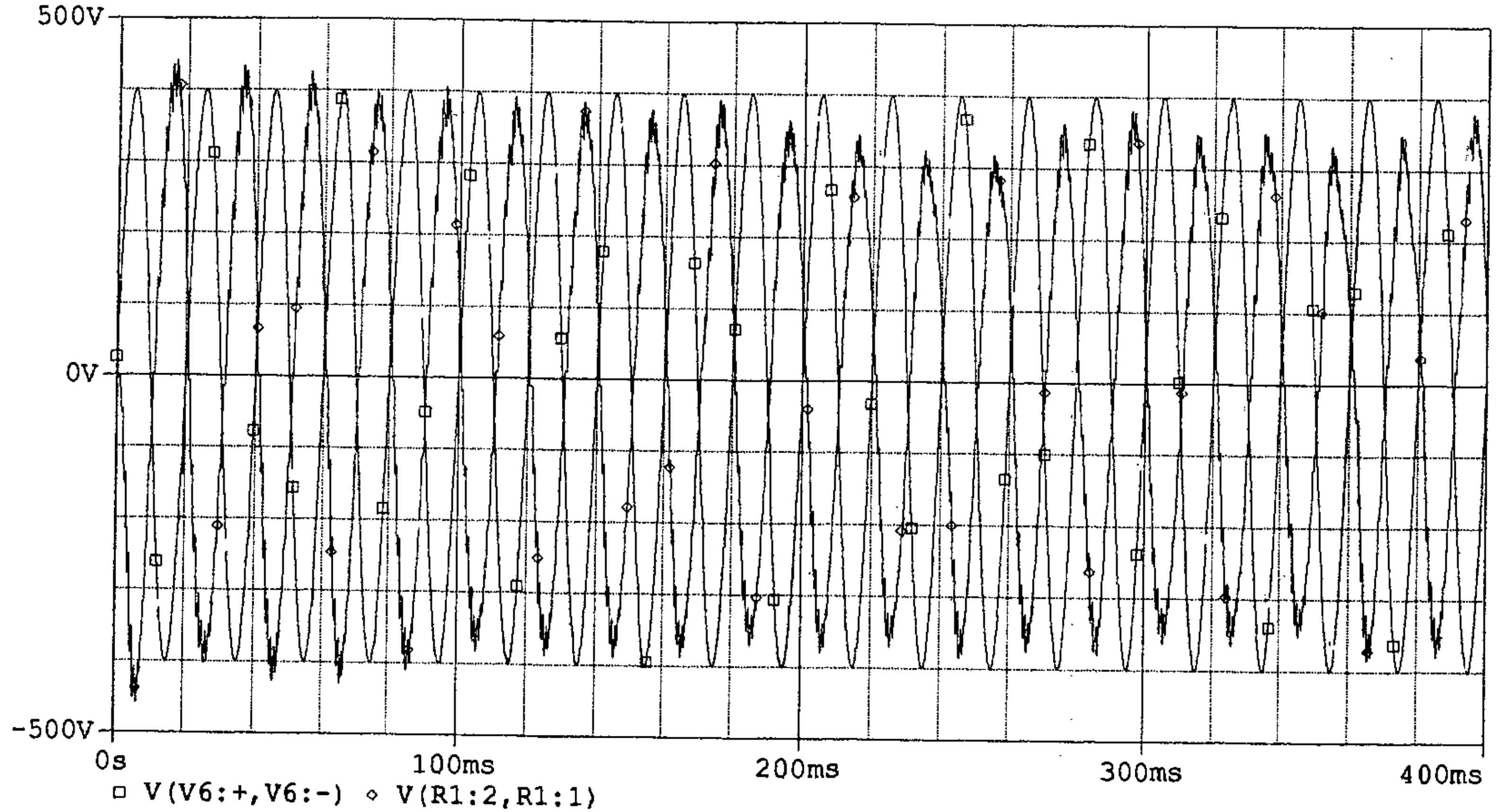


Fig.86 Input-output voltage waveforms when input voltage = 400V and load = 50 Ohm and output voltage = 300V

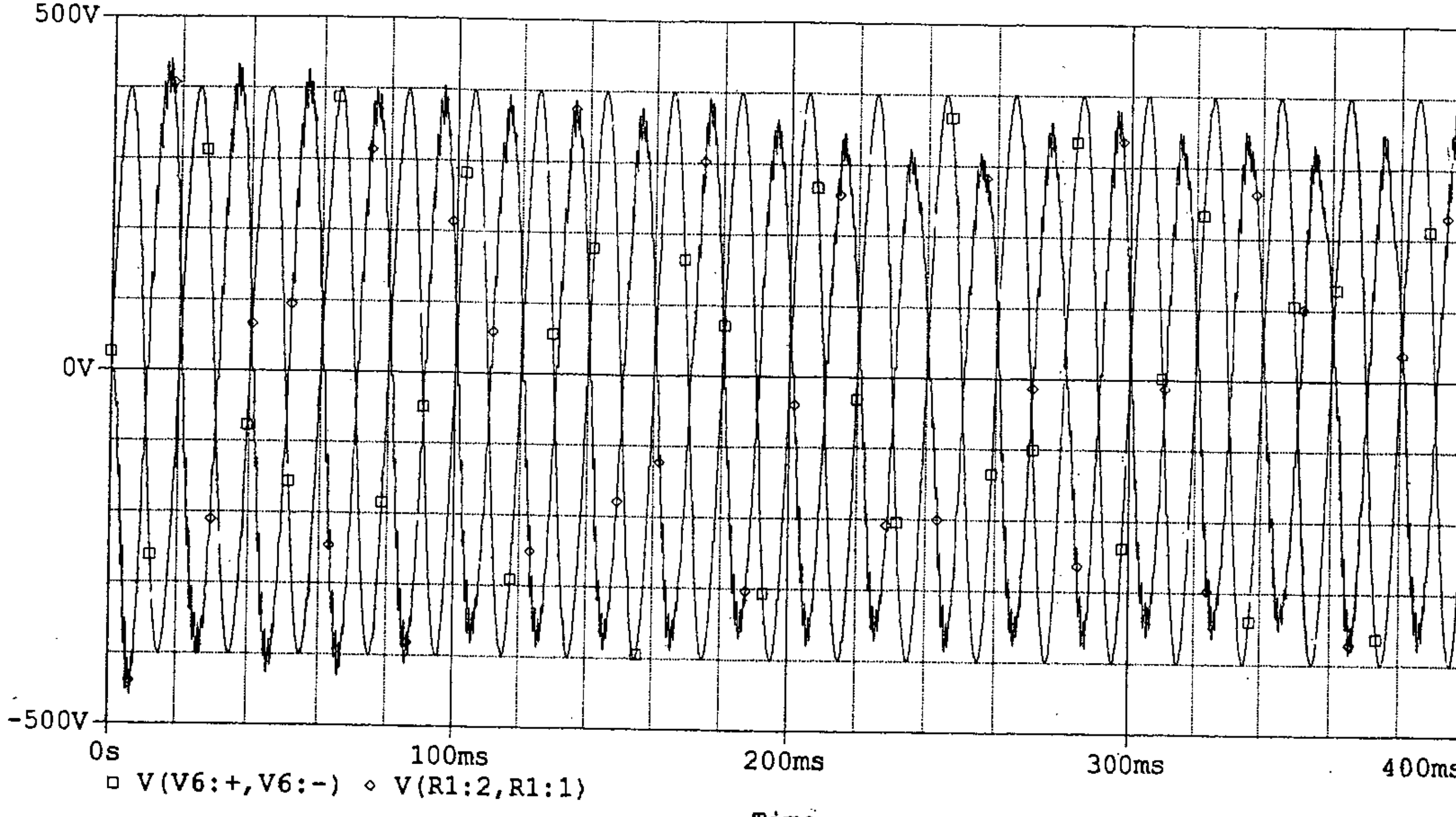


Fig.87 Input-output voltage waveforms when input voltage = 400V and load = 100 Ohm and output voltage = 300V

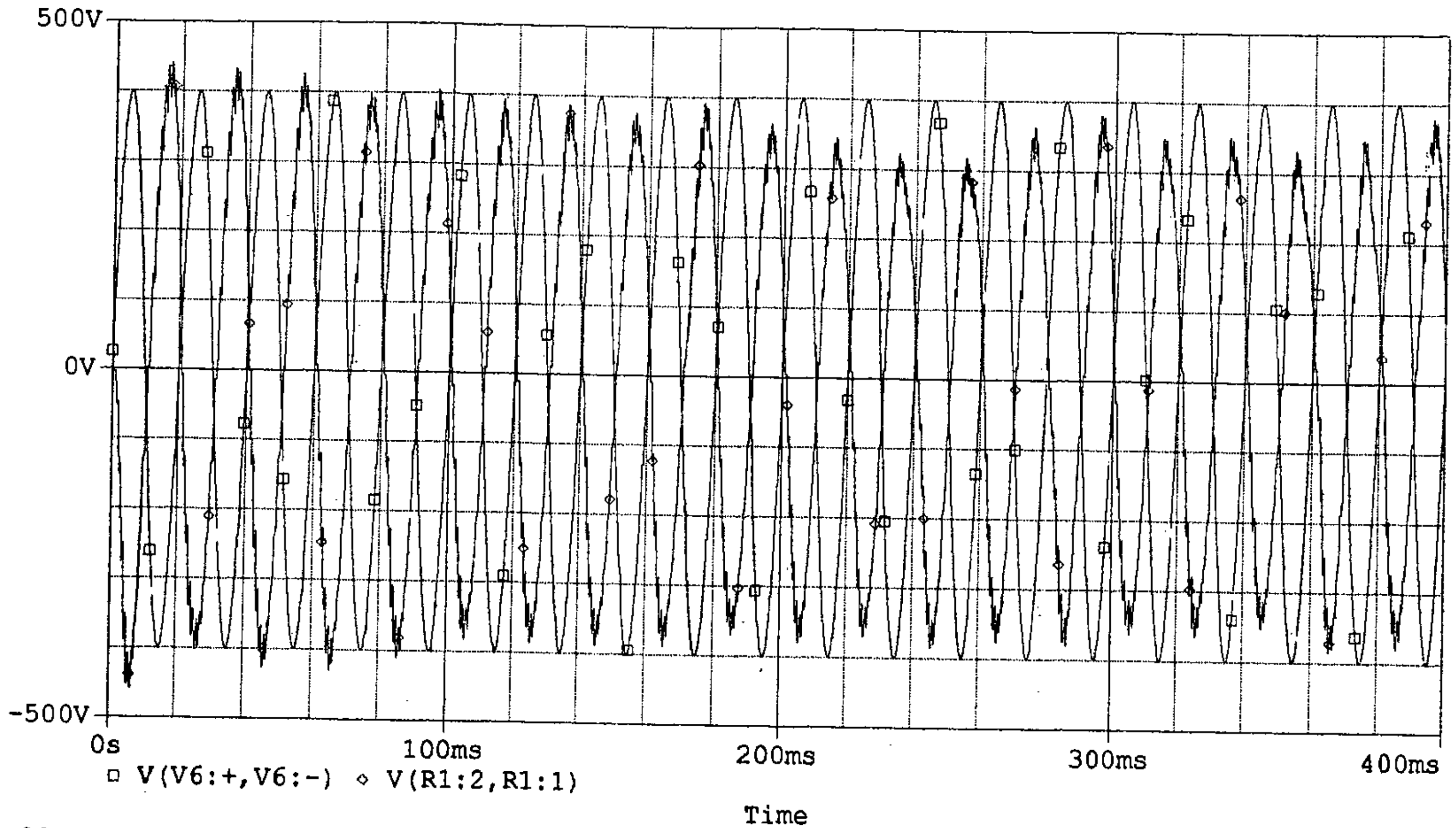


Fig.88 Input-output voltage waveforms when input voltage = 400V and load = 150 Ohm and output voltage = 300V

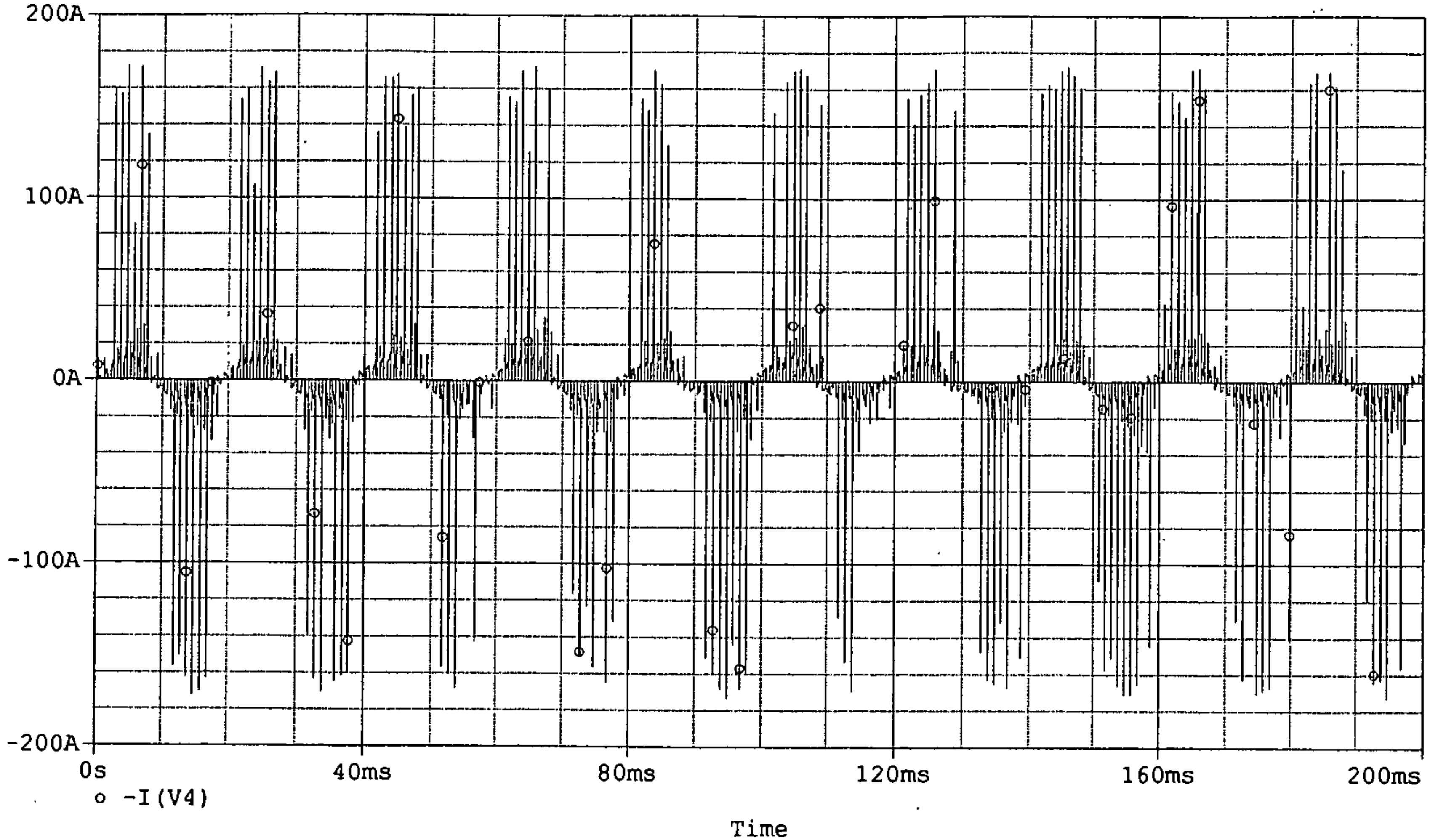


Fig. 89 Input current waveforms of AC Buck-Boost regulator without input filter circuit

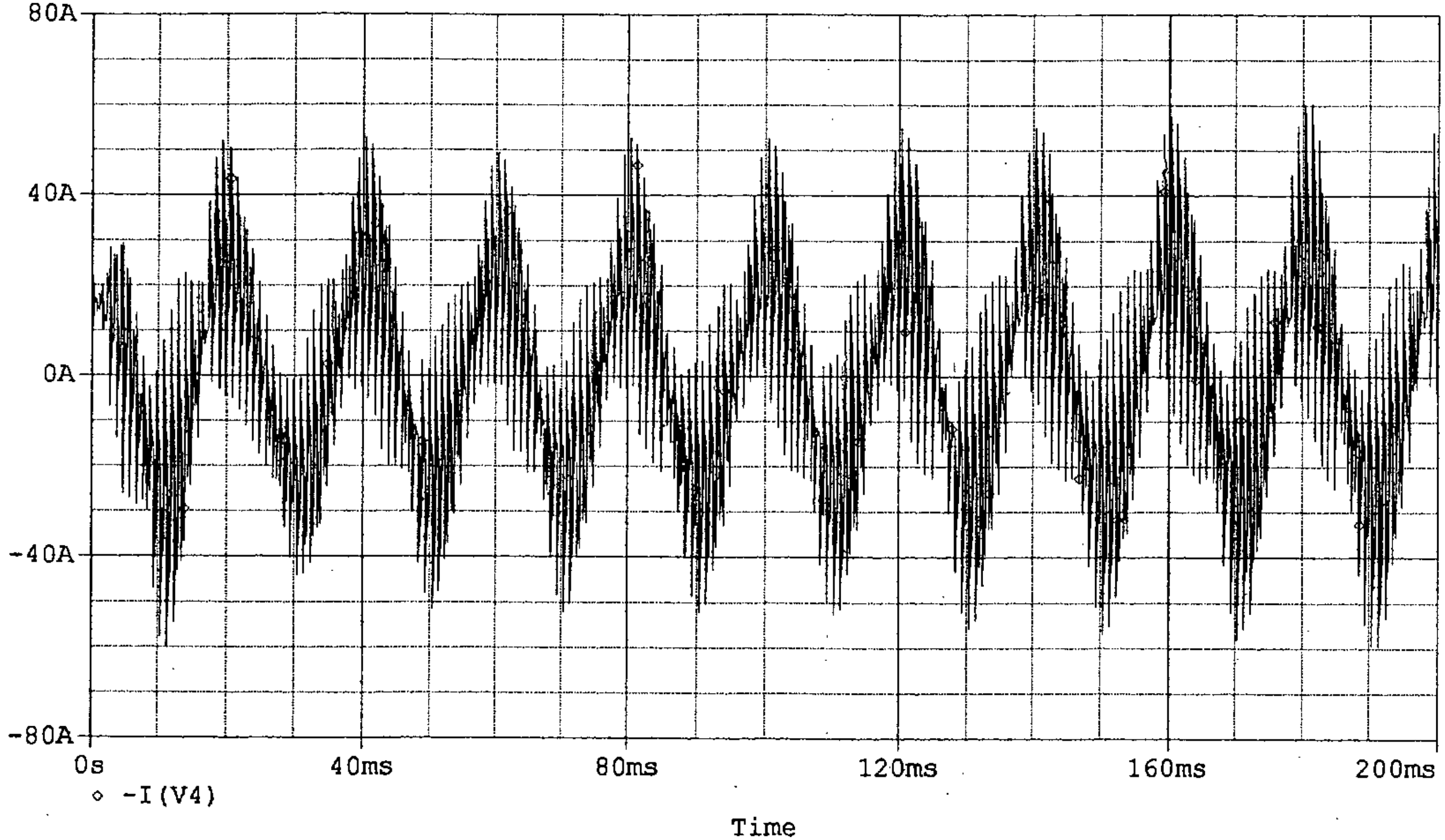


Fig. 90 Input current waveforms of AC Buck- Boost regulator with input filter circuit

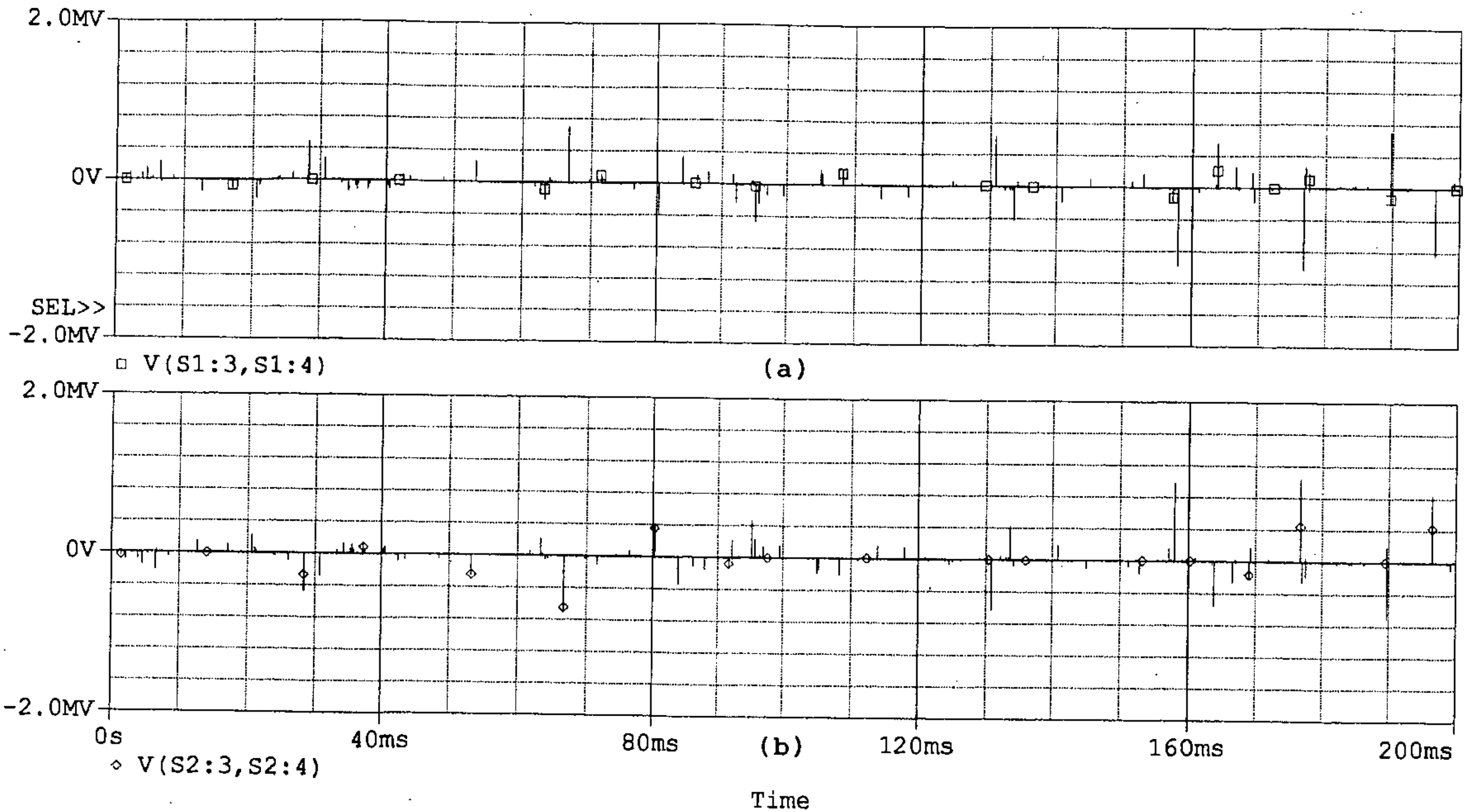


Fig. 91 Spike voltage waveforms across switches without snubber circuit
(a) For switch S1
(b) For switch S2

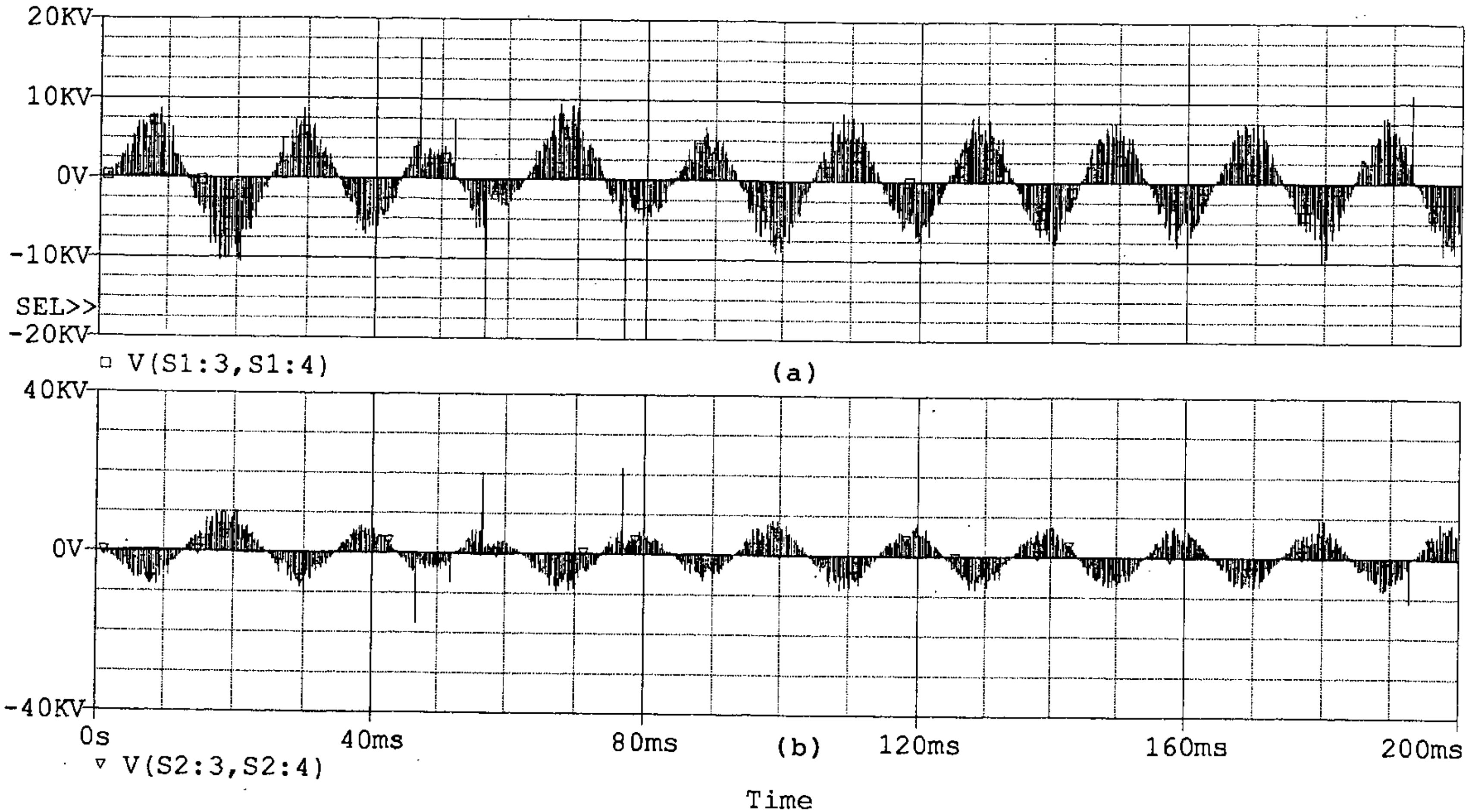


Fig. 92 Spike voltage waveforms across switches with sbubber circuit
(a) For switch S1
(b) For switch S2

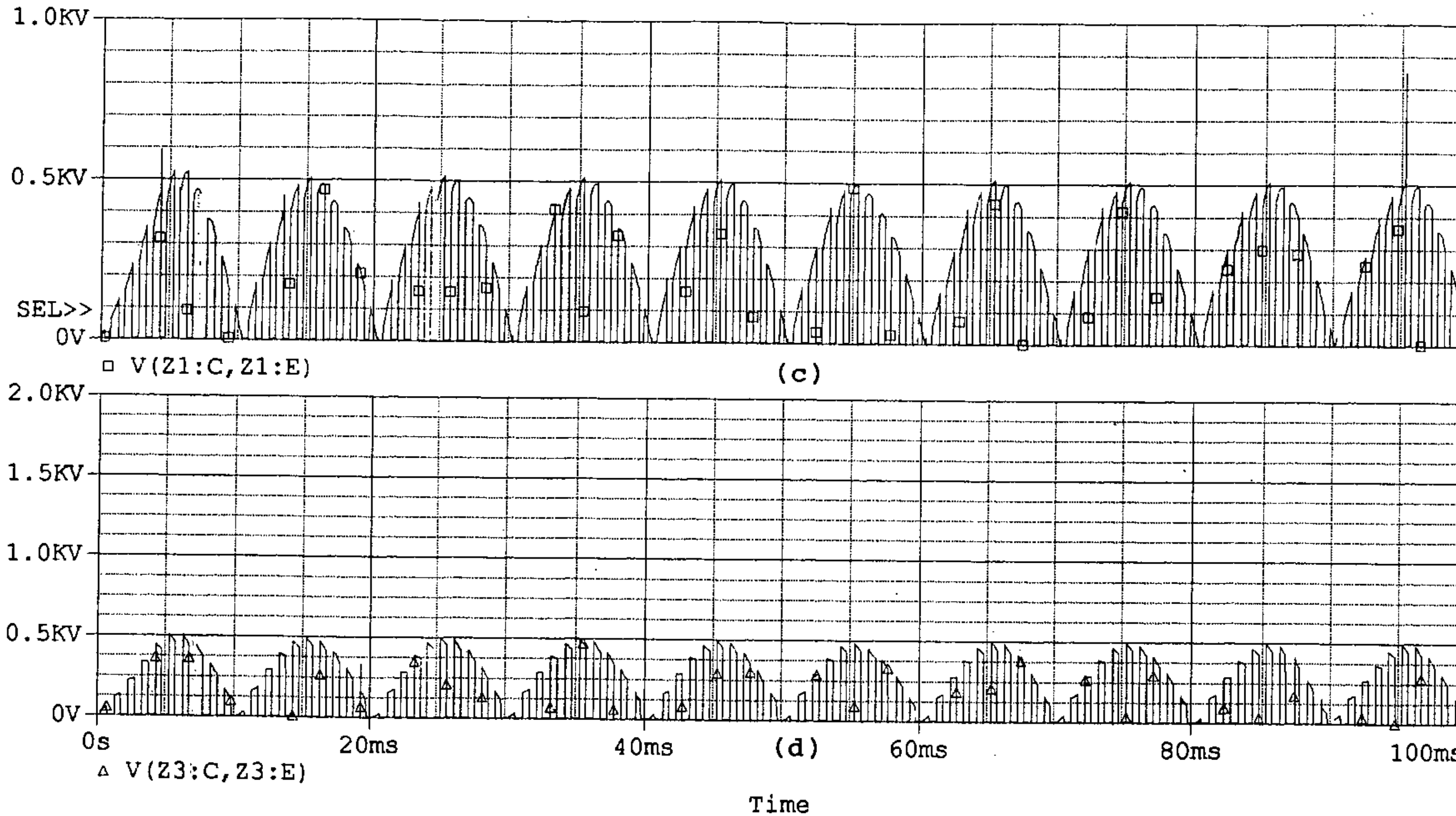


Fig. 92 Spike voltage waveforms across IGBT switches
(c) For switch IGBT-1
(d) For switch IGBT-2

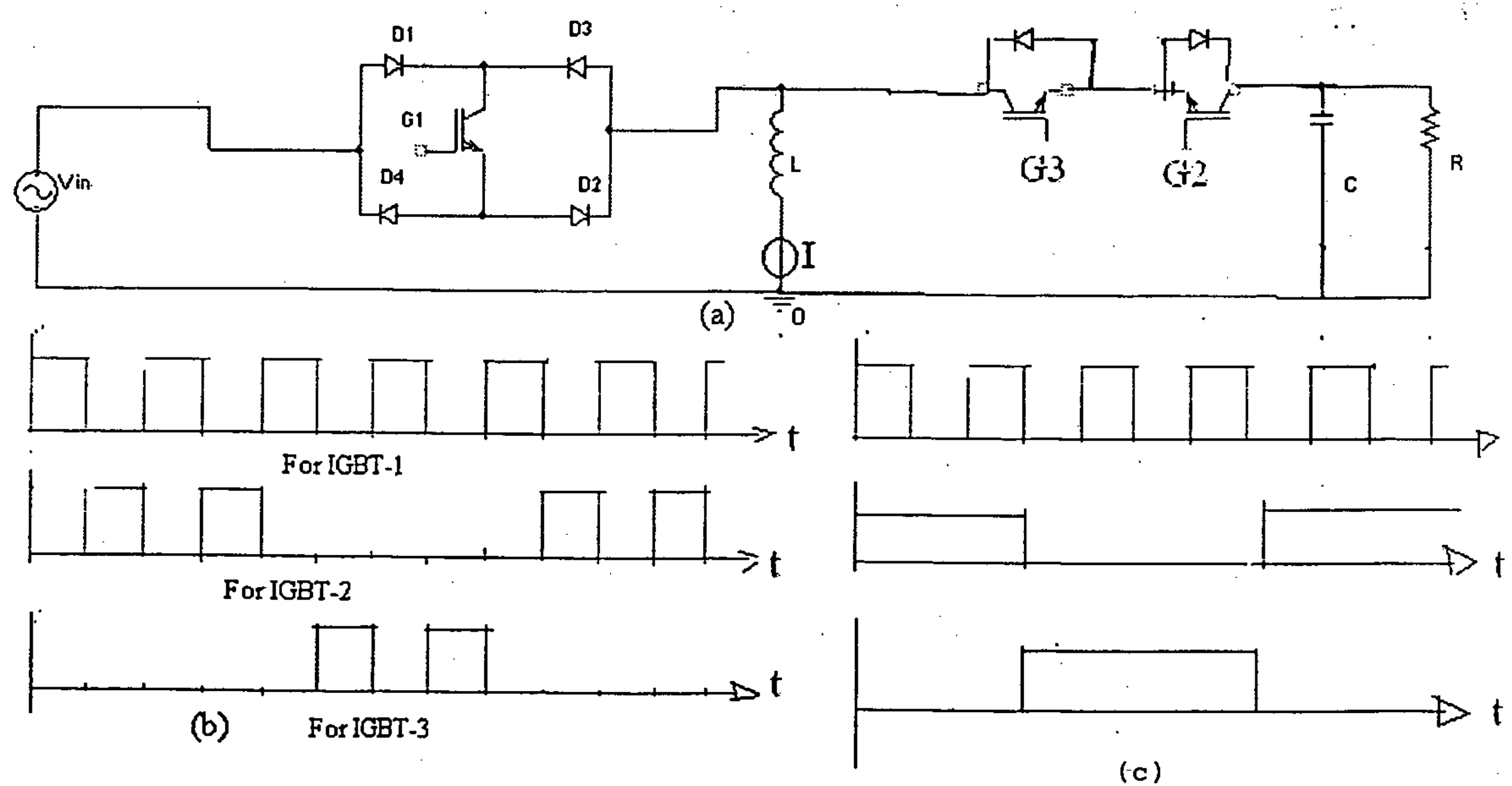


Fig 93: (a) AC Buck-Boost regulator using three IGBT switches .
(b)Gate signals for switches 1,2 and 3
(c) Gate signals for switches 1,2 and 3 which will create one spike in one half cycle

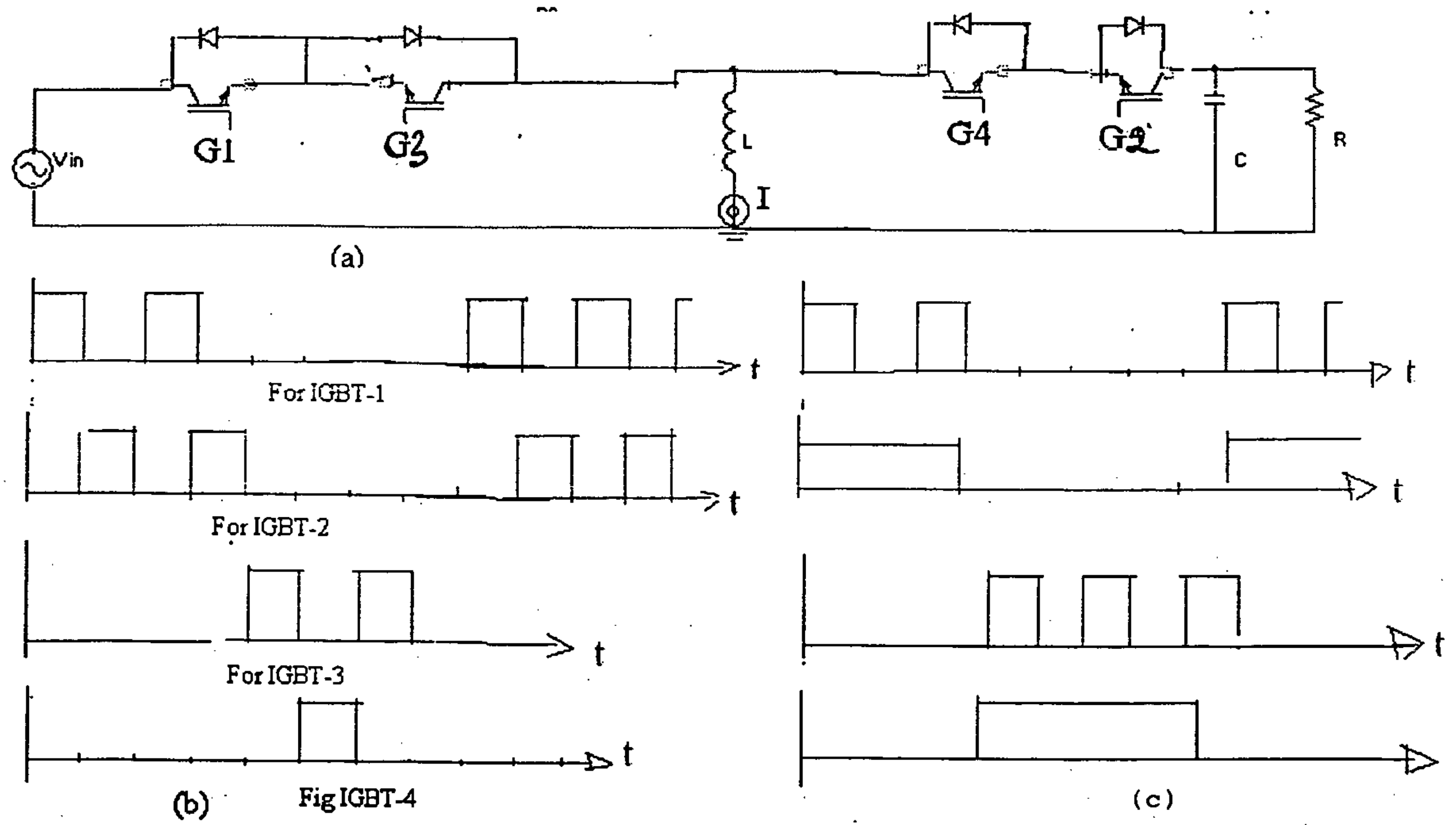


Fig 94: (a) Four switch Buck-Boost regulator
(b) Gate signales for switches 1,2,3 and 4

(c) Gate signals for switches 1,2,3 and 4 which will create one spike in one half cycle

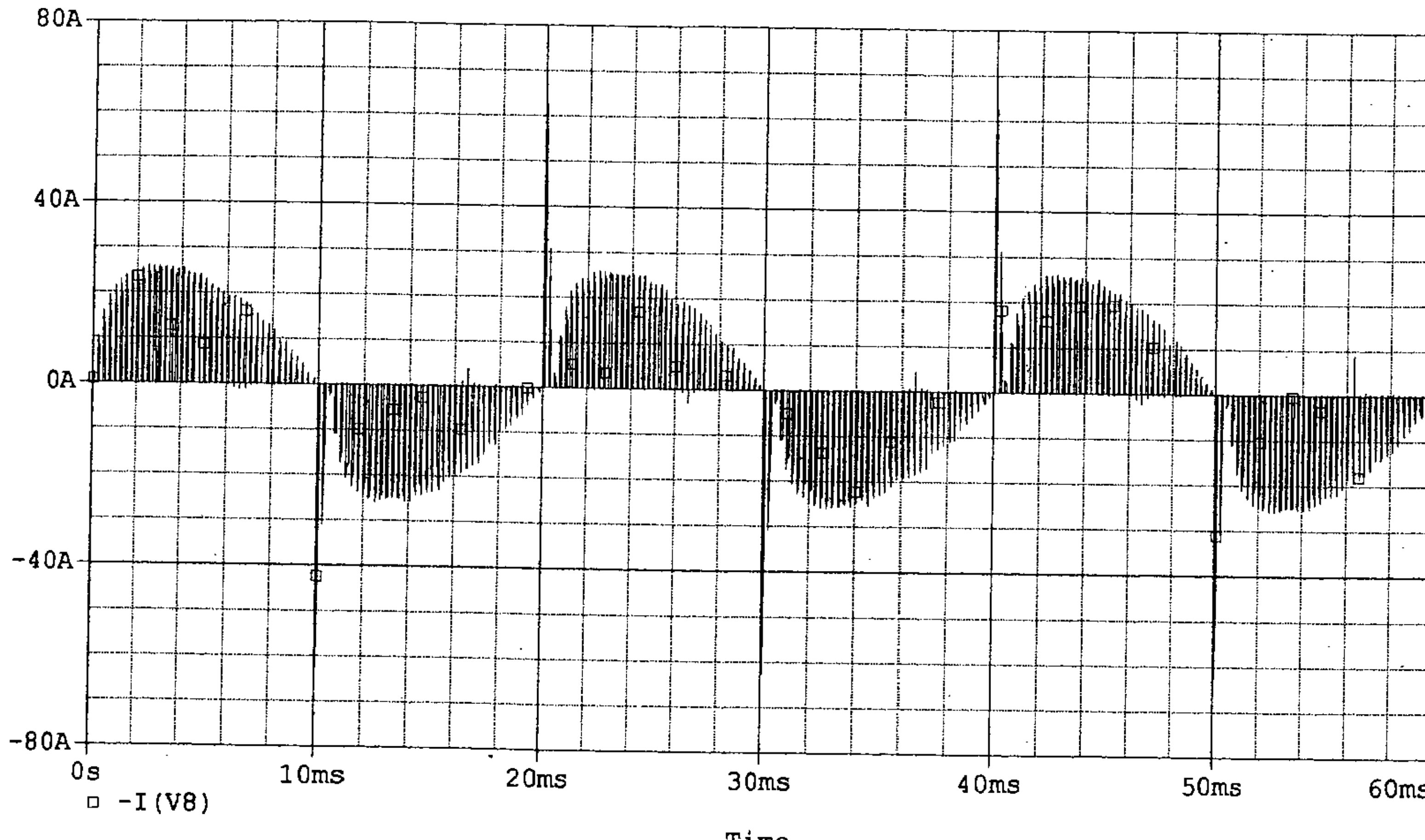


Fig.95 Input current wave; one spike in one half cycle

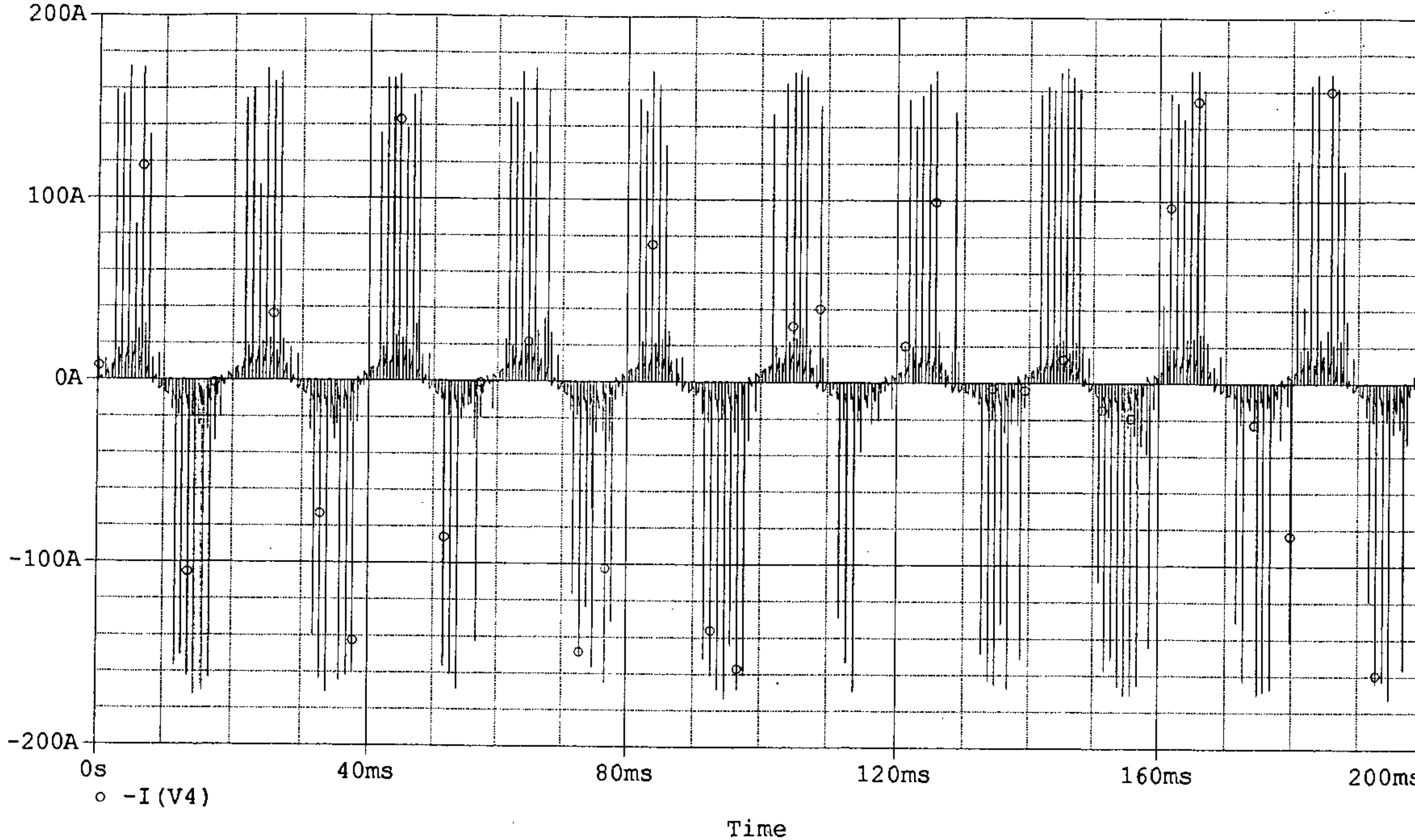


Fig. 96 Input current waveforms of AC Buck-Boost regulator without input filter circuit

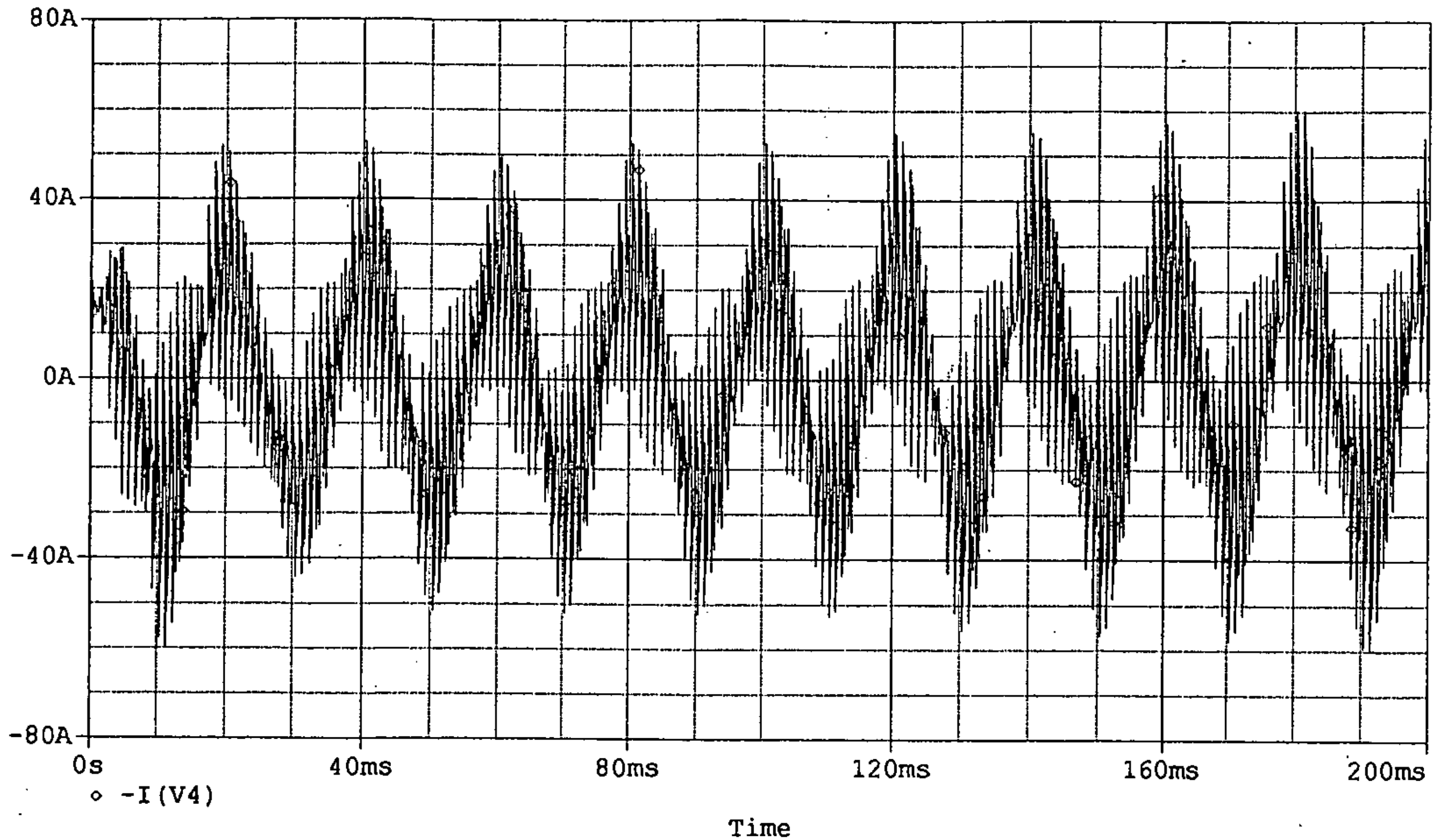


Fig. 97 Input current waveforms of AC Buck- Boost regulator with input filter circuit

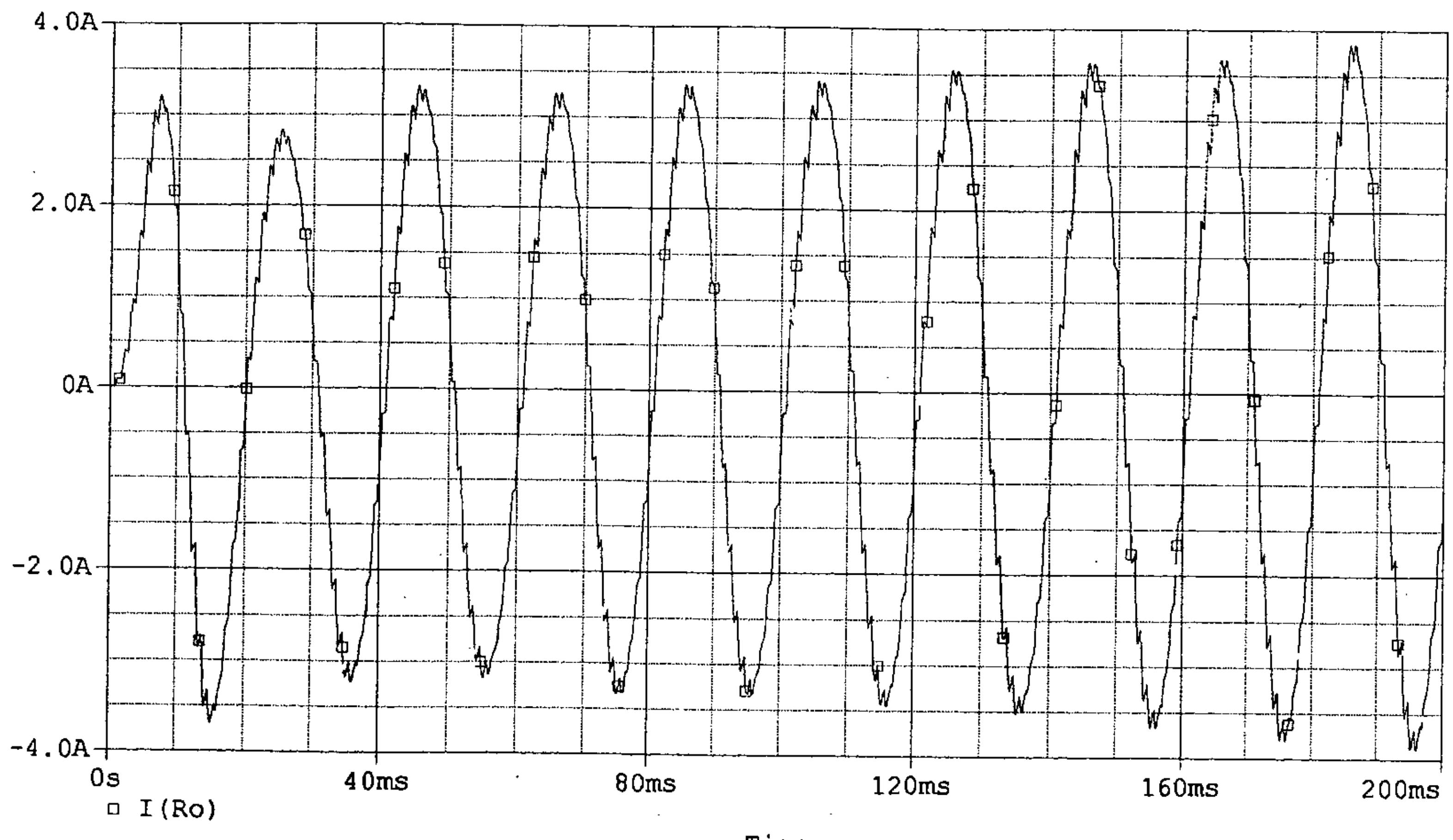


Fig. 98(a) Output current waveforms of AC Buck- Boost regulator with input filter circuit

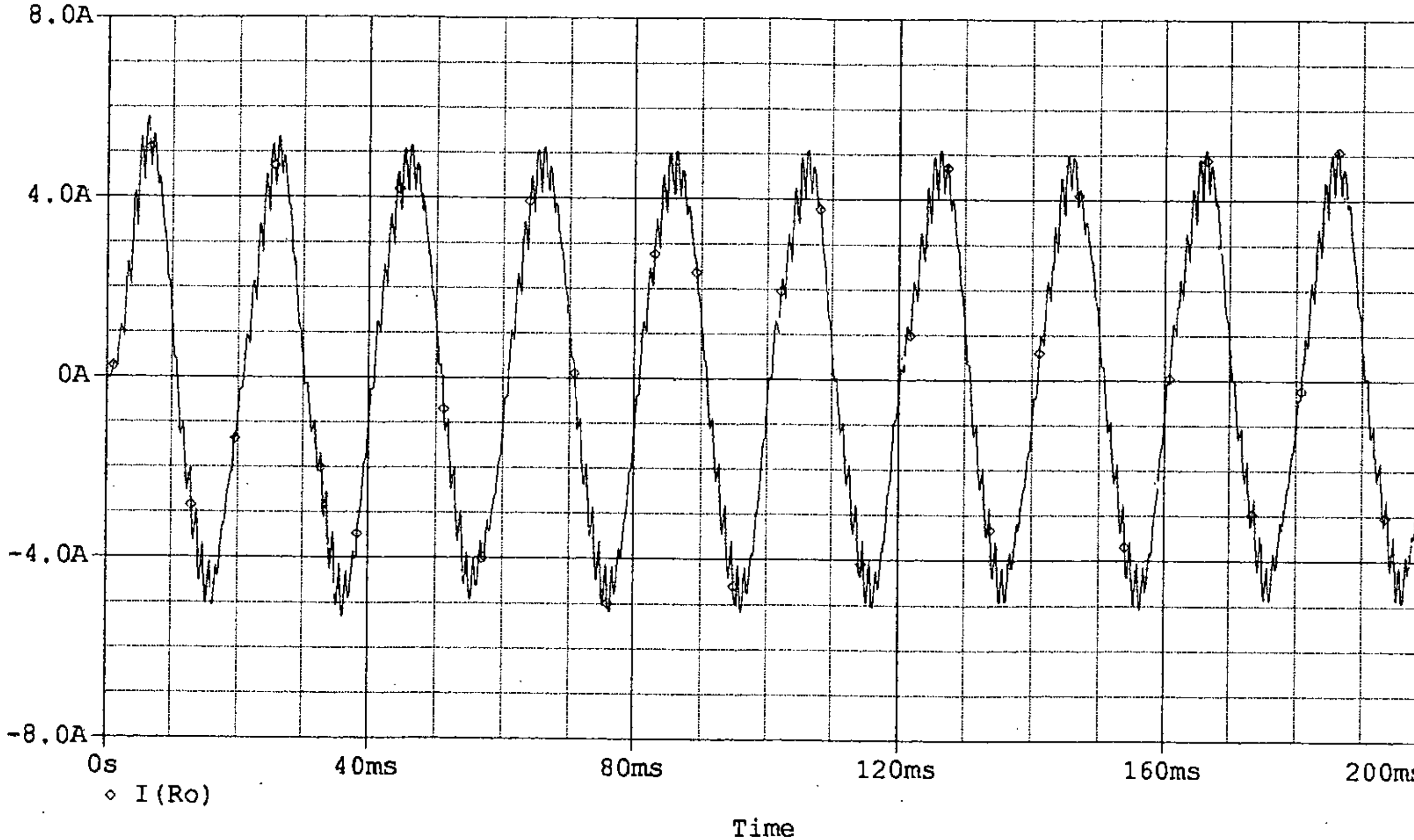


Fig. 98(b) Output current waveforms of AC Buck- Boost regulator without input filter circuit

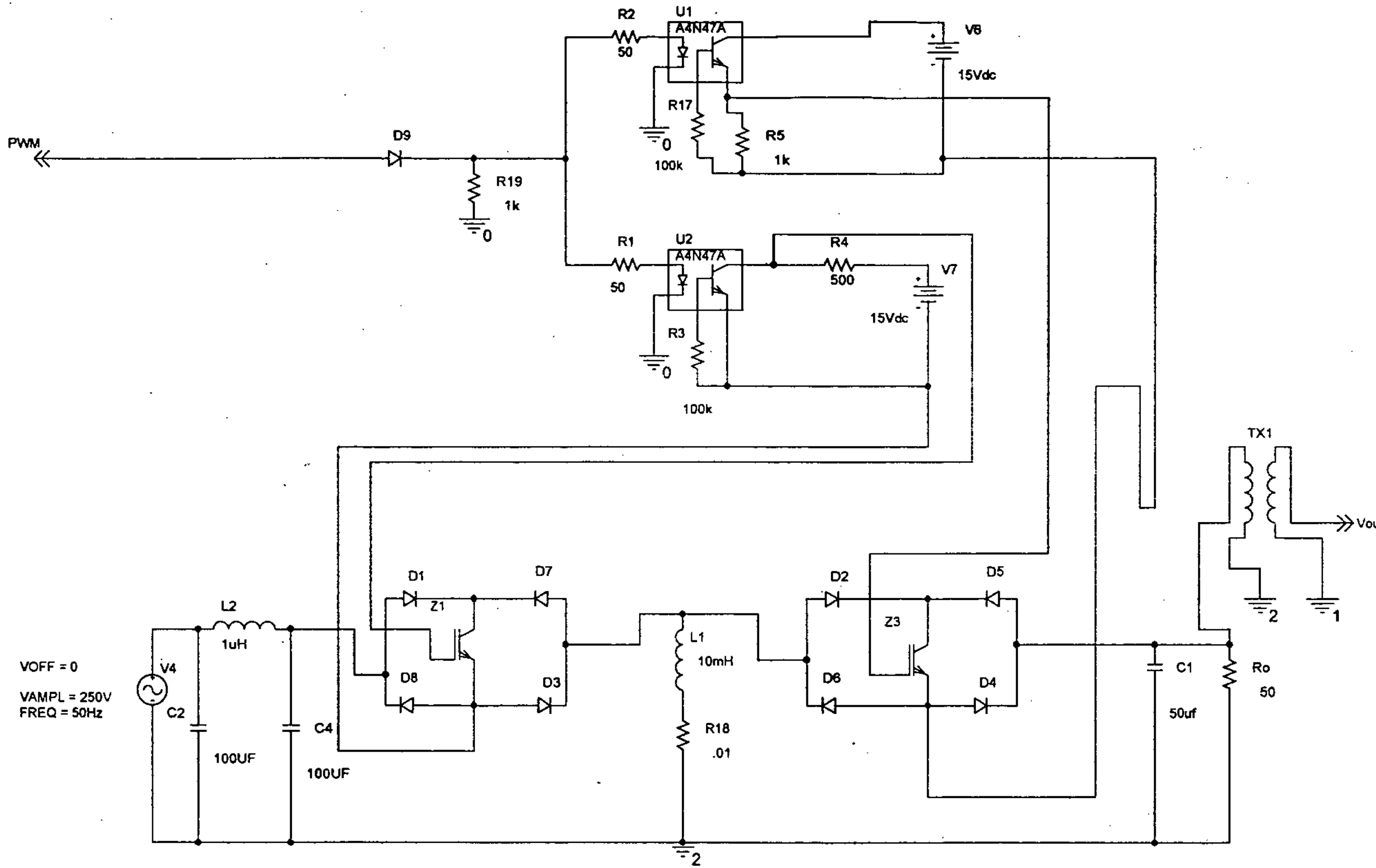


Fig.99 AC Buck-Boost regulator with input filter circuit.

2.6 INPUT / OUTPUT FILTER REQUIREMENT

Fig.100 (a) shows the Buck-Boost regulator. Fig.100 (b) shows modes of operation and Fig. 100 (c) shows the waveforms for the steady-state voltages and current of the Buck-Boost regulator used in DC-DC mode.

Let

V_{in} = The input voltage

V_a = The average output voltage

ΔV_c = Peak-to-peak ripple voltage of the capacitor.

T_{ON} = Turn on time.

T_{OFF} = Turn off time.

T = Time period

= $T_{ON} + T_{OFF}$.

D = Duty cycle = T_{ON} / T.

I_a = The average load current

f = Switching frequency

L = Inductor

C = Filter capacitance

ΔI = Peak-to-peak ripple current of the inductor.

Assuming that the inductor current rises linearly from I_1 to I_2 in time T_{ON},

$$V_{in} = L\frac{I_2 - I_1}{T_{ON}} = L\frac{\Delta I}{\Delta T} \quad \dots \quad \dots \quad \dots \quad (16)$$

or

$$T_{ON} = \frac{\Delta IL}{V_{in}} \quad \dots \quad \dots \quad \dots \quad (17)$$

and the inductor current falls linearly from I_2 to I_1 in time T_{OFF},

$$V_a = -L\frac{\Delta I}{T_{OFF}} \quad \dots \quad \dots \quad \dots \quad (18)$$

or

$$T_{OFF} = \frac{-\Delta IL}{V_a} \quad \dots \quad \dots \quad \dots \quad (19)$$

where $\Delta I = I_2 - I_1$ is the peak-to-peak ripple current of inductor L.

From equations (16) and (18) we have,

$$\Delta I = \frac{V_{in} T_{ON}}{L} = \frac{-V_a T_{OFF}}{L}$$

Substituting $T_{ON} = DT$ and $T_{OFF} = (I - D)T$, the average output voltage is

$$V_a = -\frac{V_{in} D}{1-D} \qquad \cdots \quad \cdots \quad \cdots \quad (20)$$

Assuming a lossless circuit $V_{in}I_{in} = -V_aI_a = V_{in}I_aD / (1-D)$ and the average input current I_{in} is related to the average output current I_a by,

$$I_{in} = \frac{I_a D}{1-D} \qquad \cdots \quad \cdots \quad \cdots \quad (21)$$

The switching period T can be found from

$$T = \frac{1}{f} = T_{ON} + T_{OFF} = \frac{\Delta IL}{V_{in}} - \frac{\Delta IL}{V_a} = \frac{\Delta IL(V_a - V_{in})}{V_{in}V_a} \qquad \cdots \quad \cdots \quad \cdots \quad (22)$$

and this gives the peak-to-peak ripple current,

$$\Delta I = \frac{V_{in}V_a}{fL(V_a - V_{in})} \qquad \cdots \quad \cdots \quad \cdots \quad (23)$$

or

$$\Delta I = \frac{V_{in}D}{fL} \qquad \cdots \quad \cdots \quad \cdots \quad (24)$$

When transistor Q_1 is ON, the filter capacitor supplies the load current for $t = T_{ON}$. The average discharging current of the capacitor $I_c = I_a$ and the peak-to-peak ripple voltage of the capacitor is

$$\Delta V_c = \frac{1}{C}\int_0^{T_{ON}} I_c \, dt = \frac{1}{C}\int_0^{T_{ON}} I_a \, dt = \frac{I_a T_{ON}}{C} \qquad \cdots \quad \cdots \quad \cdots \quad (25)$$

Equation (20) gives $T_{ON} = V_a / [(V_a - V_{in})f]$ and equation (24) becomes

$$\Delta V_c = \frac{I_a V_a}{(V_a - V_{in})fC} \qquad \cdots \quad \cdots \quad \cdots \quad (26)$$

or

$$\Delta V_c = \frac{I_a D}{fC} \qquad \cdots \quad \cdots \quad \cdots \quad (27)$$

or

$$C = \frac{I_a D}{f\Delta V_c} \qquad \cdots \quad \cdots \quad \cdots \quad (28)$$

Let

$D = 0.25$

$\Delta V_c = 5$ Volts

$f = 1000$ Hz

$I_a = 2$ A

∴ By equation (28) we get,

$$C = \frac{2 \times 0.25}{5 \times 1000}$$

$$= 100\mu F$$

The capacitor (100μF) connected to the circuit as a filter.

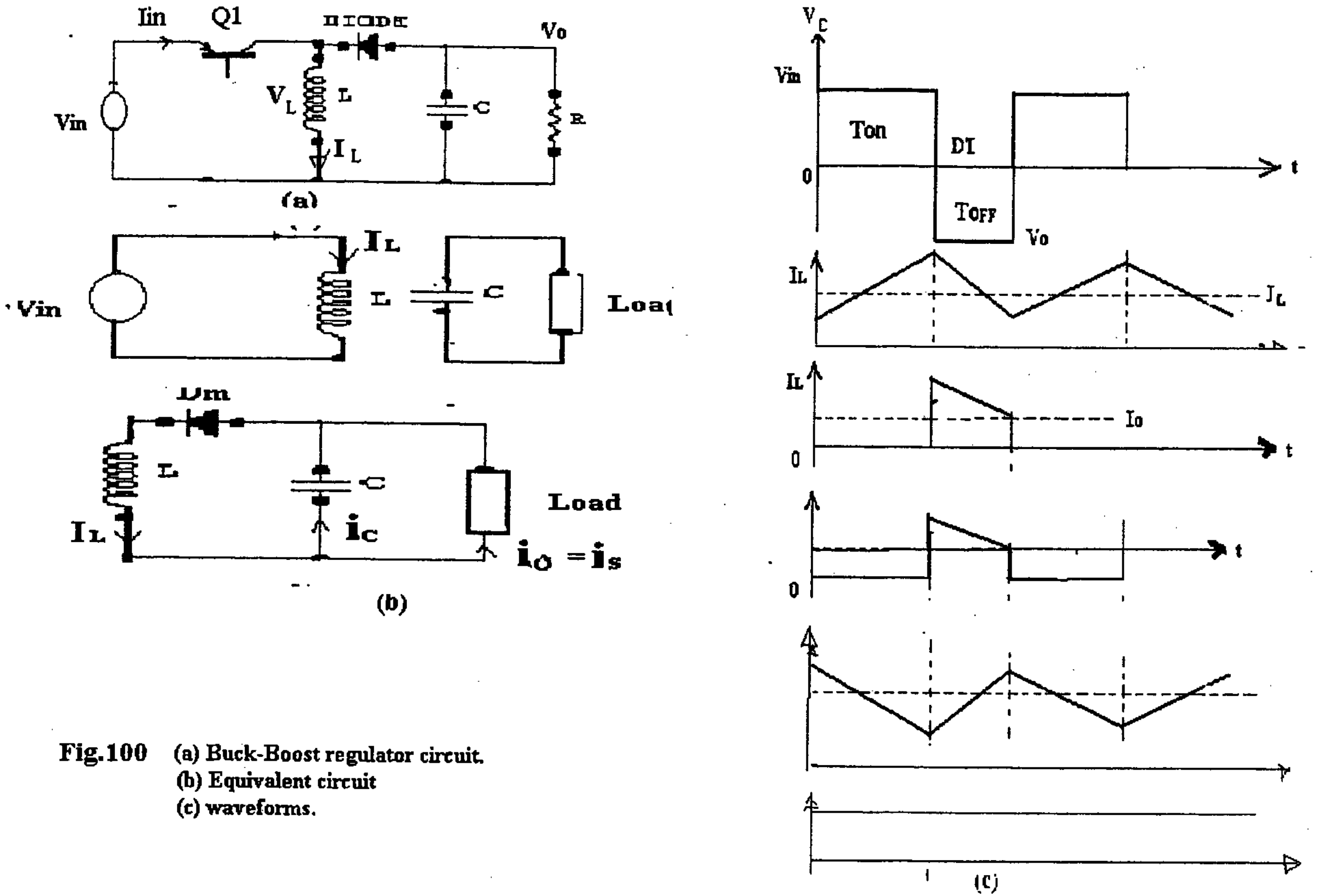


Fig.100 (a) Buck-Boost regulator circuit.
(b) Equivalent circuit
(c) waveforms.

CHAPTER – 3

CONCLUSIONS AND RECOMMENDATIONS

3.1 CONCLUSIONS

Power quality describes the quality of voltage and current of power system and is one of the most important considerations in domestic, industrial and commercial applications today. Power quality faced by industrial operations includes transients, sags, surges, outages, harmonics and impulses. Voltage sags are one of the most important power quality problems affecting domestic, industrial and commercial customers. Voltage sag is the momentary decrease or increase in the rms voltage magnitude, usually caused by faults or sudden loading on the power system. Equipment used in modern industrial plants is becoming more sensitive to voltage fluctuations as the complexity of the equipment increase. Increasing use of loads supplied by electronic power converters has led to growing problems in the quality of power supplies. Computers, adjustable speed drives and automated manufacturing processes are very susceptible to voltage sags and brief outages.

Dc to Dc converters with isolation transformers can have multiple outputs of various magnitudes and polarities. The regulated power supply of this type has wide applications, particularly in computer system, where, a low voltage high current power supply with low output ripple and fast transient response are mandatory. An essential feature of efficient electronic power processing is the use of semiconductors devices in a power supply in switch mode (to achieve low losses) to control the transfer of energy from source to load through the use of pulse width modulated techniques. Inductive and capacitive energy storage elements are used to smooth the flow of energy while keeping losses at a low level. As the frequency of switching increases, the size of the capacitive elements decreases in a direct proportion. Because of their superior performance they are replacing conventional linear power supplies.

This thesis has proposed a AC- AC Buck –Boost regulator for ac power applications. The function of AC- AC Buck –Boost regulator is to keep output voltage constant either for a input voltage increase or decrease and also during load changes.

If the output voltage remains constant equipment life time increases and outages and maintenance are reduced. The AC- AC Buck –Boost regulator are studied for ideal and practical IGBT switch. It has been observed that in the controlled AC Buck-Boost regulator when input voltage is 250v, 300v, 350v and 400v then output voltage is always maintained at 300v corresponding to 230v rms. To maintain constant output voltage PWM control is used. By varying pulse width of output of the control signals ON/OFF time to switch IGBT automatically through electronic circuit have achieved the goal of maintaining the constant output voltage across load. Due to freewheeling path surge voltage appears across the switches devices. In this work snubbers are used as a remedy to this problem. Input current is very high of this regulator. Filter circuit is used to smooth the output. As a starting work towards obtaining a practical light weight, efficient and reliable AC to AC voltage regulator the proposed Buck-Boost regulator show promising aspects. However, problems remain in the form of high input current, output voltage/current ripple and absence of freewheeling path during change of current from one switch to the other. These problems restrict immediate technical viableness of this type of regulator for commercial marketing.

3.2 RECOMMENDATION OF FURTHER WORK

The input current of the AC Buck-Boost regulator is very high and needs to be reduced by further research to make the regulator technically acceptable. To avoid surge voltage across switches an AC Buck-Boost regulator by three switches or four switches with a current changing element may be considered. To make voltage wave shapes ripple free appropriate output filter circuit design and implementation is required. The proposed AC Buck-Boost regulator should be implemented practically in laboratory in future works. Replacement of the control circuit by commercially available SMPS chips during laboratory implementation may be considered to reduce the circuit complexity and reduce cost. These chips allow soft start of SMPS converters and current regulation with proper design.

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