Experiment (1)
characteristics of the thyristor

Experiment aim
To study and plot the characteristics of the thyristor.

Apparatus
1. Power electronic trainer
2. Dual channel Oscilloscope
3. Two AVO meter
4. Two DC power supply

Introduction
A thyristor is a four-layer p-n-p-n semiconductor device consisting of three p-n junctions. It has three terminals: anode, cathode and a gate. Figure (1) shows the thyristor symbol and a sectional view of the three-pn junctions.

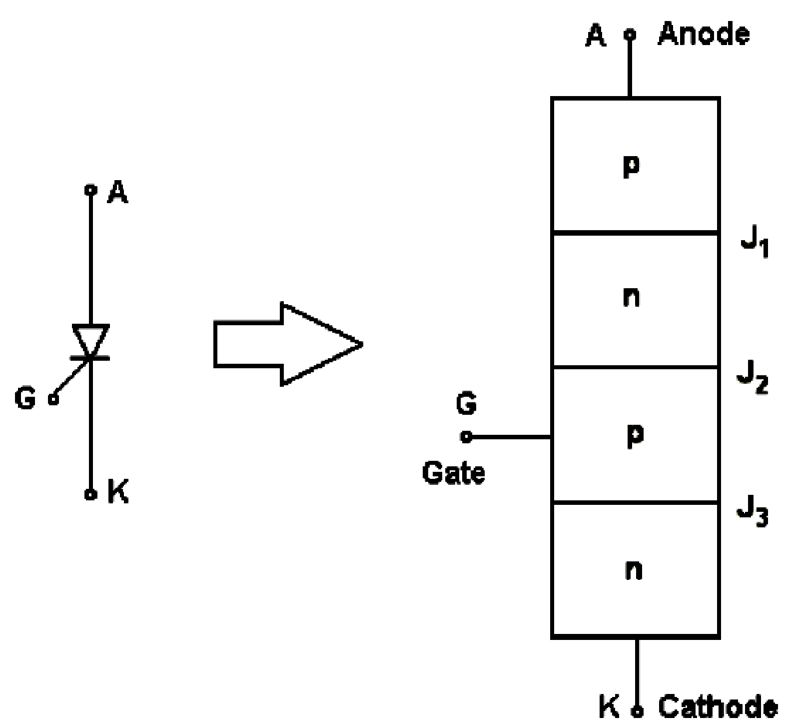


Figure (1): Thyristor Symbol & p-n Junctions

When the anode voltage made positive with respect to the cathode, junctions $\mathbf{J}_1$ and $\mathbf{J}_3$ are forward biased and junction $\mathbf{J}_2$ is reverse biased. The thyristor said to be in the *forward blocking* or *off-state condition*. A small leakage current flows from anode to cathode and is called the *off state current*. If the anode voltage $\mathbf{V}_{AK}$ is increased to a sufficiently large value, the reverse biased junction $\mathbf{J}_2$ would breakdown. This is known as *avalanche breakdown* and the corresponding voltage is called the *forward breakdown voltage* $\mathbf{V}_{BO}$. Since the other two junctions $\mathbf{J}_1$ and $\mathbf{J}_3$ are already forward biased, there will be free movement of carriers across all three junctions. This results in a large forward current. The device now said to be in a *conducting* or *on state*. The voltage drop across the device in the on-state is due to the ohmic drop in the four layers and is very small (in the region of 1 V). In the on state the anode current is limited by an external impedance or resistance as shown in figure (2-a).

V-I Characteristics of Thyristor

Figure (2) shows the V-I characteristics and the circuit used to obtain these characteristics.

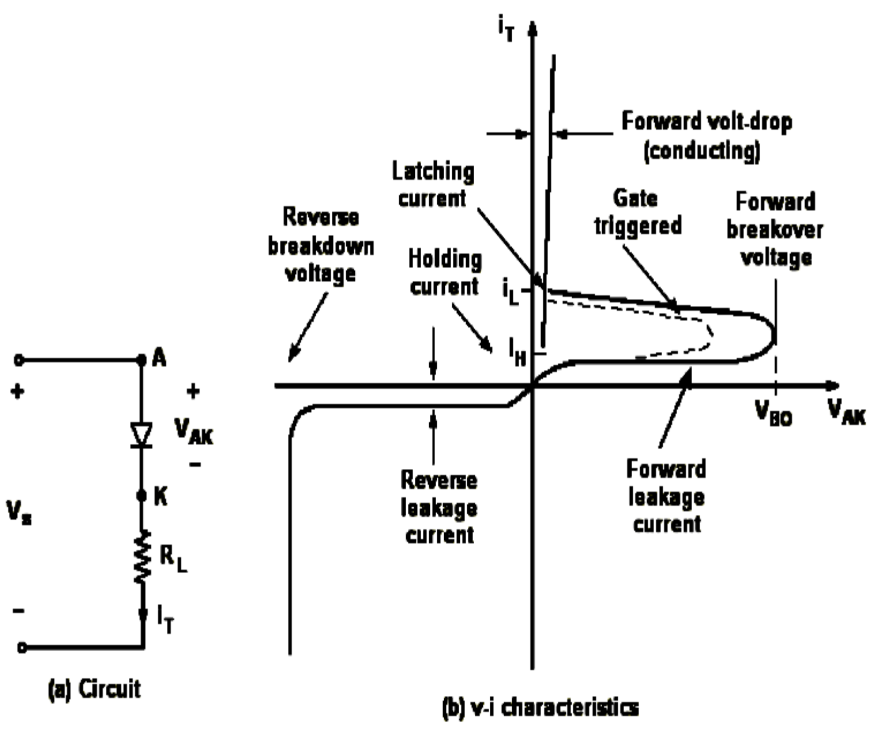


Figure (2): Thyristor Circuit & V-I Characteristics

The important points on this characteristic are:

1-Latching Current I_L

This is the minimum anode current required to maintain the thyristor in the on-state immediately after a thyristor has been turned on and the gate signal has been removed. If a gate current, greater than the threshold gate current is applied until the anode current is greater than the latching current I_L then the thyristor will be turned on or triggered.

2-Holding Current I_H

This is the minimum anode current required to maintain the thyristor in the on state. To turn off a thyristor, the forward anode current must be reduced below its holding current for a sufficient time for mobile charge carriers to vacate the junction. If the anode current is not maintained below I_H for long enough, the thyristor will not have returned to the fully blocking state by the time the anode-to-cathode voltage rises again. It might then return to the conducting state without an externally applied gate current.

3-Reverse Current I_R

When the cathode voltage is positive with respect to the anode, the junction J_2 is forward biased but junctions J_1 and J_3 are reverse biased. The thyristor is said to be in the *reverse blocking state* and a reverse leakage current known as reverse current I_R will flow through
the device.

4-Forward Break-over Voltage V_{BO}

If the forward voltage V_{AK} is increased beyond V_{BO}, the thyristor can be turned on. However, such a turn-on could be destructive. In practice, the forward voltage is maintained below V_{BO} and the thyristor is turned on by applying a positive gate signal between gate and cathode.

5-Once the thyristor is turned on by a gate signal and its anode current is greater than the holding current, the device continues to conduct due to positive feedback even if the gate signal is removed. This is because the thyristor is a latching device and it has been latched to the on state.

Procedure

1- TO observe the terminal configuration of a thyristor, thyristor's body is generally connected with anode terminal by the manufacture; hence, the anode terminal can be identified with help of a multimeter. Now, measure the resistance between other two terminals (gate and cathode) of the thyrsitor. The forward-biased p-n junction of a diode shows a low resistance than the reverse-biased junction. When the AVO meter shows a low resistance then the gate (G) terminal is the one, which connected with positive terminal of the multi-meter battery.

2- Connect the circuit shown in figure (3). Apply the 30volt across the anode and cathode terminals through 1.1 kΩ resistor. The device must be on the off state with open gate.

3- Increase the gate supply voltage gradually until the thyristor turn on. Recode the minimum gate current ($I_{gmin)}$ required turning on the thyristor.

4- Set the source voltage to zero volts. Adjust the gate voltage to a slightly higher value than what is found in the step (3). Keep the gat voltage constant over the experiment. Increase gradually the source voltage (in steps) so that the anode current (I_a) increased in steps. Open and close the gate terminal after each step. If anode current is greater than the latching current (I_L) of the device, then the device stay on even after the gate terminal is opened.

5- Increase the anode current from the latching current level by increasing slightly the supply voltage. Open the gate terminal. Now start reducing the anode current gradually by adjusting the voltage source until the thyristor goes into blocking mode. The anode current at this instant called holding current (I_H).

6- Connect the circuit shown in Fig (4). Use the oscilloscope in the X-Y mode, and then connect the point A to channel I and point B to channel II. Draw the shape will appear on the oscilloscope screen. These shape represent the V-I characteristics.

Discussion

1. What are the conditions for operating a thyristor in the normal operation?
2. From your results , explain the holding and latching current of a thyristor.
3. What is the different between the diode and a thyristor?
4. What is the relation between gate current and anode current of thyristor in conduction period?
5. What are the difference between an (ordinary switch) and a semiconductor switch such as (thyristor and transistor)?

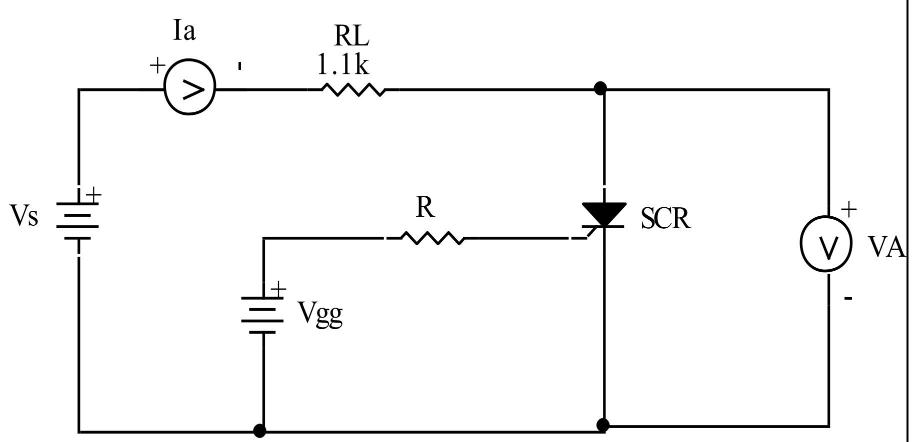


Fig.(3): circuit for measuring latching and holding

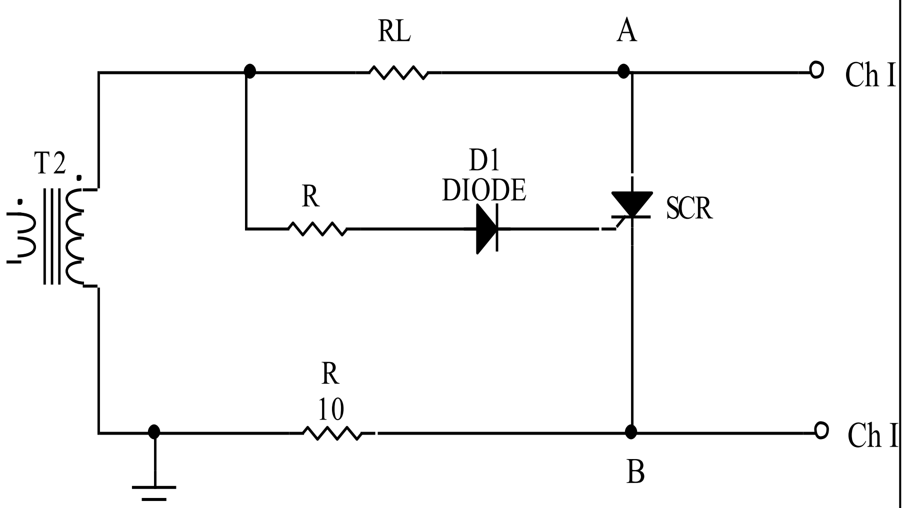


Fig.(4): Measurement of the V-I characteristics of a

Experiment No. 2
Power diode Characteristics

Experiment aim

To study and plot the characteristics of the power diode.

Apparatus

1. Power electronic trainer.
2. Dual channel Oscilloscope.
3. Set of wires.

Theory

The diode is a device formed from a junction of n-type and p-type semiconductor material. The lead connected to the p-type material is called the anode and the lead connected to the n-type material is the cathode. In general, the cathode of a diode is marked by a solid line on the diode in figure(1).

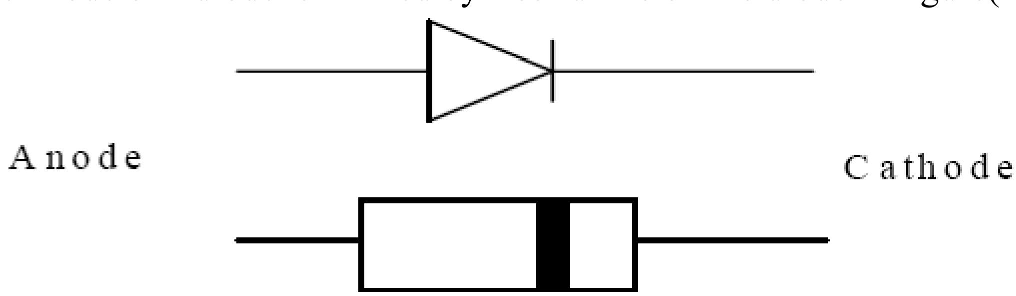


Figure 1: The symbol for a diode compared to an actual diode package.

The primary function of the diode is rectification. When it is forward biased (the higher potential is connected to the anode lead), it will pass current. When it is reversed biased (the higher potential is connected to the cathode lead), current flow is blocked. The characteristic curve for a real diode is seen in figure (2).

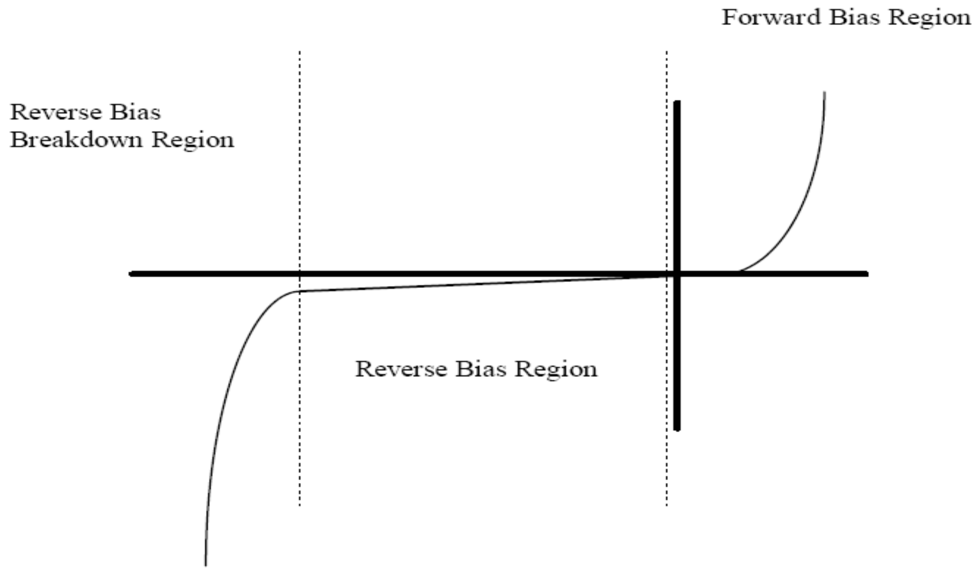


Figure (2) : I-V Curve for a real diode.

Simple model

When analyzing circuits, the real diode is usually replaced with a simpler model. In the simplest form, the diode is modeled by a switch Figure (3). The switch is closed when the diode if forward biased and open when the diode is reversed biased.

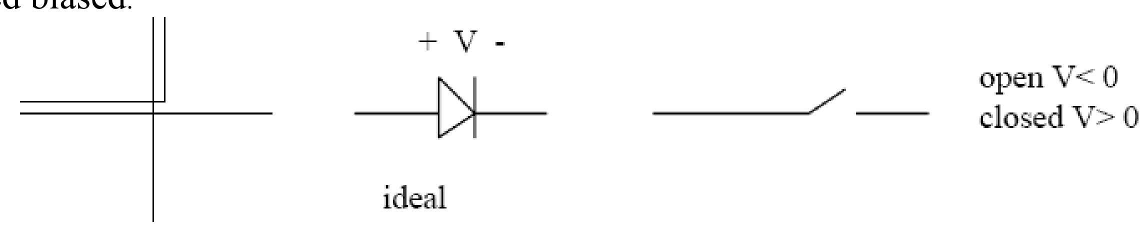


Figure (3): Simple model of a real diode with a finite turn-on voltage.

The Complete Diode Model:

- More accurate
- The forward biased diode model with both the barrier potential and low forward (bulk) resistance (*r'd*) in figure (4):

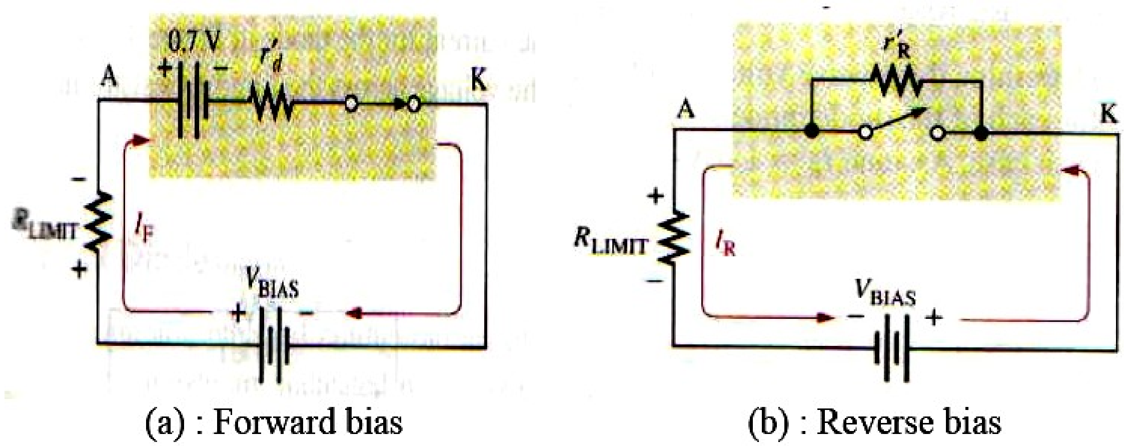


Figure (4) Forward and Reverse biases for diode

The I-V characteristics for a diode can be displayed on an oscilloscope in X-Y mode. A time varying voltage source must be used in order to trace both the forward and reverse bias characteristics of the diode.

Thus one of the oscilloscope probes must be placed across the resistor and the other across the diode in figure (5).

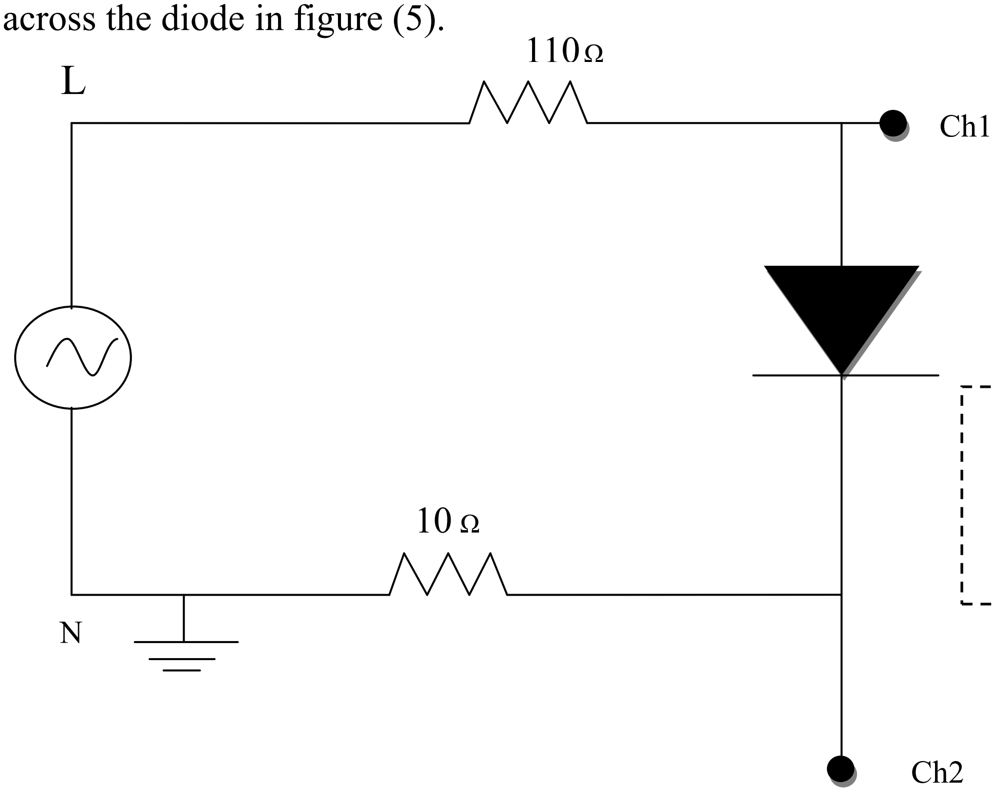


Figure (5) measurement of the I&V characteristics of a diode

Procedure

1. Connect the circuit shown in Fig.(5) on the power electronic trainer.
2. Turn on the power.
3. Plot the input waveform graph paper.
4. Plot voltage diode at CH_1 and current diode at CH_2 on the same waveforms graph paper.
5. Put the time base of oscilloscope on X-Y position, then plot the characteristic graph.
6. Turn off the power.

Discussion and calculations:

1- Comment on your results.
2- Give some application of the power diode.
3- The diode I-V characteristics can be best described as:
a) Linear.
b) Exponential.
c) Sinusoidal.
d) Quadratic.

Experiment No.3
Single-Phase half wave Rectifier

Experiment aim

The aim of this experiment is to design and analysis of a single phase uncontrolled rectifier.

Apparatus

Make the circuit for AC-DC converter using the following parts:

1- Power electronic trainer
2- Oscilloscope
3- AVO meter

Theory

Rectification is the process of conversion of alternating input voltage to direct output voltage. In diode rectifiers, the output voltage cannot be controlled. AC-DC converter (Rectifiers) can be classified as:

- Half wave rectifier HWR
- Full wave rectifier FWR

These can further be classified depending upon the rectifying element being used. If using diode, are called uncontrolled rectifiers. Whereas if using thyristor, are called controlled rectifiers. The application of these converts may include the following:

→ Variable speed dc drives,
→ Battery chargers,
→ DC power supplies and Power supply for a specific application like laser sources, electronic sets.

Single-Phase HW Uncontrolled Rectifier

The simplest type of uncontrolled rectifiers is HWR is never used industrial applications because of its poor performance. In a single phase, half wave rectifier SPHWR, for one cycle of supply voltage, there is one-half cycle of output. The load on the output side of rectifier may be resistive load (R), or inductive load (R+L). The free-wheel diode connected across the inductive load on the output side of rectifier.

-Operation with resistive load

The circuit diagram and the input and output waveforms is shown in Fig(1). At $0<\omega t<\pi$ diode is forward biased and output voltage V_o is source voltage V_s. Where $V_s = V_m \sin\omega t$, and load current is $i_o = V_o/R$. At $\pi<\omega t<2\pi$ diode is reverse biased and output voltage V_o = zero and load current is $i_o = 0$.

For R load the output current waveform same the output voltage waveforms. The average output voltage is V_m/π, and RMS value of output voltage is equal to $V_m/2$. Peak inverse voltage PIV = V_m.

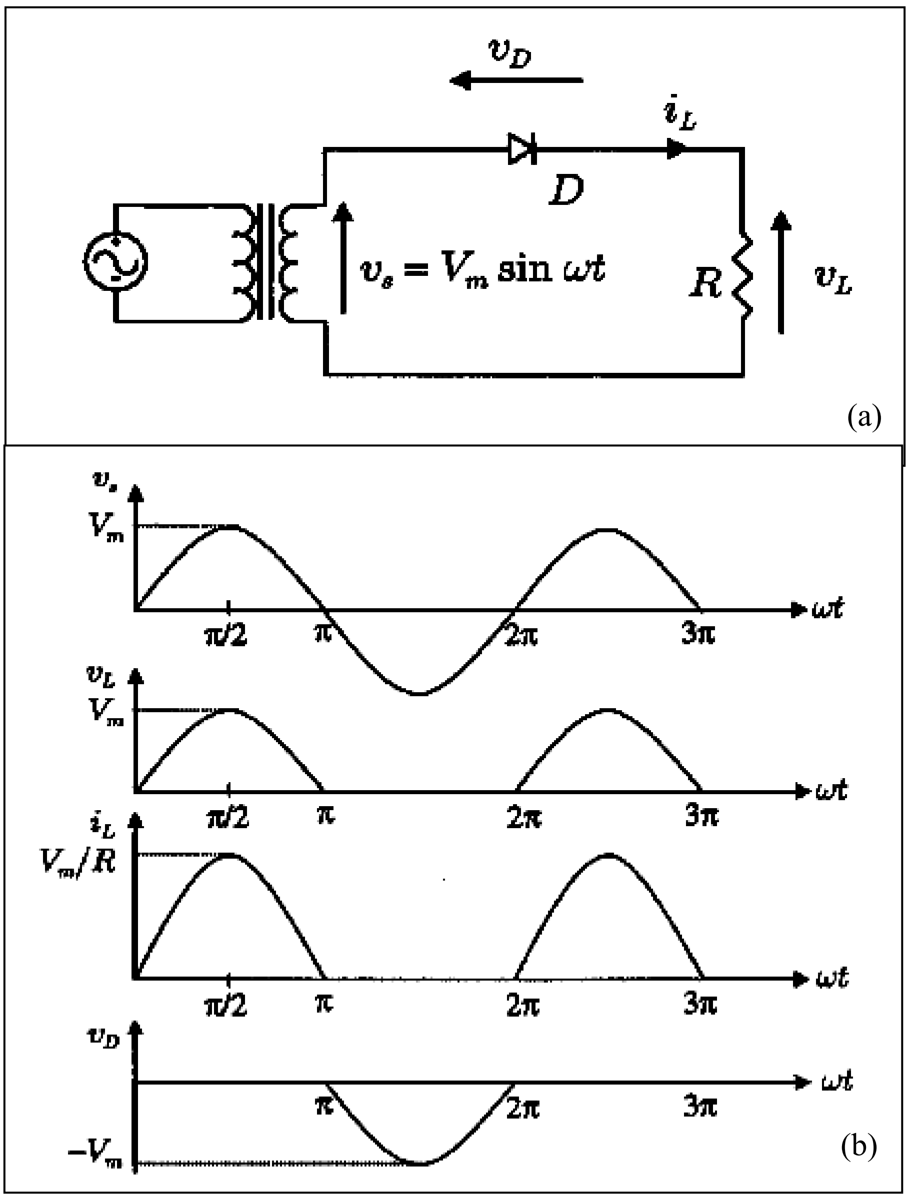


Fig.(1): a) A single-phase half-wave rectifier with resistive load.
b)Voltage and current waveforms of the half-wave rectifier with resistive load.

-Operation with inductive load

As shown in Fig.(2), after the end of the positive half cycle , the current continuous to flow due to the inductive voltage (Ldi/dt), and load experience the negative voltage of the source. The diode ceases conduction when inductance current attempt I_L to reverse at $\omega t=\beta$ and voltage source appear as reverse bias across diode D. then:

$Vo=\frac{V_m}{2\pi}(1-\cos\beta)$, $Io=\frac{V_m}{2\pi R}(1-\cos\beta)$ Without freewheeling diode

$Vo=\frac{V_m}{\pi}$, $Io=\frac{V_m}{\pi R}$ With freewheeling diode

The value of extinction angle β can be calculated from the equation below:

$$\text{Sin}(\beta-\phi)+\sin\phi\times\exp\left[-\frac{R}{\omega L}\beta\right]=0$$

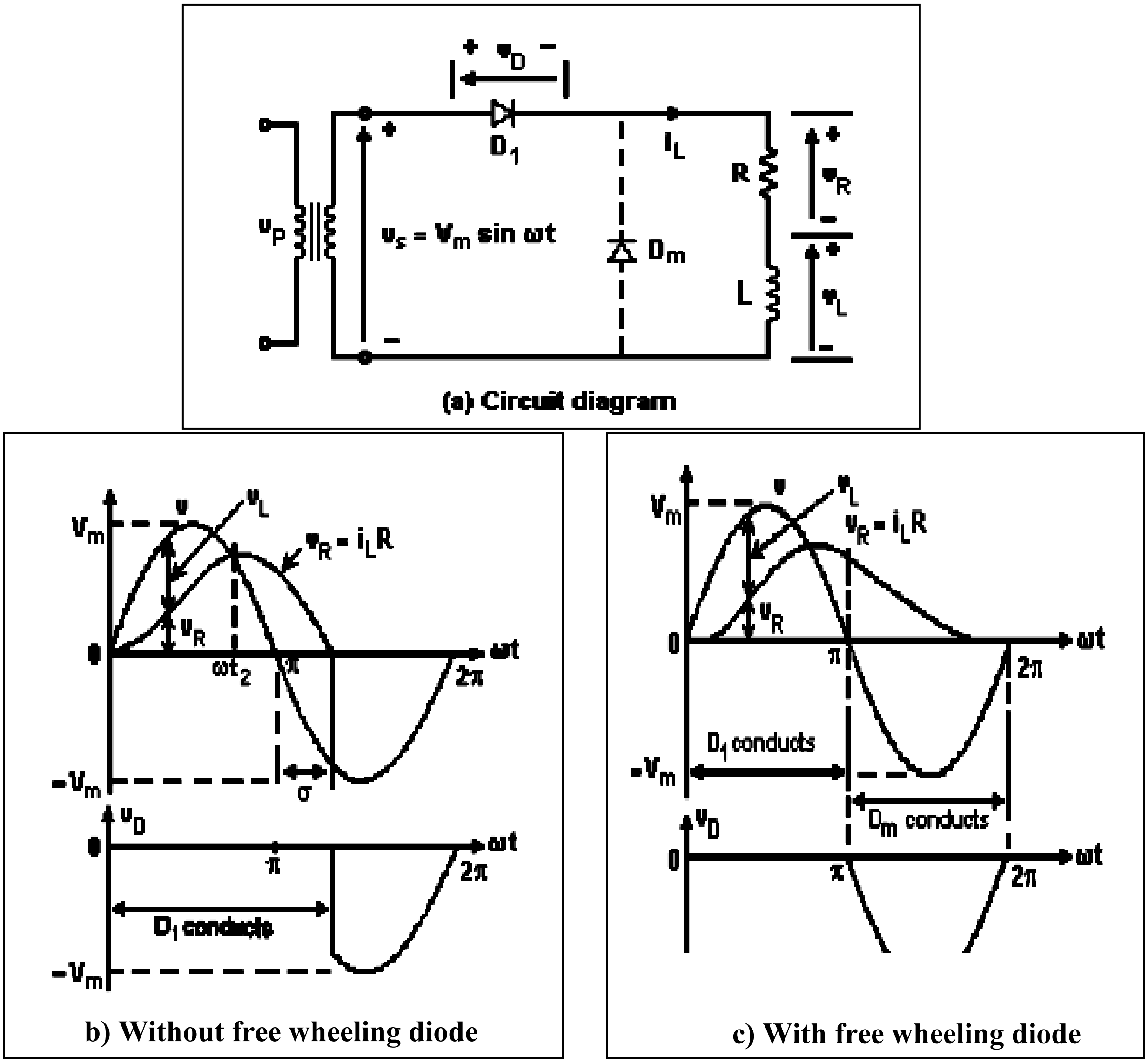
Where $\phi=\tan^{-1}(X/R)$ and ϕ is the angle by which RMS current I_s lag

Procedure

1. Connect the single phase half wave rectifier circuit shown in Fig.(1) on the power electronic trainer.
2. Turn on the power
3. Plot the input and output waveforms on the same graph paper.
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. **Turn off the power**
6. Add the inductive load on the output as shown in Fig(2). With L=10mH measure the output voltage and plot the output waveform.
7. Repeat step 6 with L=100mH, 500mH measure the output voltage and plot the output waveforms.
8. Repeat step 6 & 7 with connect the freewheeling diode across the load.

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages .
2. What design parameters of the half wave single-phase rectifier?
3. Design a Carbon dioxide laser power supply, if the voltage across discharge tube is 12kVolt and the current pass through discharge tube is 10mA.



b) Without free wheeling diode

c) With free wheeling diode

Fig(2): Single phase half-wave diode rectifier with RL load

Experiment No.4
Single-Phase full wave Rectifier

Experiment aim

The aim of this experiment is to design and analysis of a single phase uncontrolled rectifier.

Apparatus

Make the circuit for AC-DC converter using the following parts:

1- Power electronic trainer
2- Oscilloscope
3- AVO meter

Theory

Rectification is the process of conversion of alternating input voltage to direct output voltage. In diode rectifiers, the output voltage cannot be controlled. AC-DC converter (Rectifiers) can be classified as:

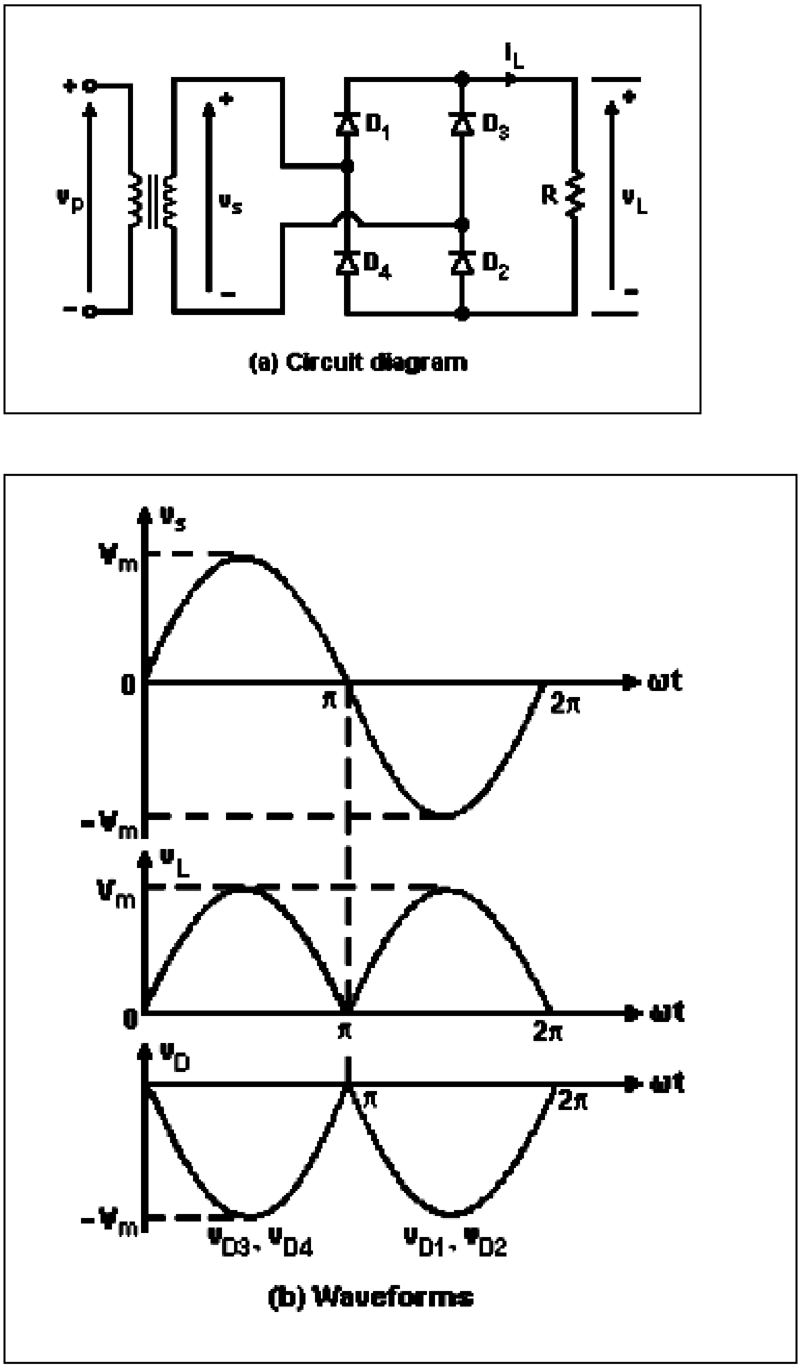
- Half wave rectifier HWR
- Full wave rectifier FWR

These can further be classified depending upon the rectifying element being used. If using diode, are called uncontrolled rectifiers. Whereas if using thyristor, are called controlled rectifiers. The application of these converts may include the following:

→ Variable speed dc drives,
→ Battery chargers,
→ DC power supplies and Power supply for a specific application like laser sources, electronic sets.

Single –Phase FW uncontrolled rectifier

Another type of uncontrolled rectifier is SPFWR or bridge rectifier, this type of rectifier is shown in Fig.(3). During the positive half cycle of the supply voltage, D_1 and D_2 are forward biased, the current $i_1$flow through D_1, load D_2. During the negative half cycle, D_3 and D_4 are forward biased and supply current i_s to the load. Thus at any time , there are two diode in series with the load. The PIV is V_m. The average and RMS voltage are $V_d = \frac{2V_m}{\pi}$ and $V_L = \frac{V_m}{\sqrt{2}}$.



Fig(1): Single phase full-wave diode rectifier with R load

Procedure

1. Connect the single phase full wave rectifier circuit shown in Fig.(1) on the power electronic trainer.
2. Turn on the power
3. Plot the input and output waveforms on the same graph paper.
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. **Turn off the power**

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages.
2. What design parameters of the full wave single-phase rectifier?
3. When you design 10kW rectifier, what type of rectifier must be use? Why?
4. Design a Carbon dioxide laser power supply, if the voltage across discharge tube is 12kVolt and the current pass through discharge tube is 100mA.

Experiment No.5
Single-Phase half wave Voltage Multiplier

Experiment aim

The aim of this experiment is to design and analysis of a single phase voltage multiplier.

Apparatus

Make the circuit for voltage multiplier using the following parts:

1-Power electronic trainer.
2-Oscilloscope .
3-AVO meter.

Theory

Voltage multipliers may also be used as primary power supplies whereAC input is rectified to pulsating dc. This dc output voltage may be increased (through use of a voltage multiplier) to as much as 1000 volts dc. This voltage is generally used as the plate or screen grid voltage for electron tubes.

Voltage multipliers may be classified as voltage doublers, triplers, or quadruples. The classification depends on the ratio of the output voltage to the input voltage. For example, a voltage multiplier that increases the peak input voltage twice is called a voltage doubler. Voltage multipliers increase voltages through the use of series-aiding voltage sources.

Half-Wave Voltage Doublers

Figure (1) below shows the schematic for a half-wave voltage doubler. Notice the similarities between this schematic and those of half-wave voltage rectifiers. In fact, the doubler shown is made up of two half-wave voltage rectifiers. C_1 and D_1 make up one half-wave rectifier, and C_2 and D_2 make up the other. The schematic of the first half-wave rectifier is indicated by the dark lines in figure below. The dotted lines and associated components represent the other half-wave rectifier and load resistor.

Notice that C_1 and D_1 work exactly like a half-wave rectifier. During the positive alternation of the input cycle, the polarity across the secondary winding of the transformer is make the top of the secondary is negative.

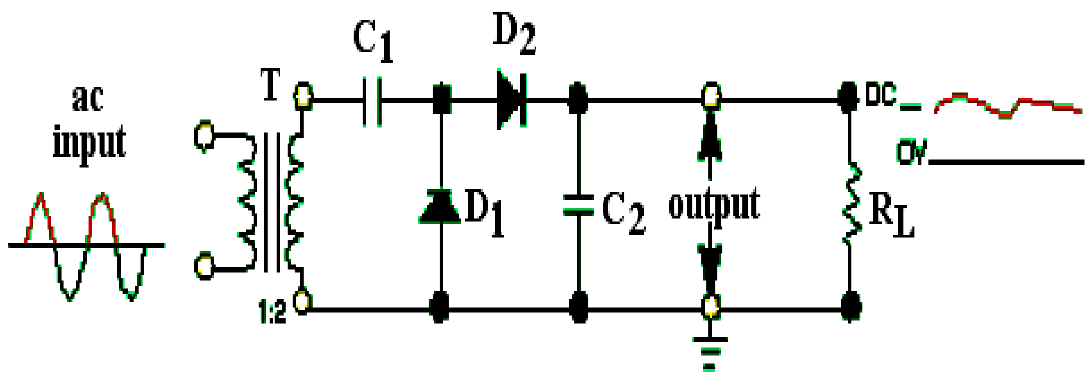
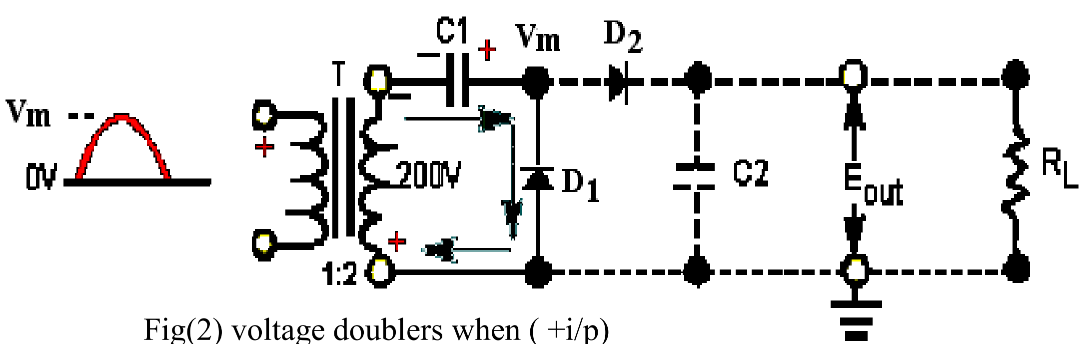


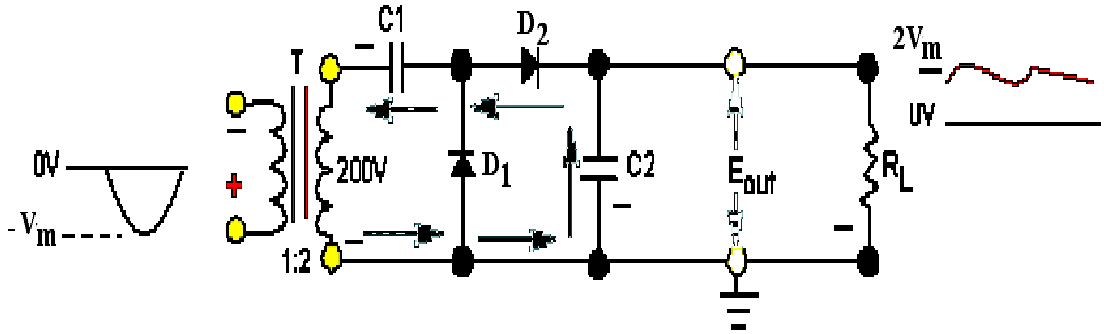
Fig.(1): Voltage doubler

Below in fig(2) at this time D_1 is forward biased (cathode negative in respect to the anode). This forward bias causes D_1 to function like a closed switch and allows current to follow the path indicated by the arrows. At this time, C_1 charges to the peak value of the input voltage.



Fig(2) voltage doublers when (+i/p)

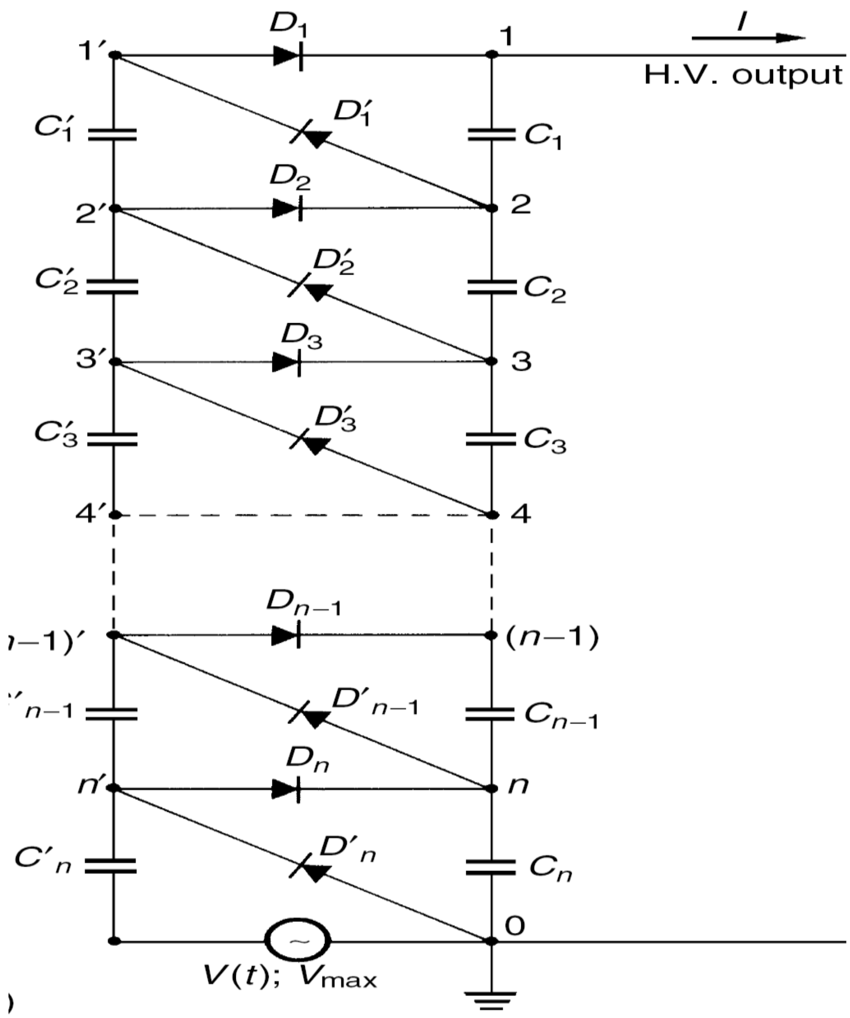
Below in fig(3) during the period when the input cycle is negative, the polarity across the secondary of the transformer is reversed. Note specifically that the top of the secondary winding is now positive. This condition now forward biases D_2 and reverse biases D_1. A series circuit now exists consisting of C_1, D_2, C_2, and the secondary of the transformer. The secondary voltage of the transformer now aids the voltage on C_1. This results in a pulsating dc voltage with $2V_m$, as shown by the waveform. The effect of series aiding is comparable to the connection of two batteries in series. As shown in figure C_2 charges to the sum of these voltages.



Fig(3) voltage doublers when (- i/p)

Cascade Voltage Multiplier

To demonstrate the principle only, an n-stage single-phase cascade circuit of the 'Cockroft–Walton type', shown in figure (4) below, will be presented.



Fig(4) cockroft-walton type

For a given number of stages, this maximum voltage

$$\mathbf{V_{o\,max} = 2nV_{max} - \Delta V_o}$$

To calculate the total voltage drop ΔV_o, we will first consider the stage n.

$$\Delta V_0 = \frac{1}{fC}\left(\frac{2n^3}{3} + \frac{n^2}{2} - \frac{n}{6}\right)$$

The average output voltage is : $V_o = V_{omax} - \delta V$
And peak to –peak ripple $2\delta v$= where :

$$\delta V = \frac{I}{fC} \times \frac{n(n+1)}{4}$$

Procedure

1- Connect the single phase half wave voltage doubler circuit shown in Fig.(1) on the power electronic trainer.
2-Turn on the power
3- Plot the input and capacitors waveforms on the same graph paper.
4- Measure the average and RMS capacitor voltage by connect the AVO meter across C_1 and C_2 resistance.
5- **Turn off the power**
6- Add load resistance at the output, then repeat steps(2-4) (R1=150k , R2=270k)

Discussion and calculations

1. Comment on your results.
2. Compare between the theoretical and practical results.
3. Design the HeNe laser power supply use the half wave voltage doubler. The input voltage is fed to the transformer with secondary voltage equal to 750V. Assume the current pass through the laser tube = 4mA.
4. Give some application of the voltage multiplier circuit.

Experiment No.6

Single-Phase Full-Wave Voltage Multiplier

Experiment aim

The aim of this experiment is to design and analysis of a single phase full-wave voltage multiplier.

Apparatus

Make the circuit for voltage multiplier using the following parts:
1-Power electronic trainer.
2-Oscilloscope.
3-AVO meter.

Theory

Voltage multipliers may also be used as primary power supplies where a input is rectified to pulsating dc. This dc output voltage may be increased (through use of a voltage multiplier) to as double volts dc.

Fig.(1) shows the schematic for a full-wave voltage doublers. Notice the similarities between this schematic and those of half-wave voltage rectifiers. In fact, the doublers shown is made up of two half-wave voltage rectifiers. C_1 and D_1 make up one half-wave rectifier, and C_2 and D_2 make up the other.

Notice that C_1 and D_1 work exactly like a half-wave rectifier. During the positive alternation of the input cycle, the D_1 is forward biasing and the current pass from the source through the diode D_1 to capacitor C_1. In this time the C_1 is charged to maximum voltage V_m.

$$2\delta v=\frac{dQ}{Ctotal}=\frac{Idc\,.\,Tr}{Ctotal}$$

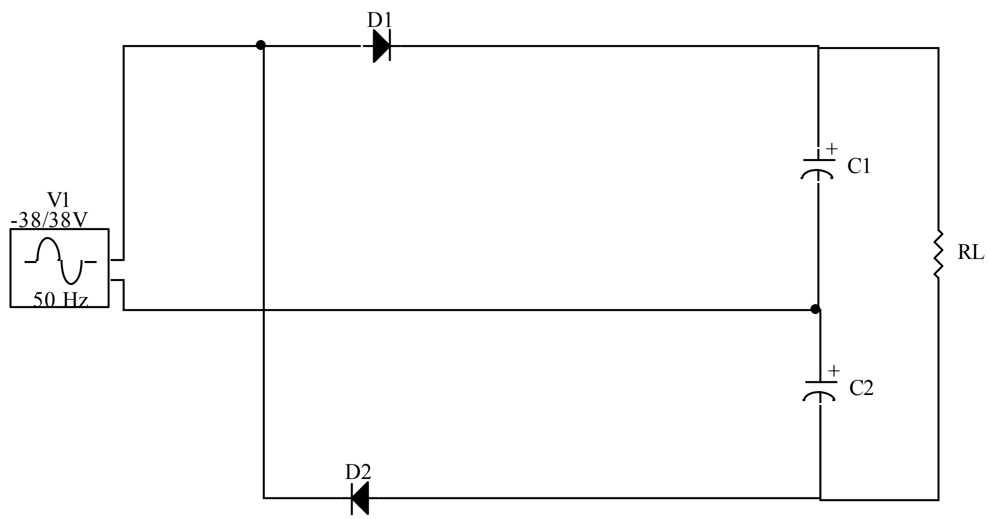


Fig.(1): Full-wave voltage doublers

During the period when the input cycle is negative, the polarity across source is reversed. The D_2 is forward biasing and the current pass from the source through the diode D_2 to capacitor C_2. In this time the C_2 is charged to maximum voltage V_m. The voltage of C_1 now aids the voltage on C_2.This results in a dc voltage with $2V_m$. The effect of series aiding is comparable to the connection of two batteries in series.

Procedure

1. Connect the single phase full-wave voltage doublers circuit shown in Fig.(1) on the power electronic trainer.
2. Turn on the power.
3. Plot the input and capacitors waveforms on the same graph paper.
4. Measure the average capacitor voltage by connect the AVO meter across C_1 and C_2 resistance.
5. **Turn off the power**
6. Add load resistance at the output, then repeat steps(2-4)

Discussion and calculations

1. Comment on your results.
2. Design the HeNe laser power supply when the input voltage is fed to the transformer with secondary voltage equal to 750V. Assume the current pass through the laser tube = 6mA.

Experiment No.7
Three-Phase half wave Uncontrolled Rectifier

Experiment aim

The aim of this experiment is to design and analysis of a three phase uncontrolled rectifier.

Apparatus

Make the circuit for AC-DC converter using the following parts:

i. Power electronic trainer
ii. Oscilloscope
iii. AVO meter

Theory

Rectification is the process of conversion of alternating input voltage to direct output voltage. In diode rectifiers, the output voltage cannot be controlled. Three phase Rectifiers can be classified as:

- Three Phase Half wave rectifier
- Three Phase Full wave rectifier

Three-Phase Half-Wave Rectifier

For higher power application and where three-phase power supply is available, a three phase bridge rectifier, as shown in figure (1), should be used. One diode is conduct at any instant. It is the diode connected to the phase having the highest instantaneous voltage. The output voltage of the successive phase voltages and varying from $V_m/2$ to V_m, three times per input cycle. The average output voltage is:.

$$V_{dc} = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} V_m \sin\theta \, d\theta$$

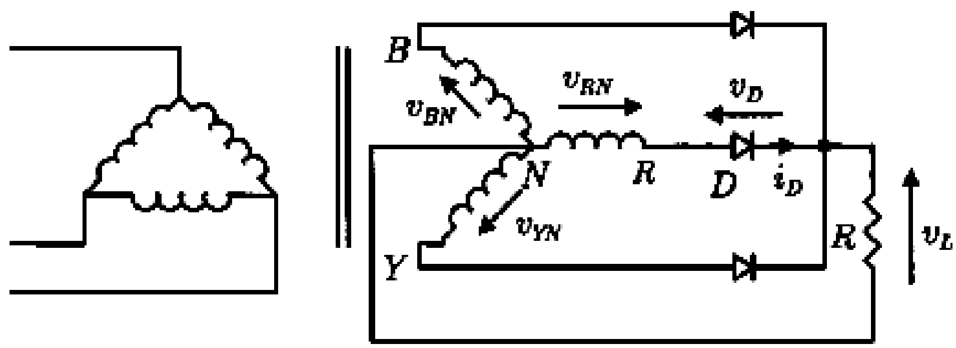
$$V_{dc} = \frac{3\sqrt{3}}{2\pi} V_m = 0.827 V_m$$

Similarly, the rms value of the output voltage can be found as:

$$V_L = \sqrt{\frac{3}{2\pi}\int_{\pi/6}^{5\pi/6}(V_m \sin\theta)^2 d\theta}$$

$$V_L = V_m\sqrt{\frac{3}{2\pi}\left(\frac{\pi}{3}+\frac{\sqrt{3}}{4}\right)} = 0.84\ V_m$$

The rectifier has a three pulse characteristics, and load current id of less ripple contents in relative to single-phase rectifiers, which characterize by two pulse output. The ripple frequency is 3f (where f is input frequency) and the required smoothing reactor at the load side is of smaller size.



(a)

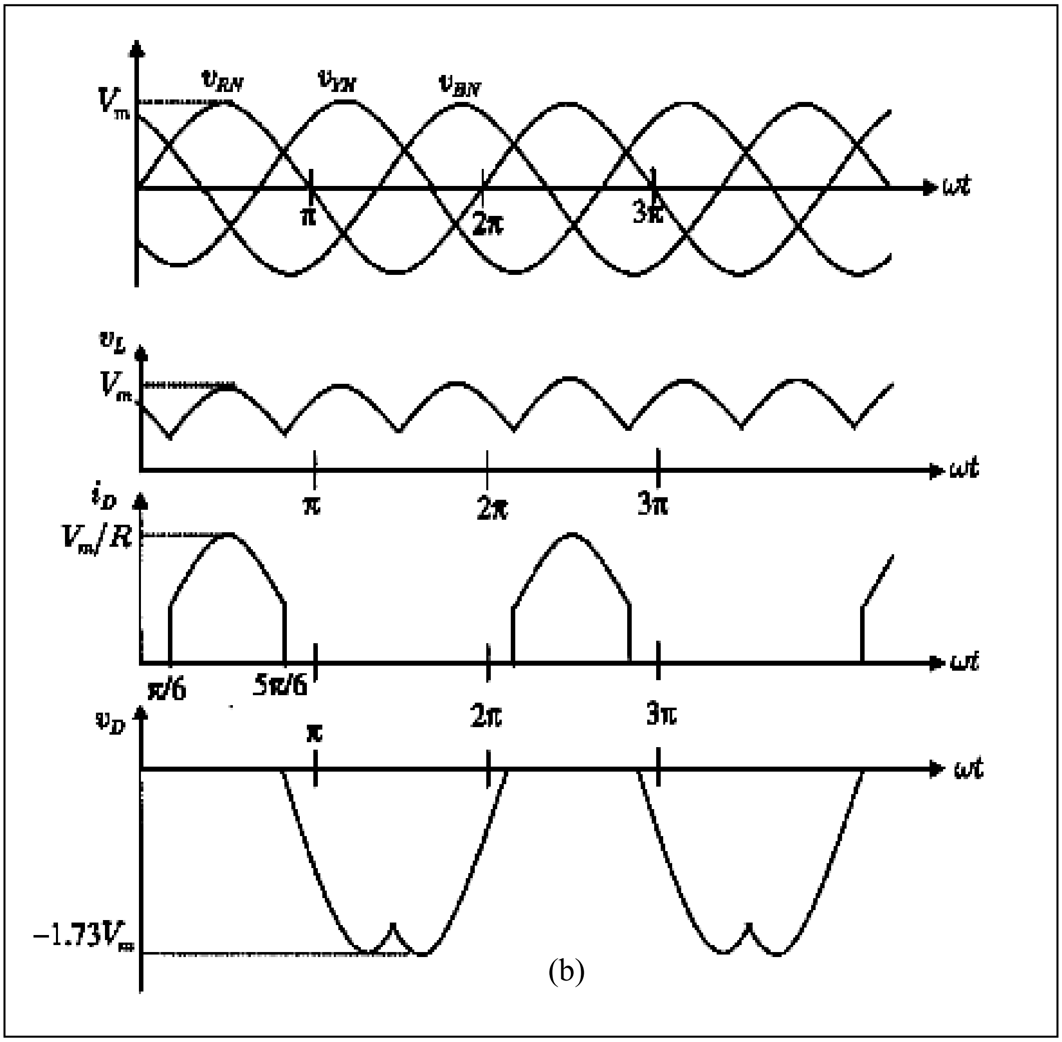


Fig.(1): a) Three-phase star rectifier.
b): Waveforms of voltage and current of the three-phase star rectifier

Procedure

1- Connect the three phase half wave rectifier circuit shown in Fig.(1) on the power electronic trainer.
2- Turn on the power
3- Plot the input and output waveforms on the same graph paper.
4- Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5- **Turn off the power**
6- Add the inductive load on the output. With L=10mH measure the output voltage and plot the output waveform.
7- Repeat step 6 with L=100mH, 500mH measure the output voltage and plot the output waveforms.
8- Repeat step 6 & 7 with connect the freewheeling diode across the load.

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. What design parameters of the three-phase half wave rectifier?
3. When you design 30kW rectifier, what type of rectifier must be use? Why?

Experiment No.8
Three phase full wave Rectifier

Experiment aim

The aim of this experiment is to design and analysis of a single phase uncontrolled rectifier.

Apparatus

Make the circuit for AC-DC converter using the following parts:

1- Power electronic trainer
2- Oscilloscope
3- AVO meter

Theory

Rectification is the process of conversion of alternating input voltage to direct output voltage. In diode rectifiers, the output voltage cannot be controlled. AC-DC converter (Rectifiers) can be classified as:

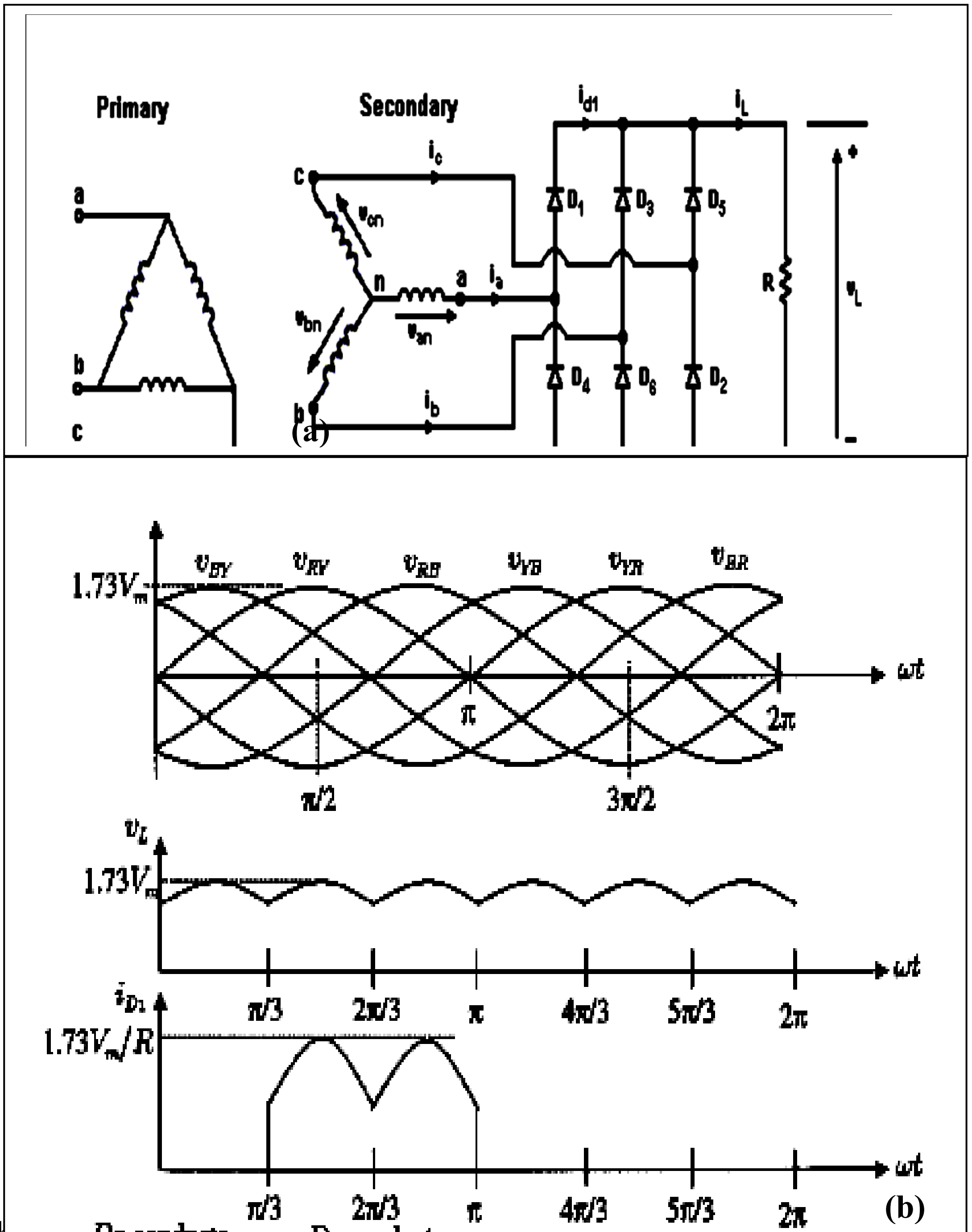
- Full wave rectifier FWR

These can further be classified depending upon the rectifying element being used. If using diode, are called uncontrolled rectifiers. Whereas if using thyristor, are called controlled rectifiers. The application of these converts may include the following:

→ Variable speed dc drives,
→ Battery chargers,
→ DC power supplies and Power supply for a specific application like laser sources, electronic sets.

Three-Phase Full Wave Rectifiers

Also called three-phase bridge rectifiers are commonly used for high power applications because they have the highest possible transformer utilization factor for a three-phase system. The circuit of a three-phase bridge rectifier is shown in Fig.(2)



The diodes are numbered in the order of conduction sequences and the

Fig.(1): a) Three-phase bridge rectifier.
b) Voltage and current waveforms of the three-phase bridge rectifier.

conduction angle of each diode is 2p=3. The conduction sequence for diodes is 12, 23, 34, 45, 56, and 61. The voltage and current waveforms of the three-phase bridge rectifier are shown in Fig.(5-b). The line voltage is 1.73 times the phase voltage of a three-phase star-connected source. It is permissible to use any combination of star- or delta connected primary and secondary windings because the currents associated with the secondary windings are symmetrical. Average value of the output can be found as:

$$V_{dc} = \frac{6}{2\pi}\int_{\pi/3}^{2\pi/3} \sqrt{3}\, V_m \sin\theta \, d\theta$$

or

$$V_{dc} = V_m \frac{3\sqrt{3}}{\pi} = 1.654\, V_m$$

Similarly, the rms value of the output voltage can be found as:

$$V_L = \sqrt{\frac{9}{\pi}\int_{\pi/3}^{2\pi/3} (V_m \sin\theta)^2 \, d\theta}$$

or

$$V_L = V_m\sqrt{\frac{3}{2} + \frac{9\sqrt{3}}{4\pi}} = 1.655\, V_m$$

Procedure

1. Connect the three phase full wave rectifier circuit shown in Fig.(1) on the power electronic trainer.
2- Turn on the power
3- Plot the input and output waveforms on the same graph paper.
4- Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5- **Turn off the power**

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. What design parameters of the three-phase rectifier?
3. When you design 50kW rectifier, what type of rectifier must be use? Why?

Experiment No.9
Single-Phase Half Wave Controlled rectifiers

Experiment aim

The aim of Experiment is to analyze the operation (Switching) of single phase controlled with resistive and inductive load.

Apparatus

1. Power electronic trainer.
2. Oscilloscope .
3. AVO meter .

Introduction

Phase controlled AC-DC converters employing thyristor are extensively used for changing constant ac input voltage to controlled dc output voltage. In phase-controlled rectifiers, a thyristor is tuned off as AC supply voltage reverse biases it, provided anode current has fallen to level below the holding current.

Controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications.

Single-Phase Half-Wave Controlled Rectifier

As shown in Fig.(1), the single-phase half-wave rectifier uses a single thyristor to control the load voltage. The thyristor will conduct, ON state, when the voltage v_T is positive and a firing current pulse i_G is applied to the gate terminal. Delaying the firing pulse by an angle α does the control of the load voltage. The firing angle α is measured from the position where a diode would naturally conduct. In Fig.(1), the angle a is measured from the zero crossing point of the supply voltage v_s . The load in Fig. (1) is resistive and therefore current i_d has the same waveform as the load voltage. The thyristor goes to the non-conducting condition, OFF state, when the load voltage and, consequently, the current try to reach a negative value. The load average voltage is given by:

$$V_{d\alpha} = \frac{1}{2\pi}\int_{\alpha}^{\pi} V_{\max} \sin \omega t d(\omega t) = \frac{V_{\max}}{2\pi}(1+\cos\alpha)$$

Where V_{max} is the supply peak voltage.

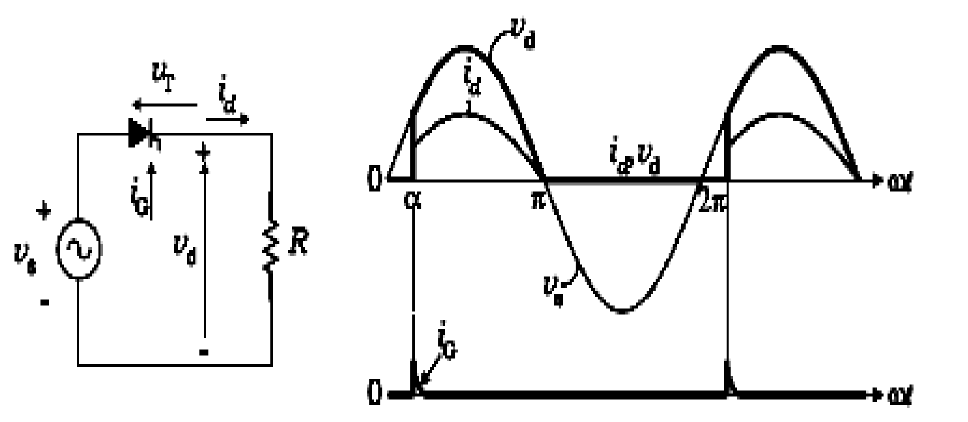


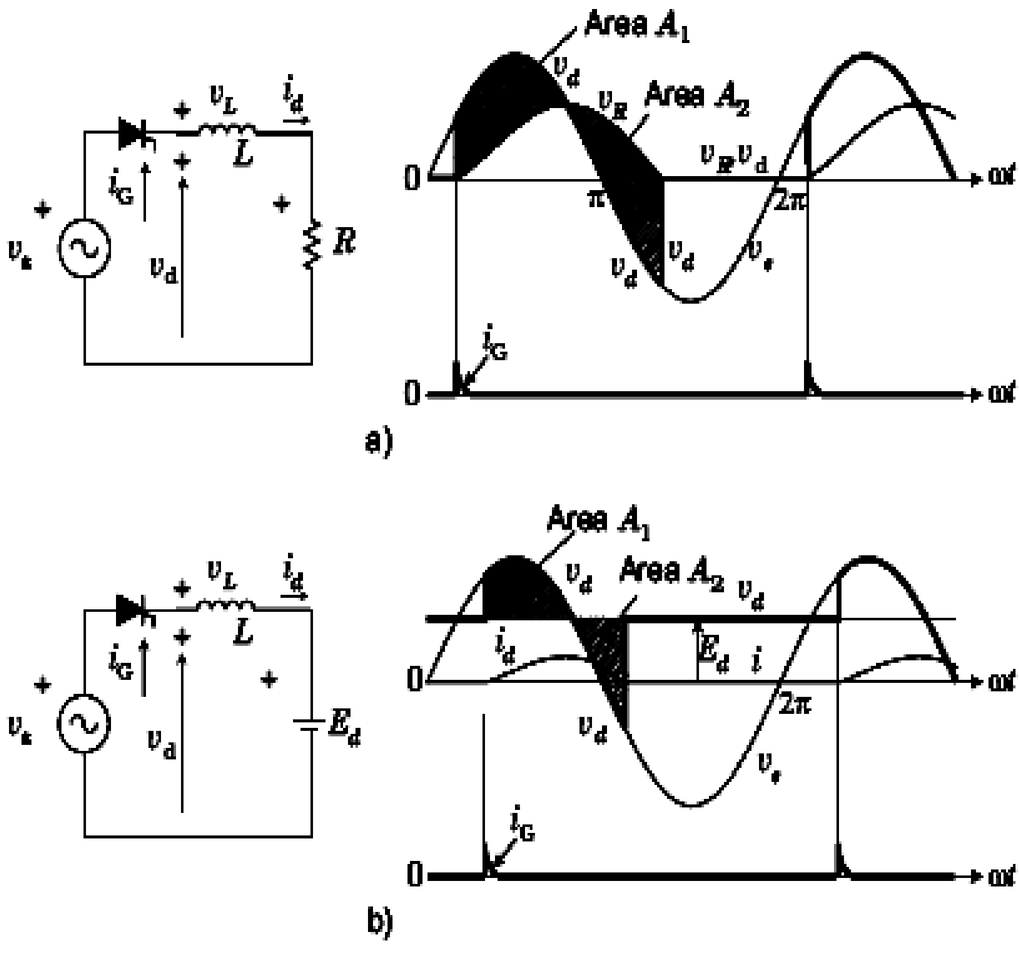
Fig.(1):Single thyristor rectifier with resistive load.

Fig.(2-a) shows the rectifier waveforms for an R ÿ L load. When the thyristor is turned ON, the voltage across the inductance is

$$v_L = v_S - v_R = L\frac{di_d}{dt}$$

The voltage in the resistance R is $v_R = R \times i_d$. While $v_S - v_R > 0$. On the other hand, i_d decreases its value when $v_S - v_R < 0$. The load current is given by:

$$i_d(\omega t) = \frac{1}{\omega L}\int_{\alpha}^{\omega t} v_L \, d\theta$$



Fig(2): Single thyristor rectifier with: (a) resistive-inductive load; and (b) active load.

Procedure

1. Connect the single phase half wave controlled rectifier circuit shown in Fig.(1) on the power electronic trainer.
2. Turn on the power
3. Plot the input and output waveforms on the same graph paper.
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. **Turn off the power**
6. Add the inductive load on the output as shown in Fig(2). With L=10mH measure the output voltage and plot the output waveform.
7. Repeat step 6 & 7 with connect the freewheeling diode across the load .

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. What does parameters of the single phase controlled rectifiers.
3. Give same application of the single phase controlled rectifiers .

Experiment No.10
Single-Phase Full Wave Controlled rectifier

Experiment aim

The aim of Experiment is to analyze the operation (Switching) of single phase controlled and semi-controlled rectifiers.

Apparatus

1. Power electronic trainer.
2. Oscilloscope.
3. AVO meter

Theory:-

Phase controlled AC-DC converters employing thyristor are extensively used for changing constant ac input voltage to controlled dc output voltage. In phase-controlled rectifiers, a thyristor is tuned off as AC supply voltage reverse biases it, provided anode current has fallen to level below the holding current.

Controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications.

Single-Phase Full-Wave Controlled Rectifier

Once of the types of controlled rectifier is fully controlled and semiconductor rectifier. A fully-controlled circuit contains only thyristers (semiconductor controlled rectifiers (SCR)), whereas a semi-controlled rectifier circuit is made up of both SCR and diodes as shown in Fig.(1). Due to presence of diodes, free-wheeling operation takes place without allowing the bridge output voltage to become negative.

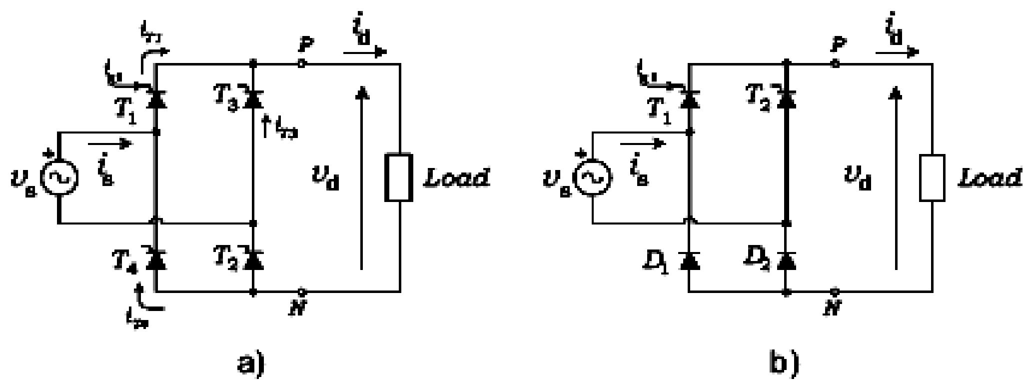


Fig.(1): Single-phase bridge rectifier: (a) fully controlled; and (b) semi-controlled.

In a semi-controlled rectifier, control is affected only for positive output voltage, and no control is possible when its output voltage tends to become negative since it is clamped at zero volts.

As shown in Fig. (2), thyristor T_1 can be fired into the ON state at any time provided that voltage $v_{T1} > 0$. The firing pulses are delayed by an angle a with respect to the instant where diodes would conduct. Thyristor T_1 remains in the ON state until the load current tries to go to a negative value. Thyristor T_2 is fired into the ON state when $v_{T2} > 0$, which corresponds in Fig. (2) to the condition at which $v_2 > 0$. The mean value of the load voltage with resistive load is given by:

$$V_{di\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_{\max} \sin \omega t d(\omega t) = \frac{V_{\max}}{\pi}(1 + \cos\alpha)$$

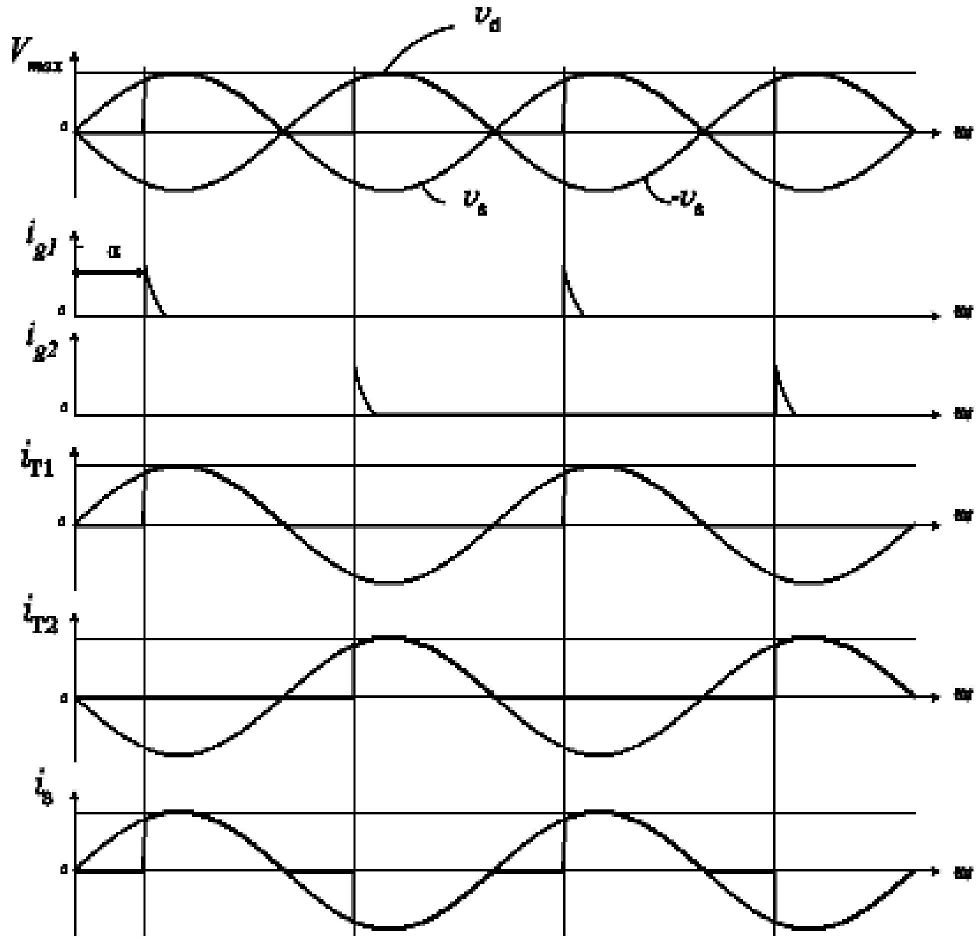


Fig.(2): Single phase semi-controlled rectifiers waveform

Figure (3) shows the voltage and current waveforms of the fully controlled bridge rectifier for a resistive load. Thyristors T_1 and T_2 must be fired simultaneously during the positive half-wave of the source voltage V_s to allow conduction of current. Alternatively, thyristors T_3 and T_4 must be fired simultaneously during the negative half wave of the source voltage. To ensure simultaneous firing, thyristors T_1 and T_2 use the same firing signal

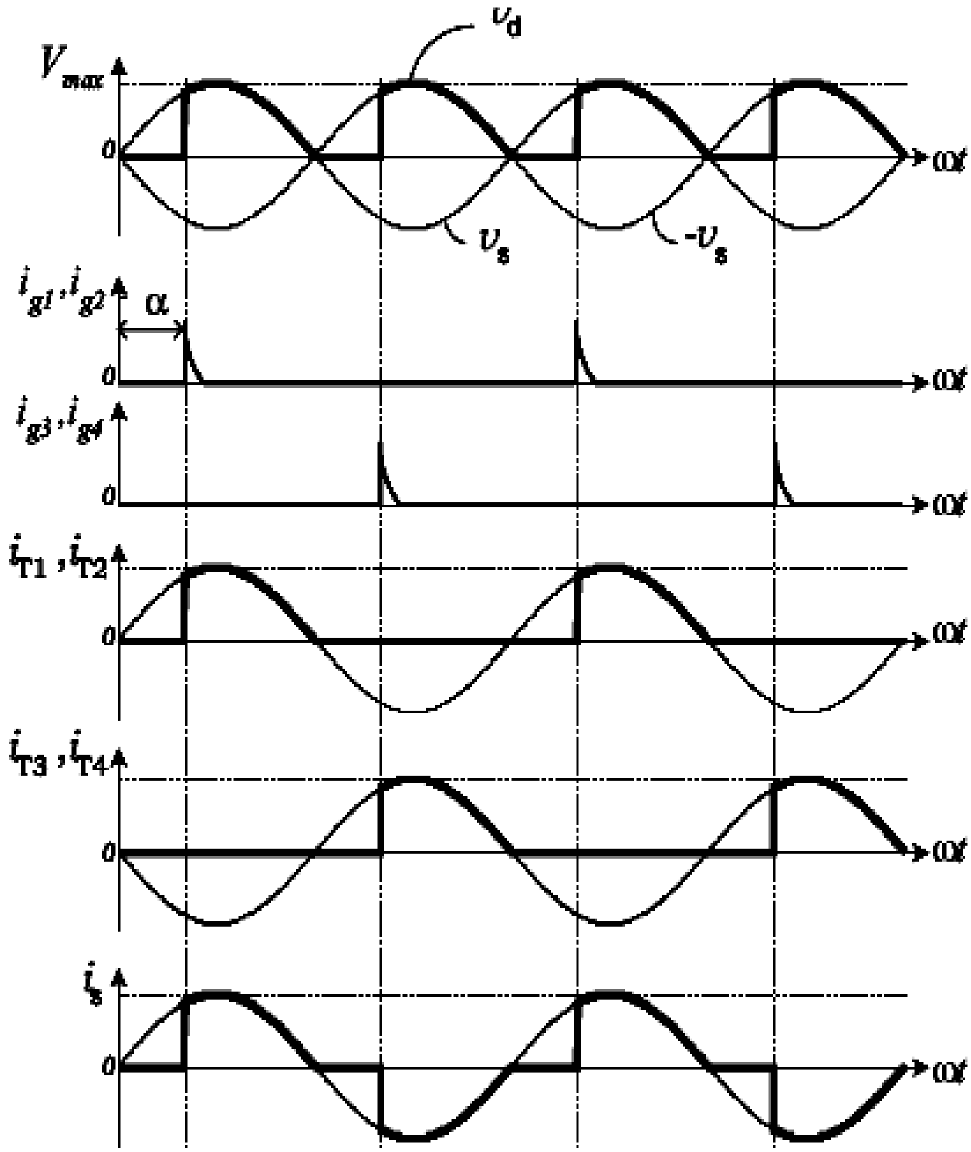


Fig.(3) Waveforms of a fully controlled bridge rectifier with resistive load.

Figure (4) presents the behavior of the fully controlled rectifier with resistive-inductive load (with L→∞). The high-load inductance generates a perfectly filtered current and the rectifier behaves like a current source. With continuous load current, thyristors T_1 and T_2 remain in the on-state beyond the positive half-wave of the source voltage V_s. For this reason, the load voltage v_d can have a negative instantaneous value. The firing of thyristors T_3 and T_4 has two effects:

a. they turn off thyristors T_1 and T_2; and
b. After the commutation, they conduct the load current.

This is the main reason why this type of converter is called a ''naturally commutated'' or ''line commutated'' rectifier. The supply current i_S has the square waveform shown in Fig.(4) for continuous conduction. In this case, the average load voltage is given by:

$$V_{di\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi+\alpha} V_{\max} \sin \omega t d(\omega t) = \frac{2V_{\max}}{\pi} \cos \alpha$$

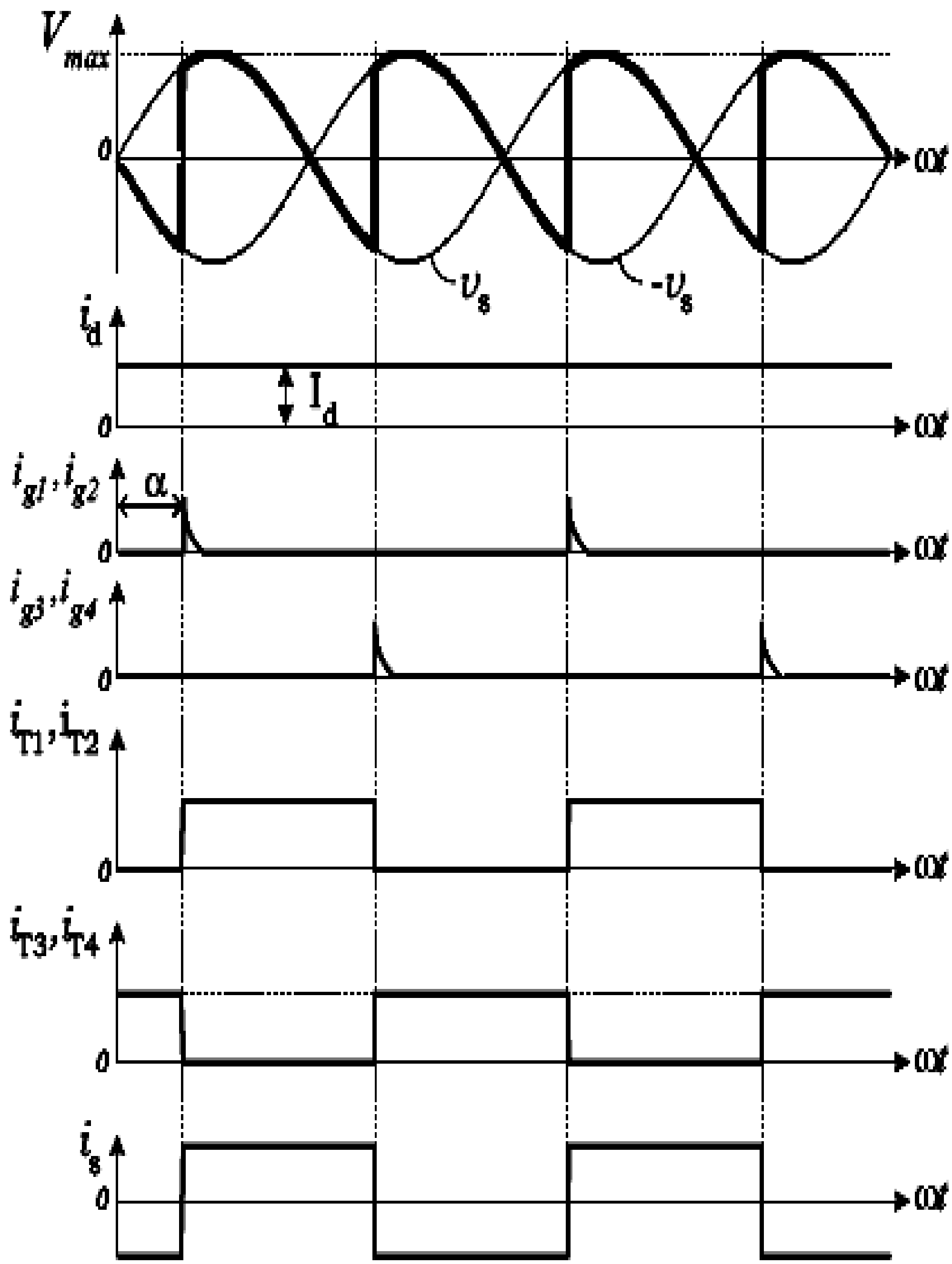


Fig.(4): Waveforms of a fully controlled bridge rectifier with resistive-inductive load (L→∞).

Procedure

1. Connect the single phase full wave controlled rectifier circuit shown in Fig.(1-a) on the power electronic trainer.
2. Turn on the power
3. Plot the input and output waveforms on the same graph paper.
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. Turn off the power

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. What does parameters of the single phase full wave controlled rectifiers.
3. Give same application of the single phase controlled rectifiers .

Experiment No.11

Three-Phase half wave Controlled Converters (Controlled rectifier)

Experiment aim

The aim of Experiment is to analyze the operation (Switching) of three phase controlled and rectifiers with resistive and inductive load.

Apparatus

1. Power electronic trainer.
2. Connection wires.
3. Oscilloscope.
4. A.V.O meter

Theory

Phase controlled AC-DC converters employing thyristor are extensively used for changing constant ac input voltage to controlled dc output voltage. In phase-controlled rectifiers, a thyristor is tuned off as AC supply voltage reverse biases it, provided anode current has fallen to level below the holding current.

Controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications.

Three- phase half wave controlled rectifier :-

Fig.(1) shows the half-wave rectifier uses three common-cathode thyristor arrangements. In this figure, the power supply and the transformer are assumed ideal. The thyristor will conduct (ON state), when the anode-to-cathode voltage V_{AK} is positive, and a firing current pulse i_G is applied to the gate terminal. To controls the load voltage delaying the firing pulse by an angle (α). As shown in Fig. (2), the firing angle α is measured from the crossing point between the phase supply voltages. At that point, the anode-to-cathode thyristor voltage V_{AK} begins to be positive.

With the help of Fig.(2) the load average voltage can be evaluated and is given by:

$$V_D = \frac{V_{max}}{2/3\pi}\int_{-\pi/3+\alpha}^{\pi/3+\alpha} \cos\omega t \cdot d(\omega t)$$

$$= V_{max}\frac{\sin\pi/3}{\pi/3}\cdot\cos\alpha \approx 1.17\cdot V_{f-N}^{rms}\cdot\cos\alpha$$

Where V_{max} is the secondary phase-to-neutral peak voltage, V_{f-N}^{rms} its root mean square (rms) value, and ω is the angular frequency of the main power supply.

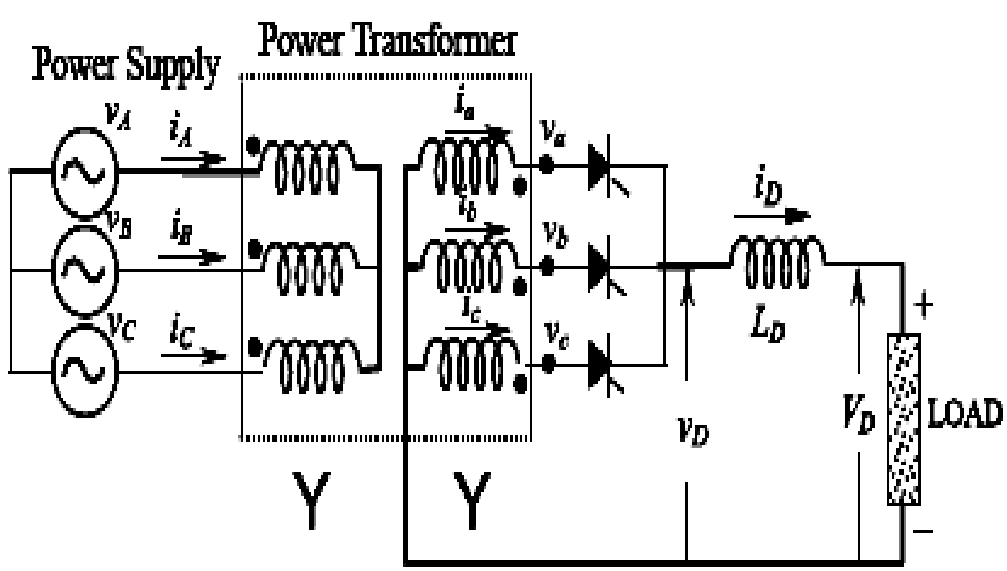


Fig.(1): Three-phase half-wave rectifier.

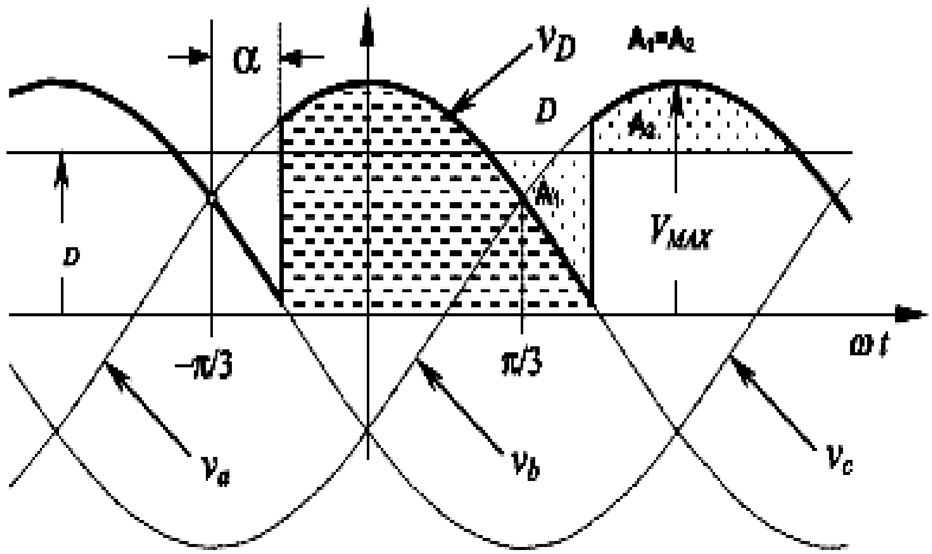


Fig.(2): Instantaneous dc voltage v_D, average dc voltage V_D, and firing angle a.

Procedure

1. Connect the three-phase half wave controlled rectifier circuit shown in Fig.(1) on the power electronic trainer.
2. Turn on the power.
3. By use oscilloscope, plot the input and output waveforms on the same graph paper" same axis".
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. **Turn off the power**
6. Use an inductive load. With L=10mH measure the output voltage and plot the output waveform.
7. Repeat step 6 with L=100mH measure the output voltage and plot the output waveforms.
8. Repeat step 6 & 7 with connect the freewheeling diode across the load.

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. Design a high voltage power supply for CO_2 laser, when the optical output power is 8watt. The current and voltage electronically highly stabilized DC power unit has a nominal output 50mA and 5kV. Pumping under optimal conditions (maximum laser output), a current of 18mA at 3 kV is observed.
3. Design three-phase half wave controlled rectifier.

Experiment No.12
Three-Phase Full wave Controlled Converters
(Controlled rectifier)

Experiment aim

The aim of Experiment is to analyze the operation (Switching) of three phase controlled and semi-controlled rectifiers with resistive and inductive load.

Apparatus

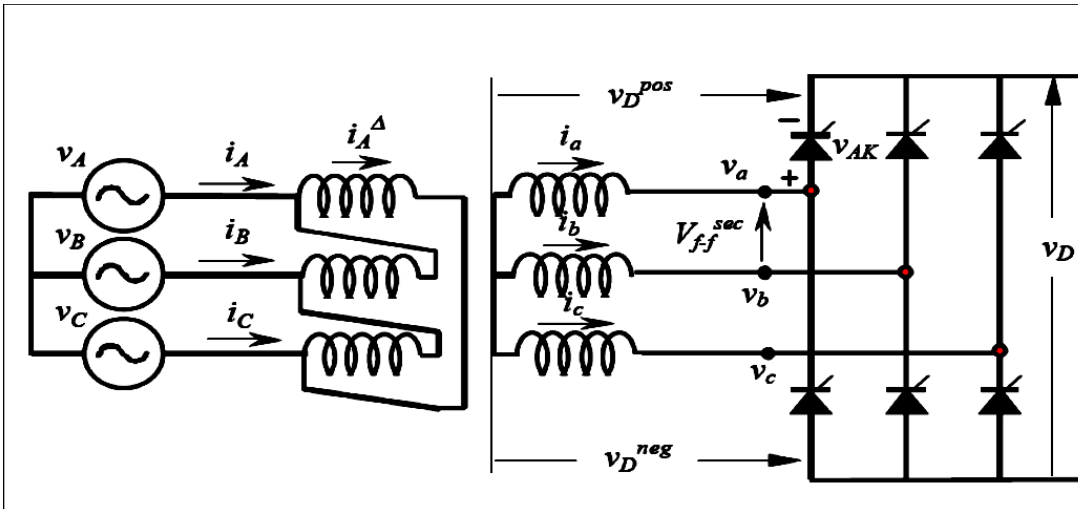
1. Power electronic trainer.
2. Connection wires.
3. Oscilloscope.

Theory

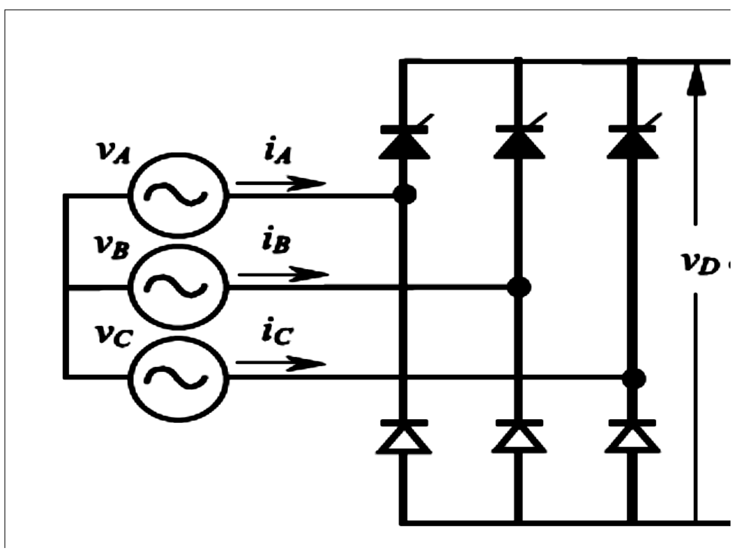
Phase controlled AC-DC converters employing thyristor are extensively used for changing constant ac input voltage to controlled dc output voltage. In phase-controlled rectifiers, a thyristor is tuned off as AC supply voltage reverse biases it, provided anode current has fallen to level below the holding current.
Controlled rectifiers have a wide range of applications, from small rectifiers to large high voltage direct current (HVDC) transmission systems. They are used for electrochemical processes, many kinds of motor drives, traction equipment, controlled power supplies, and many other applications

***Three- phase Full wave controlled rectifier*:**

Fig(1-a) shows the three-phase bridge rectifier. The configuration does not need any special transformer, and works as a 6-pulse rectifier. The series characteristic of this rectifier produces a dc voltage twice the value of the half-wave rectifier .



Fig(3-a): Three-phase full-wave rectifier



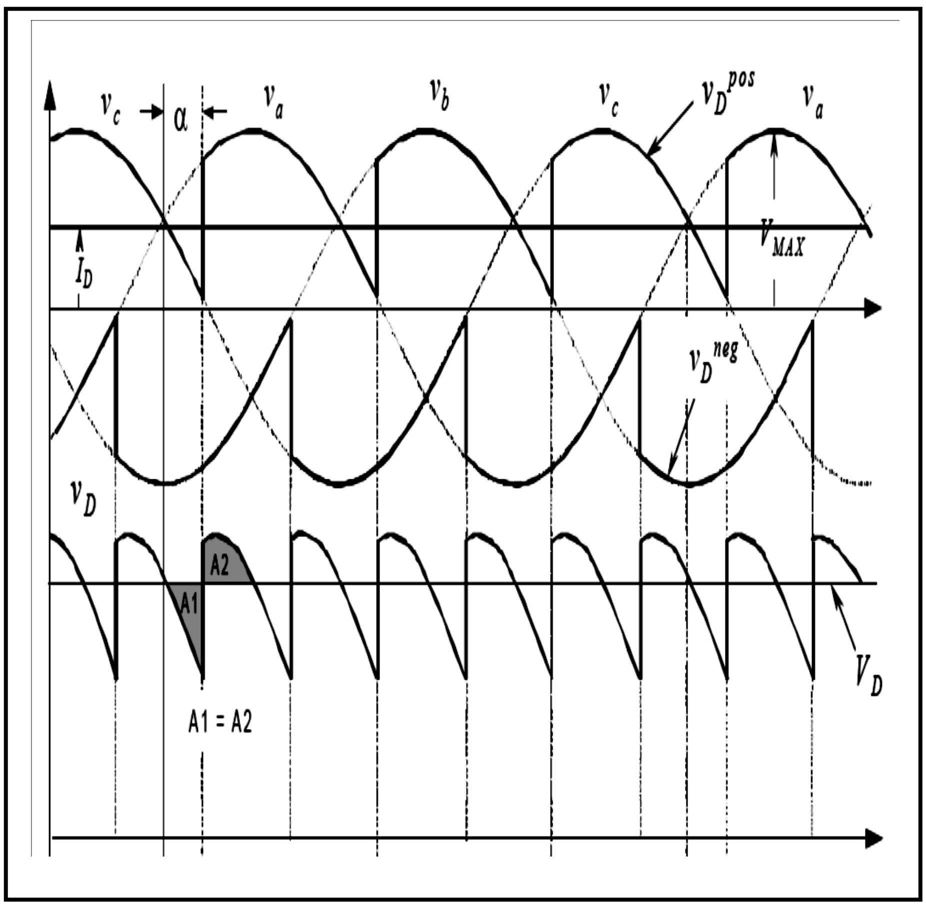
Fig(3-b): Three-phase sime control rectifier

The load average voltage is given by:

$$V_D = \frac{2 \cdot V_{max}}{2/3\pi} \int_{-\pi/3+\alpha}^{\pi/3+\alpha} \cos \omega t \cdot d(\omega t)$$

$$= 2 \cdot V_{max} \frac{\sin \pi/3}{\pi/3} \cdot \cos \alpha$$

Fig(2) shows the voltages of each half-wave bridge of this topology $\mathbf{v_D^{pos}}$ and $\mathbf{v_D^{neg}}$, the total instantaneous dc voltage v_D, and the anode-to-cathode voltage v_{AK} in one of the bridge thyristors. The maximum value of v_{AK} is $\sqrt{3}\ \mathbf{V_{max}}$, which is the same as that of the half-wave converter .



Fig(2)

Procedure

1. Connect the three-phase full wave controlled rectifier circuit shown in Fig.(1-a) on the power electronic trainer.
2. Turn on the power
3. By use oscilloscope, plot the input and output waveforms on the same graph paper" same axis".
4. Measure the average and RMS output voltage by connect the AVO meter across load resistance.
5. **Turn off the power**
6. Use an inductive load. With L=100mH measure the output voltage and plot the output waveform.
7. Repeat step 6 with L=100mH measure the output voltage and plot the output waveforms.
8. Repeat step 6 & 7 with connect the freewheeling diode across the load.
9. Connect the three-phase bridge half-control rectifier circuit shown in Fig.(1-b).
10. Repeat steps (2-7).

Discussion and calculations

1. Compare between the practical and theoretical results for input and output voltages and currents.
2. Design a high voltage power supply for CO_2 laser, when the optical output power is 12 watt. The current and voltage electronically highly stabilized DC power unit has a nominal output 70mA and 6kV. Pumping under optimal conditions (maximum laser output), a current of 20mA at 4 kV is observed.
3. Compare between the three-phase half-wave controlled rectifier and three-phase full-wave controlled rectifier

Experiment No.13
Single Pulse Width Modulation Technique (SPWM)

Experiment aim

To study the commonly used pulse-width modulation techniques

Apparatus

1. Power electronic trainer
2. oscilloscope with two probe

Theory

In many industrial applications, it is often required to control the output voltage of converters. The most efficient method of controlling the output voltage is to incorporate pulse-width modulation (PWM) control within the inverters. The commonly used techniques are:

1. single pulse-width modulation
2. multi-pulse width modulation

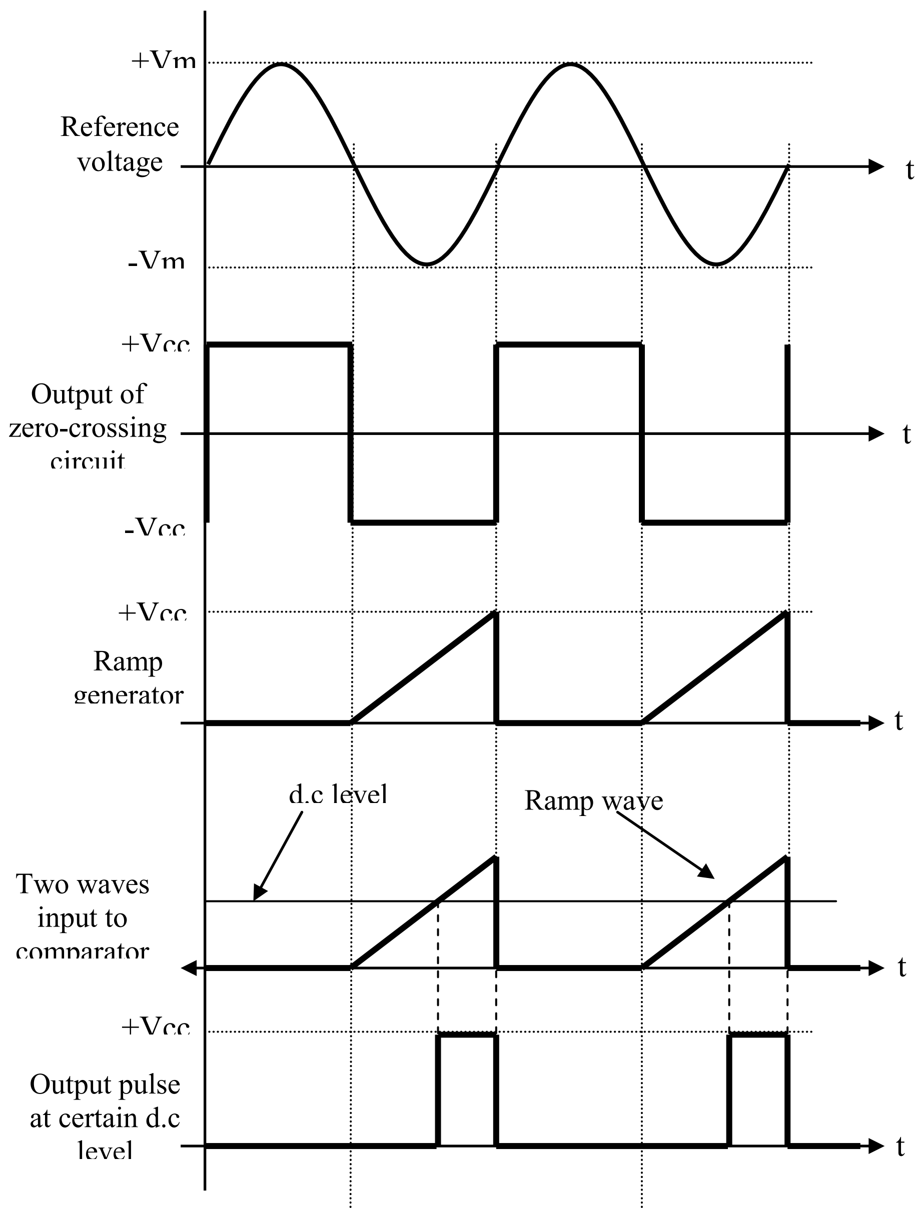
Single pulse width modulation

In single pulse-width modulation control, there is only one pulse per half-cycle and the width of the pulse is varying to control the output voltage. Fig.(1) shows the generation of gating signals of single pulse width modulation. The gating signals are generated by:

i- Convert the reference signal to the square wave signal. This process is obtained by inter the reference signal to the zero-crossing circuit witch consider the positive part of the input signal is positive part of the output signal(square wave) and the negative part of the input signal is negative part of the output signal as shown in Fig(1). That is :

$$F(t)=\begin{cases}-V_{CC} & F(t)<0\\ +V_{CC} & F(t)>0\end{cases}$$

ii- Then, the output signal of zero-crossing circuit is become control signal of the ramp generator. Figure (2) shows the Ramp generator depends on the integrator circuit with control **MOSFET** switch to limit the charging time. The input and output signals of the ramp generator is shown in Fig(1).



Fig(1): shows the generation of gating signals of single pulse width modulation

iii- Then, the output of the ramp generator inter to the comparator circuit which compare between the variable d.c level and the ramp wave. The certain d.c level gives the certain pulse width and any change in the d.c level will produce change in the pulse width as shown in Fig.(1).

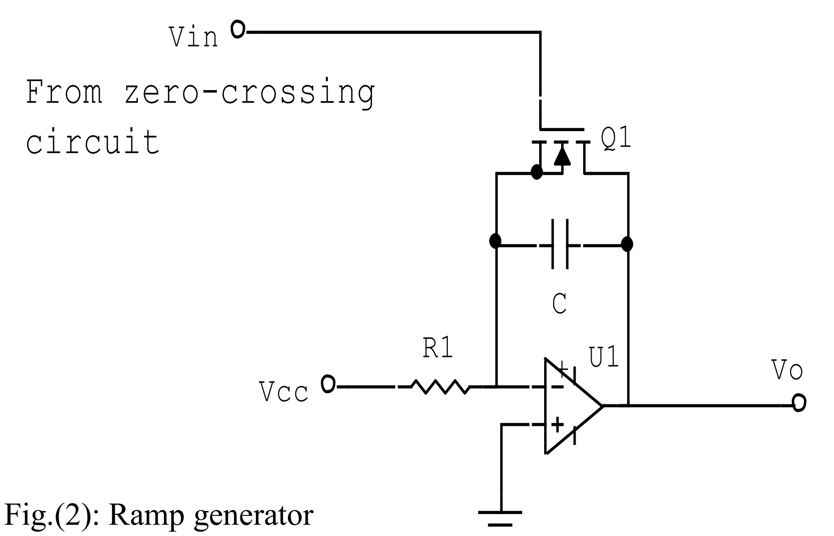


Fig.(2): Ramp generator

Procedure

1. Turn on power of pulse width modulation techniques part on the power electronic trainer.
2. Turn on the oscilloscope power and set it to suitable position.
3. Apply oscilloscope probe to sine wave generator output, then plot output signal.
4. Apply oscilloscope probe to output of zero-crossing circuit, then plot output signal on graph paper.
5. Apply oscilloscope probe to ramp generator output, then plot output signal on same graph paper.
6. Set the reference d.c voltage level to (3, 5, 6, 8) volts, then measure and plot the pulse width of comparator output for each d.c level.

Discussion

1. Comment on the your result
2. Why we use the PWM over other types of modulation
3. Suggest the digital circuit to generate the pulse-width modulation waveform.

Experiment No.(14)
Multi Pulse Width Modulation Techniques (MPWM)

Experiment aim

To study the commonly used pulse-width modulation techniques

Apparatus

1. Power electronic trainer
2. oscilloscope with two probe

Theory

In many industrial applications, it is often required to control the output voltage of converters. The most efficient method of controlling the output voltage is to incorporate pulse-width modulation (PWM) control within the inverters. The commonly used techniques are:

1. single pulse-width modulation
2. multi-pulse width modulation

Multi-Pulse width modulation

The harmonic content can be reduced by using several pulses in each half-cycle of output voltage. The generation of gating signals for turning on and off transistors is shown in Figure (3). The gating signals are produced by comparing reference signal with triangular carrier wave. The frequency of the reference signal sets the output frequency (f_o) and carrier frequency (f_c) determine the number of pulses per half cycle, p:

$$p = \frac{f_c}{2f_o}$$

The variation of modulation index (M) from 0 to 1 varies the pulse from 0 to π/p and the output voltage from 0 to Vm.

Uniform pulse width modulation (UPWM)

Figure (1) shows the uniform pulse width modulation (UPWM). It can be note the reference voltage is square wave changed from the Vm to –Vm in frequency = fo. The carrier frequency is triangle wave with amplitude equal to Vc in frequency = fc.

If the δ is the width of each pulse, the rms output voltage can be found from:

$$Vo = \left[\frac{2p}{2\pi}\int_{(\pi/p-\delta)/2}^{(\pi/p+\delta)/2} V_s^2 d(\omega t)\right]^{1/2} = V_s\sqrt{\frac{p\delta}{\pi}}$$

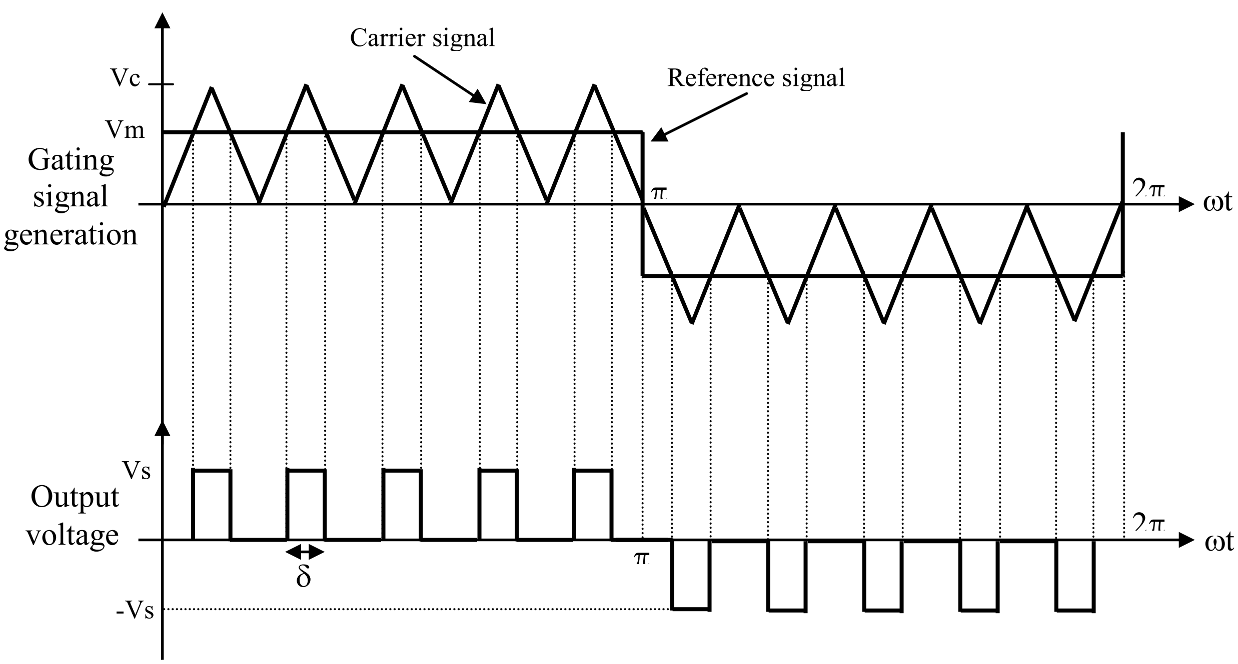


Fig.(1): uniform pulse width modulation (UPWM)

Sinusoidal Pulse Width modulation

Instead of maintaining the width of all pulses the same as in the case of uniform pulse width modulation, the width of each pulse is vary in proportion to the amplitude of a sine wave evaluated at the center of the same pulse.

The distortion factor and lower-order harmonics are reduced scientifically. The gating signals as shown in Fig.(2) are generated by comparing a sinusoidal reference signal with a triangular carrier signal of frequency f_c. This type of modulation is commonly used in industrial applications and abbreviated as SPWM. The frequency of reference signal (f_r), determine the converter output frequency (f_o) and its peak amplitude (A_r) controls the modulation index, M. The number of pulses per half cycle depends on the carrier frequency.

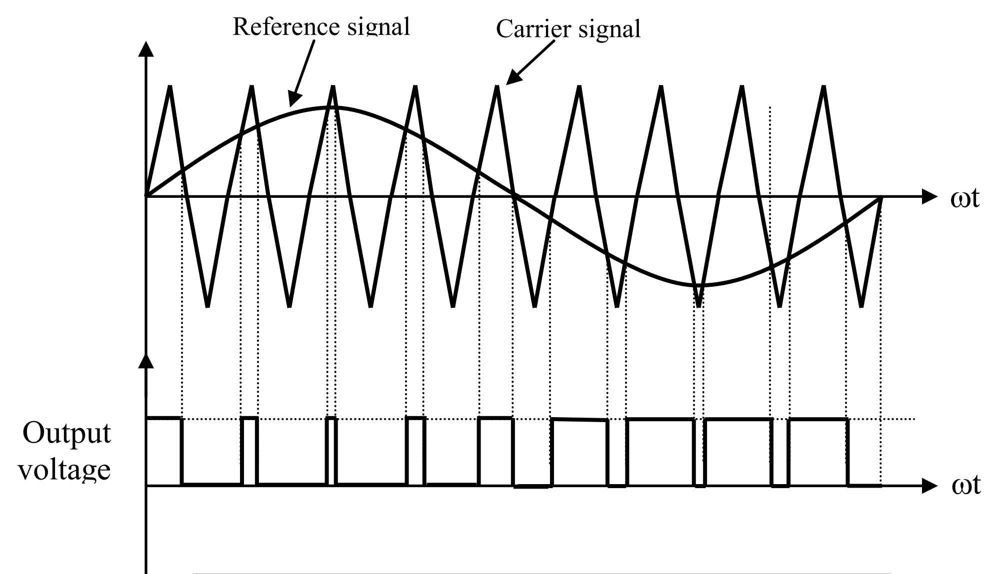


Fig.(2): Sinusoidal Pulse width modulation

Procedure

Multi-pulse width modulation

1. Apply oscilloscope probe to sine wave generator output, then plot output signal.
2. Set the triangle generator frequency to f_c=(400Hz), then determine the number of pulses per half cycle(p).
3. Set the triangle generator frequency to f_c=(1000Hz), then determine the number of pulses per half cycle(p).
4. Plot the input and output signals of comparator in the same graph paper along y-axis.

Discussion

1. Comment on the your result
2. How you can reduce the harmonic in the output of the converter.
3. What effect of the increase carrier frequency on the low order harmonic.

Experiment No.15
DC-DC Converters

Experiment aim

The aim of Experiment is to analyze the operation (Switching) of DC-DC converter with resistive load.

Apparatus

1. Power electronic trainer
2. Connection wires
3. Oscilloscope
4. AVO meter

Theory

Modern electronic systems require high-quality, small, lightweight, reliable, and efficient power supplies. Linear power regulators, whose principle of operation is based on a voltage or current divider, are inefficient. This is because they are limited to output voltages smaller than the input voltage, and also their power density is low because they require low frequency (50 or 60 Hz) line transformers and filters.

The higher the operating frequency, the smaller and lighter the transformers, filter inductors, and capacitors. In addition, the dynamic characteristics of converters improve with increasing operating frequencies.

High-frequency electronic power processors are used in dc-dc power conversion. The functions of dc-dc converters are:

- to convert a dc input voltage $\mathbf{V_S}$ into a dc output voltage $\mathbf{V_O}$;
- to regulate the dc output voltage against load and line variations;
- to reduce the ac voltage ripple on the dc output voltage below the required level;
- to provide isolation between the input source and the load (isolation is not always required);

Step-Down dc-dc Converter

The step-down dc-dc converter, commonly known as a buck converter, is shown in Figure below. It consists of dc input voltage source **VS**, controlled switch **S**, diode **D**, filter inductor **L**, filter capacitor **C**, and load resistance **R**. The state of the converter in which the inductor current is never zero for any period is called the ***continuous conduction mode*** **(CCM)**. It can be seen from the circuit that when the switch **S** is commanded to the on state, the diode **D** is reverse-biased. When the switch **S** is off, the diode conducts to support an uninterrupted current in the inductor.

$$(V_s - V_o)\,DT = V_o(1 - D)T$$

The output voltage and current are:

$$V_o = D\,V_s$$

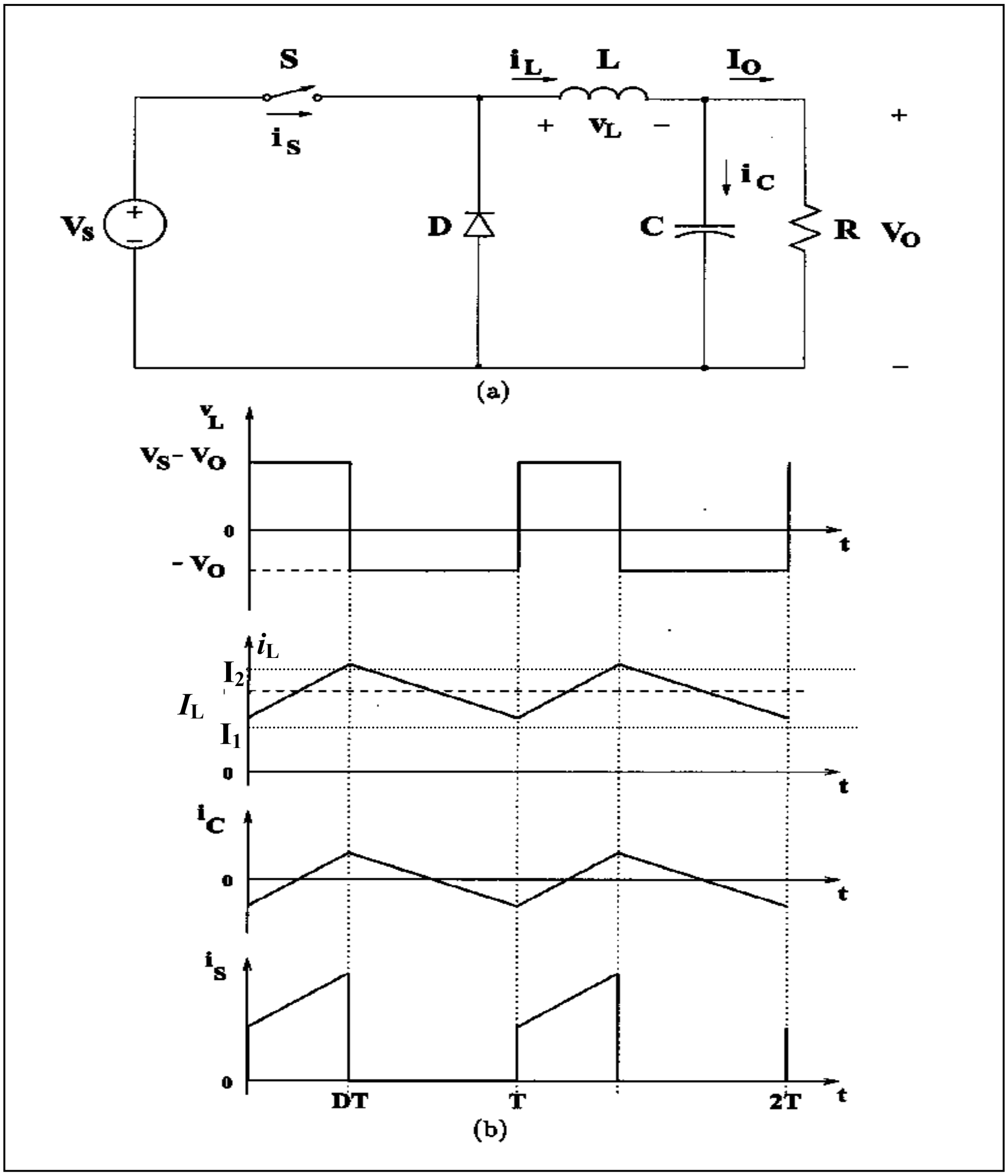
And $$I_s = DI_o$$

The ripple inductor current ΔI is:

$$\Delta I = \frac{DV_s(1 - D)}{fL}$$

The ripple capacitor voltage is:

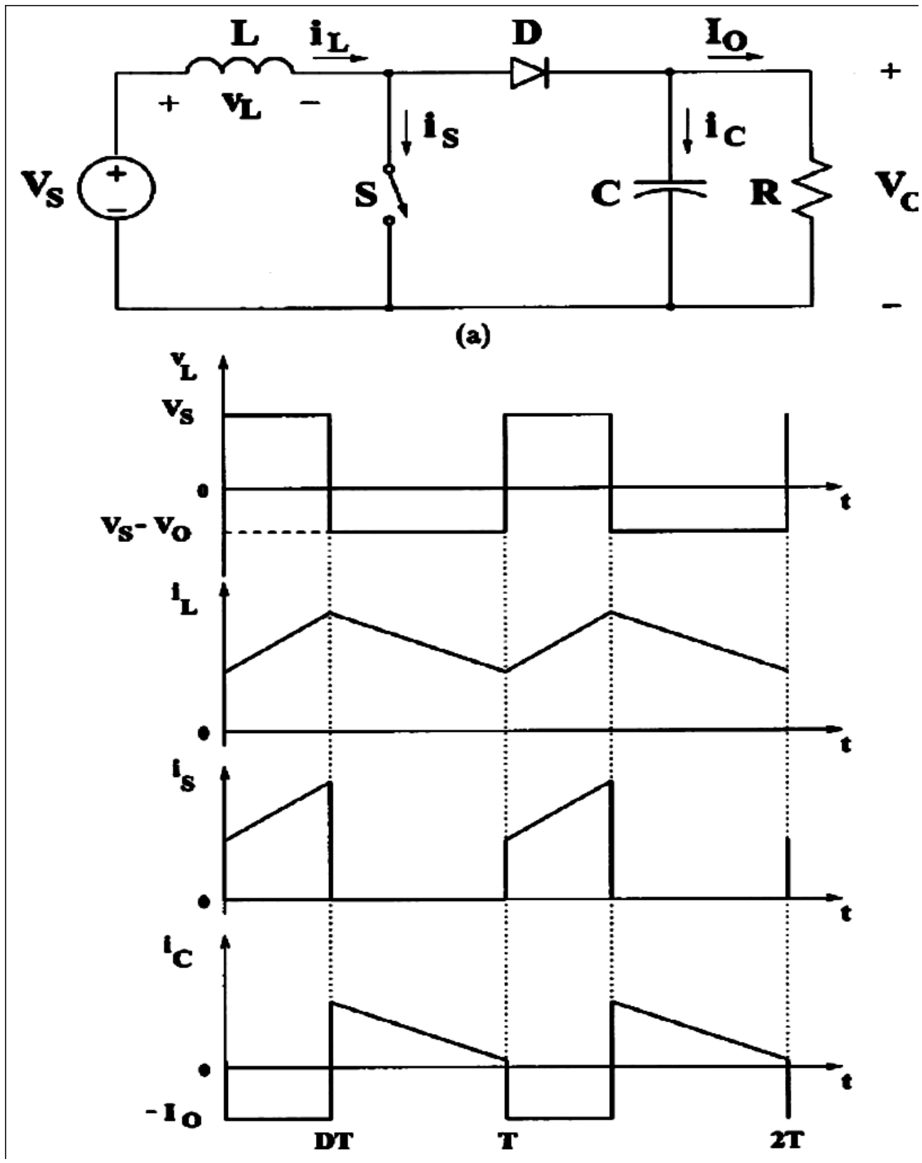
$$\Delta V_c = \frac{DV_s(1 - D)}{8CLf^2}$$



Step-Up (Boost) Converter

It consists of dc input voltage source V_S, boost inductor **L**, controlled switch **S**, diode **D**, filter capacitor **C**, and load resistance **R**. The converter waveforms in the **CCM** are shown in figure below.

When the switch **S** is in the on state, the current in the boost inductor increases linearly and the diode **D** is off at that time. When the switch **S** is turned off, the energy stored in the inductor is released through the diode to the output **RC** circuit.



$$V_s \ DT = (V_o - V_s)(1 - D)T$$

The output voltage and current are:

$$Vo = \frac{Vs}{1 - D}$$

And $$I_s = \frac{I_o}{1 - D}$$

The ripple inductor current **ΔI** is:

$$\Delta I = \frac{DV_s}{fL}$$

The ripple capacitor voltage is:

$$\Delta V_c = \frac{I_o(V_o - V_s)}{V_o fC} = \frac{I_o D}{fC}$$

Procedure

1. Connect the step-down dc-dc converter circuit on the power electronic trainer.
2. Turn on the power
3. Plot the waveforms of control circuit used to regulate the output voltage
4. By use oscilloscope, plot the inductor voltage and output waveforms on the graph paper.
5. Measure the average output voltage by connects the AVO meter across load resistance.
6. **Turn off the power**
7. Repeat step (3, 4) with L=10mH**.**
8. **Turn off the power**
9. Connect the step-down dc-dc converter circuit.
10. Repeat steps (2-7).

Discussion and calculations

1. Compare between the practical and theoretical results for inductor and output voltages and currents.
2. Design a high voltage power supply for CO_2 laser, when the optical output power is 8watt. The current and voltage electronically highly stabilized DC power unit has a nominal output 50mA and 5kV. Pumping under optimal conditions (maximum laser output), a current of 18mA at 3.0 kV is observed.
3. Explain the control circuit used to regulate the output voltage.