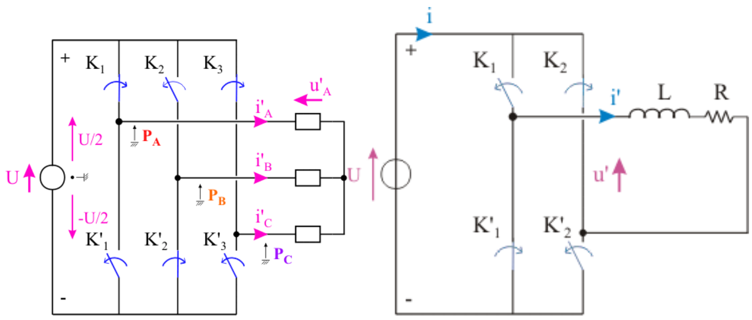
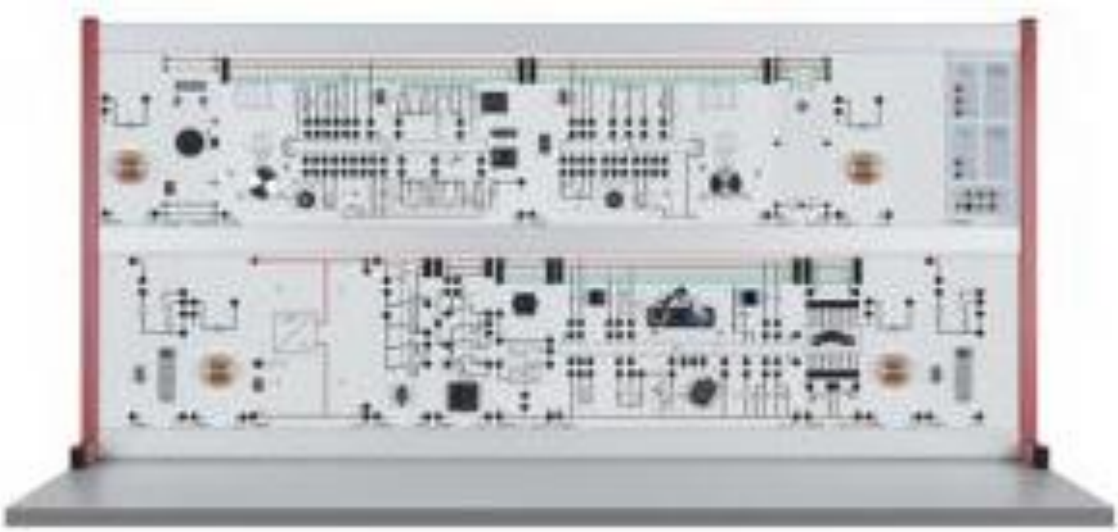
Department of Electrical Engineering
College of Engineering
University of Hail

Laboratory Manual
EE 460 – Power Electronics





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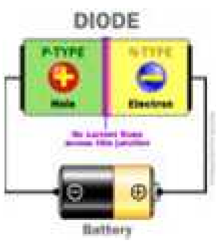
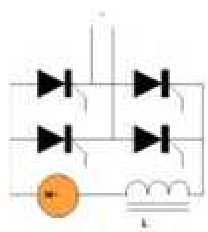
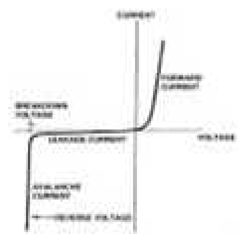
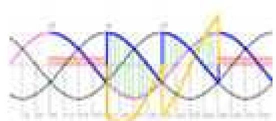
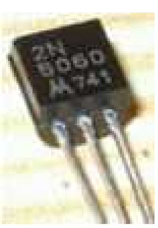
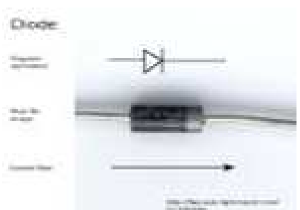


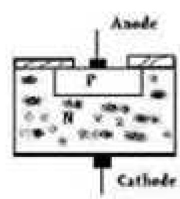












EE460_162
POWER ELECTRONICS
Laboratory Manual

Prepared By Dr. Mohamed Arbi KHLIFI

UNIVERSITY OF HAIL
ELECTRICAL ENGINEERING DEPARTMENT
POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 1
SINGLE-PHASE DIODE RECTIFIER

1. Introduction and learning objectives:

In this experiment students will perform experimental tests on a basic AC-DC uncontrolled converter (diode rectifier) circuit. And after completing this laboratory work the student will be able to:

- To get acquainted with the operation of a single-phase diode rectifier with resistive and inductive loads.
- To determine the performance characteristics of the uncontrolled rectifier with its various topologies.
- To Plot and analyze the time profiles for the DC voltage and current, and diode voltage.

2. Background

Power is distributed to consumers through AC distribution lines. Almost all electronic equipment like computers, TV, hi-fi equipment and instruments are powered by DC power sources, either by batteries or DC power supplies obtained from an AC source. AC-to-DC converters have a wide range of use as power supplies in many industrial and consumer applications.
Static converters with uncontrolled valves perform the basic function of DC rectification and are known as uncontrolled rectifiers or diode rectifiers. The ratio of input to output quantities is predetermined by its circuitry.
Its output is a pulsating DC voltage and is made of two components (DC voltage with superimposed AC component). It is thus not a pure DC quantity.

3. Experimental procedures

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains transformer	726 80
2	Silicon diodes	735 02
3	Power electronics load	735 09
4	Multi-meters	Peak
5	Oscilloscope	575 20 Hameg
6	Isolating amplifier	735 26
7	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single-phase full-wave rectifiers. Please follow the following steps carefully:

3.1. Single pulse rectifier

3.1.1 Introduction

Single pulse rectifiers or half wave rectifiers represent the simplest form of a static converter.

- ✓ When an ohmic load is inserted, the diode switches the positive half of the AC voltage to the load resistance and blocks the negative half wave. As a result, the DC voltage is made of intermittent sinusoidal half waves as well as for the DC current time profile since they are in phase.
- ✓ When a resistance and inductance are connected in series, the inductance will store magnetic energy and at the next negative half of the voltage, the current will continue to flow at a decreasing rate until the inductance has been discharged. The time profile of voltage and current will not be in phase.

3.1.2 Experimental work

- ➢ Connect the power circuit as shown in Figure 1, while using the supply voltage of 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- ➢ Using a multi-meter measure the output voltage *Vo*, the output current *Io*, the diode voltage *VD*.
- ➢ Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs*, *Vo*, *Io* , and *VD*

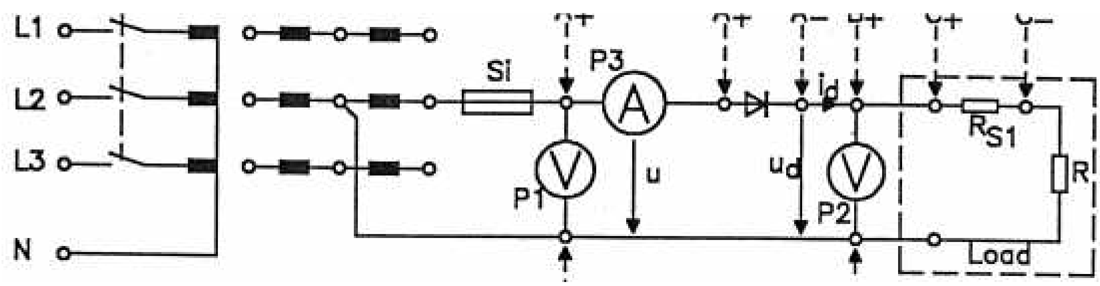


Figure 1. Single pulse rectifier rectifier with ohmic load of 33 Ω

3.1.2.1 With Ohmic load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad (3R \quad of \quad 100\Omega \quad in \quad parallel)$

- ➢ Write down the measured values in Table 1(a) provided below.
- ➢ Draw the waveforms in the provided graph plots 1(a) and take a picture of the waveforms

3.1.2.2 With Ohmic-Inductive load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad and \quad L = 50mH$

- ➢ Write down the measured values in Table 1(b) provided below.
- ➢ Draw the waveforms in the provided graph plots 1(b) and take a picture of the waveforms

Table 1(a)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 1(b)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.1.3 Conclusions

The training panel arrangement should be respected, the oscilloscope connected for visualizing the time profile of various forms with the help of the isolating amplifier connected accordingly.
Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance. Calculate the voltage and compare with the measured values.

3.2 Two-pulse mid-point circuit

3.2.1 Introduction

A center tapped transformer is used for the circuit of Figure 2. Diode D1 conducts when the source voltage Vso1 is positive and diode D2 conducts the current when the voltage Vso2 is positive. The DC voltage is thus made up of consecutive sinusoidal half-waves.
A large smoothing inductor can be used to ensure that the direct current is without harmonics. With a purely ohmic load, the time profile of the direct current is the same as that of the DC voltage as for the single pulse rectifier.

3.2.2 Experimental work

- Connect the power circuit as shown in Figure 2, while using the supply voltage of 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multi-meter measure the output voltage *Vo*, the output current *Io*, the diode voltage *VD*.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs, Vo, Io* , and *VD*

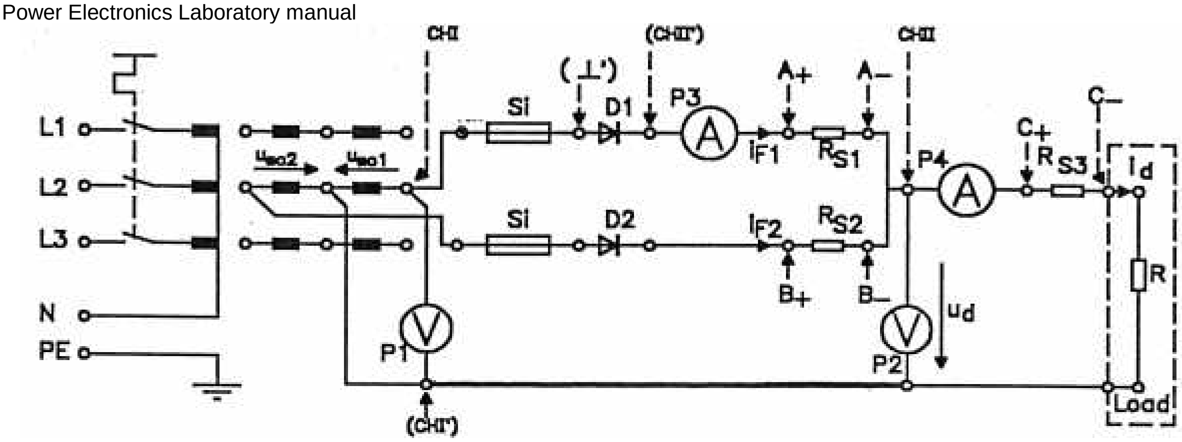


Figure 2. Two mid-point pulse rectifier with ohmic load of 33 Ω

3.2.2.1 With Ohmic load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad (3R \quad of \quad 100\Omega \quad in \quad parallel)$

- Write down the measured values in Table 2(a) provided below.
- Draw the waveforms in the provided graph plots 2(a) and take a picture of the waveforms

3.2.2.2 With Ohmic-Inductive load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad and \quad L = 50mH$

- Write down the measured values in Table 2(b) provided below.
- Draw the waveforms in the provided graph plots 2(b) and take a picture of the waveforms

Table 2(a)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 2(b)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.2.3 Conclusions

Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance. Calculate the voltage and compare with the measured values.

3.3 Two-pulse bridge circuit

3.3.1 Introduction

Bridge circuits may be considered as two midpoint circuits connected in series. The time profiles are then made up of the sum of the individual DC voltages of the two midpoint circuits. Diodes *D1* to *D4* form a bridge rectifier where this circuit topology is called an uncontrolled rectifier. Diodes *D1* and *D4* work together to rectify the positive half cycle of the sinusoidal waveform while diodes *D2* and *D3* rectify the negative half cycles. The DC voltage will be again a pulsating voltage made up of sinusoidal half-waves, but with twice the magnitude of that in a M2 circuit. In circuit with an ohmic load, the time profile of the direct current corresponds to that of the DC voltage.

3.3.2 Experimental work

- Connect the power circuit as shown in Figure 3, while using the supply voltage of 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multi-meter measure the output voltage *Vo*, the output current *Io*, the diode voltage *VD*.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs*, *Vo*, *Io* , and *VD*

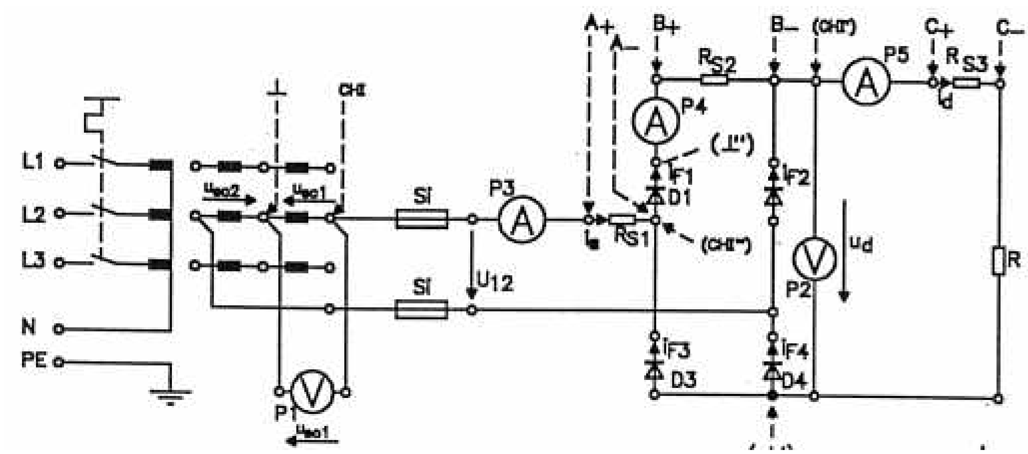


Figure 3. Two pulse bridge rectifier with ohmic load of 33 Ω

3.3.2.1 With Ohmic load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad (3R \quad of \quad 100\Omega \quad in \quad parallel)$

- Write down the measured values in Table 3(a) provided below.
- Draw the waveforms in the provided graph plots 3(a) and take a picture of the waveforms

3.3.2.2 With Ohmic-Inductive load

Basic settings: $V_s = 45V \quad with \quad R = 33\Omega \quad and \quad L = 50mH$

- Write down the measured values in Table 3(b) provided below.
- Draw the waveforms in the provided graph plots 3(b) and take a picture of the waveforms

Table 3(a)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 3(b)

V_s (v)	**45**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.3.3 Conclusions

Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance. Calculate the voltage and compare with the measured values.

4 Report

1. Complete all tables.
2. Copy the plots obtained during the experiment and put it in the report.
3. You must write a full report about what you have observed and what procedures you have done to obtain these results.
4. Compare your results with data sheets and other resources (text book or references) or simulation analysis.

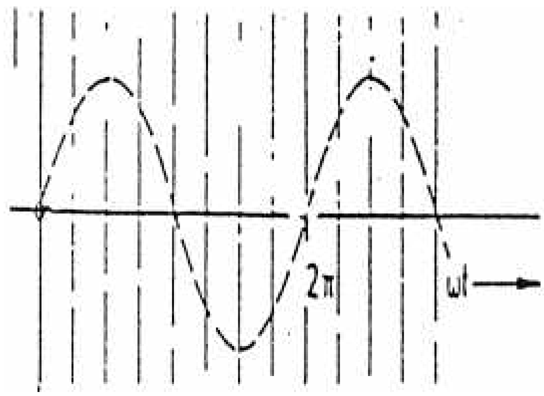
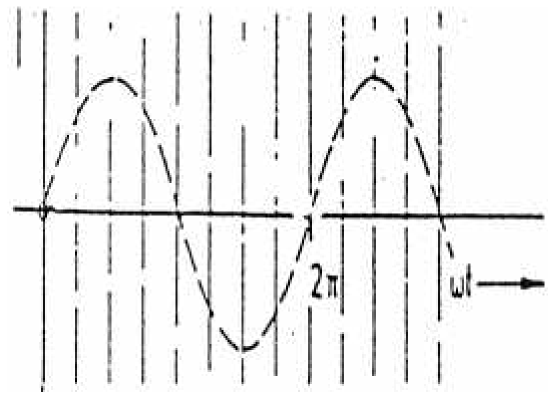
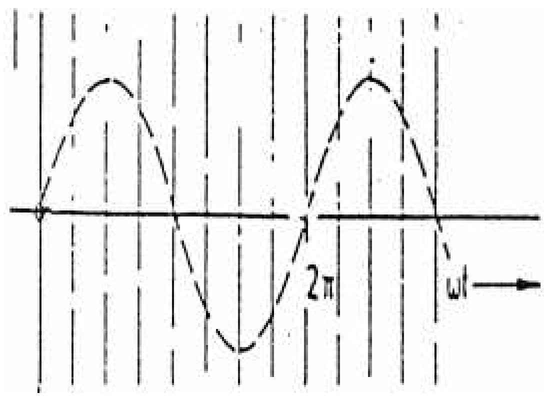
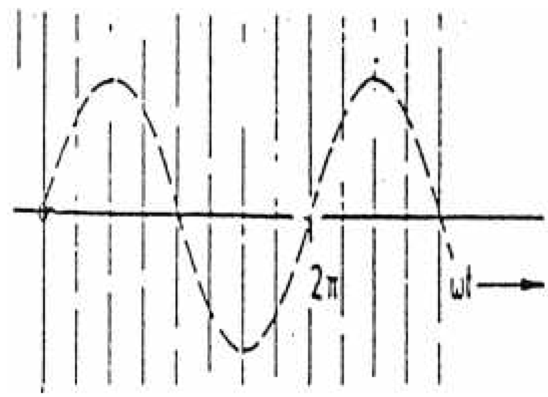
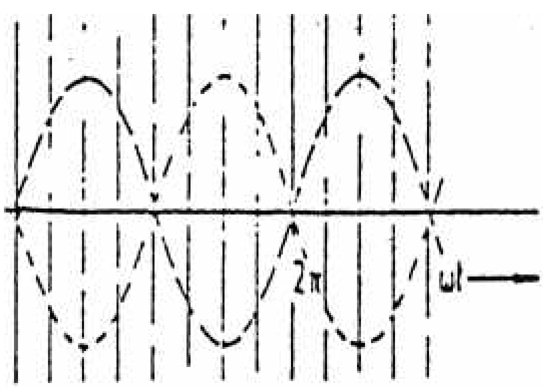
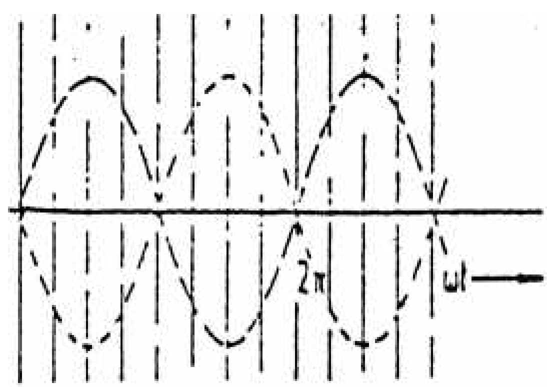
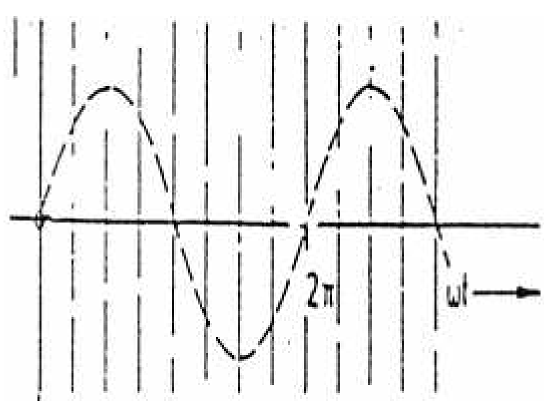
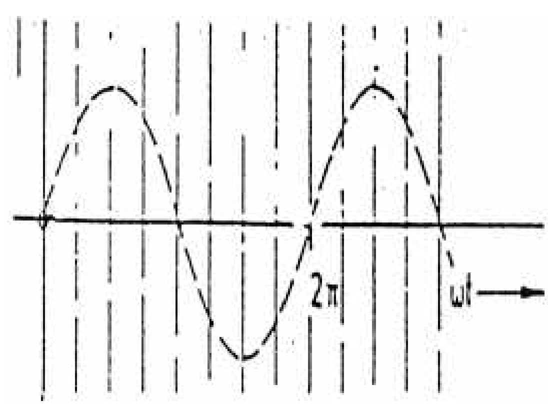
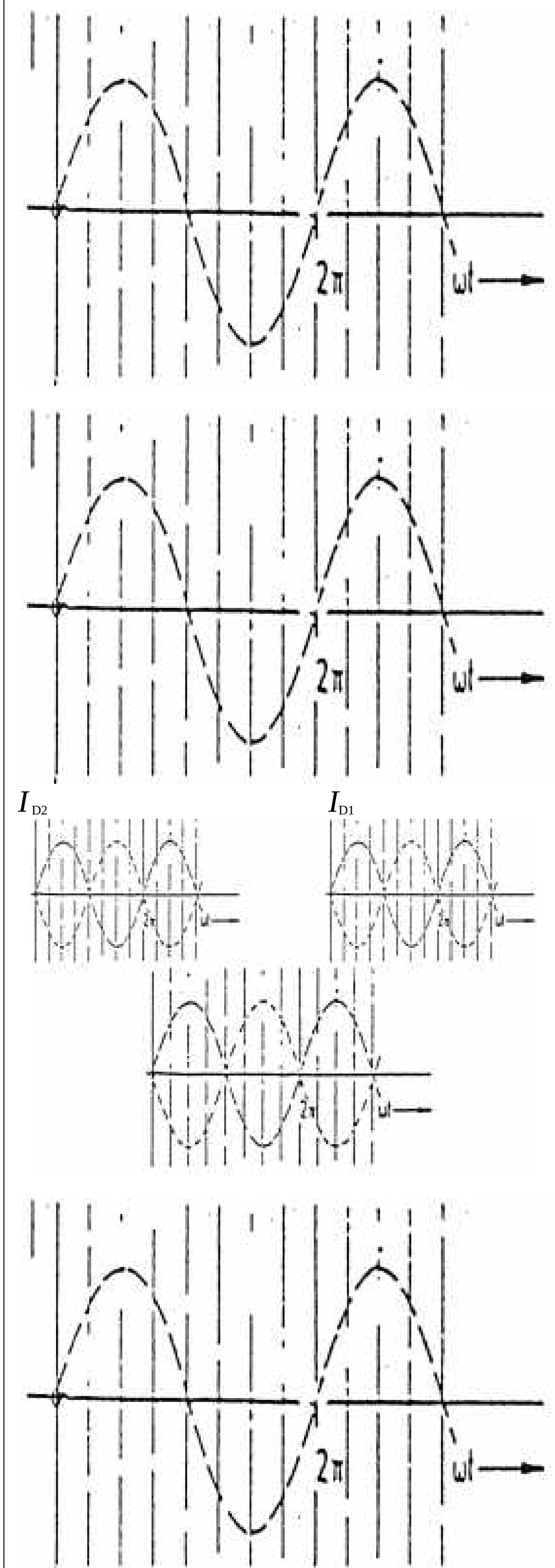
Graph 1(a) with ohmic load		Graph 1(b) with ohmic-inductive load	
V_s		V_s	
V_o		V_o	
I_o		I_o	
V_D		V_D	

Figure 1. Single pulse rectifier

Graph 2(a) with ohmic load

V_s, V_o, I_o, V_D



Graph 2(b) with ohmic-inductive load

V_s, V_o, I_o, V_D

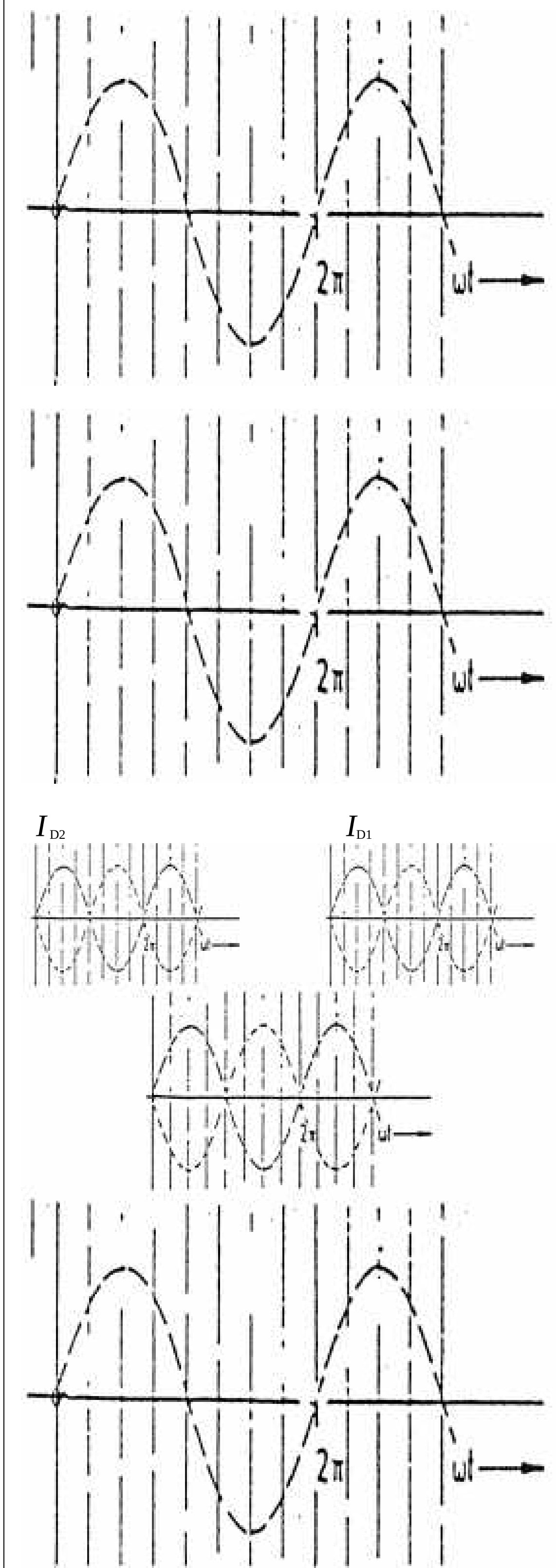


Figure 2. Two pulse midpoint circuit

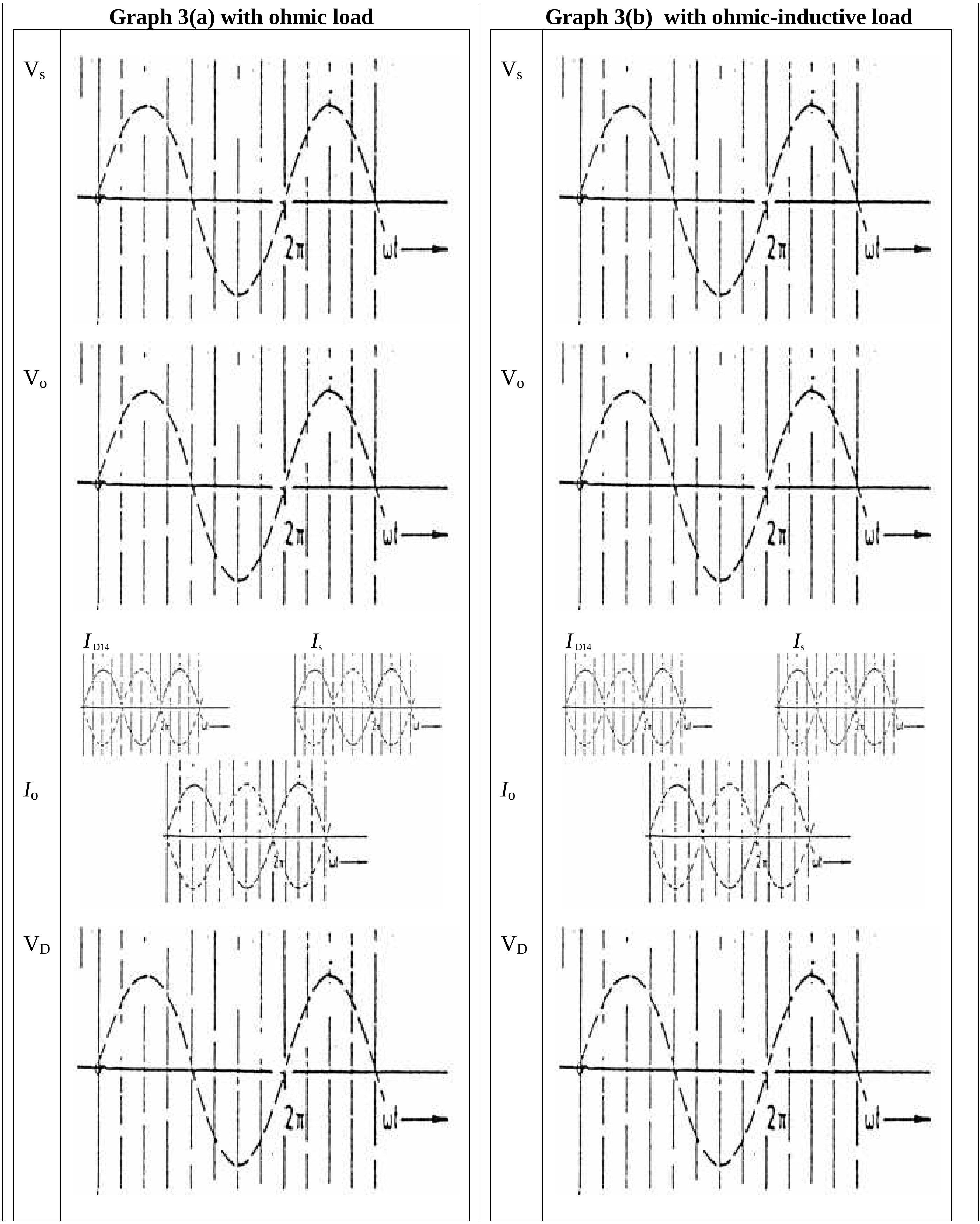


Figure 3. Two pulse bridge circuit

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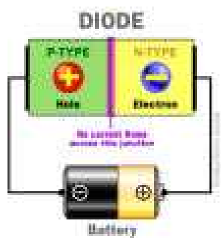

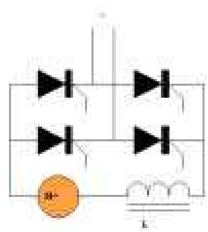

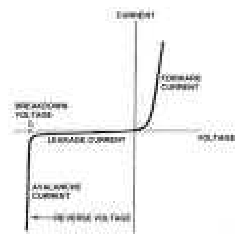

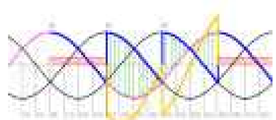

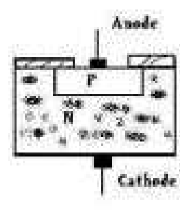

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POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 2
THREE-PHASE DIODE RECTIFIER

1. Introduction and learning objectives:

After completing this laboratory work the student will be able to:

- To get acquainted with the operation of a three-phase diode rectifier with resistive and inductive loads.
- To determine the performance characteristics of the three phase uncontrolled rectifier with its various topologies.
- To Plot and analyze the time profiles for the DC voltage and current, and diode voltage and understand the difference when an inductance is inserted.

2. Theoretical background

See single pulse rectifiers theoretical background

3. Experimental procedures

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains transformer	726 80
2	Silicon diodes	735 02
3	Power electronics load	735 09
4	Multimeter	
5	Oscilloscope	575 20 Hameg
6	Isolating amplifier	735 26
7	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about three-phase half and full-wave rectifiers. Please follow the following steps carefully as we will be performing three types of experiments:

3.1. Three pulse mid-point rectifier

3.1.1 Introduction:

The three phase star connection represent the simplest form of three-phase rectifier. Uncontrolled rectifier valves become conductive as soon as the anode voltage is positive., as a result, current always flows through the valve with a higher line potential than that of the other valves. The next following valve takes over the current at the point of intersection of the line voltages of the three phase feed system. This point corresponds to the natural firing point. The distance between these points equals to T/3 and corresponds to 120^o. Consequently, current will flow through the diode for 120^o. in each case. It is then commutated to the next following valve, thus the current alternately flows through diodes D1, D2, and D3. The time profile of the valve currents is made up of the current blocks with sinusoidal peaks. The direct current is made up of these continuous valve currents sections. The DC voltage is formed by line voltage Vs1 when valve D1 conducts, by line voltage Vs2 when valve D2 conducts and by line voltage Vs3 when valve D3 conducts. As a result, the voltage is a pulsating three pulse DC voltage with a lower residual ripple than in the case of two pulse circuits. The DC voltage and direct current display the same time profile when the load is purely resistive. The reverse voltage of the diodes equals the difference between the momentary values of the respective line voltages of the blocking and conducting diodes. Its peak value equals the peak value of the circuit voltage. On account of the smoothing effect of the inductance , the direct current includes pure harmonics much smoother than in the case of a purely resistive load.

3.1.2 Experimental procedures:

1. Connect the power circuit as shown in Figure 1, while using the supply voltage of 90 V and a load resistance of 100 Ω.
2. Using a multimeter measure the output voltage, the output current, and the diode voltage.
3. Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs, Vo, Io* , and V_D.

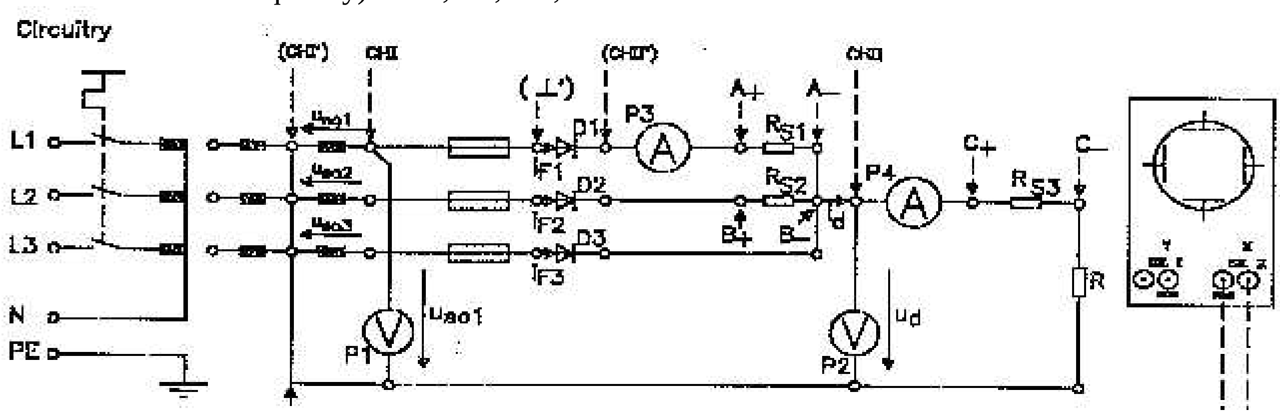

Figure 1.**Three pulse mid-point rectifier**

3.1.2.1 With Ohmic load: Basic settings: $V_s = 90V \quad with \quad R = 100\Omega$

1. Write down the measured values in Table 1(a) provided below.

2. Draw the waveforms in the provided graph plots 1(a) and take a picture of the waveforms

3.1.2.2 With Ohmic-Inductive load: Basic settings: $V_s = 90V, \quad R = 100\Omega, \quad L = 50mH$

1. Write down the measured values in Table 1(b) provided below.
2. Draw the waveforms in the provided graph plots 1(b) and take a picture of the waveforms

Table 1(a)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 1(b)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.1.3 Conclusions

Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance. Calculate the voltage and compare with the measured values.

3.2 Six pulse mid-point rectifier

3.2.1 Introduction

The six secondary line voltages of the rectifier are symmetrically phase shifted through 60^o. The diodes successively take over current conduction at the point of intersection of the line voltages. The diodes are not fully utilized (since they conduct only for 60^o) which makes this rectifier not much used in practice despite its low ripple. Diodes D1 to D6 alternatively take over conduction of the current at the natural commutation point (intersection of the line voltages). The diode currents are made up of current blocks with sinusoidal peaks and an angle of current flow of 60^o. The direct current is made up of these continuous sinusoidal diode current sections. The peak value of the reverse voltage at the diodes is equal to the peak value of the maximum circuit voltage. The time profile for the DC voltage and current is the same as in the circuits with ohmic load. It constitutes a pulsating quantity with large direct component. On account of the smoothing inductor, the harmonic content of the direct current is lower than in the case of the DC voltage.

3.2.2 **Experimental procedures:**

1. Connect the power circuit as shown in Figure 2, while using the supply voltage of 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)

2. Using a multi-meter measure the output voltage, the output current, and the diode voltage.
3. Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs*, *Vo*, *Io* , and *VD*

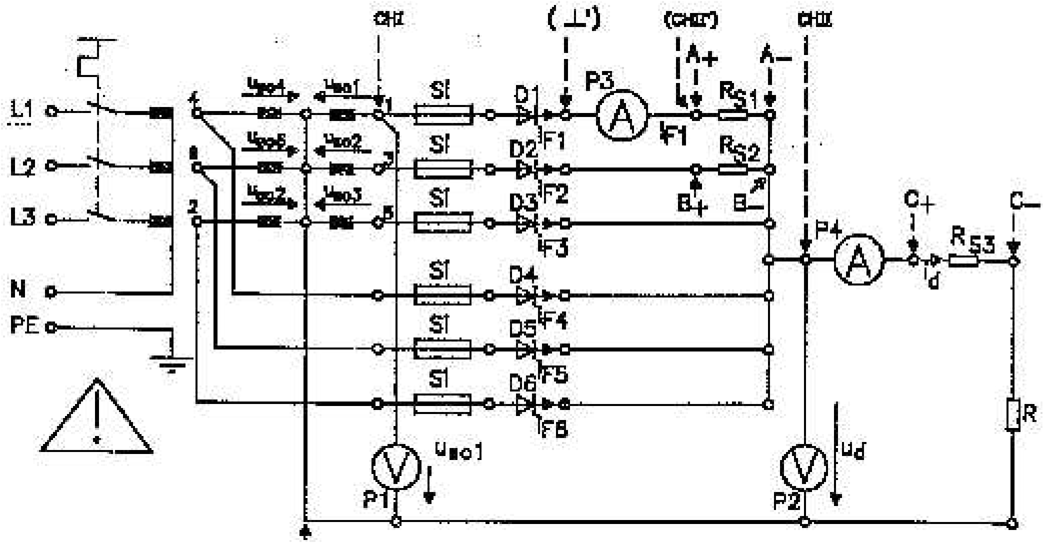

Figure 2. Two mid-point pulse rectifier with ohmic load of 100 Ω

3.2.2.1 With Ohmic load: Basic settings: $V_s = 90V \quad with \quad R = 100\Omega$

1. Write down the measured values in Table 2(a) provided below.
2. Draw the waveforms in the provided graph plots 2(a) and take a picture of the waveforms

2.2.2.2 **With Ohmic-Inductive load:** Basic settings: $V_s = 90V, \quad R = 100\Omega, \quad L = 50mH$

- ✓ For the same circuit of Figure 2 insert in series with the resistance of 33 Ω an inductance of value 50 mH.
- ✓ Record the values of the DC voltage, load current, diode voltage for V_S = 45V, and 90V.
- ✓ Insert the measured values into Table 2(b)
- ✓ Draw successively the time profile of the supply voltage, DC voltage, load current, diode voltage in graph 2(b) and take a picture of the waveforms

Table 2(a)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 2(b)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.2.3 Conclusions:

Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance. Calculate the voltage and compare with the measured values.

3.3 Six pulse bridge rectifier

3.3.1 Introduction

The six pulse bridge rectifier may be considered as two three pulse mid point circuit connected in series with their individual DC voltages mutually phase shifted through 60^o. The point by point addition of these individual DC voltages yields a six pulse DC voltage with low ripple. The angle current flow for the diode (D1, D3, D5 and D4, D6, D2) is once again 120^o, since current always flows through two diodes simultaneously in a series circuit, after half the conductive period of one diode, the current is commutated to the next following diode in series. Such a circuit is frequently used in practice when higher capacities are required.

The time profiles for the DC voltage and direct current are identical (ohmic load).

3.3.2 Experimental procedures

3. Connect the power circuit as shown in Figure 3, while using the supply voltage of 90V and a load resistance of 100 Ω.
4. Using a multi-meter measure the output voltage *Vo*, the output current *Io*, the diode voltage *VD*.
5. Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of *Vs, Vo, Io* , and *VD*

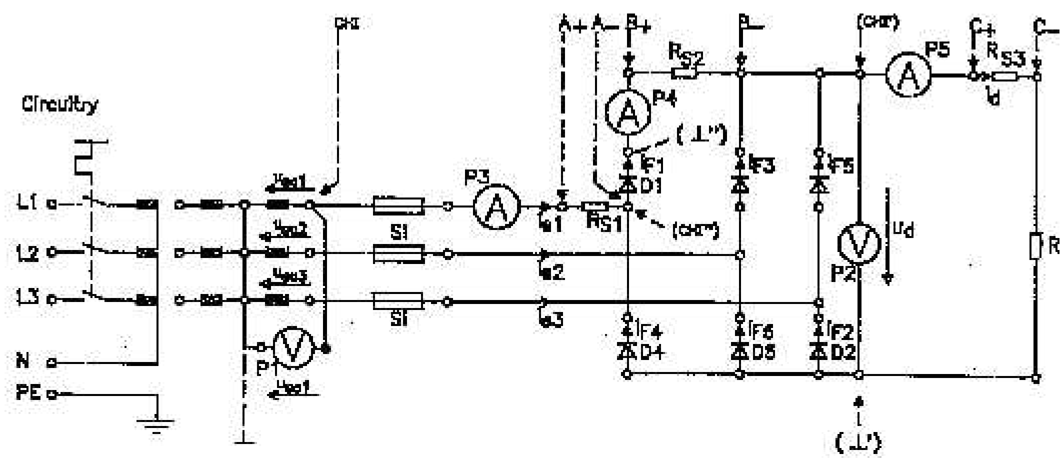

Figure 3. Two pulse bridge rectifier with ohmic load of 100 Ω

3.3.3 **With Ohmic load:** Basic settings: $V_s = 90V \quad with \quad R = 100\Omega$

1. Connect the circuit as shown in Figure 3 for a load resistance of 100 Ω
2. Record the values of the DC voltage, load current, diode voltage for V_S = 90V and insert the measured values into Table 3(a)
3. Draw successively the time profile of the supply voltage, DC voltage, load current, diode voltage in graph 3(a) and take a picture of the waveforms

3.3.4 **With Ohmic-Inductive load:** Basic settings: $V_s = 90V, \quad R = 100\Omega, \quad L = 50mH$

1. Using a multimeter measure the output voltage *Vo*, the output current *Io*, the diode voltage *VD* and insert the measured values into Table 3(b).
2. With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, diode voltage in graph 3(a) and take a picture of the waveforms

Table 3(a)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

Table 3(b)

V_s (v)	**90**
V_o_meas (v)	
V_o_calc (v)	
I_o (A)	
V_D (Diode)(v)	

3.3.5 Conclusions

Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

4. Report:

1. Record all your comments and views for the different graphs
2. Draw all the corresponding profiles as well as taking photographs
3. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

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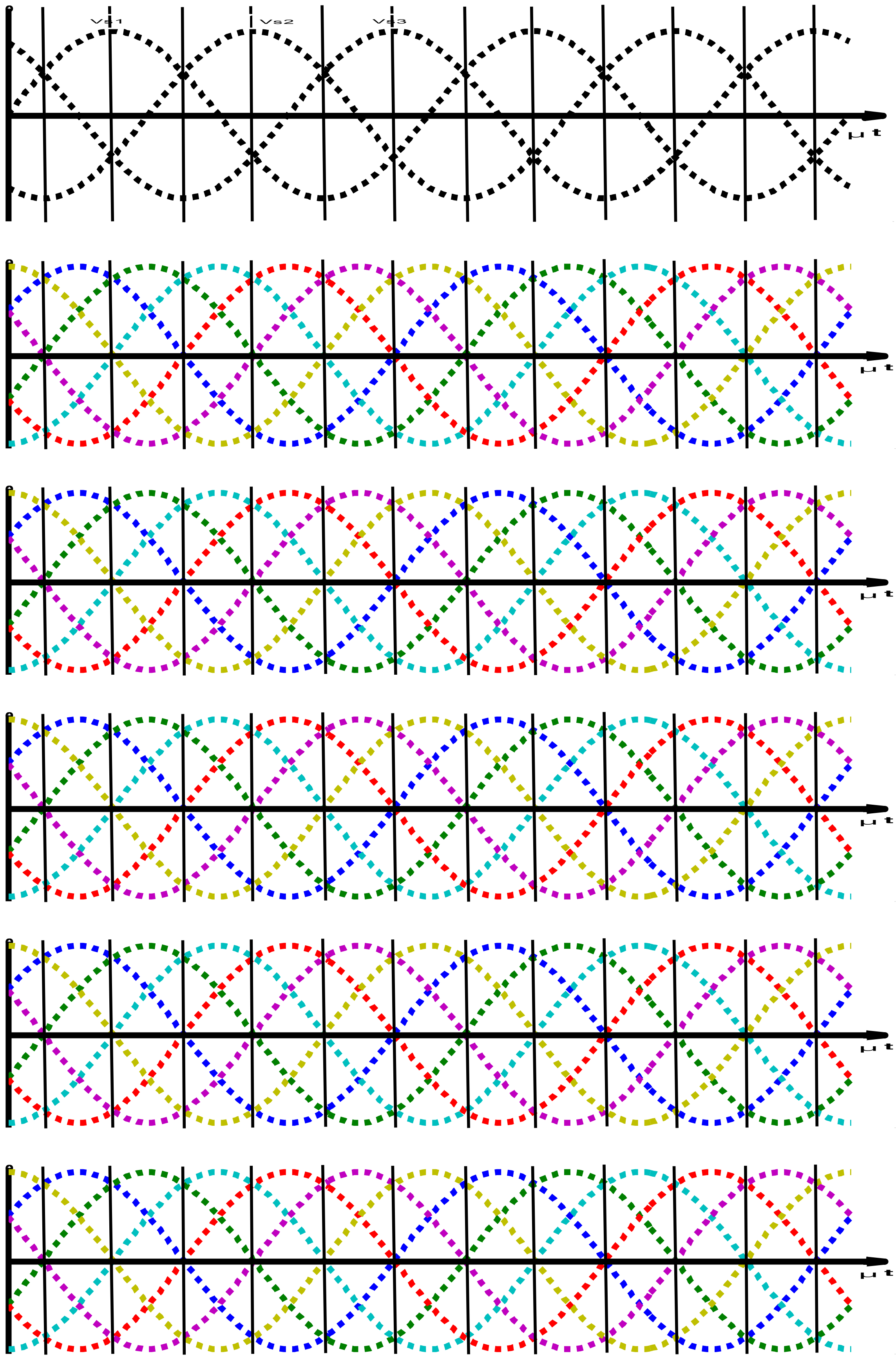
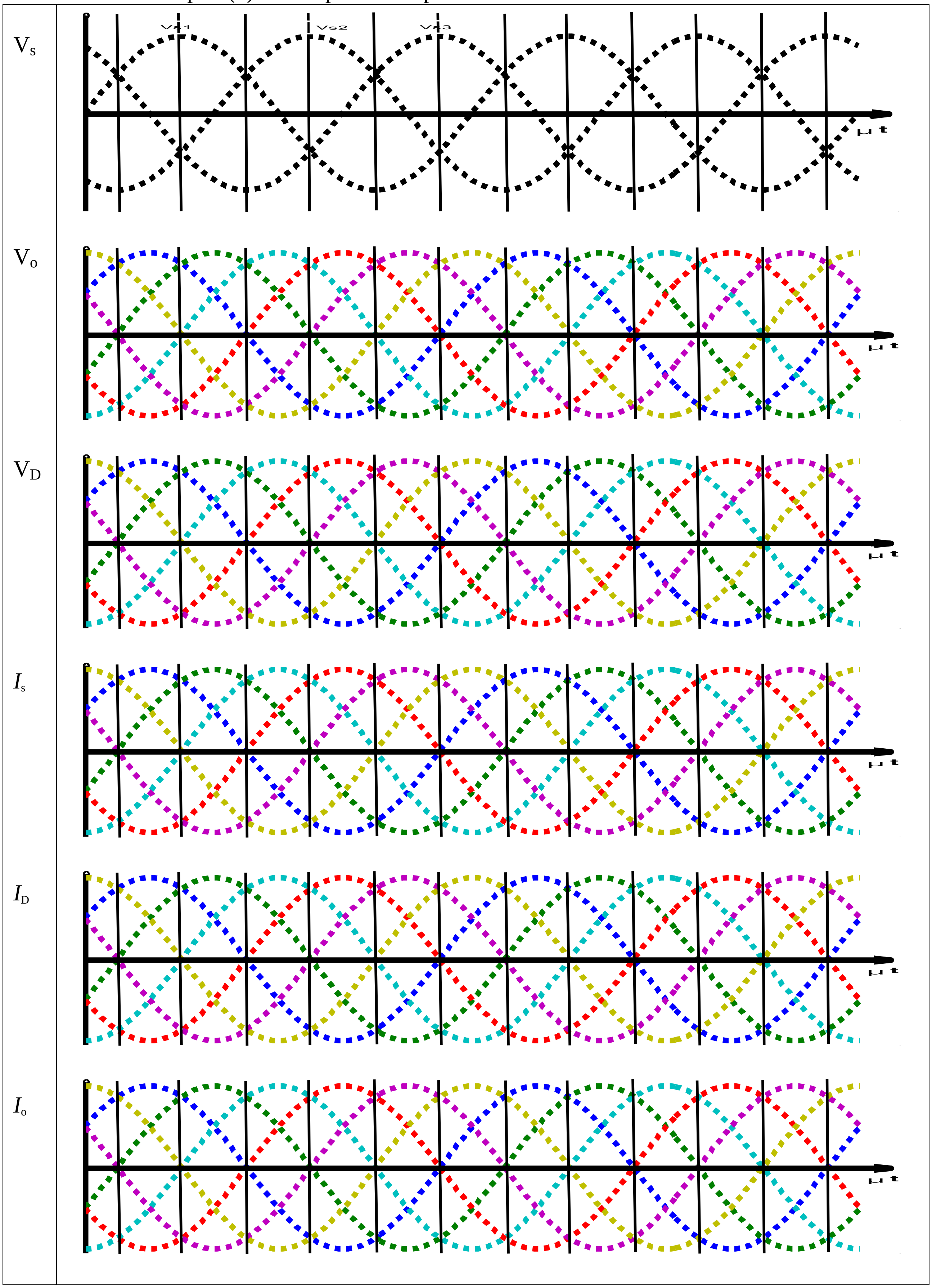
Graph 1(a). Three pulse mid-point rectifier with ohmic load

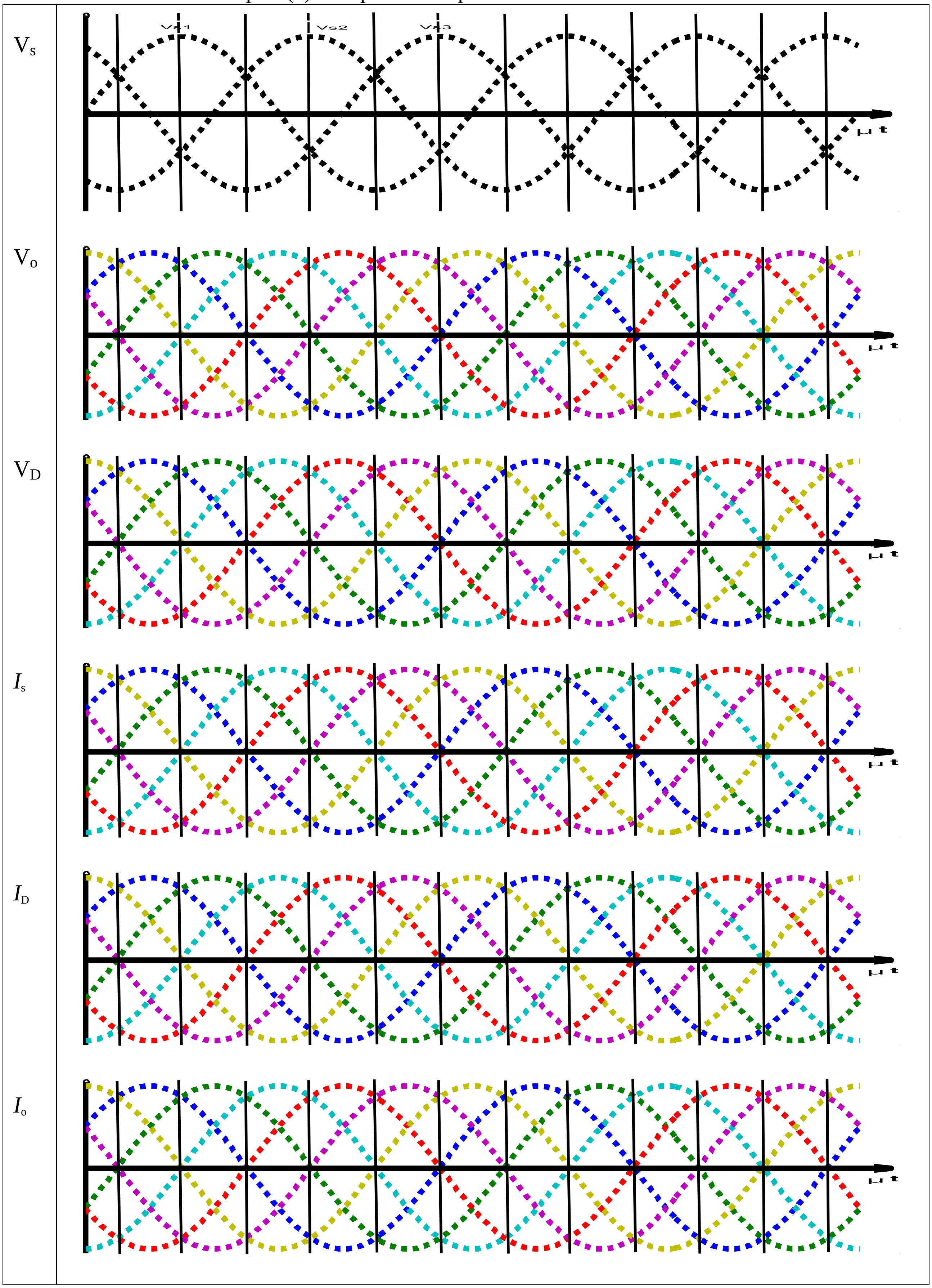
V_s	
V_o	
V_D	
I_s	
I_D	
I_o	



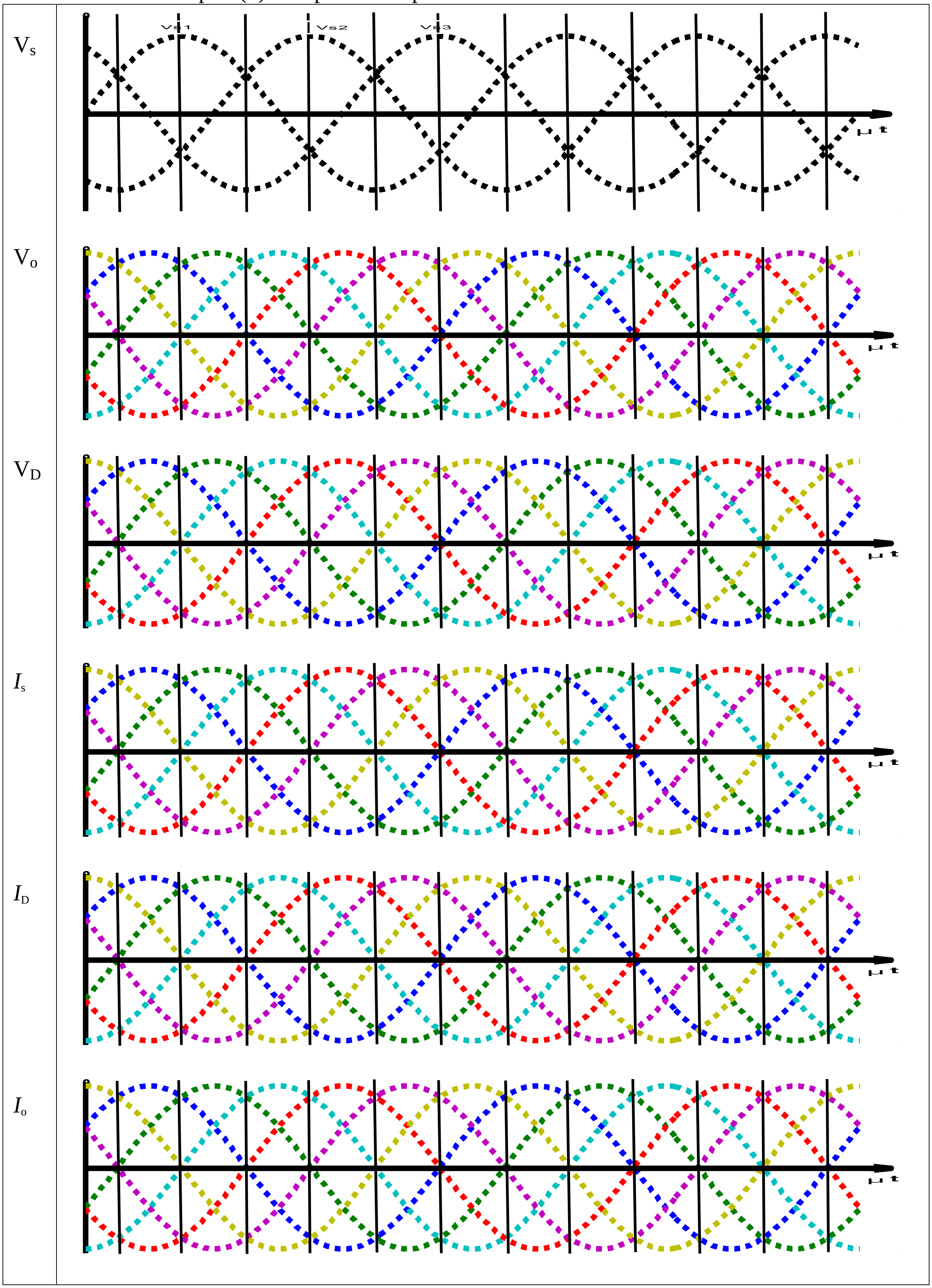
Graph 1(b). Three pulse mid-point rectifier with ohmic-inductive load



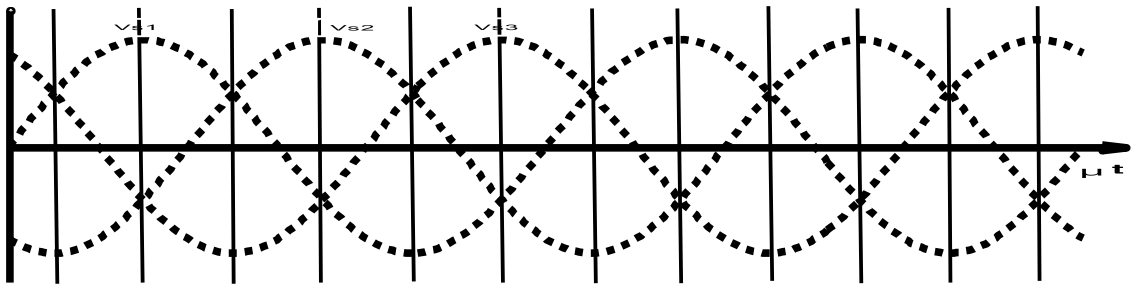
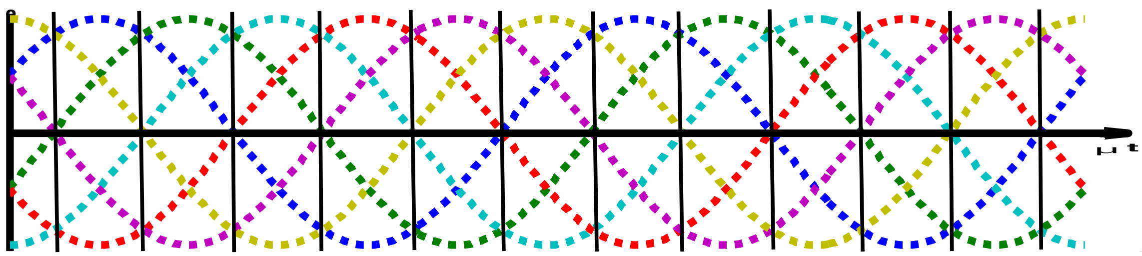
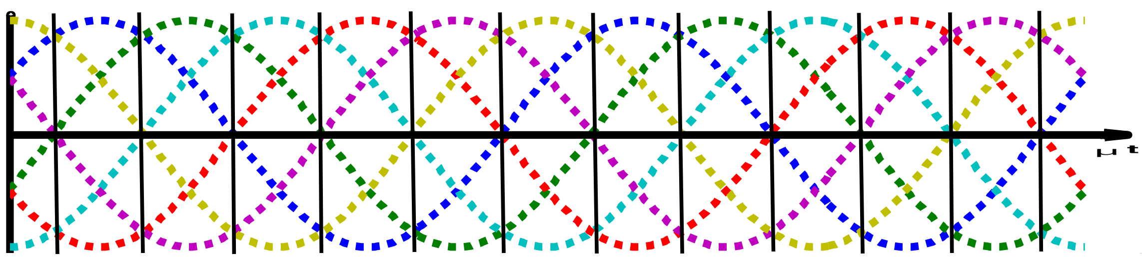
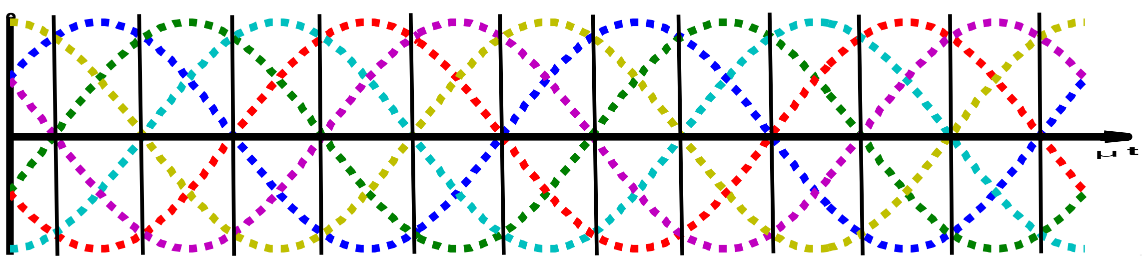
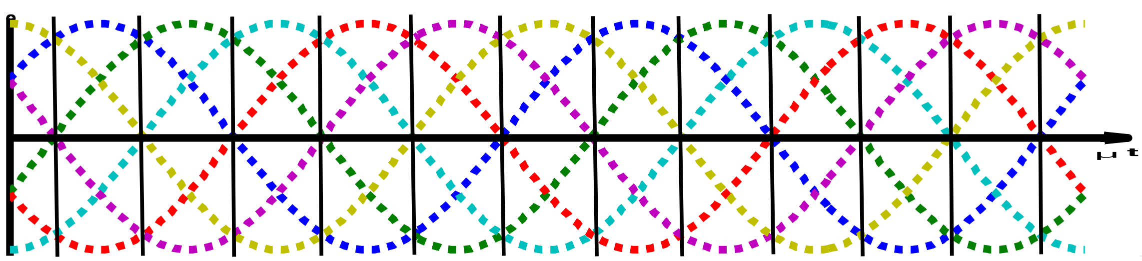
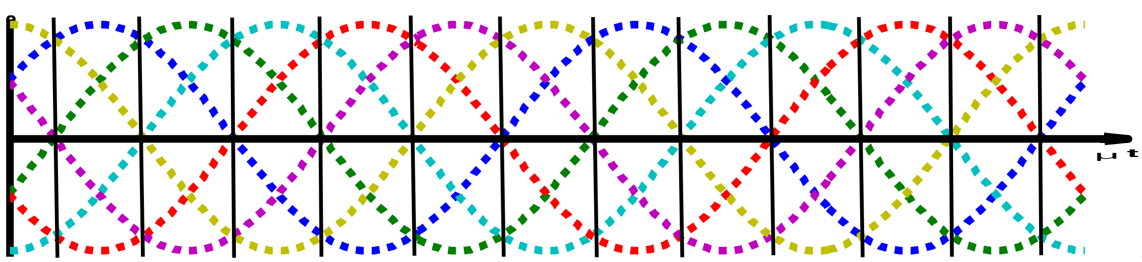
Graph 2(a). Six pulse mid-point rectifier with ohmic load



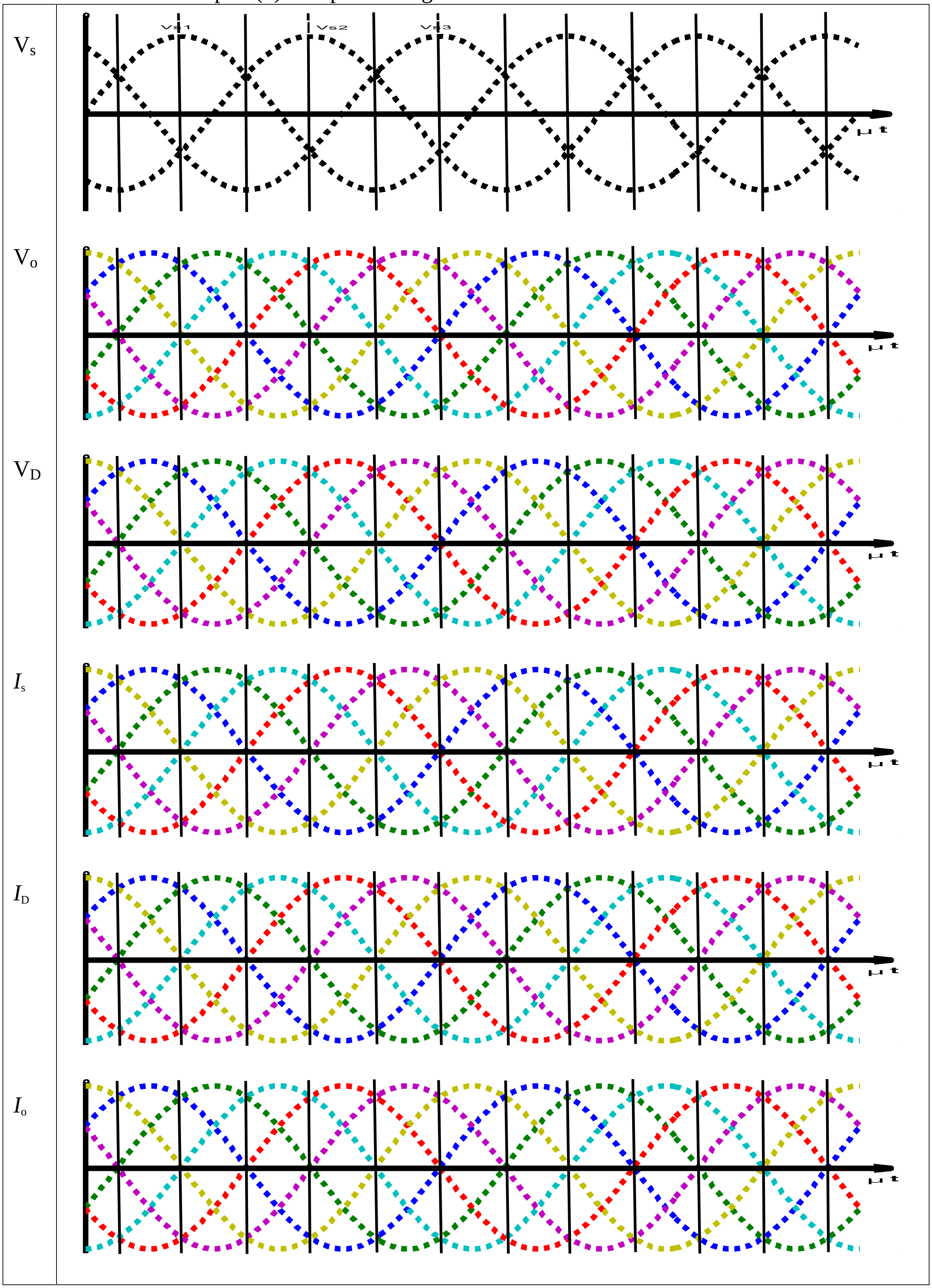
Graph 2(b). Six pulse mid-point rectifier with ohmic-inductive load



Graph 3(a). Six pulse bridge rectifier with ohmic load

V_S	
V_o	
V_D	
I_s	
I_D	
I_o	

Graph 3(b). Six pulse bridge rectifier with ohmic-inductive load



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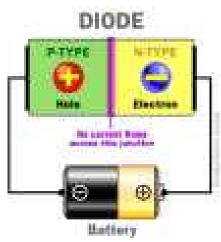
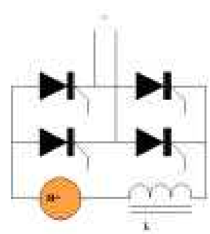
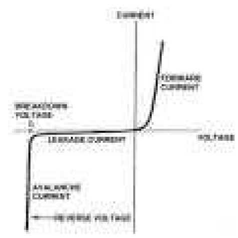
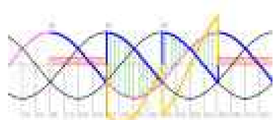
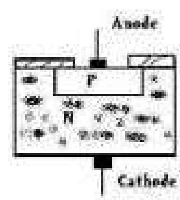










EE460_162
POWER ELECTRONICS
Laboratory Manual

UNIVERSITY OF HAIL
ELECTRICAL ENGINEERING DEPARTMENT
POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 3
SINGLE-PHASE CONTROLLED RECTIFIER

1. Introduction and learning objectives:

In this experiment students will perform experimental tests on a basic AC-DC controlled converter (thyristor rectifier) circuit. And after completing this laboratory work the student will be able to:

- To get acquainted with the operation of a single-phase controlled rectifier with resistive and inductive loads.
- To determine the performance characteristics of the controlled rectifier with its various topologies.
- To Plot and analyze the time profiles for the DC voltage and current, and thyristor voltage.

2. Theoretical background

Single-pulse static converters or single-pulse midpoint circuits (M1) are the simplest form of rectifier circuit.

In practical power electronics, this static converter is of little importance on account of the higher ripple of the DC voltage. Nevertheless, the static converter will be investigated in a separate group of experiments with different load variants, since the resultant knowledge is of fundamental importance in understanding static converters with higher pulse numbers.

In particular, the knowledge acquired with single-pulse static converters can be transferred directly to all non-commutating power converters, such as AC converters or intermittent high-pulse DC converters.

Ohmic load

The ohmic load represents the simplest and most easily described load variant for a rectifier, since the characteristic curves for a voltage and current at the ohmic load resistance are identical in time and phase.

When the anode voltage is positive, the thyristor is triggered after a delay controlled by the gate angle α. Current flows in the load circuit until the current again drops to zero when the feed voltage crosses zero and the thyristor blocks. The control range equals $\alpha = 0$ to 180° and the angle of current flow $\theta = 180^\circ - \alpha$.

The valve blocks during the negative half-wave. The feed voltage is present in the thyristor as a reverse voltage.

Ohmic-inductive load, series circuit

Ohmic and inductive resistances connected in series are a load type frequently found in practice.

Once again, the inductance prevents any abrupt current changes in the load circuit (direct current). The time profile of the direct current is made up of a sinusoidal continuous current which lags behind the peak voltage by the load phase angle $\varphi = \arctan \omega L/R$ and the equalizing current decaying with the current constant $\tau = L/R$. At the firing point, the instantaneous value of the equalizing current is opposite and equal to the instantaneous value of the sinusoidal continuous current.

The value for the angle of current flow θ lies between those for ohmic and purely inductive loads.

Since the direct current continues to flow as a result of the storage effect of the inductance when the AC feed voltage passes zero, the DC voltage is once again made up of positive and negative voltage/time segments (voltage/angle areas), but of different sizes. The negative areas reduce the mean value of the DC voltage. However, on account of the valve action the direct current and hence the voltage at the ohmic resistance always remain positive.

Ohmic-inductive load, free-wheeling diode

The free-wheeling diode is connected in parallel to the ohmic-inductive load and its polarity is such that it blocks when the DC voltage is positive. When the feed voltage passes zero, the free-wheeling diode continuously conducts the load current, thus preventing the DC voltage from moving into negative sections of the time profile and returning the stored magnetic energy into the AC feed line. As a result, the continuous load current profile displays considerably less ripple.

Since there are no negative components, the time profile of the DC voltage is the same as that in the case of an ohmic load.

3. Experimental procedures

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains transformer	726 80
2	thyristors	735 23
3	Power electronics load	735 09
4	Multimeter	
5	Oscilloscope	575 20 Hameg
6	Isolating amplifier	735 26
7	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single-phase full-wave rectifiers. Please follow the following steps carefully:

3.1. Single pulse controlled rectifier

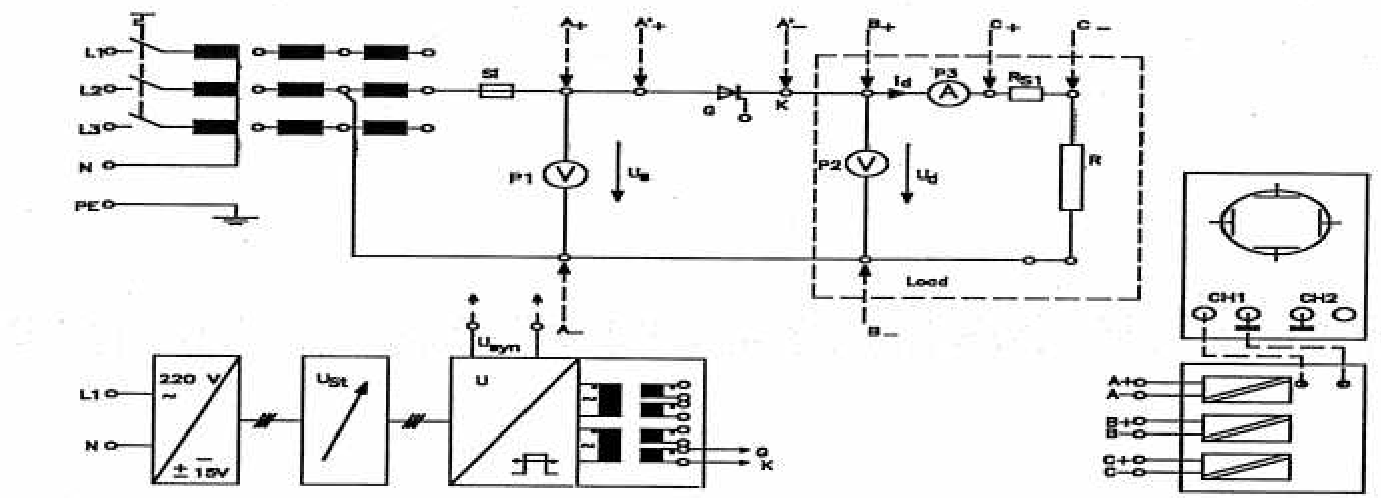


Figure 1 Single pulse controlled rectifier

3.1.1 Ohmic load

- Connect the power circuit as shown in Figure 1, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 1(a) provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 1(a)

Table 1(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 1(b) : R = 33 Ω, L = 50 MH

A	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.1.2 Ohmic-Inductive load

- Connect to the power circuit shown in Figure 1, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 1(b).
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 1(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

3.2. Single pulse controlled rectifier with a freewheeling diode

A non-intermittent load current flows when the inductance is sufficiently large. The smoothing effect becomes stronger as the inductive energy storage increases.

As a result, free-wheeling diodes represent a relatively simple technical means of reducing the ripple of rectifier load currents.

However, they also prevent negative voltage/time sections and thus also the return of energy from the load circuit to the AC power supply frequently used in drive technology and to protect static converters.

3.2.1 Ohmic load

- Connect the power circuit as shown in Figure 1 with a freewheeling diode, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 2 provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 2(a)

Table 2(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 2(b) : R = 33 Ω, L = 50 MH

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.2.2 Ohmic-Inductive load

- Connect to the power circuit shown in Figure 1, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 2.
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 2(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

3.3. Controlled two pulse Midpoint circuit

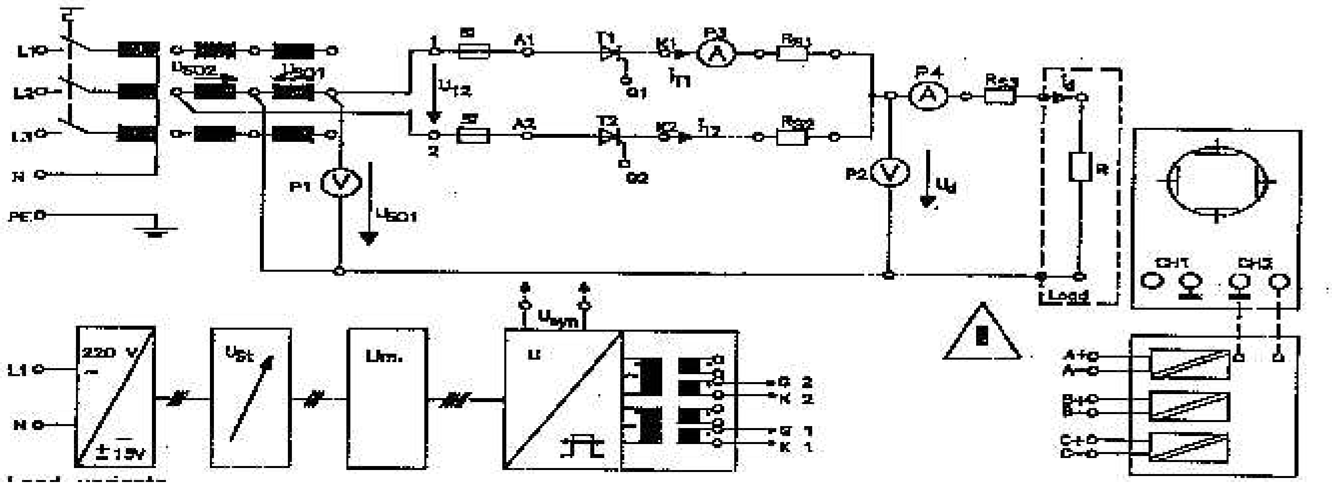


Figure 2 Two pulse midpoint controlled rectifier

3.2.3 Ohmic load

- Connect the power circuit as shown in Figure 2, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 3 provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 3(a)

Table 3(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 3(b) : R = 33 Ω, L = 50 MH

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.2.4 Ohmic-Inductive load

- Connect to the power circuit shown in Figure 2, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 3.
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 3(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

3.4. Fully controlled two pulse bridge circuit

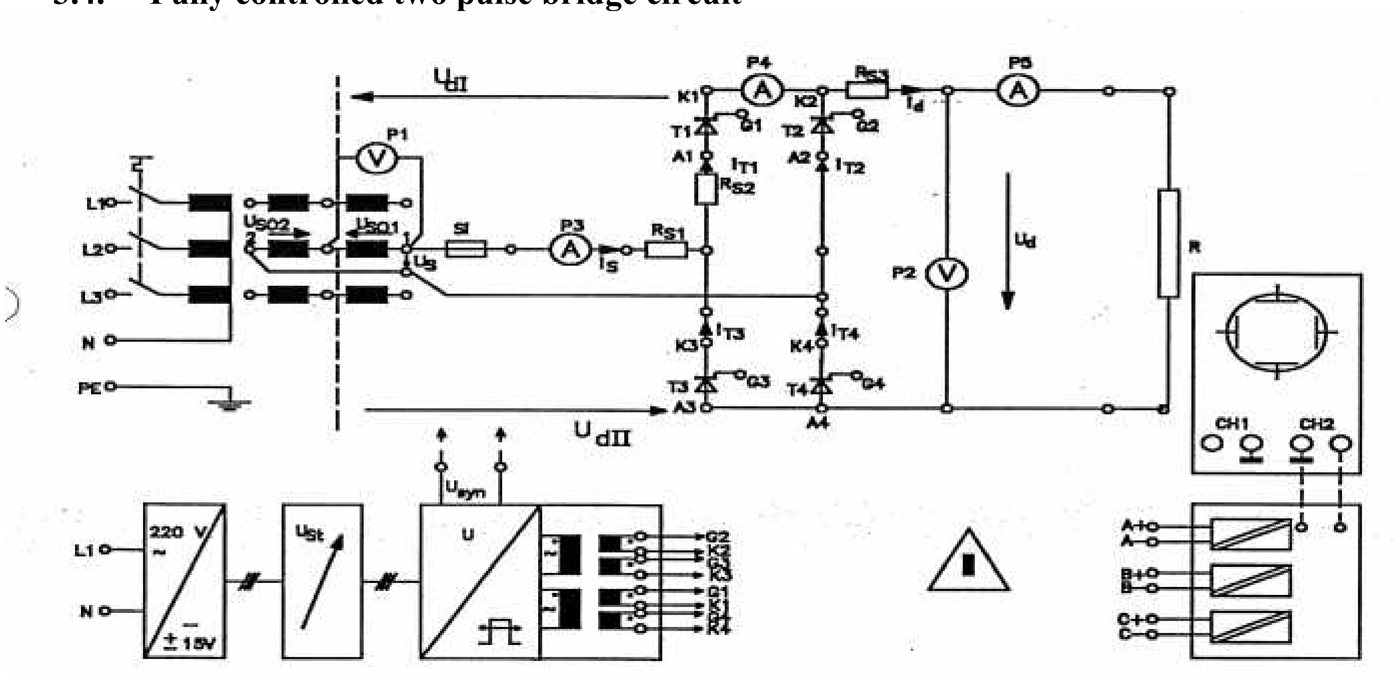


Figure 3 Two pulse bridge controlled rectifier

3.2.5 Ohmic load

- Connect the power circuit as shown in Figure 3, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)

- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 4 provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 4(a)

Table 4(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 4(b) : R = 33 Ω, L = 50 MH

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.2.6 Ohmic-Inductive load

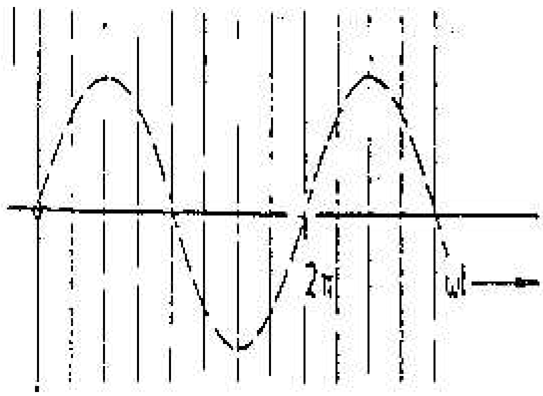
- Connect to the power circuit shown in Figure 1, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 1.
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 4(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

I. Report:

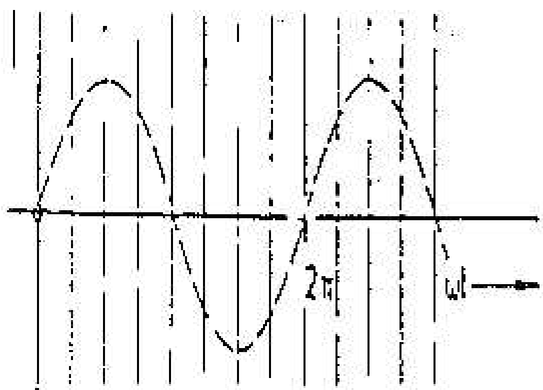
1. Record all your comments and views for the different graphs
2. Draw all the corresponding profiles as well as taking photographs
3. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

Graph 1(a) with ohmic load

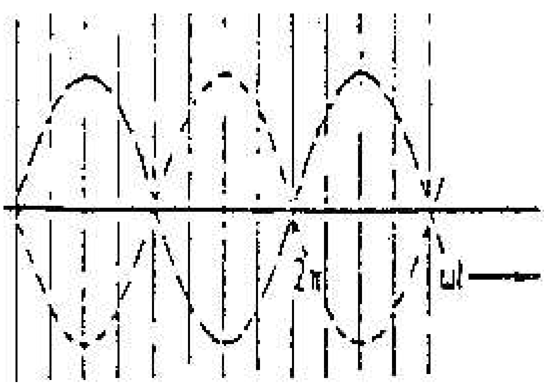
V_s



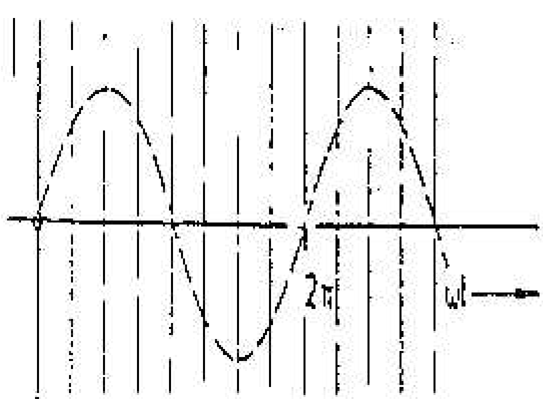
V_o



I_o

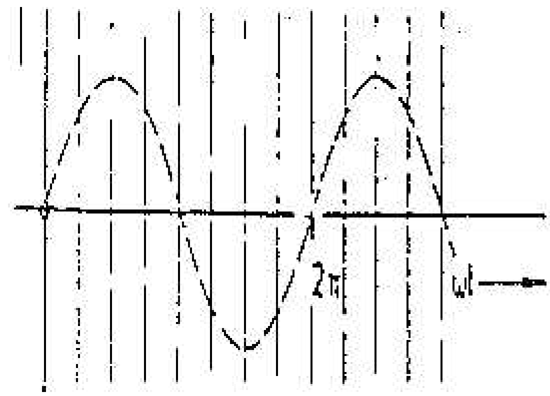


V_{th}

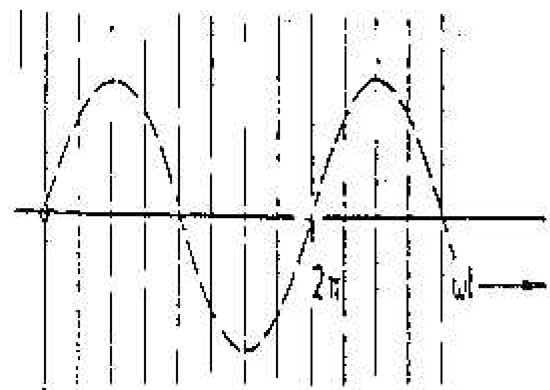


Graph 1(b) with ohmic-inductive load

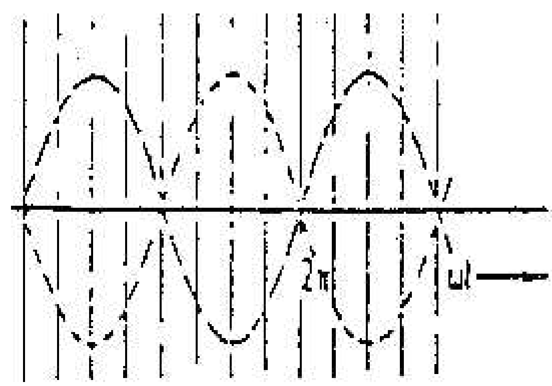
V_s



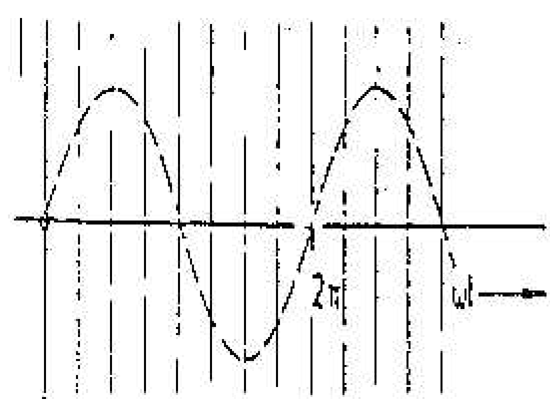
V_o



I_o

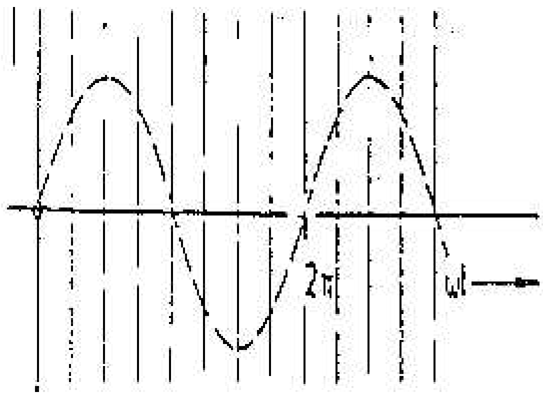


V_{th}

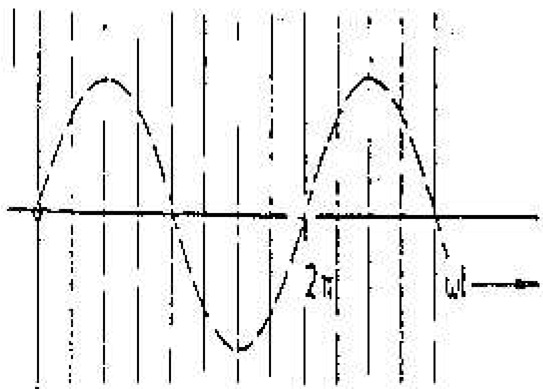


Graph 2(a) with ohmic load

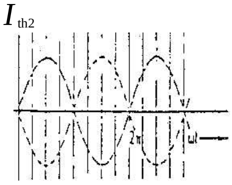
V_s



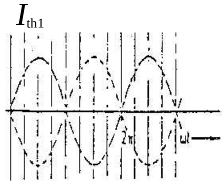
V_o



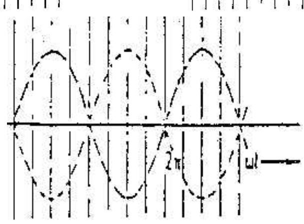
I_{th2}



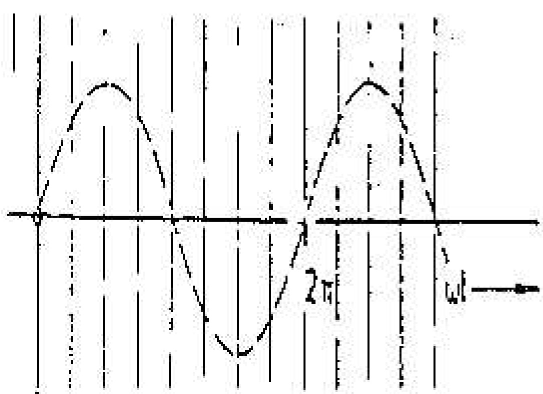
I_{th1}



I_o

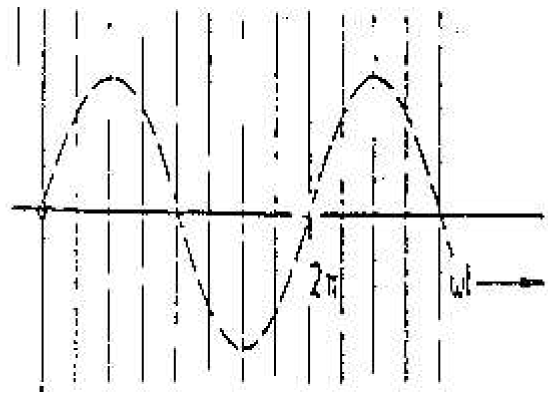


V_{th}

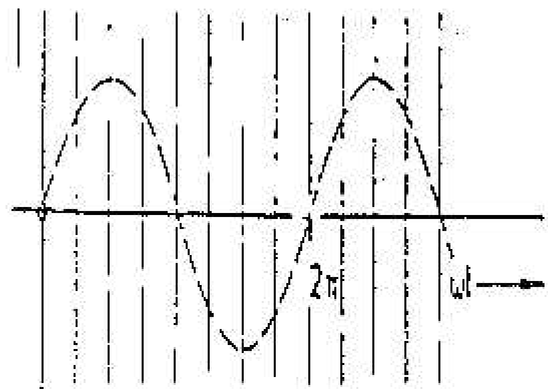


Graph 2(b) with ohmic-inductive load

V_s

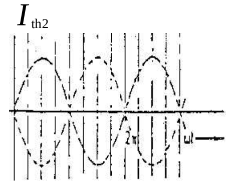


V_o

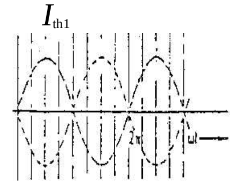


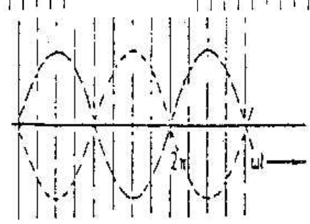
I_o

I_{th2}

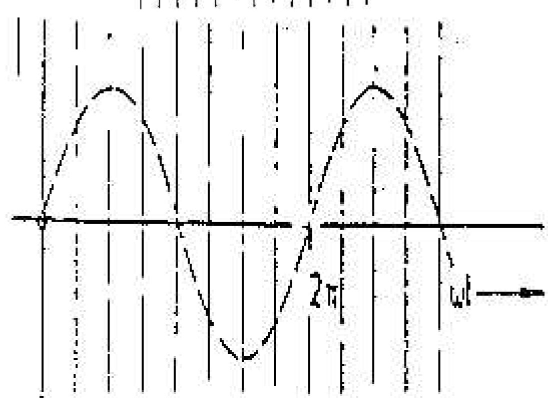


I_{th1}



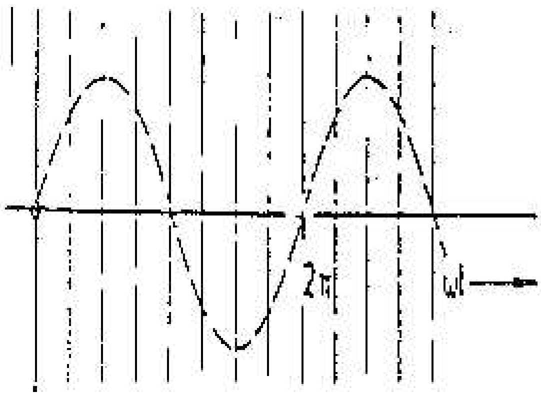


V_{th}

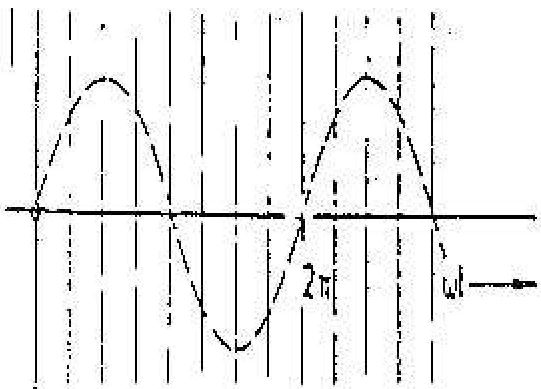


Graph 3(a) with ohmic load

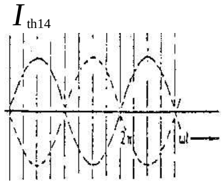
V_s



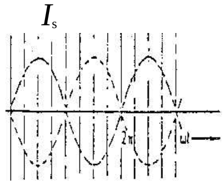
V_o



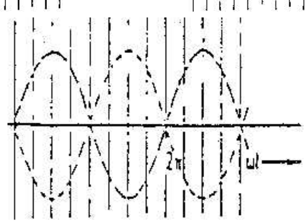
I_{th14}



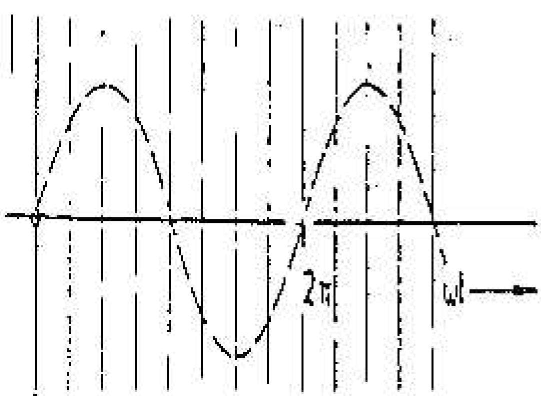
I_s



I_o

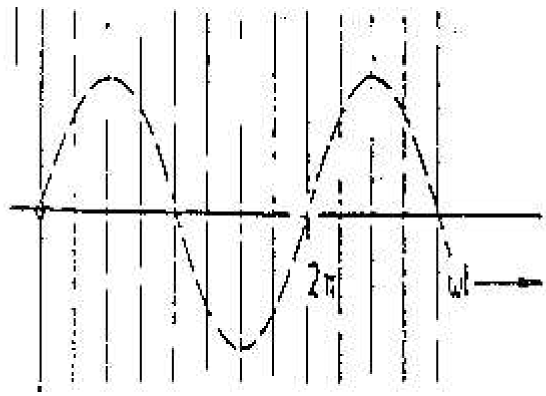


V_{th}

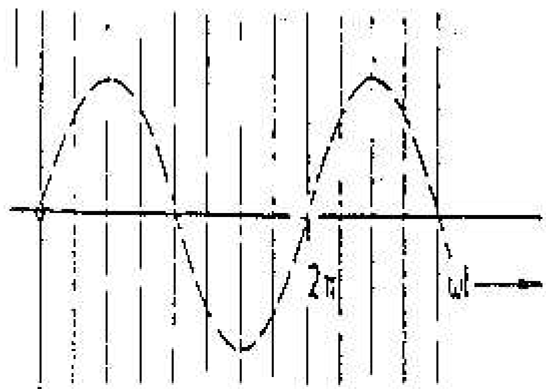


Graph 3(b) with ohmic-inductive load

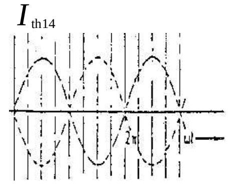
V_s



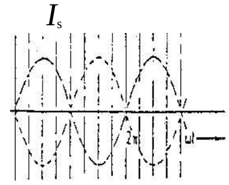
V_o



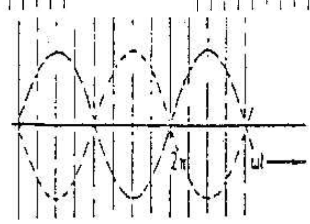
I_{th14}



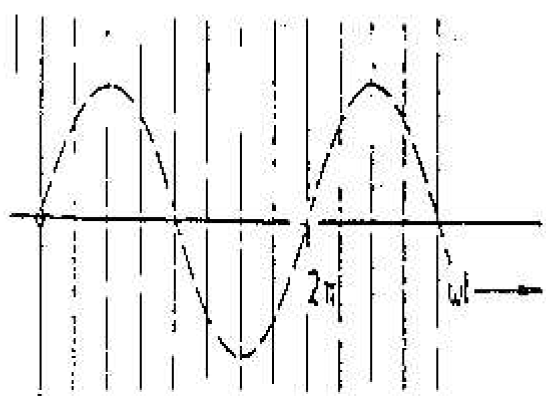
I_s



I_o



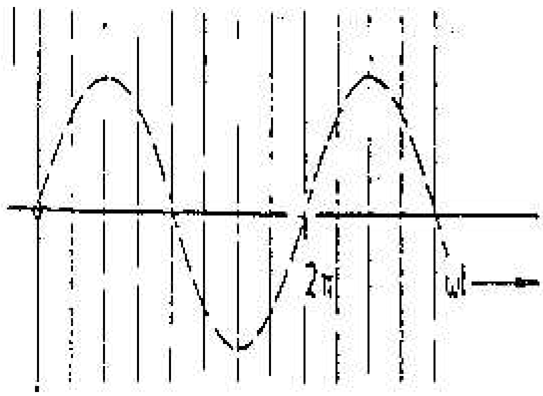
V_{th}



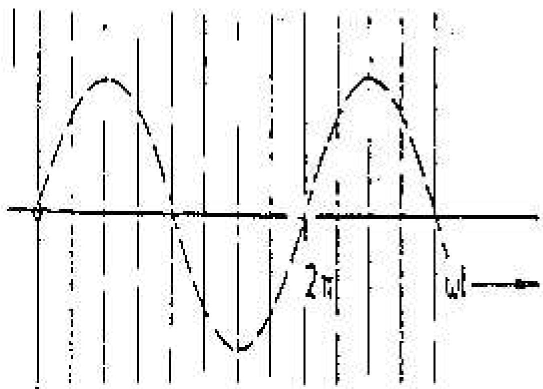
Graph 4(a) with ohmic load	**Graph 4(b) with ohmic-inductive load**

Graph 4(a) with ohmic load

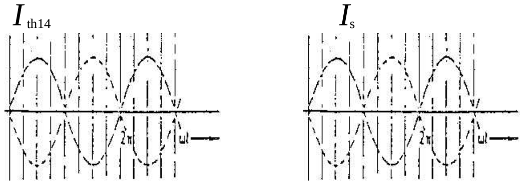
V_s



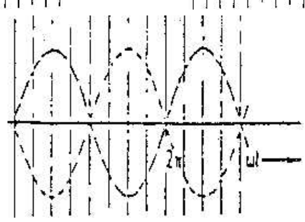
V_o



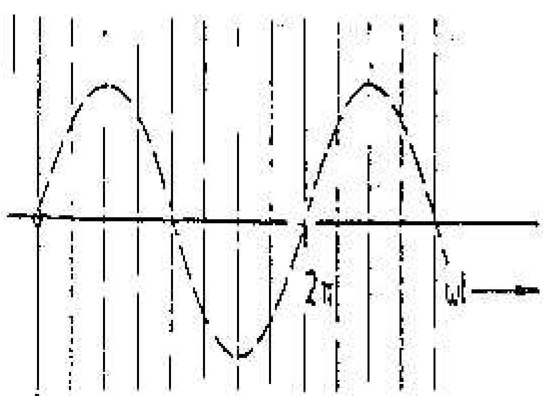
I_{th14} I_s



I_o

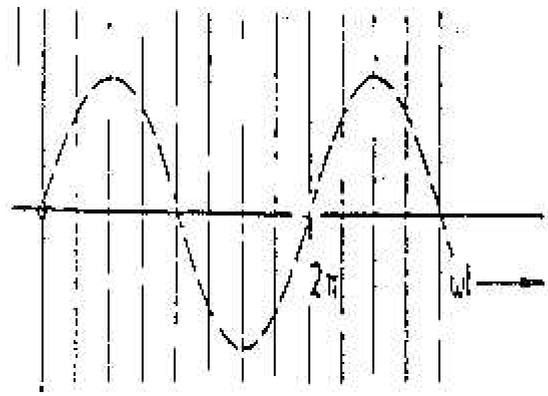


V_{th}

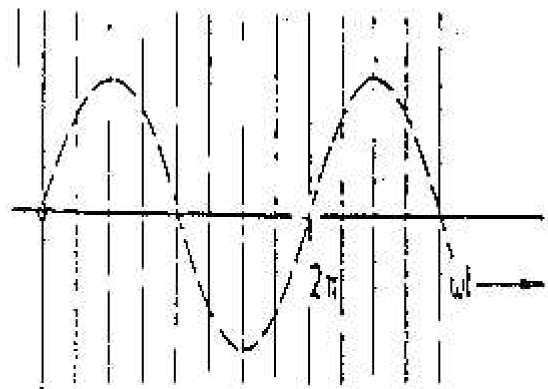


Graph 4(b) with ohmic-inductive load

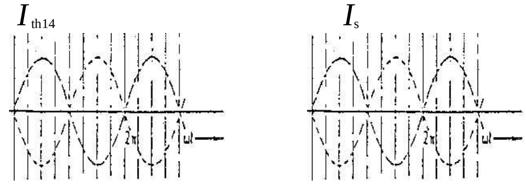
V_s



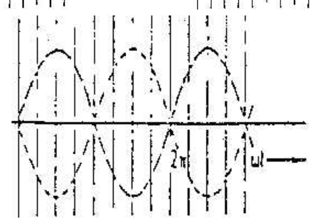
V_o



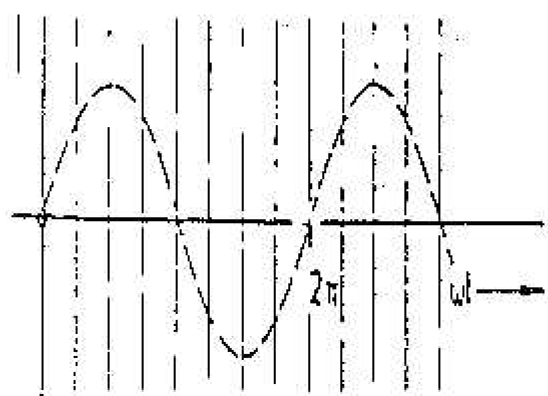
I_{th14} I_s



I_o



V_{th}



UNIVERSITY OF HAIL
ELECTRICAL ENGINEERING DEPARTMENT
POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 4
THREE-PHASE CONTROLLED RECTIFIER

1. Introduction and learning objectives:

In this experiment students will perform experimental tests on a basic AC-DC controlled converter (thyristor rectifier) circuit. And after completing this laboratory work the student will be able to:

- To get acquainted with the operation of a three-phase controlled rectifier with resistive and inductive loads.
- To determine the performance characteristics of the controlled rectifier with its various topologies.
- To Plot and analyze the time profiles for the DC voltage and current, and thyristor voltage.

2. Theoretical background

Ohmic load

The ohmic load represents the simplest and most easily described load variant for a rectifier, since the characteristic curves for a voltage and current at the ohmic load resistance are identical in time and phase.

When the anode voltage is positive, the thyristor is triggered after a delay controlled by the gate angle α. Current flows in the load circuit until the current again drops to zero when the feed voltage crosses zero and the thyristor blocks. The control range equals $\alpha = 0$ to 180° and the angle of current flow $\theta = 180^\circ - \alpha$.

The valve blocks during the negative half-wave. The feed voltage is present in the thyristor as a reverse voltage.

Ohmic-inductive load, series circuit

Ohmic and inductive resistances connected in series are a load type frequently found in practice.

Once again, the inductance prevents any abrupt current changes in the load circuit (direct current). The time profile of the direct current is made up of a sinusoidal continuous current which lags behind the peak voltage by the load phase angle $\varphi = \arctan \omega L/R$ and the equalizing current decaying with the current constant $\tau = L/R$. At the firing point, the instantaneous value of the equalizing current is opposite and equal to the instantaneous value of the sinusoidal continuous current.

The value for the angle of current flow θ lies between those for ohmic and purely inductive loads.

Since the direct current continues to flow as a result of the storage effect of the inductance when the AC feed voltage passes zero, the DC voltage is once again made up of positive and negative voltage/time segments (voltage/angle areas), but of different sizes. The negative areas reduce the mean value of the DC voltage. However, on account of the valve action the direct current and hence the voltage at the ohmic resistance always remain positive.

3. Experimental procedures

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains transformer	726 80
2	thyristors	735 23
3	Power electronics load	735 09
4	Multimeter	

5	Oscilloscope	575 20 Hameg
6	Isolating amplifier	735 26
7	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single-phase full-wave rectifiers. Please follow the following steps carefully:

Supply voltage $U_{so1} = U_{so2} = U_{s03} = 45$ V

Ohmic load R = 33 Ohm

Control unit:

Selection control "control angle" to 30°

Selection control "pulse form" to single pulse

Trigger point limiter:

Setting of rectifier stability limit $\alpha_G = 0°$

Setting of inverter stability limit $\alpha_W = 180°$

Remedial measures:

In order to use the practically relevant control range for the M circuits, only a limited control range U_{St} of the setpoint potentiometer may be used or the control unit must have a trigger point limiter connected.

Experimentally determine the setting values.

e.g. at trigger point limiter
adjust the potentiometer α_G until the control angle $\alpha = 0°$ is reached, with the setpoint potentiometer setting $U_{Stmax} = 10$ V;
additionally set α_W to 180°.

Using the isolation amplifier, display the different time profiles of

the DC voltage	u_d,	channel A
the valve voltage	u_{V1},	channel B and
the thyristor current	i_{T1},	channel C

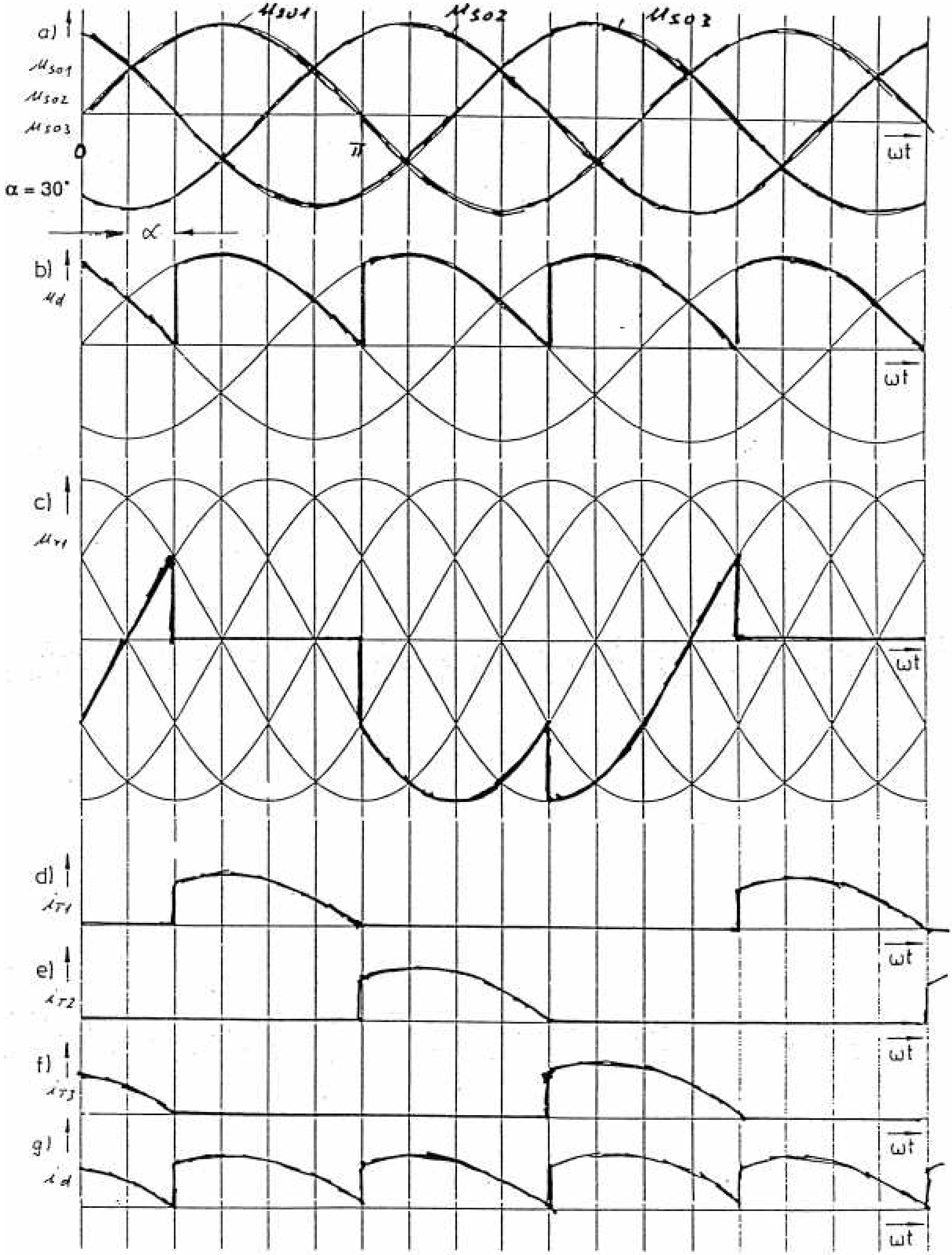
for different control angles and draw the curves in the line diagrams 3.4.2-1/1 to 3.4.2-1/4 for the control angles $\alpha = 0°$, $30°$, $60°$ and $90°$.

Results:

α in degrees	0	30	60	90	120
U_{s01}/V	44.2	45	45	45.3	45.5
$\bar{u}_{d\alpha}$/V	51	43.5	29	14.4	3.3
$U_{d\alpha}$/V	51	47	37	23.2	7.8
$I_{dAV\alpha}$/A	1.4	1.2	0.815	0.4	0.091
$I_{dRMS\alpha}$/A	1.4	1.25	1.05	0.65	0.22
$I_{TAV1\alpha}$/A	0.465	0.4	0.26	0.125	0.026
$I_{TRMS1\alpha}$/A	0.81	0.71	0.59	0.36	0.11

Evaluated results:

$\bar{u}_{d\alpha}/\bar{u}_{d0}$	1	0.85	0.57	0.28	0.065
$I_{dAV\alpha}/I_{dAV0}$	1	0.86	0.58	0.29	0.065



3.4.2-1/2 Controlled three-pulse midpoint circuit with ohmic load, time profiles

a) of the line voltages u_{s01}, u_{s02} and u_{s03}
b) of the DC voltage u_d
c) of the valve voltage u_{v1}
d) of the valve current i_{T1}
e) of the valve current i_{T2}
f) of the valve current i_{T3}
g) of the DC i_d

3.1. Controlled three-pulse midpoint circuit rectifier

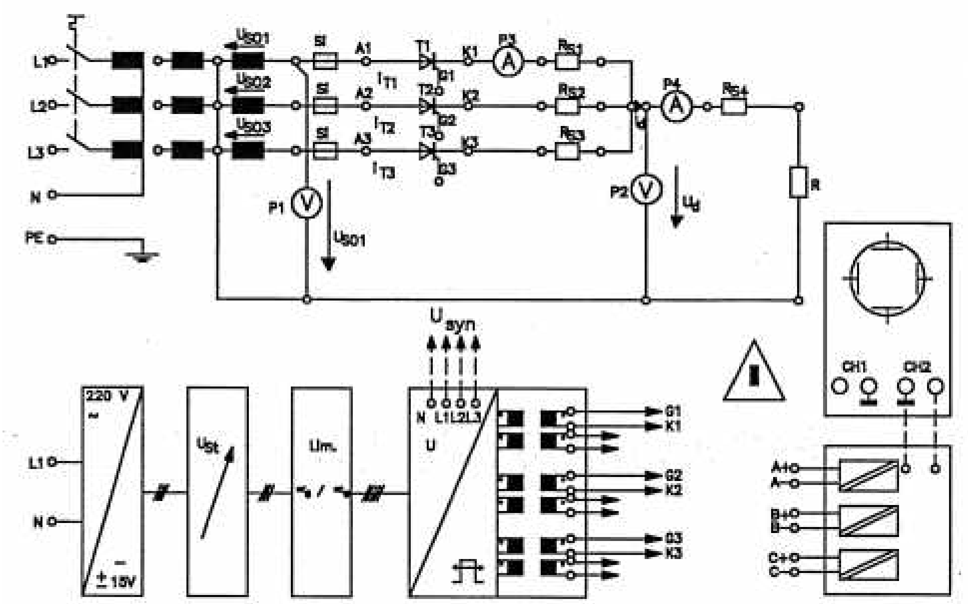


Figure 1 Three pulse controlled rectifier

3.1.1 Ohmic load

- Connect the power circuit as shown in Figure 1, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 1(a) provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 1(a)

Table 1(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 1(b) : R = 33 Ω, L = 50 MH

A	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.1.2 Ohmic-Inductive load

- Connect to the power circuit shown in Figure 1, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 1(b).
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 1(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

3.2. Half controlled six pulse bridge circuit

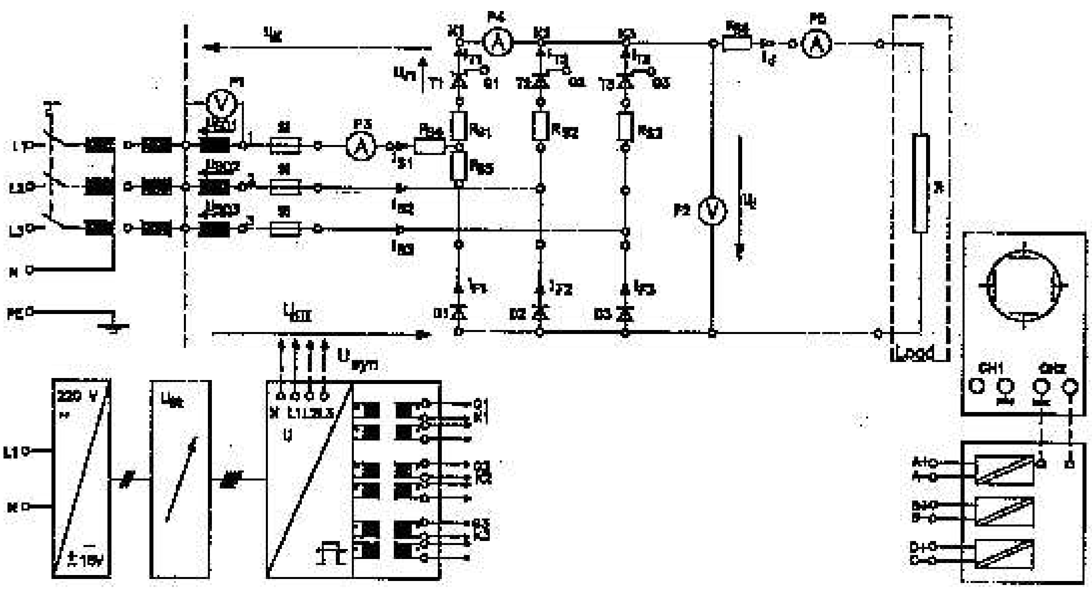


Figure 2 Half controlled six pulse bridge rectifier

Control unit:

Selection control "control angle" to 30°
Selection control "pulse form" to single pulse

Trigger point limiter:

Setting of rectifier stability limit $\alpha_G = 0°$
Setting of inverter stability limit $\alpha_W = 180°$

Oscilloscope:

Time base 5 ms/DIV
Coupling DC
Trigger "mains" (line)
Divide the zero line on the screen, dual-operation, chopped

Time profiles of voltages and currents

3.2.1 Ohmic load

- Connect the power circuit as shown in Figure 2, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 2(a) provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 2(a)

Table 2(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 2(b) : R = 33 Ω, L = 50 MH

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.2.2 Ohmic-Inductive load

- Connect to the power circuit shown in Figure 2, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.

- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 2(b).
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 2(b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

Control unit:

Selection control "control angle" to 30°
Selection control "pulse form" to single pulse

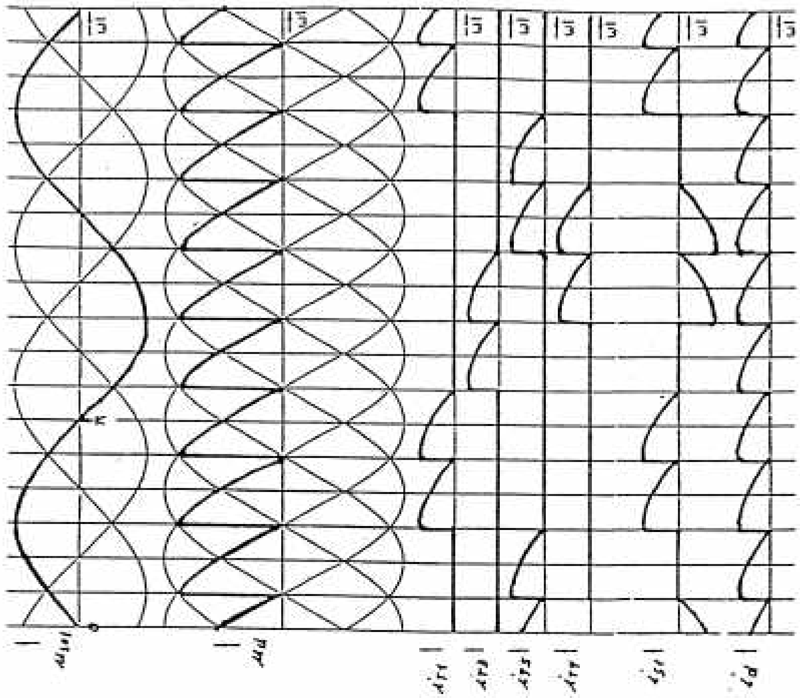
Trigger point limiter:

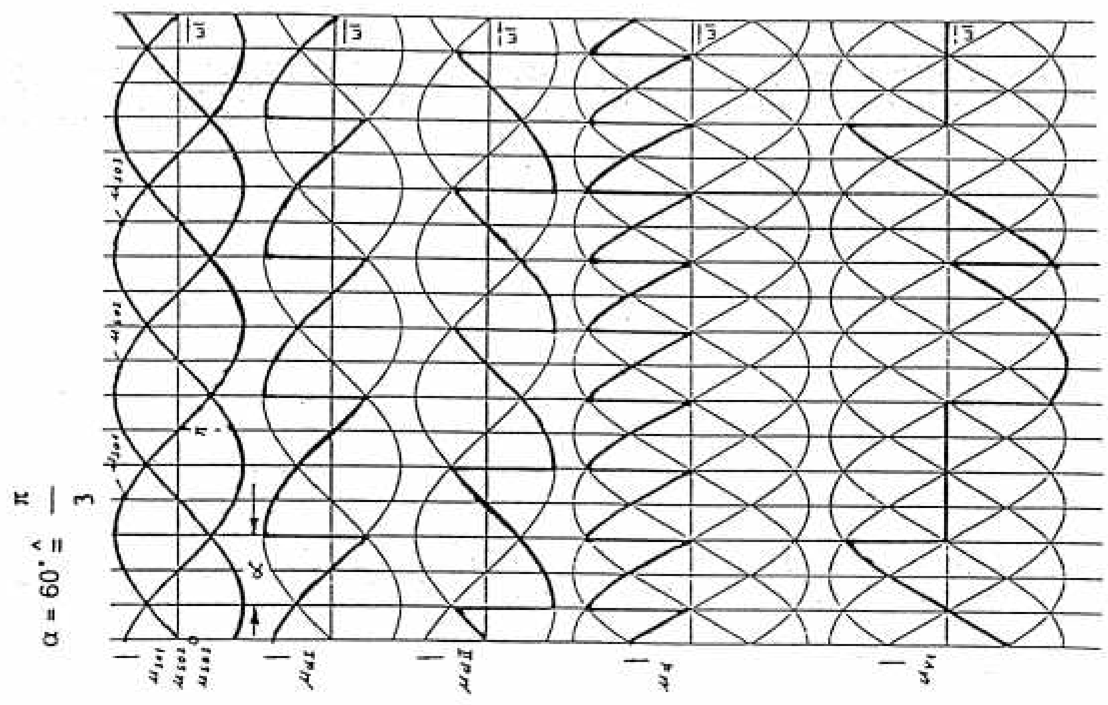
Setting of rectifier stability limit $\alpha_G = 0°$
Setting of inverter stability limit $\alpha_W = 180°$

at various control angles. Draw the curves in fig. 4.6.2-1/1 to 4.6.2-1/4 for the control angles:

$\alpha = 0°, 30°, 60°$ and $90°$

α in degrees	0	30	60	75	90
U_{s01}/V	42.5	43.5	45	45.5	46
$I_{s\alpha}$/A	2.22	1.95	1.16	0.81	0.42
$\bar{u}_{d\alpha}$/V	93	78	42.5	25.7	10.6
$U_{d\alpha}$/V	93	79.2	49.9	34	18.4
$I_{dAV\alpha}$/A	2.71	2.25	1.24	0.735	0.3
$I_{dRMS\alpha}$/A	2.71	2.29	1.41	0.985	0.52
$I_{TAV1\alpha}$/A	0.91	0.79	0.42	0.24	0.1





g. 4.6.2-1/3 Fully-controlled six-pulse bridge circuit, B6C, ohmic load, time profiles

) of the line voltages, u_{s01}, u_{s02} and u_{s03}
) of the component DC voltage u_{dI}
 of the component DC voltage u_{dII}
) of the DC voltage u_d
) of the valve voltage u_{v1}

a2) of the line voltage u_{s01}
b2) of the DC voltage u_d
c2) of the valve current i_{T1}
d2) of the valve current i_{T3}
e2) of the valve current i_{T5}
f2) of the valve current i_{T4}
g2) of the line current i_{s1}
h2) of the DC i_d

KHLIFI

3.3. Fully controlled six pulse bridge circuit

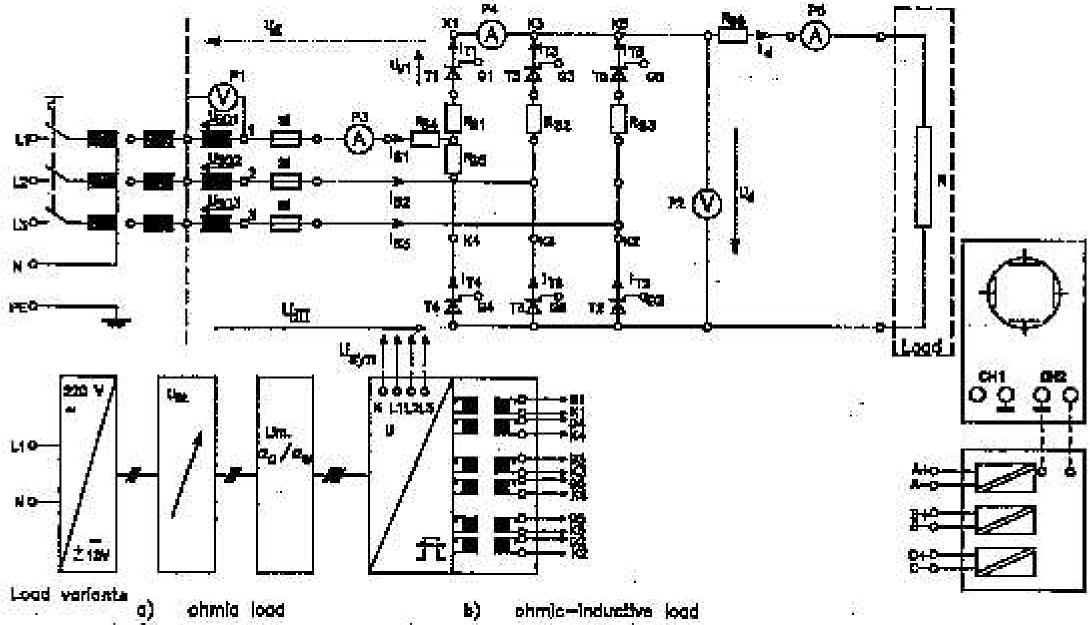


Figure 3 Six pulse bridge controlled rectifier

3.2.3 Ohmic load

- Connect the power circuit as shown in Figure 3, while using the supply voltage one at a time: 45V, 90 V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 3(a) provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (two or more complete cycles of input voltage frequency) of V_s, V_o, I_o , and V_{th}
- Draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph 3(a)

Table 3(a) : R = 33 Ω

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

Table 3(b) : R = 33 Ω, L = 50 MH

α	30	90
V_o_meas (v)		
V_o_calc (v)		
I_o (A)		
V_{th} (thyristor)(v)		

3.2.4 Ohmic-Inductive load

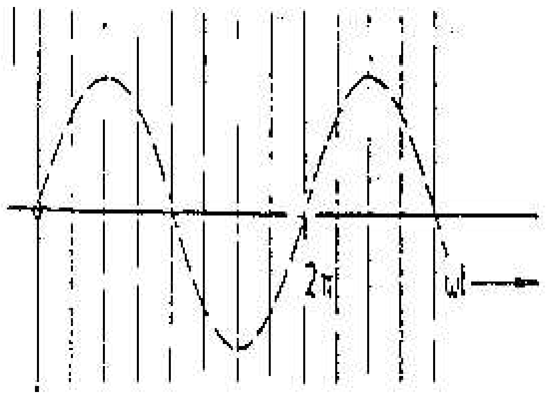
- Connect to the power circuit shown in Figure 3, a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_{th}.
- Insert the measured values into Table 3(b).
- With the aid of the isolation amplifier and the oscilloscope visualize and draw successively the time profile of the supply voltage, DC voltage, load current, thyristor voltage in graph (b)
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

I. Report:

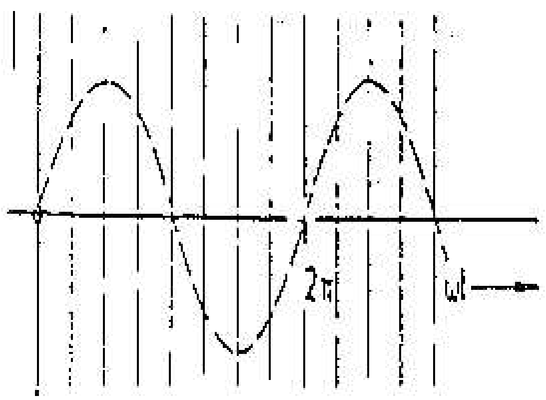
1. Record all your comments and views for the different graphs
2. Draw all the corresponding profiles as well as taking photographs
3. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

Graph 1(a) with ohmic load

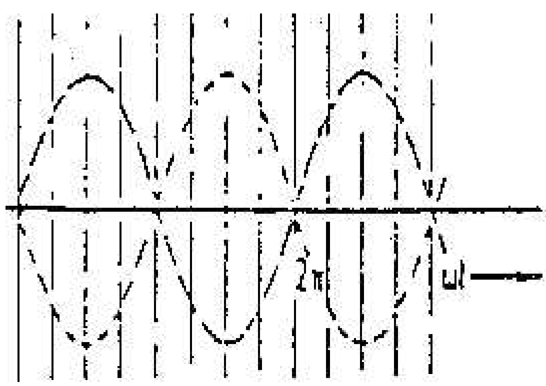
V_s



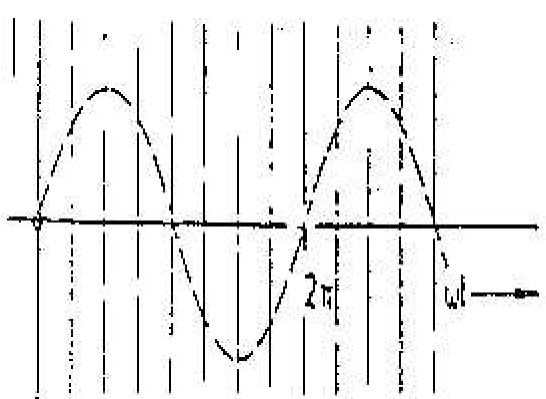
V_o



I_o

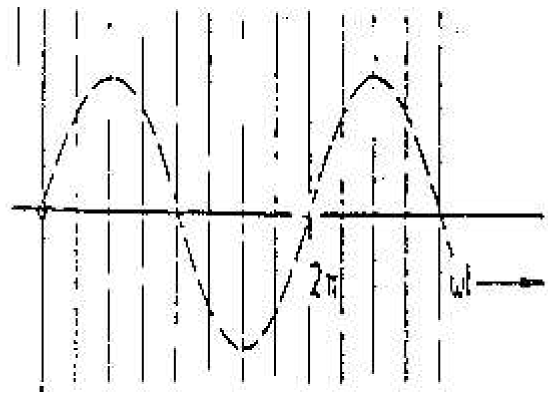


V_{th}

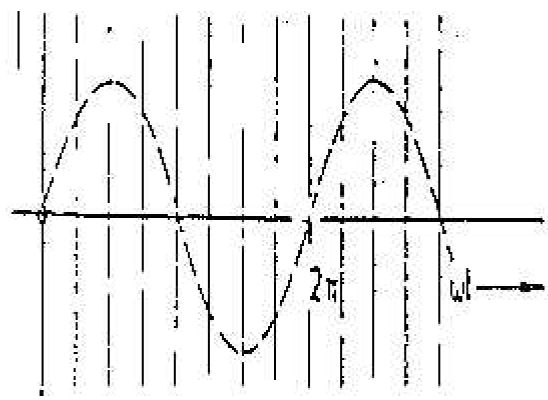


Graph 1(b) with ohmic-inductive load

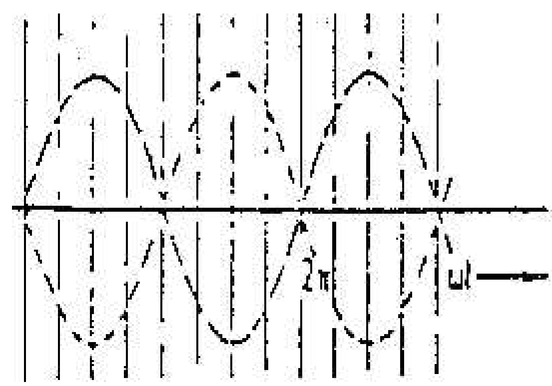
V_s



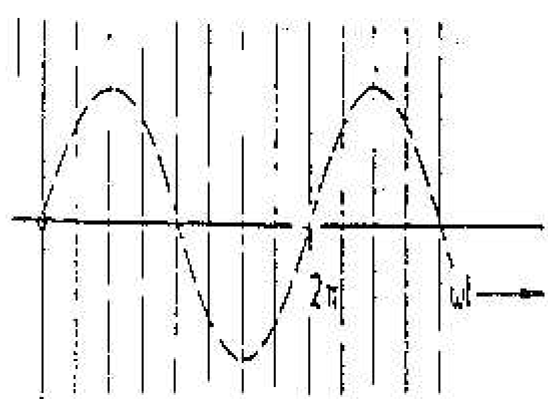
V_o



I_o

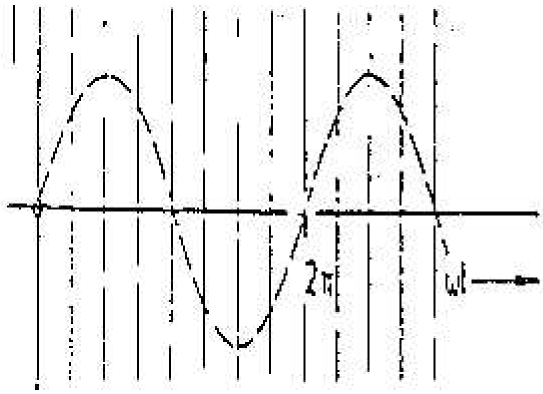


V_{th}

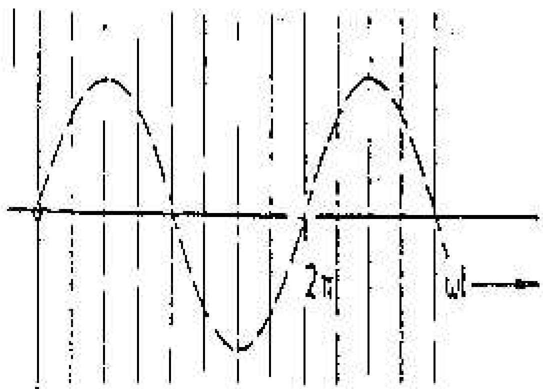


Graph 2(a) with ohmic load

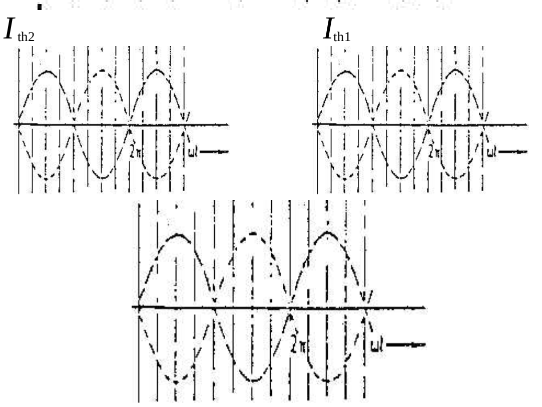
V_s



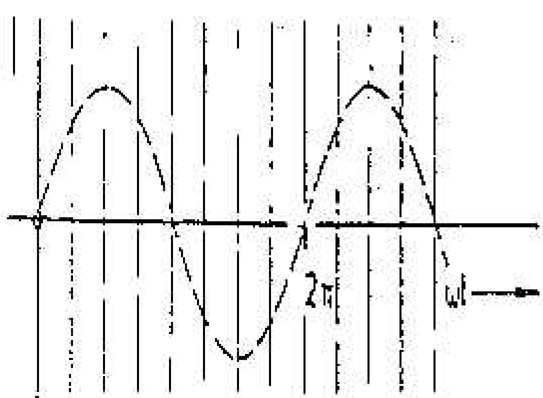
V_o



I_o

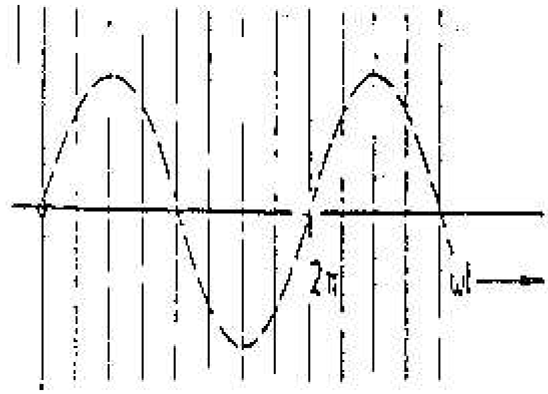


V_{th}

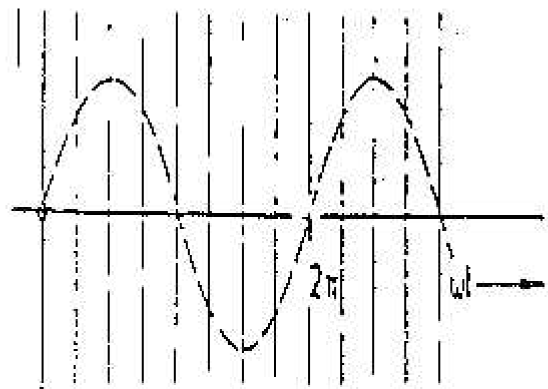


Graph 2(b) with ohmic-inductive load

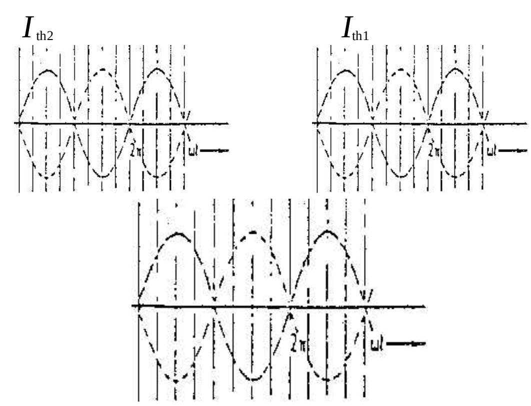
V_s



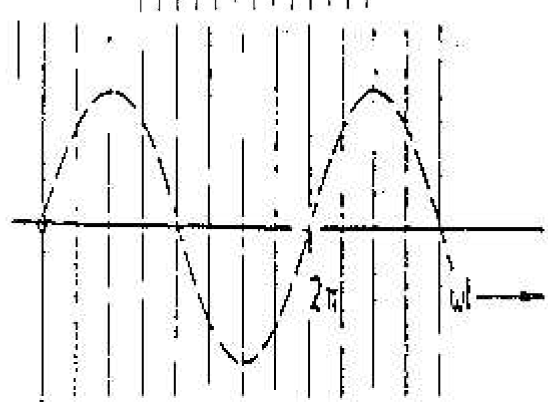
V_o



I_o

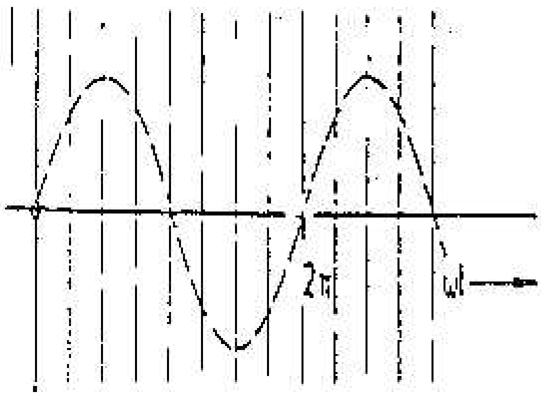


V_{th}

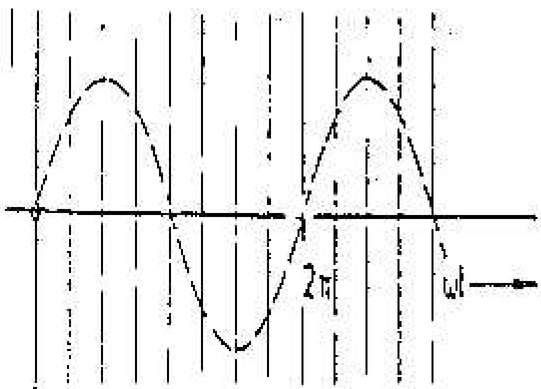


Graph 3(a) with ohmic load

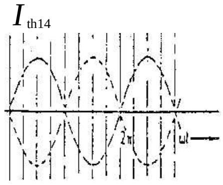
V_s



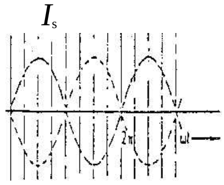
V_o



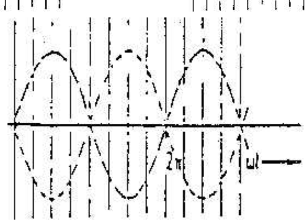
I_{th14}



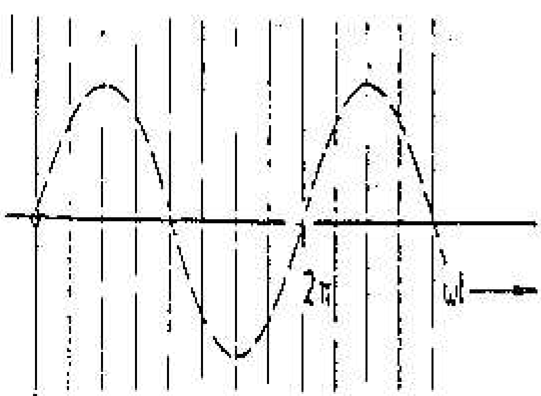
I_s



I_o

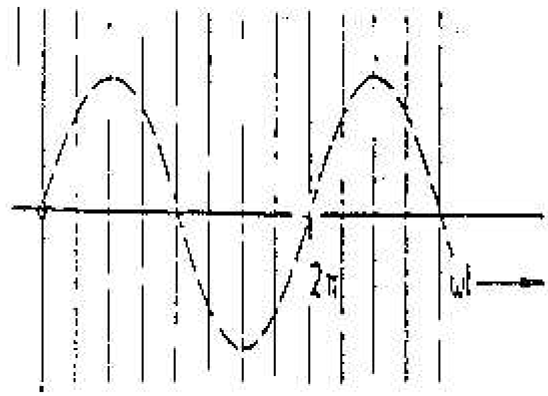


V_{th}

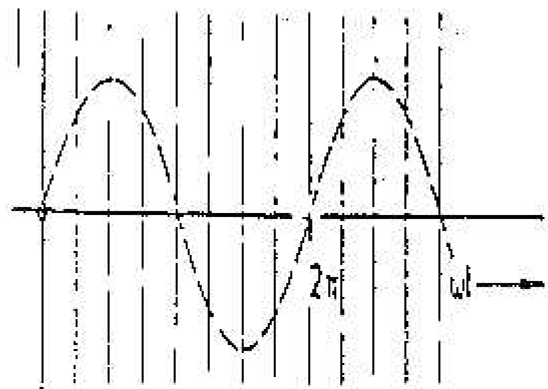


Graph 3(b) with ohmic-inductive load

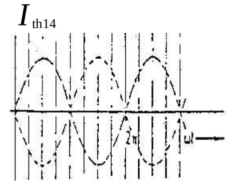
V_s



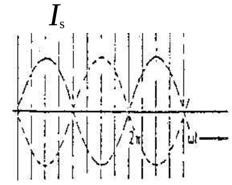
V_o



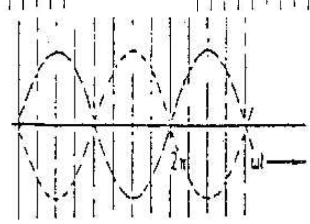
I_{th14}



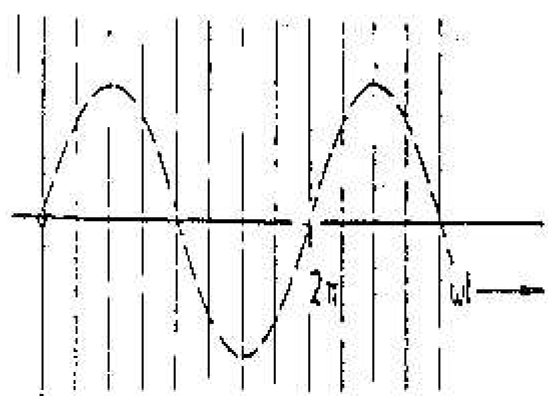
I_s



I_o



V_{th}



UNIVERSITY OF HAIL
ELECTRICAL ENGINEERING DEPARTMENT
POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 5
AC STATIC CONVERTERS

1. Introduction and learning objectives

AC-AC converters are mainly employed as controlling power in AC circuits. One of the solid-state switching devices, the triac, will be used in the construction of the AC-AC converter. This converter is also a good example in understanding the behavior of phase-controlled AC choppers. The student will also be presented with single and three phase AC controllers with different load variants and gate angles.

In this experiment students will perform experimental tests on a basic AC-AC controller circuit. And after completing this laboratory work the student will be able to:

- To get acquainted with the operation of a single-phase AC converter with resistive and inductive loads.
- To learn the mode of operation of a Triac AC converter with resistive and inductive loads.
- To determine the performance characteristics of the AC converter with its various topologies.
- To Plot and analyze the time profiles for the AC voltages and currents, and thyristor voltage.

2. Principle mode of operation

AC switches and controllers conduct electrical current in both directions. However, since semiconductor valves only conduct electrical current in one direction, namely the forward direction, two valves must always be connected back to back.
Static converters with pairs of antiparallel arms are referred to as AC static converters.
Since the current in AC circuit becomes zero and reverses its direction after every half cycle, the thyristors must be alternately trigerred at regular intervals.
Alternating current cannot only be switched on and off but also continuously controlled using pairs of antiparallel arms such as phase angle control.
AC-to-AC converters have a wide range use in the industry. Applications such as light dimmers, AC motor controllers, heat controllers, uninterruptable power supplies are some examples for AC-AC converters. There are many different types of AC converters but basically, they produce an output voltage at the same frequency as input AC signal with variable amplitudes. These converters are also known as AC choppers.

There are many different methods AC choppers use in producing variable AC output voltages. In this experiment students will construct a **Single-Phase Full-Wave Controller (Phase Controlled AC Chopper)** with resistive load. Figure 1 shows the basic phase-controlled AC chopper with resistive load.
The anti-parallel connection of SCR thyristors gives the opportunity to control current in both positive and negative directions. This switch combination is a called bidirectional switch. You have seen in the first experiment that the triac has this bidirectional property. The anti-parallel SCR thyristors in Figure 1 can be replaced by a triac, but for simplicity of understanding thyristors will be used while giving general information. Other types of bidirectional switches can be composed by thyristors or transistors. Students must make a quick research about bidirectional switches before attending the laboratory.

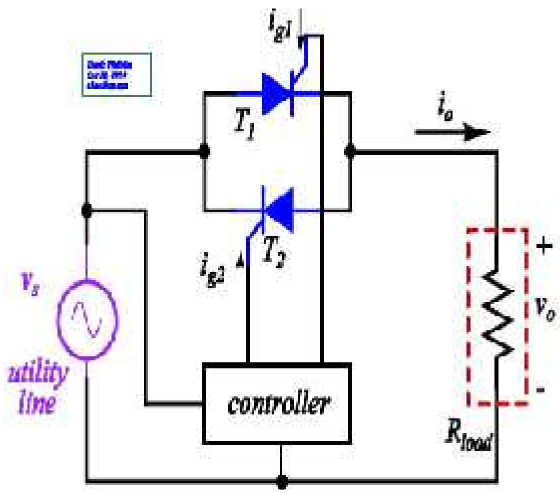


Figure 1. Phase-controlled AC chopper with resistive load.

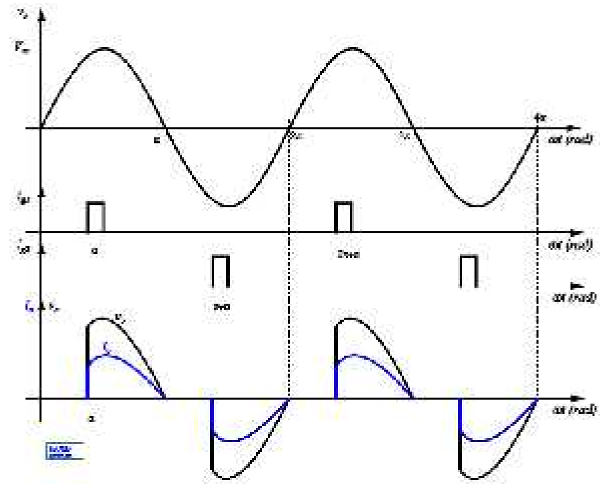


Figure 2. Waveforms of input voltage (v_s), output voltage (v_o), output current (i_o) and triggering signals (i_{g1}) and (i_{g2}).

Voltage v_s is a sinusoidal input to the basic circuit shown in Figure 1 (it can be considered as the mains 220V_{RMS}, 50 Hz). During the positive half cycle of input voltage, the power flow is controlled by varying the delay angle of the thyristor T_1; and thyristor T_2 controls the power flow during the negative half cycle. The firing pulses of T_1 and T_2 are kept 180º (π radians) apart. The waveforms for the input voltage, output voltage and gating signals for T_1 and T_2 are shown in Figure 2.

If $v_s = V_m \sin(\omega t)$ is the input voltage and the delay angles of thyristors T_1 and T_2 are equal ($\alpha_1 = \alpha_2 = \alpha$) the RMS output voltage (V_o) can be found from:

$$V_{o,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}[V_m \sin(\omega t)]^2 d(\omega t)}$$

$$V_{o,rms} = \frac{V_m}{\sqrt{2}}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin(2\alpha)}{2\pi}} = V_{s,rms}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin(2\alpha)}{2\pi}}$$

By varying α from 0 to π, $V_{o,rms}$ can be varied from $V_{s,rms}$ to 0 as can be clearly seen from Figure 3 (angle α must be in radians when substituting in the above equation). Note that the range of triggering control angle for phase controlled AC chopper with resistive load is:

$$0 \le \alpha \le \pi$$

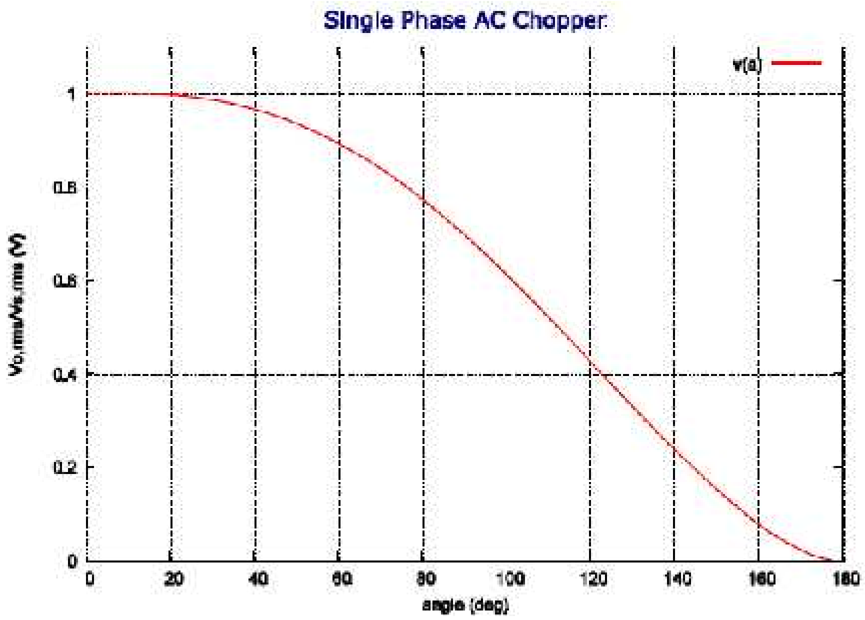


Figure 3. Variation of $V_{o,rms}$/ $V_{s,rms}$ as a function of firing angle α

3. Experimental procedures

3.1 Equipments used:

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains isolating transformer	726 80
2	Thyristors	735 03
3	Triac	735 04
4	Power electronics load	735 09
5	Control unit	735 12
6	Set point potentiometer	734 02
7	Multimeter	
8	Oscilloscope (Hameg)	575 20
9	Isolating amplifier	735 26
10	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single and three-phase AC controller. Please follow the following steps carefully:

3.2 Single phase AC controller

3.2.1 Ohmic load

- Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(a) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(a) for two values of firing angles 45 and 135.

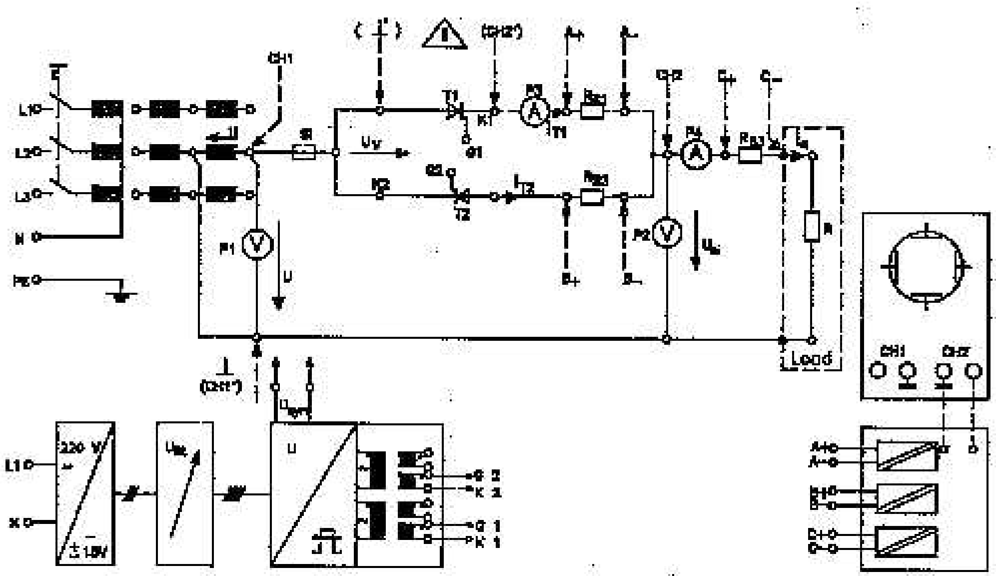


Figure 1 Single phase AC Voltage controller

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upper position)
- Set the selector switch "**pulse shape**" to individual pulse degrees (switch in lower position)

Table 1(a) : R = 33 Ω

α in degrees	0	30	45	90	135
U_α/V					
$I_{TAV1\alpha}$/V					
$U_{TRMS1\alpha}$/V					
I_α/A					

Measured values

α in degrees	0	30	60	90	120	150	180
U_α /V	41.0	41.2	37.5	29.7	18.5	7	0
$I_{TAV1\alpha}$/A	0.49	0.465	0.38	0.245	0.124	0.03	0
$I_{TRMS1\alpha}$/A	0.774	0.766	0.70	0.535	0.34	0.125	0
I_α /A	1.12	1.1	1.0	0.79	0.495	0.185	0

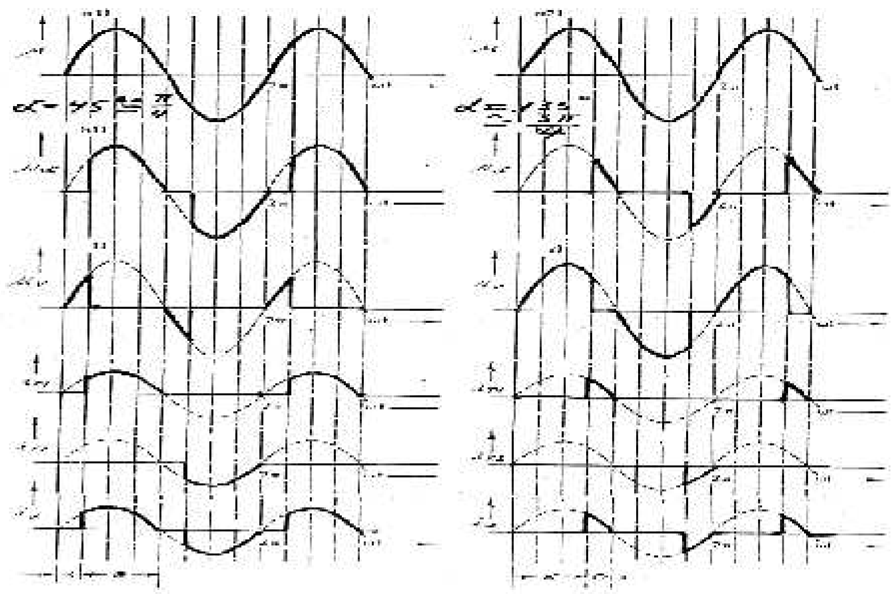


Figure 2.3.2-2 AC controller with ohmic load
a) Time profile of the AC load voltage
b) Time profile of the load voltage
c) Time profile of the valve voltage
d) Time profile of the thyristor current I_{T1}
e) Time profile of the thyristor current I_{T2}
f) Time profile of the load current I_α

3.2.2 Ohmic-Inductive load

- Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(b) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upper position)
- Set the selector switch "**pulse shape**" to pulse train (switch in upward position)
- The theoretical load phase angle for this experiment is about 30°

Table 1(b) : R = 33 Ω, L = 50 MH

α in degrees α=φ=30	30	90	120	180
U_α/V				
$I_{TAV1\alpha}$/V				
$U_{TRMS1\alpha}$/V				
I_α/A				

Measured values

α in degrees α = φ ≈	30°	60	90	120	150	180
U_α/V	43.5	41	34	22.5	10	0
$I_{TAV1\alpha}$/A	0.38	0.33	0.214	0.096	0.022	0
$I_{TRMS1\alpha}$/A	0.61	0.545	0.40	0.21	0.075	0
I_α/A	0.88	0.79	0.58	0.31	0.097	0

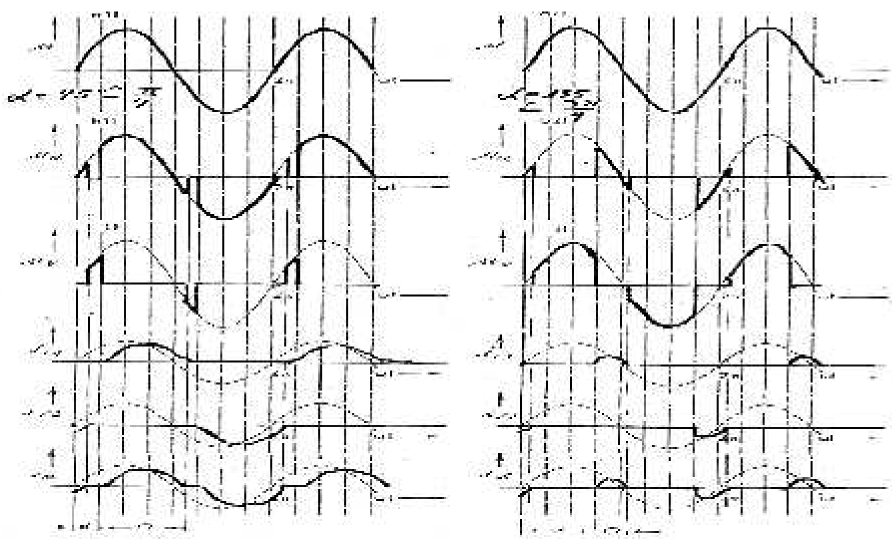


Figure 2.3.2.6 AC controller with ohmic-inductive load, series connection
a) Time profile of the AC load voltage
b) Time profile of the load voltage
c) Time profile of the valve voltage
d) Time profile of the thyristor current i_{T1}
e) Time profile of the thyristor current i_{T2}
f) Time profile of the load current i_L

3.3 Triac AC controller

Test set up:

- ✓ Make the correct panel arrangement for the experiment
- ✓ Use the circuit shown in Figure 2
- ✓ Connections as specified but connect one output of the upper and lower pulse transformers to the control units in parallel, ensuring correct polarity, and also the control line of the triac.
- ✓ Use a supply voltage of 45 V and a a resistive load of 33 Ω

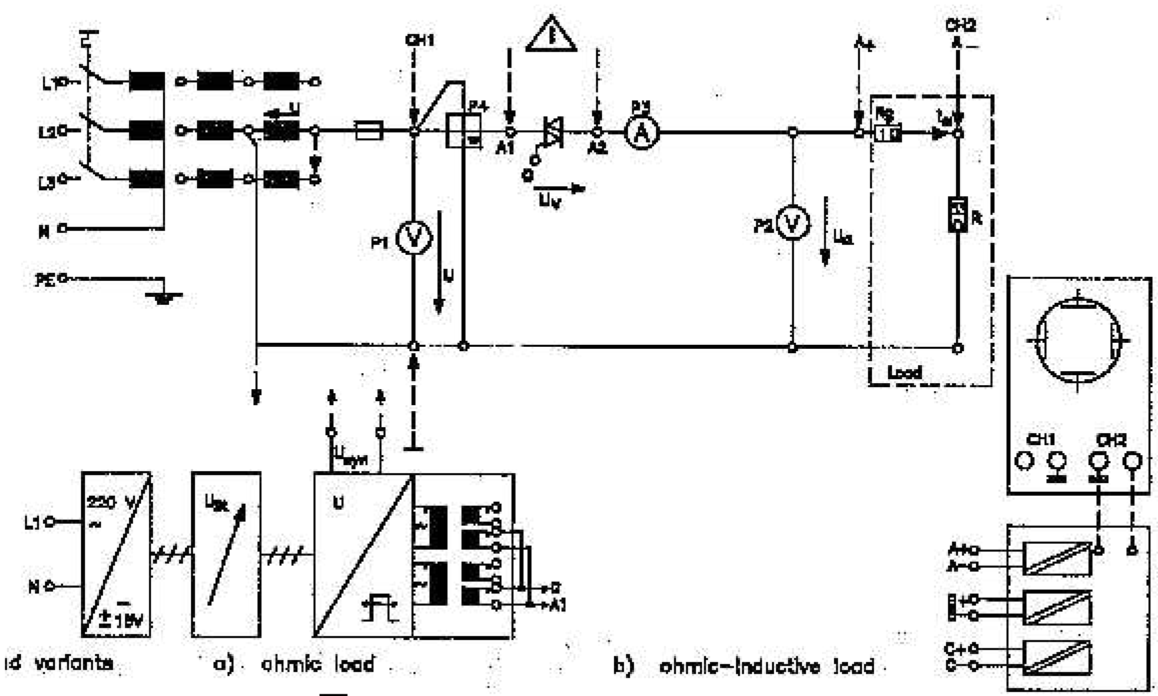


Figure 2 Triac AC controller

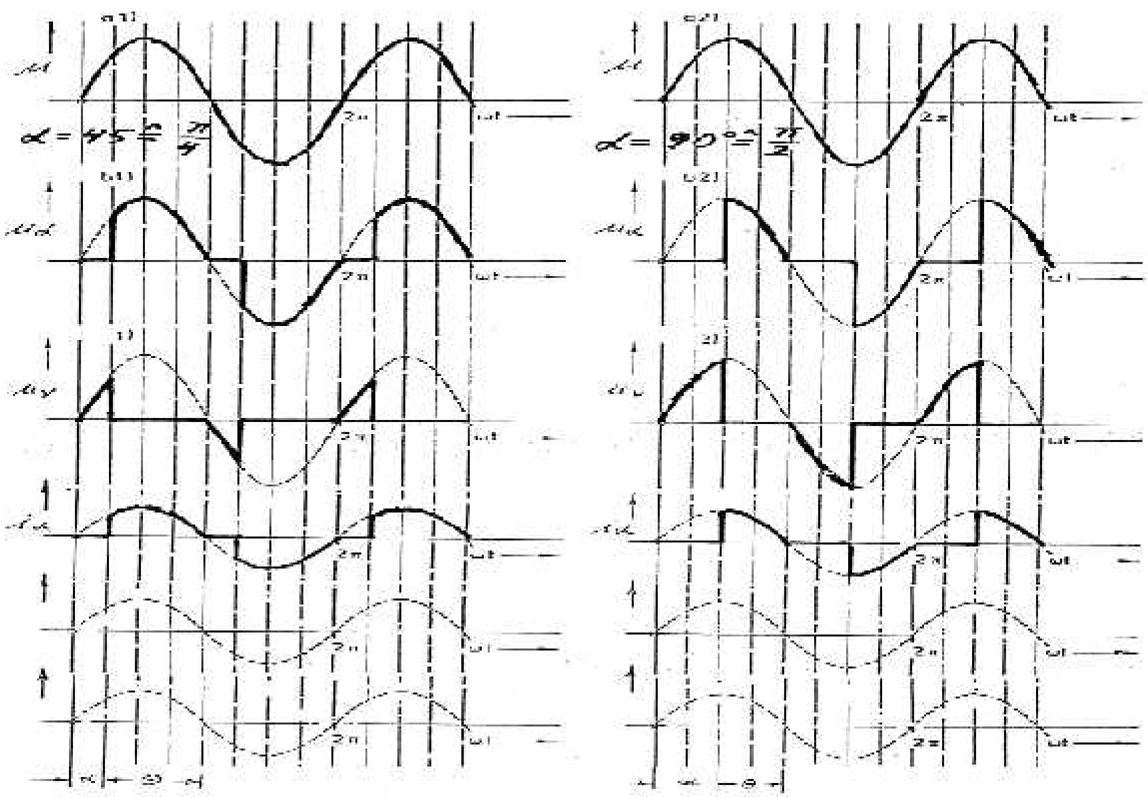
3.2.1 Triac AC controller with ohmic load

- ➢ Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel).
- ➢ Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(b) provided below.
- ➢ After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- ➢ Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- ✓ Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- ✓ Set the selector switch "**gate angle**" to zero degrees (switch in upward position)
- ✓ Set the selector switch "**pulse shape**" to single pulse degrees (switch in downward position)
- ✓ Connect the isolating amplifier to the oscilloscope for recording the time profiles of the voltages and currents and record the results for 2 gate angles (45° and 90°).
- ✓ Min alpha 30, For two values 45 et 90

Table 1(a) : R = 33 Ω

α in degrees	0	30	45	90	135
U_α/V					
$I_{TAV1\alpha}$/V					
$U_{TRMS1\alpha}$/V					
I_α/A					



2.3.2-9 Triac-AC controller with ohmic load
a) Time profile of the AC feed voltage
b) Time profile of the load voltage
c) Time profile of the valve voltage
d) Time profile of the load current

α in degrees	0	30	60	90	120	150	180
U_α/V	45	43	40	28.5	16.5	4.5	0
I_α/A	1.15	1.14	1.05	10.78	0.48	0.17	0
P_α/W	50	48	41.5	22	7.5	-	0

Evaluation results:

$\frac{I_\alpha}{I_0}$	1	0.99	0.91	0.68	0.42	0.15	0
$\frac{P_\alpha}{P_0}$	1	0.96	0.83	0.44	0.15	-	0
S_α/VA	51.8	51.3	47.3	35.1	21.6	-	0
λ	0.95	0.94	0.88	0.63	0.35	-	-

Calculated (theoretical values):

$\frac{I_\alpha}{I_0}$	1	0.985	0.897	0.707	0.442	0.17	0
$\frac{P_\alpha}{P_0}$	1	0.97	0.81	0.5	0.195	0.029	0

Table 2.3.2-4 Measured values, evaluation results and theoretical values for the experiment triac AC controller with ohmic load

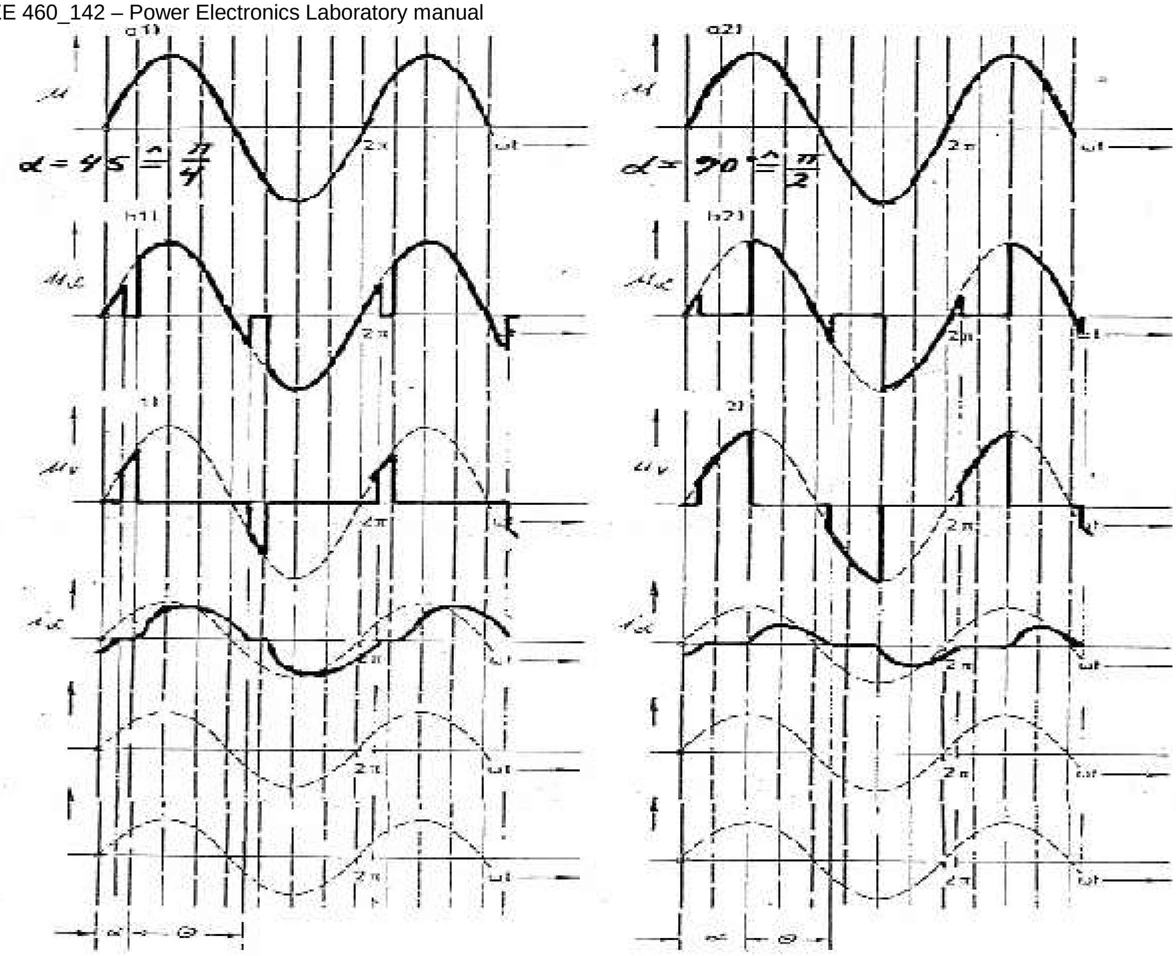
3.2.2 Triac AC controller with ohmic-inductive load

Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_v, the load current I_a, Write down the measured values to the Table 1(a) provided below.

- Connect the power circuit as shown in Figure 2, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel).

- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 2(b) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- ✓ Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- ✓ Set the selector switch "**gate angle**" to zero degrees (switch in upward position)
- ✓ Set the selector switch "**pulse shape**" to single pulse (switch in downward position)
- ✓ Connect the isolating amplifier to the oscilloscope for recording the time profiles of the voltages and currents and record the results for 2 gate angles (45^o and 90^o).
- ✓ Min alpha 30, For two values 45 et 90



ure 2.3.2-11 Triac-AC controller with ohmic-inductive load
a) Time profile of the AC feed voltage
b) Time profile of the load voltage
c) Time profile of the valve voltage
d) Time profile of the load current

Measured values

α in degrees $\alpha = \varphi =$	30	60	90	120	150	180
U_α/V	44.2	41.8	34	22.5	9.8	-0
I_α/A	0.9	0.81	0.585	0.32	0.1	0
P_α/W	34	28	15.5	5	-	0

Evaluation results:

$\frac{I_\alpha}{I_\varphi}$	1	0.9	0.65	0.36	0.11	0
$\frac{P_\alpha}{P_\varphi}$	1	0.82	0.46	0.15	-	0
S_α/VA	39.8	35.8	25.9	14.1	4.4	0
λ	0.85	0.78	0.6	0.35	-	-

Table 2.3.2-4 Measured values and evaluation results for the experiment triac AC controller with ohmic load

Report:

1. Record all your comments and views for the different graphs
2. Draw all the corresponding profiles as well as taking photographs
3. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

3.3 Three phase AC controller

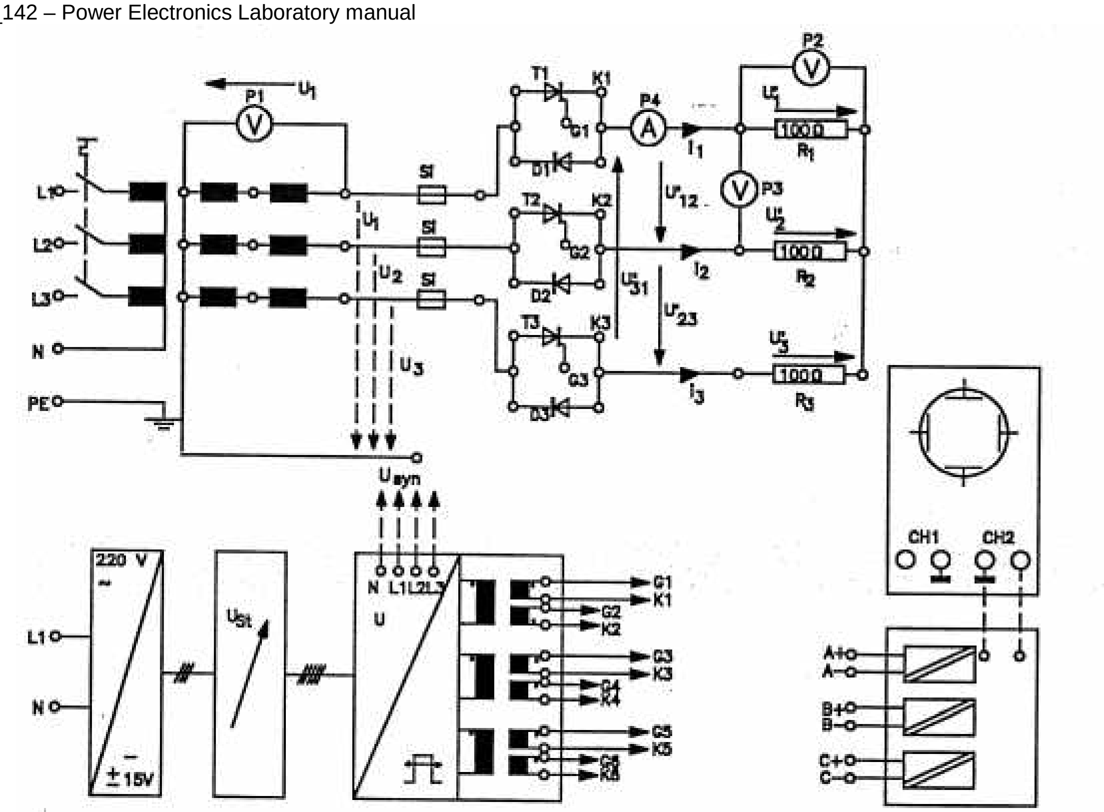
The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains transformer	726 80
2	Silicon diodes	735 02
3	Power electronics load	735 09
4	Multimeter	
5	Oscilloscope	575 20 Hameg
6	Isolating amplifier	735 26
7	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single-phase full-wave rectifiers. Please follow the following steps carefully:

1	Mains isolating transformer	726 80
3	Fuse, superfast acting	735 18
3	Silicone diode	735 02
6	Thyristor	735 03
1	Load power electronics	735 09
1	Power supply unit, +/- 15 V	726 86
1	Control unit, six-pulse	735 13
1	Setpoint potentiometer	734 02
1 (2 if necessary)	Voltmeter/ammeter	727 10
1	Multimeter, zero point left	727 16
1	Oscilloscope, e.g. HM-204-2	575 20
1	Isolating amplifier	735 26
3	Shunt, 1 Ohm	735 22
2	Probe	575 231
(As required)	Safety connecting cable	500 851
(As required)	Safety bridging plug	501 511



3.3.1 Ohmic load

Connect the synchronizing voltage for the control unit (2V1 to U_{syn} and 2V3 to 0 V).

Connect control voltage

Connect setpoint potentiometer output to input U_{St} of the control unit, control voltage range 0 to 10 V (bridge connector in middle position)

Control unit:

Set selector switch "gate angle" to zero degrees (switch in upper position)
Set selector switch "pulse shape" to individual pulse (switch in lower position)

Isolating amplifier (for recording the time profile of the currents)

Channel A: thyristor current i_{T1},
attenuator/amplifier 1,
variable control 1

Control unit:

Set selector switch "gate angle" to zero degrees (switch in downward position)
Set selector switch "pulse rate" to pulse train (switch in upward position)

- Connect the power circuit as shown in Figure 1, while using the supply voltage of 90V and a load resistance of 100 Ω,
- Using a multimeter measure the output voltage V_o, the output current I_o, the thyristor voltage V_D. Write down the measured values to the Table 1(a) provided below.
- Connect the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain the time waveforms (for two gate angles: 30° and 60°) of V_s, V_o, and V_{th}
- Draw successively the time profile of the mains line voltages, U_1, U_2, and U_3 and the load line voltages, U_{D1}, U_{D2}, and U_{D3} and the thyristor voltages V_{th1}, V_{th2}, V_{th3} in graph 1(a)

Table 1(a) : R = 100 Ω

α in degrees	0	30	45	90	135
$U_α$/V					
$I_{TAV1α}$/V					
$U_{TRMS1α}$/V					
$I_α$/A					

Measured values

α in degrees	0	60	60	90	120	150
$U_{1α}$/V	87	86	72.5	48	21.5	0
$U_{12α}$/A	152	150	126	81	35.5	0
$I_{1α}$/A	0.82	0.8	0.68	0.45	0.2	0

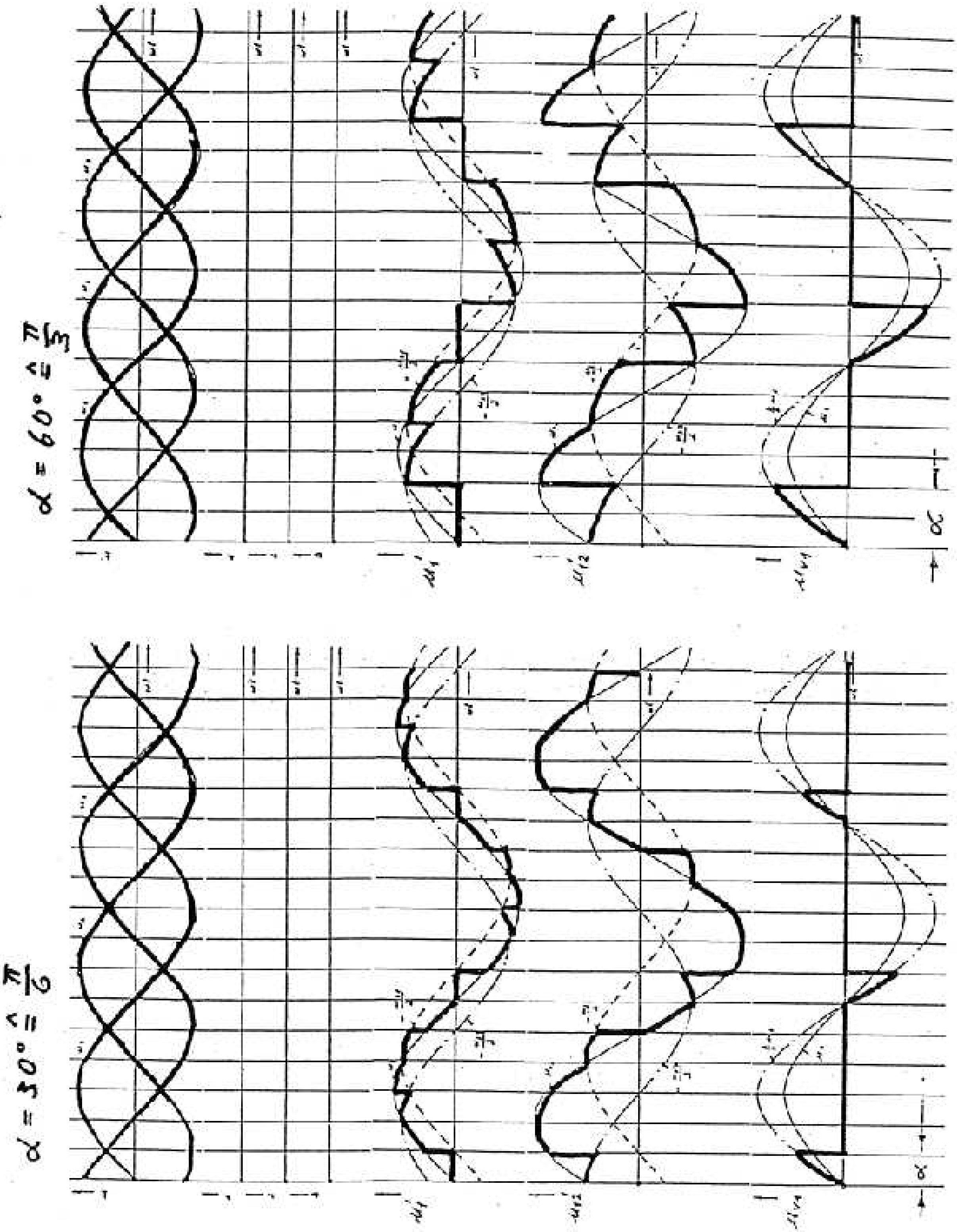


Figure 2.4.2-2 Fully-controlled three-phase controller with Y-connected symmetrical ohmic load, without neutral

a) Time profile of the mains line voltages

b) Time profile of the load line voltage u_1.

c) Time profile of the linked load voltage u_{12}.

d) Time profile of the valve voltage u_{V1}

1. Reports

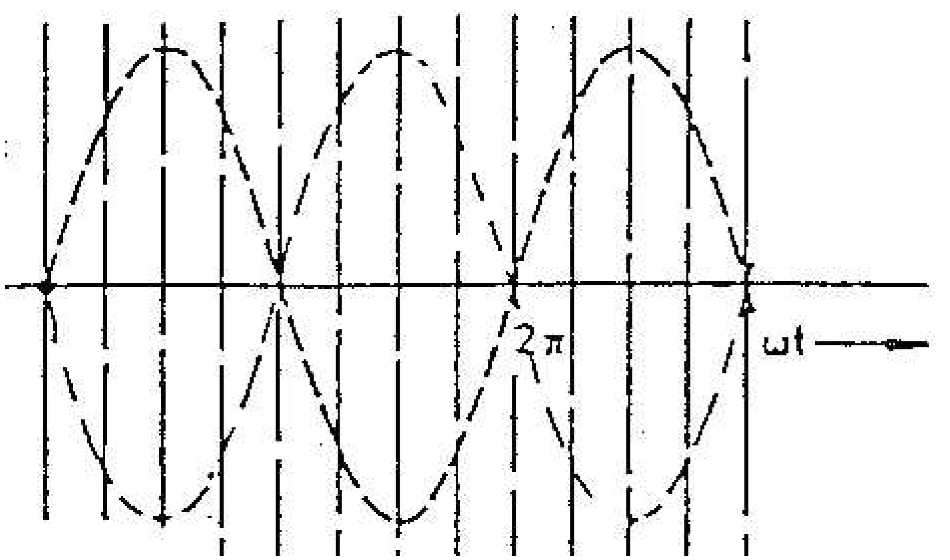
1. Complete table 1.
3. Copy the plots obtained during the experiment and put it in the report.

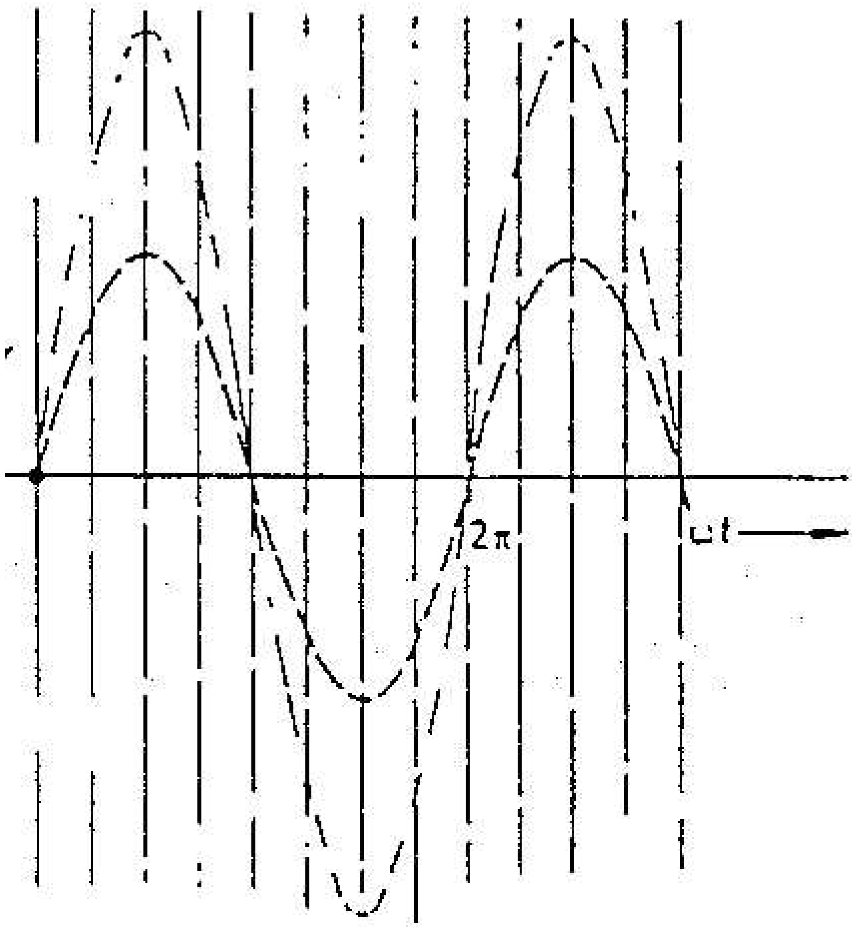
1. Conclusions

This experiment gives operational characteristics of a basic AC-DC converter by construct a simple rectifier. Four diodes are used to rectify the incoming AC line voltage. Instead of diodes, controllable solid-state switching devices such as thyristors can also be employed where the use of thyristors will give the opportunity to control the output voltage without the use of a linear regulator. This type of circuit containing controllable switches is called as a controlled rectifier and is mainly used for speed control of DC motors. The experimental analysis for such a circuit is the same as the one you have performed in this experiment. However, the triggering circuit is a bit tricky and a proper design of a feedback control circuit is necessary.
You must write a full report about what you have observed and what procedures you have done to obtain these results. Compare your results with data sheets and other resources (text book or references given below) or simulation analysis.

Report:

4. Record all your comments and views for the different graphs
5. Draw all the corresponding profiles as well as taking photographs
6. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

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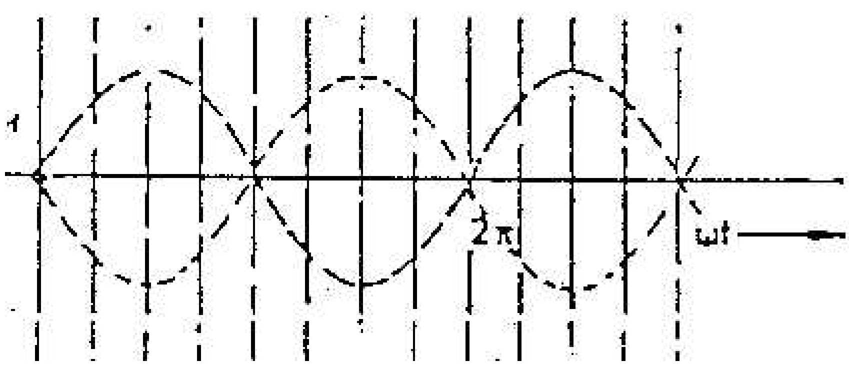
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4 Introduction and Learning objectives

EQUIPMENTS

5 Experimental procedures

UNIVERSITY OF HAIL
ELECTRICAL ENGINEERING DEPARTMENT
POWER ELECTRONICS LABORATORY

EE-460 POWER ELECTRONICS

EXPERIMENT # 8
AC STATIC CONVERTERS

1. Introduction and learning objectives

AC-AC converters are mainly employed as controlling power in AC circuits. One of the solid-state switching devices, the triac, will be used in the construction of the AC-AC converter. This converter is also a good example in understanding the behavior of phase-controlled AC choppers. The student will also be presented with single and three phase AC controllers with different load variants and gate angles.
In this experiment students will perform experimental tests on a basic AC-AC controller circuit. And after completing this laboratory work the student will be able to:

- To get acquainted with the operation of a single-phase AC converter with resistive and inductive loads.
- To learn the mode of operation of a Triac AC converter with resistive and inductive loads.
- To determine the performance characteristics of the AC converter with its various topologies.
- To Plot and analyze the time profiles for the AC voltages and currents, and thyristor voltage.

2. Principle mode of operation

AC switches and controllers conduct electrical current in both directions. However, since semiconductor valves only conduct electrical current in one direction, namely the forward direction, two valves must always be connected back to back.
Static converters with pairs of antiparallel arms are referred to as AC static converters.
Since the current in AC circuit becomes zero and reverses its direction after every half cycle, the thyristors must be alternately trigerred at regular intervals.
Alternating current cannot only be switched on and off but also continuously controlled using pairs of antiparallel arms such as phase angle control.
AC-to-AC converters have a wide range use in the industry. Applications such as light dimmers, AC motor controllers, heat controllers, uninterruptable power supplies are some examples for AC-AC converters. There are many different types of AC converters but basically, they produce an output voltage at the same frequency as input AC signal with variable amplitudes. These converters are also known as AC choppers.
There are many different methods AC choppers use in producing variable AC output voltages. In this experiment students will construct a **Single-Phase Full-Wave Controller (Phase Controlled AC Chopper)** with resistive load. Figure 1 shows the basic phase-controlled AC chopper with resistive load.
The anti-parallel connection of SCR thyristors gives the opportunity to control current in both positive and negative directions. This switch combination is a called bidirectional switch. You have seen in the first

experiment that the triac has this bidirectional property. The anti-parallel SCR thyristors in Figure 1 can be replaced by a triac, but for simplicity of understanding thyristors will be used while giving general information. Other types of bidirectional switches can be composed by thyristors or transistors. Students must make a quick research about bidirectional switches before attending the laboratory.

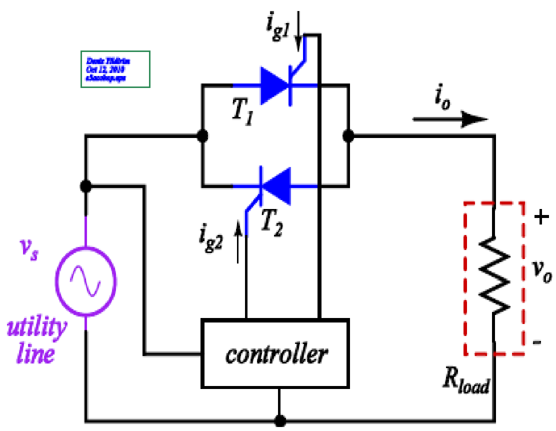


Figure 1. Phase-controlled AC chopper with resistive load.

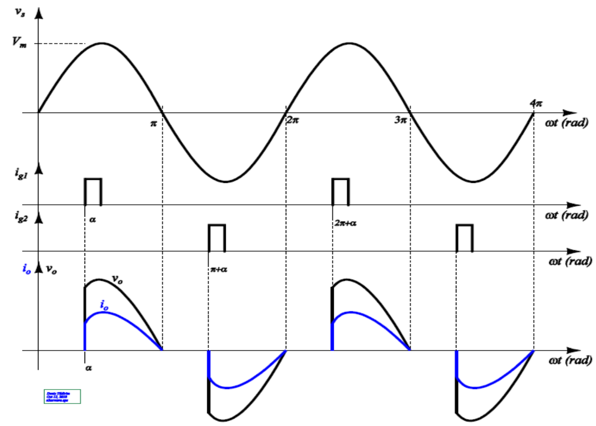


Figure 2. Waveforms of input voltage (v_s), output voltage (v_o), output current (i_o) and triggering signals (i_{g1}) and (i_{g2}).

Voltage v_s is a sinusoidal input to the basic circuit shown in Figure 1 (it can be considered as the mains 220VRMS, 50 Hz). During the positive half cycle of input voltage, the power flow is controlled by varying the delay angle of the thyristor T_1; and thyristor T_2 controls the power flow during the negative half cycle. The firing pulses of T_1 and T_2 are kept 180º (π radians) apart. The waveforms for the input voltage, output voltage and gating signals for T_1 and T_2 are shown in Figure 2.

If $v_s = V_m \sin(\omega t)$ is the input voltage and the delay angles of thyristors T_1 and T_2 are equal ($\alpha_1 = \alpha_2 = \alpha$) the RMS output voltage (V_o) can be found from:

$$V_{o,rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi}[V_m \sin(\omega t)]^2 \, d(\omega t)}$$

$$V_{o,rms} = \frac{V_m}{\sqrt{2}}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin(2\alpha)}{2\pi}} = V_{s,rms}\sqrt{1-\frac{\alpha}{\pi}+\frac{\sin(2\alpha)}{2\pi}}$$

By varying α from 0 to π, $V_{o,rms}$ can be varied from $V_{s,rms}$ to 0 as can be clearly seen from Figure 3 (angle α must be in radians when substituting in the above equation). Note that the range of triggering control angle for phase controlled AC chopper with resistive load is:

$$0 \le \alpha \le \pi$$

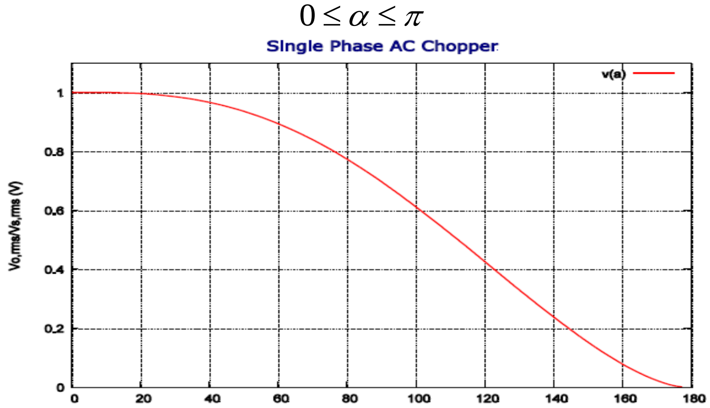


Figure 3. Variation of $V_{o,rms}$/ $V_{s,rms}$ as a function of firing angle α

3. Experimental procedures

3.1 Equipments used

The necessary equipments needed for this experimental work is given in Table 1

Table 1: List of necessary equipments

No.	Designation	Catalogue No.
1	Mains isolating transformer	726 80
2	Thyristors	735 03
3	Triac	735 04
4	Power electronics load	735 09
5	Control unit	735 12
6	Set point potentiometer	734 02
7	Multimeter	
8	Oscilloscope (Hameg)	575 20
9	Isolating amplifier	735 26
10	Connecting cables and bridging plugs	

Before coming to the laboratory students are encouraged to make a small research about single and three-phase AC controller. Please follow the following steps carefully:

3.2 Single phase AC controller

3.2.1 Ohmic load

- Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load resistance of 33 Ω, (three 100 Ω resistance connected in parallel)
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(a) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(a) for two values of firing angles 45 and 135.

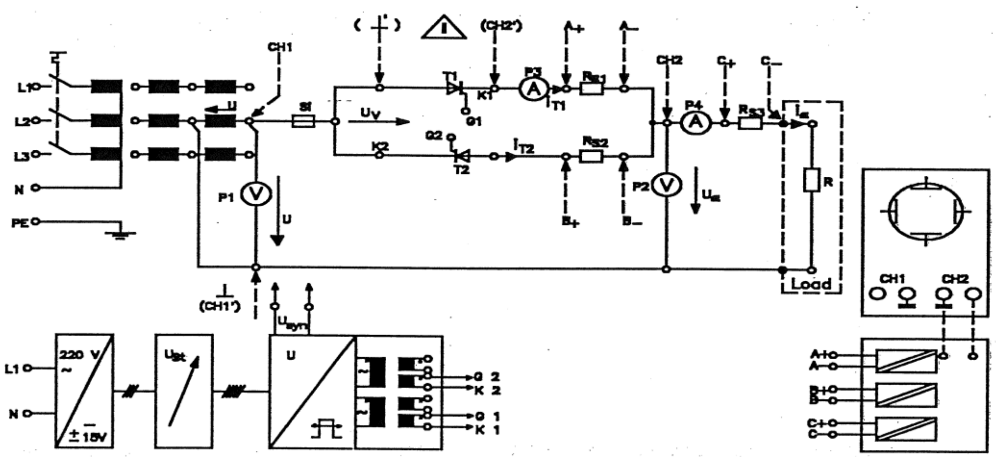


Figure 1 Single phase AC Voltage controller

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upper position)
- Set the selector switch "**pulse shape**" to individual pulse degrees (switch in lower position)

Table 1(a) : R = 33 Ω

α in degrees	0	30	45	90	135
U_{α}/V					
$I_{TAV1\alpha}/V$					
$U_{TRMS1\alpha}/V$					
I_{α}/A					

3.2.2Ohmic-Inductive load

- Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel) in series with an inductance of 50 mH.
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(b) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upper position)
- Set the selector switch "**pulse shape**" to pulse train (switch in upward position)
- The theoretical load phase angle for this experiment is about 30^{o}

Table 1(b) : R = 33 Ω, L = 50 MH

α in degrees α=φ=30	30	90	120	180
U_{α}/V				
$I_{TAV1\alpha}/V$				
$U_{TRMS1\alpha}/V$				
I_{α}/A				

3.3 Triac AC controller

Test set up:

- Make the correct panel arrangement for the experiment and use the circuit shown in Figure 2.
- Connections as specified but connect one output of the upper and lower pulse transformers to the control units in parallel, ensuring correct polarity, and also the control line of the triac.
- Use a supply voltage of 45 V and a a resistive load of 33 Ώ

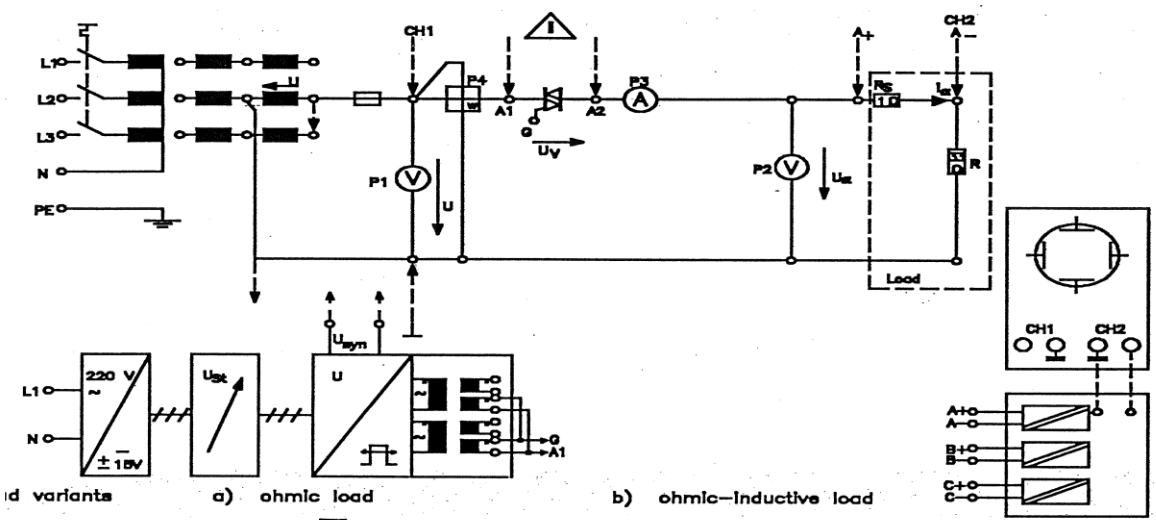


Figure 2 Triac AC controller

3.2.1 Triac AC controller with ohmic load

- Connect the power circuit as shown in Figure 1, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel).
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 1(b) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upward position)
- Set the selector switch "**pulse shape**" to single pulse degrees (switch in downward position)
- Connect the isolating amplifier to the oscilloscope for recording the time profiles of the voltages and currents and record the results for 2 gate angles (45^o and 90^o). Min alpha 30

Table 2(a) : R = 33 Ω

α in degrees	0	30	45	90	135
$U_α$/V					
$I_{TAV1α}$/V					
$U_{TRMS1α}$/V					
$I_α$/A					

3.2.2 Triac AC controller with ohmic-inductive load

Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, the load current I_a, Write down the measured values to the Table 2(b) provided below.

- Connect the power circuit as shown in Figure 2, while using the supply voltage equal to 45V and a load made up of a resistance of 33 Ω, (three 100 Ω resistance connected in parallel).
- Using a multimeter measure the AC source voltage, V_s, load voltage V_a, the thyristor voltage V_V, thyristor 1 current I_{T1}, thyristor 2 current I_{T2}, the load current I_a, Write down the measured values to the Table 2(b) provided below.
- After connecting the isolation amplifier for visualizing purposes and with the help of an oscilloscope obtain and draw the time profile of the waveforms in graph 1(b) for two values of firing angles 45 and 135.
- Give a brief description of the time profiles recorded on the oscilloscope with some explanation to the difference between a purely resistive load and one with a series of resistance and inductance.

- Connect the synchronizing voltage for the control unit with a control voltage range 0 to 10 V (bridge connector in middle position).
- Set the selector switch "**gate angle**" to zero degrees (switch in upward position)
- Set the selector switch "**pulse shape**" to single pulse (switch in downward position)
- Connect the isolating amplifier to the oscilloscope for recording the time profiles of the voltages and currents and record the results for 2 gate angles (45^o and 90^o). Min alpha 30

Table 2(b) : R = 33 Ω, L= 50 mH

α in degrees	0	30	45	90	135
$U_α$/V					
$I_{TAV1α}$/V					
$U_{TRMS1α}$/V					
$I_α$/A					

Report:

1. Record all your comments and views for the different graphs
2. Draw all the corresponding profiles as well as taking photographs
3. Explain the reason for inserting the inductance with the resistive load and its effect on the waveforms

Graph 1(a) with ohmic load

V_s

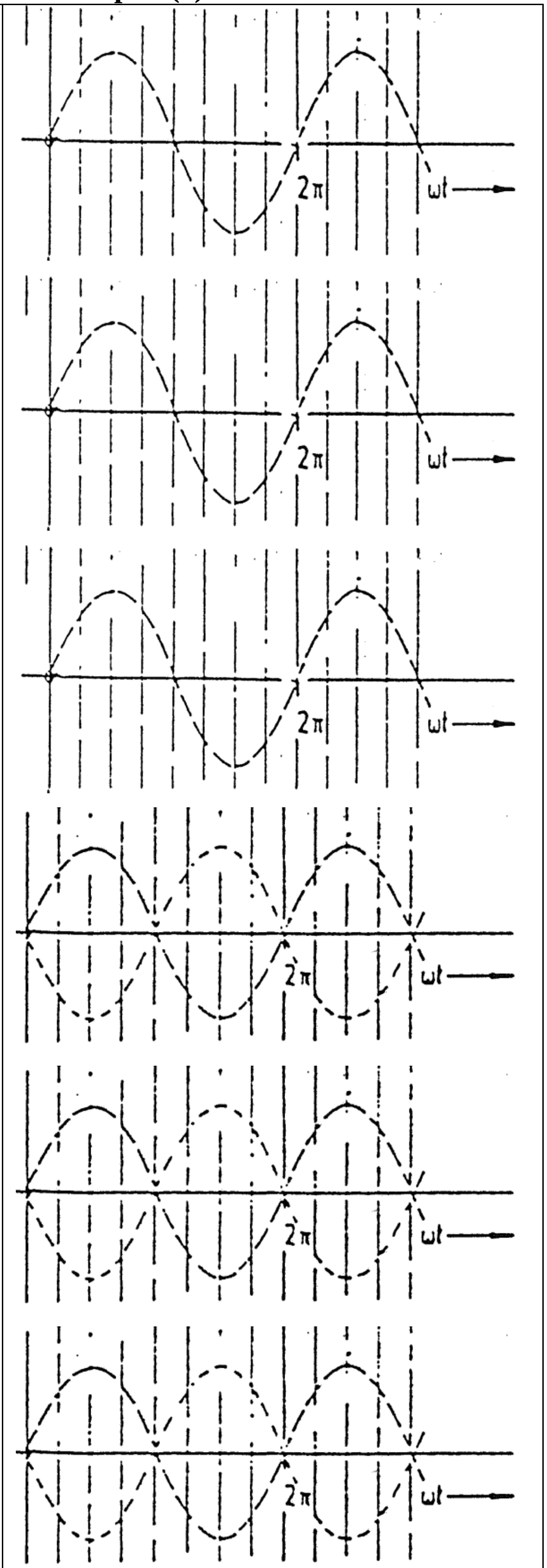
V_α

V_v

I_{th1}

I_{th2}

I_α



Graph 1(b) with ohmic-inductive load

V_s

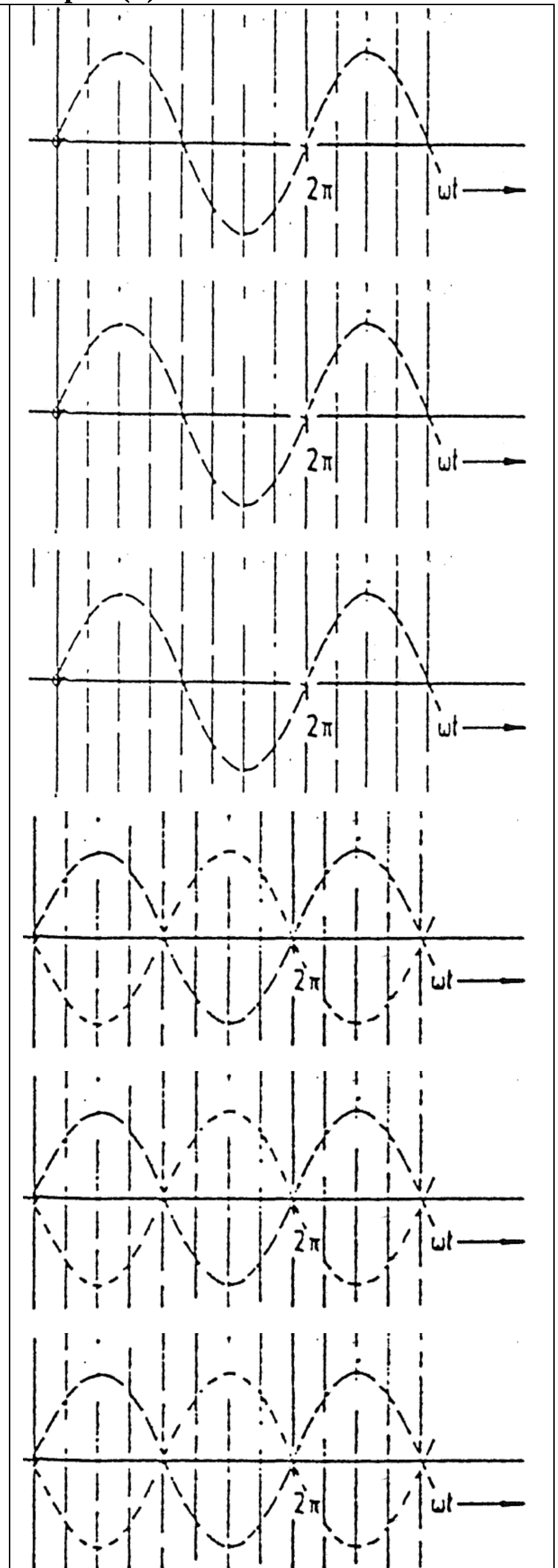
V_α

V_v

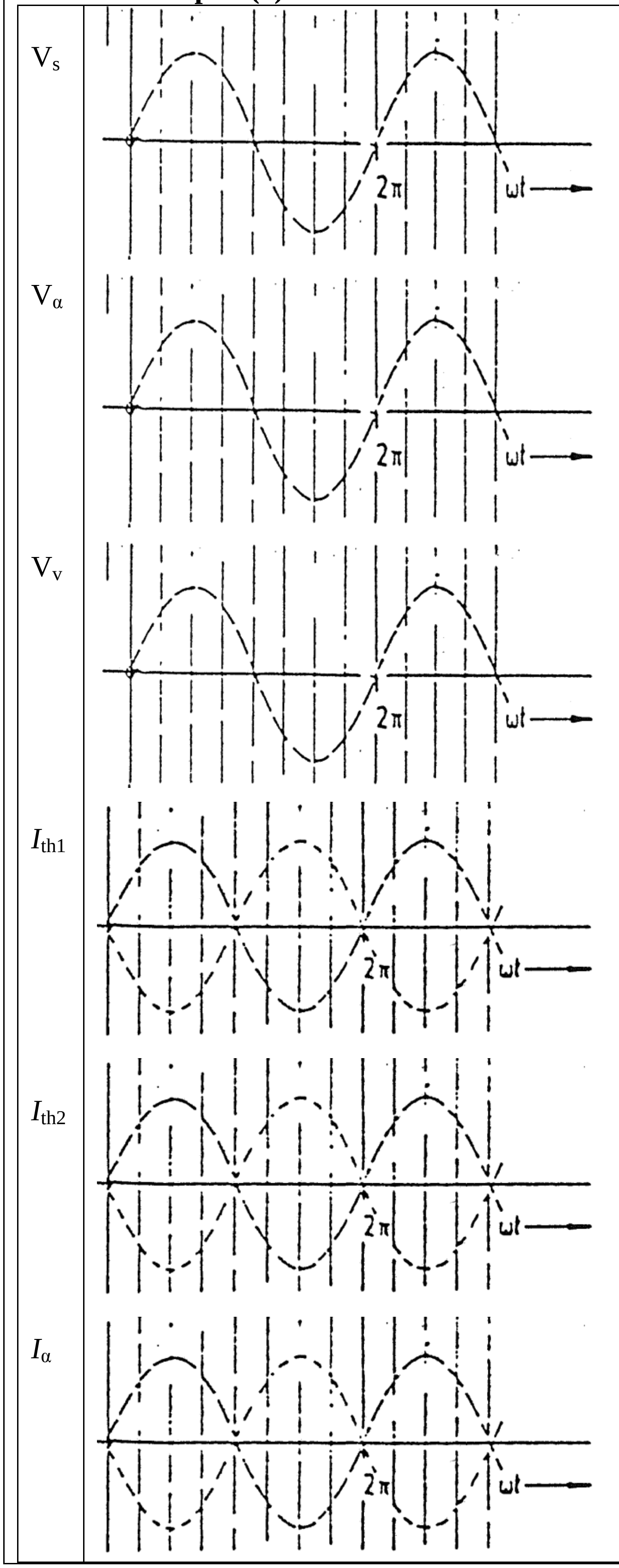
I_{th1}

I_{th2}

I_α



Graph 2(a) with ohmic load



Graph 2(b) with ohmic-inductive load