Experiment 5: Study of AC Phase Control using Power Thyristor (SCRs).

OBJECTIVE

- To become familiar with the principles of ac phase control.
- To observe the operation of full-wave and halt-wave phase control circuits.

THEORY

Control principles

In AC phase control, one or more thyristors are used to control the current in an AC circuit. The thyristors may also rectify the ac source voltage to convert it into DC.

A thyristor begins to conduct when a firing pulse is applied to the gate, providing that the thyristor is forward biased at that time. The firing pulses are timed with respect to the phase of the ac source voltage. In a single-phase circuit, the control circuit detects the beginning (0°) of each cycle of the ac source voltage, that is, when the waveform passes through zero, going from negative to positive. Then, the control circuit sends firing pulses to the various thyristors. Each pulse is delayed a certain number of degrees, so the thyristors begin to conduct at precisely the desired point (firing angle) in the cycle.

Firing angle refers to the phase angle of the ac supply voltage (sinusoidal) when the gate current is applied and thyristor turns ON. Firing angle of the thyristor varies from 0 degrees to 180 degrees.

Full-wave phase control

The circuit of Figure 5-1 can provide full-wave ac phase control. With this circuit, and the appropriate control circuitry, you can control the power P_o consumed by the load. A common example of this type of circuit is the "dimmer" circuit used to control incandescent lamps.

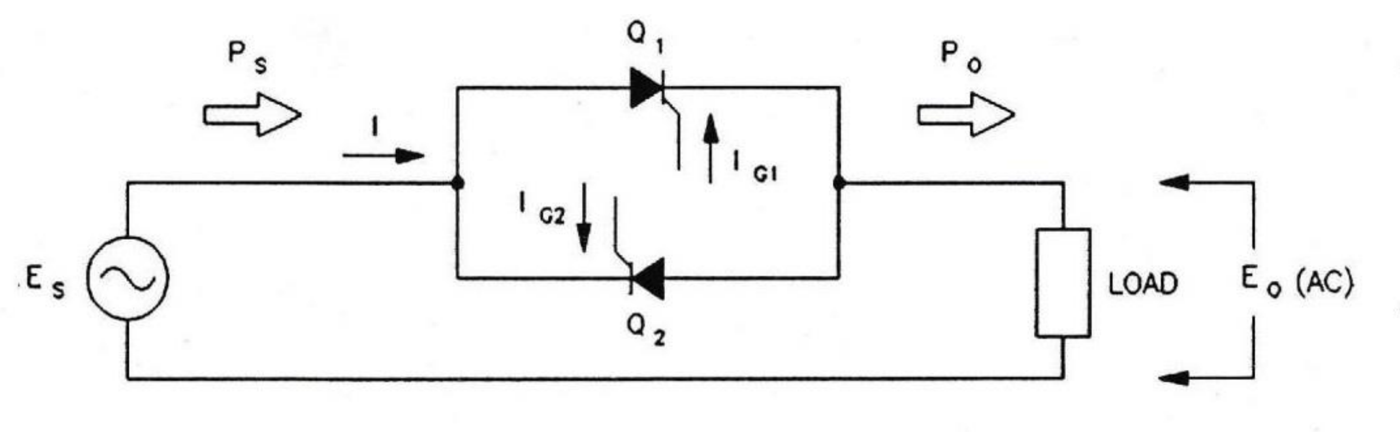


Figure 5-1. Full-wave ac phase control circuit

Figure 5-2 shows the waveforms associated with this circuit, when the load is purely resistive. The control circuit sends a firing pulse to the gate of Q_1, α° after the beginning of the cycle so that this thyristor begins to conduct. It conducts for the remainder of the first halt-cycle. A second firing pulse is sent to Q_2, 180° after the pulse to Q_1, causing Q_2 to conduct from that point to the end of the second half-cycle.

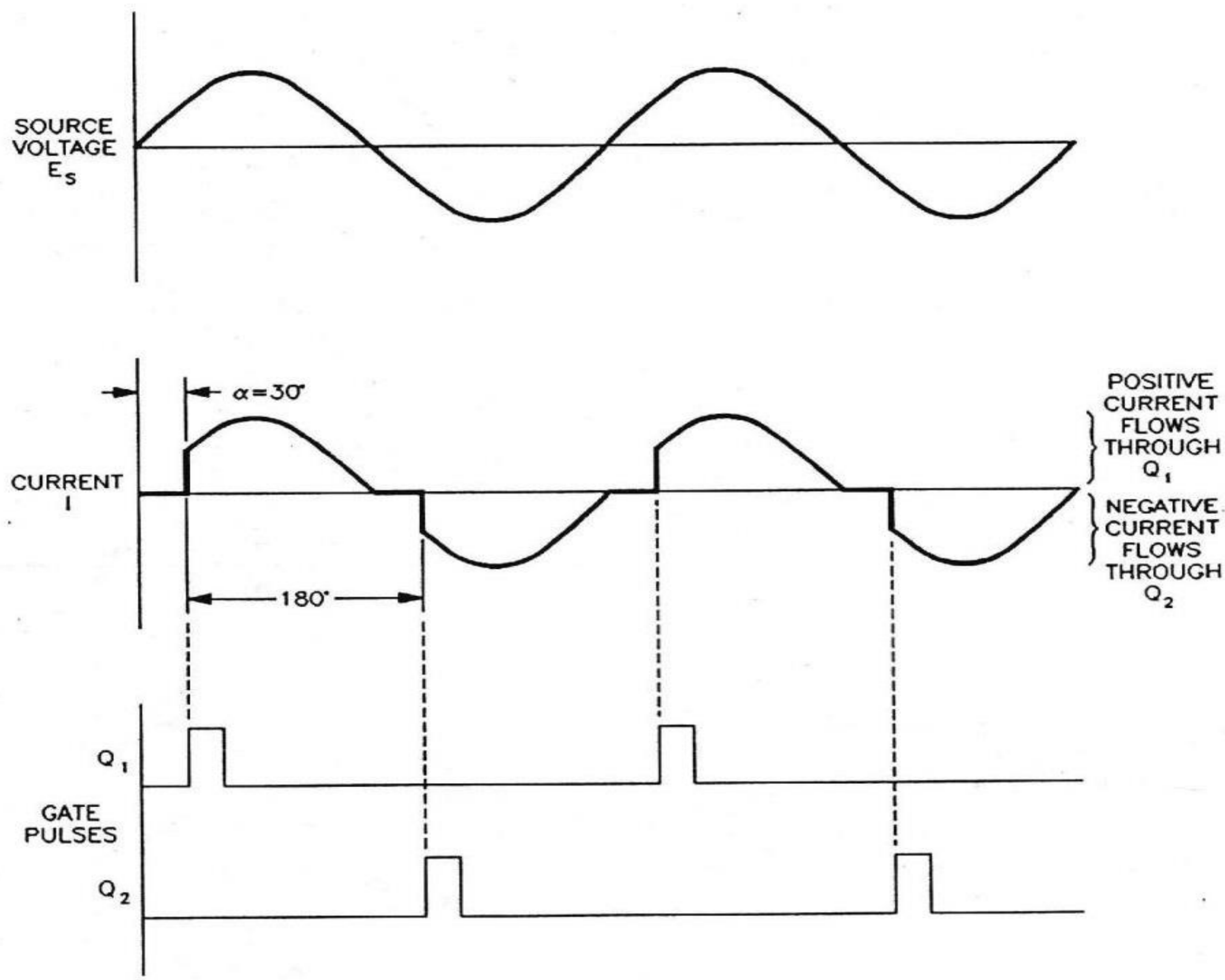


Figure 5-2. Waveforms for a full-wave phase control circuit.

When α = 0°, the phase-control circuit conducts for the entire cycle and the load receives maximum power. When α is greater than 0°, the power is "off" for part of each cycle. The RMS voltage, current, and power transferred to the load are therefore reduced.

When the load is purely resistive, the active power $P_0 = E_0 \times I$ dissipated by the load is always equal to, or less than, the apparent power $P_S = E_S \times I$ supplied by the source.

When α is greater than 0°, the current undergoes a phase shift with respect to the source voltage E_S, as shown in Figure 5-2. Because the current now lags with respect to the voltage, the ac source has to supply reactive power Q in addition to the active power P. The reactive power grows as the firing angle α is increased.

Half-wave phase control: controlled rectifier supplying a passive load

Figure 5-3 shows a half-wave phase control circuit using a single thyristor. This is a controlled rectifier supplying a passive load. When the load is purely resistive, the waveforms of this circuit as are shown in Figure 5-4.

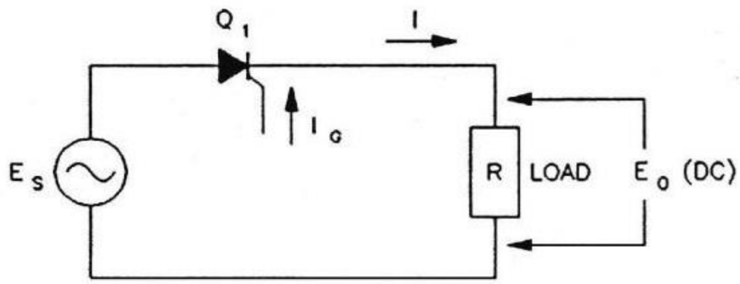


Figure 5-3. Hall-wave phase control circuit using a single thyristor.

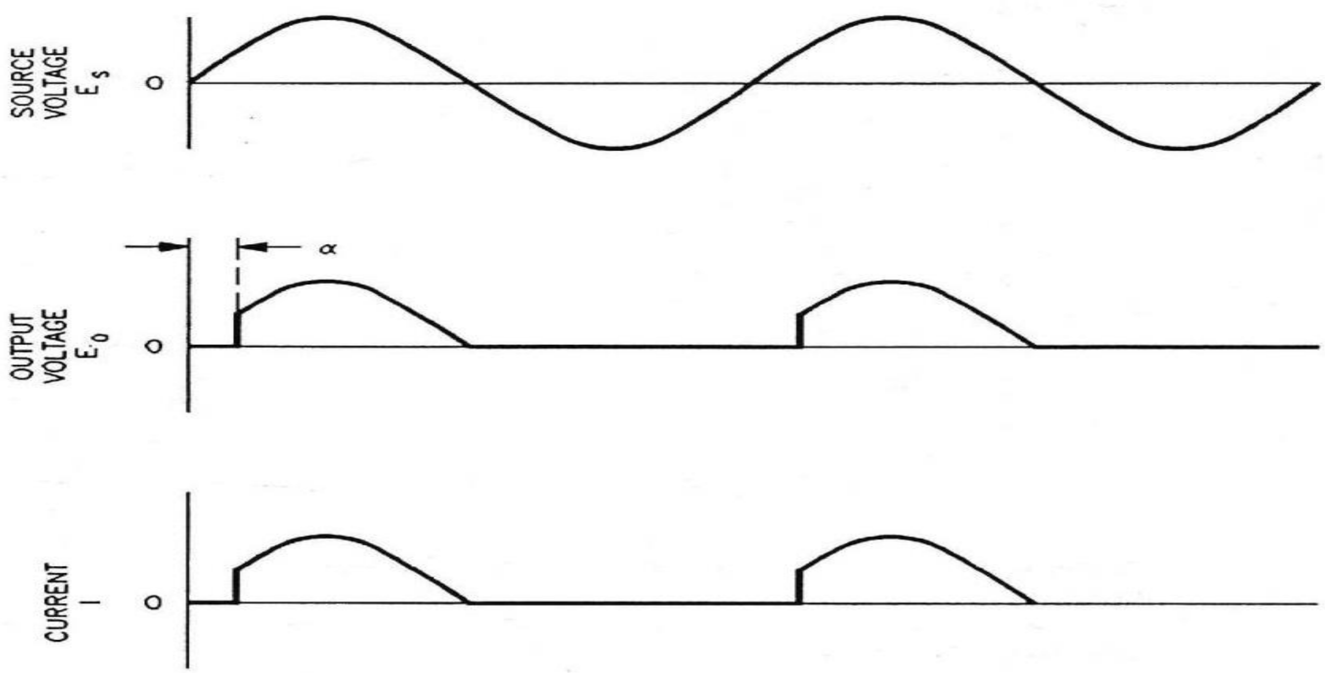


Figure 5-4. Waveforms for half-wave phase control circuit (resistive load).

When the load is inductive, the output voltage can be negative for pan of the cycle, as shown in Figure 5-5. This is because an inductor stores energy in its magnetic field for part of the cycle, then gradually releases this energy. Current continues to flow, and the thyristors continue to conduct, until all the stored energy is released. Since this occurs some time after the ac source voltage has passed through zero, the output voltage becomes negative for pan of the cycle.

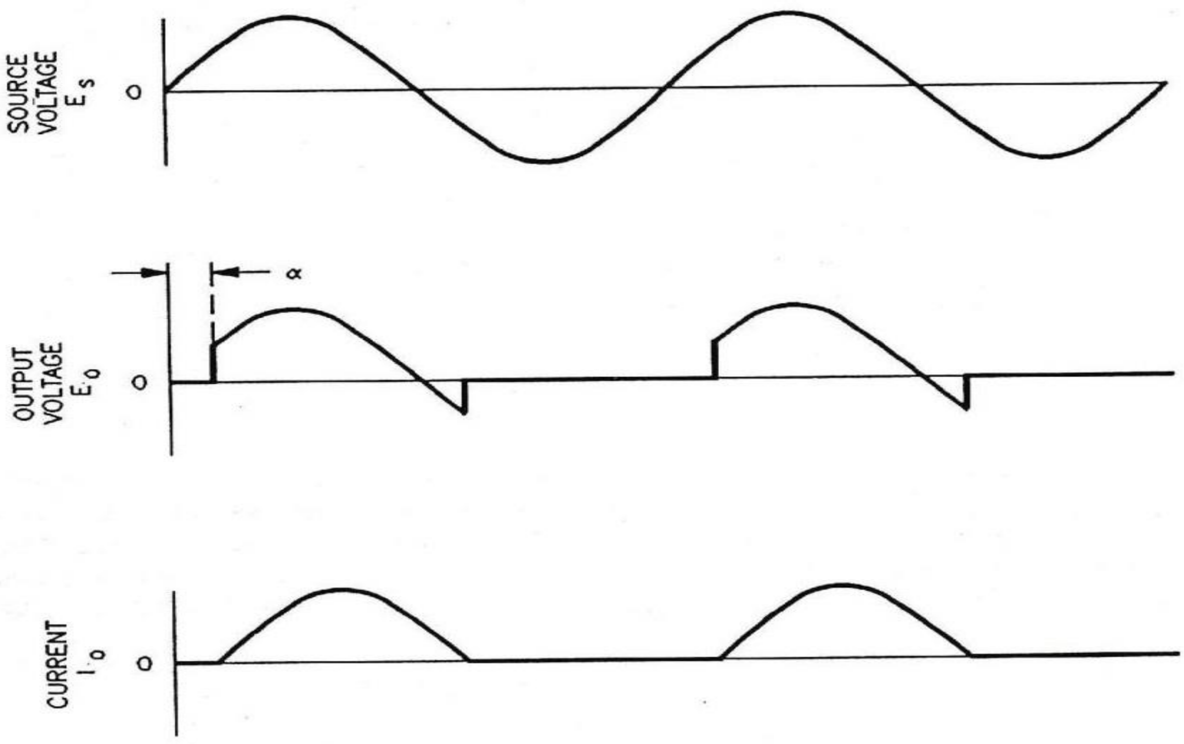


Figure 5-5. Output waveforms for half-wave phase control circuit (inductive load).

The negative part of the output voltage waveform reduces the average output voltage E_0. To prevent the output voltage from going negative, a free-wheeling diode can be place in the circuit as shown in Figure 5-6. When the output voltage begins to go negative, the free-wheeling diode begins to conduct. This maintains the output voltage at approximately zero while the energy stored in the inductor is being released. The output voltage waveform is the same as for a purely resistive load (Figure 5-4), and the average output voltage is therefore greater than it would be without the free-wheeling diode.

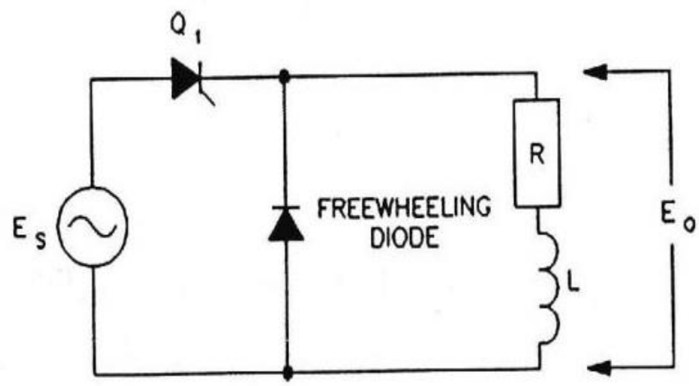


Figure 5-6. Half-wave phase control circuit with free-wheeling diode.

Controlled rectifier supplying an active load

The controlled rectifier can also supply power to an active load (dc source). Figure 5-7 shows a variable battery charger circuit using a single thyristor. The inductor in the circuit smoothens the current waveform.

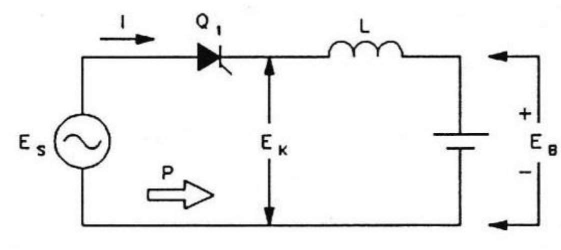


Figure 5-7. Controlled rectifier supplying power to an active load.

Waveforms for this circuit are shown in Figure 5-8. When the firing angle α is θ_1, maximum active power is supplied to the dc source. As the firing angle is increased beyond θ_1, less and less active power is supplied. Since the current lags behind the voltage, however, the source has to supply reactive power as well as active power. When α is greater than θ_2, the thyristor never conducts and the active power is zero.

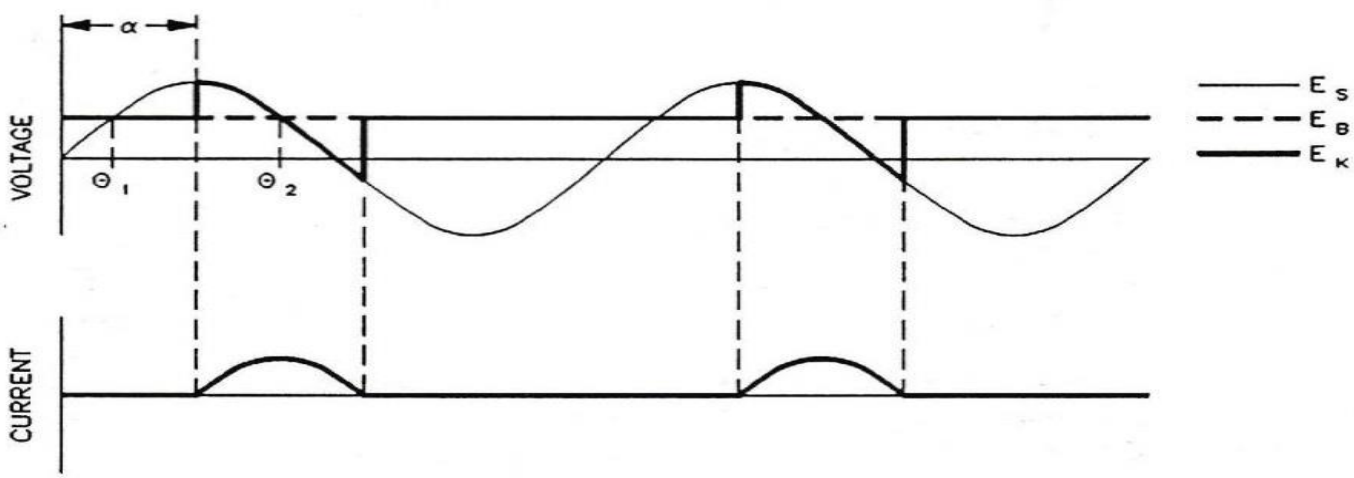


Figure 5-8. Waveforms for a controlled rectifier supplying power to an active load

PROCEDURE SUMMARY

In the first part of this exercise, you will set up the equipment.

In the second part, you will observe the operation of a full-wave phase control circuit made with two thyristors connected back-to-back.

In the third part, you will study a controlled rectifier supplying a passive load.

EQUIPMENTS

1. Power Supply Module
2. Power Thyristor Module
3. Resistive load
4. AC Voltmeter / Ammeter Module
5. DC Voltmeter / Ammeter Module
6. Single Phase Wattmeter

PROCEDURE

CAUTION!

High voltages are present in this laboratory exercise! Do not make or modify any banana lack connections with the power on unless otherwise specified!

Setting up the equipment

1. Install the Power Supply, the Resistive Load, the Inductive Load, the DC Voltmeter/Ammeter, the AC Ammeter, the AC Voltmeter, the Single-Phase Wattmeter and the Power Thyristor modules in the Mobile Workstation.

2. Install the Thyristor Firing Unit and the Current/Voltage Isolators in the Enclosure / Power Supply.

   Note: Before installing the thyristor firing Unit, make sure that switches SW1 and SW2 (located on the printed circuit board) are in the O position.

3. Make sure that the main power switch of the Power Supply is set to the O (OFF) position. Set the voltage control knob to 0. Connect the Power Supply to a three-phase wall receptacle.

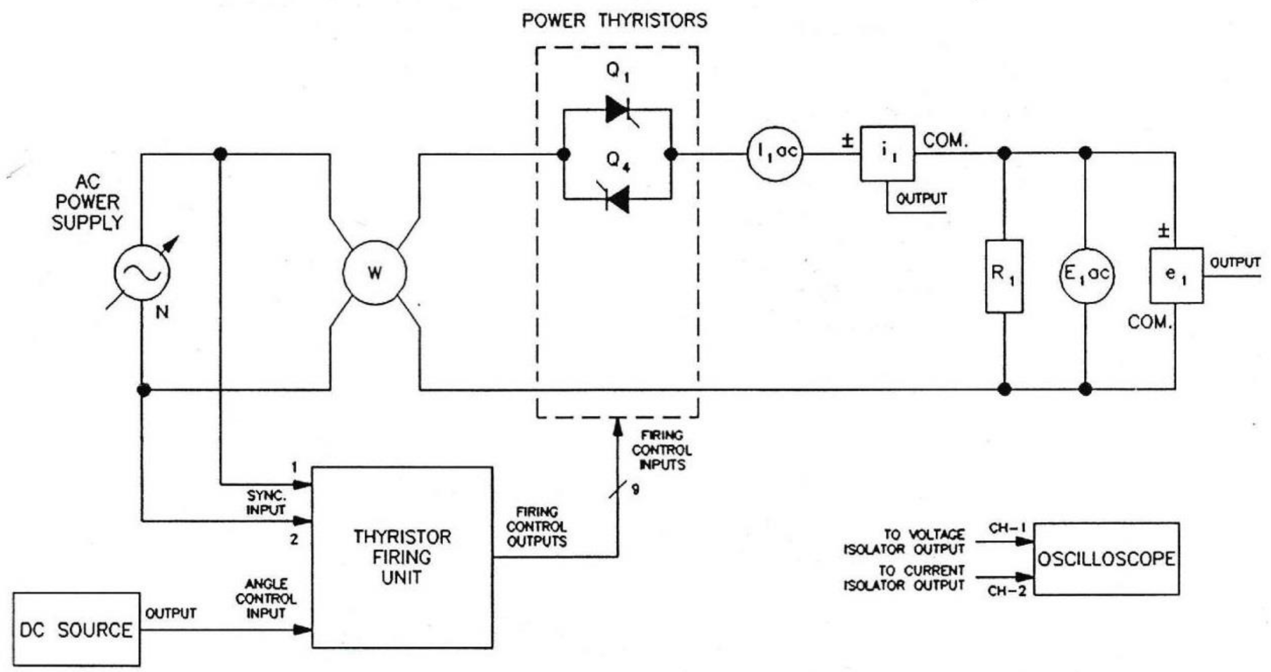
4. Plug the Enclosure / Power Supply line cord into a wall receptacle. Set the rocker switch of the Enclosure / Power Supply to the | (ON) position.

5. On the Power Supply, set the 24-V ac power switch to the | (ON) position.

6. Make sure that the toggle switches on the Power Thyristors and the Resistive Load modules are all set to the 0 (open) position.

Full wave phase control

7. Set up the circuit at Figure 5-9.



LINE VOLTAGE (Vac)	I_1ac (A)	i_1 (A)	E_1ac (V)	e_1 (V)	R_1 (Ω)
120	2.5	10	150	300	60
220	1.5	5	250	600	220
240	1.5	5	250	600	240

Figure 5-9. Circuit for full-wave phase control.

8. Make the following settings:

On the Power Supply
Voltage Selector……………………………………………………………………………4-N

On the Thyristor Firing Unit
Angle Control Compliment…………………………………………………………………O
Angle Control ARC Cosine…………………………………………………………………O
Firing Control Mode………………………………………………………………………..1-
DC Source……………………………………………………………………………….MIN.

On the Oscilloscope
Channel-1 Sensitivity……………………………………………………….5V/DIV (DC coupled)
Channel-2 Sensitivity……………………………………………………….5V/DIV (DC coupled)
Time Base……………………………………………………………………………5 ms/DIV
Trigger………………………………………………………………………………….LINE

9. On the Power Supply, make sure that the voltage control knob is set to the O position then set the main power switch to | (ON). Set the voltage control knob to 100(%).

   Vary the FIRING ANGLE on the Thyristor Firing Unit by adjusting the DC SOURCE control.

   On the Thyristor Firing Unit, set the FIRING ANGLE to 45° to fill-up table 5-1 and sketch the output voltage and current waveforms in figure 5-10.

   Describe the effect on the output waveforms and on the power delivered to the load.

   ____

   ____

   ____

   Explain the operation of this circuit.

   ____

   ____

   ____
   .

   What is the conduction angle of the thyristor when the firing angle is 120°?

   Conduction angle= ___________ [For diode pair]

   Conduction angle= ___________ [For each diode]

   On the Power Supply, set the voltage control knob to 0 then set the main power switch to 0 (OFF).

Load Z_1	Output Voltage E_1 ac	Output Current I_1 ac	Output Power P_o	Conduction Angle
	V	A	W	Degrees
(a) Resistive				
(b) Inductive				

Table 5-1. Measurements for Full wave phase control circuit

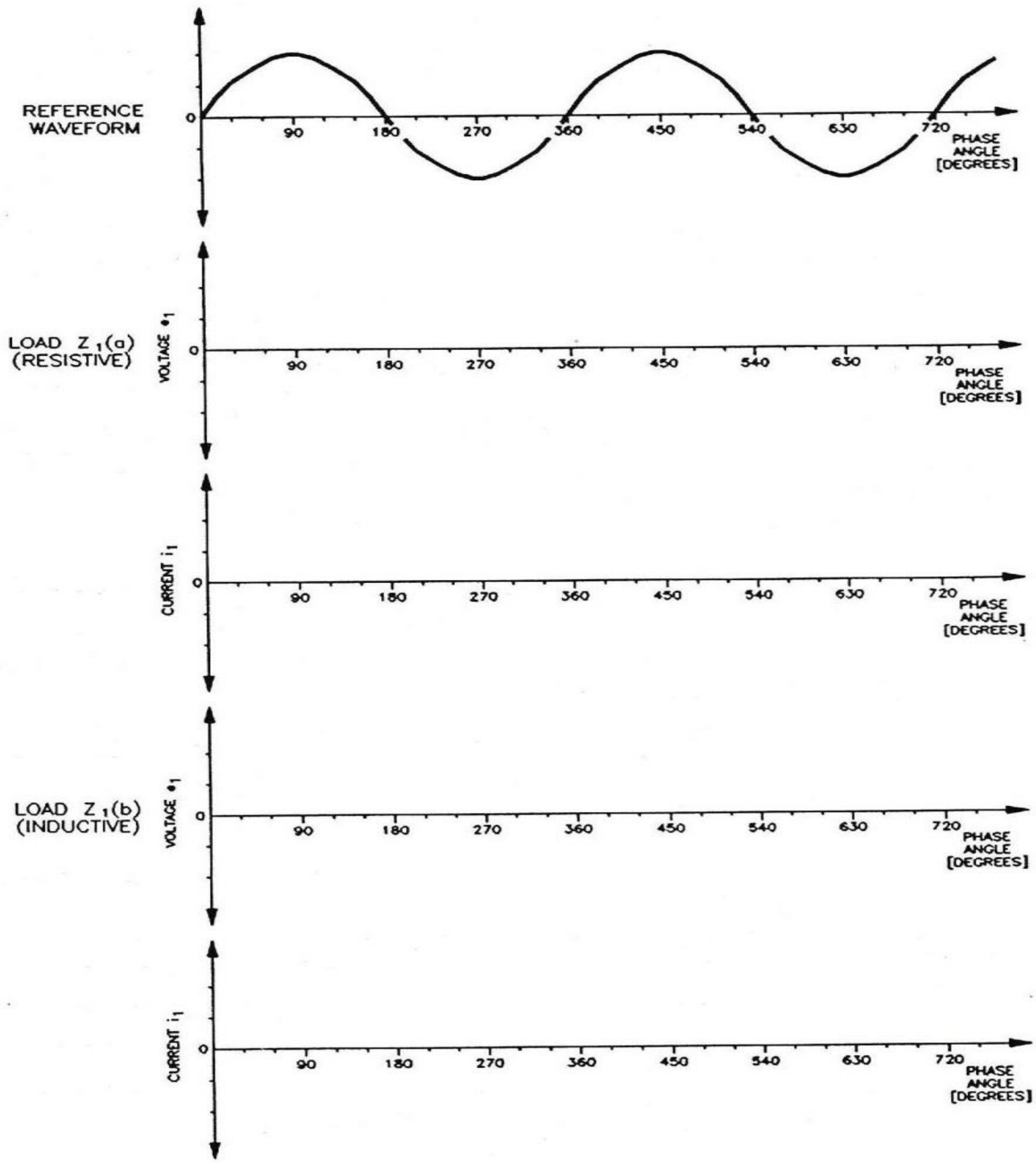
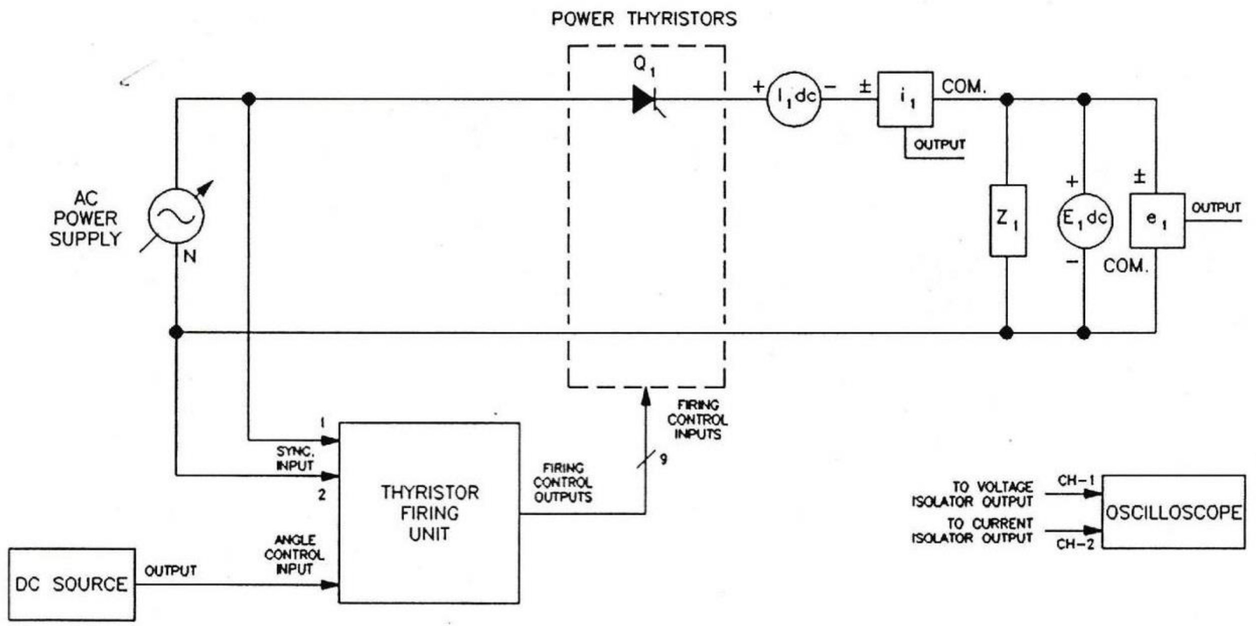


Figure 5-10. Voltage and Current waveforms (α = 45°)

Controlled rectifier supplying a passive load

10. Setup the circuit in Figure 5-11 using the resistive load Z_1 (a)



LINE VOLTAGE (Vac)	I_1dc (A)	i_1 (A)	E_1dc (V)	e_1 (V)	Z_1(a) R	Z_1(b) R L
120	2.5	10	150	300	R=60 Ω	R=60 Ω, L=0.2 H
220	1.5	5	300	600	R=220 Ω	R=220 Ω, L=0.8 H
240	1.5	5	300	600	R=240 Ω	R=240 Ω, L=0.8 H

Figure 5-11. Controlled rectifier supplying a passive load

11. On the Power Supply, set the main power switch to | (ON), and set the voltage control knob to 100(%). Vary the FIRING ANGLE and observe the waveforms on the oscilloscope.

12. On the Thyristor Firing Unit, set the FIRING ANGLE to 45° to fill-up table 5-2 and sketch the output voltage and current waveforms in figure 5-12.

    On the Power Supply, set the voltage control knob to 0 then set the main power switch to 0 (OFF).

13. Change the load in the circuit to the inductive load Z_1 (b).

14. On the Power Supply, set the main power switch to | (ON), and set the voltage control knob to 100(%). Vary the FIRING ANGLE and observe the waveforms on the oscilloscope.

15. On the Thyristor Firing Unit, set the FIRING ANGLE to 45° to fill-up table 5-2 and sketch the output voltage and current waveforms in figure 5-12.

    On the Power Supply, set the voltage control knob to 0 then set the main power switch to 0 (OFF).

Load Z_1	Output Voltage E_1 dc	Output Current I_1 dc	Output Power $P_o=E_1*I_1$	Conduction Angle
	V	A	W	Degrees
(a) Resistive				
(b) Inductive				

Table 5-2. Measurements for controlled rectifier circuit (α = 45°)

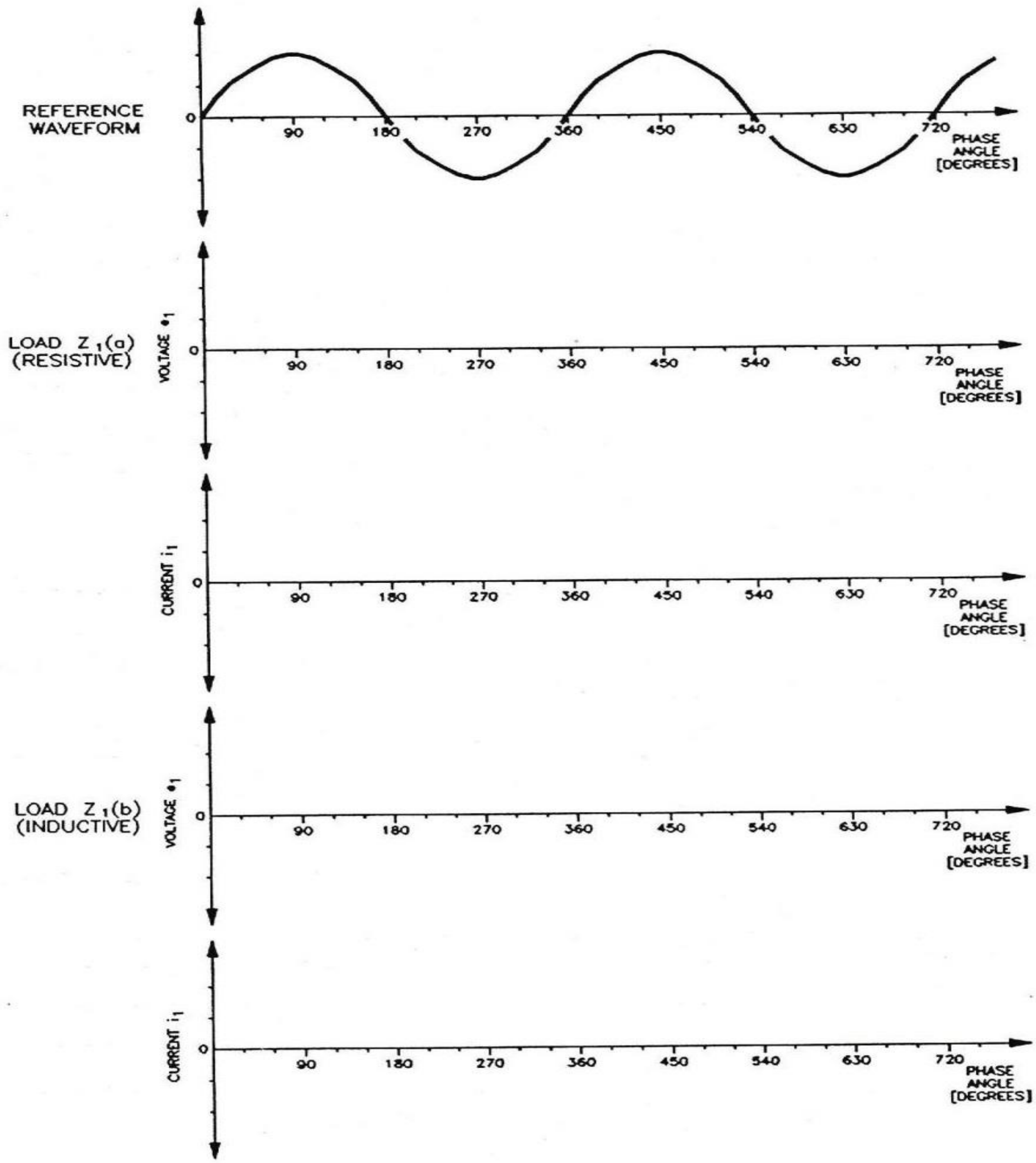


Figure 5-12. Voltage and Current waveforms (α = 45°)

CONCLUSION

In this exercise, you observed that two thyristors connected back-to-back can provide full-wave ac phase control. You also saw that a single thyristor can act as a controlled rectifier supplying either an active or a passive load.

REVIEW QUESTIONS

1. What point in a single-phase ac waveform is used as a reference point for timing the thyristor gate pulses?
2. Why are the gate pulses in a thyristor circuit delayed with respect to the reference point?
3. What is the relationship of the gate pulses to the two thyristors in a full-wave ac phase control circuit?
4. Why does the source for a thyristor circuit sometimes have to supply reactive power?
5. What is the advantage of using a thyristor in a battery charging circuit?
6. Why is the conduction angle greater with an inductive load than with a purely resistive load?
7. What effect does the inductive load have on the average output voltage and current?
8. What is the difference between this controlled rectifier circuit and the half-wave rectifier circuit seen in Experiment-2?
9. For a full-wave phase control circuit (Figure 5-9) draw the output voltage and current waveforms when firing angle $\alpha = 90°$.
10. For a half-wave phase control circuit draw the output voltage and current waveforms when firing angle $\alpha = 90°$.
11. In case of inductive loads, why do we get some negative positions in the output voltage for a half wave phase control circuit?
12. In case of inductive loads, why do we get some spikes in the output voltage for a full wave phase control circuit?