Experiment # 2
Single Phase AC Controller - Phase –Angle Bidirectional Control

Objectives

- Setting up an AC Controller and understanding its operation with various loads
- Measuring and interpreting various parameters of the AC controller
- Understanding the operation of the TRIAC and its equivalent two anti-parallel SCRs in an AC circuit
- Deriving the Control Characteristic of an AC Voltage Controller

Components and Accessories

1	735 09	Load, Power Electronics
1	735 012	Phase Commutated Converter
1	735 122	Converter Controller Unit
1	735 190	Phase Control Noise Filter 3X4.5A
1	726 80	Transformer 45/90, 3 N
1	524 013S	Sensor-CASSY 2 – Starter
1	735 012 – 11 W1C	Mask (Bridge Topology)
1	735 012 – 13 TRIAC	Mask (Bridge topology)
1	500 59	Set of 10 safety bridging plugs, black
1	500 591	Set of 10 Safety Bridging Plugs with Tap, black
2	500 640	Safety Connection Lead 100 cm yellow/green
4	500 641	Safety Connection Lead 100 cm, red

Theory

The AC Voltage Controller, when implementing a phase-angle bidirectional scheme, controls the rms value of the output voltage (for a resistive load) according to the equation:

$$V_{Orms} = V_s\sqrt{\frac{1}{\pi}\left(\pi - \alpha + \frac{\sin 2\alpha}{2}\right)}; \qquad 0 < \alpha < \pi$$

Note that, V_{Orms} varies from V_s to 0 by varying α from 0 to π; where V_s is the rms value of the input voltage.

Basic Settings:

Converter Controller Unit (cat. no. 735 122) and Phase Commutated Converter (cat. no. 735 012):

- Connect the "Phase Commutated Converter" (cat. no.735 012), the "Converter Control Unit" (cat. no.735 122), the "Transformer" (cat. no.726 80), the "Load, Power Electronics" (cat. no.735 09), and the measurement instruments in the way you can see in the figure in each corresponding paragraph.
- Lay the corresponding mask (for example "735 012 – 11 W1C") on the commutated converter.
- Disconnect the "Converter Control Unit" from the 12V power supply. Now, connect it again!
- The lower display of the "Converter Control Unit" indicates the delay angle. For the "M1C controlled" bridge for example, you can change the angle from 0° up to 150°.
- The "Converter Control Unit" automatically detects the mask of the controlled converter.
- The LED named "OK" will flash.
- With the button "MODE" select the corresponding pulse form.
- Now the LEDs to the "pulse form" and to the "bridge topology" will light up.
- Now actuate the knob "OK" for the correct pulse form and the recognized bridge.
- If the correct LED does not light up, i.e. by wrong recognizing bridge, please check the following points:
  1. Does the correct mask lay on the "Phase Commutated Converter"?
  2. Is the mask well contacted with the "Network controlled converter", so the four optical sensors can detect the pattern on the back side of the mask?
  3. Are the "Converter Control Unit" and the "Phase Commutated Converter" connected by the cable with the 25 pin D-sub?
  4. If the right LED does not shine, please change manually the settings using the knobs "MODE" and "COMMUTATION".
- Press the button "OK" if the "LEDs for the bridge topology" of the "Converter Controller Unit" light up.

Do not press "OK" if the right LED does not light up!

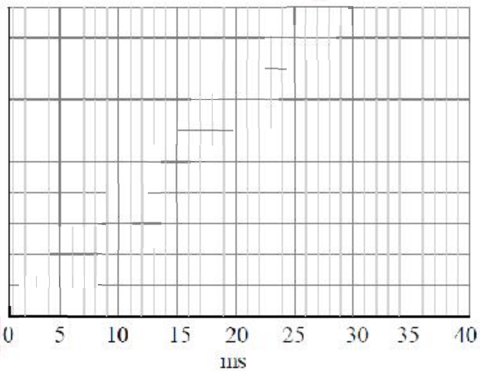
- Turn the knob to the right or to the left to change the delay angle
- Load for example the CASSY Lab file named W1C_R_90.labx to display the line diagrams of the "AC Static converter with a Resistive load" by 45°.
- Start the measurement by pressing F9.
- Repeat the measurement for the angles 0°, 30°, 45°, 90°, 120°, and 135°.

Experimental Procedure

2.1 AC Controller with Two-Anti-Parallel SCRs

Notes:

- *<u>Do not turn on any part of the equipment without a prior notice from the supervisor</u>*
- Type of load used: Resistive – inductive load: 33Ω (3 x 100Ω resistances in parallel) – 50mH (1 inductor)
- Mask (Bridge topology): “735 012 – 11 W1C”
- Pulse form: “Pulse”
- Use CASSY and its associate software (CASSY LAB) to measure/plot the currents and voltages in the AC Controller. To plot the time profiles appropriately, open the CASSY Lab file W1C_R_90.labx, for an angle of 90°, and adjust the new plots’ settings to be similar to those in the file you have just opened; set the time interval to 40ms.



- **In all the circuits to be connected, ignore the measurement probes; instead of an Ammeter put a short circuit, and just open circuit the Voltmeter.**

Symbols Table:

i_s : the input current

u_{s01} : the input voltage

u_V : the diode (valve) voltage

i_v : the valve current

u_d : the output voltage

i_d : the output current

I) AC Voltage Controller with Resistive Load

- Connect the components as shown in Figure 2.1. The load is purely resistive of 33.3Ω (3 resistors in parallel of 100Ω each)
- **Connect one transformer secondary to produce a phase-to-neutral voltage of 45V**

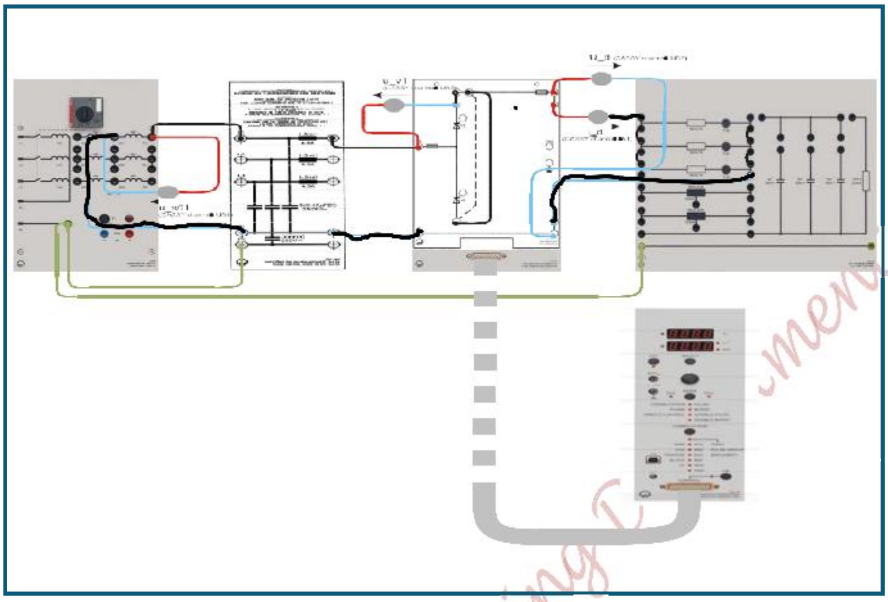


Figure 2.1 Configuration of an AC Voltage Controller supplying a resistive load

1) Initially, connect the CASSY probes to measure/plot the input voltage (u_{s01}), and valve voltage (u_{v1}); using CASSY LAB software
2) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle of 90°

Ask

3) Turn on the Transformer Supply Voltage Cat. No. 726 80
4) Plot the traces of the input voltage (u_{s01}), and the valve voltage (u_{v1}); take screen shots of these plots!
5) Measure the rms value of the input voltage (u_{s01}); using CASSY LAB software
6) Turn off the Transformer Supply Voltage Cat. No. 726 80
7) Connect the voltage probe of CASSY to measure/plot the output voltage (u_d), and the current probe to measure/plot the output current (i_d)

Ask

8) Turn on the Transformer Supply Voltage Cat. No. 726 80
9) Plot the traces of the output voltage (u_d), and the output current (i_d); take screen shots of these plots!
10) Measure the rms and average values of the output voltage (u_d) and the output current (i_d); using CASSY LAB software! Comment on the ratio between the measured voltage and current values. Comment on the average values obtained for this AC Controller!
11) Turn off the Transformer Supply Voltage Cat. No. 726 80
12) Repeat steps 2) to 10) to for a delay angle of 135°

13) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle (α°) ranging from 0° to 150° in 30° step to fill in Table 2.1.

Table 2.1: The effect of SCRs' delay angle on the rms values of the output

Delay angle (α°)	0°	30°	60°	90°	120°	150°
The rms output voltage (u_d (α)) [V]						
The rms output current (i_d (α)) [A]						
Normalized rms output voltage u_d (α) / u_d (α=0°)						
Normalized rms output current i_d (α) / i_d(α=0°)						
Calculated (Theoretical) rms output voltage [V]						
Normalized theoretical rms output voltage, u_d (α) / u_d (α=0°)						

14) Turn off the Transformer Supply Voltage Cat. No. 726 80; ***keep the connections unchanged***

15) Plot the control characteristic; the normalized measured and calculated output voltage versus the delay angle α

16) Compare the experimental and theoretical values! Explain!

17) Comment on the voltage and current waveforms of the SCRs!

II) AC Voltage Controller with Inductive Load

Modify the load connections to be as shown in Figure 2.2; the load is purely inductive of 50mH (1 inductor alone).

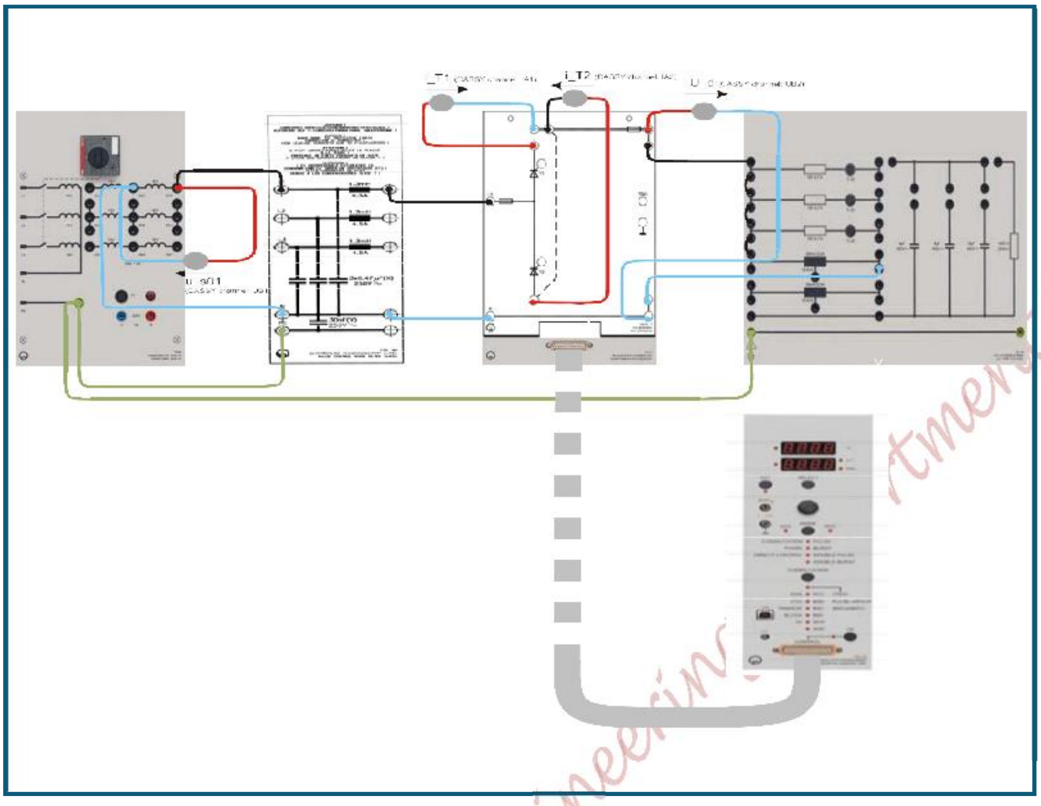


Figure 2.2 Configuration of an AC Voltage Controller supplying a 50mH inductive load

Symbols Table:

u_{s01} : the input voltage
u_d : the output voltage
i_d : the output current
i_{T1} : the valve current
i_{T2} : the valve current

1) Initially, connect the CASSY probes to measure/plot the input voltage (u_{s01}), and valve voltage (u_{v1}); using CASSY LAB software
2) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle of 90°
3) Turn on the Transformer Supply Voltage Cat. No. 726 80 (Ask)
4) Plot the traces of the input voltage (u_{s01}), and the valve voltage (u_{v1}); take screen shots of these plots!
5) Measure the rms value of the input voltage (u_{s01}); using CASSY LAB software
6) Turn off the Transformer Supply Voltage Cat. No. 726 80
7) Connect the voltage probe of CASSY to measure/plot the output voltage (u_d), and the current probe to measure/plot the output current (i_d)

Ask

8) Turn on the Transformer Supply Voltage Cat. No. 726 80
9) Plot the traces of the output voltage (u_d), and the output current (i_d); take screen shots of these plots!
10) Measure the rms and average values of the output voltage (u_d) and the output current (i_d); using CASSY LAB software!
11) Turn off the Transformer Supply Voltage Cat. No. 726 80
12) Repeat steps 2) to 10) to for a delay angle of 135°
13) Turn off the Transformer Supply Voltage Cat. No. 726 80; ***keep the connections unchanged***

Discussion:

a. Compare the output voltage in the two cases of delay angle for the inductive load.
b. Compare the rms values of the output voltage obtained with the inductive load, with the values of the comparative cases obtained for the resistive load in part **I**)! Explain!
c. What is the effect of the inductive load, compared to the resistive load, on the controllably of the AC voltage controller?

III) AC Voltage Controller with Resistive - Inductive Load

Modify the load connections to be as shown in Figure 2.3; the load is an RL load consisting of 33.3Ω (3 resistors in parallel, of 100Ω each) in series with an inductor of 50mH (1 inductor in series with the parallel resistors).

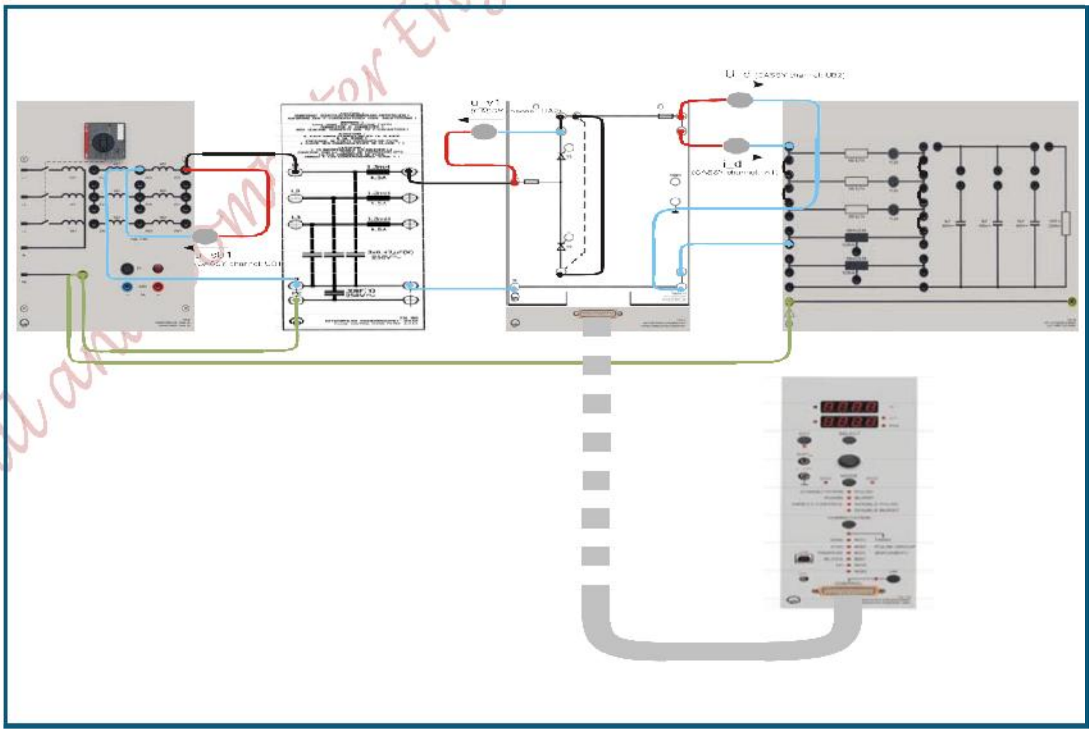


Figure 2.3 Configuration of an AC Voltage Controller supplying an RL load of 33Ω in series with 50mH

Symbols Table:

u_{s01} : the input voltage

u_d : the output voltage

i_d : the output current

u_{v1} : the valve voltage

1) Initially, connect the CASSY probes to measure/plot the input voltage (u_{s01}), and valve voltage (u_{v1}); using CASSY LAB software
2) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle of 90°
3) Turn on the Transformer Supply Voltage Cat. No. 726 80 (Ask)
4) Plot the traces of the input voltage (u_{s01}), and the valve voltage (u_{v1}); take screen shots of these plots!
5) Measure the rms value of the input voltage (u_{s01}); using CASSY LAB software
6) Turn off the Transformer Supply Voltage Cat. No. 726 80
7) Connect the voltage probe of CASSY to measure/plot the output voltage (u_d), and the current probe to measure/plot the output current (i_d)
8) Turn on the Transformer Supply Voltage Cat. No. 726 80 (Ask)
9) Plot the traces of the output voltage (u_d), and the output current (i_d); take screen shots of these plots!
10) Measure the rms and average values of the output voltage (u_d) and the output current (i_d); using CASSY LAB software!
11) Turn off the Transformer Supply Voltage Cat. No. 726 80
12) Repeat steps 2) to 11) to for a delay angle of 135°

Discussion:

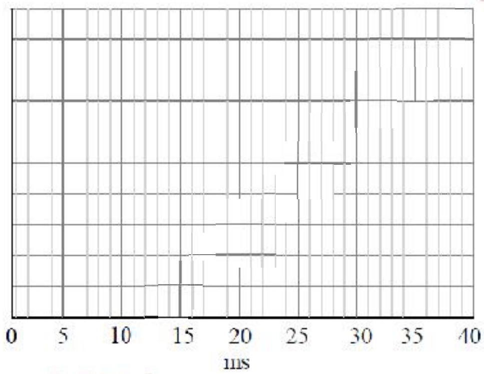
a. Compare the output voltage in the two cases of delay angle for the inductive load.

b. Compare the output voltages for the three types of loads; R, L, and RL!

2.2 AC Controller Implementing a TRIAC

Notes:

- *Do not turn on any part of the equipment without a prior notice from the supervisor*
- Type of load used: Resistive - inductive load: 33Ω (3 X 100Ω resistances in parallel) & 50mH
- Mask (Bridge topology): "735 012 – 13 TRIAC"
- Pulse form: "Pulse"
- Use CASSY and its associate software (CASSY LAB) to measure/plot the currents and voltages in the AC Controller. To plot the time profiles, for the angles 0°, 45°, 90° and 135°, appropriately, open the CASSY Lab file Triac_R_45.labx, and adjust the new plots' settings to be similar to those in the file you have just opened; set the time interval to 40ms.



Symbols Table:

u_{s01} : the input voltage

u_{V1} : the valve voltage

u_d : the output voltage

i_d : the output current

I) AC Voltage Controller Implementing a TRIAC and Supplying a Resistive Load

- Connect the components as shown in Figure 2.4. The load is purely resistive of 33.3Ω (3 resistors in parallel, of 100Ω each).
- **Connect one transformer secondary to produce a phase-to-neutral voltage of 45V**

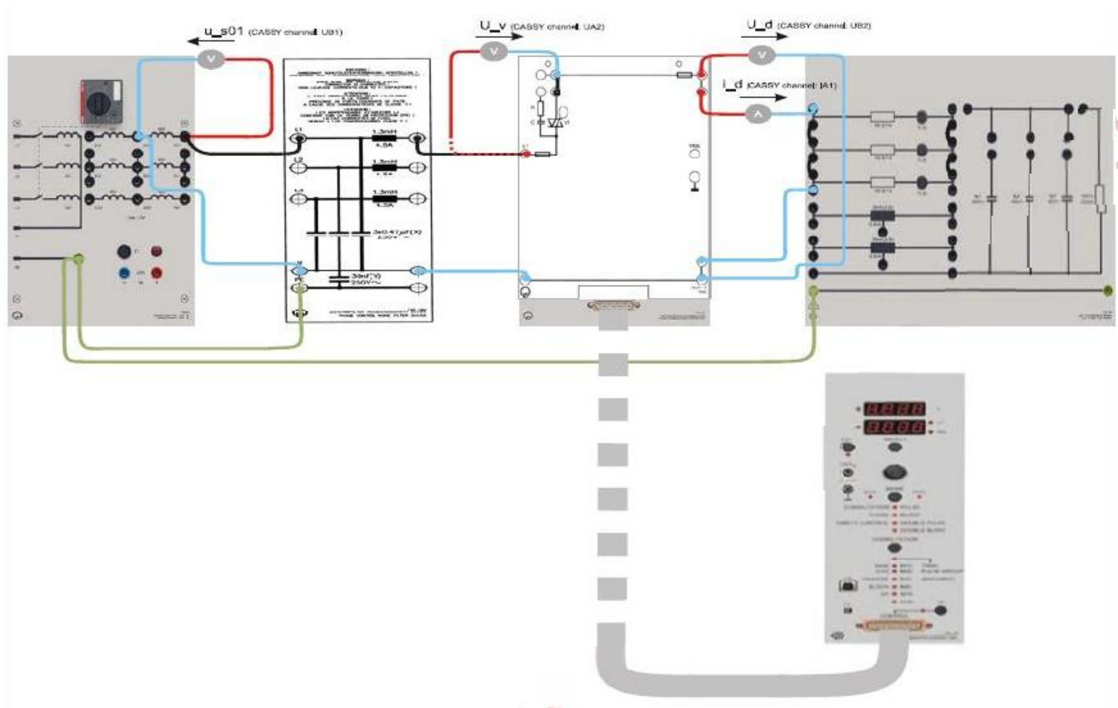


Figure 2.4 Configuration of an AC Voltage Controller implementing a TRIAC and supplying a purely resistive load of 33Ω

1) Initially, connect the CASSY probes to measure/plot the input voltage (u_{s01}), and valve voltage (u_{v1}); using CASSY LAB software
2) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle of **45º**
3) Turn on the Transformer Supply Voltage Cat. No. 726 80 (Ask)
4) Plot the traces of the input voltage (u_{s01}), and the valve voltage (u_{v1}); take screen shots of these plots!
5) Measure the rms value of the input voltage (u_{s01}); using CASSY LAB software
6) Turn off the Transformer Supply Voltage Cat. No. 726 80
7) Connect the voltage probe of CASSY to measure/plot the output voltage (u_d), and the current probe to measure/plot the output current (i_d)
8) Turn on the Transformer Supply Voltage Cat. No. 726 80 (Ask)
9) Plot the traces of the output voltage (u_d), and the output current (i_d); take screen shots of these plots!

10) Measure the rms and average values of the output voltage (u_d) and the output current (i_d); using CASSY LAB software! Comment on the ratio between the measured voltage and current values. Comment on the average values obtained for this AC Controller!

11) Turn off the Transformer Supply Voltage Cat. No. 726 80

12) Repeat steps 2) to 10) to for a delay angle of 135°

13) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle (α°) ranging from 0° to 150° in 30° step to fill in Table 2.2.

Table 2.2: The effect of the TRIAC delay angle on the rms values of the output

Delay angle (α°)	0°	30°	60°	90°	120°	150°
The rms output voltage (u_d (α)) [V]						
The rms output current (i_d (α)) [A]						
Normalized rms output voltage u_d (α) / u_d (α=0°)						
Normalized output current i_d (α) / i_d (α=0°)						
Calculated (Theoretical) rms output voltage [V]						
Normalized theoretical rms output voltage u_d (α) / u_d (α=0°)						

14) Turn off the Transformer Supply Voltage Cat. No. 726 80; ***keep the connections unchanged***

15) Plot the control characteristic; the normalized measured and calculated output voltage versus the delay angle α

16) Compare the experimental and theoretical values! Explain!

17) Comment on the voltage and current waveforms obtained with the TRIAC!

18) Connect the RC snubber across the TRIAC and repeat steps 2) to 11) for a delay angle of 45°

19) What effect does the RC snubber have on the value and shape of the output waveforms?!

II) AC Voltage Controller with Resistive - Inductive Load

Modify the load connections to be as shown in Figure 2.5; the load is RL load consisting of 33.3Ω (3 resistors in parallel, of 100Ω each) in series with an inductor of 50mH (1 inductor in series with the parallel resistors).

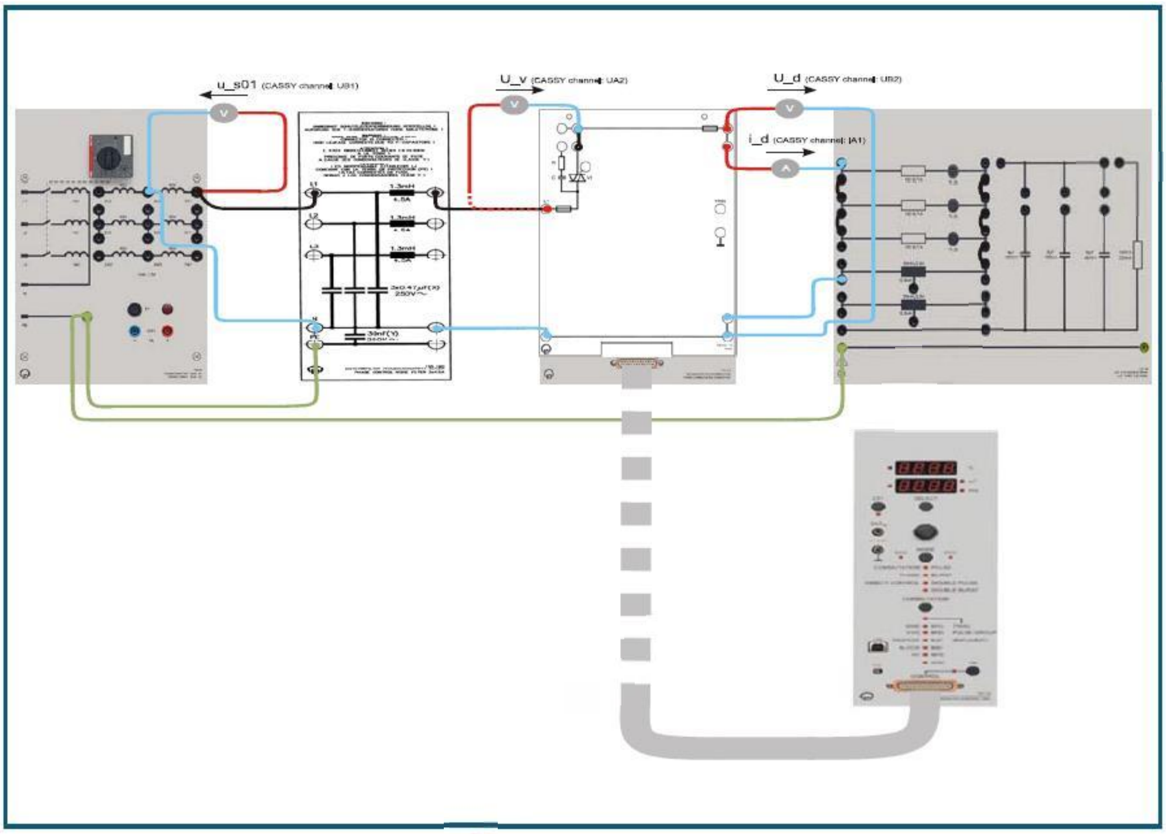


Figure 2.5 Configuration of an AC Voltage Controller implementing a TRIAC and supplying an RL load of 33Ω in series with a 50mH inductor

Symbols Table:

u_{s01} : the input voltage

u_d : the output voltage

i_d : the output current

u_v : the valve voltage

1) Initially, connect the CASSY probes to measure/plot the input voltage (u_{s01}), and valve voltage (u_{v1}); using CASSY LAB software
2) Adjust the Converter Control Unit (Cat. No. 735 122) to produce a firing angle of 90°

Ask

3) Turn on the Transformer Supply Voltage Cat. No. 726 80
4) Plot the traces of the input voltage (u_{s01}), and the valve voltage (u_{v1}); take screen shots of these plots!
5) Measure the rms value of the input voltage (u_{s01}); using CASSY LAB software

6) Turn off the Transformer Supply Voltage Cat. No. 726 80
7) Connect the voltage probe of CASSY to measure/plot the output voltage (u_d), and the current probe to measure/plot the output current (i_d)

Ask

8) Turn on the Transformer Supply Voltage Cat. No. 726 80
9) Plot the traces of the output voltage (u_d), and the output current (i_d); take screen shots of these plots!
10) Measure the rms and average values of the output voltage (u_d) and the output current (i_d); using CASSY LAB software!
11) Turn off the Transformer Supply Voltage Cat. No. 726 80
12) Repeat steps 2) to 11) to for a delay angle of 135^{o}

Discussion:

a. Compare the output voltage in the two cases of delay angle for the inductive load.

b. Compare the output voltages for the three types of loads; R, L, and RL!

c. How do you compare the results obtained with a TRIAC, as a valve, to those obtained with a two-antiparallel SCRs?