**EXPERIMENT 3**

**POWER CONTROL IN AC CIRCUITS USING AN AC CHOPPER: LAMP DIMMER**

**Introduction:**

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.

**Equipments:**

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>726 86</td>
<td>DC Power Supply</td>
</tr>
<tr>
<td>734 02</td>
<td>Reference Variable Generator</td>
</tr>
<tr>
<td>735 12</td>
<td>Control Unit Two Pulse</td>
</tr>
<tr>
<td>726 80</td>
<td>Transformer 45/90, 3N</td>
</tr>
<tr>
<td>735 09</td>
<td>Load Power Electronics</td>
</tr>
<tr>
<td>735 04</td>
<td>Triac</td>
</tr>
<tr>
<td>735 261</td>
<td>Isolation Amplifier (x 2)</td>
</tr>
<tr>
<td></td>
<td>Multi-meter (x 2)</td>
</tr>
<tr>
<td></td>
<td>Oscilloscope</td>
</tr>
</tbody>
</table>

**General Information:**

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.

Voltage $v_s$ is a sinusoidal input to the basic circuit shown in Figure 1 (it can be considered as the mains $220\text{V}_{\text{RMS}}, 50\text{ Hz})$. 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 $180^\circ$ ($\pi$ radians) apart. The waveforms for the input voltage, output voltage and gating signals for $T_1$ and $T_2$ are shown in Figure 2.

**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 ($i_{g2}$).
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:

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

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

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

\[
0 \leq \alpha \leq \pi
\]

![Graph showing variation of \( V_{o,rms} \) and \( V_{s,rms} \) as a function of firing angle \( \alpha \).](image)

**Figure 2.** Variation of \( V_{0,rms} / V_{s,rms} \) as a function of firing angle \( \alpha \).

Students are advised to take a look at the behavior, triggering properties and control range of a phase controlled AC for resistive-inductive loading from reference [1] or other references.

**Procedure of Experiment:**

Students will perform four procedures using the equipment supplied by the laboratory. Procedure 1 gives information about the working principle of the triggering unit. In procedures 2 - 4 you will set the phase controlled AC chopper shown in Figure 1 for resistive (\( R \)), resistive inductive (\( R - L \)) and purely inductive loads, respectively and observe their behavior.
Note: When capturing oscilloscope screen and include in your report, you have to specify the time base (… ms/div) and scale of voltages (…V/div).

1. Triggering Circuit

Circuit Set-up:
Set the circuit shown in Figure 3.

- View both the AC line voltage and the trigger signals on the scope. Observe the change in triggering angle as you change the reference voltage. Obtain the time waveforms of CH1 and CH2 at 1V, 5V and 9V control signal levels and capture the oscilloscope screen.

Change the reference voltage from 0 to 10 volts and write down the triggering angles in Table 2.

2. Phase Controlled AC Chopper with Resistive Load

Circuit Set-up:
Set the circuit shown in Figure 4.
Set:
\[ v_s = 90 \text{ V} \quad \text{and} \quad R = 100 \Omega \]

- Observe the change in output voltage and output current for different triggering angles.

- Obtain the time waveforms of the output current and output voltage waveforms for triggering angle \( \pi/2 \), measure their RMS values and capture the oscilloscope screen. Write result in Table 3.

What is the control range of triggering angle \( \alpha \) for resistive loads? Write result in Table 4.

### 3. Phase Controlled AC Chopper with Resistive-Inductive Load

**Circuit Set-up:**

Set the circuit shown in Figure 5.

![Figure 5. Phase Controlled AC Chopper with Resistive-Inductive Load](image-url)

Set:
\[ v_s = 90 \text{ V} \quad \text{and} \quad R = 100 \Omega \quad \text{and} \quad L = 50 \text{ mH} \]

- Observe the change in output voltage and output current for different triggering angles.

- Obtain the time waveforms of the output current and output voltage waveforms for triggering angle \( 3\pi/4 \), measure their RMS values and capture the oscilloscope screen. Write result in Table 3.

What is the control range of triggering angle \( \alpha \) for resistive inductive loads? Write result in Table 4.
4. Phase Controlled AC Chopper with Purely Inductive Load

**Circuit Set-up:**

Set the circuit shown in Figure 6.

Set:
\[ v_s = 45 \text{ V} \quad \text{and} \quad L = 50 \text{ mH} \]

![Phase Controlled AC Chopper with Purely Inductive Load Circuit](image)

**Figure 6.** Phase Controlled AC Chopper with Purely Inductive Load

- Observe the change in output voltage and output current for different triggering angles.
- Obtain the time waveforms of the output current and output voltage waveforms for triggering angle \( \pi/4 \), measure their RMS values and capture the oscilloscope screen. Write result in Table 3.

What is the control range of triggering angle \( \alpha \) for purely inductive loads? Write result in Table 4.

**IMPORTANT:**

Always check and be cautious on following the safety rules given below:

1. Before applying the mains power, always show your set-up to laboratory assistants or course instructor.
2. Check if your circuit set-up is correct.
3. Check if the protection ground is connected.
4. Always set the pulse controller reference voltage to zero before applying the mains.
5. Use a multi-meter to check the current to protect the equipment from excessive current.
Conclusion:

You have seen the basic properties and working principle of a phase controlled AC chopper with various load types. During the preparation of your final report it is asked from you to answer the following questions.

1. Draw graph representing the delay angle a function of variable reference voltage according to the data you have recovered from procedure 1.
   a. Derive an equation that fits the graph.
   b. What is reference voltage values for the phase angles; $\pi/4$, $3\pi/7$ and $\pi/6$

2. Calculate theoretically the values of RMS output voltage and RMS output current of the phase controlled AC chopper with resistive load (in procedure 2) from the waveforms for firing angle $\pi/2$.

3. Calculate theoretically the values of RMS output voltage of the phase controlled AC chopper with resistive-inductive load (in procedure 3) from the waveforms for firing angle $3\pi/4$.

4. Calculate theoretically the values of RMS output voltage of the phase controlled AC chopper with inductive load (in procedure 4) from the waveforms for firing angle $\pi/4$.

5. Make quick research on the internet about light dimmer controlled with triacs. Find a circuit (not too complicated) and shortly explain its behavior.

References:

### Table 2: Variation of firing angle with control voltage

<table>
<thead>
<tr>
<th>Variable Reference Voltage (V)</th>
<th>Triggering Angle (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Measurement values

<table>
<thead>
<tr>
<th>Resistive Load</th>
<th>Resistive-Inductive Load</th>
<th>Inductive Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firing angle (degrees)</td>
<td>Firing angle (degrees)</td>
<td>Firing angle (degrees)</td>
</tr>
<tr>
<td>$V_{\text{out,RMS}}$ (V)</td>
<td>$I_{\text{out,RMS}}$ (A)</td>
<td>$V_{\text{out,RMS}}$ (V)</td>
</tr>
<tr>
<td>----------------</td>
<td>--------------------------</td>
<td>----------------</td>
</tr>
</tbody>
</table>

### Table 4: Control range of firing angles for different loads

<table>
<thead>
<tr>
<th>Resistive Load</th>
<th>Resistive-Inductive Load</th>
<th>Inductive Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firing angle range (degrees)</td>
<td>Firing angle range (degrees)</td>
<td>Firing angle range (degrees)</td>
</tr>
<tr>
<td>Min</td>
<td>Max</td>
<td>Min</td>
</tr>
</tbody>
</table>

This form must be filled in using a PEN. Use of PENCIL IS NOT ALLOWED.