SINGLE-PHASE FULL-WAVE UNCONTROLLED and CONTROLLED RECTIFIERS

1. Introductıon

Rectifiers are used to convert AC input voltage into DC output voltage. Rectifiers can be classified according to the following criteria:

- The number of phases of the AC voltage source supplying the rectifier – single-phase and three-phase rectifiers.
- The controllability of the average output voltage – uncontrolled and controlled rectifiers.
- The ability to change the polarity of the load voltage and current – semi controlled and fully controlled rectifiers.
- The number of pulses of load current during one period of the source voltage – half-wave and full-wave rectifiers.

2. Single-Phase Full-Wave Uncontrolled Rectifier

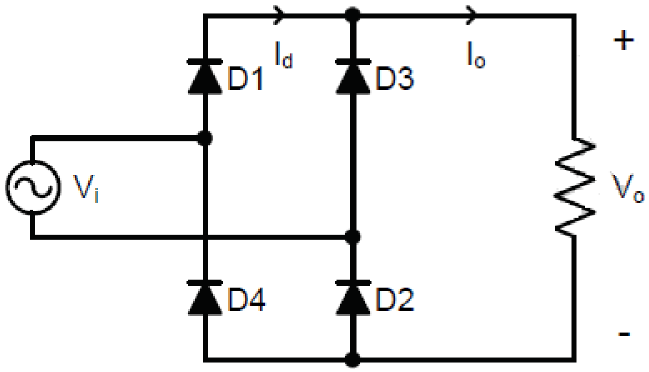
2.1. The Purpose of Experiment

- To understand the operating principle of the single-phase full-wave uncontrolled rectifier.
- To measure the current and voltage of the single-phase full-wave uncontrolled rectifier.
- To calculate the power of the single-phase full-wave uncontrolled rectifier.
- To verify the characteristics of the single-phase full-wave uncontrolled rectifier.

2.2. General Information

Compared to the single-phase half-wave uncontrolled rectifier, the single-phase full-wave uncontrolled rectifier (bridge rectifier) has better characteristics. For this reason, the single-phase full-wave uncontrolled rectifier is commonly used in power electronics applications.

In Figure 1, the circuit diagram and waveform of the single-phase full-wave uncontrolled rectifier with an omic load are shown. During the positive cycle of V_i, diodes D1 and D2 are forward biased, while diodes D3 and D4 are reverse biased. If the diodes are considered ideal, V_o will be equal to the positive cycle of V_i. During the negative cycle of V_i, diodes D3 and D4 are forward biased, while diodes D1 and D2 are reverse biased. Thus, full-wave rectification is achieved.



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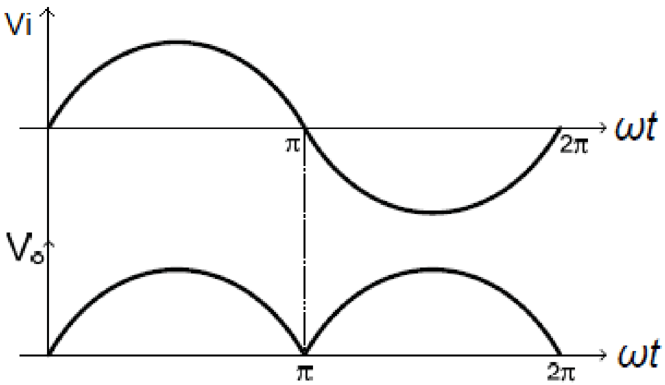


(b)

Figure 1. Circuit Diagram and Waveforms of a Single-Phase Full-Wave Rectifier with an Omic Load

Before defining the characteristics of this circuit, the symbols and abbreviations to be used are provided below.

V_i	:	Input Voltage
V_m	:	Maximum Input Voltage
I_m	:	Maximum Input Current
$V_{i(rms)}$	:	Nominal Input Voltage
V_o	:	Output Voltage
$V_{o(ort)}$	:	Average Output Voltage
$V_{o(rms)}$	:	Nominal Output Voltage
$I_{o(ort)}$	:	Average Output Current
$I_{o(rms)}$	:	Nominal Output Current
$I_{d(ort)}$	:	Average Current of Diode
$I_{d(rms)}$	:	Nominal Current of Diode
$P_{o(ort)}$	:	Average Output Power
$P_{o(rms)}$	:	Nominal Output Power

η_r : Efficiency of Rectifier

P_d : Ripple Power

λ : Ripple Coefficient

$V_{r(rms)}$: Nominal Voltage of Ripple

The following equations define the important characteristics of the single-phase full-wave uncontrolled rectifier with a purely resistive load.

$$V_m = \sqrt{2}V_{i(rms)} \quad , \quad V_i = V_m \sin(\omega t) \tag{1}$$

$$V_{o(ort)} = \frac{1}{\pi}\int_0^{\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{2V_m}{\pi} = 0.9V_{i(rms)} \tag{2}$$

$$V_{o(rms)} = \sqrt{\frac{1}{\pi}\int_0^{\pi} (V_m \sin(\omega t))^2 d(\omega t)} = \frac{V_m}{\sqrt{2}} = V_{i(rms)} \tag{3}$$

$$I_m = \frac{V_m}{R} \quad , \quad I_{o(ort)} = \frac{V_{o(ort)}}{R} = \frac{2I_m}{\pi} \quad , \quad I_{o(rms)} = \frac{V_{o(rms)}}{R} = \frac{I_m}{\sqrt{2}} \tag{4}$$

$$I_{d(ort)} = \frac{I_{o(ort)}}{2} \quad , \quad I_{d(rms)} = \sqrt{\frac{1}{2\pi}\int_0^{\pi} (I_m \sin(\omega t))^2 d(\omega t)} = \frac{I_m}{2} = \frac{\pi}{4} I_{o(ort)} \tag{5}$$

$$P_{o(ort)} = \frac{V_{o(ort)}^2}{R} = V_{o(ort)} I_{o(ort)} \quad , \quad P_{o(rms)} = \frac{V_{o(rms)}^2}{R} = V_{o(rms)} I_{o(rms)} \tag{6}$$

$$\eta_r = 100 \times \frac{P_{o(ort)}}{P_{o(rms)}} = 100 \times \frac{0.9^2}{1^2} = 80.1\ \% \tag{7}$$

$$P_d = P_{o(rms)} - P_{o(ort)} = \frac{V_{r(rms)}^2}{R} \tag{8}$$

$$\lambda = \frac{V_{r(rms)}}{V_{o(ort)}} = \frac{\sqrt{V_{o(rms)}^2 - V_{o(ort)}^2}}{V_{o(ort)}} = 0.482 \tag{9}$$

The characteristics of the single-phase full-wave rectifier, such as rectifier efficiency and ripple factor, are superior to those of the single-phase half-wave rectifier. Additionally, as can be seen in Figure 1(b), another advantage of the single-phase full-wave rectifier is that the ripple frequency of the output voltage is twice the source frequency. This results in a smaller ripple component after filtering.

The only disadvantage of the single-phase full-wave bridge rectifier is the requirement of four diodes. However, during each half-cycle of the input voltage, two diodes are forward biased while the other two are reverse biased. Therefore, the Peak Inverse Voltage (PIV) required for each diode is only half of the peak input voltage.

3. Single Phase Full-Wave Controlled Rectifiers

3.1. The Purpose of Experiment

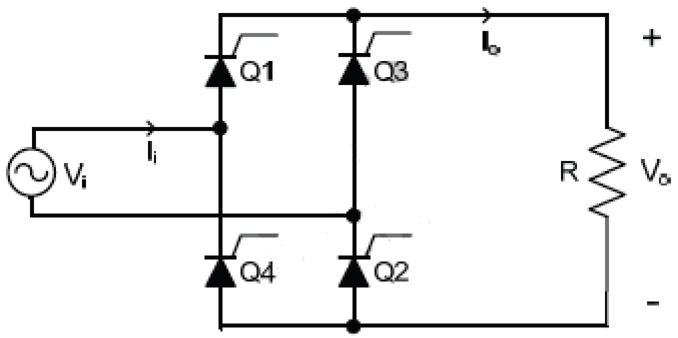
- To understand the operating principle of the single-phase full-wave controlled rectifier.
- To measure the current and voltage of the single-phase full-wave controlled rectifier.
- To investigate the effect of the thyristor triggering angle on the output voltage of the single-phase full-wave controlled rectifier.
- To verify the characteristics of the single-phase full-wave controlled rectifier.

3.2. General Information

The single-phase full-wave controlled rectifier circuit is similar to the single-phase full-wave diode rectifier. To control the average value of the output voltage, thyristors (SCRs) are used instead of diodes. By varying the triggering angle (α) of the thyristor, the average output voltage of the single-phase full-wave controlled rectifier can be adjusted.

In Figure 2, the circuit diagram and waveforms of the single-phase full-wave controlled rectifier with an omic load are shown. During the positive cycle of V_i, at $\omega t = \alpha$, thyristors Q1 and Q2 are triggered and conduct, and V_i is connected to the load through Q1 and Q2 in the range $\alpha \leq \omega t \leq \pi$. During the negative cycle of V_i, at $\omega t=\pi+\alpha$, thyristors Q3 and Q4 are triggered and conduct, and V_i is connected to the load through Q3 and Q4 in the range $\pi+\alpha \leq \omega t \leq 2\pi$. The output voltage waveform corresponding to the variation of the triggering angle (α) between 0∘ and 180∘ is shown in Figure 2(b). The output current I_o and output voltage V_o have the same waveform, but their amplitudes are different. It should be noted that the triggering signals of Q3 and Q4 are 180° out of phase with respect to the gate signals of Q1 and Q2. The triggering signals of Q1 and Q2 (Q3 and Q4) must be electrically isolated, otherwise, a short circuit will occur.

The single phase full-wave controlled rectifier is also called a **two pulse controlled rectifier** because it provides two output pulses to the load during one full period of the input voltage V_i. This rectifier eliminates the disadvantage of the half-wave controlled rectifier, which contains a DC component in the input current. As shown in Figure 2(b), the input current I_i has a symmetrical waveform and does not contain a DC component.



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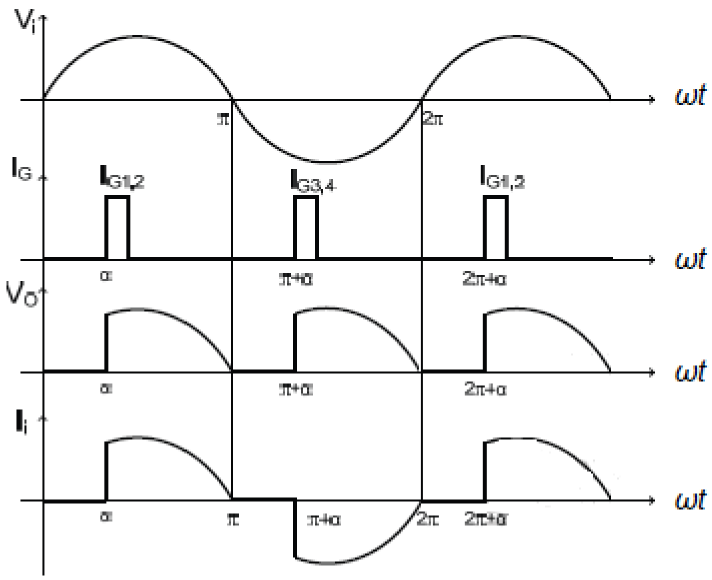


(b)

Figure 2. Circuit diagram and waveforms of an omic loaded single phase full-wave controlled rectifier

As shown in Figure 2(b), the average value of the output voltage can be changed by varying the thyristor firing angle α between 0° and 180°. When α=0, this circuit has the same function as a full-wave diode rectifier, and in this case, the average output voltage is denoted as V_{d0}. When α≠0, the average output voltage is denoted by $V_{d\alpha}$. For example, for α=90°, the average output voltage is V_{d90}.

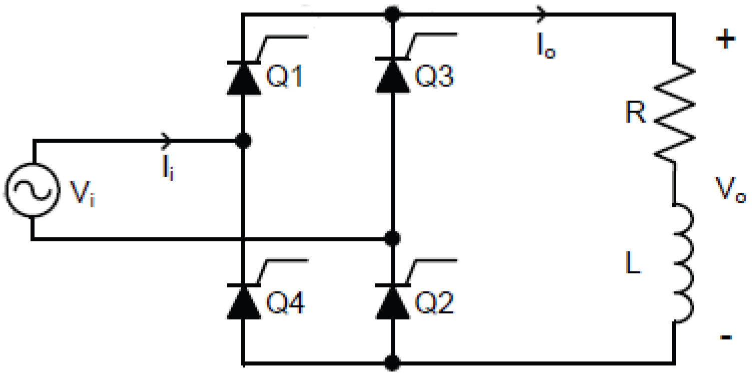
$$V_{d0} = \frac{1}{\pi}\int_{0}^{\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{2}{\pi} V_m \tag{10}$$

$$V_{d\alpha} = \frac{1}{\pi}\int_{\alpha}^{\pi} V_m \sin(\omega t)\, d(\omega t) = \frac{1}{\pi} V_m (1 + \cos\alpha) \tag{11}$$

If equation (10) is substituted into equation (11),

$$V_{d\alpha} = 0.45V_{i(rms)}(1 + \cos\alpha) = \frac{V_{d0}}{2}(1 + \cos\alpha) \quad (12)$$

Here, $V_{i(rms)}$ is the RMS input voltage. By changing the trigger angle α from 0^o to 180^o, the average output voltage can be changed from $0.9V_{i(rms)}$ to 0 V. Thus, the maximum value of $V_{d\alpha}$ is $0.9V_{i(rms)}$.



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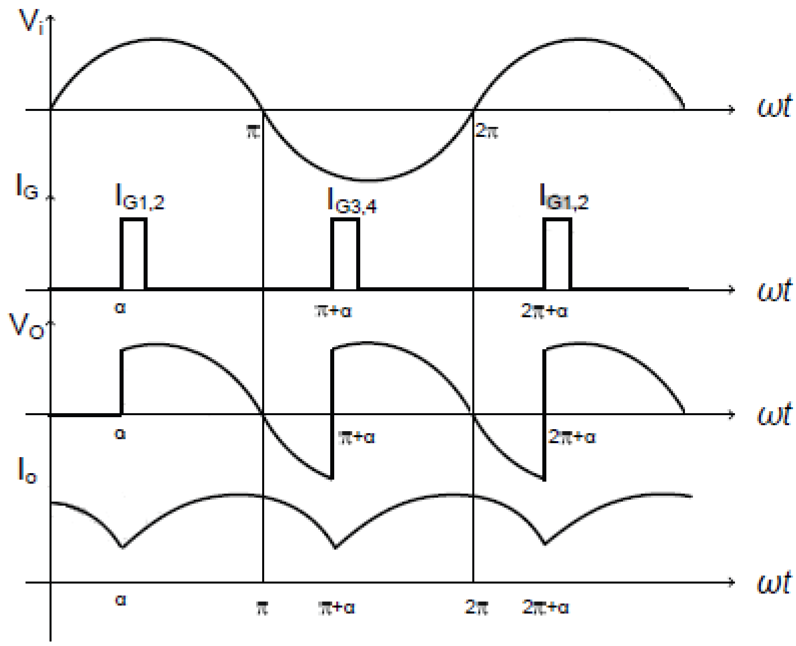

(b)

Figure 3. Circuit diagram and waveforms of a single phase full-wave controlled rectifier loaded with RL

Figure 3 shows the circuit and waveforms of a single-phase full-wave controlled rectifier with an RL load. During the positive cycle of V_i, at ωt=α, Q1 and Q2 are triggered and conduct, connecting V_i to the load through Q1 and Q2 in the range α≤ωt≤π. During this time, the L inductance stores energy in the form of a magnetic field. During the negative cycle of V_i, in the range π≤ωt≤π+α, Q1 and Q2 continue to conduct, and during this range, the inductance L discharges the stored energy. At ωt=π+α, Q1 and Q2 are off, and Q3 and Q4 are on.

From Figure 3(b), the average output voltage of the single phase full-wave controlled rectifier can be made positive or negative by changing the trigger angle α. In the case of a purely inductive load, the load current can be continuously varied, and the output voltage can be expressed as follows.

$$V_{d\alpha} = \frac{1}{\pi} \int_{\alpha}^{\pi+\alpha} V_m \sin(\omega t)\, d(\omega t) = \frac{2}{\pi} V_m \cos\alpha \tag{13}$$

If equation (10) is substituted into equation (13),

$$V_{d\alpha} = 0.9 V_{i(rms)} \cos\alpha = V_{d0} \cos\alpha \tag{14}$$

By changing the trigger angle α from 0° to 180°, the average output voltage can be changed from $-0.9V_{i(rms)}$ to $0.9V_{i(rms)}$. Thus, the maximum value of $V_{d\alpha}$ is $0.9V_{i(rms)}$.

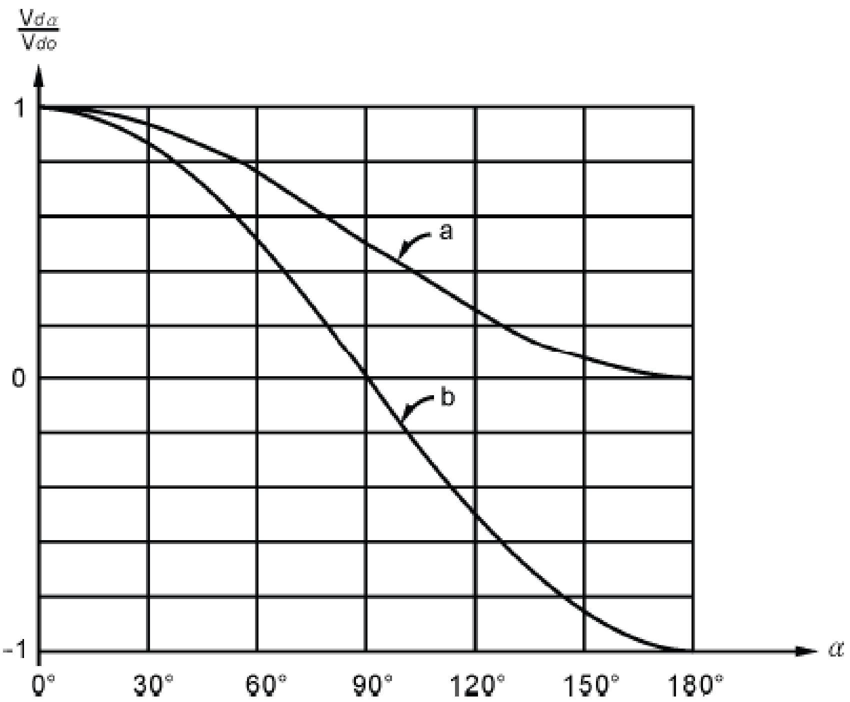

Figure 4. $V_{d\alpha}/V_{d0} - \alpha$ curve of a single phase full-wave controlled rectifier

According to equations (12) and (14), the variation of $V_{d\alpha}/V_{d0}$ with according to the trigger angle α in a single phase full-wave controlled rectifier is shown in Figure 4. Curve a shows the characteristic curve of a rectifier with a purely resistive load, while curve b shows the characteristic curve of a rectifier with a purely inductive load. The characteristic curve of a rectifier with an inductive load should be between curves a and b.

4. Experimental Procedure

4.1. Single Phase Full-Wave Uncontrolled Rectifier

1. Using the connection cables and bridging clips, make the connections shown in Figure 5. Short-circuit the terminals of the inductive load. This will ensure that only a resistive load remains in the circuit.
2. To observe the voltage waveforms before and after rectification, use the CH1 input of the oscilloscope to measure the AC source voltage and the CH2 input to measure the load voltage. ***Measurements will be performed using the oscilloscope measurement unit***. Record the obtained waveforms in the report log.
3. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.
4. Use the CH1 input of the oscilloscope to measure the voltage across diode D1, and the CH2 input to measure the voltage across diode D2. Record the obtained waveforms in the report log.
5. Connect the inductive load to the circuit. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.

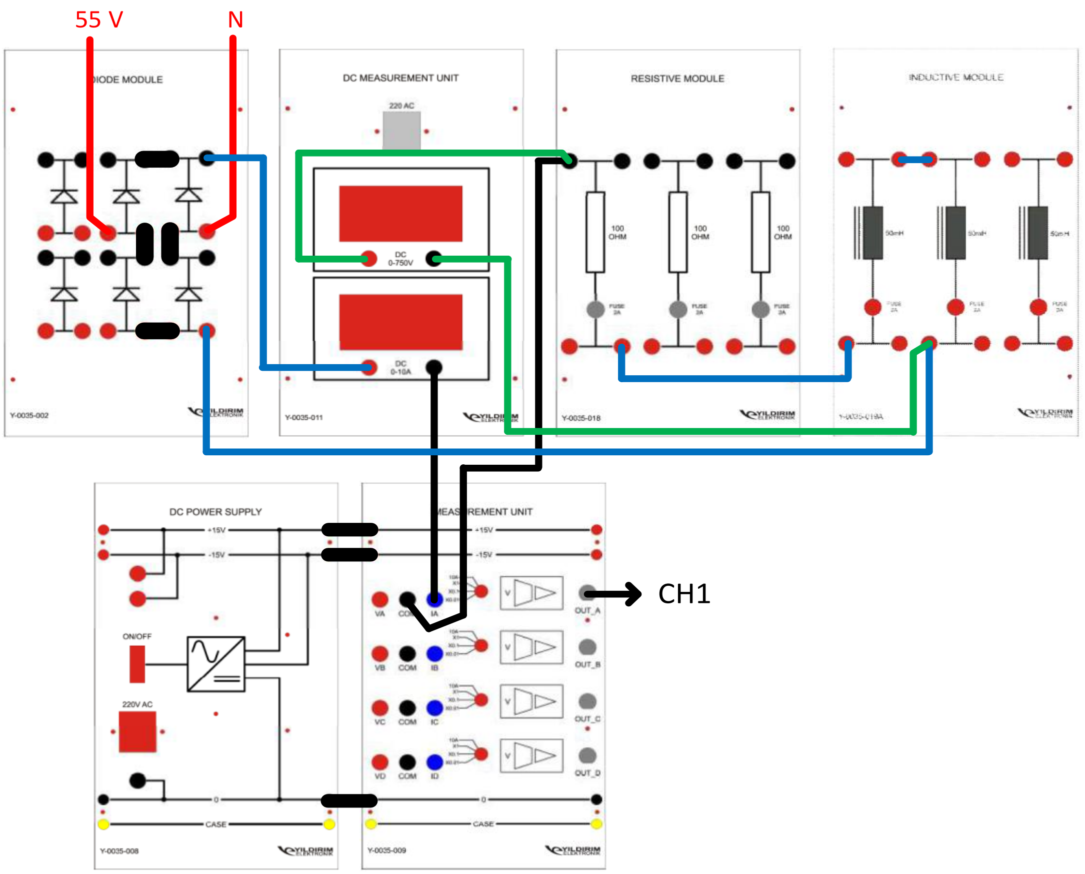

Figure 5. Single Phase Full-Wave Uncontrolled Rectifier Connection

4.2. Single Phase Full-Wave Controlled Rectifier (Omic Load)

1. Using the connection cables and bridging clips, make the connections shown in Figure 6. Short-circuit the terminals of the inductive load. This will result in only a resistive load in the circuit.
2. To observe the voltage waveforms before and after rectification, use the CH1 input of the oscilloscope to measure the AC source voltage and the CH2 input to measure the load voltage. ***The measurements will be made using the oscilloscope measurement unit.*** Record the obtained waveforms in the report log.
3. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.
4. Use the CH1 input of the oscilloscope to measure the T1 thyristor voltage and the CH2 input to measure the T2 thyristor voltage. Record the obtained waveforms in the report log.
5. Connect the inductive load to the circuit. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.

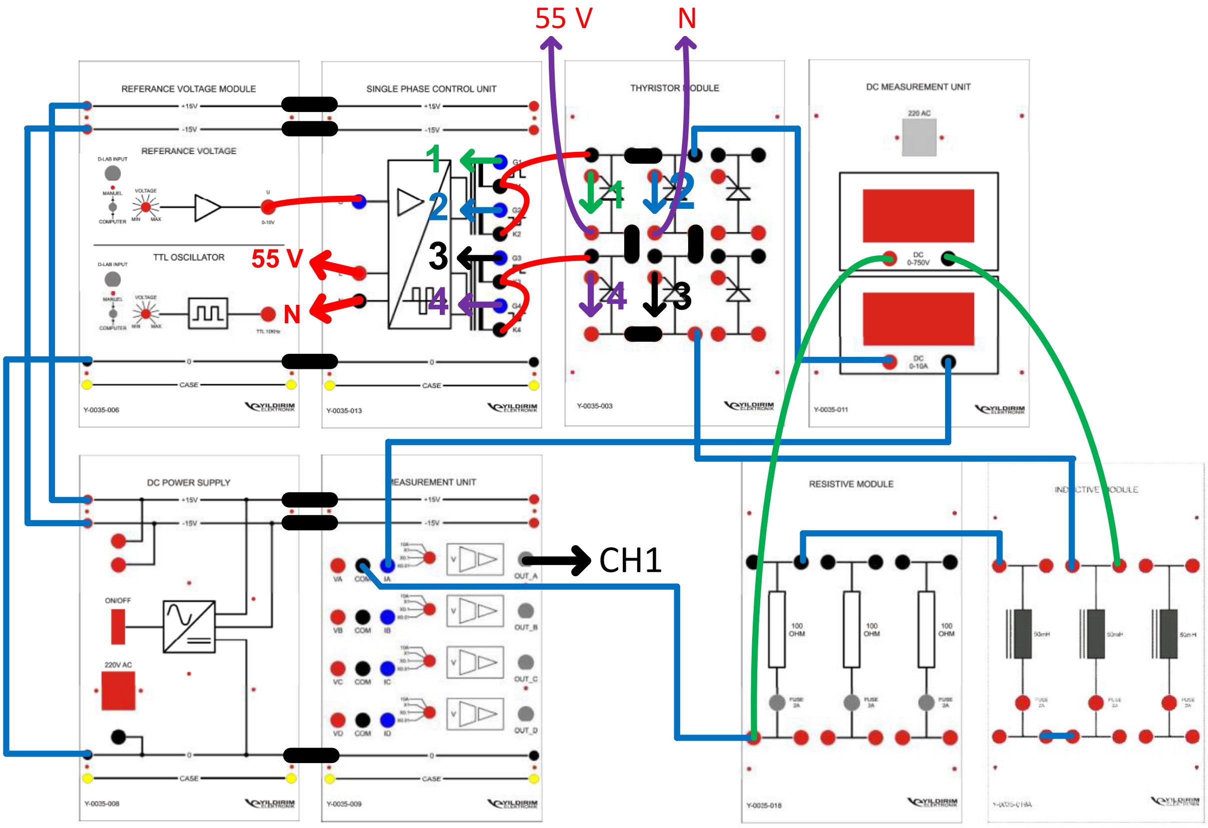

Figure 6.

4.2. Single Phase Full-Wave Controlled Rectifier (Inductive Load)

6. Using the connection cables and bridging clips, make the connections shown in Figure 7. Short-circuit the terminals of the inductive load. This will result in only a resistive load in the circuit.
7. To observe the voltage waveforms before and after rectification, use the CH1 input of the oscilloscope to measure the AC source voltage and the CH2 input to measure the load voltage. ***The measurements will be made using the oscilloscope measurement unit***. Record the obtained waveforms in the report log.
8. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.
9. Use the CH1 input of the oscilloscope to measure the T1 thyristor voltage and the CH2 input to measure the T2 thyristor voltage. Record the obtained waveforms in the report log.
10. Connect the inductive load to the circuit. Use the CH1 input of the oscilloscope to measure the load current and the CH2 input to measure the load voltage. Record the obtained waveforms in the report log.

Run the circuit and plot the waveform of the output voltage at the Y1 channel and the resistance voltage at the Y2 channel. Measure and record the average and RMS values of the output voltage and current. What effects did the inductive load cause in the bridge rectifier? In bridge rectifiers, under inductive load conditions, is there a need for a freewheeling diode (FWD) similar to half-wave rectifiers?

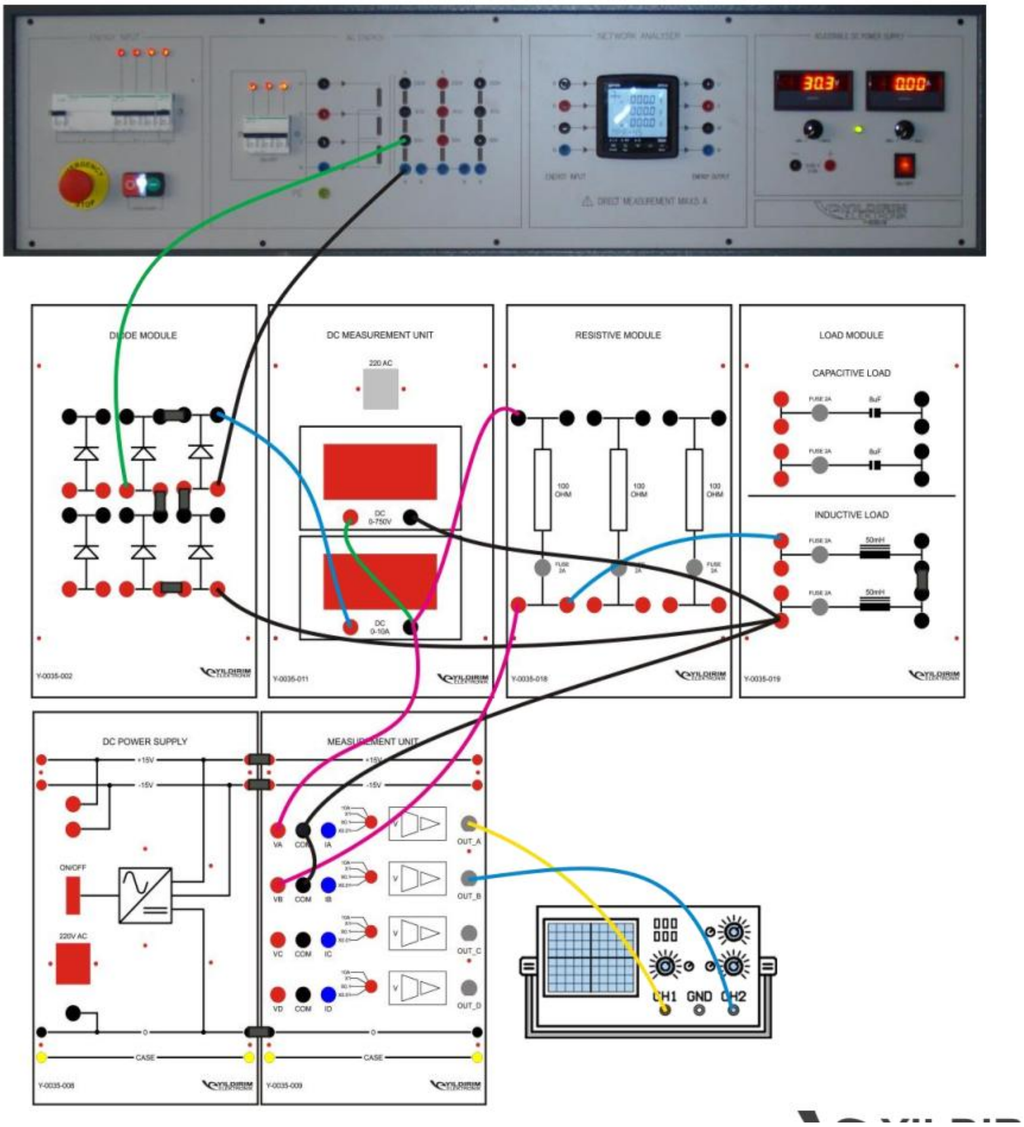
DIODE MODULE
DC MEASUREMENT UNIT
RESISTIVE MODULE
LOAD MODULE
CAPACITIVE LOAD
INDUCTIVE LOAD
DC POWER SUPPLY
MEASUREMENT UNIT
CH1
GND
CH2

Figure 7.