SINGLE-PHASE CONTROLLED RECTIFIER WITH MATLAB SIMULATION

1.0 AIM

Enable the students to understand the principle of Single Phase Half Wave Controlled Rectifier and Single Phase Full Wave Controlled Rectifier.

2.0 OUTCOMES

At the end of the session, students will be able to:-

a) Create the circuit of single phase half wave controlled rectifier and single phase full wave controlled rectifier using a MATLAB simulink.
b) Learn and explain the operation of single phase half wave controlled rectifier and single phase full wave controlled rectifier.
c) Determine the input voltage (Vs), inductor current (Io) and output voltage (Vo) waveforms.
d) Simulate and calculate the input voltage (Vs), inductor current (I_o) and output voltage (Vo).

3.0 MATERIAL NEEDED

1. MATLAB Version 2011a
2. SIMULINK
3. Personal Computer

4.0 THEORY

Controlled rectifiers are line commutated ac to dc power converters which are used to convert a fixed voltage, fixed frequency ac power supply into variable dc output voltage. The input supply fed to a controlled rectifier is ac supply at a fixed rms voltage and at a fixed frequency. By employing phase controlled thyristors in the controlled rectifier circuits, the variable dc output voltage and variable dc (average) output current can be obtain by varying the trigger angle (phase angle) at which the thyristors are triggered.

The thyristors are forward biased during the positive half cycle of input supply and can be turned ON by applying suitable gate trigger pulses at the thyristor gate leads. The thyristor current and the load current begin to flow once the thyristors are triggered (turned ON) say at $\omega t = \alpha$. The load current flows when the thyristors conduct from $\omega t = \alpha$ to β . The output voltage across the load follows the input supply voltage through the conducting thyristor. At $\omega t = \beta$, when the load current falls to zero, the thyristors turn off due to AC line (natural) commutation. In some bridge controlled rectifier circuits the conducting thyristor turns off, when the other thyristor is (other group of thyristors are) turned ON.

The thyristor remains reverse biased during the negative half cycle of input supply. The type of commutation used in controlled rectifier circuits is referred to AC line commutation or Natural commutation or AC phase commutation. When the input ac supply voltage reverses and becomes negative during the negative half cycle, the thyristor becomes reverse biased and hence turns off.

There are several types of single phase controlled rectifier:

1. Single Phase Half Wave Controlled Rectifier
2. Single Phase Full Wave Controlled Rectifier

A. Single Phase Half Wave Controlled Rectifier

Single-phase half wave controlled rectifier circuits will use silicon controlled rectifier (SCR) instead of the diode. Furthermore, the circuits are also known as phase-controlled converters. Controlled SCR rectifiers have a wide range of industrial and residential applications, especially applications in which power flows in both directions.

Let us consider the circuit in Figure 4.1(a) with a resistive load. During the positive half-cycle of input voltage, the thyristor anode is positive with respect to its cathode and the thyristor is said to be *forward biased*. When thyristor T_1 is fired at $\omega t = \alpha$, thyristor T_1 conducts and the input voltage appears across the load. When the input voltage starts to be negative at $\omega t = \pi$, the thyristor is anode is negative with respect to its cathode and the thyristor T_1 is said to be *reverse biased*; and it is turned off.The time after the input voltage starts to go positive until the thyristor is fired at $\omega t = \alpha$ is called the ***delay or firing angle*** $\boldsymbol{\alpha}$.

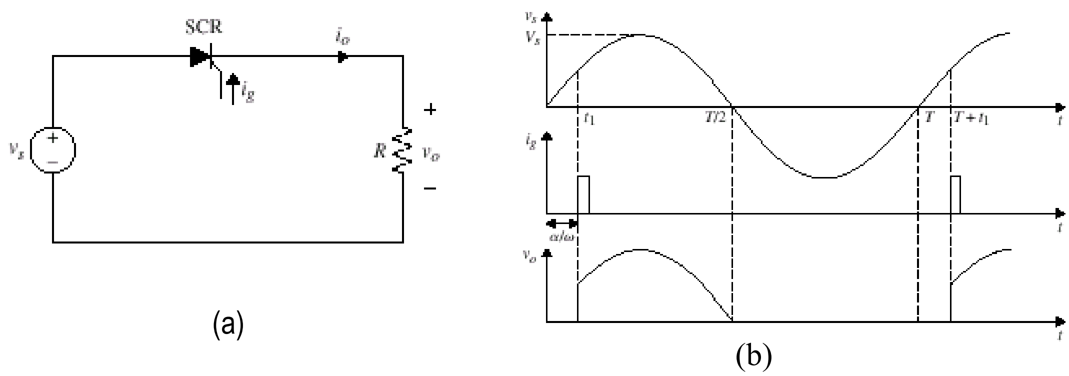


Figure 4.1 - Single-phase half wave controlled rectifier circuit with a resistive load.

Figure 3.1(b) shows the waveforms for input voltage, output voltage, load current, and gate current. This converter not normally used in industrial applications because its output has high ripple content and low ripple frequency. If V_m is the peak input voltage, the average output voltage V_{dc} can be found from,

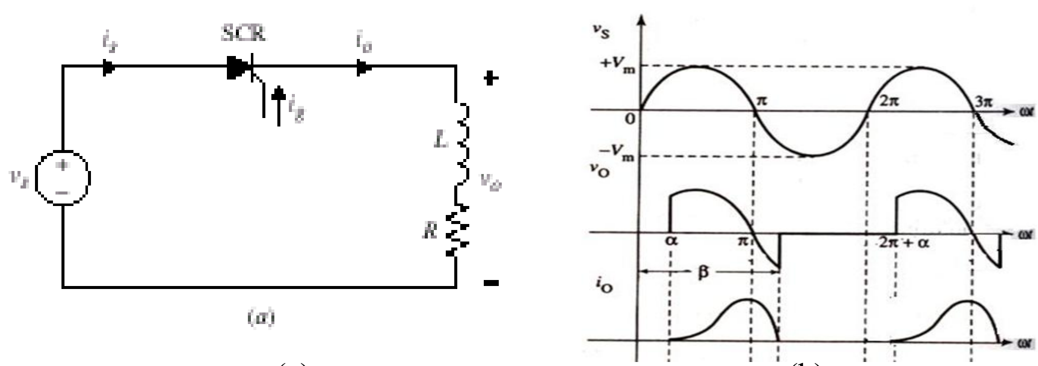
$$V_{dc} = \frac{V_m}{2\pi}\left(1+\cos\alpha\right)$$

B. Single-Phase Half Wave Controlled Rectifier with Resistive and Inductive Load

Figure 4.2(a) shows a single-phase half wave controlled with an inductive-resistive load. During the positive half-cycle of input voltage, the SCR is *forward biased*. When SCR T_1 is fired at $\omega t = \alpha$, SCR T_1 conducts and the input voltage appears across the load. The output voltage is the sum of voltage across resistor (V_R) and the voltage across inductor (V_L).

When v_s changes from a positive to a negative value, the current through the load does not fall to zero value at the instant wt = β radians, since the load contains an inductor and the SCRs continue to conduct, with the inductor acting as a source. When the input voltage starts to be negative at wt = Л + β, the SCR is in the blocking condition so the output voltage is zero (i_L = 0 and V_L = 0) until ωt = 2π. The average output voltage *V*dc can be found from:

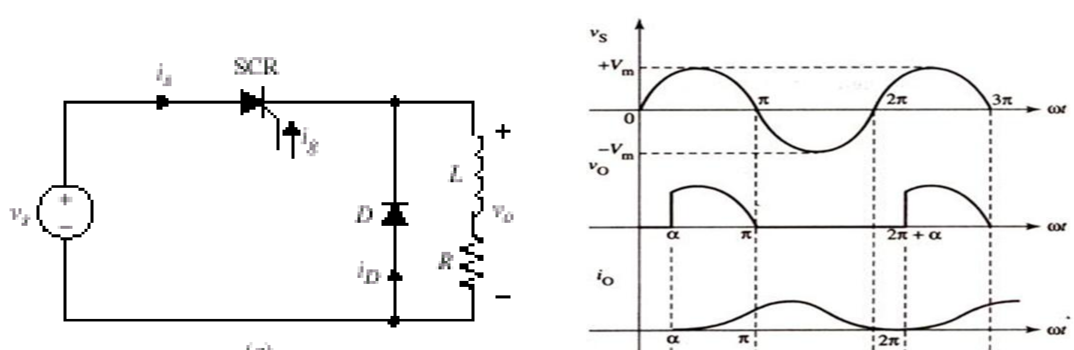
$$Vdc = \frac{V_m}{2\pi}\left[\cos(\alpha) - \cos(\beta)\right]$$



(a) (b)

Figure 4.2 - Single-phase half wave controlled rectifier circuit with a resistive and inductive load

C. Single-Phase Half Wave Controlled Rectifier with Resistive, Inductive Load and a Free-Wheeling Diode (FWD)



(b)

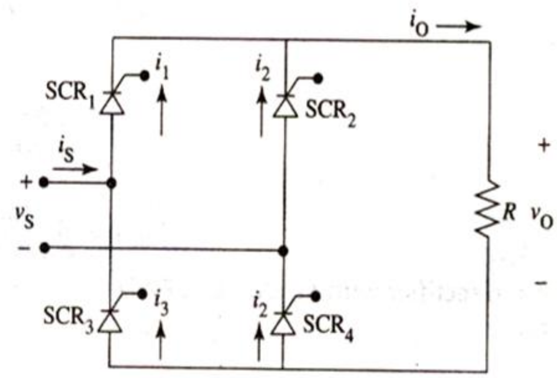
Figure 4.3 - Single-phase half wave controlled rectifier circuit with a resistive - inductive load and a free-wheeling diode (FWD)

Figure 4.3(a) shows a single-phase half wave controlled with an inductive-resistive load and free wheeling diode. The effect of this diode is to prevent a negative voltage appearing across the load. So in this situation freewheeling diode is used:

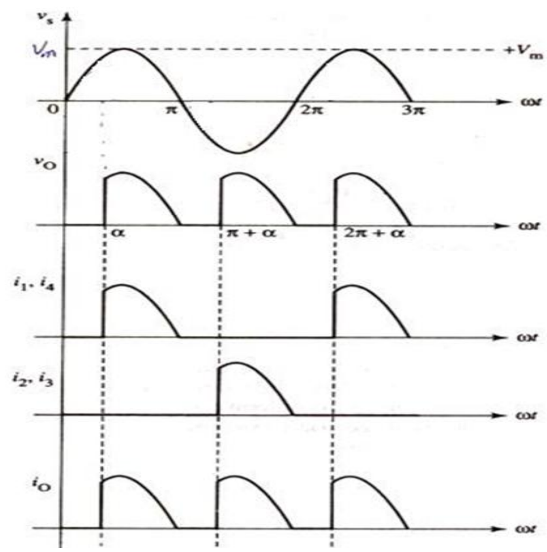
i. to supplies an alternate path for current to flow in the negative half-cycle
ii. to cut off the negative portion of instantaneous output voltage and smooth the output current ripple.

D. Single-Phase Full Wave Controlled Bridge Rectifier with Resistive Load.

The circuit of a single-phase fully-controlled bridge rectifier circuit is shown in the figure 4.4 above. The circuit has four SCRs. It is preferable to state that the circuit has two pairs of SCRs, with S_1 and S_4 forming one pair and, S_2 and S_3 the other pair. For this circuit, the source is marked as V_s and it is a sinusoidal voltage source.



(a)



(b)

Figure 4.4 – Single-phase full wave bridge rectifier with resistive load
(a) Circuit Diagram (b) Output Waveform

When it is positive, SCRs S_1 and S_4 can be triggered and then current flows from v_s through SCR S_1, load resistor R, SCR S_4 and back into the source. In the next half-cycle, the other pair of SCRs conducts. Even though the direction of current through the source alternates from one half-cycle to the other half-cycle, the current through the load remains unidirectional.

The main purpose of this circuit is to provide a variable dc output voltage, which is brought about by varying the firing angle. Let $V_s = V_m \sin wt$, with $0 < wt < 360^o$. If $wt = 30^o$ when S_1 and S_4 are triggered, then the firing angle is said to be 30^o. The other pair is triggered when $wt = 210^o$.The average load voltage *V*dc is simply *twice* the half-wave average,

$$Vdc = \frac{Vm}{\pi}(1 + \cos\alpha)$$

5.0 PROCEDURE

A. Single Phase Half Wave Controlled Rectifier With Resistive Load

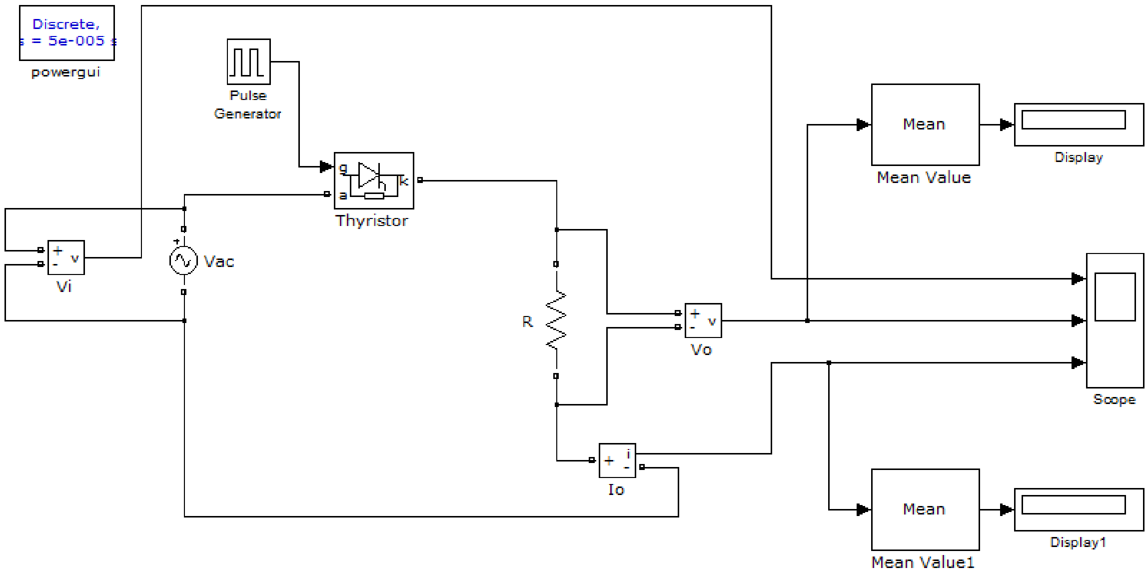


Figure 4.5 – Single Phase Half Wave Controlled Rectifier With Resistive Load Circuit

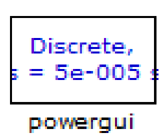
1. Open MATLAB and type Simulink in the MATLAB command window or click on the Simulink button  located on the MATLAB toolbar.

2. A new window should open and this window is the Simulink Model Library. Click File > New > Model > Untitle workspace > File > Save > name your file.

3. On the model sheet, create and complete the Single Phase Half Wave Controlled Rectifier With Resistive Load circuit as shown in Figure 4.5.

4. Find the component in the Simulink Library Browser and follow the parameter below:

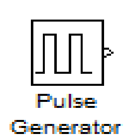
   a) POWER GUI:

   Click powergui > 'Configure Parameter' > 'Block Parameters powergui' should display and set the parameter below:

   - Simulation type: **Discrete**
   - Sample time (s): **5e-005** (50µs)

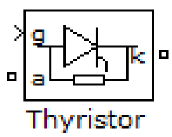
   b) PULSE GENERATOR:

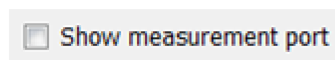
Click PULSE GENERATOR and change the parameter below:

- Pulse type: **Time Based**
- Time (t): **Use Simulation Type**
- Amplitude: **1**
- Period (s): **1/50**
- Pulse Width: **50**
- Phase Delay (s): **(1/50) *(45/360)**

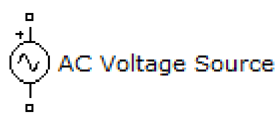
c) THYRISTOR:



Click THYRISTOR and change the parameter below :

- Unclick show measurement port > 

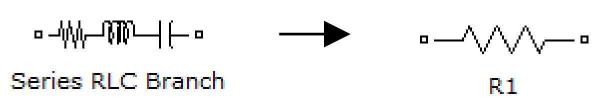
d) AC VOLTAGE SOURCE:



Click AC VOLTAGE SOURCE and change the parameter below:

- Peak Amplitude: **100V**
- Phasee (deg): **0**
- Frequency (Hz): **50**
- Sample Time: **0**
- Measurement: **Voltage**

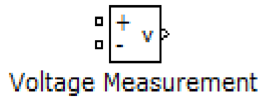
e) SERIES RLC BRANCH:



Click Series RLC Branch and change the parameter below:

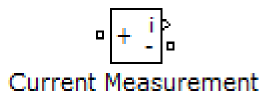
- Branch type : **R**
- Resistance (R) : **100**
- Measurements: **Branch voltage and current**

f) VOLTAGE MEASUREMENT:



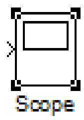
Select voltage measurement block that is used to measure the input voltage and output voltage.

g) CURRENT MEASUREMENT:

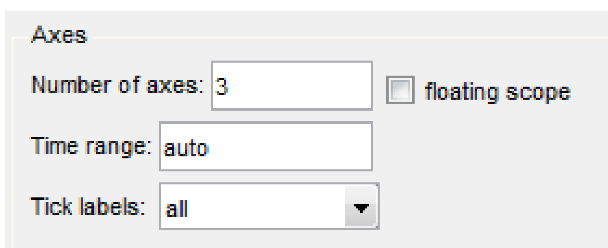


Select a current measurement block that is used to measure the output current.

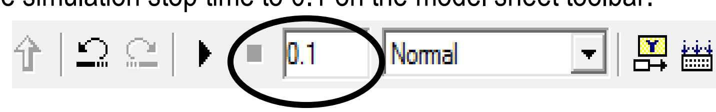
h) SCOPE:



Click SCOPE and click button  located on the scope toolbar and change the parameter below:



5. Create and complete the circuit diagram shown in Figure 4.5.
6. Set the simulation stop time to 0.1 on the model sheet toolbar.



7. Run the simulation and observe the simulation result on the scope.
8. Capture the waveform of input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.
9. Repeat steps from 4 to 8 by changing **the firing angle, α=90°**
10. Run the simulation and observe the simulation result on the scope.
11. Capture the waveform input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.

B. Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load

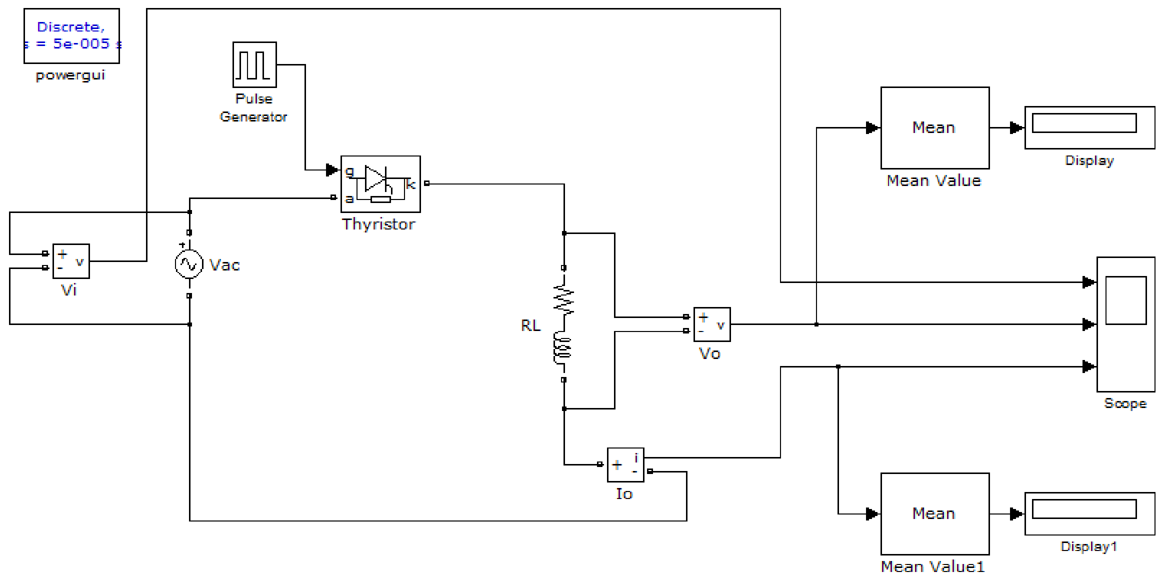
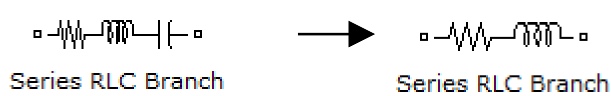


Figure 4.6 – Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load Circuit

1. On the new model sheet, create and complete the Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load circuit as shown in Figure 4.6.
2. **Repeat steps from 4 to 6 in the Procedure A with firing angle 45°.**
3. For RL load, find the component in the Simulink Library Browser and follow the parameter below:

   a) SERIES RLC BRANCH:



Click Series RLC Branch and change the parameter below:

- Branch type : **RL**
- Resistance (Ohm): **100**
- Inductance (H) : **250e-3**
- Measurements: **Branch voltage and current**

4. Run the simulation and observe the simulation result on the scope.
5. Capture the waveform input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.

C. Single Phase Half Wave Controlled Rectifier With Resistive, Inductive Load and Freewheeling Diode

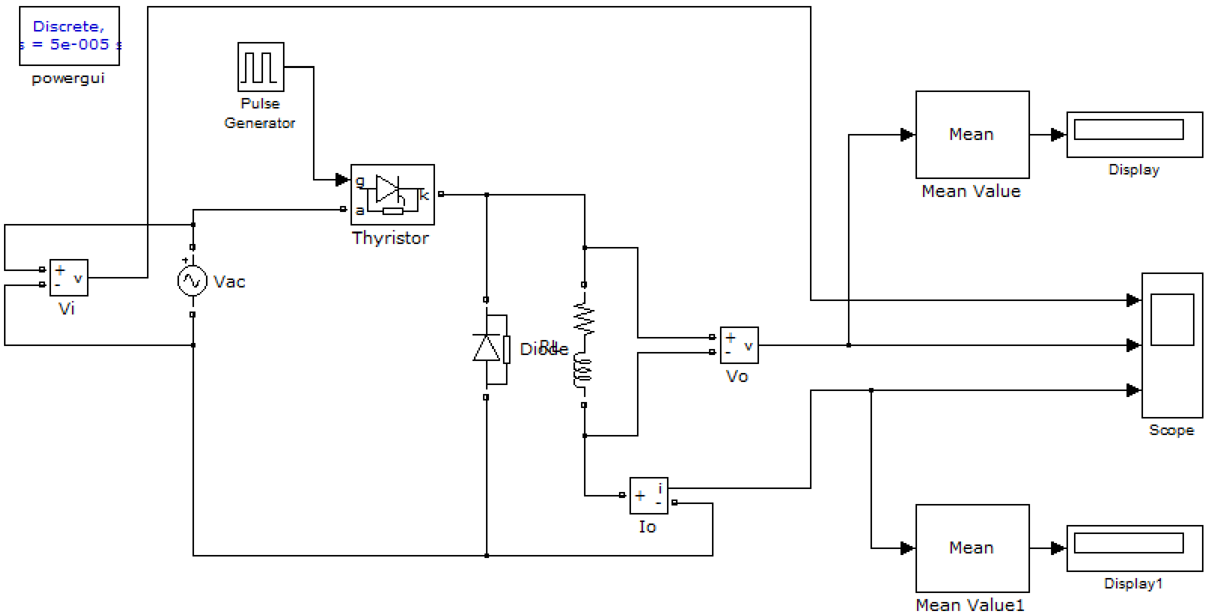
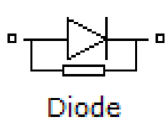


Figure 4.7 – Single Phase Half Wave Controlled Rectifier With R-L and Freewheeling Diode Load Circuit

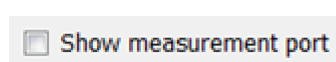
1. On the new model sheet, create and complete the Single Phase With Resistive, Inductive Load and Freewheeling Diode circuit as shown in Figure 4.7.
2. **Repeat steps from 4 to 6 in the Procedure A with firing angle 45°.**
3. For freewheeling diode, find the component in the Simulink Library Browser and follow the parameter below:

   a) DIODE:

   Click Diode and change the parameter below :

   - Unclick show measurement port >

4. Run the simulation and observe the simulation result on the scope.

5. Capture the waveform input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.

D. Single Phase Full Wave Controlled Bridge Rectifier

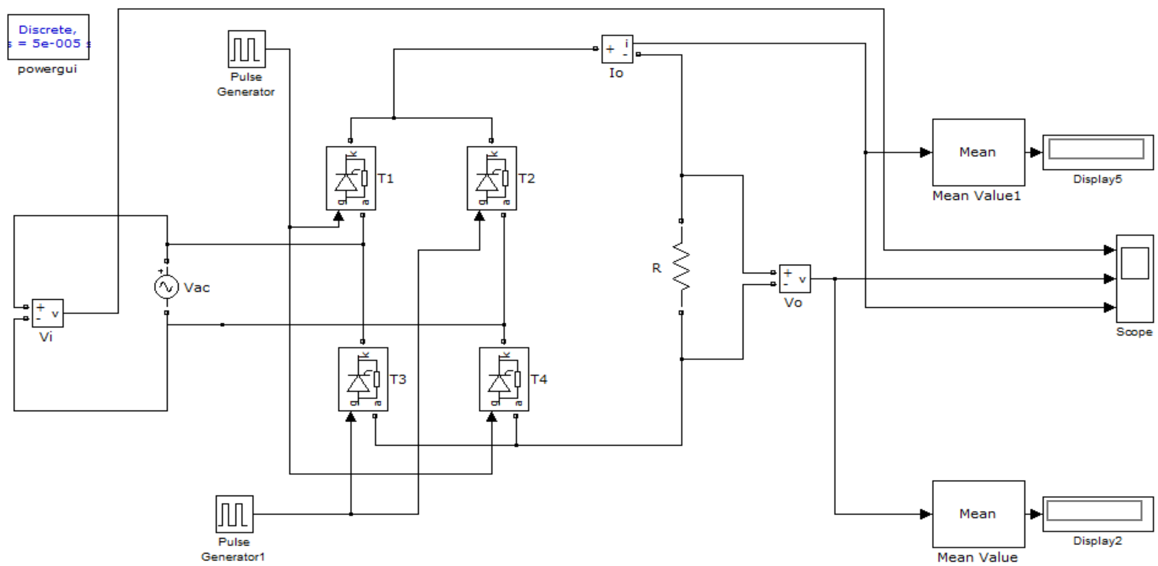


Figure 4.8 – Single Phase Full Wave Controlled Bridge Rectifier

1. On the new model sheet, create and complete the Single Phase With Resistive, Inductive Load and Freewheeling Diode circuit as shown in Figure 4.7.
2. **Repeat steps from 4 to 6 in the Procedure A with firing angle 0°.**
3. Run the simulation and observe the simulation result on the scope.
4. Capture the waveform input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.
5. **Repeat steps from 4 to 6 in the Procedure A by changing firing angle, 90°**
6. Run the simulation and observe the simulation result on the scope.
7. Capture the waveform input voltage (Vi), output voltage (Vo), output current (Io) and analyse the result.

6.0 RESULTS

A. Single Half Wave Controlled Rectifier With Resistive Load

1. Print screen the circuit diagram of Single Half Wave Controlled Rectifier With Resistive Load. (1 marks)
2. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Single Half Wave Controlled Rectifier With Resistive Load when the firing angle, α is 45°. (1 marks)
3. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Single Half Wave Controlled Rectifier With Resistive Load when the firing angle, α is 90°. (1 marks)

B. Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load

1. Print screen the circuit diagram of Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load. (1 marks)
2. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Single Phase Half Wave Controlled Rectifier With Resistive and Inductive Load. (1 marks)

C. Single Phase Half Wave Controlled Rectifier With Resistive, Inductive Load and Freewheeling Diode

1. Print screen the circuit diagram of Single Phase Half Wave Controlled Rectifier With Resistive, Inductive Load and Freewheeling Diode. (1 marks)
2. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Phase Half Wave Controlled Rectifier With Resistive, Inductive Load and Freewheeling Diode. (1 marks)

D. Single Phase Full Wave Controlled Bridge Rectifier

1. Print screen the circuit diagram of Single Phase Full Wave Controlled Bridge Rectifier. (1 marks)
2. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Single Full Wave Controlled Bridge Rectifier when the firing angle, α is 0°. (1 marks)
3. Print screen the waveform of input voltage (Vi), output voltage (Vo) and output current (Io) of the Single Full Wave Controlled Bridge Rectifier when the firing angle, α is 90°. (1 marks)