Department of Electrical and Electronics Engineering

Ability Enhancement Course

Simulation and Control of Power Electronics Circuits

BEEL657B

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INSTITUTIONAL VISION AND MISSION

VISION:

- Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION:

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

Department Vision and Mission

VISION:

- To create Electrical and Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

MISSION:

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research& industry interaction.

Program Educational Objectives (PEOs)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make students continuously acquire and enhance their technical and socio-economic skills.

PEO3: To aspire students on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1:Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design / Development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineeractivities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive Clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12: Life-long learning: Recognise the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

The students will develop an ability to produce the following engineering traits:

PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics.

PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning.

EXPERIMENT - 1(a)

SIMULATION OF SINGLE-PHASE HALF-WAVE DIODE BRIDGE RECTIFIER

1. OBJECTIVE

To simulate and analyze the performance of a single-phase half-wave diode bridge rectifier using MATLAB Simulink with specified input and output parameters.

2. THEORY

A half-wave rectifier is a circuit that converts an alternating current (AC) input signal into a direct current (DC) output signal by allowing only one half of the AC waveform to pass through while blocking the other half.

2.1 Working Principle

The single-phase half-wave rectifier uses a single diode to convert AC to DC. During the positive half cycle of the input AC voltage, the diode is forward biased and conducts, allowing current to flow through the load resistor. During the negative half cycle, the diode is reverse biased and does not conduct, resulting in no current flow through the load.

2.2 Important Parameters

- **Average (DC) Output Voltage:** $V_{dc} = \frac{V_m}{\pi}$
- **RMS Output Voltage:** $V_{rms} = \frac{V_m}{2}$
- **Form Factor:** $FF = \frac{V_{rms}}{V_{dc}} = \frac{\pi}{2\sqrt{2}} = 1.57$
- **Ripple Factor:** $RF = \sqrt{FF^2 - 1} = 1.21$
- **Efficiency:** $\eta = 40.6\%$

Where $V_m = \sqrt{2} \times V_{rms(input)} = \sqrt{2} \times 100 = 141.42$ V

3. CIRCUIT SPECIFICATIONS

- Input Voltage: 100 V (RMS)
- Input Frequency: 50 Hz
- Load Resistance: 50 Ω
- Diode: Ideal diode model

4. SIMULINK MODEL DEVELOPMENT

4.1 Required Blocks

1. **AC Voltage Source:** Simscape → Electrical → Specialized Power Systems → Electrical Sources → AC Voltage Source
2. **Diode:** Simscape → Electrical → Specialized Power Systems → Power Electronics → Diode
3. **Resistor:** Simscape → Electrical → Specialized Power Systems → Elements → Series RLC Branch
4. **Voltage Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Voltage Measurement
5. **Current Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Current Measurement
6. **Scope:** Simulink → Sinks → Scope
7. **Powergui:** Simscape → Electrical → Specialized Power Systems → Fundamental Blocks → Powergui

4.2 Step-by-Step Procedure

1. Open MATLAB and create a new Simulink model (File → New → Model)
2. Place the AC Voltage Source and configure:
   - Peak amplitude: 141.42 V ($100\sqrt{2}$)
   - Phase: 0 degrees
   - Frequency: 50 Hz
3. Add a Diode from the Power Electronics library
4. Add a Series RLC Branch and configure:
   - Resistance R: 50 Ω
   - Inductance L: 0 H
   - Capacitance C: inf (open circuit)
5. Connect the circuit in series: AC Source → Diode → Resistor → Ground
6. Add Voltage Measurement across the load resistor

7. Add Current Measurement in series with the load
8. Connect both measurements to a Scope using a Mux block
9. Add powergui block and set to Continuous mode
10. Configure simulation parameters:
    - Solver: ode23tb (stiff/TR-BDF2)
    - Stop time: 0.1 s (5 cycles)

5. OBSERVATIONS AND RESULTS

5.1 Theoretical Calculations

$$V_m = 141.42 \text{ V}$$
$$V_{dc} = \frac{V_m}{\pi} = \frac{141.42}{3.14159} = 45.01 \text{ V}$$
$$V_{rms} = \frac{V_m}{2} = \frac{141.42}{2} = 70.71 \text{ V}$$
$$I_{dc} = \frac{V_{dc}}{R} = \frac{45.01}{50} = 0.9 \text{ A}$$
$$I_{rms} = \frac{V_{rms}}{R} = \frac{70.71}{50} = 1.414 \text{ A}$$

5.2 Observation Table

S.No	Parameter	Theoretical Value	Simulated Value
1	Input Voltage (V_{rms})	100 V	
2	Output DC Voltage (V_{dc})	45.01 V	
3	Output RMS Voltage (V_{rms})	70.71 V	
4	DC Load Current (I_{dc})	0.9 A	
5	RMS Load Current (I_{rms})	1.414 A	
6	Ripple Factor	1.21	
7	Efficiency (%)	40.6%	

Table 1: Comparison of Theoretical and Simulated Values

5.3 Waveform Analysis

Observe and sketch the following waveforms from the Scope:

- Input AC voltage waveform
- Output voltage across load resistor
- Load current waveform

Note: Use the Powergui block to measure DC and RMS values. Right-click on signals → FFT Analysis for harmonic content.

6. RESULT ANALYSIS

Analyze the simulation results by comparing theoretical and simulated values. Calculate the percentage error using:

$$\% \text{ Error} = \left| \frac{\text{Theoretical Value} - \text{Simulated Value}}{\text{Theoretical Value}} \right| \times 100 \quad (1)$$

7. DISCUSSION

- The output voltage contains significant ripple content as indicated by the high ripple factor (1.21)
- Only positive half cycles appear in the output, confirming half-wave rectification
- The efficiency is relatively low (40.6%) due to utilization of only half the input waveform
- The diode conducts for 180° and blocks for 180° of the input cycle
- Peak Inverse Voltage (PIV) across the diode = V_m = 141.42 V

8. APPLICATIONS

- Low-power DC power supplies
- Battery charging circuits
- Signal demodulation in communication systems
- Simple unregulated power supplies

9. PRECAUTIONS

1. Ensure proper configuration of AC source parameters
2. Set appropriate simulation time to capture multiple cycles
3. Use correct solver settings for power electronics simulation
4. Always include powergui block in the model
5. Verify ground connections in the circuit

10. CONCLUSION

The single-phase half-wave rectifier was successfully simulated using MATLAB Simulink. The simulation results closely match the theoretical calculations, validating the rectifier's operation. The half-wave rectifier converts AC to pulsating DC with moderate efficiency and high ripple content, making it suitable for low-power applications.

11. VIVA QUESTIONS

1. What is the main function of a rectifier?
2. Why is the efficiency of a half-wave rectifier only 40.6%?
3. What is ripple factor and why is it high in half-wave rectifiers?
4. What is Peak Inverse Voltage (PIV) and its value in this circuit?
5. How can we reduce the ripple in the output voltage?
6. What is the difference between half-wave and full-wave rectification?
7. Why do we need a powergui block in Simulink power electronics circuits?

EXPERIMENT - 1(b)

SIMULATION OF SINGLE-PHASE FULL-WAVE DIODE BRIDGE RECTIFIER

1. OBJECTIVE

To simulate and analyze the performance of a single-phase full-wave diode bridge rectifier using MATLAB Simulink and compare its characteristics with half-wave rectifier.

2. THEORY

A full-wave bridge rectifier is a circuit that converts alternating current (AC) into direct current (DC) by utilizing both positive and negative half cycles of the AC input. It uses four diodes arranged in a bridge configuration to achieve full-wave rectification.

2.1 Working Principle

The full-wave bridge rectifier consists of four diodes (D1, D2, D3, D4) connected in a bridge configuration. During the positive half cycle of input AC voltage, diodes D1 and D2 conduct, allowing current to flow through the load. During the negative half cycle, diodes D3 and D4 conduct, maintaining the same direction of current flow through the load. Thus, both half cycles of the input AC are utilized to produce DC output.

Positive Half Cycle: Diodes D1 and D2 are forward biased → Current flows through D1 → Load → D2

Negative Half Cycle: Diodes D3 and D4 are forward biased → Current flows through D3 → Load → D4

2.2 Important Parameters

- **Average (DC) Output Voltage:** $V_{dc} = \frac{2V_m}{\pi}$
- **RMS Output Voltage:** $V_{rms} = \frac{V_m}{\sqrt{2}}$
- **Form Factor:** $FF = \frac{V_{rms}}{V_{dc}} = \frac{\pi}{2\sqrt{2}} = 1.11$
- **Ripple Factor:** $RF = \sqrt{FF^2 - 1} = 0.48$
- **Efficiency:** $\eta = 81.2\%$
- **Peak Inverse Voltage (PIV):** $PIV = V_m$

Where $V_m = \sqrt{2} \times V_{rms(input)} = \sqrt{2} \times 100 = 141.42$ V

3. CIRCUIT SPECIFICATIONS

- Input Voltage: 100 V (RMS)
- Input Frequency: 50 Hz
- Load Resistance: 50 Ω
- Number of Diodes: 4 (Bridge configuration)
- Diode Model: Ideal diode

3.1 Advantages over Half-Wave Rectifier

1. Higher efficiency (81.2% vs 40.6%)
2. Lower ripple factor (0.48 vs 1.21)
3. Better DC output (twice the half-wave value)
4. Improved power utilization
5. Higher output voltage
6. Better transformer utilization factor

4. SIMULINK MODEL DEVELOPMENT

4.1 Required Blocks

1. **AC Voltage Source:** Simscape → Electrical → Specialized Power Systems → Electrical Sources → AC Voltage Source
2. **Diode (4 units):** Simscape → Electrical → Specialized Power Systems → Power Electronics → Diode
3. **Resistor:** Simscape → Electrical → Specialized Power Systems → Elements → Series RLC Branch
4. **Voltage Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Voltage Measurement
5. **Current Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Current Measurement
6. **Scope:** Simulink → Sinks → Scope
7. **Powergui:** Simscape → Electrical → Specialized Power Systems → Fundamental Blocks → Powergui
8. **Mux:** Simulink → Signal Routing → Mux

4.2 Step-by-Step Procedure

1. Open MATLAB and create a new Simulink model (File → New → Model)
2. Place the AC Voltage Source and configure:
   - Peak amplitude: 141.42 V ($100\sqrt{2}$)
   - Phase: 0 degrees
   - Frequency: 50 Hz
3. Add four Diodes from the Power Electronics library and arrange them in bridge configuration:
   - D1: Top left (Anode to AC source positive terminal)
   - D2: Top right (Cathode to positive load terminal)
   - D3: Bottom left (Cathode to AC source positive terminal)
   - D4: Bottom right (Anode to negative load terminal)
4. Add a Series RLC Branch and configure:
   - Resistance R: 50 Ω
   - Inductance L: 0 H
   - Capacitance C: inf (open circuit)
5. **Bridge Connection:**
   - Connect AC source positive to junction of D1 (anode) and D3 (cathode)
   - Connect AC source negative to junction of D2 (anode) and D4 (cathode)
   - Connect D1 (cathode) and D2 (cathode) to positive terminal of load
   - Connect D3 (anode) and D4 (anode) to negative terminal of load
6. Add Voltage Measurement across the load resistor
7. Add Current Measurement in series with the load
8. Add a Voltage Measurement across the AC source (for input waveform)
9. Connect all three measurements to a Scope using a Mux block (3 inputs)
10. Add powergui block and set to Continuous mode
11. Configure simulation parameters:
    - Solver: ode23tb (stiff/TR-BDF2)
    - Stop time: 0.1 s (5 cycles)
    - Max step size: 1e-5

5. OBSERVATIONS AND RESULTS

5.1 Theoretical Calculations

$$V_m = 141.42 \text{ V}$$
$$V_{dc} = \frac{2V_m}{\pi} = \frac{2 \times 141.42}{3.14159} = 90.03 \text{ V}$$
$$V_{rms} = \frac{V_m}{\sqrt{2}} = \frac{141.42}{1.414} = 100 \text{ V}$$
$$I_{dc} = \frac{V_{dc}}{R} = \frac{90.03}{50} = 1.80 \text{ A}$$
$$I_{rms} = \frac{V_{rms}}{R} = \frac{100}{50} = 2.0 \text{ A}$$
$$P_{dc} = V_{dc} \times I_{dc} = 90.03 \times 1.80 = 162.05 \text{ W}$$
$$P_{ac} = V_{rms} \times I_{rms} = 100 \times 2.0 = 200 \text{ W}$$
$$\eta = \frac{P_{dc}}{P_{ac}} \times 100 = \frac{162.05}{200} \times 100 = 81.2\%$$

5.2 Observation Table

S.No	Parameter	Theoretical Value	Simulated Value
1	Input Voltage (V_{rms})	100 V	
2	Output DC Voltage (V_{dc})	90.03 V	
3	Output RMS Voltage (V_{rms})	100 V	
4	DC Load Current (I_{dc})	1.80 A	
5	RMS Load Current (I_{rms})	2.0 A	
6	Ripple Factor	0.48	
7	Form Factor	1.11	
8	Efficiency (%)	81.2%	
9	Peak Inverse Voltage (PIV)	141.42 V	
10	DC Output Power	162.05 W	

Table 1: Comparison of Theoretical and Simulated Values

5.3 Waveform Analysis

Observe and sketch the following waveforms from the Scope:

1. Input AC voltage waveform (sinusoidal)
2. Output voltage across load resistor (full-wave rectified)
3. Load current waveform (pulsating DC)
4. Voltage across individual diodes (to verify PIV)

Note: Use the Powergui block to measure DC and RMS values. Right-click on signals → FFT Analysis to observe that the fundamental ripple frequency is 100 Hz (twice the input frequency).

5.4 Comparison with Half-Wave Rectifier

S.No	Parameter	Half-Wave	Full-Wave
1	DC Output Voltage	$\frac{V_m}{\pi} = 45.01$ V	$\frac{2V_m}{\pi} = 90.03$ V
2	Ripple Factor	1.21	0.48
3	Efficiency	40.6%	81.2%
4	Form Factor	1.57	1.11
5	Ripple Frequency	f (50 Hz)	$2f$ (100 Hz)
6	Number of Diodes	1	4
7	PIV per Diode	V_m	V_m
8	TUF	0.287	0.812

Table 2: Comparison between Half-Wave and Full-Wave Rectifiers

6. RESULT ANALYSIS

Analyze the simulation results by comparing theoretical and simulated values. Calculate the percentage error using:

$$\% \text{ Error} = \left| \frac{\text{Theoretical Value} - \text{Simulated Value}}{\text{Theoretical Value}} \right| \times 100 \tag{1}$$

Expected Observations:

- Output voltage should show two pulses per input cycle
- DC voltage should be approximately twice that of half-wave rectifier
- Ripple should be significantly lower than half-wave rectifier
- Ripple frequency should be 100 Hz (double the input frequency)

7. DISCUSSION

- The full-wave bridge rectifier utilizes both half cycles of the input AC waveform, resulting in higher DC output voltage and efficiency
- The ripple factor is significantly lower (0.48) compared to half-wave rectifier (1.21), indicating smoother DC output
- The efficiency of 81.2% is double that of the half-wave rectifier (40.6%)
- Each diode conducts for 180° but in pairs (D1-D2 during positive cycle, D3-D4 during negative cycle)
- The ripple frequency is twice the input frequency (100 Hz), making it easier to filter
- Peak Inverse Voltage (PIV) across each diode is $V_m = 141.42$ V
- Transformer Utilization Factor (TUF) is 0.812, much better than half-wave rectifier
- Two diodes are always in conduction path, resulting in 2 diode drops in practical circuits

8. APPLICATIONS

- DC power supplies for electronic equipment
- Battery charging circuits
- Regulated power supplies when combined with voltage regulators
- Motor drive circuits
- Audio amplifier power supplies
- Industrial DC drives
- Welding equipment
- Electroplating applications

9. PRECAUTIONS

1. Ensure correct orientation of all four diodes in the bridge configuration
2. Verify proper polarity connections before simulation
3. Set appropriate simulation time to capture multiple cycles
4. Use correct solver settings for power electronics simulation (ode23tb recommended)
5. Always include powergui block in the model
6. Check that all ground connections are properly made
7. Ensure voltage and current measurements are connected correctly
8. Save the model frequently during development
9. Verify diode parameters (use default ideal diode for simplicity)
10. Check scope display settings for proper waveform visualization

10. CONCLUSION

The single-phase full-wave bridge rectifier was successfully simulated using MATLAB Simulink. The simulation results demonstrate that the full-wave rectifier provides:

- Double the DC output voltage compared to half-wave rectifier (90.03 V vs 45.01 V)
- Significantly higher efficiency (81.2% vs 40.6%)
- Much lower ripple content (RF = 0.48 vs 1.21)
- Better power utilization with both half cycles contributing to output

The theoretical calculations closely match the simulation results, validating the rectifier's operation and making it suitable for most practical DC power supply applications.

11. VIVA QUESTIONS

1. What is the main advantage of full-wave rectifier over half-wave rectifier?
2. Why are four diodes used in a bridge rectifier?
3. What is the PIV across each diode in a full-wave bridge rectifier?
4. Why is the ripple frequency in full-wave rectifier twice the input frequency?
5. How does efficiency compare between half-wave and full-wave rectifiers?
6. Which diodes conduct during positive and negative half cycles?
7. What is Transformer Utilization Factor (TUF)?
8. Can we use a center-tapped transformer instead of a bridge configuration?
9. What happens if one diode in the bridge fails (open circuit)?
10. How can we further reduce the ripple in the output?
11. Why is the RMS output voltage equal to input RMS voltage?
12. What is the form factor and its significance?
13. How many diode drops are present in the conduction path?
14. What is the conduction angle for each diode?
15. Why is ode23tb solver preferred for power electronics simulation?

12. POST-LAB ASSIGNMENT

1. Plot input voltage, output voltage, and load current on the same graph
2. Perform FFT analysis and identify the harmonic components
3. Calculate and verify the Transformer Utilization Factor (TUF)
4. Simulate the circuit with different load resistances (25 Ω, 100 Ω) and observe changes
5. Add a filter capacitor (1000 μF) across the load and compare the ripple
6. Design a regulated power supply using this rectifier with Zener diode regulation
7. Compare simulation results with manual calculations and prepare a detailed report

EXPERIMENT - 2(a)

SIMULATION OF SINGLE-PHASE HALF-CONTROLLED FULL-WAVE RECTIFIER

1. OBJECTIVE

To simulate and analyze the performance of a single-phase half-controlled full-wave rectifier (semi-converter) using MATLAB Simulink and study the effect of firing angle on output voltage and current.

2. THEORY

A half-controlled rectifier or semi-converter is a power electronic circuit that uses a combination of controlled devices (thyristors/SCRs) and uncontrolled devices (diodes) to convert AC to controlled DC output. It provides control over the output DC voltage by varying the firing angle of the thyristors.

2.1 Working Principle

The single-phase half-controlled full-wave rectifier consists of two thyristors (T1, T2) and two diodes (D1, D2) connected in a bridge configuration. The thyristors are fired at controlled firing angles, while the diodes conduct naturally when forward biased.

Positive Half Cycle ($0 < \omega t < \pi$):

- At $\omega t = \alpha$: Thyristor T1 is triggered and conducts along with diode D2
- Current path: AC source $\rightarrow$ T1 $\rightarrow$ Load $\rightarrow$ D2 $\rightarrow$ AC source
- T1 conducts from α to π

Negative Half Cycle ($\pi < \omega t < 2\pi$):

- At $\omega t = \pi + \alpha$: Thyristor T2 is triggered and conducts along with diode D1
- Current path: AC source $\rightarrow$ D1 $\rightarrow$ Load $\rightarrow$ T2 $\rightarrow$ AC source
- T2 conducts from $\pi + \alpha$ to 2π

2.2 Important Parameters

For resistive load, the average output voltage is:

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

Other parameters:

- **RMS Output Voltage:** $V_{rms} = \frac{V_m}{2}\sqrt{1 + \cos\alpha}$
- **Maximum DC Voltage (at $\alpha = 0$):** $V_{dc(max)} = \frac{2V_m}{\pi}$
- **Minimum DC Voltage (at $\alpha = 180$):** $V_{dc(min)} = 0$

- **Firing Angle Range:** $0 \leq \alpha \leq 180$
- **Peak Inverse Voltage (PIV):** $PIV = V_m$ (for both thyristors and diodes)

Where:

- $V_m = \sqrt{2} \times V_{rms(input)} = \sqrt{2} \times 100 = 141.42$ V
- α = Firing angle in degrees

3. CIRCUIT SPECIFICATIONS

- Input Voltage: 100 V (RMS)
- Input Frequency: 50 Hz
- Load Resistance: 50 Ω
- Number of Thyristors: 2 (T1, T2)
- Number of Diodes: 2 (D1, D2)
- Firing Angles to be tested: $\alpha = 0°, 30°, 60°, 90°, 120°, 150°$

3.1 Advantages of Half-Controlled Rectifier

1. Controlled DC output voltage
2. Lower cost compared to fully-controlled rectifiers (uses only 2 thyristors)
3. Simple gate circuit design
4. Reduced commutation problems
5. Better power factor than fully-controlled rectifiers
6. No negative voltage at output (always positive or zero)

3.2 Disadvantages

1. Cannot operate in inverting mode
2. Asymmetrical thyristor and diode currents
3. Higher harmonic content compared to uncontrolled rectifier
4. Freewheeling diode required for inductive loads

4. SIMULINK MODEL DEVELOPMENT

4.1 Required Blocks

1. **AC Voltage Source:** Simscape → Electrical → Specialized Power Systems → Electrical Sources → AC Voltage Source
2. **Thyristor (2 units):** Simscape → Electrical → Specialized Power Systems → Power Electronics → Thyristor
3. **Diode (2 units):** Simscape → Electrical → Specialized Power Systems → Power Electronics → Diode
4. **Resistor:** Simscape → Electrical → Specialized Power Systems → Elements → Series RLC Branch
5. **Pulse Generator (2 units):** Simulink → Sources → Pulse Generator

6. **Voltage Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Voltage Measurement
7. **Current Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Current Measurement
8. **Scope:** Simulink → Sinks → Scope
9. **Powergui:** Simscape → Electrical → Specialized Power Systems → Fundamental Blocks → Powergui
10. **Mux:** Simulink → Signal Routing → Mux

4.2 Step-by-Step Procedure

1. Open MATLAB and create a new Simulink model (File → New → Model)
2. Place the AC Voltage Source and configure:
   - Peak amplitude: 141.42 V ($100\sqrt{2}$)
   - Phase: 0 degrees
   - Frequency: 50 Hz
   - Sample time: 0
3. Add two Thyristors and two Diodes, arranging them in bridge configuration:
   - T1: Top left (Anode to AC source terminal A)
   - D2: Top right (Cathode to positive load terminal)
   - D1: Bottom left (Cathode to AC source terminal A)
   - T2: Bottom right (Anode to negative load terminal)
4. Configure each Thyristor:
   - Resistance Ron: 0.001 Ω
   - Forward voltage Vf: 0.8 V (or 0 for ideal)
   - Initial current Ic: 0 A
   - Snubber resistance Rs: 500 Ω
   - Snubber capacitance Cs: inf (for simplicity)
5. Add a Series RLC Branch (Load) and configure:
   - Resistance R: 50 Ω
   - Inductance L: 0 H
   - Capacitance C: inf
6. **Bridge Connection:**
   - Connect AC source terminal A to junction of T1 (anode) and D1 (cathode)
   - Connect AC source terminal B to junction of D2 (anode) and T2 (cathode)
   - Connect T1 (cathode) and D2 (cathode) to positive terminal of load
   - Connect D1 (anode) and T2 (anode) to negative terminal of load
7. Add two Pulse Generators for firing pulses:

   Pulse Generator 1 (for T1):
   - Amplitude: 1
   - Period: 0.02 s (50 Hz = 1/50)
   - Pulse width: 10% (pulse width in % of period)
   - Phase delay: $\frac{\alpha}{360} \times 0.02$ seconds

   Pulse Generator 2 (for T2):

- Amplitude: 1
- Period: 0.02 s
- Pulse width: 10%
- Phase delay: $\frac{180+\alpha}{360} \times 0.02$ seconds

For example, if $\alpha = 60$:

- T1 phase delay = $(60/360) \times 0.02 = 0.00333$ s
- T2 phase delay = $(240/360) \times 0.02 = 0.01333$ s

8. Connect Pulse Generator 1 output to gate (g) terminal of T1
9. Connect Pulse Generator 2 output to gate (g) terminal of T2
10. Add Voltage Measurement across the load
11. Add Current Measurement in series with the load
12. Add Voltage Measurement across AC source (for input waveform)
13. Connect all measurements to Scope using Mux block (3 inputs)
14. Add powergui block and configure:
    - Simulation type: Continuous
    - Sample time: 0
15. Configure Simulation Parameters (Modeling → Model Settings):
    - Solver: ode23tb (stiff/TR-BDF2)
    - Stop time: 0.1 s (5 complete cycles)
    - Max step size: 1e-5
    - Relative tolerance: 1e-3
16. Run the simulation and observe waveforms
17. Repeat for different firing angles by changing phase delay in pulse generators

5. OBSERVATIONS AND RESULTS

5.1 Theoretical Calculations

For different firing angles with $V_m = 141.42$ V and $R = 50\ \Omega$:

α (degrees)	$\cos\alpha$	V_{dc} (V)	I_{dc} (A)	P_{dc} (W)
0°	1.000	90.03	1.80	162.05
30°	0.866	84.04	1.68	141.19
60°	0.500	67.52	1.35	91.15
90°	0.000	45.01	0.90	40.51
120°	-0.500	22.51	0.45	10.13
150°	-0.866	6.00	0.12	0.72

Table 1: Theoretical Values for Different Firing Angles

Where:

$$V_{dc} = \frac{V_m}{\pi}(1 + \cos\alpha) = \frac{141.42}{\pi}(1 + \cos\alpha)$$
$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_{dc}}{50}$$
$$P_{dc} = V_{dc} \times I_{dc}$$

5.2 Observation Table

For Firing Angle $\alpha = 60$:

S.No	Parameter	Theoretical Value	Simulated Value
1	Input Voltage (V_{rms})	100 V	
2	Firing Angle (α)	60°	
3	Output DC Voltage (V_{dc})	67.52 V	
4	DC Load Current (I_{dc})	1.35 A	
5	DC Output Power (P_{dc})	91.15 W	
6	Peak Inverse Voltage (PIV)	141.42 V	

Table 2: Observations for $\alpha = 60$

5.3 Comparative Analysis Table

Record simulated values for different firing angles:

α (degrees)	V_{dc} (V) Theoretical	V_{dc} (V) Simulated	I_{dc} (A) Theoretical	I_{dc} (A) Simulated	% Error V_{dc}	% Error I_{dc}
0°	90.03		1.80			
30°	84.04		1.68			
60°	67.52		1.35			
90°	45.01		0.90			
120°	22.51		0.45			

Table 3: Comparative Analysis for Various Firing Angles

5.4 Waveform Analysis

Observe and sketch the following waveforms from the Scope for different firing angles:

1. Input AC voltage waveform (sinusoidal)
2. Output voltage across load resistor (controlled rectified DC)
3. Load current waveform
4. Gate pulses for T1 and T2
5. Voltage across thyristor T1 (to observe commutation)

Key Observations:

- Output voltage waveform shows discontinuous conduction for $\alpha > 0$
- As firing angle increases, average output voltage decreases
- Current flows only when thyristors are triggered
- Zero voltage periods appear in output for large firing angles

Note:

- Use Powergui → Steady-State Voltages and Currents to get DC values
- Verify that gate pulses are synchronized with AC voltage zero crossings
- For $\alpha = 0$, the circuit behaves like an uncontrolled full-wave rectifier

6. RESULT ANALYSIS

6.1 Error Calculation

Calculate percentage error for each firing angle:

$$\% \text{ Error} = \left| \frac{\text{Theoretical Value} - \text{Simulated Value}}{\text{Theoretical Value}} \right| \times 100 \quad (2)$$

6.2 Graphical Analysis

Plot the following graphs:

1. V_{dc} vs α (Output DC voltage variation with firing angle)
2. I_{dc} vs α (Output DC current variation with firing angle)
3. P_{dc} vs α (Output power variation with firing angle)
4. Waveforms for $\alpha = 0, 60, 120$ (comparative)

6.3 Expected Characteristics

- Output voltage decreases as firing angle increases
- At $\alpha = 0$: Maximum output $= \frac{2V_m}{\pi} = 90.03$ V (same as uncontrolled)
- At $\alpha = 180$: Minimum output = 0 V
- Linear decrease in output voltage with increasing $\cos\alpha$
- Conduction angle $= (180 - \alpha)$ for each half cycle

7. DISCUSSION

- The half-controlled rectifier provides variable DC output by controlling the firing angle of thyristors
- During positive half cycle, T1 conducts when fired at angle α, and D2 provides return path
- During negative half cycle, T2 conducts when fired, and D1 provides return path
- The output voltage is always positive or zero (no negative voltage)
- For resistive load, current becomes zero when voltage becomes zero (natural commutation)
- The circuit is more economical than fully-controlled converter (uses only 2 thyristors)
- Gate circuits are simpler as only 2 thyristors need firing pulses
- Average output voltage: $V_{dc} = \frac{V_m}{\pi}(1 + \cos\alpha)$
- Power factor is better than fully-controlled rectifier for same output
- Asymmetrical currents flow through thyristors and diodes
- Cannot operate in inverting mode (regenerative braking not possible)
- For inductive loads, a freewheeling diode is essential to provide path for load current

8. APPLICATIONS

1. DC motor speed control drives
2. Battery charging with voltage control
3. Electroplating with controlled current
4. Heating applications with temperature control
5. Magnet power supplies
6. Welding power supplies
7. DC power supplies for laboratory equipment
8. Traction systems (one quadrant operation)

9. PRECAUTIONS

1. Ensure correct placement of thyristors and diodes in bridge configuration
2. Verify gate pulse timing - must be synchronized with AC voltage
3. Check that firing angle is within valid range (0° to 180°)
4. Ensure proper polarity of gate pulses (positive pulse for triggering)
5. Set appropriate pulse width (minimum 10% for reliable triggering)
6. Use correct solver (ode23tb) for thyristor circuits
7. Set small max step size (1e-5) for accurate commutation
8. Always include powergui block in continuous mode
9. Ground the circuit properly at one point
10. For inductive loads, add freewheeling diode across load
11. Save model frequently during development
12. Verify that thyristor snubber circuits are properly configured
13. Check scope settings to display all relevant waveforms
14. Allow sufficient simulation time for steady-state (at least 5 cycles)

10. TROUBLESHOOTING

Problem	Solution
Thyristor not triggering	Check gate pulse amplitude (should be > 0), verify pulse timing
Continuous conduction even at high α	Check firing angle calculation in pulse generator, verify phase delay
No output voltage	Verify circuit connections, check ground, ensure AC source is configured
Simulation error	Add snubber circuits to thyristors, reduce max step size, use ode23tb solver
Irregular waveforms	Increase simulation time, check for algebraic loops, verify measurements

Table 4: Common Problems and Solutions

11. CONCLUSION

The single-phase half-controlled full-wave rectifier was successfully simulated using MATLAB Simulink. The key findings are:

- Output DC voltage can be controlled by varying the firing angle from 0° to 180°
- At $\alpha = 0$, maximum output voltage of 90.03 V is obtained (same as uncontrolled rectifier)
- As firing angle increases, output voltage decreases following the relation $V_{dc} = \frac{V_m}{\pi}(1 + \cos\alpha)$
- The circuit uses only 2 thyristors, making it economical compared to fully-controlled rectifiers
- Simulation results closely match theoretical calculations with minimal error
- The circuit is suitable for applications requiring one-quadrant operation with voltage control

The half-controlled rectifier provides a cost-effective solution for DC voltage control in applications where inverting operation is not required.

12. VIVA QUESTIONS

1. What is the difference between half-controlled and fully-controlled rectifiers?
2. Why is it called a "half-controlled" or "semi-converter"?
3. What is the range of firing angle for half-controlled rectifier?
4. Derive the expression for average output voltage.
5. Which devices conduct during positive and negative half cycles?
6. What is the maximum and minimum output voltage obtainable?
7. Can this rectifier operate in inverting mode? Why?
8. What is the purpose of a freewheeling diode in inductive loads?
9. How do you generate synchronized gate pulses for the thyristors?
10. What is the PIV across thyristors and diodes?
11. Why is the output voltage always positive or zero?
12. What happens when $\alpha = 90$?
13. Compare the cost of half-controlled vs fully-controlled rectifiers.
14. What is natural commutation?
15. How does power factor vary with firing angle?
16. What are the advantages over phase-controlled AC voltage controllers?

17. Why is asymmetrical current a concern in this circuit?
18. How would you add output filtering to reduce ripple?
19. What is the conduction angle for each device?
20. Explain the commutation process in this rectifier.

13. POST-LAB ASSIGNMENT

1. Simulate the circuit for firing angles: 0°, 45°, 90°, 135°, 180° and plot V_{dc} vs α graph
2. Perform FFT analysis on output voltage for $\alpha = 60$ and identify dominant harmonics
3. Add an R-L load (R = 50 Ω, L = 100 mH) and observe the effect on output waveforms
4. Design and add a freewheeling diode for the R-L load and compare results
5. Calculate and plot the power factor vs firing angle
6. Compare the performance with:
   - Uncontrolled full-wave rectifier
   - Fully-controlled rectifier (full bridge thyristor)
7. Design a gate pulse generator circuit using discrete components (ramp, comparator, pulse shaper)
8. Simulate with different load resistances (25 Ω, 100 Ω, 200 Ω) and analyze results
9. Add LC filter at output and study ripple reduction for different firing angles
10. Prepare a detailed report with:
    - All waveforms for different firing angles
    - Comparison tables
    - Graphs and FFT analysis
    - Conclusion on control characteristics

14. REFERENCES

1. M.H. Rashid, "Power Electronics: Circuits, Devices and Applications", Pearson Education
2. P.S. Bimbhra, "Power Electronics", Khanna Publishers
3. Ned Mohan, "Power Electronics: Converters, Applications and Design", Wiley
4. MATLAB Simulink Documentation - Specialized Power Systems
5. IEEE Standards for Power Electronics

EXPERIMENT - 2(b)

SIMULATION OF SINGLE-PHASE FULLY-CONTROLLED FULL-WAVE RECTIFIER

1. OBJECTIVE

To simulate and analyze the performance of a single-phase fully-controlled full-wave rectifier (full converter) using MATLAB Simulink and study the effect of firing angle on output voltage, current, and power factor.

2. THEORY

A fully-controlled rectifier or full converter is a power electronic circuit that uses four thyristors (SCRs) to convert AC to controlled DC output. It provides bidirectional power flow capability and precise control over the output DC voltage by varying the firing angle of the thyristors. The circuit can operate in both rectifying and inverting modes.

2.1 Working Principle

The single-phase fully-controlled full-wave rectifier consists of four thyristors (T1, T2, T3, T4) connected in a full-bridge configuration. The thyristors are fired in pairs at controlled firing angles to provide continuous current flow through the load.

Positive Half Cycle ($0 < \omega t < \pi$):

- At $\omega t = \alpha$: Thyristors T1 and T2 are triggered simultaneously
- Current path: AC source positive → T1 → Load → T2 → AC source negative
- T1 and T2 conduct from α to $\pi + \alpha$

Negative Half Cycle ($\pi < \omega t < 2\pi$):

- At $\omega t = \pi + \alpha$: Thyristors T3 and T4 are triggered simultaneously
- Current path: AC source negative → T3 → Load → T4 → AC source positive
- T3 and T4 conduct from $\pi + \alpha$ to $2\pi + \alpha$

2.2 Operating Modes

1. **Rectification Mode ($0 \leq \alpha < 90$):** Power flows from AC source to DC load, positive average output voltage
2. **Inversion Mode ($90 < \alpha \leq 180$):** Power flows from DC source to AC supply, negative average output voltage

2.3 Important Parameters

For resistive load, the average output voltage is:

$$V_{dc} = \frac{2V_m}{\pi} \cos\alpha \tag{1}$$

Other parameters:

- **RMS Output Voltage:** $V_{rms} = \frac{V_m}{\sqrt{2}}\sqrt{1 - \frac{2\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}}$
- **Maximum DC Voltage (at $\alpha = 0$):** $V_{dc(max)} = \frac{2V_m}{\pi} = 90.03$ V
- **Zero DC Voltage (at $\alpha = 90$):** $V_{dc} = 0$
- **Minimum DC Voltage (at $\alpha = 180$):** $V_{dc(min)} = -\frac{2V_m}{\pi} = -90.03$ V
- **Firing Angle Range:** $0 \leq \alpha \leq 180$
- **Peak Inverse Voltage (PIV):** $PIV = V_m$ (for all thyristors)
- **Form Factor:** $FF = \frac{V_{rms}}{V_{dc}}$
- **Ripple Factor:** $RF = \sqrt{FF^2 - 1}$

Where:

- $V_m = \sqrt{2} \times V_{rms(input)} = \sqrt{2} \times 100 = 141.42$ V
- α = Firing angle in degrees

3. CIRCUIT SPECIFICATIONS

- Input Voltage: 100 V (RMS)
- Input Frequency: 50 Hz
- Load Resistance: 50 Ω
- Number of Thyristors: 4 (T1, T2, T3, T4)
- Firing Angles to be tested: $\alpha = 0°$, 30°, 45°, 60°, 90°, 120°, 150°

3.1 Advantages of Fully-Controlled Rectifier

1. Bidirectional power flow capability (rectification and inversion)
2. Precise control over output DC voltage
3. Can operate in all four quadrants (with appropriate load)
4. Regenerative braking capability in motor drives
5. Better dynamic response
6. Suitable for reversible DC drives
7. No freewheeling diode required for pure resistive loads

3.2 Disadvantages

1. Higher cost (requires 4 thyristors)
2. Complex gate drive circuitry
3. Poor power factor, especially at large firing angles
4. Higher harmonic content in input current
5. Commutation problems may occur
6. Requires forced commutation for some loads

3.3 Comparison with Half-Controlled Rectifier

S.No	Parameter	Half-Controlled	Fully-Controlled
1	Number of Thyristors	2	4
2	Number of Diodes	2	0
3	Output Voltage Range	0 to $\frac{2V_m}{\pi}$	$-\frac{2V_m}{\pi}$ to $+\frac{2V_m}{\pi}$
4	Inverting Mode	Not possible	Possible
5	Cost	Lower	Higher
6	Complexity	Simple	Complex
7	Power Factor	Better	Poorer
8	Applications	One quadrant	Four quadrant

Table 1: Comparison between Half-Controlled and Fully-Controlled Rectifiers

4. SIMULINK MODEL DEVELOPMENT

4.1 Required Blocks

1. **AC Voltage Source:** Simscape → Electrical → Specialized Power Systems → Electrical Sources → AC Voltage Source
2. **Thyristor (4 units):** Simscape → Electrical → Specialized Power Systems → Power Electronics → Thyristor
3. **Resistor:** Simscape → Electrical → Specialized Power Systems → Elements → Series RLC Branch
4. **Pulse Generator (4 units):** Simulink → Sources → Pulse Generator
5. **Voltage Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Voltage Measurement
6. **Current Measurement:** Simscape → Electrical → Specialized Power Systems → Sensors and Measurements → Current Measurement
7. **Scope:** Simulink → Sinks → Scope
8. **Powergui:** Simscape → Electrical → Specialized Power Systems → Fundamental Blocks → Powergui
9. **Mux:** Simulink → Signal Routing → Mux
10. **Universal Bridge (Alternative):** Simscape → Electrical → Specialized Power Systems → Power Electronics → Universal Bridge

4.2 Step-by-Step Procedure

4.2.1 Method 1: Using Individual Thyristors

1. Open MATLAB and create a new Simulink model (File → New → Model)
2. Place the AC Voltage Source and configure:
   - Peak amplitude: 141.42 V ($100\sqrt{2}$)
   - Phase: 0 degrees
   - Frequency: 50 Hz
   - Sample time: 0
3. Add four Thyristors and arrange them in full-bridge configuration:
   - T1: Top left (Anode to AC source terminal A)
   - T2: Top right (Cathode to positive load terminal)
   - T3: Bottom left (Cathode to AC source terminal A)
   - T4: Bottom right (Anode to negative load terminal)
4. Configure each Thyristor:
   - Resistance Ron: 0.001 Ω

- Forward voltage Vf: 0.8 V (or 0 for ideal)
- Initial current Ic: 0 A
- Snubber resistance Rs: 500 Ω
- Snubber capacitance Cs: inf (for simplicity)

5. Add a Series RLC Branch (Load) and configure:
   - Resistance R: 50 Ω
   - Inductance L: 0 H (for resistive load)
   - Capacitance C: inf
6. **Full Bridge Connection:**
   - Connect AC source terminal A to junction of T1 (anode) and T3 (cathode)
   - Connect AC source terminal B to junction of T2 (anode) and T4 (cathode)
   - Connect T1 (cathode) and T2 (cathode) to positive terminal of load
   - Connect T3 (anode) and T4 (anode) to negative terminal of load
7. Add four Pulse Generators for firing pulses:

   Pulse Generator 1 (for T1):
   - Amplitude: 1
   - Period: 0.02 s (50 Hz)
   - Pulse width: 10%
   - Phase delay: $\frac{\alpha}{360} \times 0.02$ seconds

   Pulse Generator 2 (for T2):
   - Amplitude: 1
   - Period: 0.02 s
   - Pulse width: 10%
   - Phase delay: $\frac{\alpha}{360} \times 0.02$ seconds (same as T1)

   Pulse Generator 3 (for T3):
   - Amplitude: 1
   - Period: 0.02 s
   - Pulse width: 10%
   - Phase delay: $\frac{180+\alpha}{360} \times 0.02$ seconds

   Pulse Generator 4 (for T4):
   - Amplitude: 1
   - Period: 0.02 s
   - Pulse width: 10%
   - Phase delay: $\frac{180+\alpha}{360} \times 0.02$ seconds (same as T3)

   For example, if $\alpha = 60$:

- T1, T2 phase delay = $(60/360) \times 0.02 = 0.00333$ s
- T3, T4 phase delay = $(240/360) \times 0.02 = 0.01333$ s

8. Connect Pulse Generator outputs to respective thyristor gates:
   - PG1 → T1 gate
   - PG2 → T2 gate
   - PG3 → T3 gate
   - PG4 → T4 gate
9. Add Voltage Measurement across the load
10. Add Current Measurement in series with the load
11. Add Voltage Measurement across AC source (for input waveform)
12. Connect all measurements to Scope using Mux block (3 inputs)
13. Add powergui block and configure:
    - Simulation type: Continuous
    - Sample time: 0
14. Configure Simulation Parameters (Modeling → Model Settings):
    - Solver: ode23tb (stiff/TR-BDF2)
    - Stop time: 0.1 s (5 complete cycles)
    - Max step size: 1e-5
    - Relative tolerance: 1e-3
15. Run the simulation and observe waveforms
16. Repeat for different firing angles

4.2.2 Method 2: Using Universal Bridge (Simplified)

1. Follow steps 1-2 from Method 1
2. Add **Universal Bridge** block
3. Configure Universal Bridge:
   - Number of bridge arms: 1
   - Power electronic device: Thyristor
   - Snubber resistance Rs: 500 Ω
   - Snubber capacitance Cs: inf
4. Connect AC source to bridge input terminals
5. Connect load to bridge output terminals
6. Add pulse generators or use synchronized pulse generator for gate signals
7. Configure remaining blocks as in Method 1

5. OBSERVATIONS AND RESULTS

5.1 Theoretical Calculations

For different firing angles with $V_m = 141.42$ V and $R = 50\ \Omega$:

α (degrees)	$\cos\alpha$	V_{dc} (V)	I_{dc} (A)	P_{dc} (W)
0°	1.000	90.03	1.80	162.05
30°	0.866	77.97	1.56	121.63
45°	0.707	63.66	1.27	80.85
60°	0.500	45.01	0.90	40.51
90°	0.000	0.00	0.00	0.00
120°	-0.500	-45.01	-0.90	40.51
150°	-0.866	-77.97	-1.56	121.63

Table 2: Theoretical Values for Different Firing Angles

Where:

$$V_{dc} = \frac{2V_m}{\pi}\cos\alpha = \frac{2 \times 141.42}{\pi}\cos\alpha = 90.03\cos\alpha$$

$$I_{dc} = \frac{V_{dc}}{R} = \frac{V_{dc}}{50}$$

$$P_{dc} = |V_{dc} \times I_{dc}|$$

5.2 Observation Table

For Firing Angle $\alpha = 60$:

S.No	Parameter	Theoretical Value	Simulated Value
1	Input Voltage (V_{rms})	100 V	
2	Firing Angle (α)	60°	
3	Output DC Voltage (V_{dc})	45.01 V	
4	DC Load Current (I_{dc})	0.90 A	
5	DC Output Power (P_{dc})	40.51 W	
6	Peak Inverse Voltage (PIV)	141.42 V	
7	Operating Mode	Rectification	

Table 3: Observations for $\alpha = 60$

5.3 Comparative Analysis Table

Record simulated values for different firing angles:

α	V_{dc} (V)		I_{dc} (A)		% Error	
(degrees)	Theoretical	Simulated	Theoretical	Simulated	V_{dc}	I_{dc}
0°	90.03		1.80			
30°	77.97		1.56			
45°	63.66		1.27			
60°	45.01		0.90			
90°	0.00		0.00			
120°	-45.01		-0.90			

Table 4: Comparative Analysis for Various Firing Angles

5.4 Waveform Analysis

Observe and sketch the following waveforms from the Scope for different firing angles:

1. Input AC voltage waveform (sinusoidal)
2. Output voltage across load resistor
3. Load current waveform
4. Gate pulses for all four thyristors (T1, T2, T3, T4)
5. Voltage across thyristor T1 (to observe commutation and PIV)
6. Input current waveform (to observe harmonics)

Key Observations:

- For $\alpha < 90$: Positive average output voltage (rectification mode)
- For $\alpha = 90$: Zero average output voltage
- For $\alpha > 90$: Negative average output voltage (inversion mode)
- Output voltage waveform shows both positive and negative portions
- Conduction angle for each pair = 180
- Output ripple frequency = $2f$ = 100 Hz

Note:

- Use Powergui → Steady-State Voltages and Currents to measure DC values
- For $\alpha > 90$, the output voltage becomes negative (inverting operation)
- At $\alpha = 90$, output voltage oscillates around zero with no DC component
- Verify gate pulse synchronization for proper commutation

6. RESULT ANALYSIS

6.1 Error Calculation

Calculate percentage error for each firing angle:

$$\%\ \text{Error} = \left| \frac{\text{Theoretical Value} - \text{Simulated Value}}{\text{Theoretical Value}} \right| \times 100 \tag{2}$$

6.2 Graphical Analysis

Plot the following graphs:

1. V_{dc} vs α (Output DC voltage variation with firing angle) - cosine characteristic
2. I_{dc} vs α (Output DC current variation)
3. $|P_{dc}|$ vs α (Output power variation)
4. Power factor vs α
5. Comparative waveforms for $\alpha = 0, 45, 90, 120$

6.3 Expected Characteristics

- Output voltage follows cosine relationship: $V_{dc} = \frac{2V_m}{\pi} \cos \alpha$
- At $\alpha = 0$: Maximum positive output = 90.03 V
- At $\alpha = 90$: Zero output voltage
- At $\alpha = 180$: Maximum negative output = -90.03 V
- Continuous conduction for all firing angles (with resistive load)
- Each thyristor conducts for 180° when triggered
- Output can be positive, zero, or negative based on firing angle

7. DISCUSSION

- The fully-controlled rectifier uses four thyristors to achieve bidirectional power flow
- Firing angle controls both magnitude and polarity of output voltage
- During positive half cycle: T1 and T2 conduct when fired at angle α
- During negative half cycle: T3 and T4 conduct, maintaining current direction through load
- For resistive load, output voltage and current can be positive, zero, or negative
- **Rectification mode ($\alpha < 90$):** Power flows from AC source to DC load
- **Inversion mode ($\alpha > 90$):** Power flows from DC source back to AC supply
- Average output voltage: $V_{dc} = \frac{2V_m}{\pi} \cos \alpha$
- Power factor decreases as firing angle increases: $PF \approx \cos \alpha$
- Input current is highly distorted, especially at large firing angles
- Total Harmonic Distortion (THD) increases with firing angle
- Line commutation occurs naturally when voltage reverses
- For inductive loads, continuous conduction is maintained even at large firing angles
- Circuit is more expensive than half-controlled rectifier but offers better control
- Suitable for four-quadrant operation in DC motor drives

8. APPLICATIONS

1. Reversible DC motor drives (traction, hoists, elevators)
2. Variable speed DC drives with regenerative braking
3. HVDC transmission systems
4. Battery charging and discharging systems
5. Electrochemical processes requiring bidirectional current
6. Metal rolling mills
7. Paper and textile mill drives
8. Crane and hoist controls
9. Four-quadrant DC choppers
10. Active power filters

9. PRECAUTIONS

1. Ensure correct placement of all four thyristors in bridge configuration
2. Verify gate pulse timing - T1 & T2 fire together, T3 & T4 fire together
3. Check that firing angle is within valid range (0° to 180°)
4. Ensure proper polarity of all gate pulses
5. Set appropriate pulse width for reliable triggering (minimum 10%)
6. Use correct solver (ode23tb) for thyristor-based circuits
7. Set small max step size (1e-5) for accurate switching simulation
8. Always include powergui block in continuous mode
9. Ground the circuit properly at one reference point
10. For inductive loads, ensure proper snubber circuit design
11. Verify that AC source and thyristors have compatible ratings
12. Check commutation overlaps at high firing angles
13. Monitor input current harmonics for power quality analysis
14. Save model frequently during development
15. For inverting mode ($\alpha > 90$), ensure proper DC source connection

10. TROUBLESHOOTING

Problem	**Solution**
Thyristors not triggering	Verify gate pulse amplitude and timing, check connections
Output voltage incorrect at $\alpha = 0$	Check that all 4 thyristors are properly configured and connected
No output for $\alpha > 90$	Verify negative voltage capability; for pure resistive load, current cannot reverse
Simulation convergence issues	Reduce max step size, add snubber circuits, check for algebraic loops
Irregular commutation	Ensure synchronized firing of thyristor pairs (T1-T2 and T3-T4)
Negative voltage not appearing	Check if load configuration allows bidirectional current flow

Table 5: Common Problems and Solutions

11. CONCLUSION

The single-phase fully-controlled full-wave rectifier was successfully simulated using MATLAB Simulink. The key findings are:

- Output DC voltage can be precisely controlled by varying firing angle from 0° to 180°
- Voltage-firing angle relationship follows: $V_{dc} = 90.03 \cos \alpha$
- At $\alpha = 0$, maximum output of 90.03 V is obtained
- At $\alpha = 90$, output voltage becomes zero
- At $\alpha > 90$, output voltage becomes negative (inversion mode)
- The circuit provides bidirectional power flow capability
- Simulation results match theoretical calculations with minimal error
- Power factor decreases significantly at higher firing angles
- Circuit is suitable for four-quadrant operation and regenerative braking applications

The fully-controlled rectifier is essential for applications requiring precise voltage control and bidirectional power flow, despite its higher cost and complexity compared to half-controlled converters.

12. VIVA QUESTIONS

1. What is the main difference between fully-controlled and half-controlled rectifiers?
2. Why is it called a ”fully-controlled” converter?
3. What is the range of firing angle and corresponding output voltage?
4. Derive the expression for average output voltage.
5. Which thyristors conduct during positive and negative half cycles?
6. Explain rectification and inversion modes of operation.
7. What happens when $\alpha = 90$?
8. Can this rectifier provide negative output voltage? How?
9. What is the significance of cosine relationship in output voltage?
10. Why does power factor decrease with increasing firing angle?
11. What is line commutation? How does it occur in this circuit?
12. Compare PIV ratings with half-controlled rectifier.
13. Why are thyristors fired in pairs (T1-T2 and T3-T4)?
14. What is the conduction angle for each thyristor?
15. How does input current waveform change with firing angle?

16. What are the advantages of four-quadrant operation?
17. Compare the cost and complexity with other rectifier types.
18. Why is this configuration preferred for reversible DC drives?
19. What is the effect of firing angle on harmonic distortion?
20. How would you implement regenerative braking using this converter?

13. POST-LAB ASSIGNMENT

1. Simulate the circuit for firing angles: 0°, 30°, 60°, 90°, 120°, 150° and plot V_{dc} vs α graph showing cosine characteristic
2. Perform FFT analysis on output voltage for $\alpha = 45$ and identify the dominant harmonics and their frequencies
3. Perform FFT analysis on input current for $\alpha = 60$ and calculate Total Harmonic Distortion (THD)
4. Add an R-L load (R = 50 Ω, L = 100 mH) and observe the effect on:
    - Output voltage waveform
    - Current waveform (continuous vs discontinuous)
    - Commutation process
5. Calculate and plot power factor vs firing angle for the range 0° to 150°
6. Compare the performance with:
    - Half-controlled rectifier (at same firing angle)
    - Uncontrolled full-wave rectifier

   Create a comprehensive comparison table
7. For firing angles in inversion mode ($\alpha = 120, 150$), explain the current flow and energy transfer mechanism
8. Simulate with different load resistances (25 Ω, 100 Ω, 200 Ω) and analyze the effect on output characteristics
9. Add output LC filter (L = 50 mH, C = 1000 μF) and study:
    - Ripple reduction
    - Effect on average output voltage
    - Steady-state response time
10. Design a closed-loop voltage control system using:
    - Voltage sensor
    - PI controller
    - Firing angle controller

- Target output: 60 V DC

11. Prepare a detailed report including:

    - All waveforms for different firing angles (both rectification and inversion modes)
    - Comparison tables with theoretical and simulated values
    - FFT analysis results and harmonic spectrum
    - Power factor and efficiency calculations
    - Graphs showing voltage-firing angle characteristics
    - Conclusion on advantages and limitations

14. REFERENCES

1. M.H. Rashid, "Power Electronics: Circuits, Devices and Applications", 4th Edition, Pearson Education

2. P.S. Bimbhra, "Power Electronics", 4th Edition, Khanna Publishers

3. Ned Mohan, Tore M. Undeland, William P. Robbins, "Power Electronics: Converters, Applications and Design", 3rd Edition, Wiley

4. Muhammad H. Rashid, "Power Electronics Handbook", 4th Edition, Butterworth-Heinemann

5. MATLAB Simulink Documentation - Specialized Power Systems

6. IEEE Std 519-2014, "IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems"

15. FORMULAE SUMMARY

15.1 Average Output Voltage

$$V_{dc} = \frac{2V_m}{\pi}\cos\alpha = 90.03\cos\alpha \text{ volts} \tag{3}$$

15.2 RMS Output Voltage

$$V_{rms} = \frac{V_m}{\sqrt{2}}\sqrt{1 - \frac{2\alpha}{\pi} + \frac{\sin 2\alpha}{2\pi}} \tag{4}$$

15.3 Average Load Current

$$I_{dc} = \frac{V_{dc}}{R} = \frac{2V_m}{\pi R}\cos\alpha \tag{5}$$

15.4 DC Output Power

$$P_{dc} = V_{dc} \times I_{dc} = \frac{4V_m^2}{\pi^2 R}\cos^2\alpha \tag{6}$$

15.5 Form Factor

$$FF = \frac{V_{rms}}{V_{dc}} \tag{7}$$

15.6 Ripple Factor

$$RF = \sqrt{FF^2 - 1} \tag{8}$$

15.7 Displacement Power Factor

$$\text{DPF} \approx \cos\alpha \tag{9}$$