THREE-PHASE CONTROLLED RECTIFIER

POWER ELECTRONICS LABORATORY(EE334)

MINI PROJECT

Report Submitted in partialfulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY in ELECTRICAL AND ELECTRONICS ENGINEERING

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1. ABSTRACT

The project is about crafting a sophisticated three-phase controlled rectifier using six thyristors arranged in a bridge setup. Our aim is to convert incoming AC power into a regulated DC supply by adjusting the firing angle. We're targeting a specific load – a 400Ω resistor – while maintaining a steady load current of 1.7A. Our focus is on efficiency, controlling power quality, and ensuring stability under various load and input conditions. To validate our design before actual implementation, we're simulating it using MATLAB and planning PCB layouts. Detailed documentation, including calculations and simulation outcomes, will be crucial for assessing the rectifier's performance for battery charging and DC motor drive applications

2. ACKNOWLEDGEMENT

We extend our heartfelt gratitude to Dr. Karthikeyan Anbalagan, our esteemed professor, for granting us the invaluable opportunity to delve deeper into the realm of Three-phase fully controlled rectifiers. Under his guidance, we not only explored the applications and constraints of this technology but also gained hands-on experience in PCB design and Arduino functionality. Dr. Karthikeyan's unwavering enthusiasm, vast expertise, and unwavering support have been a constant source of inspiration for our team.

Our sincere appreciation goes to the department for furnishing us with the essential tools, resources, and guidance essential for conducting experiments and simulations pivotal to our project's success.

Additionally, we express our gratitude to our Head of Department (HOD) for entrusting us with the experiment and enabling us to grasp vital concepts integral to our academic journey.

3. INTRODUCTION

QUESTION STATEMENT:

"Design a Three-phase controlled rectifier with the given specifications. Input voltage (line-line) =40.82V, resistive load of 400Ω, 1.7A, firing angle of $\alpha = 30°$."

Its primary role is to transform alternating current (AC) into adjustable direct current (DC) output, differing from uncontrolled rectifiers that offer fixed output. Notably advantageous due to simplicity, robustness, and cost-effectiveness, rectifiers, particularly controlled three-phase ones, hold significant importance in converter technology. Widely utilized in industries for DC motor speed regulation, these rectifiers find applications in various sectors like transportation, power systems, communication, and energy.

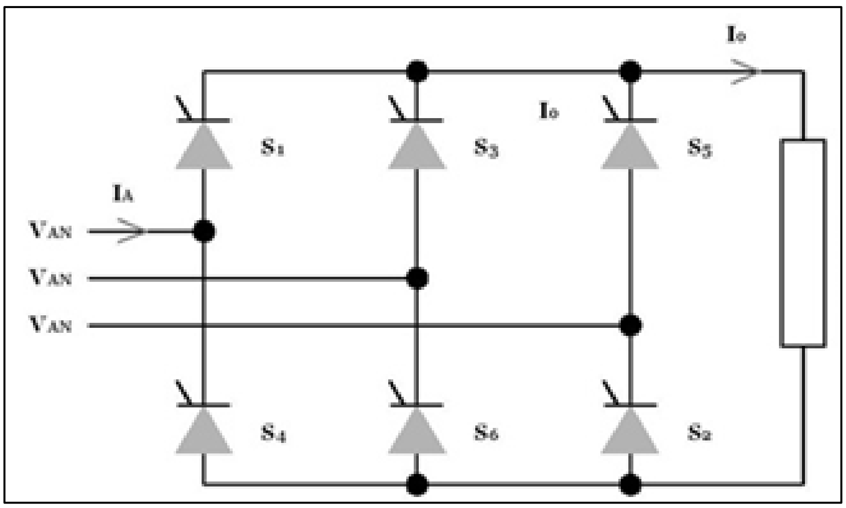


Fig.1: Three Phase Controlled Rectifier Circuit Diagram

Between $\pi/6 + \alpha$ and $\pi/2 + \alpha$, both T1 and T6 conduct simultaneously as T6 initiates conduction while T1 takes over. This simultaneous conduction enables the phase voltage Vab to power the load. At $\pi/2 + \alpha$, T2 begins conduction, causing T6 to switch off due to receiving a reverse bias. As a result, from $\pi/2 + \alpha$ to $5\pi/6 + \alpha$, T1 and T2 conduct in unison, allowing phase voltage Vac to supply the load. The rectifier circuit comprises two SCR groups: positive (T1, T3, T5) and negative (T4, T6, T2). Positive SCR group conduction relies on receiving a positive source voltage; conversely, a negative source voltage deactivates the SCR group. Consult Fig. 2 for a visual guide illustrating the control phases in the three-phase controlled rectifier.

The three-phase controlled rectifier comprises six SCRs arranged in a full wave bridge setup. It's controlled by trigger signals at intervals of $\pi/3$ or 600. The desired output voltage hinges on the trigger signal's active duration (ton). Longer active durations yield lower average output voltages, whereas shorter durations result in higher rectifier output voltages. This rectifier operates in two modes: Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM)

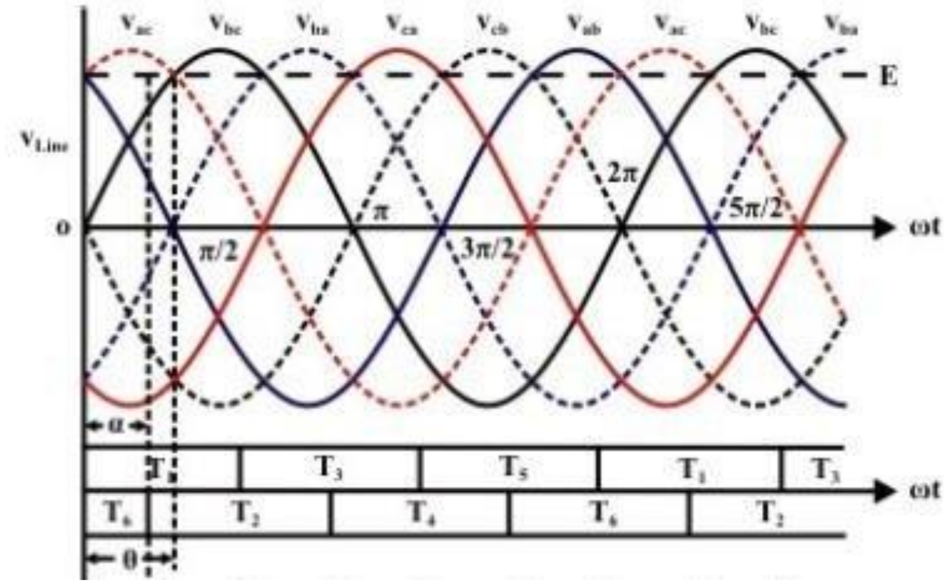


Fig.2: Three Phase Controlled Rectifier Switch Diagram

4. WORKING PRINCINPLE

The Three-Phase Controlled Rectifier with an R Load, operating with a firing angle of 30 degrees, functions by converting incoming three-phase AC power into controlled DC output using semiconductor devices like thyristors or SCRs. Configured in a full-wave bridge configuration, these devices rectify the AC input, generating a pulsating DC waveform.

By setting the firing angle at 30 degrees, the rectifier regulates the conduction timing of the thyristors in each AC cycle, allowing precise control over the portion of the cycle during which conduction occurs. This adjustment directly impacts the output DC voltage, altering the shape and amplitude of the DC waveform across the R load, effectively controlling the delivered power. This capability proves vital in applications necessitating regulated DC power supplies for various industrial and electronic systems.

5. THEORITICAL CALCULATIONS

Average output voltage with R Load, α<60:

The average output voltage is given by

$$V_{dc} = \frac{6}{2\pi} \int_{\pi/6+\alpha}^{\pi/2+\alpha} V_{ab} d(\omega t)$$

$$V_{dc} = \frac{3}{\pi} \int_{\pi/6+\alpha}^{\pi/2+\alpha} \sqrt{3} V_m \sin\left(\omega t + \frac{\pi}{6}\right) d(\omega t)$$

$$V_{dc} = \frac{3\sqrt{3} V_m}{\pi} \cos\alpha$$

The maximum output dc voltage is given by

$$V_{dm} = \frac{3\sqrt{3} V_m}{\pi}$$

RMS output voltage with R can be calculated as:

$$V_{rms} = \left[\frac{3}{\pi} \int_{\pi/6+\alpha}^{\pi/2+\alpha} \left(\sqrt{3} V_m \sin(\omega t + \frac{\pi}{6}) \right)^2 d(\omega t) \right]^{\frac{1}{2}}$$

$$V_{rms} = \sqrt{3} V_m \left(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} \cos 2\alpha \right)^{\frac{1}{2}}$$

Thyristor Current is given by

Each thyristor conducts for 120°.

$$I_{T(avg)} = I_o\left(\frac{120}{360}\right) = I_o/3$$

$$I_{T(rms)} = I_o\left(\frac{\sqrt{120}}{\sqrt{360}}\right) = I_o/\sqrt{3}$$

6. EXPERIMENTAL CALCULATIONS

Given that,

Firing angle, α = 30 deg
Source voltage V_s = 40.82 (L-L)
Resistance, R = 400 Ω
Load Current, I_o = 1.7 A

Average Voltage,

$V_{avg} = \frac{3\times\sqrt{3}}{\pi} \times V_s(\text{peak}) \cos\alpha$

V_s(peak)=40.82× √2=57.728V

Thus,

$V_{avg} = \frac{3\times\sqrt{3}}{\pi} \times 57.728\times \cos 30^o$

V_{avg} = 82.689V

RMS Voltage,

$V_{rms}=\sqrt{3} \times V_s(\text{peak})(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} cos 2\alpha)^{1/2}$

$=\sqrt{3} \times 57.728(\frac{1}{2} + \frac{3\sqrt{3}}{4\pi} cos 60^o)^{1/2}$

V_{rms}=84.058V

Thyristor Current:

$I_{r(avg)}=I_o/3=1.7/3=0.566A$

$I_{r(rms)}=I_o/\sqrt{3}=1.7/\sqrt{3}=0.9814A$

7. APPLICATION OF THREE PHASE CONTROLLED RECTIFIER

The application of three-phase controlled rectifiers spans various industrial sectors due to their ability to regulate and control power. Some notable applications include:

1. **DC Motor Drives**: Three-phase controlled rectifiers are extensively used in controlling the speed and direction of DC motors, ensuring precise and efficient motor operations in industrial machinery and automotive systems.

2. Power Supplies: These rectifiers are employed in power supply units for providing regulated DC voltage in applications such as battery charging stations, uninterruptible power supplies (UPS), and various electronic devices.

3. Variable Speed Drives: In applications requiring variable speed control like pumps, fans, and conveyor systems, three-phase controlled rectifiers offer precise speed regulation and energy efficiency.

4. Renewable Energy Systems: They play a crucial role in converting AC power generated from renewable sources like wind turbines or solar panels into usable DC power, aiding in grid integration and energy storage.

5. Industrial Heating: Controlled rectifiers are used in industries for controlling the power supplied to heating elements, ensuring precise temperature control in furnaces, ovens, and industrial heating systems.

6. Power Quality Improvement: They are utilized in power factor correction and harmonic mitigation, contributing to improving power quality and reducing harmonics in electrical networks.

Overall, the versatility and controllability of three-phase controlled rectifiers make them indispensable in various applications, contributing significantly to efficient power conversion and control in diverse industries.

8. SIMULATION

In MATLAB Simulink, simulating a Three-Phase Controlled Rectifier with an R Load involves modeling the rectifier circuit using semiconductor elements such as thyristors or SCRs. The simulation setup includes the three-phase AC source, controlled rectifier bridge, and R load. Using Simulink's Power Systems Block set or Power Electronics Toolbox, the thyristors' firing angles are controlled to mimic real-time operation. This simulation allows for analysis of the rectifier's behavior under varying firing angles, enabling observation of output voltage, current, and power characteristics across the R load. MATLAB Simulink's capability for visualizing waveforms and data aids in comprehending the rectifier's performance, facilitating optimization and control strategy evaluation before practical implementation.

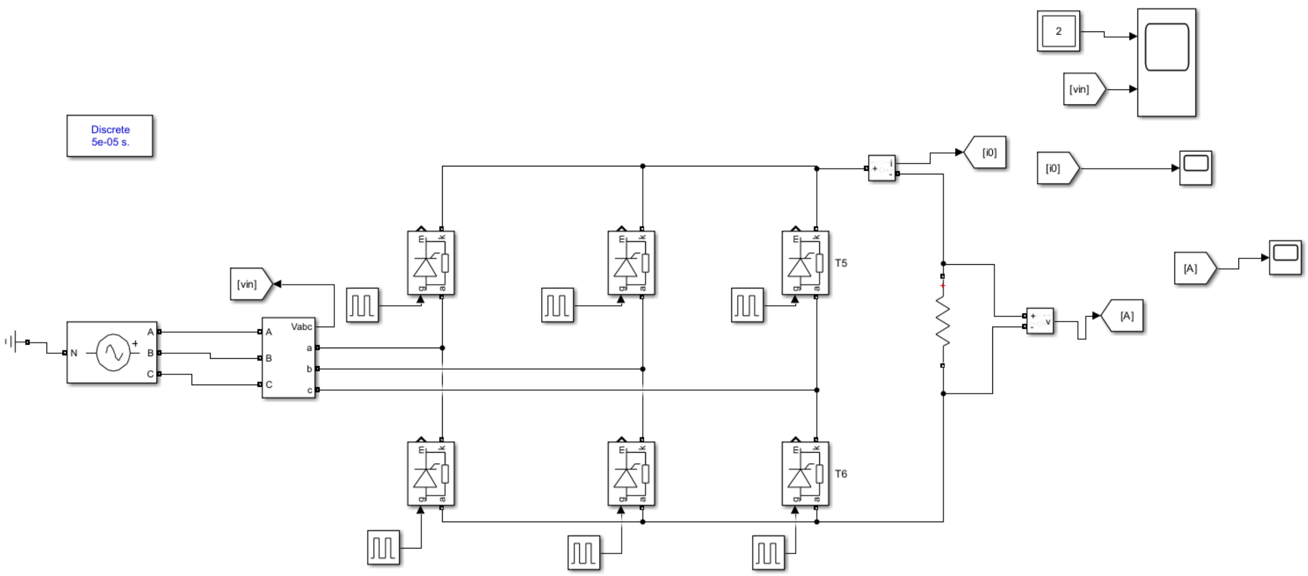


Fig.03 Matlab Simulation Model

9. WAVEFROMS

When simulating the Three-Phase Controlled Rectifier with an R Load at a firing angle of 30 degrees using

MATLAB Simulink, the output waveforms illustrate distinct characteristics

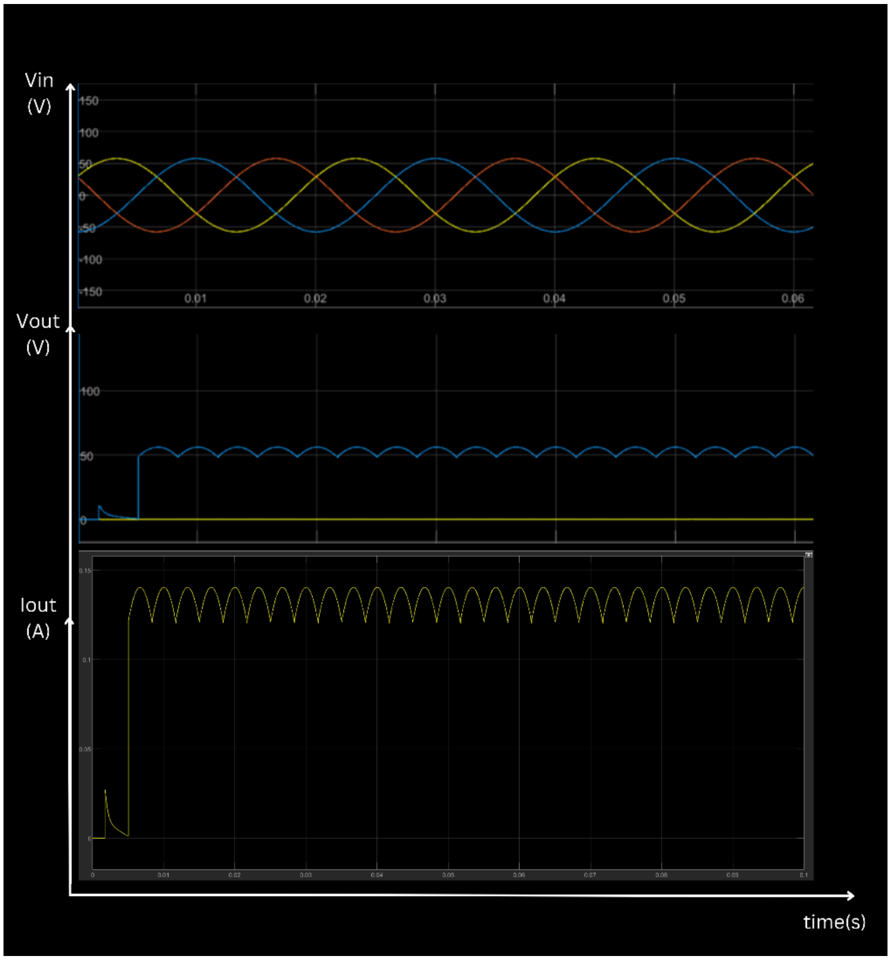


Fig.04 Matlab Simulation Waveforms

10. PCB DESIGN

In EasyEDA, we've successfully executed the PCB design for the Three-Phase Controlled Rectifier with an R Load and a firing angle of 30 degrees. This involved meticulously laying out the circuit components, including thyristors, bridge rectifiers, and resistive loads, in a structured and compact arrangement on the PCB board. The design adheres to the circuit specifications and ensures proper connectivity between the components, guaranteeing optimal functionality and performance. The software's user-friendly interface and versatile tools allowed for precise component placement and routing of traces, ensuring efficient power flow and minimal interference. The completed PCB design serves as a practical and tangible representation of the controlled rectifier circuit, providing a foundation for potential fabrication and testing phases of the project.

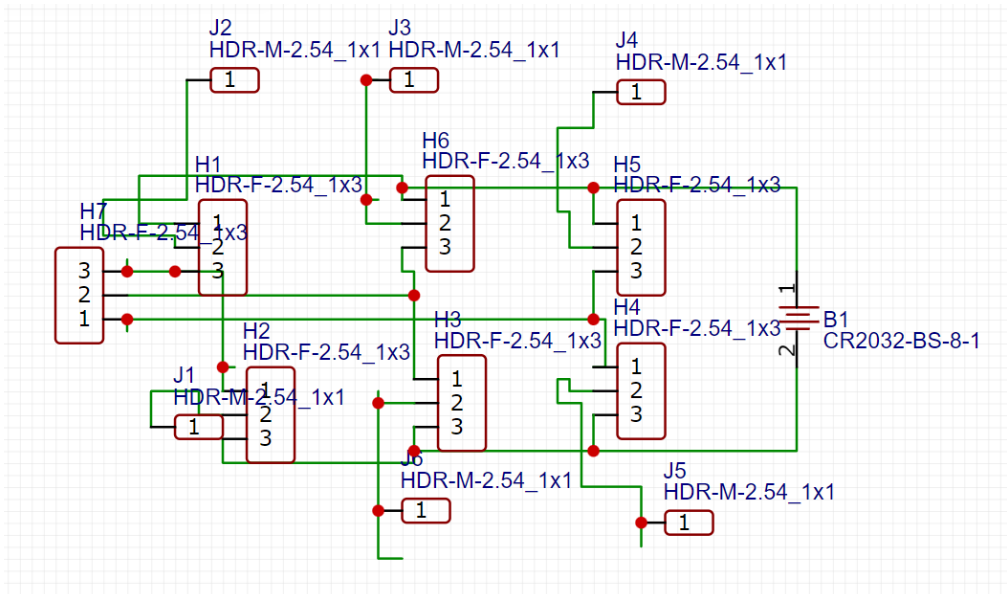


Fig.05 EasyEDA PCB Design Circuit

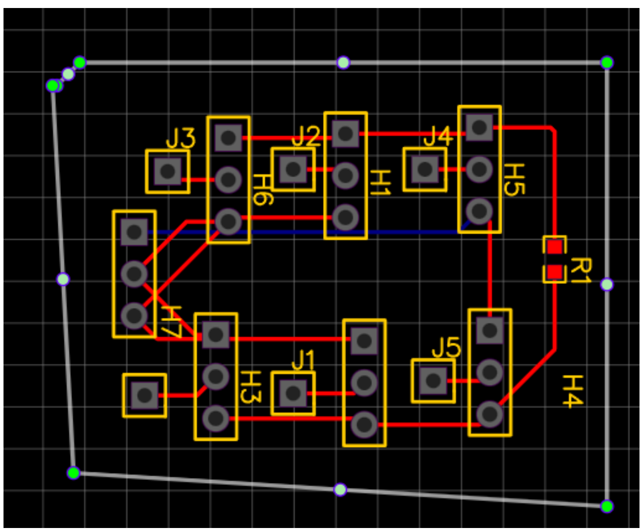


Fig.06 PCB Design Pin Diagram

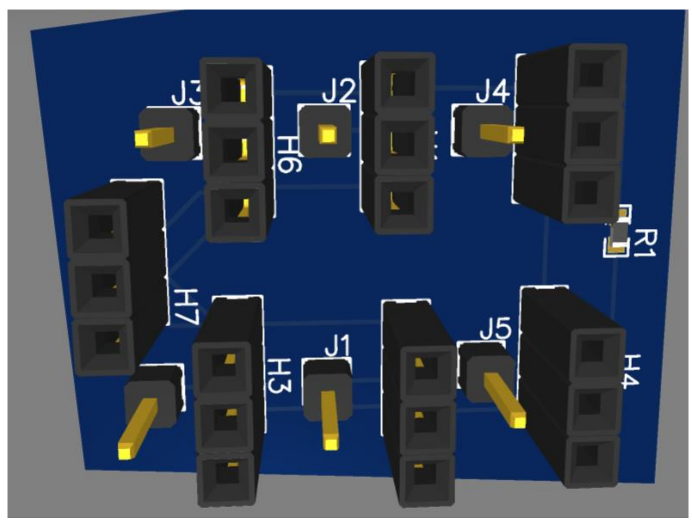


Fig.07 PCB Design 3D Diagram

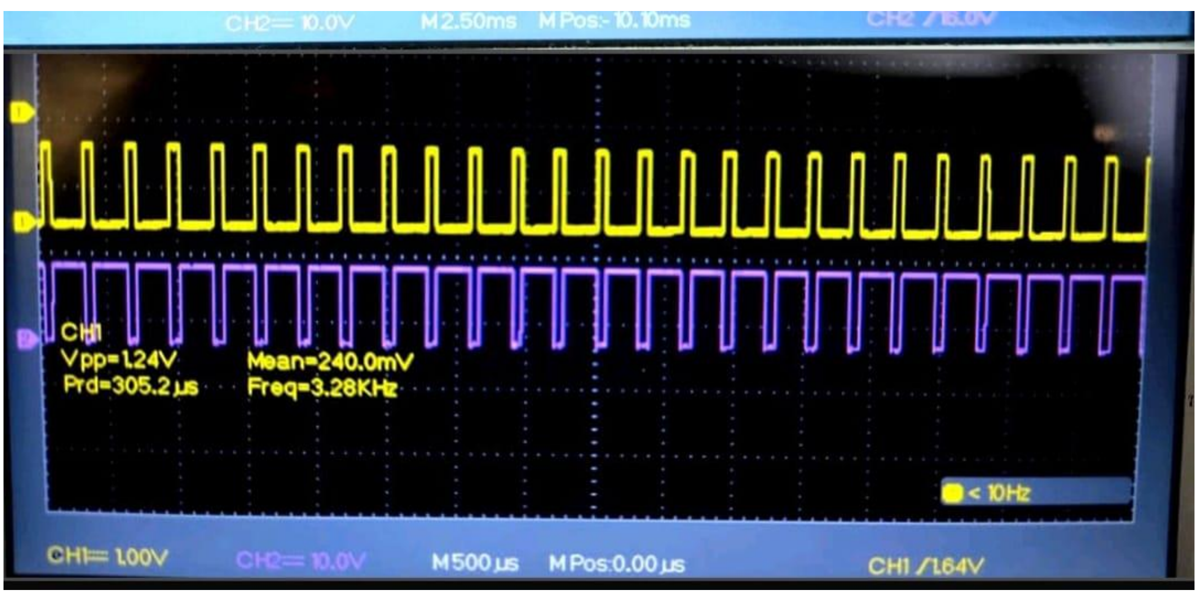
10. PCB DESIGN

The gate pulse for the above SCRs were generated by programming Arduino nano using its very own IDE. The code and output waveforms are as follows.

CODE:

```
const int gatePin = 9;  // Define the digital pin for gate control

void setup() {
  pinMode(gatePin, OUTPUT);  // Set the gate pin as an output
}

void loop() {
  int firingAngle = 30;  // Set the firing angle in degrees
  int period = 360;  // Set the complete period of the waveform in degrees

  // Calculate the duty cycle based on the firing angle
  int dutyCycle = map(firingAngle, 0, 360, 0, 255);

  // Generate the gate pulse with the calculated duty cycle
  analogWrite(gatePin, dutyCycle);

  // Wait for a short duration (adjust as needed)
  delay(1000);

  // Turn off the gate pulse
  analogWrite(gatePin, 0);

  // Wait for the next cycle
  delay(period);
}
```

OUTPUT:



11. CONCLUSION

In conclusion, our comprehensive exploration of the Three-Phase Controlled Rectifier with an R Load and a firing angle of 30 degrees has been both insightful and productive. Through MATLAB simulation, we gained valuable insights into the rectifier's behavior, analyzing its output characteristics and voltage regulation under varied firing angles. This simulation provided a solid foundation for understanding the rectifier's performance and optimizing its control strategies.

Additionally, our successful execution of the PCB design using EasyEDA further reinforced our understanding by translating the theoretical circuit into a practical, real-world representation. The PCB design meticulously incorporated components, ensuring proper connectivity and layout for efficient power flow. This combined effort in simulation and practical design not only deepened our understanding of controlled rectifier systems but also equipped us with hands-on experience crucial for real-world applications in power electronics. Overall, the successful completion of both MATLAB simulation and PCB design has enriched our learning experience, enhancing our proficiency in the realm of three-phase controlled rectifiers and their practical implementations.