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Single-phase controlled AC-DC converter using SCR

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ABSTRACT

The 1-phase controlled full-wave rectifier is one of the main components in power electronics technology that functions to convert alternating voltage (AC) into direct voltage (DC). This circuit is used in various applications, such as battery charging systems and DC motors in industry. Controlled rectifiers use a Silicon Controlled Rectifier (SCR). The use of SCRs in controlled rectifiers provides the advantage of more precise current control. The controlled rectifier uses a Silicon Controlled Rectifier (SCR), which is controlled with a microcontroller through an SCR driver. The SCR driver serves for isolation so that the converter circuit does not damage the microcontroller due to current surges. This circuit also requires a zero crossing detector to determine the intersection of point 0 on the AC wave. This research aims to design and build a 1-phase full wave rectifier system using SCR as the main controlling component. With a deep understanding of SCR characteristics, it is hoped that this research can contribute to the development of modern power supply technology that is more efficient and can be controlled with precision.

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1. INTRODUCTION

The development of power electronics technology has driven the use of single-phase full-wave rectifiers as a key component in various applications, ranging from battery charging systems to DC motors in industry [1]. A rectifier functions to convert alternating current (AC) voltage into direct current (DC) voltage, which is required for various electronic devices [2],[3]. One common method for designing a full-wave rectifier is to use a center-tapped transformer, which is capable of providing a more stable and efficient output voltage [4],[5]. This conversion is important because most modern electronic equipment, both in industry and at home, operates on DC voltage [6],[7].

Full-wave rectifiers are divided into two types: uncontrolled rectifiers and controlled rectifiers [8][9]. In uncontrolled rectifiers, the main component used is the diode [10],[11]. Diodes allow current to flow in only one direction and block current from the opposite direction [12]. Uncontrolled full-wave rectifiers typically use 2 to 4 diodes or a bridge configuration with additional resistors and capacitors for filtering [13][14]. These funcontrolled full-wave rectifiers have a fixed output voltage [15].

On the other hand, controlled rectifiers use more advanced semiconductor components, such as Silicon Controlled Rectifiers (SCR), which are a type of thyristor [16]. These controlled full-wave rectifiers use 2 to 4 SCRs. Unlike diodes, controlled full-wave rectifiers using SCRs allow for the adjustment of output voltage and waveform shape [17]. By leveraging the control capabilities of SCRs, controlled rectifiers can be tailored for applications that require power regulation, such as electric motors [18]. The use of SCRs in full-wave rectifiers also provides flexibility in adjusting the output voltage, making them highly suitable for industrial applications that require efficient power control.

To activate the SCR at a specific firing angle, an SCR driver controlled by a microcontroller is required [19]. The timing adjustment for firing the SCR necessitates a digital control system, including the use of a zero-crossing detector to detect changes in the AC waveform cycle and provide a synchronized trigger signal. Through this digital control, the SCR can be activated at the precise angle, allowing for the output voltage to be regulated according to application needs. A deep understanding of the characteristics and operation of SCRs is essential in the development of modern full-wave rectifier technology, which can provide high efficiency and improved control.

2. METHOD

This research aims to design a precision-controlled AC-DC converter using Silicon Controlled Rectifiers (SCR) [20],[21]. This converter will be used to regulate the output voltage generated from an AC voltage source. Voltage control is achieved by adjusting the firing angle of the SCR using a microcontroller-based firing angle control method. The microcontroller serves as the main controller that modulates the trigger signal for the SCR to produce the DC voltage required by the load .

The first stage of this research is to design a full-wave rectifier circuit that uses SCRs as the controlling components. The SCR is configured to control the flow of current in each cycle of the AC waveform, thereby converting AC voltage into DC. This circuit is also equipped with a zero-crossing detector to detect changes in the AC cycle and ensure that the SCR is triggered at the right time [22]. This detector provides a signal to the microcontroller to trigger the SCR at a specific angle.

In the next stage, the firing angle of the SCR is adjusted through Arduino by providing firing angles for SCR 1 during the positive pulse at 10, 30, 60, 90, 120, 150, and 180 degrees. For SCR 2, the angles are applied during the negative pulse at 190, 210, 240, 270, 300, 330, and 360 degrees. These angles serve as signals to determine when the gate of the SCR is activated. This technique is a method of delaying the firing of the SCR as an electronic switch [23].

The final stage involves the implementation of the circuit and testing the AC-DC converter system with various firing angle variations of the SCR. The magnitude of the firing angle can affect the value and shape of the output waveform of the AC-DC converter. This is in accordance with the voltage equation formulated in the following equation 1 [24] :

$$V_{DC} = \frac{V_p}{\pi}\left(1+\cos\alpha\right) \tag{1}$$

The larger the value of the firing angle, the smaller the output voltage produced at the circuit's output. The block diagram of the single-phase AC-DC converter can be seen in Figure 1.

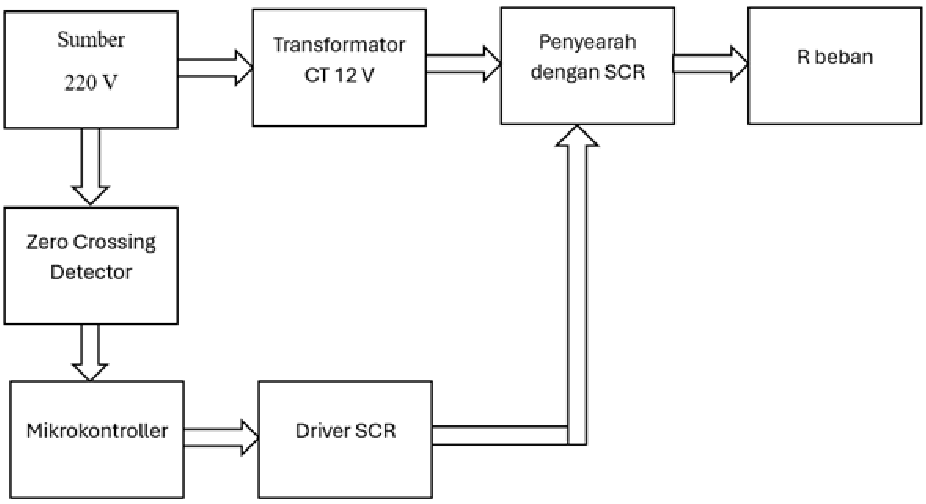


Figure 1. Block diagram of the single-phase AC-DC converter

In Figure 1, the AC voltage source of 220 V from PLN is used as the input to this circuit, which then goes into a center-tap (CT) transformer to step down the voltage to either AC 24 V or 12 V, depending on the configuration used. After that, this AC voltage is converted through a full-wave rectifier that utilizes 2 SCRs and 2 diodes to produce DC voltage. A Zero Crossing Detector (ZCD) is used to detect the zero crossing point of the AC waveform and generate a square signal, which assists in timing the delay for triggering the gate of the SCR. The microcontroller acts as the controller for the SCR firing angle with the help of the SCR driver, ensuring that the trigger signal from the microcontroller is strong enough and well isolated using an optocoupler, such as the MOC3021. A resistive load (resistor) is used as the load in this circuit to ensure that the conversion and voltage regulation operate as needed.

3. RESULTS AND DISCUSSION

This section will present the test results and analysis of the designed AC-DC converter system. This includes the working principles of the zero crossing detector, the SCR driver, as well as the measurement results of the output voltage at various firing angle variations of the SCR and the changes in the output waveform.

3.1. Zero Crossing Detector

The Zero Crossing Detector (ZCD) circuit functions to detect when an AC waveform (sinusoidal in shape) crosses the zero point and converts it into a square wave [3]. ZCD is commonly used with resistive, inductive, and capacitive loads that operate with AC voltage and control the SCR. Detecting the zero crossing of the source voltage is crucial for determining the precise timing of the trigger signal to the Gate terminal of the SCR [22]. With this ZCD and the modification of the firing angle, the performance of the SCR activation becomes more accurate [25]. The schematic diagram of the ZCD circuit can be seen in Figure 2, the output waveform of the ZCD can be seen in Figure 3.

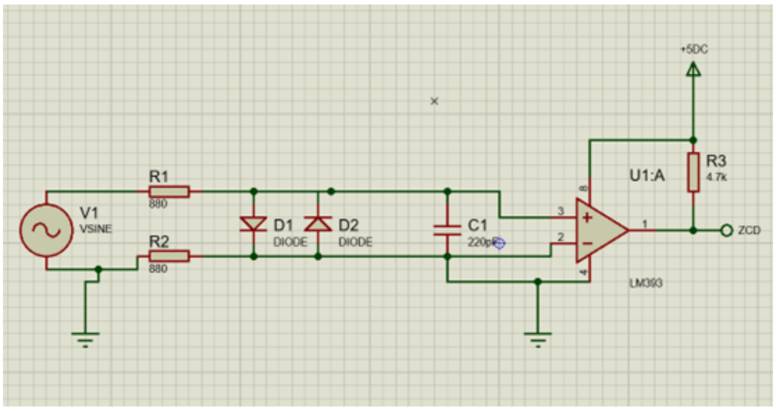


Figure 2. ZCD circuit

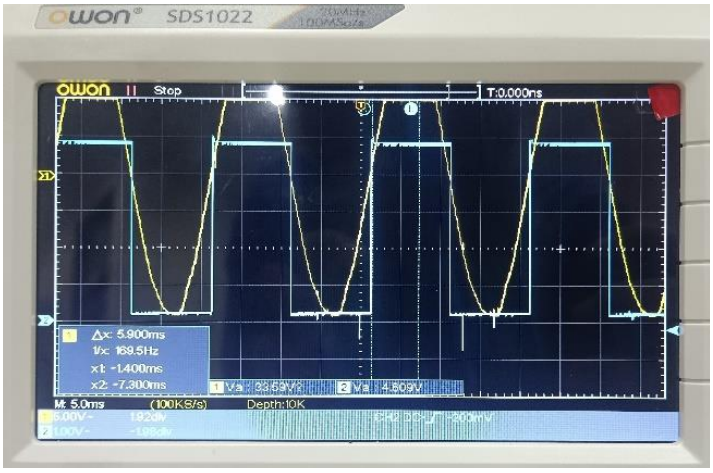


Figure 3. ZCD output waveform

3.2. SCR Driver

The output from the microcontroller cannot be used directly to trigger the gate of the SCR. This is because the current flowing from the SCR to the microcontroller can damage the microcontroller. Therefore, a driver circuit is used to isolate the AC voltage circuit (SCR side) from the DC voltage circuit (microcontroller side). The component used to form this driver circuit is an optoisolator of type MOC3021. The MOC3021 is used to provide a trigger to the gate of the SCR [26]. It operates using an infrared diode, and its output is a photo TRIAC. The circuit diagram of the SCR driver is shown in Figure 4.

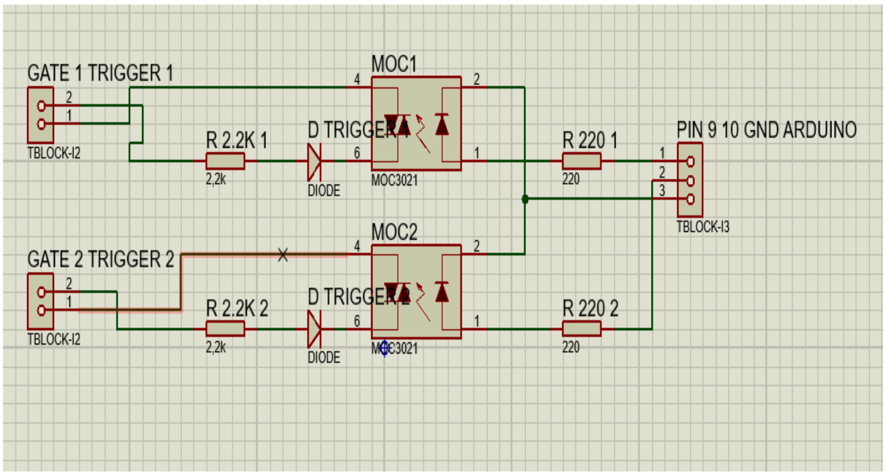


Figure 4. SCR driver circuit

3.3 Single-Phase AC-DC Converter

The full-wave rectifier circuit used in this research consists of two Silicon Controlled Rectifiers (SCR) and two diodes connected to convert AC voltage into DC voltage [27]. This circuit is also equipped with a center-tapped (CT) transformer that regulates the AC input voltage before directing it to the rectifier circuit [28]. The SCRs used in this circuit allow for better control of the output voltage through the adjustment of the firing angle. The firing angle of the SCR is adjusted by providing a trigger signal to the gate terminal, which determines when the SCR begins to conduct current. During the positive half-cycle of the AC waveform, SCR1 will act as the controller. In contrast, during the negative cycle, SCR3 will take on the role of the controller, ensuring that current continues to flow to the load even as the AC voltage experiences a phase change. With the presence of these two SCRs and two diodes, the load R1 will always receive voltage throughout the AC cycle, resulting in a DC voltage output that has been rectified from the AC waveform.

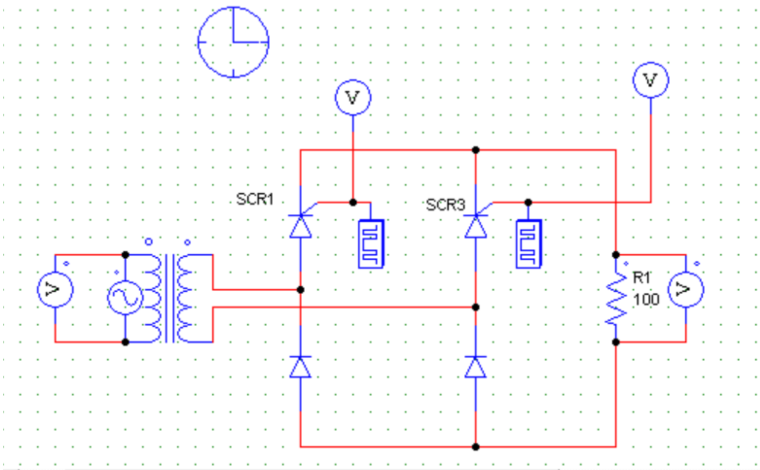
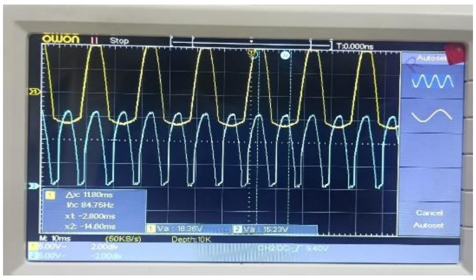


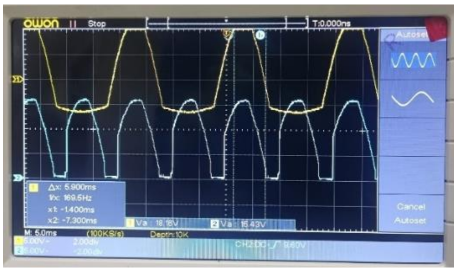
Figure 5. Single-phase ac-dc converter circuit

3.4. The influence of the firing angle on the waveform of a single-phase AC-DC converter.

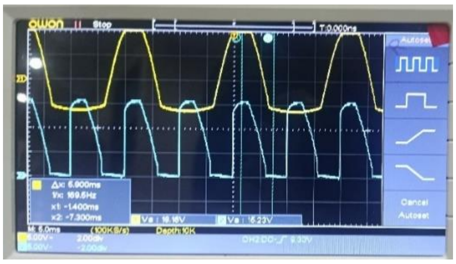
The AC-DC converter with SCR is designed to regulate the output voltage of the SCR by controlling the current at the SCR gate. This control can be achieved through the microcontroller by providing a trigger signal. The timing of this trigger will result in variations in the output voltage value and waveform in the AC-DC converter circuit. Figure 6 below shows the output waveform of the single-phase AC-DC converter from a firing angle of 10° to 190° and from a firing angle of 180° to 360°.



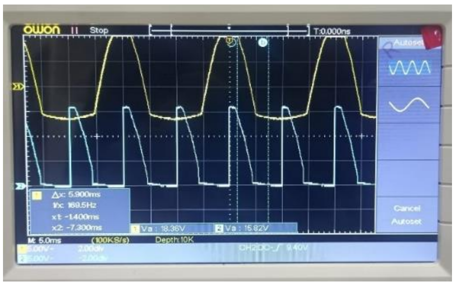
(a)



(b)



(c)



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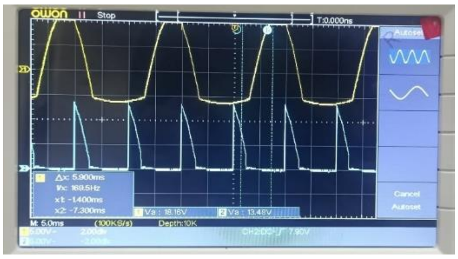
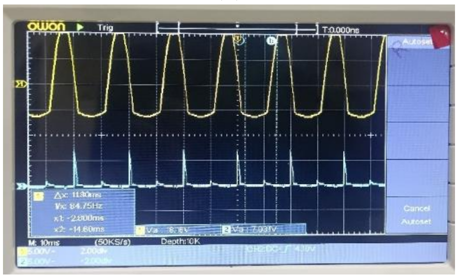


(e)



(f)

Figure 6. Output of the single-phase AC-DC converter with firing angle settings. a) firing angle 10° to 190°, b) firing angle 30° to 210°, c) firing angle 60° to 240°, d) firing angle 90° to 270°, e) firing angle 120° to 300°, f) firing angle 150° to 330°, (g) firing angle 180° to 360°

Figure 6 shows the output waveform with firing angles ranging from 10° to 190° and from 180° to 360°. These firing angles represent a technique for delaying the SCR firing as an electronic switch to produce varying DC voltage. As the firing angle increases, the input voltage waveform is clipped, resulting in a different output waveform and a decrease in output voltage. The output voltage values can be seen in Table 1.

Table 1. Testing data of the single-phase AC-DC converter output.

Sudut Penyalaan SCR 1 dan SCR 2	Input (VAC)	Output (VDC)
10° 190°	26	22
30° 210°	26	20
60° 240°	26	16
90° 270°	26	14
120° 300°	26	9
150° 330°	26	3
180° 360°	26	0

4. CONCLUSION

This research conducts testing on a single-phase AC-DC converter using SCR. SCR1 will be used as an electronic switch to control the positive pulses of the AC waveform, while SCR3 will be used to control the negative pulses of the AC waveform. The control of the SCR aims to achieve a regulated DC output voltage by adjusting the gate current of the SCR. The trigger signal for the SCR is provided through a microcontroller. The Zero Crossing Detector (ZCD) aims to determine the zero-crossing point of the AC input waveform as the starting point. By providing a trigger angle to the gate of the SCR, the SCR will activate according to the firing angle, thus producing a regulated DC voltage. As the firing angle increases, the output DC voltage of the AC-DC converter will decrease. Furthermore, variations in the firing angle also affect the shape of the output waveform, where the resulting waveform appears to be increasingly clipped as the firing angle increases, thereby influencing the value and shape of the DC voltage generated by the AC-DC converter.

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