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CIE 212 Project

Design and Implementation of a Rectifier Circuit
for 220V AC to 5V DC Conversion

Contents

Abstract

This project aims to design and implement a rectifier circuit for converting 220V AC to 5V DC. The circuit consists of a step-down transformer, a bridge rectifier, a filtering capacitor, and a voltage regulator. The theoretical calculations and practical testing were conducted to verify the circuit's performance and efficiency. The design ensures that the ripple voltage does not exceed 2% of the DC output.

1 Theory

Rectifiers are classified into different types based on their configuration and operation, such as half-wave rectifiers, full-wave rectifiers, and bridge rectifiers. Each type has distinct characteristics and efficiency levels.

1.1 Step-Down Transformer

A step-down transformer reduces the 220V AC to a lower AC voltage. The turns ratio n of the transformer is given by:

$$n = \frac{V_{\text{primary}}}{V_{\text{secondary}}}$$

For a primary voltage of 220V and a desired secondary voltage of 12V:

$$n = \frac{220}{12} \approx 18.33$$

Alternatively, transformers can be represented as conductance ratios:

$$\frac{V_{\text{primary}}}{V_{\text{secondary}}} = \left(\frac{N_{\text{primary}}}{N_{\text{secondary}}}\right)^2$$

which is crucial for our simulation.

1.2 Bridge Rectifier

A bridge rectifier, consisting of four diodes, provides a full-wave rectified output. The DC output voltage V_{DC} can be approximated by:

$$V_{\text{DC}} \approx \frac{2V_{\text{secondary}}}{\pi}$$

For a 12V AC secondary:

$$V_{\text{DC}} \approx \frac{2 \times 12}{\pi} \approx 7.64V$$

1.3 Filtering

To smooth the pulsating DC output from the bridge rectifier, a capacitor filter is used. The ripple voltage V_{ripple} is estimated by:

$$V_{\text{ripple}} = \frac{V_{\text{DC}}}{f \cdot R_{\text{load}} \cdot C}$$

where V_{DC} is the DC output voltage, f is the frequency (100Hz for full-wave rectified output), R_{load} is the load resistance, and C is the capacitance.

To achieve a ripple voltage of no more than 2% of the 5V output:

$$V_{\text{ripple}} \leq 0.02 \times 5 = 0.1V$$

Rearranging the formula to solve for C:

$$C \geq \frac{V_{\text{DC}}}{f \cdot R_{\text{load}} \cdot V_{\text{ripple}}}$$

Assuming $V_{\text{DC}} = 7.64V$, $f = 100\text{Hz}$, and a load resistance $R_{\text{load}} = 15k\Omega$:

$$C \geq \frac{7.64}{100 \times 5 \times 0.1} \approx 1000\mu F$$

1.4 Voltage Regulation

A voltage regulator, such as the 7805, ensures a stable 5V DC output. The regulator smooths out any remaining fluctuations in the voltage. It takes the input voltage and adjusts it to the desired output voltage. The 7805 regulator is a type of linear regulator that uses a series pass transistor to maintain a constant output voltage. It is commonly used in electronic circuits to provide a stable 5V supply.

An alternative is to use a Zener diode to regulate the voltage, but it is less efficient than a voltage regulator.

The zener diode is a type of diode that allows current to flow in the forward direction like a normal diode, but it also permits it to flow in the reverse direction when the voltage is above a certain value. This is known as the zener voltage.

The 7805 regulator is more efficient and reliable than a Zener diode, making it the preferred choice for voltage regulation in this project. However, the Zener diode can be used as they are cheaper and easier to find.

2 Design and Implementation

The design process includes selecting a step-down transformer with a primary voltage of 220V and a secondary voltage of 12V. A bridge rectifier, constructed using four diodes (e.g., 1N4007), is connected to the AC output of the transformer to convert it to DC. To filter the rectified output, a capacitor with a suitable value is chosen; for instance, with a load current of 1A and a ripple voltage of 0.1V, a capacitance of at least 10000 µF is required. Finally, the filtered DC output is fed into a 7805 voltage regulator to achieve a stable 5V DC output.

2.1 Simulation

The circuit is then implemented using LTspice to simulate its performance and verify the theoretical calculations. The output voltage, ripple voltage, and efficiency are measured and analyzed to ensure the circuit's reliability and effectiveness. Figure 2 shows the rectifier circuit implemented on LTspice. A special Zener diode was used to regulate the voltage in this simulation because it is what was available in stock.

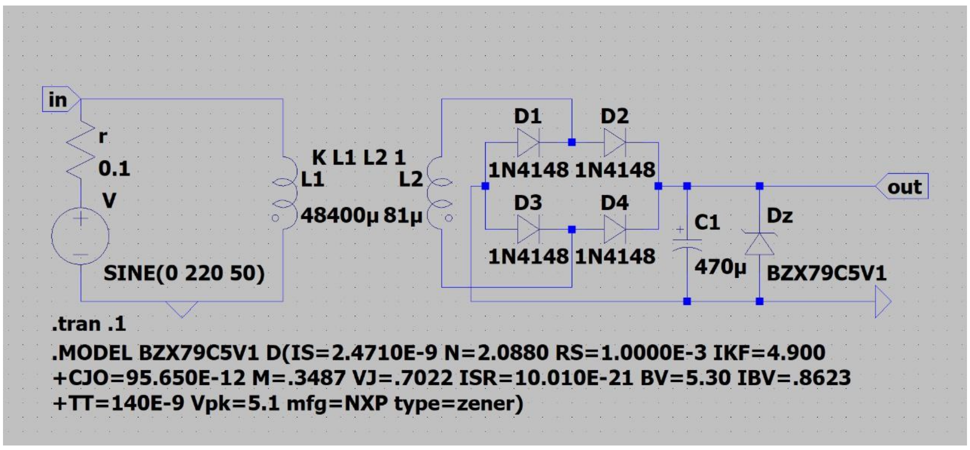

Figure 1: Rectifier Circuit on LTspice

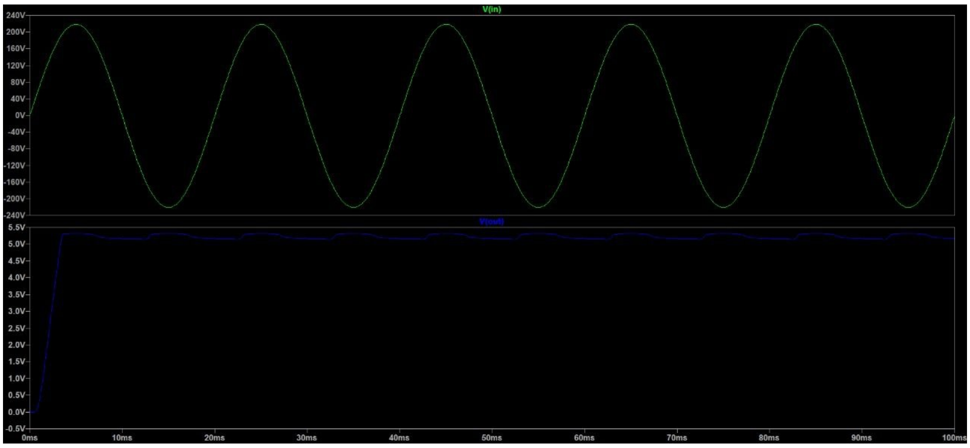

Figure 2: Graph of the output voltage

2.2 Hardware (Bonus)

This section was done with collaboration with Abdelrahman Magdy and Khaled Mahmoud.

The circuit is then implemented on a breadboard using the actual components. The transformer, diodes, capacitor, and voltage regulator are connected as per the design. The output voltage and ripple voltage are measured using an oscilloscope to verify the circuit's performance. The hardware implementation ensures that the rectifier circuit can be used in practical applications. Figure 3 shows the rectifier circuit implemented on a breadboard, and Figure 4 shows the oscilloscope measurement of the output voltage.

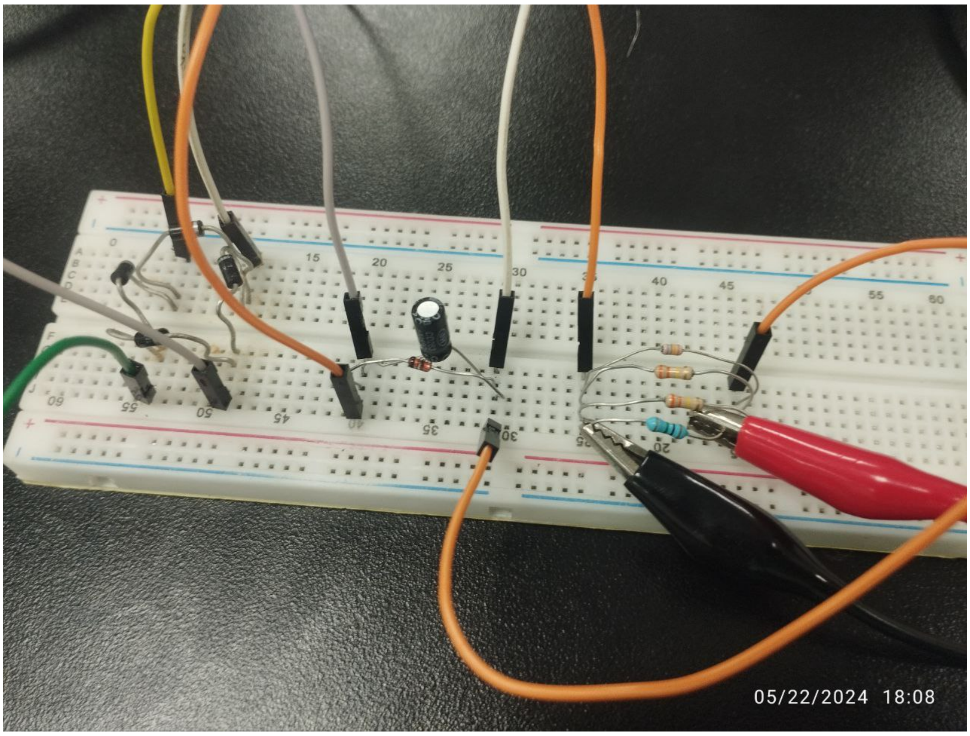

Figure 3: Rectifier Circuit on Breadboard

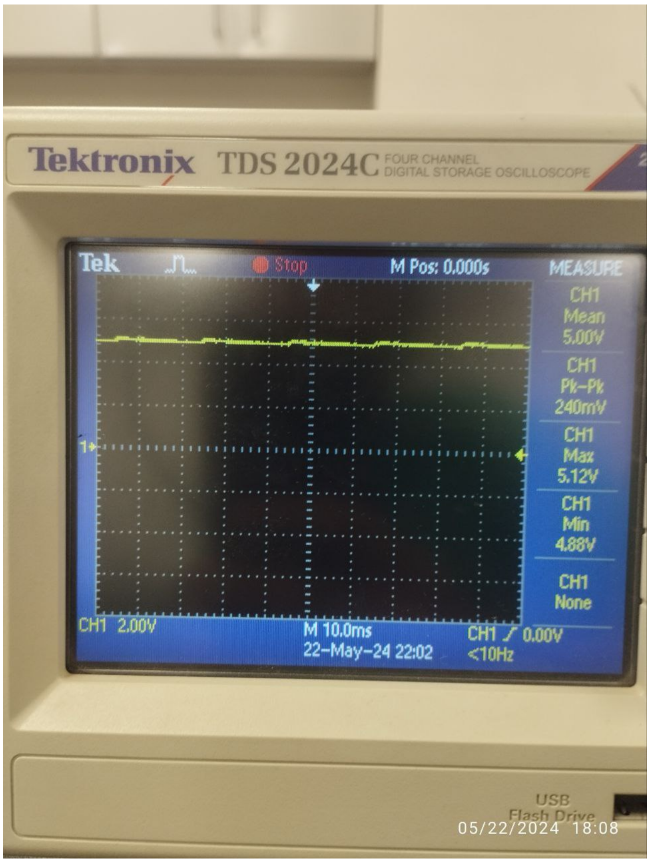

Figure 4: Oscilloscope Measurement of the Output Voltage

We also used a regulator to regulate the voltage. The regulator is a 7805 voltage regulator that provides a stable 5V output. The regulator is connected to the output of the rectifier circuit to ensure a constant voltage supply. The regulator is essential for maintaining a stable voltage output, which is crucial for electronic devices.

With the regulator, we used the circuit to power an LED to demonstrate its practical application. The rectifier circuit successfully converted 220V AC to a stable 5V DC output, which was used to light up the LED. See Figure 5.

3 Results

The rectifier circuit was tested under different load conditions. The output voltage and current were measured and analyzed to ensure the circuit's efficiency and reliability. The measured DC output voltage was consistently around 5V, confirming the effectiveness of the voltage regulator. The ripple voltage was within the 2% acceptable range, ensuring a stable DC supply for electronic devices.

4 Conclusion

This project provided hands-on experience in designing and implementing rectifier circuits. The step-down transformer, bridge rectifier, capacitor filter, and voltage regulator effectively converted 220V AC to a stable 5V DC with a ripple voltage not exceeding 2%. Understanding the different types of rectifiers and their applications is crucial for various electronic projects.

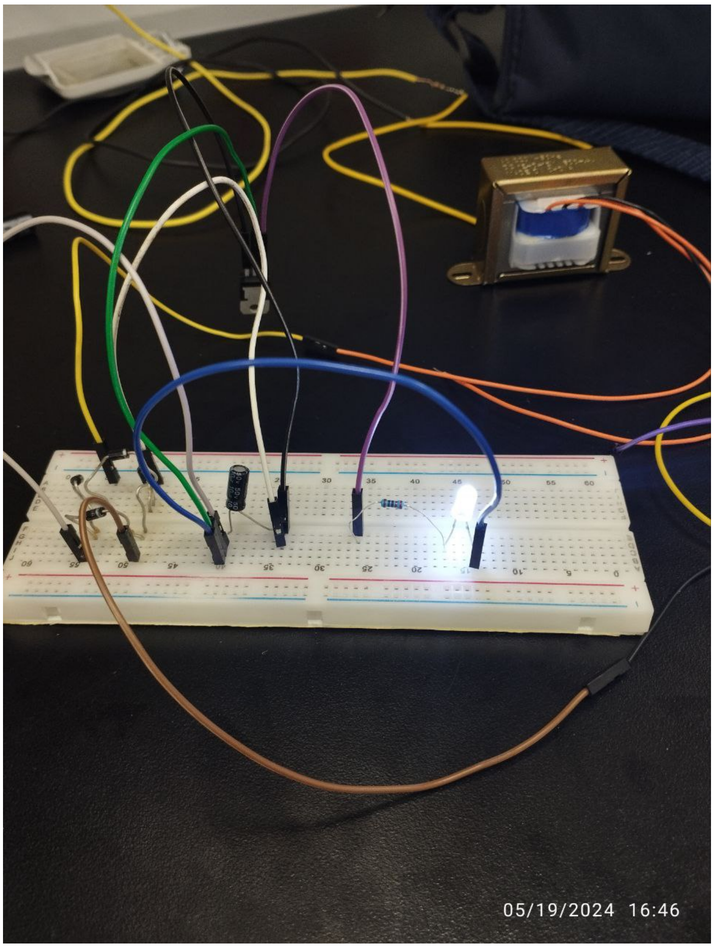

Figure 5: LED Powered by the Rectifier Circuit