Linear Power Supply Design

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Section One:

Reflecting on the feedback that we have received on previous assessments, the following issues/topics have been identified as areas for improvement:

- Relevance of content
- Flow of content
- Structure of content

Section Two:

In this assignment, we have attempted to act on previous feedback in the following ways:

- Staying within the constraints of the question and not straying too far out of context
- Maintaining proper flow within paragraphs that address particular topics
- Maintaining a clear and easy-to-follow structure for ease of reading

Section Three:

Feedback on the following aspects of this assignment (i.e. content/style/approach) would be particularly helpful to us:

- Approach towards structuring the assignment
- Style of writing, including vocabulary used

Contributions

Introduction: Manan Dua

Simulation in Multisim, Background information, Conclusion : Aness Aouissat

Calculations, Diagrams and drawings, Simulation Set-up and design : Zoya Bari

Analysis : Combined effort by Zoya and Aness

Introduction

Direct Current (DC) is generally preferred for applications like batteries, power supplies, and electronic appliances due to its reliably steady voltage. The stable and consistent flow of electricity contrasts with the fluctuating nature of Alternating Current (AC), making DC essential for devices that require a constant voltage to operate effectively and efficiently. Yet, the main electrical grid supplies AC, hence converting AC to DC is essential. For that reason, this report outlines the design of an AC-to-DC power supply to convert a 50Hz, 220V AC input to a steady and constant 12V DC output using a transformer, rectifier bridge, capacitor, resistors, and a Zener diode. Due to some of our constraints like space, this paper and analysis focused on voltage and waveform analysis. Performing a frequency analysis would have required additional time, space, analysis and interpretation which was not feasible within our scope.

Background Information

Below is a diagram that simplifies the general process:

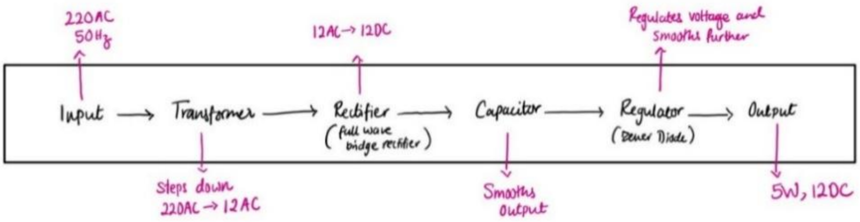

Fig1. Image displaying the general process that takes place in an AC-to-DC converter.

Before the simulation designs are displayed, it is essential to examine the independent roles of each component in the AC-to-DC conversion process. Each component is outlined below:

Transformer:

In the simulation circuits, a step-down transformer is used to reduce the primary input voltage (220V AC) from the main power supply to a lower secondary output voltage. The lower output voltage is generated by placing fewer turns in the secondary coil than in the primary coil. In this report, a variety of ratios are evaluated before concluding the final design.

Rectifier Bridge:

A full-wave bridge rectifier was chosen to convert the AC signal from the output of the transformer into pulsed DC. During each half cycle of the AC input, the current changes direction causing the two of the diodes that are forward biased in the bridge to conduct together. The selected diode for the rectifier bridge is the 1N4007GP diode which has a voltage drop of 0.7V, and since the diodes conduct in pairs, the voltage drop doubles to 1.4V. The result is a pulsating DC output with a single polarity.

Capacitor:

During the pulses of the DC output from the rectifier, the voltage eventually reaches a peak value referred to as V_{peak}. During this period, the capacitor begins to store energy and releases it as the voltage value begins to decrease. Finally, rather than a having a pulsating DC output, what is left is a DC output that contains reduced fluctuations and a steadier DC reading – although with ripples.

Zener Diode:

A Zener Diode is chosen to act as a voltage regulator. Its role is to maintain a stable final output by securing the voltage at a steady and specified level while ensuring the output is free of any ripples formed at the capacitor. It is put in reverse bias so when the input voltage from the capacitor goes through the component and reaches the Zener Diode's breakdown voltage, it begins to conduct and the voltage remains constant at the same value as its breakdown voltage. In this case, the desired output is 12V, hence the hence the Zener Diode's breakdown voltage was set to 12V to regulate the output voltage and maintain the desired result. The result is a final, steady, and constant DC voltage output that can be used in appliances and other electronic components.

Resistors:

First resistor: A low-value resistor is placed after the capacitor to limit the current entering the Zener Diode to aid in producing a stable output and protect it from an excessively large current.

Second Resistor: This resistor is placed at the end of the circuit and serves as the load. Hence, the final readings can be taken at this position and evaluated. Moreover, its value of resistance allows for the setting of the necessary current flow to achieve the desired 5W power output.

Simulation Setup and Design

To fully examine the stability and performance in designing this circuit, it is crucial to evaluate how different transformer secondary values affect the overall output. If the secondary voltage is too close to 12V, it may lead to instability as there is not enough of a margin to adjust load fluctuations as well as voltage drops. Higher secondary voltages provide stability but also result in a greater voltage drop across the regulator causing increased energy loss. By using values like 12V, 13.4V and 15V we can determine the best balance between having enough of a margin for our voltage to output a stable regulation and minimize energy loss. Multisim was used as a simulation tool to simulate the different circuit configurations due to its simplicity, its availability of components, and its ability to show how circuits perform under various conditions very effectively.

Calculations

This section provides an overview of electrical parameters that were used to determine values for our components. Some values remained the same for all circuits as they were dependent on our output power and load resistor. All values were rounded to 2 decimal places.

Turn Ratio	V_P/V_S	$\frac{220}{V_S}$	→ V_S varied
V_{peak}	$V_S \times \sqrt{2}$		→ varied for each V_S
V_{DC}	$(V_{peak} \times 2)/\pi$		→ varied for each V_S
$V_{rectified}$	$V_{peak} - 1.4$		→ varied for each V_S
V_{ripple}	10% of output	$12 \times 10/100 = 1.2V$	
I_{load}	P_{out}/V_{out}	$5/12 = 0\ 42A$	
Resistor 1	adjustment explained under figure	10Ω	
Capacitor	$C = \left(\frac{I_{load}}{V_{ripple}}\right) \times \frac{1}{2f}$	$3500\mu f$	
Zener Value	adjustment explained under figure	12V	
Resistor (load)	P/I^2	$\frac{5}{(5/12)^2} = 28.8$	

Table 1. Table containing all calculations involved in the conversion process.

	12V	13.4V	15V
V_{DC}	10.80	12.06	13.50

Table 2. Table containing all V_{dc}

Notes:

- *Resistor 1 was set to 10 ohms to limit the current to the Zener Diode without causing significant power dissipation or voltage drop, ensuring the desired output can be reached.*
- *Zener Diodes maintain an output voltage equal to their breakdown voltage. In this case, the desired output is 12V, hence the Zener Diode's breakdown voltage was set to 12V to regulate the output voltage and maintain the desired result*
- *V_{dc} was calculated for each circuit only to serve as a reference point to better understand the behaviour of the circuit.*
- *The value 1.4V ((2)0.7V) is used because in a bridge rectifier, two silicon diodes conduct in each half-cycle, each with a drop of 0.7V, so it is accounted for when calculating $V_{rectified}$.*
- *V_{dc}: The average DC voltage measured after rectification, indicating the mean output level of the rectified signal before filtering and regulation.*
- *For calculating and analysing V_{ripple}, it was assumed and taken as 10% of the desired output (12V) and Frequency(f) was taken as 2*50 (100) considering full wave rectification*

Circuit 1

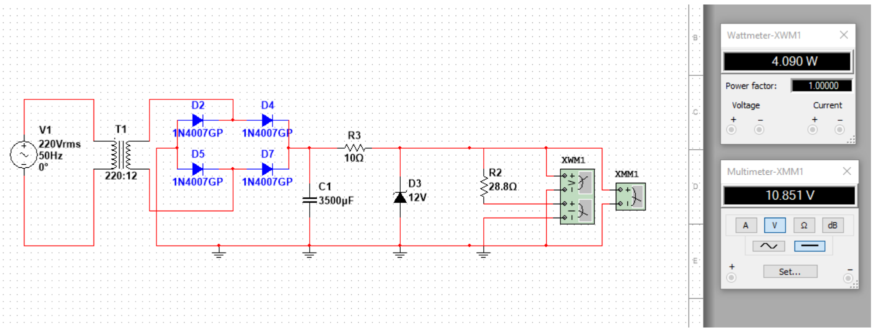

Fig2. Image displaying a simulation circuit with transformer ratio 220:12 and its outputs.

In the first circuit configuration, a transformer ratio of 220:12 (18.33) was employed to produce an output of 12V AC. Next, to find V_{peak}, the product of √2 and 12 is taken resulting in a value of 16.97V. However, the rectifier bridge is composed of silicon diodes, for which the 1.4 voltage drop must be considered. Hence, the resultant voltage ($V_{rectified}$) is further reduced to 15.57V. This value is very close to the desired output, which limits the margin for smoothing and regulating components potentially leading to instability.

Circuit 2

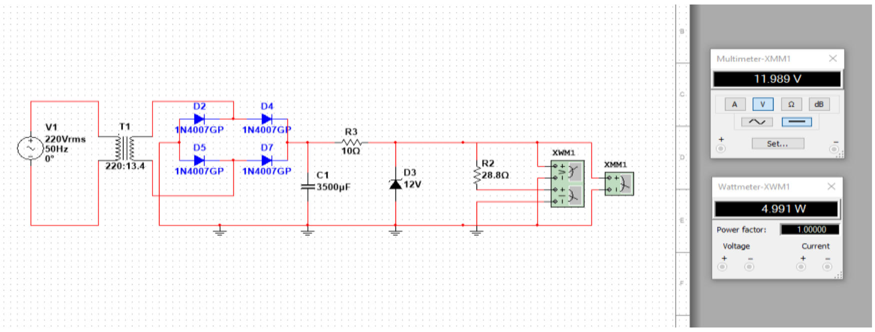

Fig3. Image displaying a simulation circuit with transformer ratio 220:13.4 and its outputs.

Circuit 2 follows a similar process but uses a transformer of ratio 220:13.4 (16.42). To find V_{peak} in this configuration, the product of $\sqrt{2}$ and 13.4 is calculated, resulting in 18.95V, later reduced to 17.55V. The increased secondary voltage at the transformer gives a larger margin for smoothing and regulation

Circuit 3

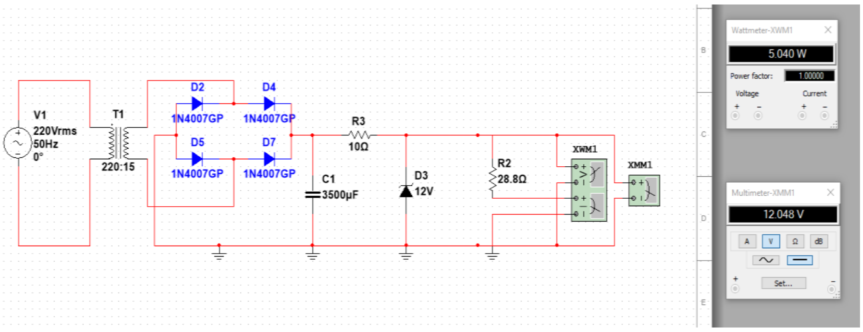

Fig4. Image displaying a simulation circuit with transformer ratio 220:15 and its outputs.

In the previous circuits, it was observed that a higher secondary voltage resulted in a closer value to the output, so to further investigate if a higher value would lead to a more stable output, 15V was used. The values calculated were 21.21 for V_{peak} and 19.81 for $V_{rectified}$, which albeit provides a larger margin of error than the previous circuit, still displays better performance and characteristics than circuit 1.

Analysis

Circuit 2 was used for the main analysis of this system as it demonstrated the closest values to what is desired – achieving 4.991W and 11.989V - when compared to circuit 1 and circuit 3. Although the values were optimal and desired, it is crucial to ensure that it provides a stable and regulated DC output with minimal ripples. To ensure that is the case, an oscilloscope was used to examine the differences between the input waveform and the output. Figure 5 below displays this comparison. As expected, the input AC waveform displays sinusoidal properties as per the characteristics of a typical AC signal. On the other hand, the output displays a straight and consistent line indicating a stable DC output signal. Therefore, circuit 2 shows all the key features of a good and sufficient AC-to-DC power supply which includes the following: stable and constant output voltage, minimal ripple, and a voltage that closely matches the target values.

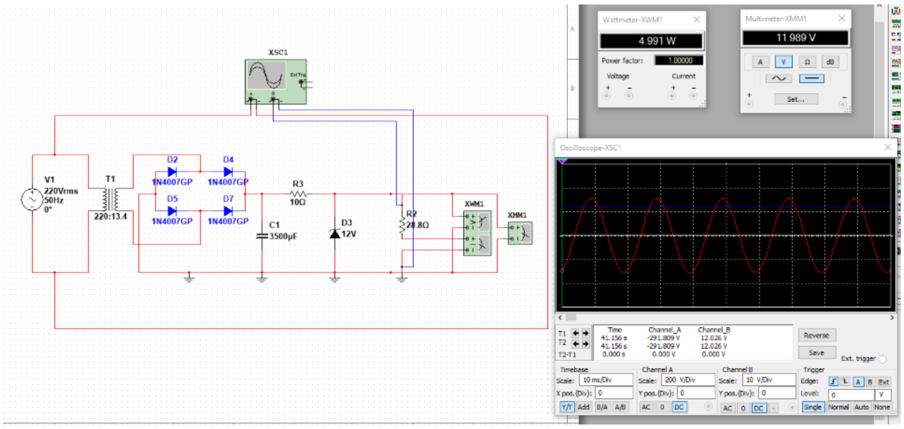

Fig5. Image displaying the input(red) and output(blue) waveforms of circuit 2.

Conclusion

The final selected AC-to-DC power supple design successfully demonstrated how the operation of each component was key to achieving a stable and reliable 12V DC and 5W output. Among the various configurations, and after an effective analysis, circuit 2 displayed the closest readings to what was initially desired while ensuring there was minimal ripple as seen in the oscilloscope in Figure 5. The use of Multisim further simplified the process; however, it is important to consider that building a physical circuit would differ due to practical limitations not accounted for in the simulation. For instance, additions like cooling solutions or heat sinks could be implemented for thermal management to further optimize the system if necessary. Despite the differences, the results provide a solid foundation for understanding the AC-to-DC conversion process that is vital in a variety of electronic components and household appliances.

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