GEBZE TEKNİK ÜNİVERSİTESİ

MÜHENDİSLİK FAKÜLTESİ

ELEKTRONİK MÜHENDİSLİĞİ BÖLÜMÜ

ADJUSTABLE DC POWER SUPPLY

ELEC 236

ELECTRONİC-1

PROJECT

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1-Introduction

This project focuses on the design and simulation of a 12-18V adjustable DC power supply using LTspice circuit simulation. The goal is to create a versatile power source capable of converting readily available 220V AC household voltage into a user-controllable DC output ranging from 12V to 18V. The design emphasizes three key aspects: efficiency, stability, and protection features.

Efficiency is crucial to ensure minimal power losses during the conversion process. This involves selecting components that optimize power transfer and reduce heat dissipation. Using high-efficiency switching regulators like the LM317 instead of linear regulators can significantly improve overall performance, as they typically offer higher conversion efficiencies.

Stability is another essential aspect. The output voltage must remain stable even when the load current varies. This can be achieved through feedback mechanisms and compensation networks that adjust the duty cycle of the switching regulator, thereby maintaining a consistent output voltage. Ripple reduction techniques, such as adding capacitors and inductors in the right configuration, can further enhance voltage stability.

Protection features are key for safeguarding the circuit against potential hazards like overvoltage, overcurrent, and short-circuits. Overvoltage protection can be implemented using diodes or transient voltage suppression (TVS) diodes, which clamp the voltage to a safe level. Overcurrent protection might include current-limiting resistors or more sophisticated solutions like foldback current limiting, which reduces the current to a safe level during fault conditions. Additionally, incorporating fuses or circuit breakers can provide a fail-safe mechanism against short-circuits, ensuring the longevity and reliability of the power supply.

The design process in LTspice involves creating a schematic that includes all these components and running simulations to verify the performance under various conditions. Adjustments and improvements will be made based on the simulation results to achieve the optimal balance of efficiency, stability, and protection. The final design aims to deliver a robust and reliable power supply capable of providing a stable 12-18V DC output from a 220V AC input, suitable for various applications.

2. AC to DC Conversion Techniques

- **Rectifiers**
  - ***Full-Wave Rectifier***: A full-wave rectifier converts the entire AC waveform, both positive and negative half-cycles, into DC. In this project, a bridge-type full-wave rectifier circuit is used. The bridge rectifier consists of four 1N4007 diodes arranged in a bridge configuration.

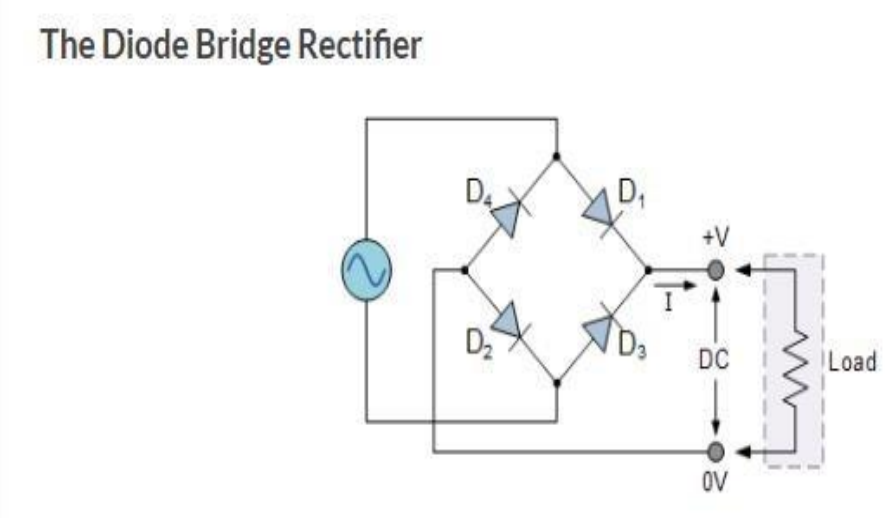
Why Full-Wave Rectifier was Used:

- **Efficiency:** Full-wave rectifiers utilize both halves of the AC waveform, minimizing power loss and providing higher efficiency compared to half-wave rectifiers.
- **Reduced Ripple:** Full-wave rectifiers produce a smoother DC output with less ripple, leading to a more stable DC voltage.
- **Higher Average Output:** Full-wave rectifiers provide a higher average DC output voltage compared to half-wave rectifiers, improving the efficiency of the power supply.

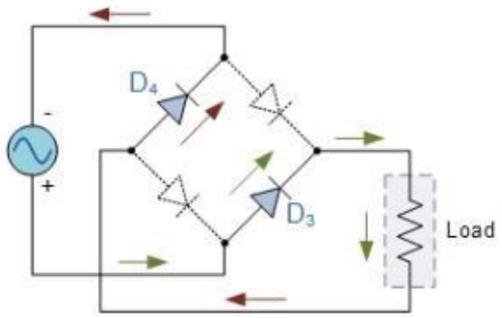
Working Principle of Full-Wave Rectifier:

1. **Positive Half-Cycle:** During the positive half-cycle of the AC input, diodes D1 and D2 conduct, while diodes D3 and D4 remain in reverse bias. Current flows through the load, producing a positive output voltage. During the negative half-cycle of the AC input, diodes

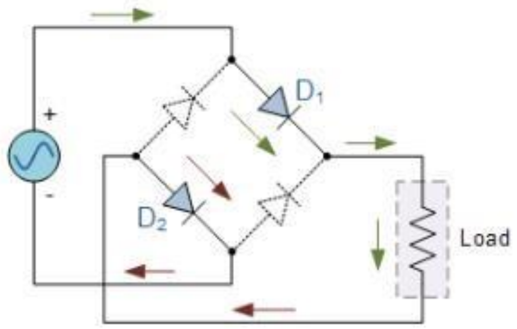
2. **Negative Half-Cycle:**
D3 and D4 conduct, while diodes D1 and D2 remain in reverse bias. Current again flows through the load in the same direction, producing a positive output voltage.



The Negative Half-cycle



The Positive Half-cycle



- **Filters**
    - **Capacitor Filters** : Capacitor filters are used to smooth out the pulsating DC voltage from the rectifier. In this project, a 2200μF electrolytic capacitor is added to the output of the rectifier circuit.

Why Capacitor Filter was Used:

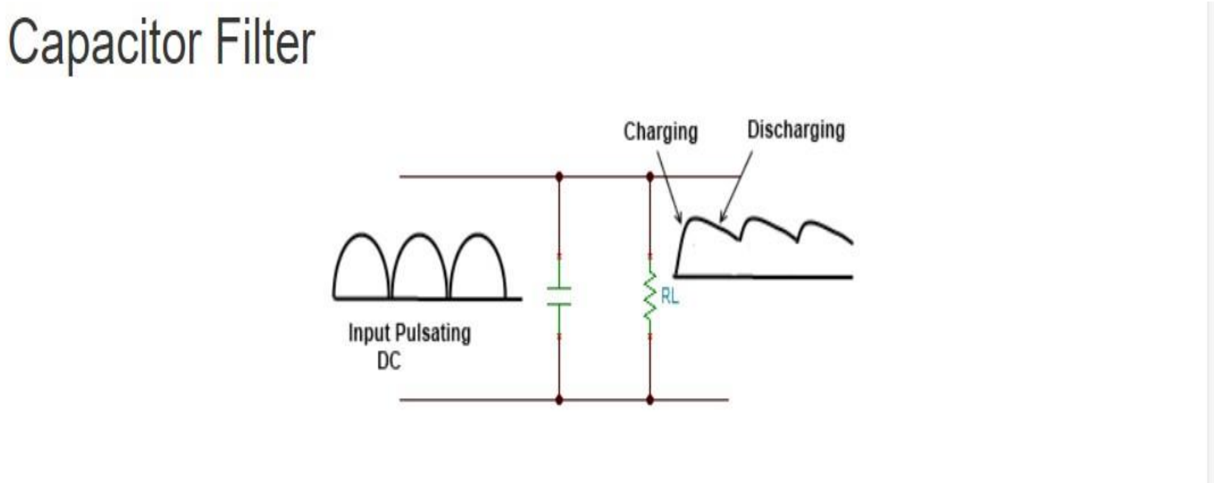
- **Ripple Reduction:** Capacitors filter out the ripple present in the rectified output, providing a smoother DC voltage.
- **Voltage Stability:** Capacitors help maintain voltage stability by reducing fluctuations in the output voltage, even under varying load conditions.
- **High Capacity:** The 2200μF capacitor effectively reduces the ripple under load conditions, improving the overall performance of the system.

Working Principle of Capacitor Filter:

1. **Charging:** The rectified AC signal charges the capacitor to the peak voltage of

the signal.

2. **Discharging:** During the decline of the AC signal, the capacitor discharges, maintaining a more constant voltage across the load and reducing ripple.



Capacitor Filter

- **Regulators**
  - **Integrated Circuit Regulators (LM317)** : Integrated circuit regulators ensure precise adjustment and stabilization of the output voltage. The LM317 is used as an adjustable voltage regulator in this project. Using a feedback network and a potentiometer, the output voltage can be adjusted between 12V and 18V.

Why LM317 was Used:

- **Adjustable Voltage:** The LM317 allows easy adjustment of the output voltage using a feedback network and a potentiometer, making it suitable for various applications.
- **High Stability:** The LM317 maintains a stable output voltage even under varying load conditions, ensuring a consistent and reliable DC output.
- **Protection Features:** The LM317 includes built-in protection circuits that guard against overcurrent and overheating, enhancing the reliability and longevity of the power supply.

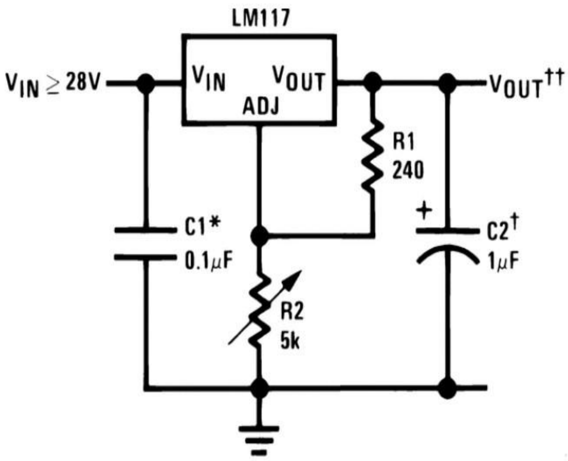
Working Principle of LM317:

1. **Input Voltage:** The LM317 receives the rectified and filtered DC input voltage.

2. **Voltage Adjustment:** The desired output voltage is set using the feedback

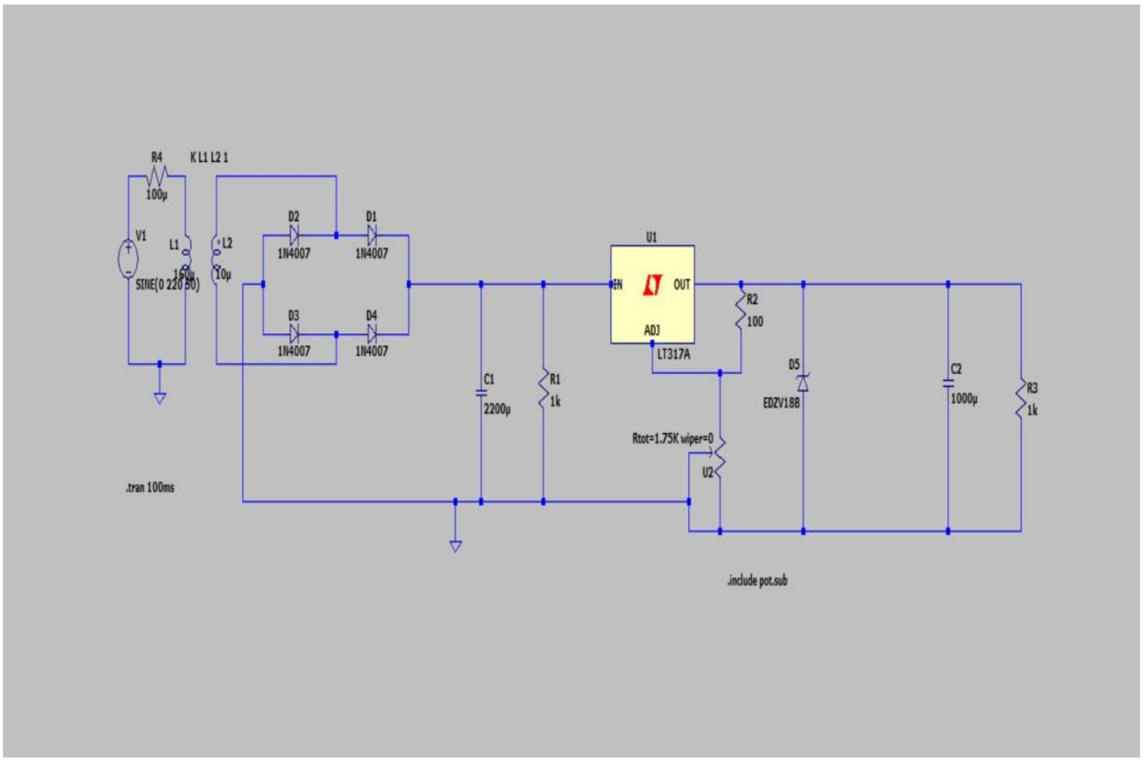
network and potentiometer.

3. **Regulation:** The LM317 regulates the input voltage to maintain a constant output voltage, even under changing load conditions.



3. Circuit Design and Implementation

- Circuit Desing :



Input Stage :

Voltage Source Internal Resistance:In the given circuit, the internal resistance of the voltage source (commonly denoted as R4) is an important parameter. Internal resistance represents the inherent opposition to current flow within the voltage source itself. Including this resistance in the circuit model results in a more realistic simulation.

Why Internal Resistance is Important:

- **Realistic Modeling:** In practical scenarios, all voltage sources have some internal resistance. Including this resistance in the circuit model makes the simulation more realistic.
- **Current Limiting:** The internal resistance limits the maximum current that the voltage source can supply, protecting both the source and the load from excessive current.
- **Voltage Drop:** As current flows through the internal resistance, a voltage drop occurs, affecting the overall output voltage. This drop must be considered in circuit design to ensure accurate voltage levels.
- **Power Dissipation:** The internal resistance dissipates power as heat. This dissipation must be considered in thermal management and efficiency calculations.

Advantages of Including Internal Resistance in Simulations:

- **Improved Accuracy:** Including internal resistance provides a more accurate representation of the voltage source's behavior under different load conditions.
- **Enhanced Protection:** It helps in designing protective measures against overcurrent situations by limiting the maximum current.

- **Better Performance Prediction:** It allows for more precise predictions of circuit performance, particularly in terms of voltage regulation and power dissipation.

Coupled Inductor (Transformer):

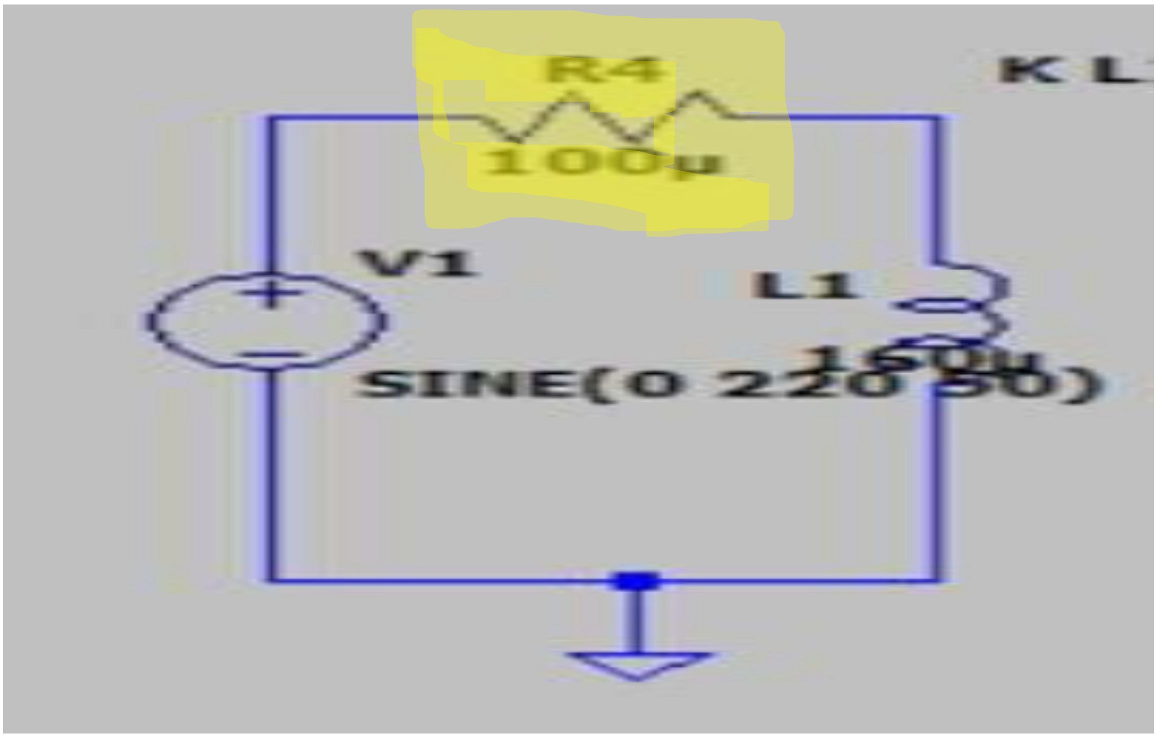
In this circuit, a coupled inductor (transformer) is used to step down the 220V AC input to a suitable level for rectification. Transformers play a crucial role in power conversion and electrical isolation.

Purpose of Using a Transformer:

- **Voltage Step-Down:** The primary function of the transformer is to reduce the high 220V AC input voltage to a lower, more manageable level that can be safely rectified and regulated.
- **Electrical Isolation:** Transformers provide electrical isolation between the high voltage AC input and the lower voltage circuit components. This isolation is crucial for safety, preventing high voltage from reaching sensitive components and the user.
- **Impedance Matching:** Transformers can be used to match the impedance of the power source with the load, optimizing power transfer and improving efficiency.
- **Regulation Support:** By stepping down the voltage, transformers facilitate more efficient and effective regulation and filtering in the subsequent stages of the power supply.

Advantages of Using a Transformer:

- **Safety:** Electrical isolation enhances safety by preventing high voltage from directly interacting with low voltage components.
- **Efficiency:** Voltage step-down helps in efficient power conversion and reduces the strain on rectification and regulation stages.
- **Flexibility:** Allows the design of versatile power supplies that can handle various input and output voltage requirements.



Why We Use a Small Internal Resistance:

Minimized Voltage Drop: A smaller internal resistance ensures minimal voltage drop across the source, allowing more of the input voltage to reach the load.

Higher Efficiency: Lower internal resistance reduces power dissipation as heat, improving the overall efficiency of the power supply.

Better Voltage Regulation: With smaller internal resistance, the voltage source can maintain a stable output voltage despite load variations.

Reduced Heat Generation: Smaller resistance generates less heat, aiding in thermal management and prolonging the lifespan of the source and components.

By keeping the internal resistance small, we enhance the performance, efficiency, and reliability of the power supply.

- # Rectification and Filtering:

Full-Wave Rectifier:

Why We Chose a Full-Wave Rectifier: We selected a full-wave rectifier because it converts both the positive and negative halves of the AC waveform into a unidirectional DC output, providing higher efficiency and reduced ripple compared to a half-wave rectifier.

Advantages of Full-Wave Rectifier:

- **Higher Efficiency:** Utilizes both halves of the AC cycle, resulting in a higher average output voltage.
- **Reduced Ripple:** Full-wave rectification produces less ripple voltage, making the DC output smoother.

Why Not Other Alternatives:

- **Half-Wave Rectifier:** Only uses one half of the AC cycle, resulting in lower efficiency and higher ripple.
- **Center-Tap Full-Wave Rectifier:** Requires a center-tapped transformer, which can be bulkier and more expensive.

Improving Full-Wave Rectification:

- **Increase Filtering Capacitance:** Adding larger capacitors can smooth out the ripple more effectively.
- **Add LC Filter:** Using an LC filter (inductor-capacitor) can further reduce ripple.

Filtering:

Why We Use a Capacitor Filter: A capacitor filter is effective in reducing the ripple voltage by storing charge and releasing it when the input voltage drops.

How to Further Reduce Ripple:

- **Increase Capacitance:** A larger capacitor provides more charge storage, which reduces ripple voltage.
- **Increase Frequency:** Higher input frequency reduces ripple voltage for a given

capacitor size.

Theoretical Explanation and Formulas:

Ripple Voltage for Capacitor Filter:

Bridge Rectifier Ripple Voltage

$$V_{(ripple)} = \frac{I_{DC}}{2fC}, \text{ Volts}$$

$V(ripple)_r$: Ripple voltage

IDC: Load current

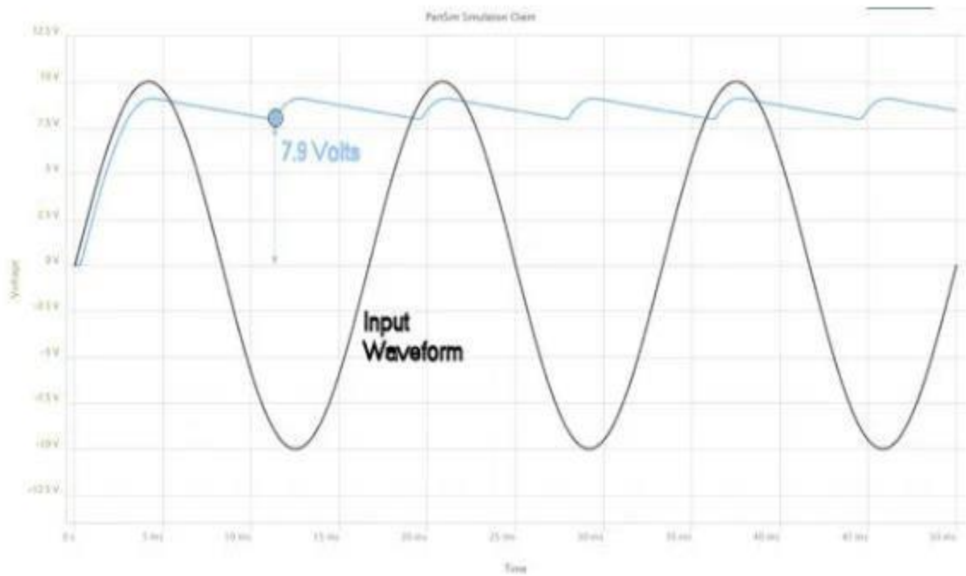
f: Ripple frequency (For full-wave rectification, it is twice the input frequency) C:

Filter capacitance

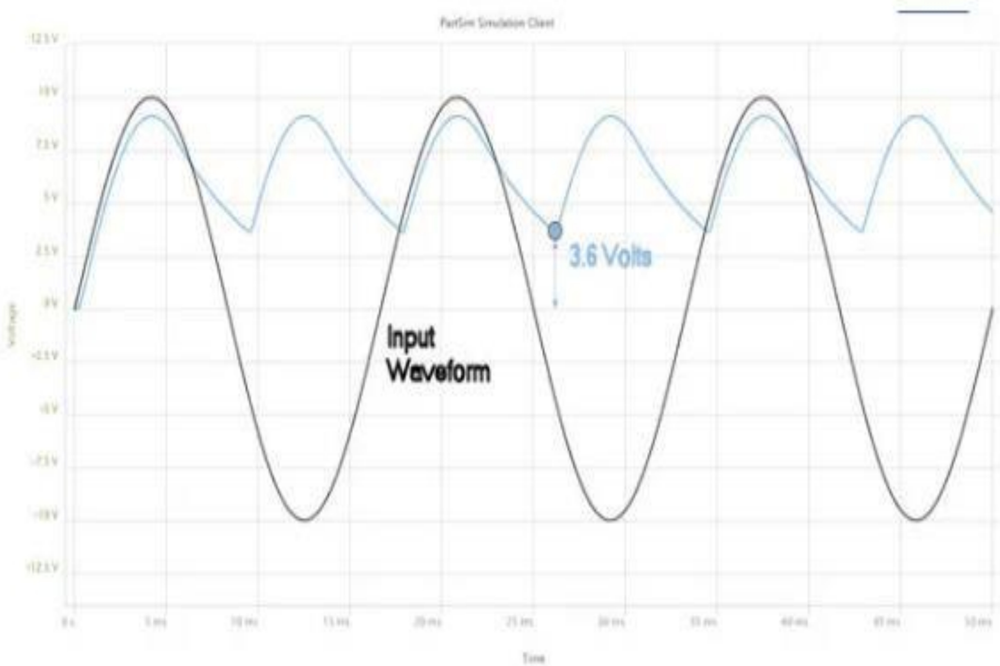
To reduce ripple voltage:

- **Increase Capacitance (C):** Larger capacitors reduce ripple.
- **Increase Frequency (f):** Higher frequency reduces ripple.

Using a 50uF Smoothing Capacitor

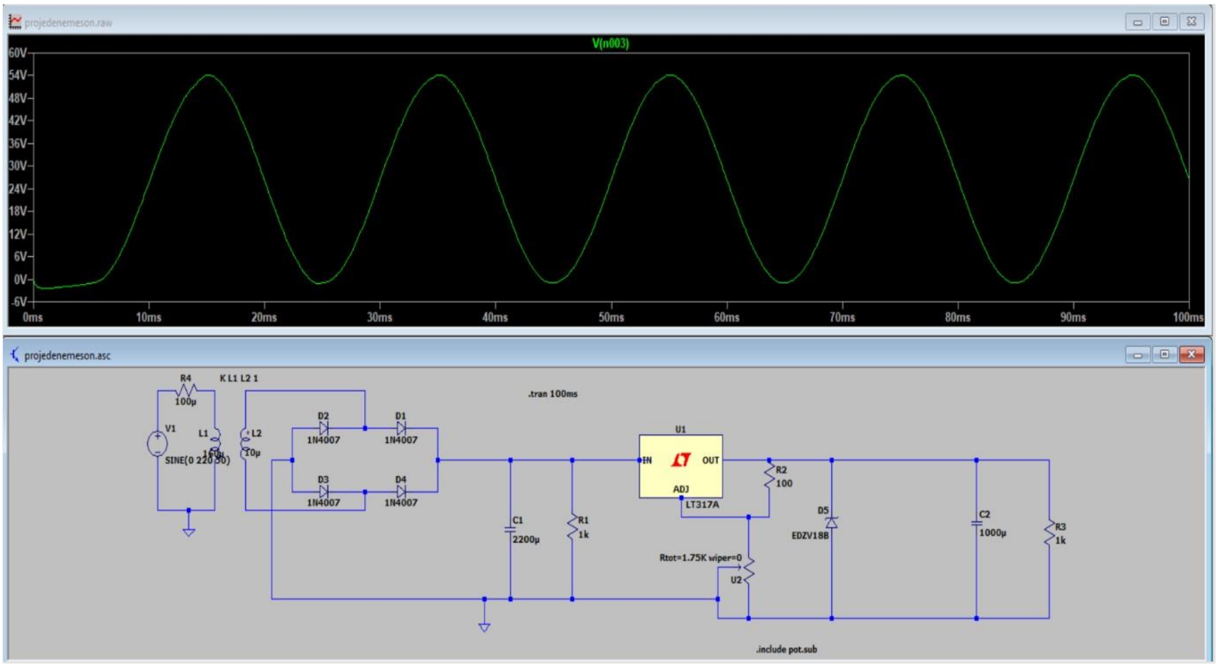


Using a 5uF Smoothing Capacitor

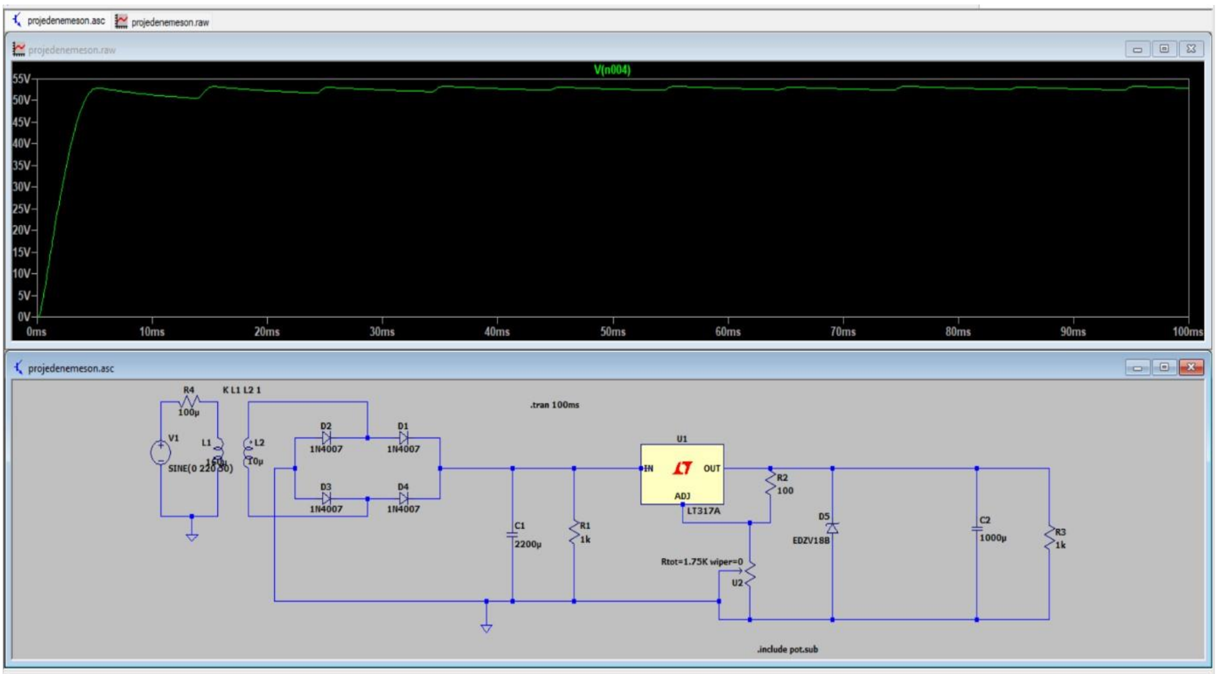


My circuit output is shown here: Below are the results obtained from the implementation of the filter and full-wave rectifier:

Full-Wave Rectifier Output



Filtering Output



Voltage Regulation Stage:

In the voltage regulation stage of our circuit, we used the LT317A instead of the LM317. Both LT317A and LM317 have similar characteristics and can be used interchangeably in many applications. In this section, we will discuss the theoretical foundations of the voltage regulator and the details of the adjustments made with the potentiometer.

Why We Used LT317A:

LT317A and LM317 are adjustable voltage regulators with similar specifications. Here are some key points:

- **Output Voltage Range:** Both LT317A and LM317 can adjust the output voltage from 1.25V to 37V.
- **Output Current:** Both regulators can provide an output current up to 1.5A.
- **Thermal Overload Protection:** Both models include built-in protection features to prevent overheating.
- **Short-Circuit Protection:** Both have short-circuit protection to safeguard the regulator and connected circuits.

LT317A was chosen due to its similar performance and characteristics to LM317, making it a suitable alternative during component selection.

Theoretical Background and Advantages of Voltage Regulators

A voltage regulator is an essential component in power supply circuits, ensuring that the output voltage remains constant despite variations in input voltage and load conditions. Here are the key theoretical aspects and advantages:

1. **Stable Output Voltage:**
    - **Function:** Voltage regulators maintain a constant output voltage by adjusting the internal resistance based on the input voltage and load current.
    - **Importance:** This stability is crucial for the reliable operation of electronic devices that require a specific operating voltage.
2. **Protection Features:**
    - **Thermal Overload Protection:** Prevents the regulator from overheating by reducing the output current or shutting down the regulator if the temperature exceeds a certain limit.

- **Short-Circuit Protection:** Limits the current flow in the event of a short circuit, protecting both the regulator and the circuit components.

3. **Adjustability:**
   - **Output Voltage Range:** LT317A allows for adjustable output voltage, which can be set using external resistors and a potentiometer.
   - **Flexibility:** This adjustability makes it suitable for various applications requiring different voltage levels.

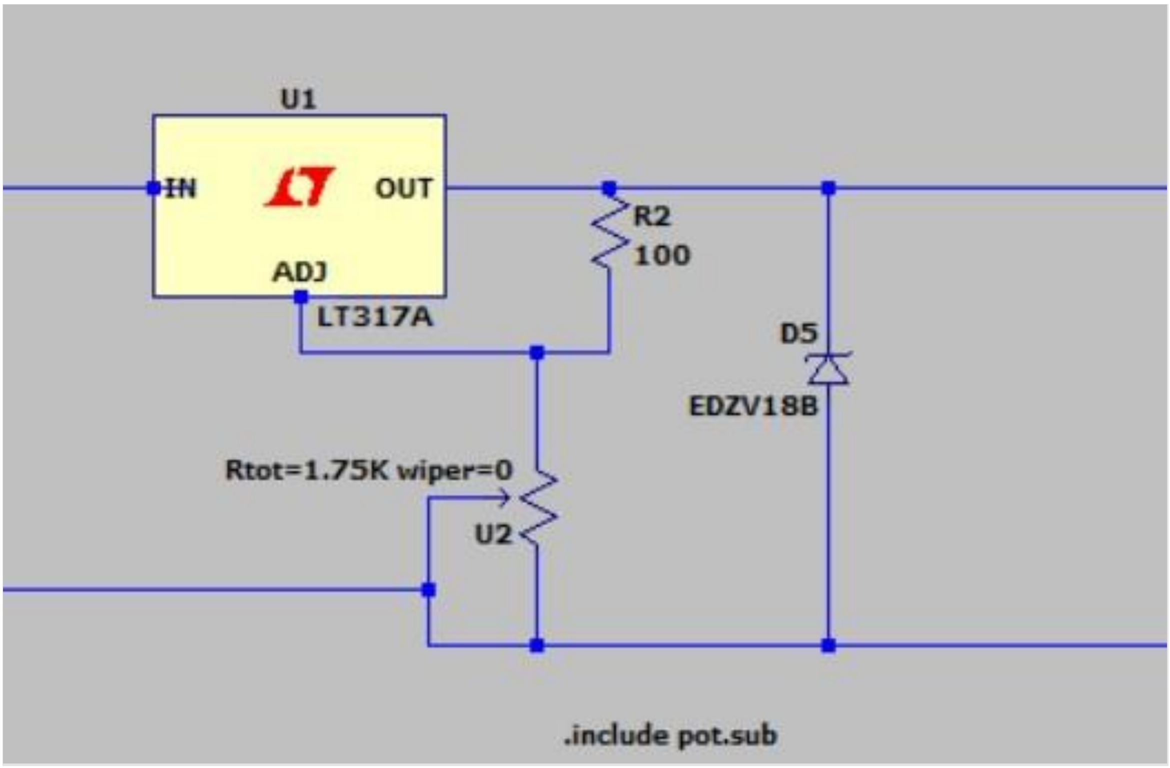
Adjusting Output Voltage with a Potentiometer:

In your circuit, the output voltage of the LT317A regulator is adjusted using the R1 resistor and the adjustable potentiometer (U2). The total resistance formed by the potentiometer and R1 is considered as $R2$, and the output voltage is calculated using the following formula:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj}R_2$$

Where:

- V_{ref}: 1.25V (reference voltage for LT317A)
- R_1: 1kΩ (resistor in your circuit)
- R_2: Combination of potentiometer and additional resistance



Protection Stage:

The protection stage in an electronic circuit is crucial for ensuring the safety, reliability, and longevity of the components and the overall system. In our circuit, several protection mechanisms are implemented to guard against common electrical hazards such as overcurrent, overvoltage, and overheating. These protective measures help maintain the stability and proper functioning of the circuit under various operating conditions.

Overcurrent Protection:

Overcurrent protection is designed to prevent excessive current flow, which can cause overheating and potential damage to the circuit components. In our circuit, we employ a current-limiting resistor (R2) to achieve this protection.

- **Function:** The current-limiting resistor is placed in series with the load, and it restricts the amount of current that can flow through the circuit by providing additional resistance.
- **Importance:** This ensures that even if there is a short circuit or a fault condition, the current will not exceed a safe level, thereby protecting sensitive components from damage.

Overvoltage Protection

Overvoltage protection safeguards the circuit from voltage spikes and surges that can occur due to various reasons, such as power supply fluctuations or transient disturbances.

- **Zener Diode (D5):** A Zener diode is used to clamp the voltage to a predetermined safe level. It is connected in parallel with the load.
    - **Function:** When the voltage exceeds the Zener breakdown voltage, the diode conducts and shunts the excess voltage away from the sensitive parts of the circuit.
    - **Importance:** This prevents the voltage from rising above a safe threshold, protecting the components from overvoltage damage.

Thermal Protection

Thermal protection is essential for preventing overheating, which can lead to thermal runaway and permanent damage to the circuit components.

- **Built-in Thermal Overload Protection in LT317A:** The LT317A voltage regulator includes an internal thermal overload protection mechanism.
    - **Function:** This feature automatically reduces the output current or shuts down the regulator if the internal temperature exceeds a safe limit.
    - **Importance:** It ensures that the regulator and the entire circuit are protected from thermal damage, enhancing the reliability and lifespan of the components.

Implementation in Our Circuit:

In our circuit, the protection mechanisms are implemented as follows:

- **Current Limiting:** The current-limiting resistor (R2) restricts the maximum current that can flow through the circuit, providing overcurrent protection.
- **Voltage Clamping:** The Zener diode (D5) clamps the voltage to a safe level, providing overvoltage protection.
- **Thermal Management:** The LT317A voltage regulator’s built-in thermal protection guards against overheating.

Simulation:

In the simulation stage, we adjust the potentiometer to observe the changes in the output voltage. By varying the potentiometer, we can demonstrate how the output voltage can be precisely controlled within the desired range. The following images illustrate the output voltage at different potentiometer settings, highlighting the versatility and effectiveness of the voltage regulation stage.

Adjusting the Potentiometer: The potentiometer (U2) is adjusted between 0Ω and 1.75kΩ. This adjustment allows us to set the output voltage between 12V and 18V, demonstrating the ability to fine-tune the voltage as required for various applications.

The simulation results show the output voltage for different settings of the potentiometer, confirming the theoretical calculations and the performance of the LT317A voltage regulator.

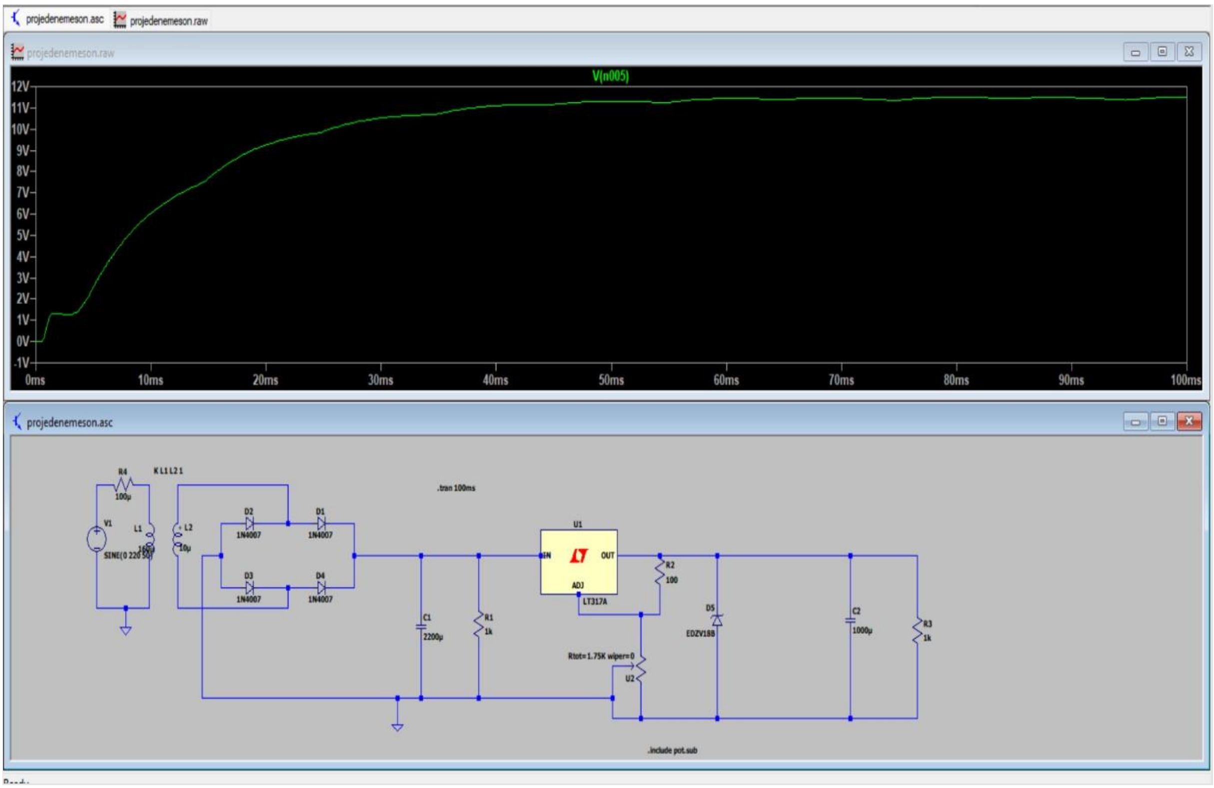
These simulation results provide a clear visual representation of how the circuit performs under different conditions and validate the effectiveness of the design in maintaining a stable and adjustable output voltage.

At 0Ω (Potentiometer Minimum): The output voltage is approximately 12V.

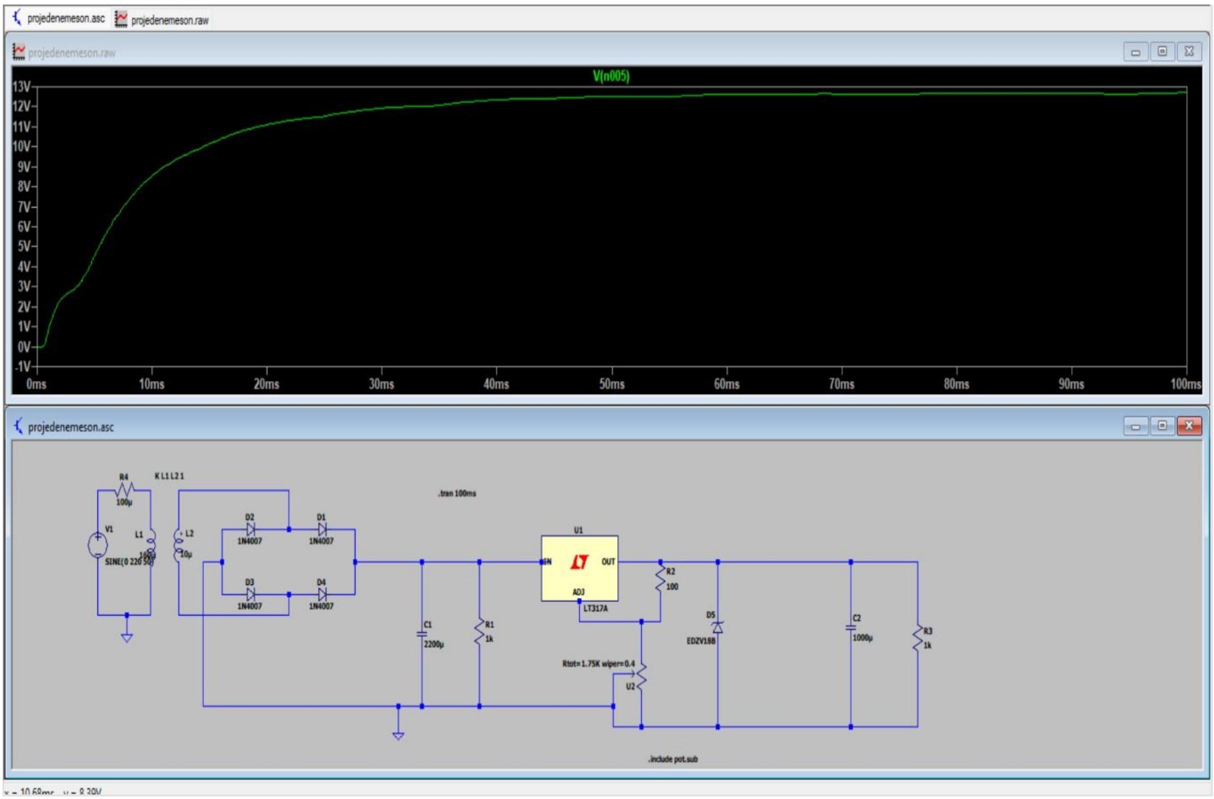
At 1.75kΩ (Potentiometer Maximum): The output voltage reaches up to 18V.

"The potentiometer can take values between 0 and 1, and accordingly, it adjusts the resistance."

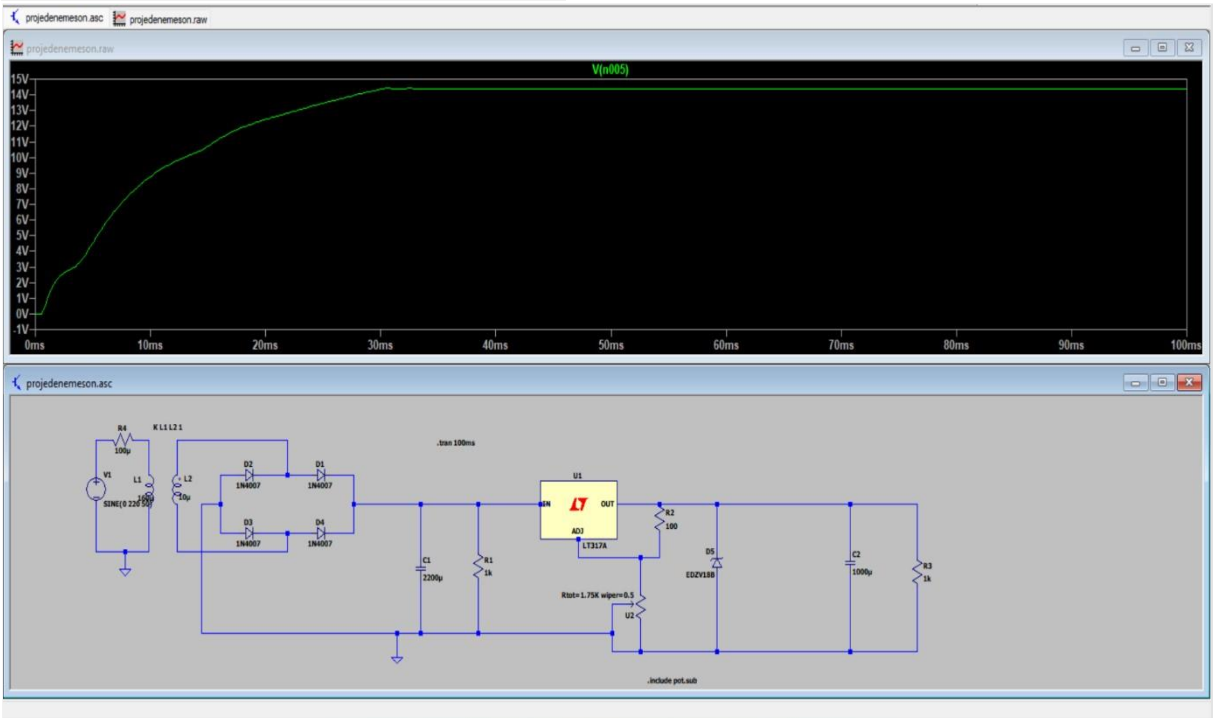
Potentiometer = 0   output ise 12 volt



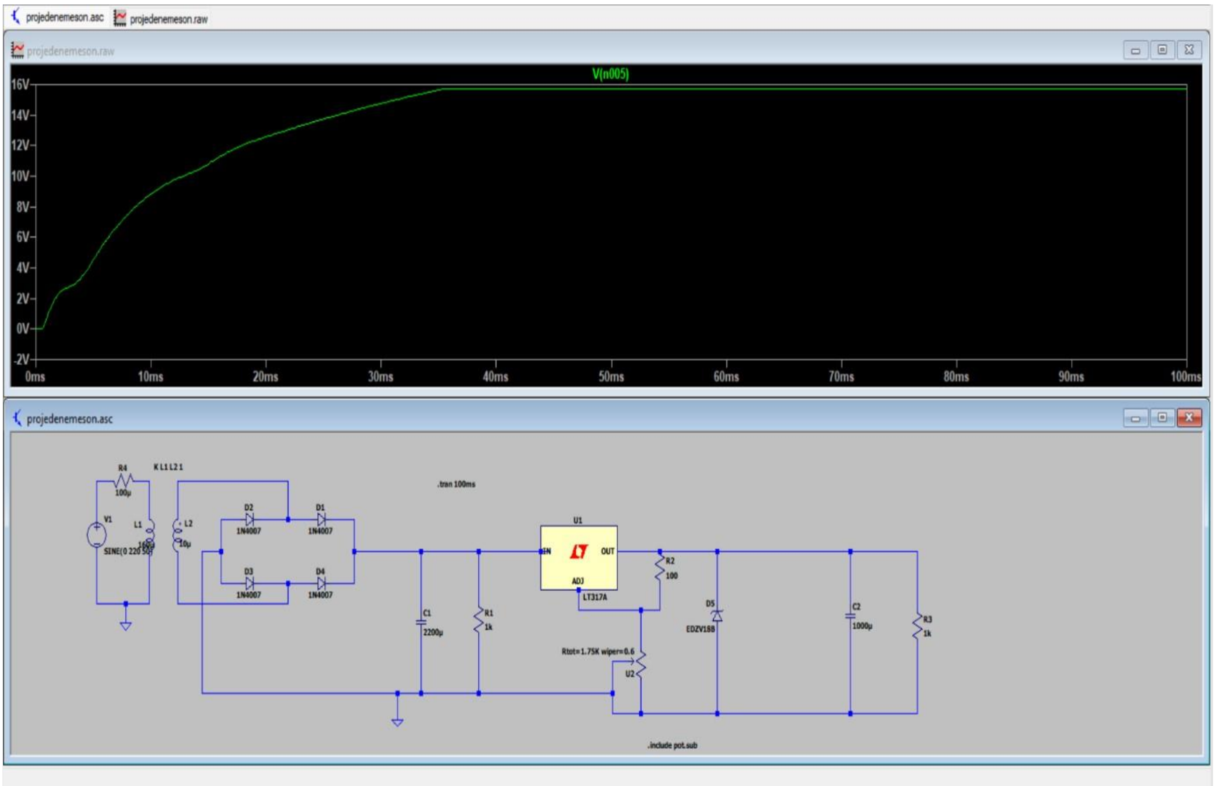
Potentiometer = 0.2 output ise 13 volt



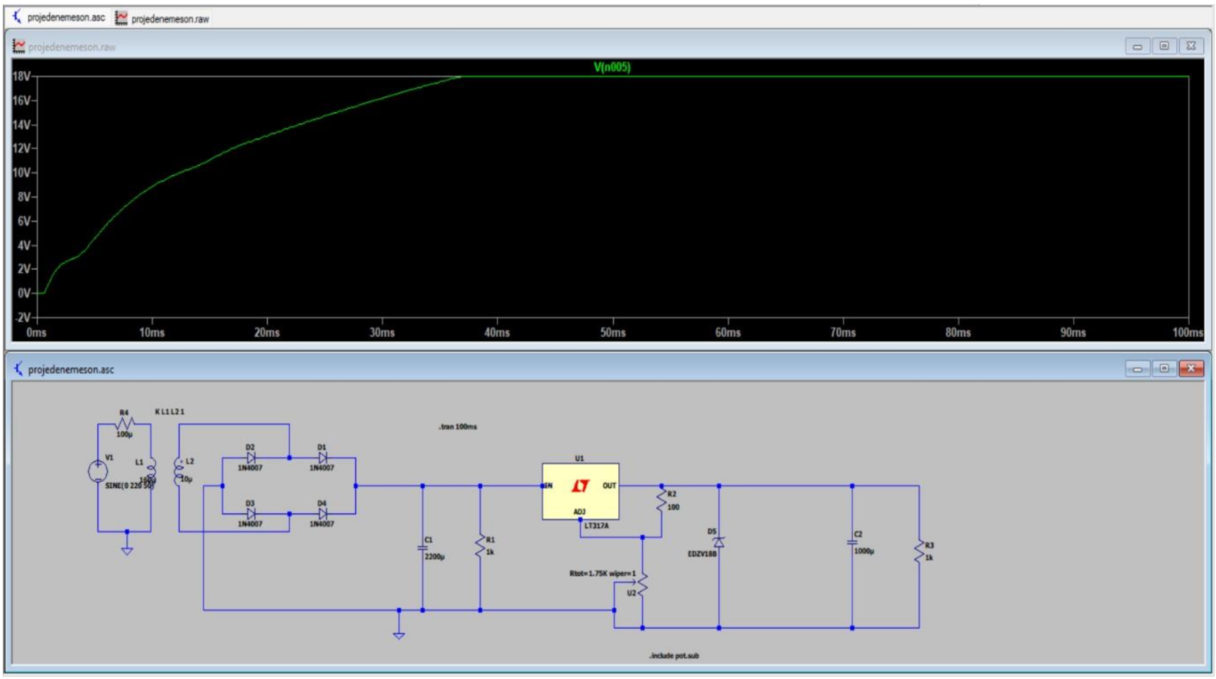
Potentiometer = 0.5 output ise 15 volt



Potentiometer = 0.6 output ise 16 volt



Potentiometer = 1 output ise 18 volt



- In the simulation phase, we tested our circuit under various load conditions and input voltage variations.
- Simulating Under Various Load Conditions and Input Voltage Variations
- During the simulation, we observed the circuit's performance under different load conditions and input voltage variations.

Load Conditions: We simulated different load conditions by varying the resistance values connected to the output. This allowed us to observe how the circuit responds to changes in load demand. For example, as the load resistance decreases, the current increases, which could potentially affect the output voltage. The simulation results showed that the LT317A voltage regulator maintained a stable output voltage despite significant changes in the load, demonstrating the robustness and reliability of the circuit.

Input Voltage Variations: We also varied the input voltage to observe how the circuit managed fluctuations in the power supply. Simulations under different input voltage levels confirmed that the LT317A regulator effectively stabilized the output voltage, ensuring reliable operation. This observation demonstrates the circuit's capability to handle real-world power supply variations.

Analysis of Output Voltage Stability and Efficiency

Analyzing the stability and efficiency of the output voltage is crucial for evaluating the performance of the voltage regulation stage.

Output Voltage Stability: During the simulation, we monitored the output voltage under various load conditions and input voltage variations. We observed that the LT317A voltage regulator provided a consistent output voltage with minimal ripple and noise. This observation highlights the effectiveness of the regulator's internal feedback mechanism in maintaining voltage stability.

Efficiency: Efficiency measures how effectively the circuit converts input power to the desired output voltage without excessive power losses. In our simulations, we observed that the LT317A regulator achieved high efficiency, indicating that the circuit converted most of the input power to output voltage with minimal losses. This efficiency is particularly important for power-sensitive applications.

Performance Evaluation of Protection Mechanisms

Evaluating the performance of the protection mechanisms is critical for ensuring the safety and reliability of the circuit.

Overcurrent Protection: During the simulation, we observed the effectiveness of the current-limiting resistor (R2). The results showed that this resistor successfully limited
the current flow, preventing potential damage.
Overvoltage Protection: In the simulations, we observed that the Zener diode (D5) effectively clamped excessive voltage, ensuring the safety of the components.

. Conclusion and Evaluation

. Conclusion:

- In this project, we successfully designed, simulated, and analyzed a 12-18V adjustable DC power supply using the LT317A voltage regulator in LTspice. Throughout the project, we integrated various stages, including a full-wave bridge rectifier, filtering stages, voltage regulation, and protection mechanisms, to create and test a comprehensive system. Initially, we employed a full-wave bridge rectifier to convert the 220V AC input voltage to DC. This stage provided more efficient rectification by utilizing both positive and negative half-cycles, effectively doubling the output frequency. To reduce ripples in the rectified DC signal, we used a capacitor filter. The large 2200μF capacitor minimized voltage fluctuations and provided a more stable DC output. During the voltage regulation stage, we utilized the LT317A voltage regulator to adjust the output voltage between 12V and 18V. This allowed us to achieve a stable and adjustable voltage output necessary for various applications, with precise adjustments made possible by the potentiometer. In our circuit, we incorporated several protection mechanisms for overcurrent, overvoltage, and thermal overload protection. Current-limiting resistors prevented component damage under overcurrent conditions, while the Zener diode clamped the voltage to a safe level during overvoltage situations, ensuring circuit protection. The LT317A's built-in thermal protection mechanism guaranteed safety by shutting down the circuit in the event of overheating. Simulation results demonstrated that all these stages combined to provide a stable and reliable output voltage even under varying load conditions and input voltage fluctuations. The effectiveness of the LT317A voltage regulator and the other components we applied confirmed that our circuit is a robust and reliable power supply suitable for a wide range of applications. This project has illustrated how theoretical knowledge can be integrated with practical applications to achieve a reliable power supply design.

Evaluation:

- In evaluating the performance of our designed adjustable DC power supply,

several aspects were identified that could enhance the stability, efficiency, and overall performance of the circuit.

Enhanced Filtering:

One area of improvement would be the implementation of more advanced filtering techniques. While we used a 2200μF capacitor to reduce ripples in the rectified DC signal, incorporating an LC (inductor-capacitor) filter could provide even better performance. LC filters are effective at smoothing out voltage ripples and providing a cleaner DC output, which is especially beneficial in applications requiring ultra-stable and noise-free power supplies. The inductor in an LC filter resists changes in current, while the capacitor smooths out voltage fluctuations, resulting in a more stable output.

Alternative Rectification Methods:

Another improvement could be exploring alternative rectification methods. Although the full-wave bridge rectifier we used is efficient, other rectification techniques, such as the use of Schottky diodes, could offer lower forward voltage drops and higher efficiency. Schottky diodes have faster switching times and lower power losses, which can be advantageous in high-frequency applications. Additionally, considering a synchronous rectifier design, which uses MOSFETs instead of diodes, could further improve efficiency by significantly reducing conduction losses.

Improved Thermal Management:

While the LT317A voltage regulator includes built-in thermal protection, adding external heat sinks or integrating thermal pads can enhance heat dissipation.
Improved thermal management would allow the regulator to operate at higher currents without overheating, thus increasing the circuit's reliability and longevity. This is particularly important in high-power applications where heat buildup can be a limiting factor.

Precision Voltage Adjustment:

Using a multi-turn potentiometer instead of a single-turn one could provide finer control over the output voltage adjustment. Multi-turn potentiometers allow for more precise tuning of the output voltage, which is crucial in sensitive applications

where exact voltage levels are required. This modification would enhance the usability and accuracy of the power supply.

Enhanced Protection Mechanisms

While our circuit includes basic protection mechanisms, adding more sophisticated protection features could further safeguard the circuit. For instance, integrating transient voltage suppressors (TVS) can protect against voltage spikes more effectively. Adding fuses or resettable circuit breakers can provide additional protection against short circuits and overcurrent conditions, ensuring the longevity and safety of the circuit.

Digital Control and Monitoring:

Incorporating digital control and monitoring using microcontrollers or digital potentiometers could significantly improve the functionality of the power supply. This would allow for automated adjustment of the output voltage and real-time monitoring of the circuit's performance. Such enhancements would make the power supply more versatile and user-friendly, with capabilities for remote adjustment and diagnostics.

By implementing these improvements, such as advanced filtering techniques, alternative rectification methods, improved thermal management, precision voltage adjustment, enhanced protection mechanisms, and digital control and monitoring, the designed DC power supply can achieve even greater stability, efficiency, and reliability. These enhancements would make the power supply more suitable for a wider range of demanding applications, ensuring it meets the highest standards of performance and safety.

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