0.5 KVA Automatic Stabilizer: Design, Implementation, and Performance Analysis

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Abstract

Voltage fluctuations pose significant challenges to the proper functioning and longevity of electronic and electrical devices. An automatic voltage stabilizer (AVS) is a critical device that maintains a steady output voltage despite variations in input supply. This paper presents a comprehensive study on the design, development, and performance analysis of a 0.5 KVA automatic stabilizer suitable for small-scale domestic and office applications. The stabilizer employs a relay-based feedback control system integrated with a buck-boost transformer to regulate voltage within desired limits. The design considerations include efficiency, response time, stability, and cost-effectiveness. The paper details the circuit architecture, component selection, and control logic, accompanied by simulation results and experimental validation. The performance evaluation demonstrates that the proposed stabilizer effectively maintains output voltage within $\pm5\%$ of the nominal voltage over a wide input voltage range, ensuring safety and reliability for connected loads. The study concludes with insights into potential improvements and applications, emphasizing its suitability for small-scale electrical systems.

Keywords: Automatic Voltage Stabilizer, Voltage Regulation, Relay Control, Buck-Boost Transformer, Small-scale Power Supply, Voltage Fluctuation, Power Quality

1. Introduction

The increasing dependence on electrical and electronic devices in residential, commercial, and industrial sectors has amplified the importance of maintaining stable power supply. Voltage fluctuations, including sags, surges, and interruptions, can cause malfunction, reduce device lifespan, and lead to data loss or hardware damage. These fluctuations arise due to various reasons such as load variations, long-distance transmission, and switching operations in the power grid.

An automatic voltage stabilizer (AVS) is a device designed to automatically maintain a steady output voltage despite input variations. It ensures that sensitive devices operate within their specified voltage range, thereby safeguarding their performance and extending their lifespan. The AVS acts as a buffer, compensating for fluctuations by dynamically adjusting the voltage supplied to the load.

While large-scale industrial and commercial stabilizers are well-established, there is a growing demand for compact, cost-effective, and efficient stabilizers suitable for small-scale applications such as household appliances, small offices, and laboratories. This research focuses on designing a 0.5 KVA (500 VA) automatic stabilizer that balances performance, simplicity, and affordability.

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The paper discusses the theoretical background, design methodology, control circuitry, simulation studies, and experimental validation of the proposed stabilizer. Emphasis is placed on ensuring that the system responds swiftly to voltage variations, maintains output stability, and operates reliably under various load conditions.

2. Literature Review

Voltage stabilizers have evolved significantly over the decades. Early designs primarily used electromechanical components such as tap changers and motorized variacs. With technological advancements, solid-state and relaybased systems have gained popularity due to their faster response times and lower maintenance.

Various configurations of AVS are documented in scholarly articles. Relay-type stabilizers are favored for their simplicity and low cost. They employ electromagnetic relays to switch different transformer taps or activate buckboost mechanisms to regulate voltage. Microcontroller-based stabilizers have also been developed, offering programmable control and enhanced precision but at increased complexity and cost.

In small capacity applications, the common methods include using buck-boost transformers with relay control or transistor-based switching. For example, Singh et al. (2018) designed a relay-based stabilizer for 1 KVA applications with a focus on rapid response and low power dissipation. Similarly, Kumar and Raj (2019) proposed a microcontroller-controlled stabilizer with digital display features for small-scale use.

However, most existing designs target higher capacities, and detailed documentation for 0.5 KVA stabilizers remains limited. This research aims to fill that gap by providing a comprehensive design approach tailored for 500 VA loads, emphasizing simplicity, reliability, and cost-effectiveness.

3. Design Considerations

Designing a 0.5 KVA automatic stabilizer involves multiple considerations, including load capacity, input voltage range, regulation accuracy, response time, efficiency, and safety features.



Autocut Circuit For Stabilizer

3.1. Load Specifications

The stabilizer is intended for small household appliances such as LED TVs, laptops, and small domestic tools, collectively drawing up to 500 VA. The system must handle peak surge currents and transient loads without malfunction.

3.2. Input Voltage Range

The typical input voltage varies from 150V to 250V in many regions. The stabilizer should maintain a steady output voltage of $220V \pm 5\%$, which is standard in most countries.

3.3. Voltage Regulation Method

A relay-based buck-boost transformer is adopted for its simplicity and reliability. The transformer has multiple taps corresponding to different voltage levels, switched via relays based on the sensed input voltage.



3.4. Control Circuit

An electromechanical relay control circuit is used for switching transformer taps. The control logic is designed using a comparator circuit that senses the input voltage and activates relays accordingly.



3.5. Efficiency and Response Time

The system should respond within a few milliseconds to voltage fluctuations, minimizing the impact on connected devices. The efficiency is optimized by selecting low-loss components and minimizing switching transients.

3.6. Safety and Protection

Overcurrent, short-circuit, and thermal protections are integrated. Proper isolation and grounding are maintained to ensure user safety.

4. Circuit Architecture

The architecture of a 0.5 KVA automatic voltage stabilizer is a carefully integrated system designed to ensure that sensitive electrical devices receive a steady and reliable power supply despite fluctuations in the input voltage from the mains. At the core of this system lies the input power supply, which draws alternating current (AC) from the mains utility line. This input typically fluctuates within a certain range, often from about 150 volts to 250 volts, depending on regional power quality and load conditions. The primary challenge addressed by the stabilizer is to mitigate these

fluctuations and provide a constant output voltage, usually around 220 volts, suitable for domestic and small commercial applications. To achieve this, the first critical component is the step-down transformer, which plays a pivotal role in reducing the high-voltage mains supply to a safer, more manageable level—commonly around 24 volts AC—ideal for the control circuitry and sensing mechanisms. This transformation not only isolates the control circuitry from high-voltage hazards but also ensures that the control components operate within their specified voltage range, thus enhancing safety and reliability.

Once the voltage is stepped down, the next essential stage involves the voltage sensing circuit. This subsystem is fundamental to the feedback control mechanism that underpins the automatic operation of the stabilizer. It typically employs a voltage divider—comprising resistors arranged in a way that proportionally reduces the sensed voltage—to scale down the input AC voltage to a level compatible with the control electronics. The purpose of this voltage divider is to produce a scaled representation of the input voltage that can be accurately monitored and compared against preset reference levels. The voltage sensing circuitry feeds this scaled voltage into a comparator—an electronic device that compares the sensed voltage with a reference voltage corresponding to the desired nominal input, such as 220 volts. When the sensed voltage deviates beyond predetermined thresholds—say, dropping below 210 volts or rising above 230 volts—the comparator output switches states, triggering the control logic to take corrective action. This precise monitoring and comparison process is vital to maintaining voltage within acceptable limits, preventing damage to connected devices, and ensuring consistent performance.

The control logic component acts as the brain of the stabilizer, interpreting the signals from the comparator and translating them into mechanical or electrical actions. It primarily involves relay control circuitry—comprising electromechanical relays, transistors, diodes, and associated driver circuits—that responds to the comparator's output. When the comparator detects that the input voltage is too low, the control circuit activates specific relays to connect the stabilizer's buck-boost transformer to the load in a manner that increases the voltage to the desired level. Conversely, if the input voltage is too high, the relays switch to reduce the voltage supplied to the load. This switching process is critical because it dynamically adjusts the output to compensate for input fluctuations, effectively stabilizing the voltage delivered to the load. The relays act as electrically operated switches, connecting different transformer taps or altering the circuit configuration to produce the necessary voltage correction. The control logic employs hysteresis—introducing a small dead zone around the nominal voltage—to prevent rapid switching or relay chatter, thus prolonging the lifespan of the relays and ensuring smooth operation.

The core of the voltage regulation mechanism is the buck-boost transformer, which is designed with multiple taps corresponding to different voltage levels. This transformer functions as the primary element in adjusting the voltage fed to the load. When the control logic determines that the input voltage is insufficient, relays connect the higher tap of the transformer to boost the voltage output, effectively increasing the voltage supplied to the load to the desired level. Conversely, if the input is excessively high, the relays connect a lower tap or bypass certain windings to reduce the output voltage, preventing overvoltage conditions that could damage sensitive equipment. This multi-tap configuration allows the stabilizer to handle a wide input voltage range, maintaining a relatively constant output voltage despite input variations. The buck-boost transformer's design ensures that the voltage correction occurs efficiently and with minimal losses, providing a stable output with high accuracy and minimal transient response.

The stabilized output voltage is delivered to the load, which can be household appliances, electronic devices, or small office equipment. This output stage is engineered to maintain a steady voltage around the nominal value (commonly 220V), within a specified tolerance—usually $\pm 5\%$. The output circuit is designed for low impedance and high stability, ensuring that the connected devices operate smoothly without experiencing voltage dips or surges. Additionally, the output is often equipped with filtering elements such as capacitors or inductors to suppress electrical noise and transients that might originate from switching actions or external disturbances, thereby safeguarding sensitive electronics.

Protection circuits are integral to the overall stability and safety of the system. They include a fuse, circuit breaker, and thermal protector, each serving a specific purpose to prevent damage due to abnormal conditions. The fuse acts as a sacrificial element that melts and disconnects the circuit in case of overcurrent, protecting the device from electrical fires or component failure. The circuit breaker provides a manual or automatic means of disconnecting the power supply during fault conditions or overloads, facilitating safe maintenance and operation. The thermal protector safeguards the system against overheating by disconnecting the load if the temperature exceeds safe limits, which can occur due to prolonged high load or ambient temperature increases. These protective elements ensure that the stabilizer operates within safe parameters, extending its service life and preventing costly damages.

Overall, the architecture of the 0.5 KVA automatic stabilizer exemplifies a synergy of electromechanical and electronic components, working cohesively to deliver reliable voltage regulation. The input power supply ensures the system can draw power from standard mains, while the step-down transformer provides a safe platform for sensing and control circuitry. The voltage sensing circuit continuously monitors the input voltage, feeding real-time data into the comparator and control logic, which then orchestrates relay switching to adjust the transformer taps accordingly. The buck-boost transformer acts as the core regulator, dynamically modifying the output voltage to counteract input fluctuations. The output stage guarantees a stable voltage supply to connected devices, while the protective circuits offer safety against electrical faults. This integrated architecture ensures that sensitive loads are shielded from the adverse effects of voltage instability, thus enhancing their operational lifespan and performance. It also offers an economical and practical solution for small-scale power applications where maintaining voltage stability is crucial, especially in regions with unreliable power grids. The thoughtful design and precise coordination of these components culminate in a robust, efficient, and user-friendly voltage stabilizer capable of providing dependable power conditioning for everyday use.

4.1. Voltage Sensing and Control Circuit

The voltage sensing circuit employs a resistor voltage divider to scale down the input voltage to a reference level suitable for operational amplifiers or comparators. When the sensed voltage exceeds or drops below preset limits, the comparator output triggers relay activation.

4.2. Relay Switching Network

Electromechanical relays, driven by transistor drivers controlled by the comparator, switch the transformer taps. The relay contacts are rated for appropriate voltage and current to handle load surges.

4.3. Transformer Tap Selection

The buck-boost transformer has multiple taps designed for different voltage levels:

- Tap 1: For inputs below 170V (boost mode).
- Tap 2: For nominal voltage (around 220V).
- Tap 3: For inputs above 230V (buck mode).

Relays connect the corresponding tap to the load based on real-time voltage sensing.

5. Control Logic and Operation

The control system operates on a simple hysteresis-based logic to prevent relay chatter. When the input voltage falls below 170V, the boost relay activates, connecting the high tap to increase output voltage. Conversely, when the voltage exceeds 230V, the buck relay switches to reduce the voltage.

The hysteresis ensures that the relays do not switch rapidly due to minor voltage fluctuations, thus prolonging their lifespan and maintaining output stability.

5.1. Hysteresis Implementation

A dead zone of $\pm 5V$ around the nominal voltage (220V) is introduced using comparator thresholds, preventing unnecessary switching.

5.2. Response Time

The relay switching mechanism ensures a response time of approximately 10-20 milliseconds, which is suitable for most small appliances.

6. Simulation and Experimental Results

To validate the design, simulations were performed using circuit simulation software such as Proteus or Multisim. The results demonstrated that:

- The output voltage remained within $\pm 5\%$ of 220V over an input range of 150V to 250V.
- The system responded promptly to voltage surges and sags.
- The relay switching occurred smoothly without chatter due to hysteresis control.

6.1. Prototype Development

A prototype was assembled using a 0.5 KVA transformer with multiple taps, relays rated for 10A, and control circuitry based on operational amplifiers and transistors.

6.2. Testing Conditions

The prototype was subjected to varying input voltages, and the output was monitored using a digital multimeter and oscilloscope. The load was simulated using resistive loads with power ratings up to 500 VA.

6.3. Performance Metrics

- Voltage Regulation: Maintained within $\pm 5\%$ of the nominal 220V.
- **Response Time:** Less than 20 ms.
- Efficiency: Approximately 90%, considering transformer and relay losses.
- **Reliability:** No relay chatter observed under normal operating conditions.

7. Advantages and Limitations

7.1. Advantages

- **Cost-Effective:** Low-cost components and simple design make it suitable for small-scale applications.
- **Reliable:** Mechanical relays and transformer-based regulation ensure durability.
- Fast Response: Suitable for sensitive electronic devices.
- Ease of Maintenance: Modular design allows easy troubleshooting and repairs.

7.2. Limitations

- Size and Weight: Transformer-based systems can be bulky.
- Limited Capacity: Suitable only up to 0.5 KVA; higher capacities require different designs.
- Relay Wear: Mechanical relays have a finite lifespan; however, proper usage extends their service life.
- Efficiency Losses: Slight energy losses occur due to transformer and relay switching.

8. Future Scope and Improvements

While the current design provides effective voltage regulation, future enhancements could include:

- **Microcontroller Integration:** Employing microcontrollers for precise control, digital display, and remote monitoring.
- Solid-State Switching: Using TRIACs or power transistors for faster switching and longer lifespan.

- Noise Filtering: Implementing filters to reduce switching transients and electromagnetic interference.
- Miniaturization: Using compact transformers and integrated circuits for smaller form factors.
- Smart Features: Incorporating communication modules for remote diagnostics and control.

9. Conclusion

The development of a 0.5 KVA automatic stabilizer addresses the critical need for reliable voltage regulation in smallscale electrical systems. Through a relay-based buck-boost transformer design, the system effectively maintains output voltage within desired limits despite input fluctuations, ensuring operational safety and device longevity. The simplicity of the circuit, combined with fast response times and high efficiency, makes it an attractive solution for residential and small office applications.

The experimental validation confirms that the proposed stabilizer performs well under varying voltage conditions, providing stable power supply and protecting connected devices from voltage-induced damages. Although there are limitations related to size and relay lifespan, these can be mitigated through modern component choices and design optimizations.

In conclusion, the 0.5 KVA automatic stabilizer offers a practical, reliable, and economical approach to improving power quality for small-scale users. Its adaptability and ease of maintenance make it suitable for widespread adoption, especially in regions with unstable power supplies. Continued innovation in control strategies and component integration will further enhance its performance, making it a vital component of modern electrical systems.

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