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IOT AND ARDUINO BASED AC VOLTAGE CONTROL

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Abstract: Integral cycle switching, facilitated by Arduino and IoT technologies, offers precise control of AC voltage, targeting the modulation of light bulb intensity and AC motor speed. The method involves manipulating complete cycles of an AC signal to achieve the desired outputs. A comparator is employed for zero crossing detection, which sends triggers to an Arduino. These triggers are then used to generate pulses that control opto-isolators, effectively driving a TRIAC for accurate cycle control based on user inputs interfaced with the microcontroller. The power supply configuration includes a step-down transformer, a bridge rectifier, a capacitive filter, and a voltage regulator to ensure stable operation of system components. A lamp is utilized in the setup to visually demonstrate the output, highlighting the ability to maintain load activation at the zero crossing of the voltage waveform, despite random switching. The focus is on validating the effectiveness of the voltage control strategy and examining potential waveform imbalances resulting from the switching technique. The approach demonstrates a scalable method for AC power control, applicable to various industrial and domestic applications requiring precise voltage adjustments.

Keywords: IoT (Internet of Things), Arduino UNO, Zero Crossing Detection, AC Voltage Control

I. INTRODUCTION

The management of alternating current (AC) power is integral to the efficient functioning of a vast array of devices within both residential and industrial settings. In contrast to direct current (DC) systems, which have been significantly simplified through innovations in light-emitting diodes (LEDs) and DC motors, AC power management presents a substantially more complex array of challenges. This complexity originates from the inherent characteristics of AC power, which, unlike DC's steady state, cycles between different voltage levels. It is widely utilized in inductive loads such as lamps, AC motors, and heaters, which are staples in numerous applications.

The delivery of AC power to these devices is facilitated through power electronic switches. These switches require precise control to ensure that they operate smoothly and efficiently, a task made challenging due to the need to minimize energy losses while managing the intricate dynamics of AC systems. Traditionally, this level of precise control has been achieved using devices like Silicon Controlled Rectifiers (SCRs), which, while effective in regulating power, introduce their own set of complexities. These include the need for accurate phase synchronization and the effective management of reactive power, elements that are absent in DC power systems.

The management of AC power involves not just dealing with a dynamic voltage supply but also ensuring that the phase angles are correctly aligned and that reactive power is effectively handled. These factors are critical as they affect the efficiency and reliability of power delivery. In response to these challenges, there has been a significant shift towards developing and implementing more advanced control strategies. Among these, Pulse Width Modulation (PWM) and sophisticated microcontroller-based solutions stand out. These technologies offer more refined control over power delivery, optimizing energy consumption and minimizing the generation of electrical noise and harmonics that can degrade power quality.

Recognizing the limitations of traditional AC power control methods, such as phase-controlled switching—which, despite being effective for regulating the speeds of single-phase induction motors, generate considerable high-order harmonics—a new approach has been developed. This method, known as discontinuous phase-controlled switching, combines the strengths of integral cycle switching with the precision offered by phase control. This innovative technique enables precise, incremental adjustments to voltage levels, accommodating both fine-tuning and more substantial changes as required by different applications. Such versatility is especially beneficial in scenarios involving rotor fan-type loads, where the ability to finely adjust the main winding voltage directly correlates with improved operational efficiency and reduced energy consumption.

The overarching goal is to leverage advanced IoT and Arduino technologies to demonstrate a sophisticated method of AC power control. This method is designed not only to improve the efficiency and performance of AC systems but also to reduce harmonic distortion significantly. By achieving this, the method enhances the overall energy efficiency of AC-powered systems and contributes positively to environmental sustainability. The integration of IoT and Arduino brings a new level of intelligence to power management, enabling more responsive and adaptive systems that can optimize energy usage in real-time and reduce the environmental footprint of power consumption. This approach does not merely signify an advancement in power management technology; it aligns closely with broader objectives of promoting sustainable energy practices and minimizing environmental impacts.

II. LITERATURE SURVEY

"A review on power quality enhancement using integral cycle switching technique" - Singh (2018) This [1] paper examines the impact of integral cycle switching on power quality, highlighting its efficacy in minimizing disturbances within AC power systems. The paper aggregates various case studies and experimental data, providing substantial evidence of how integral cycle switching enhances system efficiency. The results underscore the practical benefits of adopting this technique across modern electrical infrastructures, offering valuable insights into its deployment for improved stability and performance.

"A comparative study of integral cycle switching technique for AC voltage regulators" - Shrivastava (2016) In [2] The paper scrutinizes the integral cycle switching technique against traditional methods of AC voltage regulation. The findings indicate that integral cycle switching excels in reducing unwanted harmonics and in boosting the durability and efficiency of power systems. This paper is pivotal in illustrating the superior performance and potential advantages of integral cycle switching over conventional voltage regulation techniques.

"Analysis and implementation of integral cycle control technique for AC voltage regulators" - Tomy (2017) In [3] Tomy focused on the practical implementation aspects of integral cycle control in industrial settings. This paper details the design considerations, experimental setups, and outcomes of deploying integral cycle control systems, highlighting their robustness and adaptability. The documented experimental results offer proof of the technique's effectiveness, emphasizing its utility in real-world industrial applications.

"Integral cycle switching based AC voltage regulator": - Jena (2018) In [4] The review provides a comprehensive examination of AC voltage regulators utilizing integral cycle switching. The paper traces the technological evolution, analyzes current methodologies, and discusses prospects of these systems. It offers an extensive analysis of the regulatory mechanisms, assessing their influence on overall system performance and emphasizing the technology's potential for future advancements in power regulation.

"Integral Cycle Control for Power Quality Improvement in AC Voltage Regulators," by A. Tripathi and A.K. Rastogi, 2018.In [5] The paper examines the use of integral cycle control in AC voltage regulators to enhance power quality. They detail how this method effectively manages voltage by excluding entire cycles of AC input, maintaining a distortion-free sine wave, and reducing harmonics. The paper emphasizes the benefits of this technique, including improved power factor, increased component longevity, and overall system efficiency, positioning integral cycle control as a viable and cost-effective solution for electrical power systems.

III. PROBLEM STATEMENT

A comparator circuit is utilized to detect zero crossings within an AC waveform, a crucial juncture where the AC signal intersects the zero-voltage line. This detection is vital as it marks the optimal moment for initiating switching operations in power control, helping to reduce the generation of transients and decrease electromagnetic interference. The zero-crossing signal generated by the comparator triggers an interrupt signal that is then relayed to an Arduino microcontroller.

Upon receipt of this interrupt, the Arduino processes the signal to produce precise triggering pulses. These pulses are critical for the functioning of opto-isolators, which serve as conduits to manage the activation of power electronic components such as thyristors or triacs in the circuit. The opto-isolators provide necessary electrical isolation between the low-power control circuitry and the high-power load, thus enhancing both safety and the reliability of the system.

The primary purpose of this configuration is to enable integral cycle control—a technique where the power supplied to the load is regulated by switching the AC signal on and off for complete cycles. This approach is facilitated by the Arduino, which is based on inputs from interfaced switches, modulates the number of cycles that the load remains powered.

IV. OBJECTIVES

- To design a system that can detect zero crossing pulses using a C-program.
- To design a system that can control AC output at different levels by changing the firing angles of the thyristor using the opto-coupler and pushbuttons.
- To integrate IoT capabilities for remote monitoring and control of the AC motor and bulb via a mobile application.
- To implement real-time data collection and analytics for performance monitoring and predictive maintenance.
- To ensure safe operation through automated system checks and fault detection.

V. METHODOLOGY

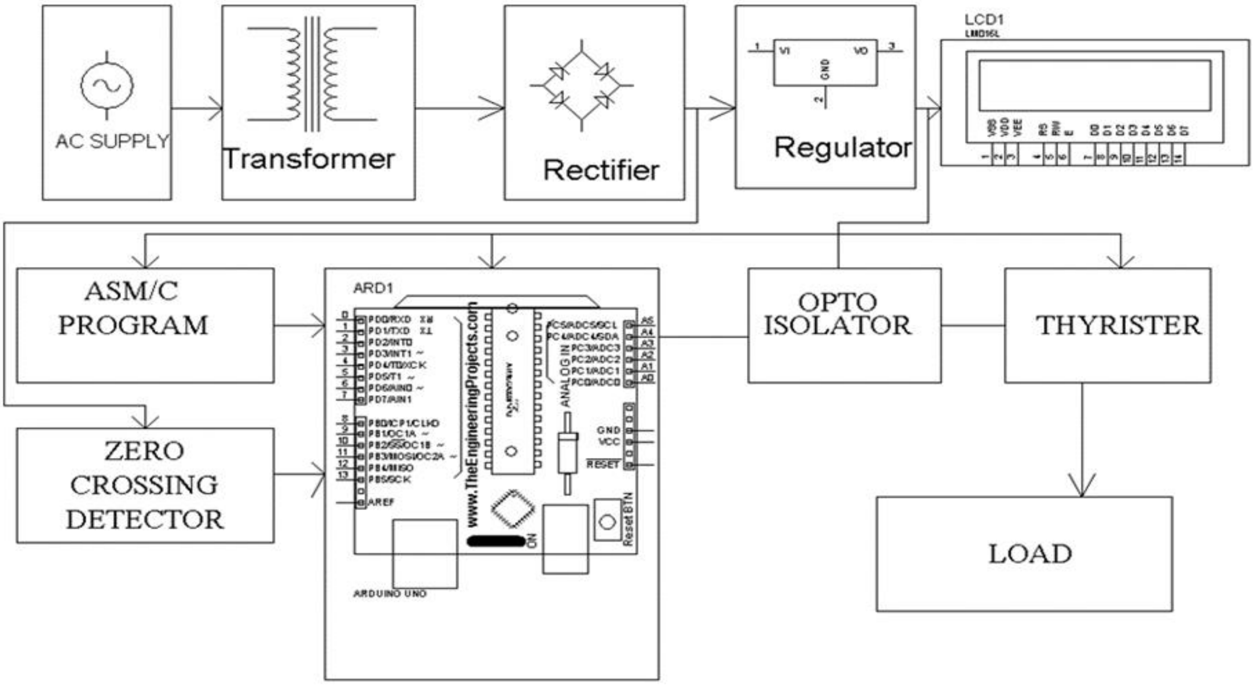

Fig 5.1 Block Diagram of Arduino Based AC Voltage Control

System Overview:
The system aims to control the intensity of a bulb and the speed of an AC induction motor using an Arduino.
The system is connected to the AC supply, and its output controls the thyristor (SCR) that regulates the load (bulb and motor).

Components:

- **AC Supply:** The source of alternating current (usually from a wall outlet).
- **Transformer:** Steps up or steps down the voltage level.
- **Rectifier:** Converts AC to pulsating DC.
- **Regulator:** Stabilizes the DC voltage.
- **Arduino:** Monitors the AC waveform and controls the thyristor.
- **Zero Crossing Detector:** Synchronizes control signals with the AC waveform.
- **Opto-Isolator:** Provides electrical isolation.
- **Thyristor (SCR):** Controls the AC load.
- **Bulb:** Represents the light source.
- **AC Induction Motor:** Represents the motor load.

Programming the Arduino:

1. Write an ASM/C program for the Arduino.
2. The program should:
3. Detect zero-crossing points of the AC waveform.
4. Adjust the thyristor firing angle based on user input (brightness control for the bulb, speed control for the motor).
5. Communicate with the mobile app via Wi-Fi or another wireless protocol.

Mobile Application Integration:
Develop a mobile app (IoT control interface).
Features:

- Turn the bulb on/off remotely.
- Adjust bulb brightness (send commands to the Arduino).
- Start/stop the motor.
- Change motor speed.
- Display system status and notifications.

Control Algorithm:

1. The Arduino continuously monitors the AC waveform.
2. When a zero-crossing point is detected:
3. Calculate the desired firing angle for the thyristor (based on user input).
4. Send control signals to the thyristor.
5. The thyristor allows current flow during the desired portion of each AC half-cycle.
6. This controls the power delivered to the load (bulb or motor).

VI. CIRCUIT DIAGRAM

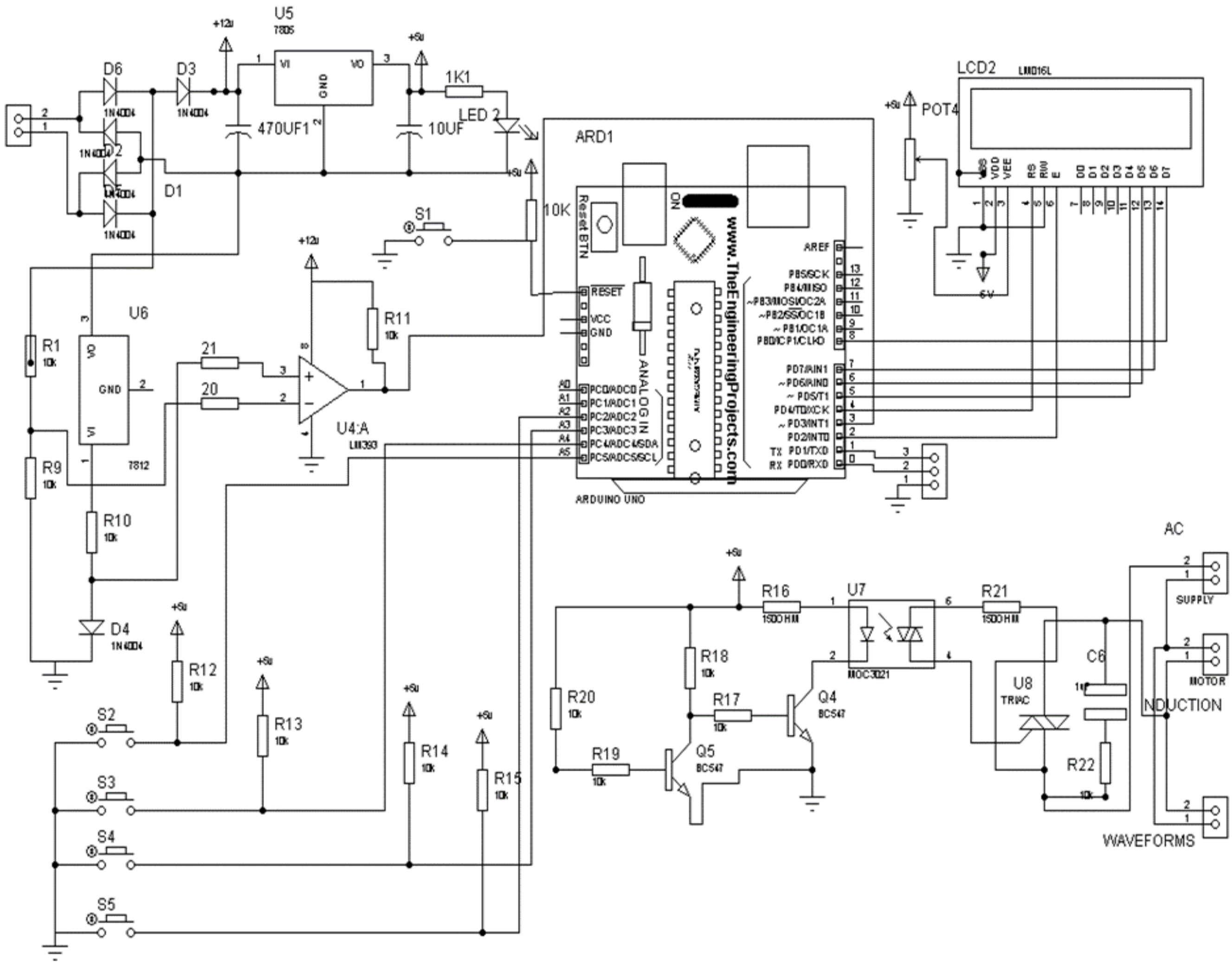

Fig 6.1 Circuit Diagram

The system starts with a bridge rectifier, which is instrumental in transforming the incoming alternating current (AC) signal into a pulsating direct current (DC) output. This conversion is crucial as it stabilizes the current for further processing within the circuit. Following this stage, the pulsating DC output is fed into an opto-coupler. The role of the opto-coupler is critical; it acts as a gatekeeper, only allowing current to pass when it detects the presence of voltage. This functionality not only ensures operational safety but also provides vital electrical isolation between the high-voltage AC components and the low-voltage control elements of the system.

At the core of the system's control mechanism is the detection of zero-crossing points by the opto-coupler. Zero-crossing detection is a key feature, as these points represent the moments when the AC waveform crosses the zero-voltage line, making them ideal for timing the activation of switching devices to minimize power loss and interference. Upon detecting a zero-crossing point, the opto-coupler sends a signal to the Arduino microcontroller. The microcontroller is programmed to respond to these signals by generating appropriate outputs to control further stages of the circuit.

The Arduino microcontroller plays a pivotal role in activating a TRIAC (Triode for Alternating Current) for regulating power to the load. It accomplishes this using an MOC 3021 chip, a component specifically chosen for its capability to handle the nuances of AC-to-DC communication, which involves managing higher voltage levels than the microcontroller can typically tolerate. The integration of the MOC 3021 ensures that the TRIAC is triggered accurately, allowing for precise control over the connected AC load, whether it be a bulb or an AC motor.

User interaction with the system is facilitated through a set of four switches connected to the Arduino. These switches enable users to manually adjust the power levels supplied to the load. To ensure the stability and reliability of these inputs, resistors are incorporated into the connections, safeguarding against potential voltage spikes, and providing a stable operation environment.
Overall, this setup not only demonstrates the practical application of controlling a bulb or an AC motor through sophisticated electronic components and circuit design but also showcases how modern electronics can integrate safety, user interaction, and precise control in effective AC power management systems.

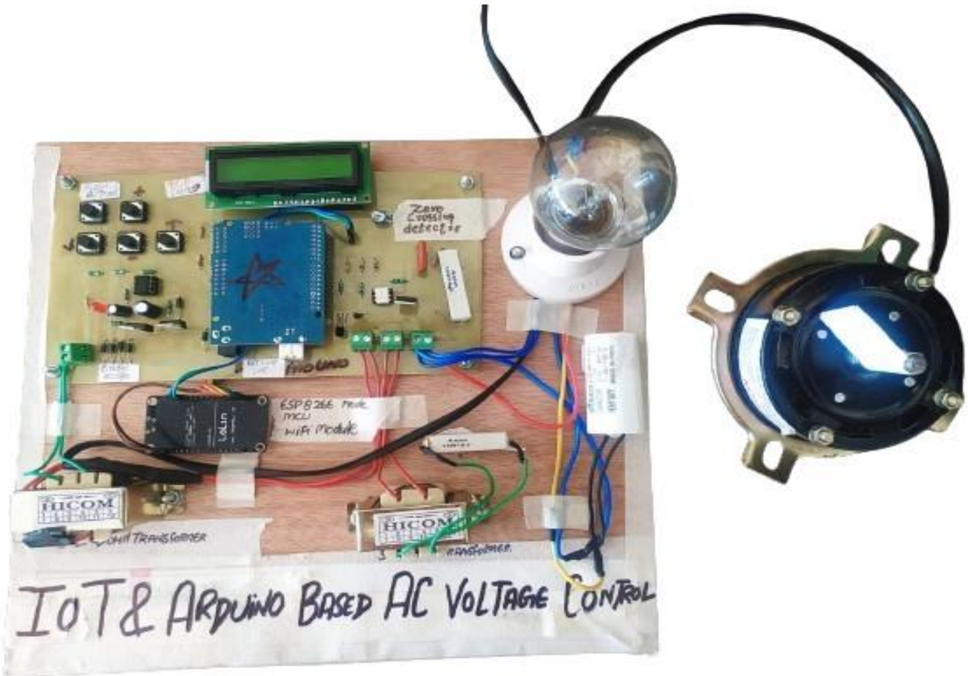

Fig 6.2 Overview of Proposed System Architecture

Incorporating integral cycle switching into the "IoT and Arduino-Based AC Voltage Control" project, the proposed hardware architecture is designed to effectively manage and adjust AC voltage levels using precise cycle-by-cycle control. This method enhances the efficiency and responsiveness of the voltage control system.

Central to the hardware setup is the Arduino microcontroller, which orchestrates the integral cycle switching process. By leveraging the computational capabilities of the Arduino, the system is programmed to turn the AC load on and off at zero-cross points of the AC waveform. This timing precision minimizes the generation of electrical noise and reduces power losses, which are common in other types of voltage control methods.

The system includes a zero-cross detection circuit, crucial for ensuring that the switching occurs at the optimal moment for both safety and efficiency. A solid-state relay, controlled by the Arduino, facilitates the rapid switching required for integral cycle control. This setup allows for adjusting the power output to the load by skipping a predefined number of cycles, based on the desired voltage output and load requirements.

Additionally, the inclusion of a Wi-Fi module in the architecture enables the system to be connected to the internet, thus harnessing IoT capabilities. Users can remotely adjust settings, monitor system performance, and receive real-time updates on system status through a dedicated IoT platform. This connectivity not only enhances user interaction but also enables easy integration into smart home systems, providing a modern, adaptable solution for AC voltage control.

VII. ADVANTAGES AND DISADVANTAGES

ADVANTAGES

- This method minimizes harmonic distortion, enhancing both system stability and efficiency.
- It surpasses conventional firing angle modulation in efficiency, significantly reducing energy loss.
- The load operates more safely, which boosts both the longevity and reliability of the equipment.
- Implementation and maintenance are simpler and less costly, making this method more economical.
- It is highly scalable, suitable for both small and extensive applications, and provides flexibility across various scenarios.
- This approach allows for precise power output control, tailored to meet specific operational demands.
- It is compatible with renewable energy sources, facilitating integration with systems like solar panels.

DISADVANTAGES

- The system allows power delivery at fixed intervals (20%, 60%, 80%, 100%), which may not provide the granularity needed for applications requiring more precise power adjustments.
- The entire system relies heavily on the performance of the Arduino microcontroller. Any limitations in the microcontroller's processing power, memory capacity, or compatibility with other components could affect the system's efficiency and reliability.

VIII. APPLICATIONS

- This method is used in industry for controlling power.
- It is used to control the power in linear loads.
- Where we must control the speed, intensity, and power then this method is applicable.
- **HVAC Systems:** Utilized in the fans and blowers of heating, ventilation, and air conditioning systems to control airflow rates and motor speeds, enhancing energy efficiency and comfort.
- **Conveyor Systems:** Employed in the speed control of conveyor belts in manufacturing and packaging industries to adjust the processing speed based on the production demand.
- **Pump Systems:** Used in controlling the speed of water pumps in municipal water supply, irrigation systems, and industrial cooling processes, optimizing flow rates and reducing energy consumption.
- **Compressor Systems:** Applied in controlling the speed of compressors in refrigeration and air compression systems, allowing for variable output depending on the load requirements.
- **Textile Machinery:** Utilized in textile machines to adjust the speed of spinning and weaving machines, ensuring precision and quality control in fabric production.

IX. CONCLUSION

Voltage regulation using integral cycle control (ICC) is a sophisticated method of modulating AC power by selectively omitting complete cycles from the primary supply. This technique focuses on aligning switch-off and switch-on events with the AC waveform's zero-cross points—moments when the voltage transitions through zero volts. By synchronizing the switching to these specific intervals, ICC ensures that no additional harmonics are introduced during the process, thereby preserving the waveform's pristine sinusoidal shape.

The outcome is a significant reduction in harmonic distortion and an improvement in the power factor of the system. This method is particularly advantageous for applications requiring high efficiency and minimal electrical noise, as it maintains the integrity and quality of the power being supplied.

Verification of the waveform's integrity and the effectiveness of the ICC can be conducted by observing the output through a Cathode Ray Oscilloscope (CRO), which visually confirms the maintenance of a distortion-free sinusoidal waveform.

The benefits of integral cycle switching are numerous. It offers a cost-effective and simple implementation that doesn't require sophisticated or expensive components, making it widely accessible for various applications. Additionally, by preserving a pure sine wave output, the method minimizes harmonic generation, which commonly leads to power quality problems in electrical systems. Lowering harmonics not only enhances the power factor but also diminishes the stress on electrical components, potentially increasing their durability.

Another notable advantage of this technique is the reduction in AC power losses. Since the switching process involves removing entire cycles, it naturally bypasses the phase-shifting problems that often result in inefficiencies with other AC voltage control techniques. Consequently, this method achieves improved efficiency in AC power distribution. Overall, integral cycle switching in AC voltage control emerges as an effective, economical, and reliable approach that boosts the overall efficiency and sustainability of power systems.

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