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Design Of A Single Phase AC Voltage Controller Using SIMULINK

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Abstract : This research paper explores the design and implementation of a single-phase AC voltage controller aimed at providing precise control over electrical power. The study focuses on utilizing thyristors, specifically silicon-controlled rectifiers (SCRs), to manipulate the voltage supplied to loads. The implementation leverages MATLAB Simulink as a virtual platform to simulate and assemble an electrical system, comprising AC voltage sources, thyristors, and resistive loads.The core objective lies in the accurate adjustment of thyristor conduction timing to regulate the average voltage delivered to the load, analogous to controlling water flow from a faucet. The research delves into understanding transient responses, steady-state characteristics, and harmonic content of the output voltage, essential for fine-tuning voltage control strategies. Furthermore, emphasis is placed on analyzing and mitigating harmonics to ensure high-quality, industry-standard compliant controlled power. Overall, this paper provides insights into the intricacies of single-phase AC voltage control, equipping practitioners with the knowledge and skills to achieve precise voltage regulation, comprehend power behavior intricacies, and guarantee clean, efficient, and reliable controlled electricity.

IndexTerms **- Single phase AC (SPAC) voltage controller, Phase Triggering Control (PTC), Power quality improvement**

I. Introduction

The investigation into single-phase AC voltage controllers extends beyond theoretical considerations to practical applications, showcasing the adaptability of the proposed design. Real-world implementation involves testing the voltage controller in various load scenarios, evaluating its performance under dynamic conditions, and validating the simulation results. Additionally, the paper addresses the challenges associated with scaling up the system for three-phase applications, acknowledging the broader implications and potential advancements in industrial and commercial settings.

Furthermore, the research highlights the economic and environmental advantages of employing voltage controllers in power systems. The precise control achieved through thyristor-based manipulation contributes to energy efficiency and reduced wastage, aligning with global efforts towards sustainable energy practices. The potential for integration with smart grid technologies and renewable energy sources is also explored, emphasizing the role of single-phase AC voltage controllers in shaping the future of intelligent power distribution systems.

In the context of emerging technologies, the paper discusses ongoing developments in semiconductor devices and control algorithms that could enhance the performance and reliability of AC voltage controllers. The evolution of these controllers is positioned within the broader landscape of power electronics, illustrating their role in advancing the overall efficiency and resilience of electrical networks.In conclusion, this research paper not only serves as a comprehensive guide to understanding the intricacies of single-phase AC voltage control but also contributes to the ongoing discourse on the evolution of power systems. By bridging the gap between theoretical concepts and practical applications, the study provides a valuable resource for engineers, researchers, and industry professionals seeking to optimize voltage control strategies for diverse applications in our increasingly electrified world.

II. LITERATURE SURVEY:

Muhammed Rezit et. al explains [1] that the phase triggering control (PTC) of single-phase AC (SPAC) voltage controllers. The main advantage of the SPAC voltage controller topology is the fact that it can generate an output AC voltage lower than the input AC voltage, depending on the phase triggering angle (PTA)., singlephase AC voltage controllers with phase triggering control were investigated. Firstly, mathematical expressions were obtained with the help of the electrical equivalent circuit. Then, these expressions were modelled in Matlab/Simulink environment and the output voltage was observed with different phase triggering angles.

Bilal Saracogolu explains [2] the application of phase triggering control (PTC) in single-phase AC (SPAC) voltage controllers, with a specific focus on their capability to generate output AC voltage levels lower than the input. The research commences with a theoretical analysis, proceeds to the development of a Matlab/Simulink model, and culminates in experimental validation. The study highlights the effectiveness of PTC in achieving reduced AC voltages. The introductory section underscores the significance of voltage adjustment for diverse devices, leading to the development of SPAC voltage controllers. The research makes a valuable contribution by scrutinizing SPAC controllers with PTC, specifically addressing concerns related to harmonic distortion and power factor. In essence, the paper provides valuable insights into the practical implementation and efficacy of PTC in SPAC voltage controllers.

E.S. Oluwasogo et. al explains that [3] the performance characteristics of a thyristorized inverse parallel controller (IPC), or AC voltage controller, under a singlephase induction motor load. The study focuses on the continuous variation of rotor speed and rotational force achieved by the device, which is composed of two thyristors connected in an inverse-parallel manner. The paper emphasizes the expanding applications of thyristors in industrial automation due to their low power consumption when manipulating electric power flow.

Ali S. Saleh et. al explains [4] the development of a single-phase PV power system, highlighting its importance in the face of increasing electricity demands and diminishing conventional energy sources. It seamlessly integrates PV cells, boost converters with MPPT algorithms, and H-bridge inverters using SPWM for efficient power conversion. The Arduino Uno plays a key role in PWM signal generation, controlling IGBTs in both the inverter and boost circuits. MPPT performance is enhanced through the Perturbation and Observation (P&O) algorithm, ensuring optimal power utilization. Simulation results demonstrate minimal Total Harmonic Distortion (THD) in AC voltage and current waveforms, with practical validation confirming the system's efficacy in real-world scenarios. Additionally, the paper cites previous studies, enriching understanding of PV system intricacies and advancing discourse on renewable energy technologies.

M Narayanan et. al explains [5] the concept of AC voltage controllers, which convert fixed AC to variable AC without altering frequency, using SCR switches. Various control strategies are discussed, including On-Off cycle control, Phase angle control, Integral cycle switching control, Pulse Width Modulation (PWM) control, Section control, and Sector control. Each method has its advantages and drawbacks, affecting factors such as output voltage control, Total Harmonic Distortion (THD), commutation circuit requirements, and system cost. MATLAB simulation demonstrates the feasibility of these strategies. Additionally, considerations for implementation, such as effectiveness, THD, cost, and switch requirements, are highlighted for selecting the most suitable method for specific applications.

III. METHODOLOGY:

The simulation process was initiated by launching Simulink, an indispensable tool within the MATLAB environment, to construct a comprehensive model of the controlled rectifier circuit. The intricate components of the circuit, including the AC Voltage Source, Thyristor (SCR), Load, and Control blocks, were meticulously selected from the Simulink block library.

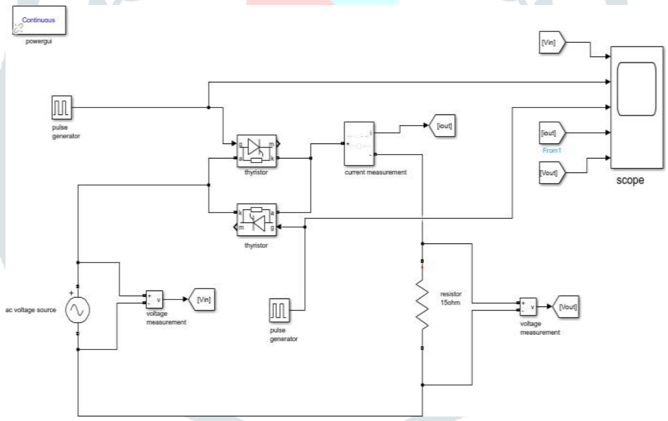

Fig.1 Simulation model for SPAC low voltage controller

The AC Voltage Source block was meticulously configured to emulate a sinusoidal waveform, simulating the characteristics of the input power supply. The Thyristor (SCR) block, serving as the core of the controlled rectifier, was parameterized with exacting values, encompassing the forward voltage drop and onstate resistance, mirroring the specifications of real-world devices.

To dynamically regulate the circuit operation, a control block was seamlessly incorporated to dictate the firing angle of the Thyristor. Leveraging a Pulse Generator block facilitated the generation of firing pulses, with the pulse width precisely set to correspond to an 80-degree firing angle. The integration of a Load block, embodying the characteristics of a resistor or RL load, further enhanced the fidelity of the model. Adjustable parameters within the Load block were judiciously configured to represent diverse load scenarios, ensuring a comprehensive analysis.

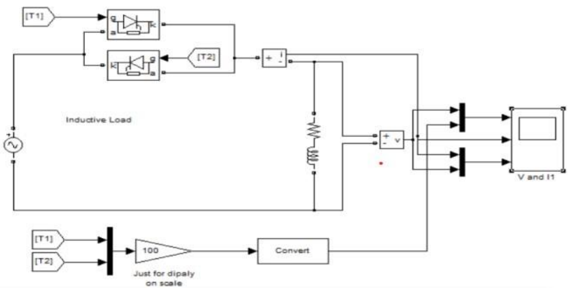

Fig.2 Simulink circuit for varying the firing angle[7]

Critical to the simulation's accuracy, various simulation parameters were meticulously set, encompassing simulation time, solver type (ode45), and step size. These parameters were fine-tuned to capture the transient and steady-state behaviors of the controlled rectifier circuit effectively. The interconnection of blocks was executed with precision, replicating the physical layout of the circuit. The inclusion of a Scope block served as a visual aid, providing an intuitive representation of the output voltage waveform.

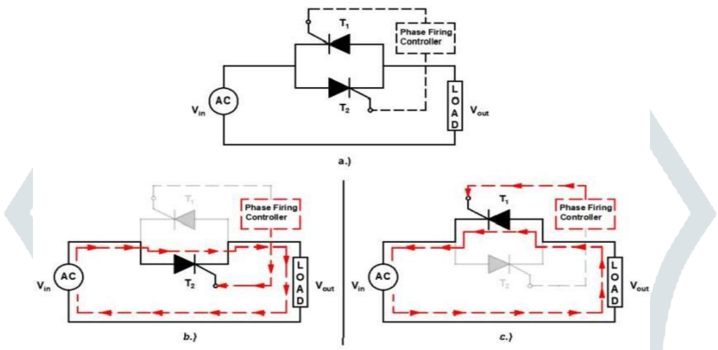

Fig.3 Electrical equivalent circuit of SPAC voltage controller[1]

The electrical representation of the single-phase AC (SPAC) voltage controller is depicted in **Figure 3**. In Figure 3a, anti-parallel thyristors T1 and T2 are interposed between the load and the AC source. Figure 3b illustrates the activation of switch T2, connecting the load directly to the source based on the phase triggering angle's magnitude. In Figure 3c, this operation is executed by switch T1. To examine the impact on the effective value (RMS) of the output voltage, the phase triggering angle is systematically varied within the range of 0 to 18 degrees.

$$V_{0(RMS)}=V_{in}\left[\frac{1}{\prod}\left((\prod-\propto)+\frac{\sin 2\propto}{2}\right)\right]^{\frac{1}{2}} \qquad (1)$$

Here, Vo(RMS) denotes the effective output voltage, Vin represents the input voltage, and θ signifies the phase triggering angle in radians. Equation (1) reveals that when the phase triggering angle is zero, the effective output voltage equals the effective input voltage. Consequently, single-phase AC (SPAC) voltage controllers facilitate power flow from the effective input voltage to zero. It is crucial to consider the variation in power factor (PF) during this power flow. PF, a key parameter constraining the application of AC voltage controllers, can be expressed as shown in Equation (2).

$$PF=\frac{{I_{o(RMS)}}^{2}R_{l}}{V_{in(RMS)}I_{in(RMS)}} \qquad (2)$$

IV. Components Used:

AC Voltage Source: The AC Voltage Source serves as the foundation of the single-phase AC voltage controller design. It represents the primary power supply providing the sinusoidal AC voltage to the system. The voltage source's amplitude, frequency, and phase characteristics are crucial parameters to set, ensuring that the controller operates within the desired voltage range and frequency.

Voltage and Current Measurement: Voltage and Current Measurement blocks are strategically placed within the circuit to monitor key electrical parameters. In the context of a singlephase AC voltage controller, these measurements are vital for feedback and control purposes. By monitoring the voltage and current waveforms at specific points, the controller can dynamically adjust its operation to regulate the output voltage effectively.

Resistor (15Ω): The Resistor block in this context represents the load in the single-phase AC voltage controller circuit. The load resistance determines the current flowing through the circuit and influences the overall performance of the voltage controller. By adjusting the resistance value, designers can simulate different load conditions, ensuring the controller's robustness under varying scenarios.

Thyristors: Thyristors, as controlled switches, play a central role in the design of an AC voltage controller. They are used to control the flow of current through the load by adjusting the firing angle. In the implementation, multiple thyristors are often configured in a controlled rectifier circuit. The firing pulses generated by the controller determine when the thyristors conduct, allowing for the regulation of the output voltage.

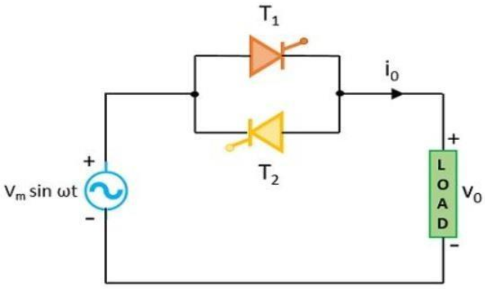

Fig.4 Single Phase AC Voltage Controller[8]

Pulse Generator: The Pulse Generator block is essential for generating firing pulses that control the thyristors' operation. In a single-phase AC voltage controller, the firing angle dictates when the thyristors are triggered to conduct. By adjusting the parameters of the Pulse Generator, designers can set the desired firing angle, influencing the portion of the AC cycle during which the thyristors conduct and, consequently, the output voltage level.

Scope: The Scope block is a valuable tool for visualizing the output voltage waveform. Designers use the Scope to observe how the AC voltage controller affects the shape and magnitude of the output waveform. This visual feedback is crucial for tuning the controller parameters and ensuring that the output voltage meets the desired specifications.

Goto and From Blocks: Goto and From blocks aid in organizing the Simulink model of the single-phase AC voltage controller. They establish connections between different sections of the model, facilitating a clear and modular design. By using Goto blocks to mark specific signals and From blocks to retrieve these signals, the model becomes more readable, making it easier to understand and modify during the design and implementation phases.

V. RESULTS AND DISCUSSIONS:

In the design of a single-phase AC voltage controller incorporating thyristors, meticulous attention is required to intricately structure the circuit, effectively managing thyristors and fine-tuning firing angles. The chosen thyristors should precisely match the specified voltage and current requirements, accompanied by the implementation of suitable isolation and protection measures. The control mechanism governing firing angles demands careful execution for optimal performance. Concurrently, rigorous testing and simulation are imperative to validate the circuit's functionality across varied load conditions.

FIRING ANGLE(α) in degrees°	**RMS Output Voltage(V) MATLAB**
30°	34.3
60°	31.6
90°	24.62
120°	15.13

Table 1: **Observed output voltage in Simulink**

Particularly noteworthy is the examination of the conductive behavior during positive and negative half cycles after specific firing angles, notably at 80 degrees and π + 80 degrees (260 degrees) from equation (1). Practical tests should confirm these observations, including voltage levels at different firing angles and under diverse loads, showcasing the controller's versatility. Furthermore, a comprehensive assessment covering efficiency, power factor, and real-world applications, such as motor speed control or light dimming, contributes to a thorough understanding of the controller's capabilities.

The detailed documentation, encompassing circuit diagrams, specifications, and practical findings, establishes a robust groundwork for subsequent refinements and applications, ensuring a comprehensive and reliable resource for future endeavors.

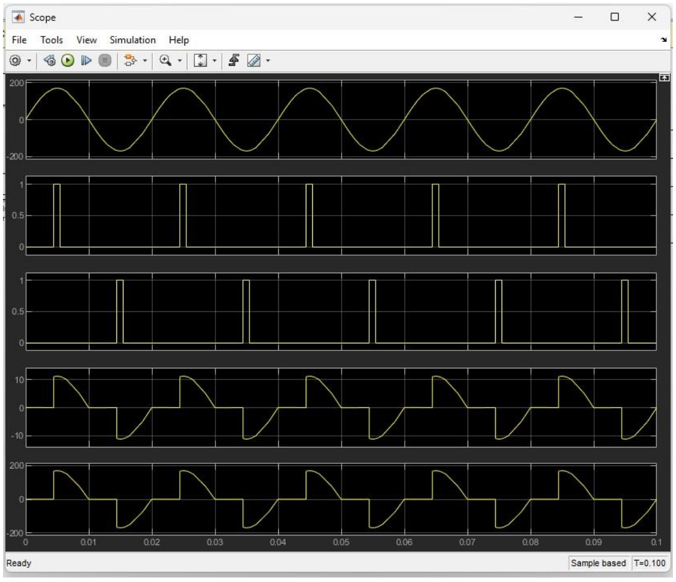

Figure 5: Input and output waveforms(α=80).

VI. CONCLUSION:

In conclusion, the single-phase AC voltage controller assumes a critical role within contemporary electrical systems, offering meticulous control over the distribution of electrical power to various loads. By managing thyristors and carefully adjusting firing angles, this technology enables customization of voltage levels to suit a diverse range of applications.

In summary, the single-phase AC voltage controller exemplifies the innovation within electrical engineering. It grants us the ability to tailor electricity to our requirements, ensuring the efficient and reliable operation of electrical systems in sync with the demands of our modern world. Continuously evolving, this technology advances the precision and efficiency of voltage control, shaping the landscape of electrical engineering.

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