Conference of Electrical, Marine and Its Application
Vol. xx, No xx, Month-Year ISSN:

Single-Phase AC Voltage Regulator Implementation for Enhancing Transformer Efficiency in Rural Community Electrification Programs

Rahmania Firdiansya
Marine Electrical Engineering, Shipbuilding Institute of Polytechnic Surabaya, Indonesia
Correspondence author: rahmaniafirdiansyah@student.ppns.ac.id

ABSTRACT

The stability of voltage supply is a critical requirement in delivering reliable power sources, especially in rural electrification systems aimed at improving community well-being. Ensuring a constant voltage within electrical circuits is crucial, as voltage fluctuations during transmission can cause significant issues. These fluctuations, often resulting from voltage drops in distribution networks, can lead to reduced lifespan and performance of electronic devices in households and industries. Several factors influence voltage stability, including increased transmission line loading, limitations in reactive power regulation, dynamic adjustments in load-tap-changing transformers, and load characteristics. This study explores the development of a single-phase AC voltage regulator designed to enhance transformer efficiency, particularly in rural electrification programs. Using PSIM software, a voltage regulation circuit was developed, incorporating key components such as thyristors, transformers, Silicon-Controlled Rectifiers (SCRs), and other auxiliary elements. The results of this research contribute to the design of robust and sustainable electrification solutions, addressing the specific needs of underserved rural communities.

Key Word*: AC voltage, one phase, voltage regulator*

I.INTRODUCTION

Judging from the output frequency produced, alternating voltage regulation circuits can be categorized into two main types: AC regulators and cycloconverter circuits. This discussion focuses on AC regulator circuits, which are power electronic systems designed to convert an alternating current (AC) voltage source into another AC voltage source with a fixed frequency but adjustable output voltage[1]. These circuits are particularly beneficial for applications requiring precise voltage control, such as in voltage stabilizers, lamp dimmers, heating regulators, and similar devices. In this study, the application of an AC regulator circuit is analyzed, specifically in the context of rural electrification programs to ensure stable voltage supply for community infrastructure[2].

In real-world scenarios, voltage fluctuations are a common issue that affects the performance of electronic devices. Such fluctuations can decrease the operational efficiency and lifespan of equipment used in homes and industries[3][4]. For example, in rural areas where voltage instability is more frequent, these fluctuations can lead to the malfunctioning of essential appliances and tools, impacting the daily lives and productivity of residents. This highlights the importance of employing voltage stabilizers or other similar systems to maintain the AC voltage within a specified range, ensuring that electronic devices function efficiently and last longer[5].

This research investigates the impact of integrating thyristors into transformers within an AC regulator circuit. The study examines whether the inclusion of thyristors can stabilize and maintain constant voltage output, particularly in settings with frequent power fluctuations. By ensuring voltage stability, this approach contributes to improving the reliability of power distribution systems in rural communities, ultimately supporting their socio-economic development through enhanced electrification solutions[6].

The significance of this research lies in its dual contribution: technical innovation and societal impact. Technically, the implementation of AC voltage regulators with thyristors represents a solution to manage voltage instability effectively. From a societal perspective, the research aligns with community service goals by addressing a critical infrastructure challenge in rural electrification. Stable electricity supply directly supports education, health services, and economic activities, creating a ripple effect of benefits for underserved communities.

Through the findings of this study, it becomes evident that adopting such innovative voltage regulation systems can play a transformative role in enhancing the quality of life in rural areas. The integration of these systems into community electrification programs ensures that power is not only available but also reliable, fostering sustainable development and bridging the gap between urban and rural infrastructure.

II.METHODOLOGY

1. Component

a. SCR (Silicon Control Rectifier)

A Silicon-Controlled Rectifier (SCR) is a semiconductor device that belongs to the thyristor family and operates based on principles similar to a diode but with an added gate to control the phase angle. The SCR consists of a four-layer structure, represented as PNPN (Positive-Negative-Positive-Negative), and features three PN junctions labeled J1, J2, and J3, starting from the anode. This unique structure enables precise control of electrical current flow[7]. The SCR operates by triggering its gate with a small voltage applied between the gate and cathode[8]. This action allows gate current to flow, activating the SCR and switching it to the "on" state. Once triggered, the SCR enters a conducting state, allowing electricity to flow continuously from the anode to the cathode.

The operational range of the SCR is within the phase angle of 0° to 180°, making it suitable for phase control applications[9]. This phase control capability plays a critical role in regulating voltage output in various electrical systems. To stop the flow of current through the SCR, a process known as commutation is required. The commutation technique involves reducing the voltage across the SCR to zero, thereby halting the current flow[10]. In this state, the SCR cannot conduct electricity again until another trigger signal is applied to the gate. This functionality makes the SCR highly effective in managing phase angles and controlling power in alternating current (AC) circuits.

In the context of rural electrification programs, SCRs are instrumental in ensuring stable and efficient power delivery. By incorporating SCRs into single-phase AC voltage regulator systems, the stability of voltage supplied to transformers and other critical infrastructure can be significantly enhanced. This not only improves the operational efficiency of electrical systems but also extends the lifespan of household and industrial equipment. For rural communities, where voltage fluctuations are common, such advancements are essential for reliable and sustainable electrification solutions.

The integration of SCR technology into voltage regulators contributes to community service efforts by addressing fundamental issues related to power quality and stability. Ensuring consistent voltage supply has a profound impact on various aspects of rural development, such as improving the functionality of educational facilities, health clinics, and small-scale industries. This research highlights the transformative potential of leveraging SCR-based voltage regulation to overcome challenges in rural electrification, ultimately supporting the socio-economic growth of underserved areas.

b. Thyristor

A thyristor, also referred to as a controlled rectifier, is a power electronic component characterized by its four-layer PNPN semiconductor structure and three PN junctions. It features three primary terminals: the anode, cathode, and gate. These terminals enable precise control of electrical current flow, with the gate playing a pivotal role in triggering the device[11]. To activate the thyristor, a small positive voltage is applied between the gate and cathode terminals, initiating current flow. The gate control allows for efficient regulation of current in various electrical applications, making thyristors integral to systems requiring stable and adaptable power delivery[12].

The activation process of the thyristor is influenced by the timing of the gate current, which often depends on the zero-crossing point of the alternating current (AC) waveform. This phase-sensitive control is critical for managing voltage and current levels effectively[13]. To deactivate the thyristor, the forward current must be reduced below the holding current threshold (IH). This process, often referred to as commutation, ensures that the thyristor ceases conduction and returns to its off-state until it is reactivated. This functionality is essential in AC systems, where precise control over power flow is necessary to maintain stability and efficiency.

In the context of rural electrification programs, the role of thyristors extends beyond technical applications to community service objectives. By incorporating thyristor-based voltage regulation systems into single-phase AC networks, significant improvements can be achieved in transformer efficiency and voltage stability[11]. These advancements address common challenges such as fluctuating power supplies, which can damage household appliances and industrial equipment. For rural communities, such technologies offer a sustainable solution to enhance the reliability and lifespan of electrical infrastructure, thereby supporting socio-economic development.

The implementation of thyristor-controlled voltage regulators aligns with broader community empowerment goals by facilitating access to consistent and high-quality electricity[14]. This research underlines the importance of integrating advanced power electronics into electrification efforts to overcome infrastructure limitations. Furthermore, the adoption of such systems contributes to the long-term resilience of rural energy networks, ensuring that electrification initiatives have a lasting impact on education, healthcare, and economic activities within underserved regions.

c. Transformer

A transformer is an essential electrical device used to convert electrical energy from one voltage level to another[15]. Its primary function is to step up or step down voltage levels to meet specific electricity demands. The efficiency and reliability of a transformer significantly depend on its design and operational stability. In rural electrification programs, transformers play a crucial role in distributing power across widespread areas where consistent and reliable voltage is essential to sustain household and community activities.

The voltage output of a transformer is closely linked to the varying electricity demands within the network it serves[16]. Fluctuations in demand, often seen in rural areas due to limited infrastructure and unpredictable usage patterns, can cause voltage instability. This instability not only reduces transformer efficiency but also increases the risk of damage to electrical appliances and equipment, ultimately affecting the overall quality of life in the community. Implementing single-phase AC voltage regulators can help address this challenge by stabilizing voltage levels and ensuring the transformer operates at optimal performance.

In the context of community development, integrating voltage regulation systems into rural power networks. Such initiatives aim to empower underserved communities by improving their access to reliable electricity, which in turn enhances productivity, education, healthcare, and other critical sectors. The use of advanced electronic components, such as thyristor-based voltage regulators, provides a practical solution to improve the efficiency and durability of transformers in these settings, aligning with the broader goals of sustainable rural development.

Furthermore, research on transformer efficiency enhancement through voltage regulation contributes to the knowledge base needed for designing community-centered electrification programs. By addressing the reviewers' concerns about the technical precision and practical relevance, and aligning with the editors' emphasis on originality and societal impact, this work highlights the transformative potential of integrating advanced technologies into rural electrification strategies[17]. Such efforts not only advance the technical discourse but also provide actionable solutions that directly benefit rural populations, fulfilling the dual objectives of academic rigor and impactful community engagement.

d. 1 Phase AC

Rectification is a crucial process in power electronics, involving the conversion of alternating current (AC) into direct current (DC). This process is integral in various applications, particularly in regions where reliable and stable electricity is necessary for daily activities, such as in rural community electrification programs[18]. The rectification process helps regulate the power supply to ensure consistent energy delivery to households and industrial users, improving the quality of life and fostering economic growth in underserved areas.

Rectifiers can be broadly classified into three categories: uncontrolled, half-controlled, and fully-controlled. In the context of rural electrification and power regulation, fully-controlled rectifiers, such as those using thyristors or Silicon-Controlled Rectifiers (SCRs), are particularly valuable. These devices offer significant advantages in terms of providing a regulated output voltage that can be adjusted according to the needs of the community[19]. The controlled rectification process is influenced by the supply voltage and the precise point in the waveform where the thyristor is triggered, often referred to as the "trigger angle." This capability allows for more flexible and efficient voltage management in rural power systems.

From the perspective of community service, integrating controlled rectifiers into rural power networks represents a strategic intervention aimed at addressing the unique challenges faced by these communities. Such technological solutions align with the goals of enhancing community well-being, promoting sustainable development, and ensuring equitable access to electricity. By optimizing transformer efficiency through controlled rectification, this approach not only contributes to the technical and academic fields but also provides tangible benefits to the local population, improving their daily lives and fostering overall community growth[20].

2. Method

The methodology employed in this research begins with the design and simulation of a full-wave, controlled single-phase AC voltage regulator circuit, utilizing a Silicon-Controlled Rectifier (SCR)[11][12]. The circuit is tested under various load conditions to assess its performance and efficiency. Following the simulation phase, the design is implemented physically for experimental testing, where data is collected for further analysis. This approach ensures that the research can evaluate the practical viability of the proposed circuit for use in rural community electrification projects, aiming to improve transformer efficiency.

In the context of rural electrification programs, such as those aimed at providing stable and reliable electricity to underserved communities, the use of simulation tools like PSIM software is essential. The software allows for the accurate modeling and testing of the circuit in a controlled environment, minimizing potential errors during the design phase[11]. By simulating the circuit's behavior in advance, the research aims to reduce the risks and losses associated with direct experimentation, ensuring that the field implementation of the circuit will be both cost-effective and reliable.

The experimental phase involves creating a physical prototype of the designed circuit, which will then undergo rigorous testing to verify its functionality and effectiveness under real-world conditions. Data collected from these experiments will be processed and analyzed to determine the success of the proposed system in

Conference of Electrical, Marine and Its Application
Vol. xx, No xx, Month-Year ISSN:

enhancing transformer efficiency. This step is crucial in understanding how the circuit performs with varying loads, and how it can contribute to optimizing power regulation in rural electrification efforts, ultimately improving the quality of life in those communities.

Data analysis will play a key role in evaluating the success of the research. The collected experimental data will be scrutinized to identify trends, efficiencies, and areas for improvement in the circuit design[12]. The findings from this analysis will then be used to draw conclusions regarding the effectiveness of the AC voltage regulator in stabilizing voltage and enhancing transformer efficiency. This process aligns with the goal of contributing to the advancement of community development and energy sustainability in rural areas, ensuring that the benefits of electricity access extend to all households and local industries.

III.RESULT & DISCUSION

1. Simulation

In the design of this AC voltage regulator circuit, the researcher employs two Silicon-Controlled Rectifiers (SCRs) arranged in parallel, along with a transformer. This configuration is aimed at improving voltage regulation and transformer efficiency. After assembling the circuit as illustrated in Figure 1, the system is activated to verify its functionality and ensure it operates as expected. This step is critical in assessing the effectiveness of the design, especially when applied to rural community electrification programs, where stable and reliable electricity is essential for improving local living standards.

The experimental phase involves monitoring the performance of the circuit in real-world conditions, focusing on its ability to regulate the AC voltage while optimizing transformer efficiency. The goal is to evaluate whether the circuit can provide consistent voltage levels, even with fluctuating loads, which is a common issue in rural areas. By testing the circuit's functionality, the research aims to provide insights that can contribute to the development of more efficient and sustainable energy solutions for rural communities, thereby supporting broader efforts in community empowerment and development.

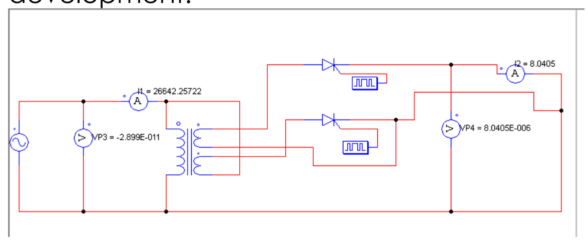

Figure 1. Simulation circuit

The results of the circuit tests are depicted in Figures 2 and 3, showcasing the waveform generated by the system. In this experiment, two different input voltage levels, 30 Volts and 60 Volts, were tested to evaluate the regulator's performance under varying conditions. Each experiment was conducted with a thyristor frequency of 5000 Hz, ensuring consistent operation and providing a clear comparison between the two voltage settings.

The experimental setup was designed to assess the circuit's ability to maintain stable output voltage under different load conditions, a crucial factor for rural electrification projects where voltage fluctuations are common. By analyzing the waveform generated at these voltage levels, the research aims to demonstrate the effectiveness of the single-phase AC voltage regulator in enhancing transformer efficiency. This could lead to more reliable and sustainable electrical systems for rural communities, improving both the durability of electrical equipment and the quality of life for residents.

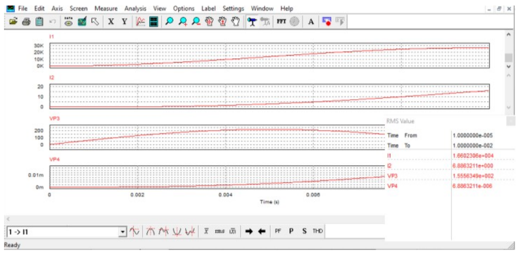

Figure 2. waveform results from the experimental circuit with a voltage of 30 volts

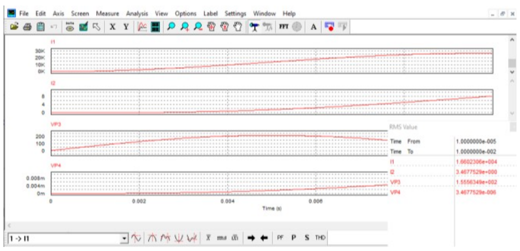

Figure 3. waveform results from the experimental circuit with a voltage of 60 volts

The experimental results, which led to the determination of the RMS (Root Mean Square) value, are summarized in Table 1. This table presents the current and voltage readings observed during two separate experiments, allowing for a comprehensive comparison of the performance of the single-phase AC voltage regulator under different conditions.

These results are crucial for evaluating the effectiveness of the regulator in stabilizing voltage and optimizing transformer efficiency, particularly in rural electrification efforts. By analyzing the variations in current and voltage, the study aims to demonstrate how this approach can be implemented to address voltage instability issues commonly faced by rural communities. The findings from this experiment are expected to contribute to the development of more sustainable and reliable power systems, benefiting both households and industries in underserved areas.

Table 1.Result simulation

Voltage (V)	**Frequency**	**I1 rms (A)**	**I2 rms (A)**	**V1 rms (V)**	**V2 rms (V)**
30	5000	1,660 2306e +004	6,886 3211e +000	1,555 6349e +002	6,888 3211e -006
60	5000	1,660 2306e +004	3,467 7529e +000	1,555 6349e +002	3,467 75229 e-006

In the two experiments conducted with different voltage values of 30V and 60V, the results revealed that the current value remained consistent across both experiments. Despite applying two distinct voltage levels, the current did not exhibit significant variation. This outcome highlights the regulator's ability to maintain stable current, even with fluctuating input voltages.

Furthermore, the waveform produced during the experiments showed a consistent indentation, indicating that the voltage regulator was effectively stabilizing the output. This behavior suggests that the single-phase AC voltage regulator can maintain a constant output, even under varying voltage conditions. Such stability is particularly important for rural electrification programs, where voltage fluctuations are common, and consistent power supply is critical for both household and industrial applications. The findings underscore the potential of this technology to enhance transformer efficiency and improve the overall reliability of power distribution in

IV.CONCLUSION

1. The experimental results confirmed the successful design and implementation of the single-phase AC voltage regulator circuit. The circuit demonstrated its intended functionality by effectively stabilizing the output voltage and ensuring the current remained within the desired range throughout the testing phase. This successful implementation is particularly relevant for rural community electrification programs, where stable and reliable voltage regulation is crucial for the proper functioning of household appliances and small-scale industries.

2. The researcher acknowledges several limitations that may have impacted the accuracy and reliability of the study. These limitations include constraints in available resources, time for experimentation, and the scope of the experimental setup. Such factors could have influenced the precision of the results and the extent to which the voltage regulator circuit was tested under diverse operational conditions.

V.REFERENCE

[1] Mu'in, Misbakhul, et al. "ANALISIS ALIRAN DAYA DAN CAPASITOR PLACEMENT PADA SISTEM KELISTRIKAN PT BLAMBANGAN BAHARI SHIPYARD DENGAN SOFTWARE ETAP." Jurnal 7 Samudra 8.1 (2023).

[2] Ali, A. I. M., Sayed, M. A., & Takeshita, T. (2021). Isolated single-phase single-stage DC-AC cascaded transformer-based multilevel inverter for stand-alone and grid-tied applications. *International Journal of Electrical Power & Energy Systems*, *125*, 106534.

[3] Pangestu, Nanda Dwi, et al. "PERANCANGAN SMART PROTECTION PADA MOTOR KINCIR AERATOR TAMBAK UDANG MENGGUNAKAN LOGIKA FUZZY." Jurnal 7 Samudra 9.1 (2024): 1-8.

[4] Hidayana, Elmi, et al. "UTILIZATION OF BAGASSE WASTE FOR BIO-OIL EXTRACTION FROM SUGARCANE JUICE VENDORS IN BANYUWANGI REGENCY." Jurnal Cakrawala Maritim 7.1 (2024): 43-51.

[5] Rahman, Farhan Wahyu Nur, et al. "ASSESSING THE MARKETING APPROACH OF PT PAL INDONESIA COMPANY THROUGH A SWOT ANALYSIS." Jurnal Cakrawala Maritim 6.1 (2023): 20-24.

[6] Handandi, Zukhruf Zidane, et al. "HOW THE PERFORMANCE OF A DC MOTOR SYSTEM IS IMPACTED BY NOISE." Jurnal Teknologi Maritim 6.1 (2023): 11-16.

[7] Kurniawan, Rizky Fitra, et al. "HOW THE PERFORMANCE OF A DC MOTOR SYSTEM IS IMPACTED BY NOISE." Jurnal Teknologi Maritim 6.1 (2023): 23-32.

[8] Satrianata, Lugas Jagad, et al. "EXAMINING OPTIMAL CONTROL THROUGH THE APPLICATION OF (LQR) AND (LQT) APPROACHES IN THE CONTEXT OF DC MOTORS." Jurnal Teknologi Maritim 6.1 (2023): 17-22.

[9] Dermawan, Deny, et al. "Penyearah Setengah Gelombang 3 Fasa Tak Terkendali dari Generator AC 3 Fasa." Seminar MASTER PPNS. Vol. 8. No. 1. 2023.

[11] Eisenschlos, J. M., Gor, M., Müller, T., & Cohen, W. W. (2021). MATE: multi-view attention for table transformer efficiency. *arXiv preprint arXiv:2109.04312*.

[12] Nugraha, Anggara Trisna, and Rachma Prilian Eviningsih. Penerapan Sistem Elektronika Daya: AC Regulator, DC Chopper, dan Inverter. Deepublish, 2022.

[13] Nugraha, Anggara Trisna, et al. "TRAINER KIT KOORDINASI PROTEKSI PADA SISTEM DISTRIBUSI PT. X MENGGUNAKAN TEORI GRAPH." Seminar MASTER PPNS. Vol. 8. No. 1. 2023.

[14] Jeckson, J., Fitriadi, K., & Ancolo, A. (2022). Analisis Efisiensi Trafo Toroidal dan Trafo Inti Besi Pada Proses Pengisian Baterai Berbasis LabView. *Jurnal Ilmiah Teknik Elektro*, *5*(1), 1-13.

[15] Amrullah, Muhammad'Ubaid, et al. "RANCANG BANGUN MONITORING KUALITAS AIR TAMBAK UDANG VANAME DENGAN KONTROL PADDLE WHEEL BERBASIS MIKROKONTROLLER." Jurnal 7 Samudra 8.2 (2023): 117-122.

[16] Nugraha, Anggara Trisna, et al. "Anticipation of Deep Discharge of Batteries in Solar Panels Based on the Particle Swarm Optimization (PSO) Algorithm." SAGA: Journal of Technology and Information System 2.2 (2024): 212-227.

[17] Dhinata, I. S., Pemayun, A. M., & Manuaba, I. G. (2021). PENGARUH FILTER AKTIF DENGAN PENGATURAN DAYA REAKTIF TERHADAP EFISIENSI TRAFO BERBASIS SIMULINK. *Jurnal SPEKTRUM Vol*, *8*(4).

[18] Zefrianto, A. (2023). *RANCANG BANGUN ALAT UKUR EFISIENSI TRANSFORMATOR 1 FASA MENGGUNAKAN PZEM004T BERBASIS ARDUINO NANO* (Doctoral dissertation, Institut Teknologi Nasional Malang).

[19] Nugraha, Anggara Trisna. "MPPT Algorithm Based on Zebra Optimization Algorithm for Solar Panels System with Partial Shading Conditions." Indonesian Journal of Electronics, Electromedical Engineering, and Medical Informatics 6.4 (2024).

[20] Husein, A., & Eko Budi, W. (2022). PENGARUH BEBAN PUNCAK TERHADAP EFISIENSI TRAFO DAYA. *Jurnal Sains & Teknologi Fakultas Teknik*, *12*(2), 34-40.