Analysis and Application of Single-Phase Controlled Rectifier in Half-Wave AC Motor Systems: Empowering Technical Education

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Abstract: *This study explores the regulation of single-phase motor rotation through various methods, including adjusting motor frequency, voltage, resistance, and increasing the number of motor poles. Utilizing a stable oscillator circuit, the frequency parameters of a single-phase motor can be controlled by modifying the variable resistor value. A thyristor-based trigger circuit is employed to manage the motor's rotational speed by adjusting the trigger phase angle, which directly influences frequency and motor speed. Simulations conducted using PSIM software demonstrate the relationship between variable resistor adjustments and changes in motor rotation frequency. These simulations analyze the rotational behavior of single-phase motors based on the transformer output voltage, providing a foundational understanding of electronic circuit functionality. By leveraging PSIM, this study minimizes potential failures in practical circuit applications, contributing to enhanced technical education and skill development. The findings have significant implications for community-based technical training programs, equipping individuals with practical knowledge in electronic motor control systems and fostering community empowerment through applied technical education.*

Keyword: *Single Phase Motor, PSIM simulation, Thyristor, Frequency*

Introduction

The single-phase half-wave controlled rectifier circuit represents the simplest form of a controlled rectifier, consisting of only one silicon-controlled rectifier (SCR)[1]. These circuits are commonly employed for DC loads that do not require high stability, such as indicator lights in electronic systems. In single-phase half-wave rectifiers, the mismatch between the power supply and load requirements can be addressed through power conversion techniques[2]. By utilizing a thyristor, the output voltage can be controlled by triggering at specific angles during both the positive and negative half-cycles, with the thyristor functioning as an open circuit during the negative half-cycle[3].

The thyristor, a critical semiconductor power device, finds extensive application in converter circuits, controlled rectifiers, and AC voltage controllers. It plays a pivotal role in industrial applications, such as controlling AC motor drives, DC motor drives, and heaters. The operational mechanism of the thyristor involves adjusting the firing angle, which determines the time from when the input voltage becomes positive until the thyristor is activated, thereby enabling the regulation of output voltage according to specific requirements[4].

This study focuses on analyzing the performance of single-phase induction motors (commonly referred to as AC motors), which are widely utilized in industrial applications. Single-phase motors are preferred due to their relatively low cost, robust construction, favorable operational characteristics, and ease of maintenance. Despite these advantages, single-phase motors exhibit certain limitations, such as a high starting current ranging between three to five times the nominal current and a relatively constant rotation speed, making them challenging to regulate. However, the rotation of single-phase motors can be adjusted to match the desired load by modifying parameters such as frequency, torque, or stator voltage. Achieving stable motor rotation often involves the control of frequency parameters.

Single-phase induction motors typically consist of two coils: the main coil and the auxiliary coil, which are designed with different specifications to optimize motor performance. These motors can be effectively simulated using software like Power Simulator (PSIM)[5]. PSIM is a versatile tool for simulating electrical power circuits and analyzing the operational characteristics of designed systems. It enables visualization of results in the form of voltage, current, motor rotation speed, and torque graphs, providing critical insights into motor rotation settings and their impact[6].

The application of PSIM not only aids in identifying and mitigating potential errors in actual circuit implementation but also serves as a valuable resource for technical education and training programs[7]. By utilizing such simulation tools, this research contributes to community empowerment through the dissemination of practical knowledge in electrical engineering. It aligns with community engagement goals by enabling individuals to acquire technical skills in motor control systems, fostering their capacity to address real-world challenges in industrial and educational settings.

Methodology

1. Rectifier

An apparatus or circuit known as a rectifier is used to convert voltage from an alternating current (AC) source to a direct current (DC) source signal[8]. Only using a CRO (Cathode Ray Oscilloscope) measuring device can one see AC waves as sine waves and DC waves as steady state waves[9]. Many step-down transformers are employed in the rectifier circuit to lower the voltage in accordance with the transformer transformation ratio.

a. Half wave Rectifier

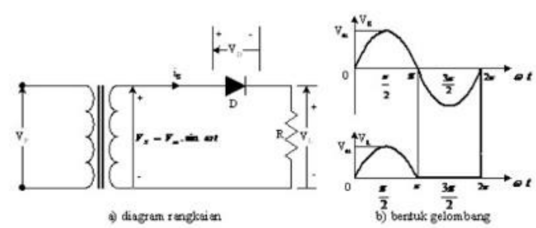

Figure 1. half wave rectifier

The most basic kind of rectifier is the half wave rectifier. This is due to the fact that this circuit only passes the positive signal and blocks the negative signal from the AC signal using a single diode[10].

b. Full wave Rectifier

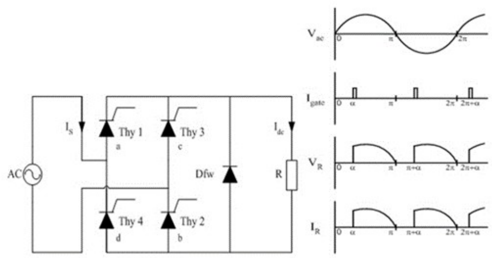

Figure 2. full wave rectifier

There are two methods for creating a full wave rectifier[11]. There are two methods: employing two diodes or four diodes. A CT transformer is required in a full wave rectifier circuit with two diodes. However, a CT transformer is not required for the full wave rectifier with four diodes[12].

Because it performs better than other types of rectifiers, the 4-diode full-wave rectifier also known as a full-wave bridge rectifier is the type of rectifier most frequently seen in power supply circuits.

2. Single Phase Half Wave Rectifier

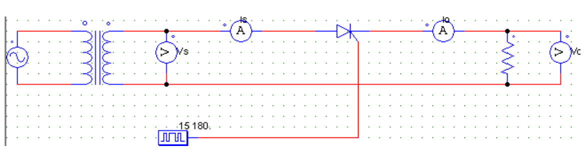

Figure 3. Single phase half wave rectifier

With just one silicon-controlled rectifier, the single-phase half-wave controlled rectifier circuit is the most basic type of controlled rectifier circuit[13]. Circuits with half-wave rectifiers are typically utilized for DC loads that don't need to be very stable, such electronic circuit indication lights. Utilize the disparity between the power supply and load needs in a single phase half wave rectifier, provided that a power converter is present. The thyristor functions as an opening in the negative half cycle and may be triggered at any angle in both the positive and negative half cycles to provide a programmable output voltage[14].

3. Thyristor

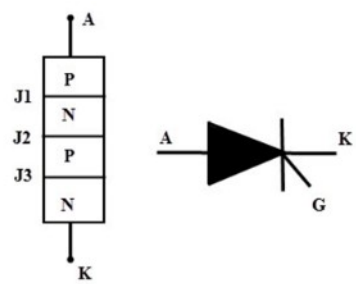

Figure 4. Thyristor

An electrical device with three pn-junctions and four layers of pnpn semiconductors is called a thyristor. As seen in the image, a thyristor has three legs, or terminals: the anode, cathode, and gate. Furthermore, because the thyristor contains a gate to regulate the current in a circuit, it is also known as a controlled rectifier.[11]

4. SCR (Silicon Controlled Rectifier)

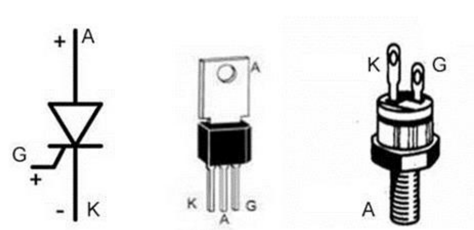

Figure 5. Silicon Controlled Rectifier

Silicon Controlled Rectifier (SCR) is a type of thyristor whose working principle is similar to a diode but is equipped with a gate to regulate the amount of phase that is carried out. SCR is a semiconductor component formed with a four-layer pnpn (positive-negative-positive-negative) structure with three pn junction layers[15]. SCR has three terminals anode, cathode and gate.

The method used in the SCR is triggering through the gate (giving gate current) which is done by giving only a small voltage to the cathode gate, then the gate current can flow and make the SCR condition on. The working area of the SCR is 0o – 180o (general nature of the diode), so only in that area phase control can be done[16].
If the SCR has been triggered, then the SCR is in a state of conducting electric current[17]. To adjust the phase or stop the electric current, a commutation method is needed, which is to try to keep the voltage on the SCR at zero, so that the current does not flow[18]. At that time it can be ascertained that the SCR is in a condition unable to conduct electric current from the diode to the cathode until the trigger is re-entered.[13]

5. Motor AC 1 phase

Figure 6. Motor ac 1 phase

Motor is defined as a device that can convert electrical energy into mechanical energy or can be in the form of torque due to the current flowing in the armature winding. [8] Single-phase AC motors can be regulated by changing the frequency, torque, or stator voltage[19]. In addition, the I-phase AC motor has a weakness in the form of a large starting current of about 3 to 5 times, while the nominal current and rotation are relatively constant or difficult to regulate[20].

6. Software usage

In this simulation of a single-phase half-wave controlled rectifier circuit using PSIM software. Where PSIM is one of the software used to simulate an electronic circuit. PSIM consists of a schematic program PSIM (PSIM schematic), a simulation engine (PSIM simulator), and a waveform processing program (SIMVIEW).[12]

a. Block diagram

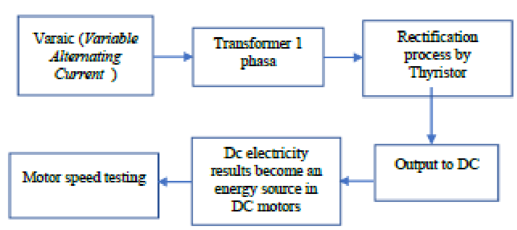

Figure 7. Block diagram

b. Simulation design

In the circuit described, a variac serves as a voltage source providing 220V AC. This voltage is then reduced using a single-phase transformer to 25V, and the output is connected in parallel. The step-down transformer ensures that the voltage is brought to a level suitable for the next stage of the circuit.

Once the voltage is lowered, it is converted or rectified into DC voltage using a thyristor (SCR). The SCR functions as a key component in the rectification process, enabling the transformation of AC to DC by controlling the conduction angle or phase. The harmonic analyzer is then used to adjust the angle as required, allowing precise control over the voltage characteristics.

Finally, the rectified and adjusted voltage flows to the load. This sequence of operations ensures that the desired DC voltage, regulated by the SCR and harmonic analyzer, is delivered to the connected load for its intended application.

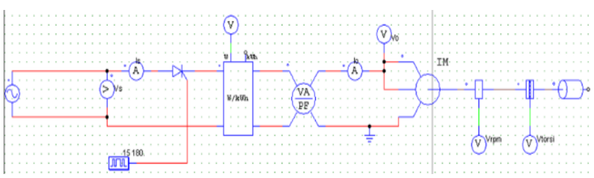

Figure 8. Circuit design

Results and Discussions

Table 1. Result

Vo (rms) [V]	∝	Io (dc) [A]	Vo (dc) [V]	Vo (rms) [V]	Rpm	Torque
25	15	79,42	49,86	120,25	6,95e - 005	0,70
25	30	74,35	46,71	118,71	3,66e - 006	1
25	45	66,53	41,74	114,98	9,47e - 005	1
25	60	56,64	35,56	108,53	1,67e - 004	1
25	75	45,52	28,62	99,16	2,10e - 004	1
25	90	34,10	21,36	86,89	1,68e - 004	1
25	100	26,78	16,86	77,48	2,38e - 004	1

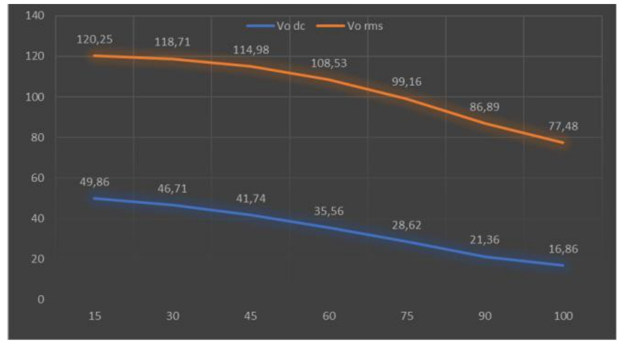

Figure 9. Comparation Vo(dc) and Vo(rms) with eagle

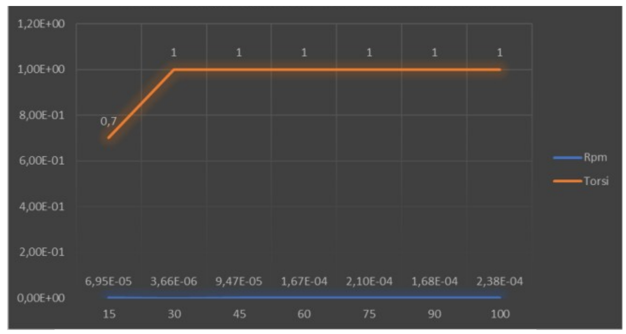

Figure 10. Comparation RPM with torque

Testing the controlled circuit of a single-phase half-wave rectifier was performed using a single-phase AC motor load with an input voltage of 220V. The analysis of the data presented in the tables and graphs reveals that the output voltage decreases as the alpha (α) angle increases. Similarly, the output current (amperage) also declines progressively with an increase in the α value.

The table provides detailed variations in the output voltage (V) and current (A) under different conditions. For the single-phase AC motor load, characterized by torque and rpm, an increase in the α value at the thyristor gate leads to higher output values of rpm and torque. Notably, while the rpm increases, the torque for the single-phase AC motor remains constant at a value of 1.

The accompanying graph offers a visual representation of these trends, further validating the data shown in the table. It clearly illustrates how the output voltage and current decrease with rising α values and how the rpm output increases proportionally to the adjustments made at the thyristor gate.

This analysis demonstrates the impact of the α angle on the performance of the circuit, emphasizing its role in controlling output voltage, current, and motor parameters such as rpm and torque. This information is critical for optimizing the operation of single-phase half-wave rectifiers in various applications.

Conclusion

Based on the comprehensive analysis and results of simulation experiments conducted using PSIM software, it can be concluded that the single-phase half-wave controlled rectifier circuit is a feasible and effective solution for regulating output voltage and current. This circuit allows precise control of electrical parameters, which directly impacts the performance of single-phase AC motor systems.

Furthermore, the application of this circuit demonstrates the potential to determine and optimize the operational output of single-phase AC motor loads. By adjusting the firing angle of the thyristor within the rectifier circuit, the motor's performance can be tailored to meet specific load requirements, ensuring both efficiency and adaptability.

This study highlights the significant role of controlled rectifier circuits in technical education and training programs. By integrating PSIM simulations into community-based learning initiatives, participants can acquire practical skills in motor control and power electronics. This approach not only enhances technical competency but also contributes to community empowerment by addressing real-world challenges in industrial and educational contexts.

The findings from this research underscore the importance of utilizing controlled rectifier systems as both a learning tool and a practical solution in the development of sustainable and impactful community engagement programs.

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