Journal for Maritime in Community Service and Empowerment ISSN:
Vol. xx, No xx, Month-year

A Study on the Application of One-Phase Controlled Wave Rectifiers for Full Resistive Load in Community

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Abstract: *A rectifier is a vital electronic device used to convert alternating current (AC) into direct current (DC), serving critical roles in industrial applications such as Uninterruptible Power Supplies (UPS), constant voltage regulation, motor speed control, and power factor correction. Its versatility extends to supporting small-scale industries, educational institutions, and public utilities, making it a key technology for community energy solutions. This study focuses on the design and implementation of a single-phase controlled rectifier utilizing the Pulse Width Modulation (PWM) method. The PWM approach enables precise regulation of output voltage while improving power factor efficiency. Experimental analysis was conducted under two key conditions to evaluate performance: (1) maintaining a constant resistive load with varying input voltages and (2) adapting to variable resistive loads with a fixed input voltage. These tests measured the rectifier's ability to provide stable output under dynamic operational scenarios. The results indicate that the single-phase controlled rectifier employing PWM demonstrates high reliability and efficiency. It consistently maintains stable output voltages, even when subjected to fluctuations in load or input voltage. These capabilities underscore its potential as a robust energy solution for diverse applications, including renewable energy systems, microgrids, and small-scale industrial processes. By addressing energy challenges and offering dependable performance, the single-phase controlled rectifier with PWM presents an innovative tool for improving energy access in underserved areas. This technology supports sustainability goals and enhances the resilience of energy infrastructure in community-focused projects.*

Keyword: *control, rectifier, PWM*

Introduction

In the modern era, technology in the industrial sector plays a crucial role in advancing human civilization, particularly in the fields of electricity and its diverse applications. For industries today, the demand for technologies that operate automatically and efficiently in controlling equipment has become indispensable. These advancements are particularly relevant in addressing challenges faced by underserved communities, where efficient energy solutions are often lacking[1].

Rectifier technology, which is widely utilized in various industrial applications, holds significant potential for enhancing energy accessibility in community-based projects. However, existing rectifier systems present several limitations. Traditional rectifiers rely on manual or outdated control processes, employing feedback systems to regulate output voltage automatically[2]. These systems often exhibit low efficiency, inability to improve the power factor, and limited adaptability to varied load conditions. Such shortcomings hinder their broader application in addressing community energy needs, where reliability and cost-effectiveness are paramount[3].

In response to these challenges, this research aims to develop a rectifier capable of consistently regulating output voltage automatically, ensuring optimal performance for fixed or variable resistive loads. By leveraging Pulse Width Modulation (PWM) techniques and employing MOSFET switches, this study introduces an innovative rectifier design that addresses existing inefficiencies. The proposed system is envisioned not only to advance industrial applications but also to provide scalable, efficient energy solutions for community-based projects, supporting sustainable development and improving quality of life in underserved areas[4][5].

Methodology

1. Controlled rectifier

A rectifier is an electrical device composed of power switches strategically arranged to convert alternating current (AC) voltage into direct current (DC) electricity[6]. This conversion is essential in various applications, particularly in providing reliable energy solutions for community-based projects. For effective rectifier control, the Pulse Width Modulation (PWM) technique is commonly employed[7]. This technique offers significant advantages, including the ability to regulate the conduction and cutoff times of power switches, thereby allowing precise control over the rectifier's output voltage.

The full-wave controlled rectifier configuration involves four power switches, each with a controllable ignition angle. These switches are arranged in pairs on each arm of the rectifier circuit, forming a full-bridge structure[8]. A schematic diagram of the single-phase controlled full-wave rectifier is illustrated in Figure 1, which highlights its operational components and design.

The circuit incorporates an inductor positioned on the input side of the voltage source. This inductor serves to stabilize the AC current before rectification, ensuring smoother operation and enhanced performance[10]. On the output side, a capacitor is included to function as an energy storage element and output voltage filter, ensuring a consistent and stable DC voltage. This configuration is particularly beneficial for applications in community-based energy systems, where maintaining voltage stability is critical for supporting various load conditions.

By integrating these features, the rectifier demonstrates its potential for addressing energy challenges in underserved communities, providing a sustainable and efficient solution for powering essential equipment and improving living conditions. This study aims to explore the implementation of such rectifiers in real-world scenarios, emphasizing their applicability in promoting sustainable development and enhancing the quality of life in communities.

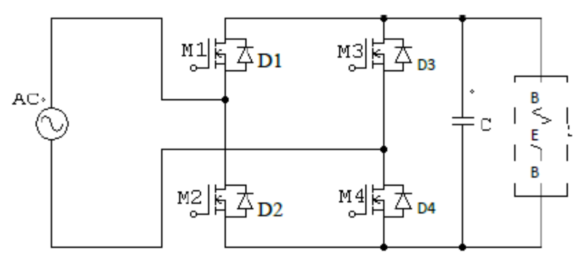

Figure 1. Full bridge single phase controlled rectifier power circuit

2. Pulse Width Modulation (PWM)

The Pulse Width Modulation (PWM) technique is employed to regulate the output voltage generated by a controlled rectifier[11]. This technique is typically implemented by comparing a control voltage, often in the form of a DC signal, with a triangular waveform voltage using a comparator circuit, as illustrated in Figure 2.

By utilizing the PWM technique, the output voltage of the controlled rectifier can be precisely adjusted to meet the desired requirements or the specific needs of the load[12]. Furthermore, by integrating a feedback system, the control circuit can automatically modify the output voltage of the controlled rectifier, ensuring consistent and reliable operation even under varying load conditions.

3. MOSFET

In full-bridge single-phase controlled rectifier power circuits, power components are selected based on the control characteristics and the specific power requirements of the application. Various power components can be used, such as transistors, thyristors, MOSFETs, and IGBTs. Among these, MOSFETs are commonly utilized due to their nature as voltage-controlled components, which require only a small input current for operation[13.

MOSFETs offer ultra-high switching speeds, with switching times in the range of nanoseconds, making them highly efficient for high-frequency applications[17]. To control the switching action of MOSFETs, a dedicated driver circuit is typically used. This driver circuit operates the MOSFET through its gate terminal, ensuring precise and reliable control of the switching process[14].

The configuration of the rectifier power circuit, as well as the connection of the driver circuits to the MOSFETs, is critical to proper operation. An example of the rectifier power circuit and its driver circuit connections is illustrated in Figure 2.

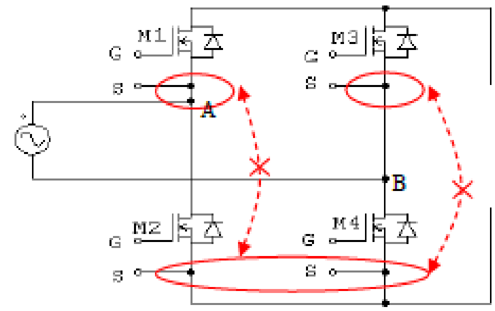

Figure 2. Single arm power circuit

4. Closed loop control system

A control system is an arrangement of physical components interconnected in a manner that allows them to command, direct, and regulate either their own operation or the operation of other systems. Alternatively, a control system can be described as a reciprocal relationship between its components, forming a unified system configuration that delivers a desired outcome[15].

A closed-loop control system is a specific type of regulatory system in which the output signal is continuously monitored and compared with a reference input.[16] This comparison influences the control action, ensuring that the system adjusts dynamically to maintain the desired performance. In essence, a closed-loop control system utilizes feedback to achieve its objectives.

5. Method

This research focuses on the design and implementation of a full-bridge single-phase controlled rectifier circuit utilizing a closed-loop control system. The methodology involves several key steps: designing and simulating the rectifier circuit, constructing the power circuit, conducting experimental tests, collecting data, and performing data analysis. The rectifier circuit, featuring a full waveform with feedback, is simulated in real-time using software such as PSIM and Electronic Workbench. These tools enable precise analysis and evaluation of the circuit's performance, ensuring that the design meets the intended operational standards[18].

The circuit testing process is broadly divided into two stages: testing the control circuit and testing the power circuit. These tests are conducted systematically to measure the input and output parameters, providing insights into the overall performance of the rectifier circuit. Testing is carried out using a resistive load under two distinct conditions: varying the rectifier input voltage while keeping the resistive load constant, and fixing the input voltage while varying the resistive load. This approach ensures a comprehensive understanding of the circuit's behavior under different operational scenarios.

The performance evaluation includes measurements of key specifications to validate the design's efficiency and reliability. The rectifier circuit is designed to produce an output voltage of 25V DC with an input voltage ranging from 15 to 20 Vrms and operating at a line frequency of 50 Hz. It incorporates a switching frequency of 15 kHz, an inductance of 5 mH, and a capacitance of 4700 μF. The power switch used in the circuit is an IRFP MOSFET, chosen for its high-speed switching capabilities and efficiency.

By integrating simulation tools, rigorous testing, and detailed performance evaluation, this research successfully demonstrates the design and functionality of the full-bridge single-phase controlled rectifier[19]. The combination of theoretical design and practical experimentation ensures that the system can deliver reliable and efficient performance, meeting the desired operational specifications under various load and input conditions[20].

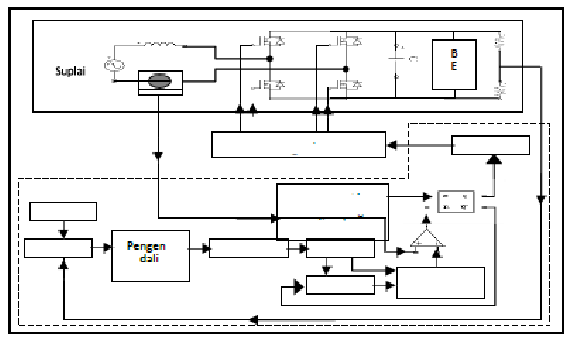

Figure 3. Block diagram of a full-wave controlled rectifier

above shows a block diagram of a full-wave phase with feed come back. It can be seen that there are three main circuit blocks, namely the control circuit block, block MOSFET driver circuit, and power circuit block. The power circuit is a circuit a switch that uses a MOSFEET as a switch.

Results and Discussions

1. Testing a controlled rectifier circuit using a resistance load under Variable rectifier input voltage, fixed load.

Table 1. Experimental data for constant load conditions (Io), input voltage (Vs) varies.

No.	Vs (Volt)	Is (A)	Vo (Volt)	Io (A)	Cos φ
1	15	4,5	25	0,45	0,98
2	17	5,2	25	0,45	0,97

3	20	5,7	25	0,45	0.97

In this condition the load is set, namely = 55 . With an input voltage of varied between 15 Vrms s / d 20 Vrms. The data from the experimental results obtained show that that the output voltage of the rectifier remains constant at 25 volts and cos also always approaches value one. The results of the entire experiment are shown in table 1.

The voltage and current waveforms for each input voltage value can be seen in Figure 4, Figure 5, Figure 6.
From the experimental data above, it shows that the average output voltage value is always constant at a value of 25 volts, as well as the value of the output current which remains at a value of 0.45 Ampere although the value of the input voltage is changed from 15 Vrms to 20 Vrms.

Figure 4. The input voltage and current waveform for the load constant for Vs = 15 Vrms

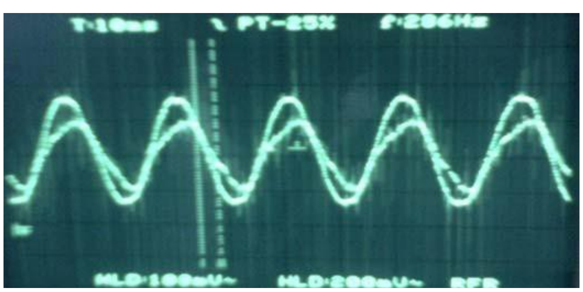

Figure 5. The input voltage and current waveforms for constant load for Vs = 17 Vrms.

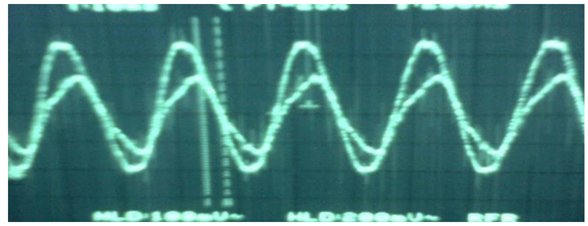

Figure 6. The waveform of the input voltage and current for constant load for Vs = 20 Vrms

From the experimental data above, it shows that the average output voltage value is always constant at a value of 25 volts, as well as the output wear value which remains at a value of 0.45 Ampere although the value of the input voltage is changed from 15 Vrms to 20 Vrms. It can also be seen that the value of The resulting power factor is always above the value of 0.97 which means the value of the power factor is always close to one. This can occur due to feedback to the control circuit and voltage

output and then compared with the reference voltage value. Likewise with the input current which is fed back so that the bias is compared with the reference current in the comparator. On the result data Experiments above the output voltage are only set at a value of 25 Volts, the maximum current capability of The AC power supply used is only 3 Ampere.

From the waveform of the input current (Is) it appears that it is always sinusoidal and follows the shape of input voltage waveform (Vs) with almost zero phase shift which means the power factor is always right close to one. There is also a small note consisting on the waveform of this current caused by the very high switching frequency of the MOSFET is 15 kHz, and also bias is caused by several factors such as the characteristics of the MOSFET, the components of the control circuit, the system grounding (grounding) in the circuit that is not so good and the connections components and circuit paths printed on the PCB are not very good because of the process the work is still done manually.

2. Testing a pressure load controlled rectifier circuit to use a resistance load

for a constant input voltage condition, the load varies In this condition the input voltage value is set to a constant value at 16 Vrms because this value is is the nominal value obtained from the experimental variable voltage and constant load, and load varied from Io = 0.4 Ampere to 0.8 Ampere. Experimental data obtained shows that the output voltage of the rectifier remains constant at 25 volts and the input current is always sinusoidal shape with the power factor is always close to the value of one. Overall result of the experiment can be seen in table 2.

Table 2. Experimental data for varying load conditions (Io), input voltage (vs) constant.

Table 2. Experimental data for varying load conditions (Io), input voltage (vs) constant.

No.	Vs (Volt)	Is (A)	Vo (Volt)	Io (A)	Cos φ
1	16	4,9	25	0,4	0,99
2	16	4,9	25	0,6	0,98
3	16	4,9	25	0,8	0.97

The input voltage and current waveforms for each output current value can be seen in figure 7, picture 8, picture 9.

From the experimental data that has been carried out, it shows that the average output voltage The rectifier can be kept constant at a value of 25 volts at the respective input voltage and current values. respectively 16 volts and 3.5 amperes even though the load value varies.

It can also be seen that the value of the power factor will always be above the value of 0.96 which means the power factor will always approach one. It can be proven that the feedback technique used in This paper is very effective at maintaining the output voltage and improving the power factor in Certain limitations. power factor whose input current will also always be above the value of 0.97 or bias is said to be nearly in phase with the input voltage.

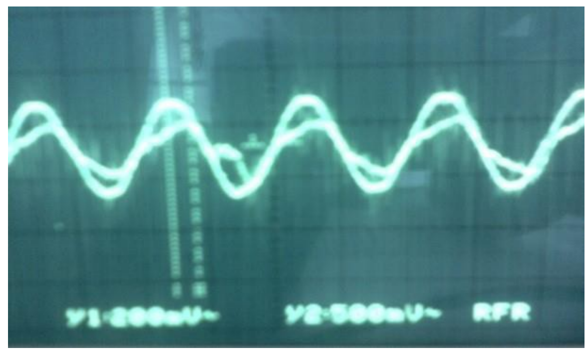

Figure 7. Waveform of input voltage and current for variable load for Io = 0.4 Ampere

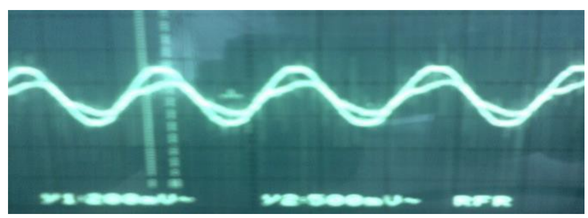

Figure 8 Input voltage and current waveforms for variable load for Io = 0.6 Ampere

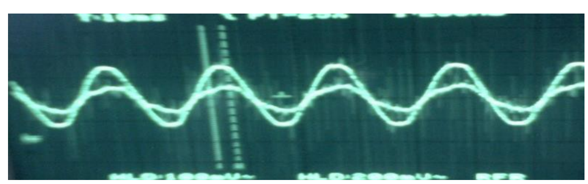

Figure 9. Waveform of input voltage and current for variable load for Io = 0.8 Ampere

Conclusion

Based on the experimental results and analysis, several conclusions can be drawn as follows:

- Output Control Capabilities: The controlled rectifier system effectively regulates the output voltage, output current, and input current in a full-wave rectifier with voltage stepper functionality. This capability allows for precise determination of desired output current values, which is particularly advantageous in ensuring reliable power delivery for diverse community applications, such as powering small-scale industries or public facilities.
- Improved Power Factor: The controlled rectifier system ensures that the sinusoidal waveform of the input current is consistently in phase with and closely matches the sinusoidal waveform of the input voltage. This synchronization results in a corrected power factor. With the application of a closed-loop control system, the output voltage remains stable and constant, even when input voltage and resistive load conditions fluctuate within specific limits. This stability is critical for maintaining reliable energy supply in community service projects, especially in rural or underserved areas.
- High Efficiency: The system consistently achieves a power factor above 0.97, indicating near-unity performance. This high efficiency minimizes energy losses, making the rectifier system highly suitable for applications in community development initiatives. For instance, it can support renewable energy systems, such as solar panel installations or microgrid networks, ensuring optimal energy utilization and sustainability.

By integrating these features, the controlled rectifier system demonstrates significant potential for use in community-based energy projects. Its ability to provide stable and efficient power under varying conditions aligns with the goals of improving access to reliable electricity and supporting socioeconomic development in underserved communities. This study highlights the importance of integrating advanced rectifier technology in community service applications, fostering sustainable growth and better quality of life.

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