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Efficiency Enhancement and Ripple Mitigation Analysis of Advanced Controlled Half-Bridge Rectifier Systems

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Abstract:

Controlled half-bridge rectifiers are widely used in AC–DC conversion applications due to their simple structure, controllable output voltage, and improved power management capability. However, conventional rectifier systems suffer from reduced efficiency and increased output voltage ripple under variable load conditions. This paper presents the analysis and performance enhancement of an advanced controlled half-bridge rectifier system focusing on efficiency improvement and ripple reduction. The proposed system employs controlled switching devices with optimized firing angle operation to achieve improved voltage regulation and reduced harmonic distortion. The mathematical analysis of the rectifier operation is carried out, and a simulation model is developed using Python to evaluate input AC voltage, gate switching pulses, output voltage, load current, and ripple characteristics. The simulation results demonstrate that controlled operation significantly improves DC output quality by reducing voltage fluctuations and enhancing conversion efficiency. The proposed architecture is suitable for industrial power supplies, battery charging systems, renewable energy interfaces, and high-performance AC–DC conversion applications.

Keywords: Controlled Rectifier, Half-Bridge Converter, Ripple Reduction, Efficiency Improvement, AC–DC Conversion, Power Electronics.

I. Introduction:

AC–DC converters are essential components in modern electrical and electronic systems, providing regulated DC power for industrial, commercial, and renewable energy applications. Among different converter topologies, controlled rectifiers offer the advantage of adjustable output voltage through controlled semiconductor switching.

A half-bridge controlled rectifier uses thyristors or power switches to regulate the energy transferred from an AC source to the DC load. The output voltage can be controlled by varying the firing angle of the switching devices. However, conventional controlled rectifiers experience limitations such as high output ripple, reduced efficiency, increased switching losses, and poor dynamic response during load variations.

To overcome these challenges, advanced control techniques are introduced to optimize switching operation and improve converter performance. This research focuses on efficiency enhancement and ripple mitigation analysis of a controlled half-bridge rectifier architecture. The performance of the proposed system is evaluated through simulation analysis of voltage waveforms, current response, and ripple characteristics.

II. Controlled Half-Bridge Rectifier Operation

A single-phase controlled half-bridge rectifier consists of:

- AC voltage source
- Two thyristors (SCRs)
- Two diodes
- DC load
- Filtering capacitor/inductor

The firing angle (α) controls the conduction period of SCR switches.
The average output voltage is expressed as:

$$V_{dc} = \frac{V_m}{\pi}(1 + \cos \alpha)$$

where:

- V_{dc}= Average DC output voltage
- V_m= Maximum AC input voltage
- α = Firing angle

By reducing the firing angle, conduction time increases, resulting in higher DC output voltage.

Efficiency Enhancement Technique
The efficiency of a controlled rectifier is improved by:
Optimized Switching Control
Proper firing pulse generation reduces unnecessary conduction losses.
Ripple Reduction Filter
An LC filter is used at the output to smooth the DC voltage.
The ripple factor is:

$$RF = \frac{V_{ac(rms)}}{V_{dc}}$$

A lower ripple factor indicates better output voltage quality.
Improved Power Semiconductor Utilization
Advanced switching reduces:

- Switching losses
- Conduction losses
- Thermal stress

III. Mathematical Analysis

The output voltage waveform depends on the firing angle.
For a controlled rectifier:

$$V_o = V_m sin(\omega t)$$

during conduction intervals.
The output current for resistive load is:

$$I_o = \frac{V_o}{R}$$

The converter efficiency is calculated as:

$$\eta = \frac{P_{out}}{P_{input}} \times 100$$

where:

$$P_{out} = V_{dc} I_{dc}$$

IV. Simulation Results

This present system is simulated and the resulta are displayed below.

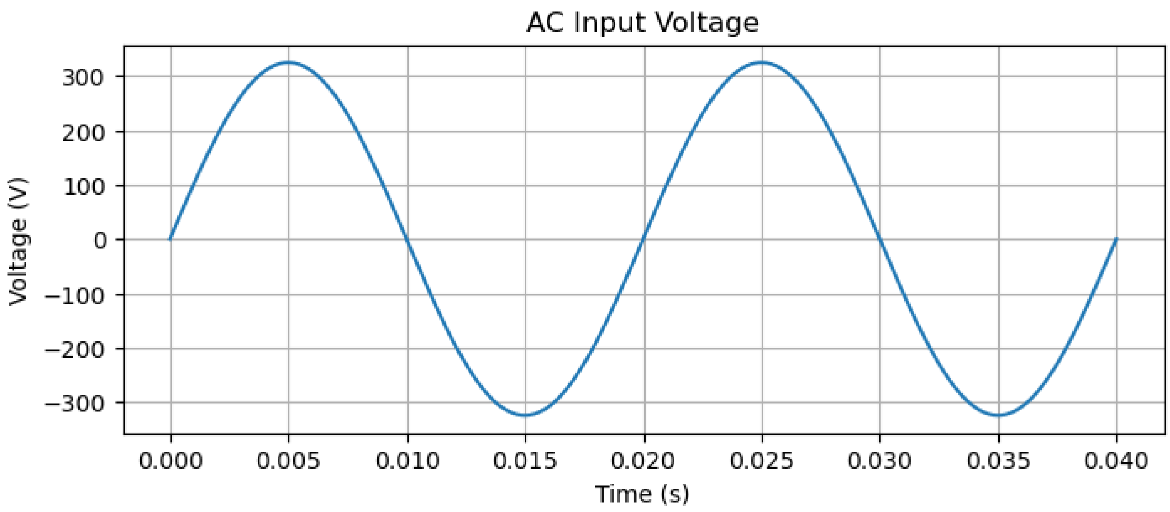

Fig.1 Input Voltage

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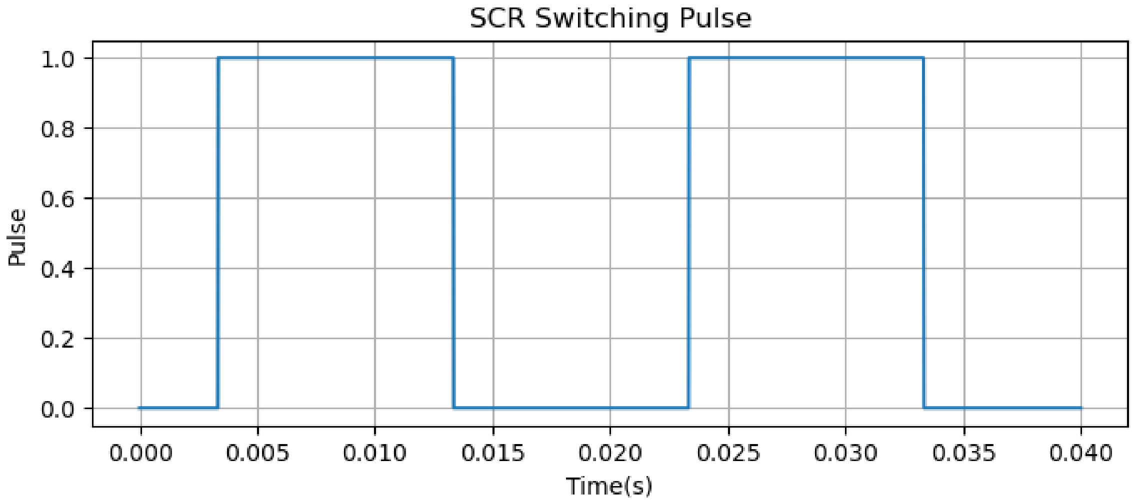

Fig.2 Switching Pulse

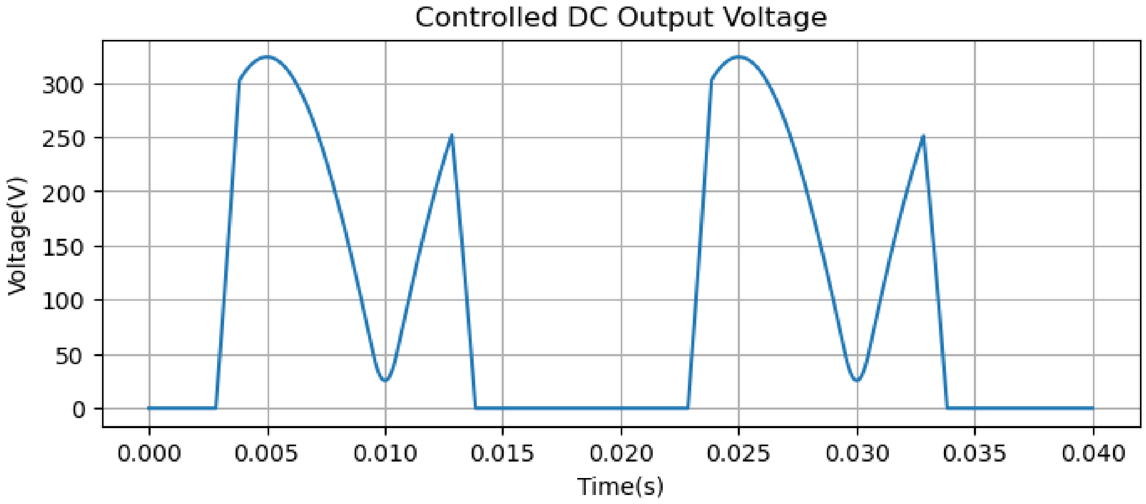

Fig.3 Controlled DC Output Voltage

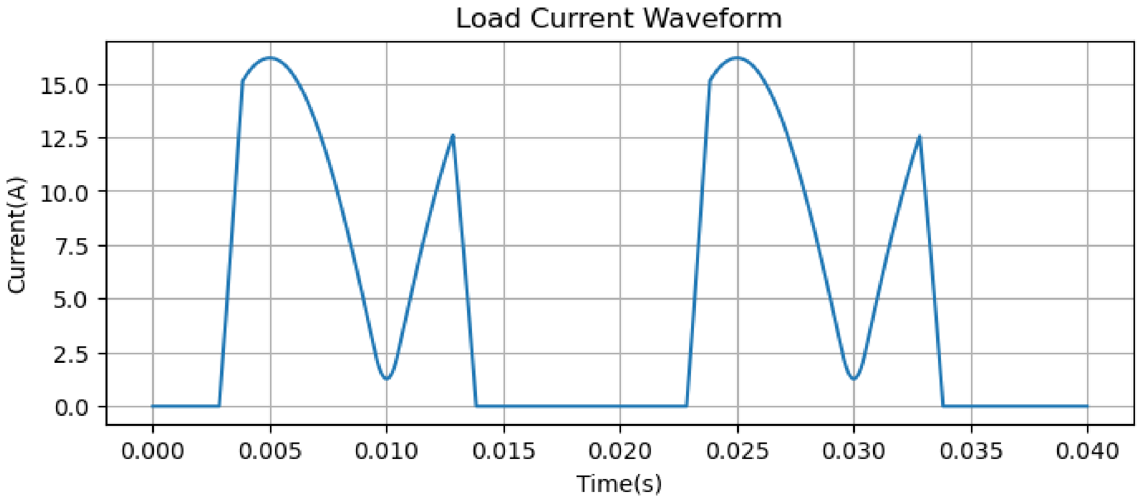

Fig.4 Load Current

Performance Analysis

Parameter	Conventional Rectifier	Controlled Improved Rectifier
Voltage Regulation	Moderate	High
Ripple Content	High	Reduced
Efficiency	Lower	Improved
Dynamic Response	Slow	Faster
Output Quality	Poor	Enhanced

The controlled half-bridge rectifier provides better power conversion performance by optimizing switching operation and reducing output ripple.

Conclusion:

This paper presents the efficiency enhancement and ripple mitigation analysis of an advanced controlled half-bridge rectifier system. The proposed converter utilizes controlled switching operation and filtering techniques to improve DC output performance. A Python-based simulation model was developed to analyze input voltage, switching pulses, output voltage, and load current waveforms. The results confirm that optimized control operation improves voltage regulation, reduces output ripple, and enhances overall conversion efficiency. The proposed rectifier architecture is suitable for high-performance AC–DC conversion applications including industrial power supplies, battery chargers, renewable energy systems, and electric vehicle charging infrastructure.

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