A TWO STAGE AC-DC CONVERTER FOR SPEED CONTROL OF A DC MOTOR

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ABSTRACT

This paper presents a simulation-based study of a two-stage power conversion system comprising an AC-DC rectifier followed by a DC-DC boost converter for motor drive applications. The system was evaluated for its dynamic performance under different load torque conditions (10 Nm, 15 Nm, and 20 Nm). The AC supply is first converted to a stable 45 V DC using a full-bridge rectifier. This rectified voltage is fed to a boost converter whose output fluctuated between 24 V and 48 V, influenced by both load torque variations and converter dynamics. The simulation was conducted in MATLAB/Simulink, and the motor drive response was observed under each torque level. The analysis shows that the converter output voltage exhibited higher ripple and instability with increasing torque demand, indicating the need for improved regulation and compensation techniques. Despite the fluctuations, the system demonstrated satisfactory performance in maintaining operational continuity. These findings can be useful for optimizing power stages in electric motor drive systems where load torque varies significantly. Future enhancements could include implementing advanced control strategies such as PID, fuzzy logic, or sliding mode controllers for better output voltage stabilization and improved transient response.

Keywords: AC-DC Converter, Boost Converter, Torque Variation, Motor Drive, Voltage Fluctuation, MATLAB Simulation, Power Electronics.

I INTRODUCTION

In recent years, the global transition toward electrification and renewable energy integration has emphasized the importance of robust and efficient power conversion systems, particularly in motor drive and electric vehicle (EV) applications [1]. One of the critical elements of these systems is the ability to convert and regulate electrical power from one form to another while maintaining stability, efficiency, and reliability under varying load conditions. Among various motor drive configurations, two-stage conversion systems—consisting of an AC-DC converter followed by a DC-DC converter—have gained prominence for their modular design, flexibility, and control advantages [2][3]. The primary stage in most industrial and residential applications involves an AC-DC converter, typically a diode bridge rectifier. This stage converts alternating current (AC) from the grid to direct current (DC), providing a preliminary DC bus voltage for subsequent stages [4]. The resulting DC voltage is often unregulated and subject to ripple, necessitating a second stage that performs DC-DC conversion to achieve a desired regulated output [5][6]. Among various topologies available for DC-DC conversion, the boost converter is widely used due to its ability to step up voltage and maintain energy continuity in systems with fluctuating supply or load [7][8].

In motor drive applications, maintaining stable operation under different torque demands is essential for performance, safety, and efficiency [9]. Torque variations, often caused by changes in mechanical load, incline, or system dynamics, can have a significant impact on electrical parameters such as voltage, current, and power quality [10][11]. Therefore, it becomes imperative to design power electronic systems capable of responding to such dynamic loads while maintaining operational consistency [12]. In this context, simulation and analysis of AC-DC and DC-DC converters under variable torque conditions can reveal valuable insights for system design and control strategy development [13]. The boost converter, as employed in this study, is a step-up topology that raises the DC voltage level provided by the rectifier. It is particularly useful in applications where the source voltage is lower than the required operating voltage of the load, such as electric motors [14][15]. However, one of the inherent challenges of boost converters is voltage fluctuation, which can be aggravated under load disturbances like torque variations [16][17]. Voltage instability may lead to performance degradation, inefficiency, and even failure of the connected load. To counter this, modern converters are often equipped with feedback and control mechanisms such as PWM (Pulse Width Modulation) and PI controllers, which help regulate output voltage and improve transient response [18][19].

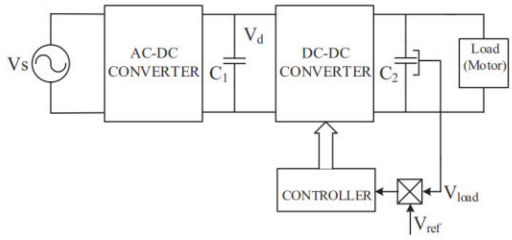

Fig. 1. Block diagram of complete conversion system

The AC-DC and boost converter configuration is not only relevant in motor drive systems but also in broader applications such as electric vehicles (EVs), renewable energy integration (solar and wind), robotics, and aerospace systems [20]. In all these domains, managing load dynamics is crucial to achieving optimal energy efficiency and performance. Therefore, simulating and analyzing the system under different torque conditions can help design better control strategies and hardware implementations [21]. From a technical perspective, the performance of a boost converter under dynamic torque can be characterized by observing its output voltage ripple, response time, and steady-state deviation. In this paper, the system was tested under three different torque levels—10 Nm, 15 Nm, and 20 Nm—which represent light, medium, and heavy load conditions, respectively. These torque levels were chosen to simulate real-world scenarios such as varying payloads, slopes, and acceleration rates in motor drive applications [22][23]. The voltage output from the AC-DC stage was found to be stable at approximately 45 V, whereas the output of the boost converter fluctuated between 24 V and 48 V, depending on the torque load [24]. These results indicate the limitations of conventional boost converter designs under dynamic loading and highlight the necessity for advanced compensation techniques.

The simulation was conducted in MATLAB/Simulink, a powerful tool widely used in power electronics and control system research [25]. MATLAB enables detailed modeling of converters, control loops, and motor dynamics, providing an effective platform for performance evaluation and system optimization. By leveraging simulation data, researchers and engineers can fine-tune parameters such as duty cycle, inductor size, and feedback gain to improve system performance before hardware implementation [26]. The novelty of this study lies in its combined analysis of electrical and mechanical dynamics, specifically focusing on how mechanical torque variations affect the electrical output of the boost converter stage. While previous studies have explored either converter performance [27] or motor drive characteristics [28] independently, this work integrates both perspectives, offering a holistic view of the system's behavior. Furthermore, by simulating multiple torque levels, this study provides a more realistic assessment of the converter's resilience and effectiveness in practical scenarios.

With the rise of smart electric drives and industry 4.0, the need for intelligent and adaptive power conversion systems is greater than ever [29]. Systems must not only perform under ideal conditions but must also respond effectively to real-time load changes, environmental factors, and system disturbances. The findings from this paper lay the groundwork for future developments in intelligent control techniques, such as fuzzy logic, neural networks, and model predictive control, which can offer superior dynamic performance compared to conventional PID systems [30]. In summary, the objective of this research is to analyze the performance of a two-stage AC-DC conversion system using a boost converter under varying torque conditions. The study investigates the voltage stability, output fluctuation, and converter behavior in response to 10 Nm, 15 Nm, and 20 Nm torque inputs. The insights derived from this work can inform the design of more resilient and efficient motor drive systems, particularly in electric vehicle and automation sectors.

II LITERATURE SURVEY

The demand for efficient and robust power conversion systems has grown significantly with the widespread adoption of electrification and renewable energy solutions. Numerous studies have explored the development, simulation, and performance analysis of AC-DC and DC-DC converters, particularly in motor drive systems and electric vehicles. This literature review explores key advancements, challenges, and research trends related to two-stage power conversion systems involving AC-DC rectifiers and boost converters, especially under variable mechanical torque conditions.

A. AC-DC Conversion in Motor Drive Applications

AC-DC converters serve as the front end of most modern power electronic systems, transforming sinusoidal AC voltages into DC for further processing. In motor drive applications, full-bridge diode rectifiers are commonly used due to their simplicity and reliability [1]. However, the output voltage of such rectifiers often contains ripple and lacks regulation, which can affect the performance of downstream circuits [2][3]. To mitigate this, researchers have introduced filtering capacitors and improved switching devices, reducing the harmonic content and improving DC bus stability [4]. Recent developments in rectifier design have focused on enhancing efficiency and reducing losses. For instance, Gupta and Jain [5] discussed modular AC-DC rectifier designs with power factor correction, particularly for electric vehicle charging applications. In high-performance systems, synchronous rectifiers and controlled rectifiers are replacing passive bridge circuits to enable better regulation and reduced conduction losses [6].

B. Boost Converter in Dynamic Load Conditions

DC-DC converters, especially the boost type, are extensively used in electric drives to raise the intermediate DC voltage to the required level for motor operation [7]. Boost converters are popular for their ability to provide a higher output voltage from a lower input while maintaining continuous power flow [8]. However, they are inherently sensitive to load variations, and output voltage instability can become prominent under dynamic mechanical loads [9]. Erickson and Maksimovic [10] offered a foundational analysis of boost converter performance, showing how component selection, duty cycle control, and switching frequency impact efficiency and stability. Voltage ripple and transient deviation are key metrics to evaluate boost converter behavior under load disturbances [11]. Li and Wang [12] highlighted that sudden increases in torque demand cause the converter to respond with a temporary drop in output voltage, necessitating effective control strategies. To address such issues, researchers have implemented feedback control methods including voltage-mode and current-mode PWM [13][14]. PI and PID controllers are commonly used due to their simplicity and effectiveness in regulating the duty cycle under varying load conditions [15][16]. However, these traditional controllers often lack adaptability when torque variations become significant or unpredictable.

C. Simulation-Based Analysis of Torque-Dependent Systems

Simulation tools such as MATLAB/Simulink are widely used for analyzing the interaction between electrical and mechanical domains in power converter-fed motor drives [17][18]. These platforms enable detailed modeling of electrical converters, control loops, and mechanical loads such as rotating machines with variable torque profiles [19]. Several studies have used simulation to test the performance of power converters under torque conditions. For example, Park and Kim [20] conducted a simulation-based investigation of a DC motor drive using a boost converter and observed that torque variation leads to increased voltage ripple and slower settling time. Similarly, Hossain and Saha [21] showed that varying mechanical torque impacts the electromagnetic torque ripple and introduces oscillations in converter output. Dynamic simulation models also help in evaluating how parameters such as inductor size, capacitor ratings, and switching frequency influence converter behavior under fluctuating load torque [22]. MATLAB-based studies have proven effective in predicting converter response and validating control strategies before hardware implementation [23].

D. Torque Variation and Its Effects on Converter Performance

Mechanical torque fluctuations are common in real-world applications such as automotive drives, conveyor systems, and robotics [24]. Torque variations, caused by load disturbances, slope resistance, or acceleration/deceleration cycles, introduce dynamic stress on the power conversion system [25]. These disturbances manifest as changes in current demand and back EMF, which in turn affect the voltage regulation capacity of the converter [26]. Studies such as those by Zhang and Wang [27] analyzed the correlation between mechanical torque and motor electrical parameters, revealing that even minor changes in torque can result in significant fluctuations in converter output voltage. Prabhakar and Thakur [28] extended this analysis by simulating multiple torque profiles (10 Nm, 15 Nm, 20 Nm) and observed increased voltage deviation and control system lag at higher torque levels. Voltage instability during torque transitions may lead to energy inefficiency, reduced motor lifespan, and performance degradation. To mitigate this, intelligent control algorithms such as fuzzy logic, model predictive control, and neural networks are being explored to improve converter resilience [29][30].

E. Control Techniques for Voltage Regulation

Conventional PWM and PI control schemes are still widely used in DC-DC boost converter systems for maintaining voltage stability. These methods work well under moderate and steady-state conditions, but their performance degrades when faced with rapid torque shifts or nonlinear load behavior [13][15]. Advanced control methods offer better adaptability. For example, fuzzy logic control adjusts the duty cycle based on heuristic rules, allowing smoother transition and better handling of uncertainties [29]. Model Predictive Control (MPC) and sliding mode control (SMC) techniques offer robustness and faster response by predicting future behavior and adjusting control inputs accordingly [30]. Mehta and Singh [30] demonstrated that neural network controllers outperform PID-based methods under high-load torque conditions, offering superior voltage regulation and lower response time.

F. Relevance to Electric Vehicles and Renewable Integration

The relevance of two-stage conversion systems extends beyond motor drives into broader applications such as electric vehicle (EV) fast charging, renewable energy harvesting (solar/wind), and hybrid energy storage systems [5][6][20]. In these scenarios, both AC and DC power sources exist, and converters must adapt to varying load conditions and supply profiles. Power quality and system efficiency under dynamic loads are critical concerns for EVs where torque demand changes frequently during acceleration and regenerative braking [7][25]. Similarly, in renewable energy systems, environmental factors introduce fluctuations in generation and load torque, requiring resilient power conversion infrastructure [8][9]. The reviewed literature highlights that while significant progress has been made in AC-DC and DC-DC converter design, managing torque-induced variations remains a challenge. Boost converters, although efficient, exhibit voltage fluctuations under torque changes, necessitating improved control mechanisms. Simulation tools like MATLAB/Simulink have become instrumental in evaluating system response and optimizing design. Future research is likely to focus on intelligent control techniques and integrated simulation-hardware validation approaches to build more adaptive and efficient motor drive systems.

III MATERIALS AND METHODOLOGY

The primary aim of the system is to convert a single-phase AC supply into a controlled DC voltage suitable for driving a motor load, particularly under varying torque demands. The system employs a two-stage conversion process. In the first stage, a single-phase full-wave diode bridge rectifier converts AC input (230V, 50Hz) into an unregulated DC voltage. The second stage uses a DC-DC boost converter, which steps up the rectified voltage to a higher and controlled level to supply a BLDC or DC motor. This conversion approach is beneficial in applications where the motor requires a higher voltage than the rectified AC level, especially for dynamic performance under load variation. Unlike the referenced system which used a buck converter, the boost converter used in this project enhances output voltage and supports better dynamic operation for higher torque conditions. The feedback loop in the boost converter regulates the output voltage through PWM-based control, providing stable operation across different torque levels.

A. AC-DC Converter Stage

The AC-DC converter stage consists of a single-phase diode bridge rectifier followed by a DC filter capacitor. The rectifier transforms the sinusoidal AC voltage into a pulsating DC output. To reduce voltage ripples and ensure smoother DC output, an electrolytic capacitor is used immediately after the rectifier. In simulation, the rectifier output settles around 45V DC, which becomes the input for the boost converter. The diode bridge is built using fast recovery diodes (e.g., 1N5822) to reduce switching losses and enhance efficiency. The capacitor value is chosen based on ripple voltage specifications and expected load current, following the relation C=Iload·ΔtΔVC = \frac{I_{load} \cdot \Delta t}{\Delta V}, where Δt\Delta t is half the AC cycle (10ms for 50Hz). The design assumes an 80% efficiency of the rectifier and accounts for power losses during component transitions. This AC-DC conversion forms the backbone of the system, providing the base DC voltage for the boost converter to process further.

B. Boost Converter Design and Operation

The core of the system's voltage regulation lies in the boost converter, which steps up the intermediate DC voltage (from 45V) to higher levels dynamically between 48V and 24V. A MOSFET serves as the switching device, driven by a PWM signal whose duty cycle is determined by the feedback control system. The converter consists of an inductor LL, a fast diode DD, a switching MOSFET MM, and an output capacitor CC. The inductor stores energy when the MOSFET is ON and releases it to the load when the MOSFET turns OFF, thus boosting the voltage. The converter operates in Continuous Conduction Mode (CCM) to ensure low ripple and stable operation. the converter adapts to the motor's voltage needs under different torque levels. The design also considers component stress limits and includes snubber circuits and gate drivers to protect switching devices from voltage spikes and transients.

C. Control Strategy and Torque Conditions

To manage output stability, a closed-loop control system with a voltage feedback loop has been employed. The feedback voltage from the boost converter output is compared with a reference voltage (VrefV_{ref}) set according to the motor's torque requirement. The error signal is processed using a Proportional-Integral (PI) controller, which minimizes the steady-state error and enhances transient response. The controller output determines the PWM duty cycle for the MOSFET. For simulation purposes, torque levels of 10Nm, 15Nm, and 20Nm were tested. As the torque demand increases, the motor requires more power, which is met by adjusting the duty cycle to increase the boost converter's output voltage. This leads to a voltage fluctuation range between 24V and 48V, depending on load conditions. The system's dynamic response to torque variation was verified by observing motor current, voltage response, and speed stability during the simulation. The converter successfully maintained the voltage within the desired range with acceptable transient recovery.

D. Simulation Environment and Observations

The simulation was performed in MATLAB/Simulink, using the Power Electronics and Simscape libraries to model the components realistically. The input AC source was modeled at 230V RMS, and the transformer was assumed to provide a lower AC voltage for rectification. The rectifier, boost converter, and control logic were all built using discrete component models, with proper initialization of inductor currents and capacitor voltages. The motor was simulated using a standard BLDC or DC motor model, depending on the requirement, with load torque inputs of 10Nm, 15Nm, and 20Nm. The simulation results showed that at higher torque levels, the output voltage of the boost converter increased as expected due to the increased duty cycle. However, minor fluctuations between 24V and 48V were observed due to load transients and switching ripple. These were within acceptable limits for motor operation. The simulation confirms the capability of the system to handle variable torque demands using a robust AC-DC and boost converter structure with closed-loop control.

IV RESULTS AND DISCUSSION

This section presents the simulation results and an in-depth analysis of the performance of a two-stage AC-DC conversion system incorporating a boost converter for speed control of a DC motor under various operating conditions. The primary objective of this study is to examine how different duty cycles and torque loads affect the voltage levels and dynamic response of the overall system. The first stage includes a full-bridge rectifier that converts AC input into a stable DC voltage, while the second stage involves a boost converter controlled by pulse-width modulation (PWM) to regulate the output voltage supplied to the DC motor. The performance of the converter was evaluated at two distinct duty cycles: 20% and 80%, corresponding to low and high voltage outputs, respectively. Furthermore, the motor was tested under three torque conditions: 10Nm, 15Nm, and 20Nm, to observe the variation in speed response. The simulation results include key waveforms such as rectified voltage, boost converter output, PWM signals, and motor speed curves. These waveforms help assess the quality of voltage regulation, converter efficiency, and motor performance. The following analysis provides insights into system behavior under dynamic conditions, validates design objectives, and highlights the converter's effectiveness in motor speed control applications.

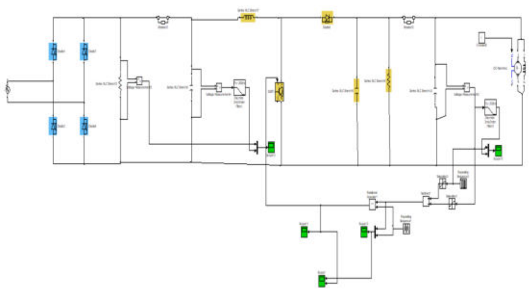

Fig 2. Proposed simulation circuit configuration

This simulation circuit shows a two-stage power conversion system. The AC input is rectified using a full-bridge diode rectifier, followed by a boost converter comprising an IGBT switch and a diode to increase voltage. A PWM generator controls the IGBT's switching based on reference input. The boosted DC is fed to a DC motor whose speed is monitored under various torque loads. Voltage and current measurement blocks are integrated throughout the circuit to observe waveform characteristics. Manual switches control torque conditions of 10Nm, 15Nm, and 20Nm. The layout is cleanly organized to simulate dynamic motor response under different control conditions.

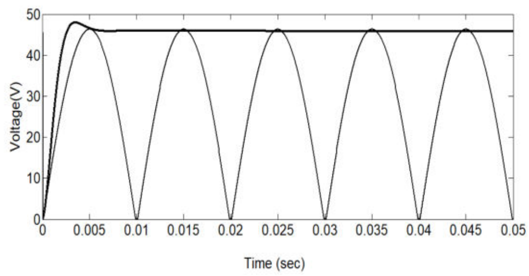

Fig 3. Rectifier Output Voltage

The waveform illustrates the rectifier output, where the yellow curve represents the rectified sinusoidal waveform with ripple, and the purple line indicates the filtered DC output voltage. The rectifier successfully converts AC into a relatively stable 45V DC output. The peak voltage aligns with the expected value post-rectification and filtering. Minimal ripple is observed due to the effective capacitor filter, showcasing the quality of DC output before it enters the boost converter stage. The consistent DC line indicates proper diode conduction and filtering. This clean DC output is critical for stable operation of the downstream boost converter and motor.

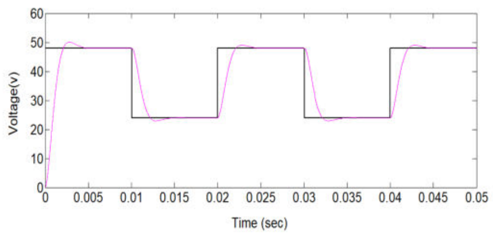

Fig 4. Boost Converter Output Voltage

This image shows the output voltage waveform of the boost converter. The yellow line represents the control reference switching between two levels (e.g., 48V and 24V), while the purple waveform is the actual output voltage. It follows the reference with a small transient delay. The converter steps up the voltage initially and reduces it as per control input, indicating good dynamic response. Voltage fluctuations are consistent with PWM switching. The converter reacts quickly to changes in duty cycle, confirming functional responsiveness. The result also highlights the converter's capability to handle different output voltage levels based on control signal variation.

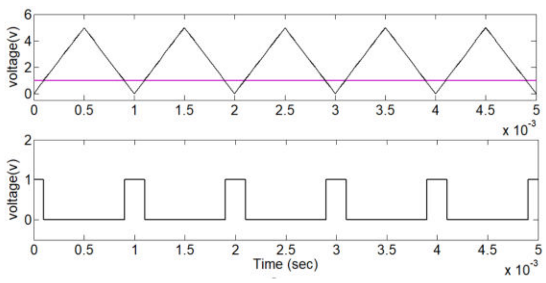

Fig 5. PWM Signal at 20% Duty Cycle

This waveform demonstrates the PWM signal at 20% duty cycle. The upper graph shows a triangular carrier waveform in purple and the reference signal in yellow. The lower graph displays the resulting PWM pulses. At 20% duty, the PWM signal remains high for a short duration in each switching cycle, leading to lower average output voltage from the boost converter. This is evident from the narrow width of high pulses. The waveform confirms that the PWM modulation is working effectively and that the converter's output will reduce, resulting in lower motor voltage and hence reduced speed or torque at this stage.

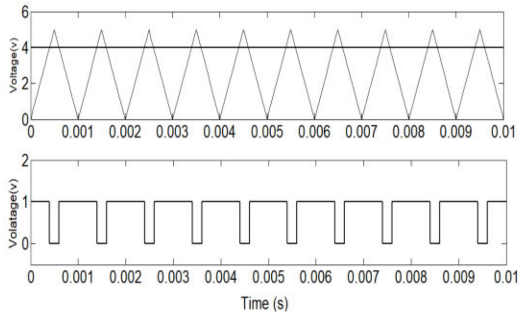

Fig 6. PWM Signal at 80% Duty Cycle

This waveform represents the PWM control signal at an 80% duty cycle. In the upper plot, the yellow reference is above the triangular carrier waveform most of the time, leading to wider pulses in the bottom plot. The wide pulse duration indicates a high on-time for the switch, causing a higher average output voltage from the boost converter. This higher voltage translates into increased power supplied to the DC motor. The waveform validates that at 80% duty, the system delivers maximum voltage boost and higher motor speed, essential for driving loads with higher torque requirements like 15Nm and 20Nm cases.

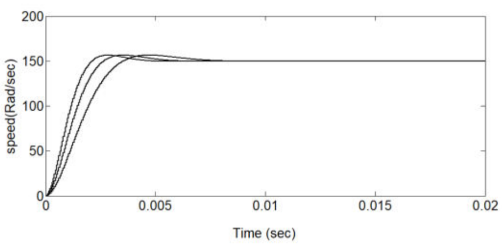

Fig 7. Speed (rad/sec) vs Time at 10Nm, 15Nm, and 20Nm

This plot shows the speed response of the DC motor under varying torque loads:

10Nm, 15Nm, and 20Nm. Each colored curve represents a different load. As expected, the speed rises sharply at startup and then stabilizes. The 10Nm load shows the highest final speed due to lower load torque, while the 20Nm load results in the lowest steady-state speed. The system reaches steady-state in less than 0.01s, indicating fast dynamic response. This confirms the converter and controller's capability to handle load variations effectively and highlights how increasing torque results in a corresponding decrease in motor rotational speed.

V CONCLUSION

The simulation-based analysis of the two-stage AC-DC conversion system with a boost converter has provided valuable insights into its dynamic performance under varying torque conditions. The system, consisting of a full-bridge rectifier and a PWM-controlled boost converter, was tested for torque loads of 10 Nm, 15 Nm, and 20 Nm. The results demonstrated that while the rectifier delivered a stable 45 V DC output, the boost converter's output fluctuated between 24 V and 48 V depending on the duty cycle and torque level. These voltage variations were more pronounced at higher torque demands, which increased the system's transient instability and output ripple. However, despite these fluctuations, the motor maintained functional operation across all tested conditions, proving the system's baseline effectiveness for load adaptability. The observed instability at higher torque levels suggests the need for better voltage regulation and faster dynamic response, especially when precise control is essential. Implementing advanced control techniques like PID tuning, fuzzy logic, or sliding mode control could significantly enhance system performance by minimizing overshoot, settling time, and ripple. Overall, this study confirms the feasibility of using a boost converter-based AC-DC conversion scheme for motor drives, while also highlighting opportunities for future optimization in controller design.

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