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OPTIMIZED CONTROL ARCHITECTURE FOR EV MOTOR DRIVE SYSTEMS UTILIZING VIENNA RECTIFIER AND SVPWM

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Abstract

The electric vehicle (EV) motor drive system comprises essential components such as the electric motor, power electronics, and control systems, which collaboratively convert electrical energy into mechanical power. This paper presents a control architecture for an EV motor drive system incorporating a Vienna rectifier and Space Vector Pulse Width Modulation (SVPWM) techniques. The architecture integrates a three-phase voltage source inverter (VSI) with a Vienna rectifier for enhanced efficiency. The proposed system employs Proportional-Integral (PI) controllers for voltage and speed regulation, ensuring optimal performance under varying load conditions. SVPWM is used for generating inverter pulses to maximize output voltage and minimize harmonics. Simulation results using MATLAB 2021a confirm the system's fast transient response, improved torque control, and robustness against fluctuations. The proposed control scheme contributes significantly to EV drive system advancements, promoting sustainable transportation solutions.

Keywords: Electric Vehicle (EV), Vienna Rectifier, Space Vector Pulse Width Modulation (SVPWM), Voltage Source Inverter (VSI), PI Controller, MATLAB Simulation.

1. Introduction

With the global emphasis on reducing carbon emissions and improving energy efficiency, electric vehicles (EVs) have gained prominence as a viable alternative to conventional internal combustion engine vehicles. However, efficient power conversion and control strategies are crucial for enhancing EV performance. This paper introduces a novel control architecture integrating a Vienna rectifier and SVPWM to improve the overall efficiency and stability of EV motor drive systems. The Vienna rectifier ensures high power factor correction (PFC) and low harmonic distortion, while SVPWM optimizes inverter switching to reduce losses.

Electric propulsion systems have evolved significantly over the past decade. Various control methods such as Direct Torque Control (DTC), Model Predictive Control (MPC), and Field-Oriented Control (FOC) have been employed to enhance motor efficiency. Each method presents distinct advantages and trade-offs. The Vienna rectifier and SVPWM combination proposed in this paper offers a highly efficient alternative with minimized harmonics, enhanced robustness, and improved power factor correction.

2. Literature Review

Several studies have explored different control techniques for EV motor drives. Model Predictive Control (MPC) and Field-Oriented Control (FOC) have been widely used for precise torque and speed control. However, their computational complexity often limits real-time applications. Additionally, fuzzy logic control (FLC) and adaptive control systems have been investigated for robustness in unpredictable conditions. This research builds upon existing control strategies by combining a Vienna rectifier with SVPWM to achieve superior performance with reduced complexity.

Deepak Mohanraj *et al* [2022] developed critical aspects of electric motor drive controllers and the mitigation of torque ripple are essential for enhancing the performance and reliability of electric vehicles (EVs).Advanced control techniques, such as field-oriented control (FOC) and model predictive control (MPC), can significantly reduce torque ripple, leading to more efficient energy utilization and extended battery life. Moreover, effective torque ripple mitigation enhances the overall longevity of motor components by reducing mechanical stress and vibrations, contributing to lower maintenance costs. However, there are notable disadvantages to consider.

Andrea Credo *et al* [2022] proposed adoption of synchronous reluctance motors (SRMs) in electric vehicles (EVs), particularly with a focus on their flux weakening capability.The primary benefits of SRMs is their simplicity and robustness, which often leads to lower manufacturing costs compared to other motor types. The flux weakening capability is particularly advantageous, as it allows the motor to maintain performance at higher speeds, extending the operational range of the EV

Utkal Ranjan Muduli *et al* [2022] introduced Predictive control with a battery power sharing scheme for dual open-end-winding induction motor-based four-wheel drive electric vehicles (EVs) represents a notable innovation in enhancing vehicle dynamics and efficiency

Heejune Cha *et al* [2023] developed operation strategy of Electric Vehicle (EV) aggregators within integrated power and transportation systems .On the positive side, EV aggregators optimize energy usage and enhance grid stability by balancing supply and demand, especially during peak load periods. They facilitate the integration of renewable energy sources, promoting sustainability while providing financial incentives for EV owners through dynamic pricing and compensation for grid services

Utkal Ranjan Muduli *et al* [2023] proposed dual motor power sharing control for electric vehicles (EVs) with battery power management is a significant advancement in optimizing vehicle performance and efficiency. This method offers several benefits, primarily by improving the overall power distribution between the motors, which can enhance acceleration, traction, and stability, especially in varying driving conditions

Yiyan Su *et al* [2023] presented MPC-based (Model Predictive Control) torque distribution for the planar motion of four-wheel independently driven electric vehicles (EVs), considering motor models and iron losses, presents a significant advancement in vehicle control strategies

Sang Hyuk Kim *et al* [2023] presented Model Predictive Control (MPC) for energy-efficient yaw-stabilizing torque vectoring in electric vehicles (EVs) with four in-wheel motors represents a significant advancement in vehicle dynamics and control strategies

Pemmareddy Saiteja *et al* [2023] presented development of an efficient energy management strategy to mitigate speed and torque ripples in switched reluctance (SR) motors through an adaptive supervisory self-learning technique for electric vehicles (EVs) introduces promising advancements in motor control and performance optimization

Elie Libbos *et al* [2023] introduced Winding layout considerations for variable-pole induction motors in electric vehicles (EVs) are critical for optimizing performance and efficiency. The Variable-pole designs is to adjust the motor's operational characteristics based on driving conditions, allowing for improved torque output and energy efficiency at varying speeds. This adaptability lead to a more versatile power train, enhancing the vehicle's overall performance and extending the driving range.

G. Mathesh *et al* [2023] introduced novel intelligent controller-based power management system with instantaneous reference current for hybrid energy-fed electric vehicles (EVs) represents a significant advancement in optimizing energy efficiency and performance. This system has the ability to adjust power distribution between various energy sources, such as batteries and fuel cells, based on real-time demand and operating conditions

Paolo Pescetto *et al* [2023] developed galvanically isolated on-board chargers fully integrated with 6-phase traction motor drives present a significant innovation in electric vehicle (EV) technology, combining charging and propulsion systems into a cohesive unit. The integration of the galvanic isolation, which helps protect both the vehicle and its occupants from electrical faults and reduces the risk of ground loops

Mehdi Monadi *et al* [2024] presented Permanent Magnet Synchronous Motors (PMSMs) are crucial in electric vehicle (EV) applications due to their high efficiency and power density, making speed control a key aspect of optimizing their performance for sustainable energy mobility. Several control techniques are employed, each with its own advantages and disadvantages. Field-

Oriented Control (FOC) is a popular method, offering precise speed and torque regulation, smooth operation, and high dynamic response, but its complexity and high computational demand increase system cost

Pemmareddy Saiteja ***et al*** **[2024]** presented Adaptive self-learning-based energy management controllers for Brushless DC (BLDC) motors in electric vehicles (EVs) are gaining attention due to their potential to optimize motor performance under real-world driving conditions. These controllers leverage machine learning and adaptive algorithms to adjust parameters in real-time, improving efficiency and extending battery life

Sarah Adnan Albarri ***et al*** **[2024]** introduced High-gain adaptive controllers are increasingly being employed in electric vehicle (EV) traction systems to enhance performance, especially in response to the complex and dynamic driving conditions typical of EV applications. These controllers are designed to adjust system parameters in real-time, compensating for changes in load, speed, and environmental factors, thus ensuring optimal performance

Mahbub Ul Islam Khan ***et al*** **[2024]** presented Machine learning-driven fault detection and classification techniques are emerging as essential tools for securing electric vehicle (EV) performance by ensuring system reliability and safety. These techniques use advanced algorithms to analyze real-time data from various EV components, such as motors, batteries, and power electronics, to detect faults before they cause significant performance degradation or system failure

Douglas G. Scruggs ***et al*** **[2024]** developed Neural network-based cyber-threat detection strategies are becoming increasingly relevant for enhancing the security of four motor-drive autonomous electric vehicles, which are particularly vulnerable to cyber-attacks due to their reliance on interconnected systems and autonomous functionalities

Kexiang Wei ***et al*** **[2024]** presented Research into the economic benefits and adaptability of different End-of-Life Vehicle (ELV) powertrain topologies highlights the balance between cost-effectiveness, performance, and system flexibility. Powertrain designs, including series, parallel, and hybrid configurations, offer distinct advantages

T. Faheem Ali ***et al*** **[2024]** presented development of a bidirectional interleaved totem pole Power Factor Correction (PFC)-based integrated on-board charger for electric vehicle (EV) Switched Reluctance Motor (SRM) drives offers significant advantages in terms of efficiency and system integration. This architecture allows the on-board charger to function both as a charger and as a power source for motor drive operations, optimizing space and reducing component costs.

Md. Shahin Munsi ***et al*** **[2024]** implemented Energy management systems (EMS) for electric vehicles (EVs) are pivotal in optimizing energy consumption, enhancing vehicle performance, and extending battery life. These systems integrate various technologies, such as battery management systems (BMS), power electronics, and control algorithms, to ensure efficient energy distribution between the battery, motor, and auxiliary systems

Juanying Zhou ***et al*** **[2024]** proposed Cost-based research on energy management strategies for electric vehicles (EVs) utilizing hybrid energy storage systems (HESS) focuses on optimizing the balance between performance, efficiency, and economic viability.

Despite significant improvements, existing motor control methods still face challenges. High computational requirements, sensitivity to parameter variations, and difficulty in real-time implementation hinder widespread adoption. The proposed Vienna rectifier and SVPWM-based control architecture addresses these challenges by ensuring high power factor, reduced harmonic distortion, and efficient torque control.

3. Proposed System

The proposed control architecture shown in Fig.1comprises the following components:

- **AC Source**: Supplies power to the Vienna rectifier.
- **Vienna Rectifier**: Converts AC power to a stable DC output, ensuring improved PFC and reduced harmonic distortion.
- **PI Controller**: Regulates the output voltage and speed for optimal performance.
- **SVPWM Generator**: Generates precise PWM pulses for VSI control, maximizing efficiency.

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- **Three-Phase VSI**: Converts DC voltage back to AC to drive the EV motor.
- **EV Motor**: Executes propulsion based on the controlled power supply.

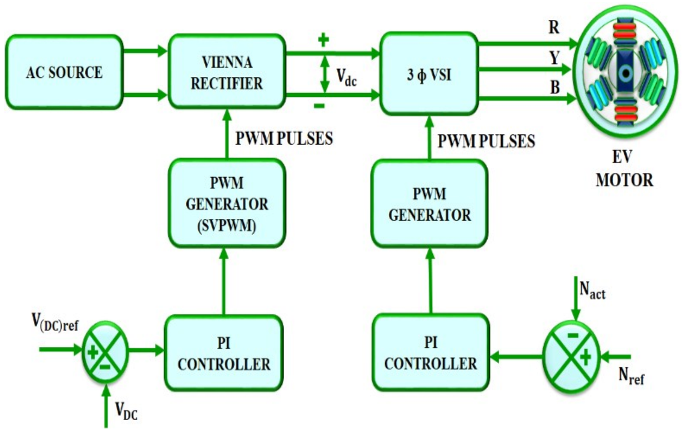

Fig.1- Block diagram of the proposed system

This paper proposes a control architecture for EV motor drive system with VIENNA rectifier and SVPWM. The system begins with an AC source connected to the VIENNA rectifier, which converts AC power to a controlled DC voltage. This rectifier employs a PI controller to maintain output voltage stability and regulate the power flow, ensuring optimal energy conversion. The resulting DC voltage is then fed into a three-phase voltage source inverter (VSI), which employs a PWM generator utilizing SVPWM techniques to generate precise control signals for the inverter switches. The SVPWM optimizes the output voltage waveform and minimizes harmonic distortion, enhancing the overall system efficiency. The three-phase VSI converts the DC voltage back into an AC supply suitable for driving the EV motor. A second PI controller regulates the output voltage and current to ensure stable operation under varying load conditions. This coordinated control architecture provides improved dynamic response and efficiency, facilitating smooth operation of the EV motor while maximizing battery utilization.

3.1 Operation of Vienna Rectifier

A Vienna Rectifier is a three-level AC-DC converter that provides better efficiency than conventional rectifiers. It improves power factor correction by reducing reactive power losses and harmonics. Figure 1 illustrates the functional block diagram of the Vienna rectifier within the proposed system.

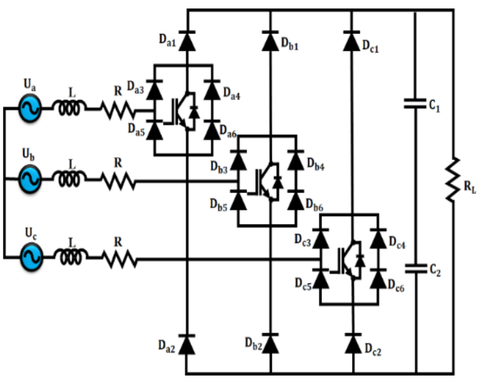

Fig.2- Vienna Rectifier

3.2 Implementation of SVPWM

SVPWM is a sophisticated modulation technique used to enhance inverter performance. By optimizing switching states, SVPWM reduces total harmonic distortion and increases DC bus voltage utilization. The proposed system integrates SVPWM to ensure a smooth sinusoidal waveform, improving motor efficiency and reducing heat dissipation.

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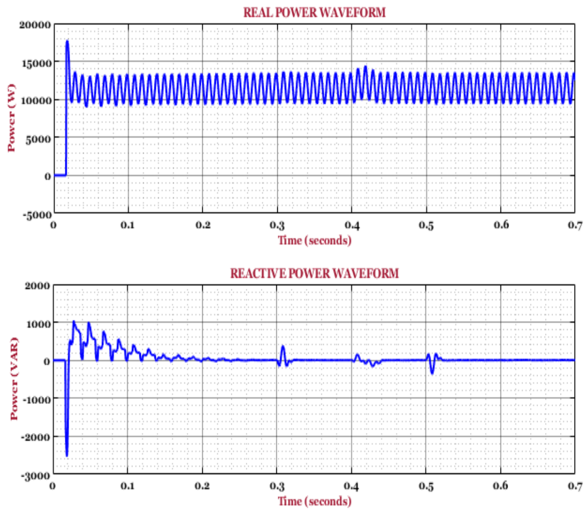
4. SIMULATION RESULTS AND DISCUSSION

The proposed control system was simulated in MATLAB 2021a.



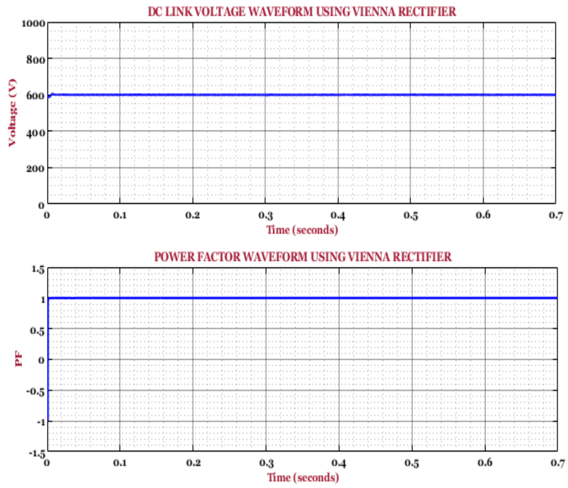


Fig.3 Real and Reactive Powers   Fig. 4 DC Link Voltage and Power Factor

This waveform typically shows fluctuations in active power due to varying load conditions but maintains a generally stable trend The reactive power waveform often demonstrates smaller fluctuations compared to real power, indicating its role in maintaining voltage levels and supporting the operation of electrical devices.

The DC link voltage and power factor at Vienna rectifier is illustrated in Fig.4

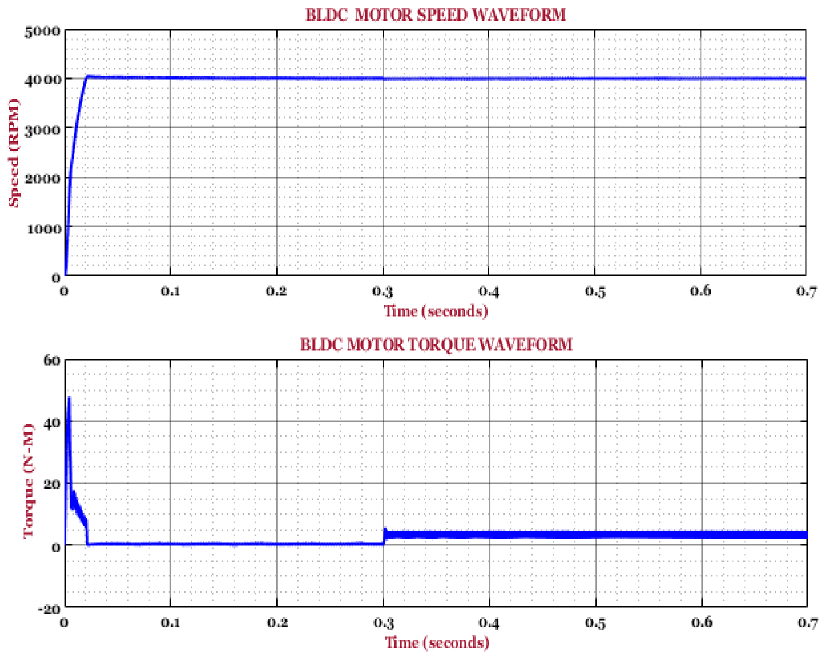


Figure.5 Illustration of BLDC Motor Speed And Torque with4000 RPM and 3Nm torque

Fig.5 shows the performance of a Brushless DC (BLDC) motor over a duration of 0.7 seconds. The upper graph shows the speed waveform, where the motor quickly accelerates to around 5000 RPM and then maintains that speed. The lower graph presents the torque waveform, which initially exhibits a negative spike before stabilizing near zero.

The results demonstrate:

- **Improved Power Factor**: The Vienna rectifier achieved a power factor close to unity.
- **Reduced Harmonic Distortion**: SVPWM minimized Total Harmonic Distortion (THD) in inverter output.
- **Efficient Torque and Speed Control**: The PI controller ensured smooth acceleration and deceleration.
- **Robust Operation**: The system exhibited resilience to input voltage fluctuations and load variations.

5. Conclusion

The proposed control architecture integrating a Vienna rectifier and SVPWM offers a robust and efficient solution for EV motor drive systems. The simulation results validate its advantages in power quality improvement, harmonic reduction, and enhanced motor performance. Future research can focus on real-time hardware implementation and optimization of the control algorithms for further improvements. The use of AI-driven control techniques can be explored to enhance system adaptability to varying load conditions.

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