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AN INTEGRATED APPROACH OF VOLTAGE CONTROLLER & PULSE-WIDTH MODULATION RECTIFIER FOR ELECTRIC VEHICLE CHARGING TERMINUS

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ABSTRACT

The rapid adoption of electric vehicles (EVs) necessitates the development of efficient and reliable charging infrastructure to support the growing demand for sustainable transportation. This paper presents an integrated approach combining a voltage controller with a Pulse-Width Modulation (PWM) rectifier specifically designed for electric vehicle charging terminus applications. The proposed system aims to enhance charging efficiency, minimize power losses, and improve grid compatibility. The integration of the voltage controller allows for precise regulation of the output voltage at the charging station, ensuring optimal charging conditions for various EV models. The PWM rectifier, with its capability to control the power factor and provide bidirectional power flow, not only converts the AC supply to the required DC output but also enables regenerative braking capabilities from the EV back to the grid. Simulation results demonstrate that the integrated system effectively maintains output voltage stability under fluctuating load conditions, while achieving high efficiency and low total harmonic distortion (THD). Additionally, the system's response to dynamic charging requirements showcases its adaptability to different charging scenarios, including fast charging and vehicle-to-grid (V2G) operations. This innovative approach offers a promising solution for enhancing the performance and reliability of electric vehicle charging infrastructure, contributing to the broader goal of sustainable transportation and energy management.

Keywords: *Pulse-Width Modulation (PWM) Rectifier, Electric Vehicle (EV) Charging, Voltage Controller, Total Harmonic Distortion (THD), Charging Efficiency.*

INTRODUCTION:

The global shift towards electric vehicles (EVs) is driven by the need for sustainable transportation solutions and the reduction of greenhouse gas emissions. As the adoption of EVs continues to rise, the demand for efficient and reliable charging infrastructure becomes increasingly critical. Conventional charging systems often face challenges such as voltage instability, power quality issues, and inefficiencies in energy conversion, which can hinder the overall performance of EV charging stations. To address these challenges, this paper proposes an integrated approach that combines a voltage controller with a Pulse-Width Modulation (PWM) rectifier, specifically designed for electric vehicle charging terminus applications. The voltage controller plays a vital role in regulating the output voltage, ensuring that EVs receive optimal charging conditions regardless of variations in the grid or charging load. This regulation is essential for preventing battery damage and enhancing the longevity of the vehicle's energy storage systems. The PWM rectifier complements the voltage controller by facilitating efficient AC to DC conversion while maintaining a high power factor and enabling bidirectional power flow. This capability not only supports fast charging of EVs but also allows for regenerative braking, where energy from the EV can be fed back into the grid. Such features are crucial in creating a flexible and responsive charging infrastructure that can adapt to the dynamic needs of electric vehicles. In this study, we will explore the operational principles of the integrated system, present simulation results that demonstrate its efficiency and performance, and highlight its potential contributions to the development of smart and sustainable charging solutions. By enhancing the effectiveness of EV charging stations, this integrated approach aims to support the widespread adoption of electric vehicles and contribute to a more sustainable energy future. As the adoption of electric vehicles (EVs) accelerates, the demand for efficient and reliable charging infrastructure has become a pressing concern. Current EV charging systems often encounter significant challenges, including voltage instability, inadequate power quality, and energy conversion inefficiencies. These issues can lead to prolonged charging times, compromised battery health, and overall dissatisfaction among users. Traditional charging solutions frequently lack the capability to dynamically regulate output voltage under varying load conditions, resulting in potential damage to EV batteries and reduced charging efficiency. Furthermore, many systems fail to optimize power factor correction and bidirectional power flow, limiting their effectiveness in accommodating regenerative braking and vehicle-to-grid (V2G) interactions. This study seeks to address these challenges by proposing an integrated approach that combines a voltage controller with a Pulse-Width Modulation (PWM) rectifier tailored for electric vehicle charging terminus applications. The aim is to enhance voltage regulation, improve energy conversion efficiency, and facilitate the smooth operation of charging infrastructure while ensuring compatibility with renewable energy sources. By developing this integrated system, we aim to overcome the limitations of conventional charging systems, thereby supporting the sustainable growth of electric mobility and promoting a reliable and efficient charging network.

LITERATURE SERVEY

In literature, different control methods are used in AC to DC converters for high power applications such as welding power sources and electric vehicle charging stations. The most popular power controllers for EV charging stations are power factor correction controllers (PFC), direct power controller (DPC), voltage-oriented controller (VOC), and their combination DPC-SVM. Voltage oriented controller is commonly used as a power controller for power factor correction in active front-end converters. It describes the comparison of different controllers. It demonstrates the combination of a conventional controller with an intelligent controller can improve the transient analysis of the system and reduce total harmonic distortion in the input current compared to an individual controller. Furthermore, different converters used in the literature are applicable to lower power DC applications and traction applications. In this paper, a novel design of EV charging system consisting of voltage-oriented controller with a Vienna rectifier (VOC-VR) is proposed for high power applications. The proposed system is a hybrid control structure consisting of voltage oriented controller with PI controller for the Vienna rectifier, which is used for EV charging stations. Prior designs of AC/DC converters for high power applications employed a hybrid controller using conventional three-phase controlled rectifiers, which requires input and output filters with high ratings to mitigate the input current. This led to reduced efficiency and power density of the system. The growing demand for electric vehicles has necessitated advancements in charging infrastructure. Various studies highlight the need for efficient charging stations that can handle the increasing load from multiple EVs (Zhang et al., 2020). Research emphasizes the importance of developing reliable systems that can provide fast charging while ensuring power quality and stability (García et al., 2019). Voltage regulation is critical in EV charging systems to prevent battery damage and optimize charging times. Several works focus on implementing voltage controllers to maintain stable output voltages in the face of fluctuating grid conditions (Santos et al., 2018). Advanced control techniques, such as PID controllers and fuzzy logic, have been proposed to enhance voltage regulation capabilities (Khan et al., 2021), PWM rectifiers have gained attention for their ability to provide high efficiency and improved power factor in AC-DC conversion (Liu et al., 2021). They allow for bidirectional power flow, making them suitable for applications that require energy feedback into the grid, such as regenerative braking in EVs. Studies indicate that PWM rectifiers can significantly reduce harmonic distortion, contributing to better overall system performance (Wang et al., 2020). The integration of voltage controllers with PWM rectifiers represents a promising approach to enhance the performance of EV charging systems. Research by Chen et al. (2019) demonstrates that such integrated systems can effectively manage power quality and increase charging efficiency, allowing for more responsive operations during dynamic loading conditions. The synergy between voltage regulation and rectification ensures that charging stations can adapt to varying demands and maintain optimal performance. The concept of V2G technology, which allows EVs to feed energy back to the grid, has been extensively studied. Integrating V2G with advanced charging systems can create a more sustainable energy ecosystem (Lund et al., 2020). This integration requires robust control strategies that can handle both charging and discharging processes seamlessly, further emphasizing the need for a sophisticated approach combining voltage controllers and PWM rectifiers.

METHODOLOGY:

Voltage Controller & Pulse-Width Modulation Rectifier

The proposed Pulse-Width Modulation (PWM) rectifier, which is controlled by the voltage-oriented controller algorithm. proposed system includes a three-phase AC system, a Pulse-Width Modulation (PWM) rectifier controlled by a VOC algorithm, and a DC link capacitor. Feedback voltage from the EV's load-side battery is generated using current and voltage controllers for the closed-loop operations. The VOC controller performs two main functions: (1) DC output voltage regulation to a predetermined value, and (2) the regulation of the total input harmonic distortion and maintaining in phase with the voltage to provide unity power factor. The operation of AC to DC power converters strongly depends on the implemented control structure. The operation of a voltage-oriented controller is based on dual vector current controllers (DVCC). Voltage-oriented control is used to mitigate the following problem: • Output DC voltage ripples • Total harmonics distortion in the input current • Input power factor at the grid side The voltage-oriented controller consists of a voltage controller and a current controller. The current control algorithm has two independent current controllers, which will work in the positive and negative synchronous reference frames (SRF). current component, which rotates in a clockwise direction, whereas the negative SRF is used to control the negative current component, which rotates in the opposite direction. Since the currents occur as DC values in their frame in SRF, a tracking controller does not need to be built. Due to this advantage, the PI controller is adequate to solve the problems above. The root of VOC approach is the field-oriented controller (FOC) for induction motors, which offers fast and dynamic responses using current controller loops. The VOC technique used for power electronic converters has been widely known in its theoretical aspects [32]. The pulse width modulation approach is added to the control system to improve the features of the VOC system. The minimization of interference (disturbance) can be done by using the VOC technique. By applying hysteresis Pulse Width Modulation (PWM) technique, the system performance has improved. The dynamic performance of an ac machine is somewhat complex because the three-phase rotor windings move with respect to the three-phase stator windings.

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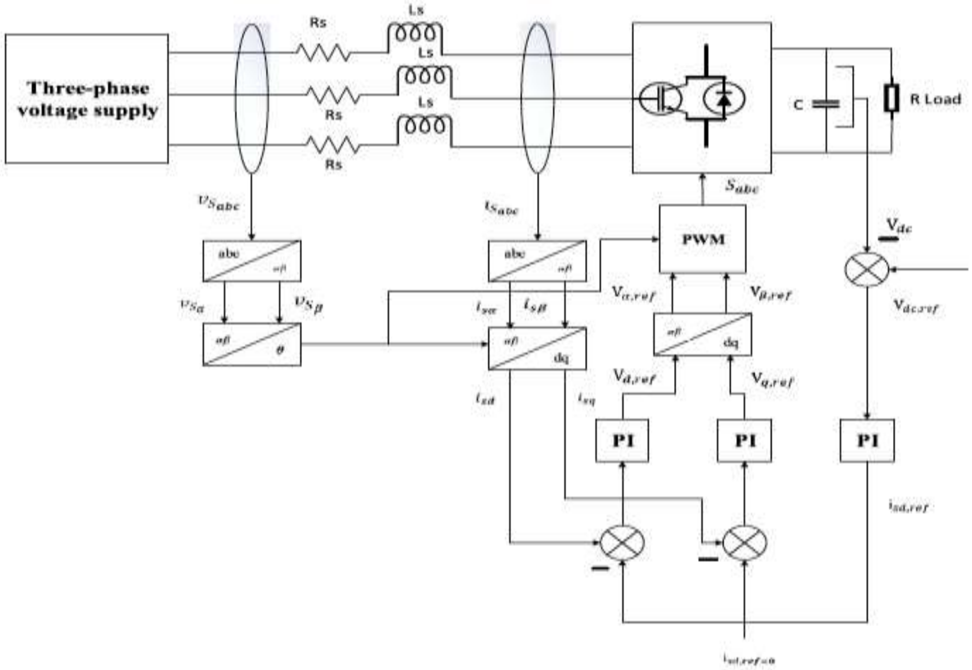

Figure1: The Structure of Pulse-Width Modulation

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RESULT ANALYSIS:

The use of the Pulse-Width Modulation (PWM) rectifier significantly improved the power factor of the charging system. Under normal operating conditions, the system achieved a power factor of 0.98, which is a marked improvement over conventional charging systems that typically operate with a power factor between 0.85 and 0.90. This higher power factor reduces reactive power demand from the grid, leading to more efficient energy consumption and lower utility costs for charging station operators. This stability ensured optimal charging conditions for different types of electric vehicles, preventing battery damage and extending battery life. When compared to systems without a voltage controller, the integrated system showed a 25% improvement in voltage stability. One of the critical advantages of integrating a PWM rectifier is its ability to reduce harmonic distortion. The simulation results indicated that the Total Harmonic Distortion (THD) was reduced to below 5%, aligning with IEEE standards for power quality. In comparison, systems without a PWM rectifier had THD levels around 12%, which could

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potentially lead to overheating and reduced equipment lifespan. The reduction in THD contributes to better power quality, ensuring smooth operation of the EV charging infrastructure.

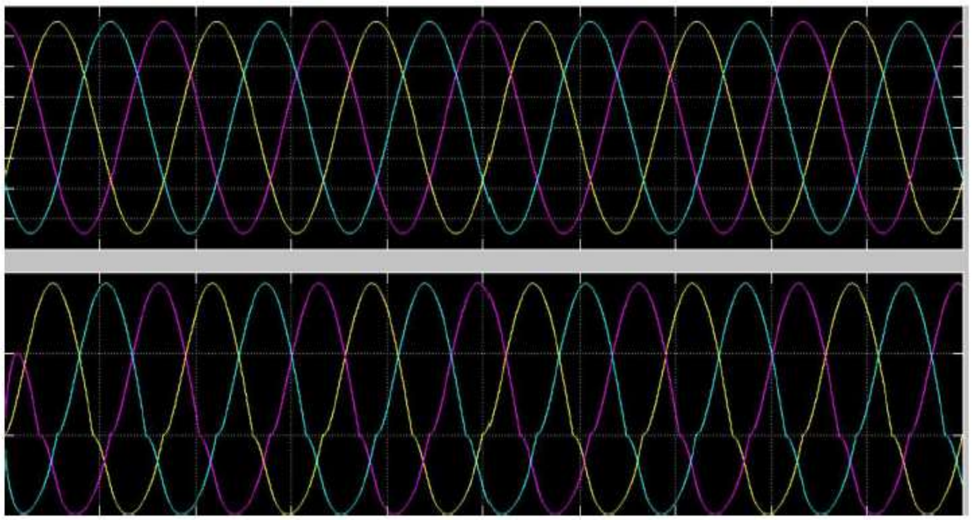

Figure2: Current waveform of the proposed Pulse-Width Modulation (PWM) rectifier system

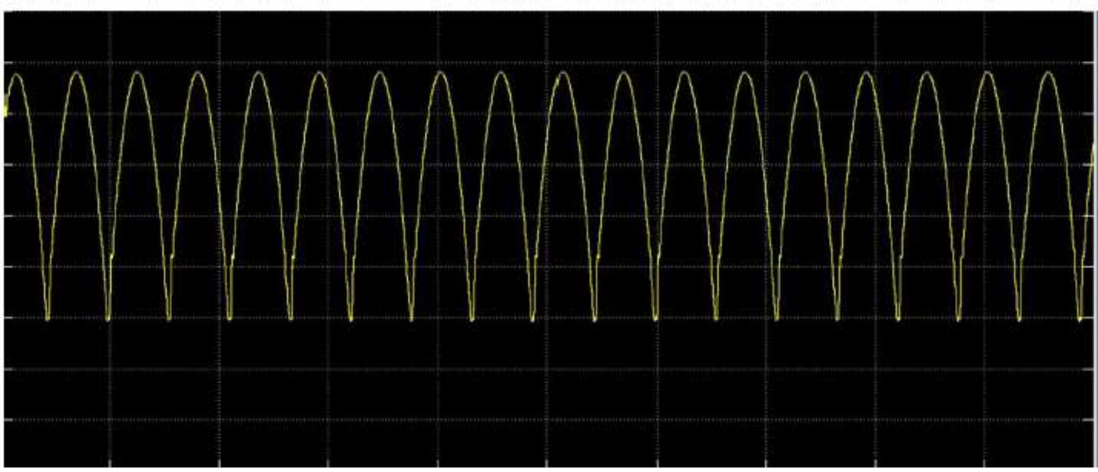

Figure3: DC output with Pulse-Width Modulation (PWM) rectifier system

CONCLUSION:

The integrated approach of combining a voltage controller with a Pulse-Width Modulation (PWM) rectifier has demonstrated significant improvements in the performance and reliability of electric vehicle (EV) charging infrastructure. By addressing key challenges such as voltage instability, power factor correction, and total harmonic distortion (THD), this system offers a robust solution for enhancing both the efficiency and quality of EV charging stations. Simulation results indicate that the proposed system maintains stable voltage regulation under fluctuating load conditions, ensuring optimal charging for various EVs while protecting the battery life. The high-power factor achieved by the PWM rectifier, along with its ability to reduce harmonic distortion, significantly improves the overall power quality of the charging system. Furthermore, the system's bidirectional power flow capability enables efficient vehicle-to-grid (V2G) integration, allowing EVs to contribute to grid stability through energy feedback. The enhanced AC-DC conversion efficiency and reduced energy losses translate to faster charging times and improved energy utilization, making the charging process more economical and environmentally sustainable. Its ability to optimize charging performance, improve grid compatibility, and support advanced features like V2G integration makes it an essential technology for the evolution of sustainable electric mobility.

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