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THREE-STAGE SYNCHRONOUS RECTIFIER TECHNOLOGY USED FOR WIRELESS CHARGING SOLUTION INCORPORATING IN ELECTRIC VEHICLES

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Abstract: Traditional Electric Vehicle (EV) charging methods predominantly rely on wired connections, which can be inconvenient and restrict user flexibility. The integration of three-stage synchronous rectifier technology into wireless charging systems offers the potential for enhanced efficiency and performance, meeting the increasing need for practical and effective EV charging solutions. This paper introduces a power conversion system aimed at optimizing energy management within a single-phase grid. The system initiates with a Vienna rectifier that transforms AC input from the grid into DC. A high-frequency inverter is employed to ensure optimal performance through pulse-width modulation (PWM) techniques. A notable aspect of this design is the use of a cascaded fuzzy controller that manages the output voltage and current, thereby improving system stability and responsiveness. Additionally, the incorporation of various control strategies, including a proportional-integral (PI) controller, further enhances the system's operation. In summary, this configuration presents a robust solution for contemporary energy applications, effectively balancing performance and reliability in power management.

Index Terms **- Electric Vehicles (EV); Pulse-Width Modulation (PWM); Three Stage Synchronous Rectifier; Wireless Charging Stations**

I. INTRODUCTION

The prevalence of combustion vehicles reliant on non-renewable fuels is leading to significant energy and environmental challenges. In response, numerous countries are advocating for new energy vehicles (NEVs) as a viable alternative to conventional automobiles, aiming to decrease reliance on oil and mitigate pollution. China, recognized as the largest automobile market globally, is actively promoting NEVs to lower fuel consumption and emissions. In a similar effort, Germany announced its goal to deploy one million electric vehicles by 2020 to help reduce carbon dioxide emissions across Europe. New energy vehicles that utilize natural gas include electric vehicles (EVs), hydrogen vehicles, gasoline vehicles, as well as methanol and ethanol vehicles.

Among these options, EVs are regarded as the most efficient in terms of environmental, social, and economic advantages. The first electric vehicle was developed by Thomas Parker in 1884, and currently, EVs represent 28% of the automotive fleet. However, the uptake of electric vehicles has been slow, primarily due to the high costs associated with electricity and the rapid growth of traditional vehicles. Since the early 2000s, there has been a surge in research focused on electric vehicles, driven by concerns over electricity supply and environmental pollution. In 2016, global sales of electric vehicles surpassed one million, and by 2018, over five million plug-in hybrids and light electric vehicles were sold worldwide.

EVs emerged to meet long-term transportation needs [1]. Unlike EVs, EVs rely on electricity as the primary means of propulsion. There are many types of EVs, each with unique technology and applications. The main types include the BEV, Plug-in Hybrid Electric Vehicle (PHEV), and Fuel Cell Electric Vehicle (FCEV). Each type has different characteristics in terms of power consumption, range, emissions, and storage.

Battery electric vehicles (BEVs) represent the purest form of electricity. These cars are fully electric and use large batteries to generate electricity. Unlike hybrids, pure electric cars emit zero carbon dioxide, making them good for the environment. The batteries in fully electric cars are usually lithium-ion and come in many types, but the variety can vary from model to model. Most electric cars today can travel between 150 and 300 miles on a single charge, which is important for the environment they grow in.

From charging stations to public fast chargers, charging technology continues to expand, making it easier for users to charge their vehicles.

PHEVs combine the features of EV [2] and traditional gasoline vehicles to offer more options for efficient transportation. These cars feature a dual powertrain: an engine connected to an electric motor and an electric motor connected to an electric motor. Plug-in hybrids operate in different modes, allowing drivers to switch between electric and gasoline, which can expand the driving experience even further than electric cars. In general, plug-in hybrids only have an electric range of 20 to 50 miles, making them suitable for day trips and short excursions. For longer trips, the gasoline engine takes over, eliminating much of the stress of an EV. The FCEV represents a new avenue for an EV that uses hydrogen fuel to generate electricity. In an FCEV, hydrogen is stored in a pressurized tank and converted into electricity by reacting with oxygen in the fuel cell, producing only water vapor. This system allows FCEVs to have a good range per refueling, typically between 300 and 400 miles, compared to gasoline vehicles. An FCEV refueling takes only five minutes, making it a quick alternative to the long charging times of BEVs. However, widespread use of gasoline vehicles has been plagued by problems, primarily due to the limited hydrogenation infrastructure and the energy-intensive nature of the hydrogen process.

Hybrid Energy Storage Systems (HESS) combine two or more types of energy storage technologies to increase the strengths and compensate for the weaknesses of each system. In EVs, HESS usually refers to a combination of batteries and supercapacitors, as well as additional components. Batteries have more energy and are suitable for long-term power, while supercapacitors have more energy and can provide a quick burst of energy. By combining these two technologies, HESS can improve the performance of EVs, especially in situations where power and energy are needed. Supercapacitors can provide more power without straining the battery, which can extend battery life and improve the overall performance of the vehicle. During regenerative braking, the supercapacitor also absorbs the generated electricity and slowly transfers it to the battery over a long period of time. Supercapacitors charge faster than batteries, making them ideal for applications that require rapid power transfer.

II. LITERATURE SURVEY

The majority of vehicles depend on natural resources, mainly fossil fuels, which contribute to global warming and air pollution. In contrast, electric vehicles (EVs) do not utilize gasoline or diesel, resulting in zero emissions. Consequently, the adoption of EVs helps mitigate certain environmental challenges. Additionally, electric vehicles are generally quieter and require less maintenance compared to traditional cars. However, a significant limitation of electric vehicles is their efficiency.

Muhammad Usman Nawaz et al [2024] have suggested a comprehensive assessment of the environmental and economic impact of solar EVs (SEVs) compared to conventional EVs. Integrating solar technology into EVs (EVs) offers a great way to reduce carbon monoxide emissions and reduce dependency on fossil fuels. The environmental assessment evaluates the entire life cycle of the SEV, including production, operation, end-of-life stages, including energy consumption, greenhouse gases, and resource depletion. In addition, the business analysis investigated the total cost of ownership (TCO) of the SEV, including initial investment, operating costs, capital savings from reduced fuel consumption and maintenance [3].

Anahita Jannesar Niri et al [2024] have proposed Consider the actions taken by governments, regulators, businesses and all stakeholders in the battery industry. The global commitment to decarbonize the transportation industry has led to incredible growth in the EV and battery market. As a result, demand for battery products continues to grow. Uncertainty about battery sustainability, environmental, social and regulatory complexities, geopolitical tensions in the battery value chain have raised concerns about the success of transportation decarburization both globally and regionally [4].

Alejandro Jimenez et al [2024] have suggested Discuss the integration of renewable energy into the energy system. In order to discover renewable energy concerns, the energy sector is first examined utilizing the smart energy concept. Electricity is assessed to ensure it satisfies stability and safety standards. Energy balance is always a surprise, not equal power, and the novel approach blends comprehensive energy system analysis from an energy planning perspective with in-depth energy consumption analysis [5].

Pandav Kiran Maroti et al [2022] have proposed role of the electric power converter in EVs is described in detail. Internal combustion engines (ICEs) are gradually being replaced by electric motors, increasing efficiency and reducing greenhouse gas emissions. Electric cars are powered entirely or partially by electricity generated by batteries and supercapacitors. The battery or supercapacitor can be charged by grid-connected AC power in an electric car or by the internal combustion engine in a hybrid electric car [6].

Khalid S. Mohammad et al [2022] have presented Comparison of main electric motors used in electric cars and electric car drive system requirements. In order to reduce environmental pollution and replace hybrid EVs (ICE) with EVs (EVs), many people are working on the development of these vehicles. The main feature of electric cars is that the electric motor should choose high-performance, excellent response electric motor, the driving power has a positive effect on the performance of electric cars [7].

Sai Sudharshan Ravi et al [2022] have demonstrated to discuss the challenges, barriers, future market penetration of V2G technology. Create a bidirectional charger that allows energy to flow in and out of an EV. We witness the global environmental impact of fossil fuels and carbon emissions every second; countries around the world are setting significant goals for carbon neutrality and energy conservation to counter this impact. Meanwhile, EVs have been developed as a solution to achieve the goals of creating a cleaner environment and promoting better transportation models [8].

Jonna Hynynen et al [2023] have proposed six large-scale fire tests were conducted, including three electric cars, two electric cars inside, one electric car with the battery pack removed. EV fires have made headlines worldwide. Carbon monoxide emissions from the combustion of EVs and lithium-ion batteries were highlighted. Single battery tests were also conducted. Two vehicle fire tests used a water sprayer to measure the effect of water spray on fuel. Heat output, maximum output value and total heat output calculations were also performed, as well as oil and dust analyses [9].

Daniel De Wolf et al [2023] have demonstrated to the background is the ban on fossil fuel vehicles in many European cities. First, the main benefits/limitations of the two types of transfers are compared for the users. Hydrogen cars are used for freedom and fast charging. Battery-powered cars are cheaper and the grid is widely used. There are existing studies on the deployment of new hydrogen phones and the comparison of the installation costs of hydrogen and electricity distribution networks. A significant advantage of hydrogen is that its only oxidation product is water vapor [10].

Objectives:

- To enhance energy efficiency by utilizing a Vienna rectifier and a three-stage synchronous rectifier for optimal AC to DC conversion and battery charging processes.
- To improve system stability and response through the implementation of a cascaded fuzzy controller and proportional-integral (PI) controller for precise regulation of output voltage and current.
- To maintain waveform integrity during the inversion process by incorporating a sinusoidal PWM generator, ensuring high-quality power delivery in one-phase grid applications.

III. DESIGN AND IMPLEMENTATION OF EV CHARGING SYSTEM

EV wireless charging solutions using three-phase synchronous rectifier technology represent a significant advancement in EV charging systems. Electric devices transfer electricity from the grid to the EV without the need for physical connections or power lines, making charging easier and better. Wireless charging eliminates the need for cables by using inductive switches, reducing wear and tear and simplifying the user experience, especially in public or social environments. The addition of three-phase synchronous rectifier technology increases the overall performance of the wireless charging system. This optimization helps improve energy conversion and minimizes power loss during transmission. As a result, EV owners will benefit from faster charging times, better energy efficiency and lower operating costs. Three-phase synchronous rectifiers are particularly effective at managing the changing characteristics of wireless transmission and ensure that power is converted to a stable and consistent level. In addition to increasing the life and reliability of residential payments, they also improve thermal management. This wireless solution has great potential and can be adapted to different vehicle types, from passenger cars to commercial vehicles, providing great potential for cities and fleets.

In this proposed system a power conversion system designed for efficient energy management in a one-phase grid was proposed in below figure 1. A single-phase grid that supplies alternating current (AC) to a Vienna rectifier, which efficiently converts the AC voltage into direct current (DC). The DC output from the rectifier is then fed into a single-phase high-frequency inverter, which transforms the DC back into high-frequency AC voltage. This AC voltage is passed through an isolation transformer, providing safety and voltage adjustments. The system employs a PWM generator that creates pulse-width modulation signals to control the inverter's operation, ensuring efficient performance. A hysteresis current controller is integrated within the PWM generator to regulate the output current based on real-time feedback. To enhance performance, a cascaded fuzzy controller adjusts the voltage reference in relation to the actual voltage, optimizing the system's response to varying conditions. Following this, a three-stage synchronous rectifier converts the high-frequency AC back into DC to charge a connected battery, ensuring energy storage for later use. A sinusoidal PWM generator is utilized to maintain the desired waveform for the inverter, contributing to the system's overall stability. Additionally, a PI controller continuously monitors the output voltage and compares it to the reference voltage, making necessary adjustments to the PWM signals.

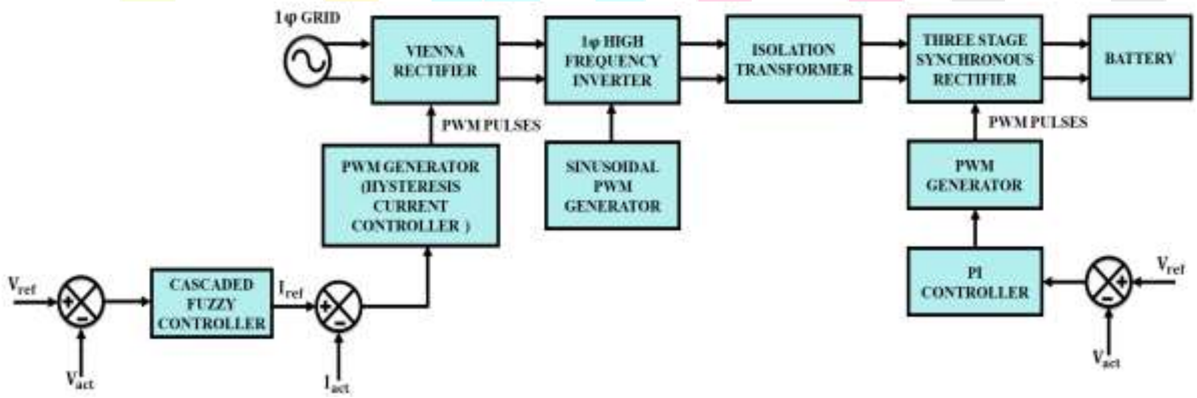

Figure 1. Block Diagram of Proposed System

A. Vienna Rectifier

The Vienna rectifier is an efficient three-phase rectifier circuit designed to convert direct current (AC) to direct current (DC) while minimizing harmonics is shown in figure 2. This new circuit uses diodes or thyristors arranged in a special configuration, allowing it to use a three-phase AC input. In operation, the Vienna rectifier always connects two of the three phases to the output, affecting the third phase. This connection choice typically results in a higher average output compared to standard three-phase rectifiers that use all three phases simultaneously. One of the greatest features of the Vienna rectifier is its ability to reduce harmonics. By drawing power from only two phases at a time, unwanted compromises can occur that can cause inefficiencies and problems in low-power products.

This means that only two of the three AC inputs are used at any time, which helps in reducing harmonic distortion.

- Voltage Generation: The output voltage is derived from the peak of the two conducting phases. This results in a higher average output voltage compared to traditional three-phase rectifiers.
- Smoothing: Capacitors connected at the output help to smooth the DC voltage, reducing ripple and providing a more stable output.
- Control (if applicable): If using thyristors, a control mechanism is implemented to manage the firing angle, allowing for adjustable output voltage and better power quality.

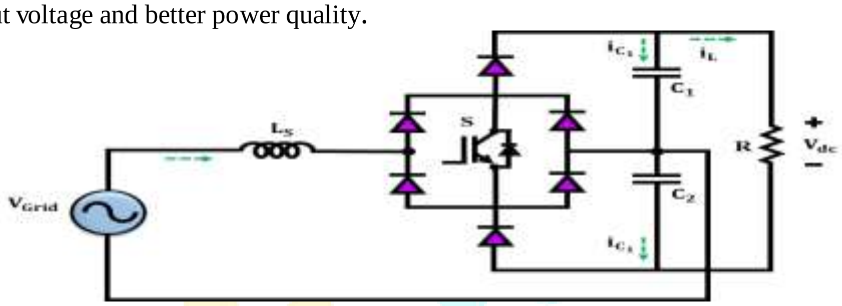

Figure 2 Vienna Rectifier

B. 1ϕ High Frequency Inverter

Single-phase high-frequency inverters are basic electronic devices that convert direct current (DC) to alternating current (AC), usually at a few kilohertz. This process is important for applications such as renewable energy systems, uninterruptible power supplies (UPS), many other electronic devices. The operating process of a single-phase high-frequency inverter can be divided into several main stages. The inverter automatically receives a DC input, which can be from a battery, solar panel, or other DC source. The main components of a high-frequency inverter include the DC-DC converter, oscillating circuit, power transistor (usually MOSFET or IGBT), transformer, output filter. The first stage consists of a DC-DC converter that steps up or down the DC voltage to the desired level and optimizes the inverter's performance.

C. Isolation Transformer

Isolation transformers operate on the principle of electromagnetic induction, which provides electrical isolation between the primary and secondary windings while allowing AC power to be transferred. A generator has two separate coils (primary and secondary) wrapped around a magnetic field but electrically isolated from each other. A magnetic field is produced in the core when the primary winding is subjected to AC current. By means of mutual inductance, this magnetic field causes a voltage to be induced in the secondary winding. The primary and secondary circuits can function separately thanks to the isolation transformer's design. This means that any fault or interruption on one side will not directly affect the other side, increasing safety and reliability.

D. Three Stage Synchronous Rectifier

An effective electrical design known as a three-phase synchronous rectifier uses synchronous transformers, typically MOSFETs, rather than diodes to convert alternating current (AC) to direct current (DC) is shown in figure 3. An AC input that can be converted to high voltage, often from a three-phase system, is used to start the process. The MOSFET is activated by the control circuitry in the first stage during the positive half cycle of the AC waveform, which reduces the voltage drop and permits current to flow through the load. During the negative half cycle, the synchronous rectifier continues to operate by controlling the same MOSFET to provide the correct operating current, reducing the high reverse loss in diode-based systems [11,12].

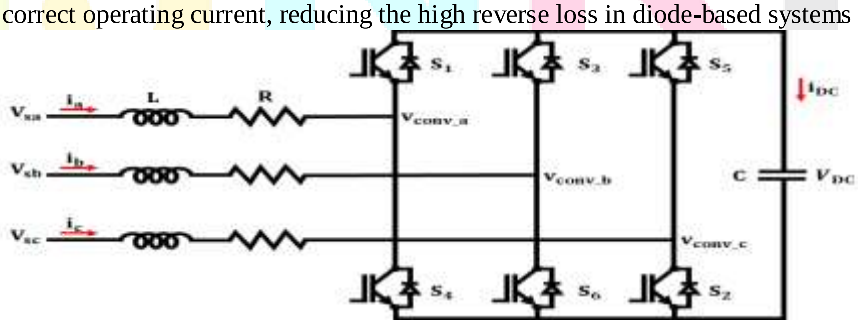

Figure 3 Three-Stage Synchronous Rectifier

E. Cascaded Fuzzy Controller

The cascade fuzzy controller is an advanced control system that uses multiple layers of fuzzy logic controllers to control complex processes is shown in figure 4. This hierarchy divides control tasks into more controllable components, allowing the control system to handle nonlinearities and uncertainties. The working process begins with the input, where sensors collect relevant information such as temperature, pressure, or speed. The data is then fuzzified and converted into fuzzy sets using predefined membership functions. Once fuzzified, different strategies are processed by the first set of fuzzy controllers, each of which uses the fuzzy process as an expert.

The primary controller typically manages broader system goals, while secondary controllers fine-tune specific parameters or sub-processes. This structure enhances system performance by allowing more granular control and adapting to dynamic conditions. The fuzzy logic approach facilitates handling uncertainties and imprecise data, making it suitable for nonlinear and time-variant systems.

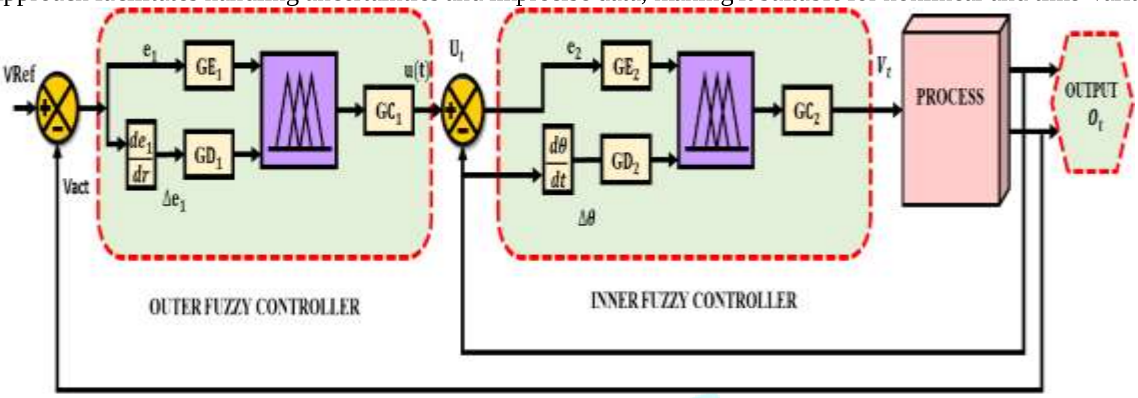

Figure 4 Cascaded Fuzzy Controller

F. Hysteresis Current Controller

The hysteresis current controller is a high-performance control concept widely used in electronic devices, especially drives and transformers shown in figure 5. Its main purpose is to strictly control the current output according to the current instructions to provide fast response to changes while maintaining stability. The working process begins with the current usage generated according to the controller's target value. This reference value is determined based on the performance of the system (such as the required torque or power output). The controller uses sensors to continuously measure the output current. The hysteresis band is then defined around the reference current, creating an upper and lower limit within which the current is allowed to vary. This hysteresis band is very important; if the measured current exceeds the upper limit of the range, the controller will start to control the operation, usually turning off the power supply (such as MOSFETs or IGBTs) to reduce the current.

IV. RESULTS AND DISCUSSIONS

The simulation results were analyzed using the program called MATLAB/SIMULINK. MATLAB is a language that can be used to calculate, visualize and compute in the user environment, where the problem and its solution are expressed using the information method. MATLAB is the best tool for signal analysis. The proposed work is implemented in MATLAB simulation are shown in figure 5.

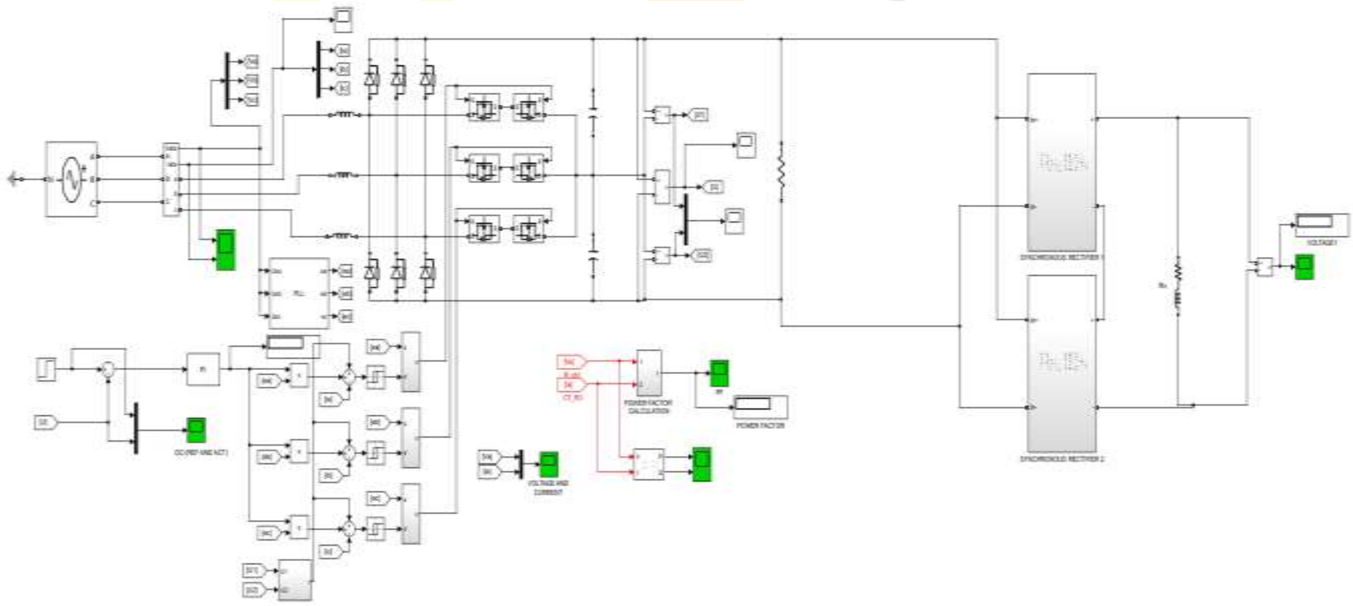

Figure 5. Over All Simulation Diagram

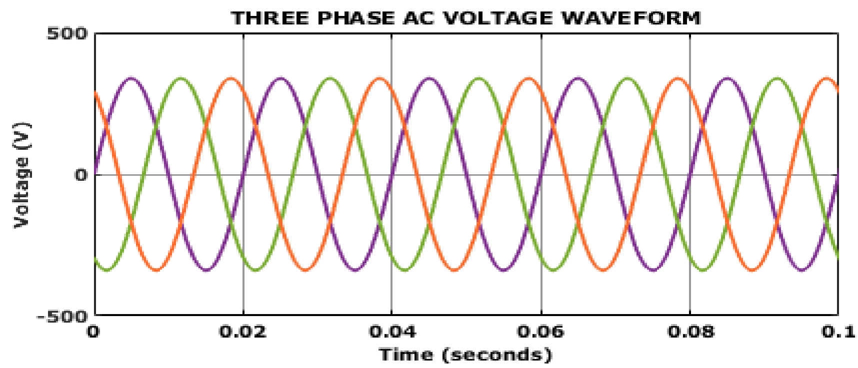

Figure 6 Three Phase AC Voltage Waveform

Figure 6 represent as the three-phase alternating current (AC) voltage waveform shows changes in voltage over time. Each of the three different waveforms (shown in red, orange, green) shows sinusoidal oscillations that represent different phases.

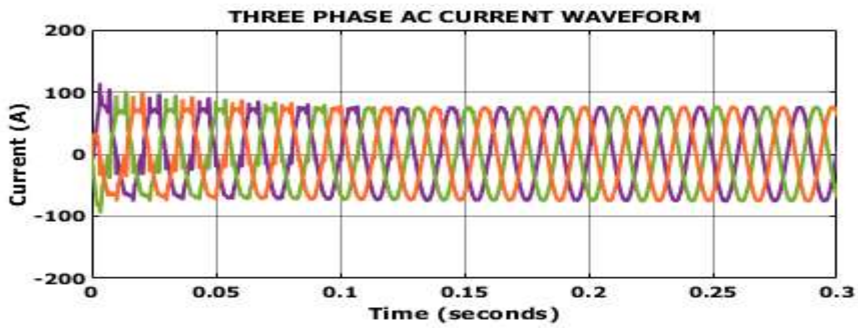

Figure 7 Three Phase AC Current Waveform

Figure 7 represent as a three-phase alternating current (AC) waveform shows changes in electric current over time. Each waveform, represented by purple, orange, green, oscillates sinusoidally with a different phase.

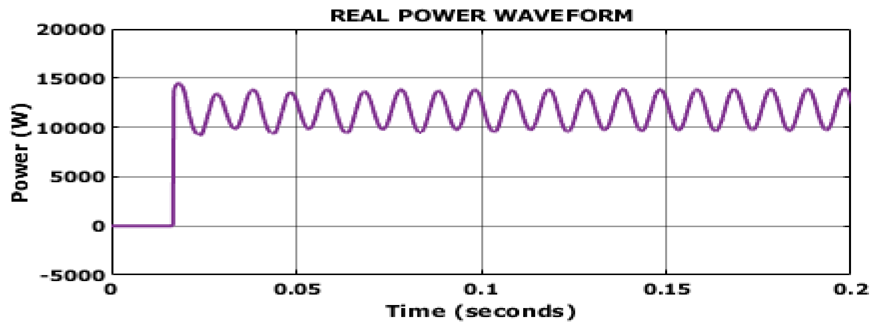

Figure 8 Real Power Waveform

Figure 8 represent as the Electrical power is a function of time, with time (in seconds) on the horizontal axis and power (in watts) on the vertical axis. The waveform oscillates, indicating a change in intensity.

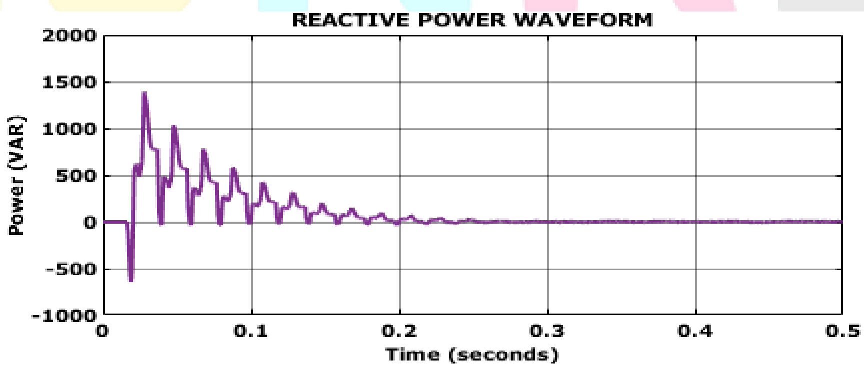

Figure 9 Reactive Power Waveform

Figure 9 represent as the graph shows the reactive power waveform over time; the horizontal axis represents the time in seconds and the vertical axis represents the reactive power in VAR units.

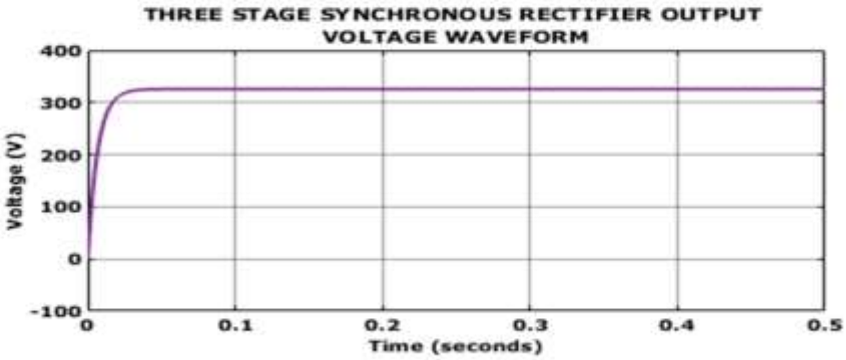

Figure 12 Three Stage Synchronous Rectifier Output Voltage Waveform

Figure 12 represent as output voltage waveform of a three-phase synchronous rectifier varies with time. The horizontal axis represents time (in seconds) and the vertical axis represents voltage (in volts).

V. CONCLUSION

The proposed power conversion system marks a notable improvement in energy management for single-phase grids. By incorporating a Vienna rectifier, a high-frequency inverter utilizing PWM techniques, and a cascaded fuzzy controller, this design achieves superior stability and effective regulation of both voltage and current. The integration of a sinusoidal PWM generator maintains the integrity of the waveform, while the three-stage synchronous rectifier enhances battery charging efficiency. Additionally, the implementation of a proportional-integral (PI) controller optimizes system performance, allowing for adaptability across various operational scenarios. This holistic approach not only tackles the challenges faced in contemporary energy applications but also lays the groundwork for a dependable and high-performance framework for future developments in power conversion technology.

REFERENCES:

1. S. Vendoti, A. C. Shekhar, S. V. V. G. Bapuji and G. L. Reddy, "Controlling of Electrical Vehicle Charging Conditions using PV based Multi-Mode Converter," 2023 International Conference on Intelligent and Innovative Technologies in Computing, Electrical and Electronics (IITCEE), Bengaluru, India, 2023, pp. 146-149, doi: 10.1109/IITCEE57236.2023.10090924.
2. S. Vendoti, K. A. Swami, S. K. Govindaraju and D. V. S. S. Varma, "Microgrid Design For EV Fast Charging Station Using Interleaved DC-DC Converter," 2023 International Conference for Advancement in Technology (ICONAT), Goa, India, 2023, pp. 1-5, doi: 10.1109/ICONAT57137.2023.10080139
3. Nawaz, M.U., Umar, S. and Qureshi, M.S., 2024. Life Cycle Analysis of Solar-Powered Electric Vehicles: Environmental and Economic Perspectives. International Journal of Advanced Engineering Technologies and Innovations, 1(3), pp.96-115.
4. Niri, A.J., Poelzer, G.A., Zhang, S.E., Rosenkranz, J., Pettersson, M. and Ghorbani, Y., 2024. Sustainability challenges throughout the electric vehicle battery value chain. Renewable and Sustainable Energy Reviews, 191, p.114176.
5. Jiménez, A., Cabrera, P., Medina, J.F., Ostergaard, P.A. and Lund, H., 2024. Smart energy system approach validated by electrical analysis for electric vehicle integration in islands. Energy Conversion and Management, 302, p.118121.
6. Maroti, P.K., Padmanaban, S., Bhaskar, M.S., Ramachandaramurthy, V.K. and Blaabjerg, F., 2022. The state-of-the-art of power electronics converters configurations in electric vehicle technologies. Power Electronic Devices and Components, 1, p.100001.
7. Mohammad, K.S. and Jaber, A.S., 2022. Comparison of electric motors used in electric vehicle propulsion system. Indonesian Journal of Electrical Engineering and Computer Science, 27(1), pp.11-19.
8. Ravi, S.S. and Aziz, M., 2022. Utilization of electric vehicles for vehicle-to-grid services: Progress and perspectives. Energies, 15(2), pp.589.
9. Hynynen, J., Willstrand, O., Blomqvist, P. and Andersson, P., 2023. Analysis of combustion gases from large-scale electric vehicle fire tests. Fire Safety Journal, 139, p.103829.
10. De Wolf, D. and Smeers, Y., 2023. Comparison of battery electric vehicles and fuel cell vehicles. World Electric Vehicle Journal, 14(9), pp.262.
11. Vendoti, S., Muralidhar, M. & Kiranmayi, R. "Techno-economic analysis of off-grid solar/wind/biogas/biomass/fuel cell/battery system for electrification in a cluster of villages by HOMER software". Environ. Dev. Sustain., 23, 351–372 (2021). https://doi.org/10.1007/s10668-019-00583-2.
12. Vendoti Suresh, Muralidhar M., R. Kiranmayi, "Modelling and optimization of an off-grid hybrid renewable energy system for electrification in a rural areas", Energy Reports, Volume 6, 2020, Pages 594-604, ISSN 2352-4847.