ENERGY SAVINGS IN FUEL CELL POWERED MODERN DAY VEHICLES: A MACHINE LEARNING APPROACH

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INTELLIGENT ENERGY MANAGEMENT SYSTEM USING RBFNN FOR PV FUEL CELL POWERED BLDC EV WITH HIGH GAIN LANDSMAN CONVERTER

Abstract

This study introduces a Hybrid Renewable Energy System (HRES) that combines a Photovoltaic (PV) system with a fuel cell to power a Brushless DC (BLDC) motor, aimed at improving electric vehicle (EV) performance. To optimize the power production from the photovoltaic system, a Radial Basis Function Neural Network (RBFNN) based Maximum Power Point Tracking (MPPT) algorithm is used, guaranteeing that the photovoltaic system functions at its peak efficiency under fluctuating environmental circumstances. A Landsman converter is used to connect the photovoltaic system to the DC bus, facilitating efficient energy conversion and control. The major objective is to maintain a constant DC bus voltage while maximizing energy efficiency from the photovoltaic system and fuel cells. The system includes a battery and supercapacitor with a bi-directional buck-boost converter, allowing adaptable energy storage and retrieval, crucial for sustaining power equilibrium during peak demand and regenerative braking scenarios. This integration of a fuel cell, photovoltaic system, and battery guarantees uninterrupted and dependable power supply to the BLDC motor, hence improving the electric vehicle's range and performance. This project was executed on MATLAB 2021a Simulink Software.

Keywords: Simulnk, Renewable, Energy, Algorithm, Electric Vehicle

1. Introduction

Ecological and energy concerns have emerged as significant global challenges. In comparison to gasoline-powered cars, electric vehicles have considerable benefits regarding fuel efficiency and the reduction of carbon emissions. It has garnered the interest of governments and automotive manufacturers globally, and the adoption of electric vehicles persists.

Nonetheless, few incidents involving electric vehicles and fires have resulted in significant injuries to owners and workers, while safety concerns have also impacted electric vehicle manufacturing and related industries. The comprehensive execution of the nation's big data plan has validated the trend of digitalisation and intelligence within the automobile sector. Utilising big data to examine and address the issue of electric vehicle safety has emerged as a significant approach. The profound integration of electric cars and big data will catalyse a technological revolution in vehicular safety and further enhance the quality of China's electric vehicle power. Investigations into safety alerts and infractions during the charging of electric cars have commenced.

Routine vehicle electrical checks and preliminary warning assessments are often conducted by developing electrical models of the battery. Xu et al. used the open circuit voltage and state of charge (SOC) of the battery as inputs, using the equation model and the least squares approach to determine the battery's short circuit. Zhang and colleagues Develop an electrical model of the battery and analyse the simulated charging area data against the battery's illumination data to assess performance, control violations, and early warning indicators. By include state of charge (SOC), temperature, and state of health (SOH), power balance models for lithium-ion batteries may be formulated to precisely represent monitoring and control mechanisms. Certain researchers further use criminal detection and early warning systems. Mr. Song devised a security evaluation methodology for testing that encompasses three components: batteries, charging equipment, and cables. He used expert assessments and other methodologies, including the grey matching approach to ascertain the significance of each parameter. Qian and colleagues investigated Electronic vehicle protection apparatus has been created, and preliminary warning models have been established based on the fuzzy assessment of compensation devices. The structural integrity of electric vehicle batteries is inadequate, making it challenging to develop an accurate model for them. This necessitates considerable modelling work, which poses challenges from an engineering standpoint, since most models are only applicable to certain failure types.

Figure 1.1: Electric Vehicle

Hybrid systems use several electric motors to enhance power production and dependability. These systems are especially effective for tackling the convergence of renewable energy sources, like solar and wind. The attainment of renewable and sustainable energy may be realised via the integration of diverse technologies.

Figure 1.2: Intelligent Energy Systems

Hybrid systems at electric vehicle (EV) charging stations reduce dependence on the conventional grid while facilitating the attainment of sustainability objectives via the integration of renewable energy sources. This novel strategy addresses the need for more economical housing, diminishes environmental repercussions, and enhances energy security. With the increasing popularity of electric cars driven by worldwide initiatives to diminish carbon emissions and facilitate a clean energy transition, hybrid systems provide viable alternatives to aid this transformation. Hybrid systems are designed to use many energy sources, enhancing efficiency and dependability. By merging technologies like solar photovoltaic (PV) panels with generators or other electrical equipment, these systems may provide sustainable energy. The incorporation of supplementary electrical components is a crucial element of hybrid systems, particularly for EV charging stations. By integrating diverse technologies, including photovoltaic (PV) systems, wind turbines, and generators, these systems may enhance energy output and guarantee dependability. Photovoltaic panels create power under bright conditions, but wind turbines harness energy when sunlight is absent, such as on overcast days or at night. High-quality generators may serve as backup power sources to maintain uninterrupted functionality during electrical disruptions.

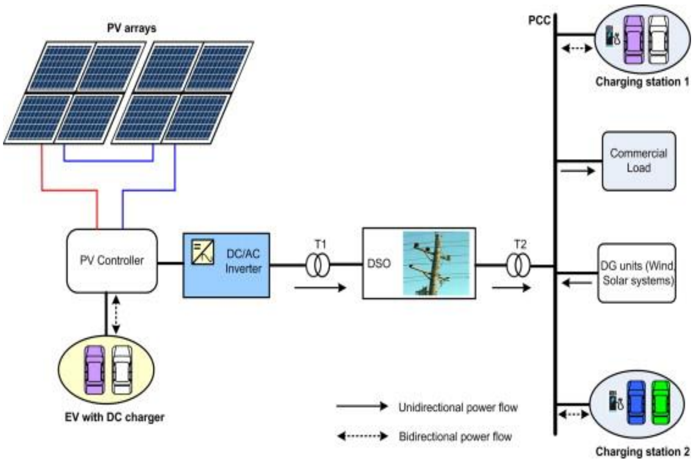

Figure 1.3: Integration of Complementary Energy Sources

Energy storage solutions are crucial for enhancing the reliability and performance of hybrid systems, particularly in electric vehicle (EV) charging stations. By harnessing surplus energy from renewable sources like solar panels or wind turbines, these systems may equilibrate supply and demand, maintaining a stable energy output even at low power levels. Battery technologies, including lithium-ion, together with advances like solid-state and rechargeable batteries, provide the necessary capacity and quick responsiveness for control. These technologies enhance substation efficiency by facilitating power acquisition from the grid during off-peak hours when energy costs are lower, enabling storage for subsequent usage.

Figure 1.4: Energy Storage Solutions

The design and engineering of intelligent electrical systems are crucial for their efficiency and performance, particularly in applications like electric vehicle (EV) charging stations. An effective hybrid system often has an integrated framework that amalgamates several energy storage options, with management that enhances their functionality. The design typically has a central controller that manages power production, consumption, and storage, allowing smooth transitions among various power sources based on prevailing circumstances. This system architecture facilitates the astute distribution of energy, guaranteeing that charging stations function dependably even throughout peak demand or inclement weather. Furthermore, the design may integrate smart grid technologies to improve connectivity with the larger energy network, therefore enabling demand response and energy trading. By emphasising flexibility and scalability in the design, hybrid systems may be customised to meet unique site circumstances and future energy requirements, rendering them adaptable solutions that respond to the changing dynamics of renewable energy and electric mobility. A strong design and architecture allow hybrid energy systems to provide sustainable and efficient electricity for electric vehicle charging stations, fostering a cleaner transportation ecology.

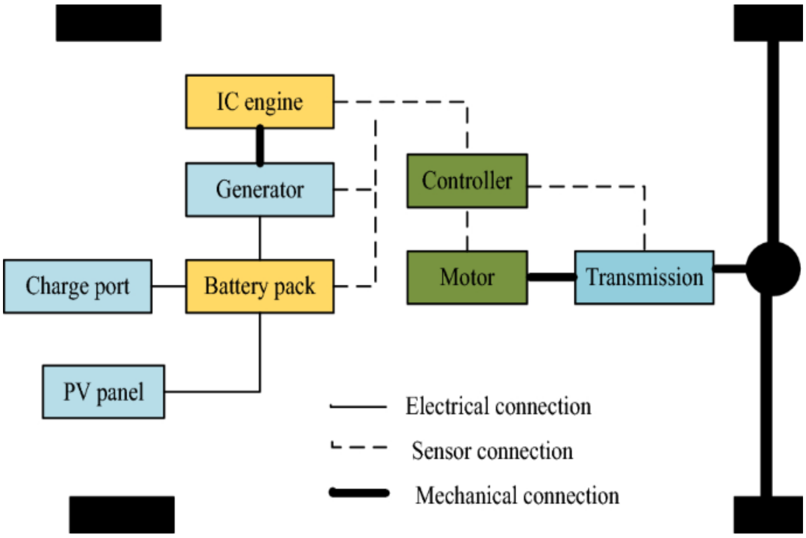

Figure 1.5: Design and Architecture of Hybrid Systems

Grid connectivity and smart grid integration are critical components of the electrical system, particularly concerning electric vehicle (EV) charging stations. These technologies interface with smart grids, enabling bidirectional communication between energy providers and consumers, hence enhancing power availability for fire management purposes.

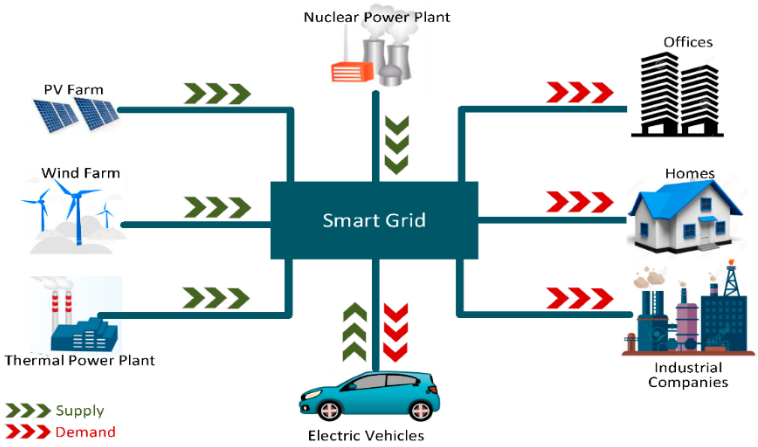

Figure 1.6: Grid Interaction and Smart Grid Integration

Smart grids use technology like sensors and real-time data analytics to enhance energy distribution and augment system dependability. In hybrid systems, electricity from renewable sources like photovoltaic (PV) panels or wind turbines may be reintegrated into the grid, enhancing earnings and sustaining whole firms. Moreover, during high demand times, EV charging stations may either take electricity from the grid or use stored energy from their integrated battery systems, so providing continuous operation. This connection facilitates the equilibrium of supply and demand while also endorsing demand response activities, allowing for the modification of charging schedules in accordance with grid circumstances. Integrating hybrid energy systems with smart grid technology improves the operating efficiency of EV charging stations and fosters a more robust and sustainable energy ecology. Public engagement and awareness are crucial for the efficacy and endorsement of hybrid electric systems, especially for electric vehicle (EV) charging stations. Robust community support may assist individuals in comprehending the advantages of the technology, including less carbon emissions, energy autonomy, and financial savings. Engaging community members in planning and decision-making enables stakeholders to mitigate fears and misunderstandings while fostering a feeling of ownership and support for the project. Educational activities, including seminars and educational campaigns, may emphasise the benefits of renewable energy and electric car adoption, therefore motivating more inhabitants to see electric vehicles as a feasible transportation alternative. Moreover, collaborations with local organisations and enterprises may augment visibility and foster cooperative initiatives, therefore further integrating hybrid systems into the community framework. A robust focus on community participation enhances project execution and fosters a culture of sustainability and environmental stewardship, guaranteeing the enduring success of hybrid energy solutions.

Technological advancements in photovoltaic (PV) systems have markedly improved their efficiency, cost-effectiveness, and versatility, rendering them more appropriate for hybrid energy systems, particularly in electric vehicle (EV) charging stations. Recent innovations, like bifacial solar panels, enable energy absorption from both surfaces, so enhancing total energy production. Moreover, advancements in solar cell materials, particularly perovskite technology, are extending efficiency beyond conventional silicon cells. Smart inverter technology is essential for enhancing grid integration and optimising energy generation according to real-time circumstances.

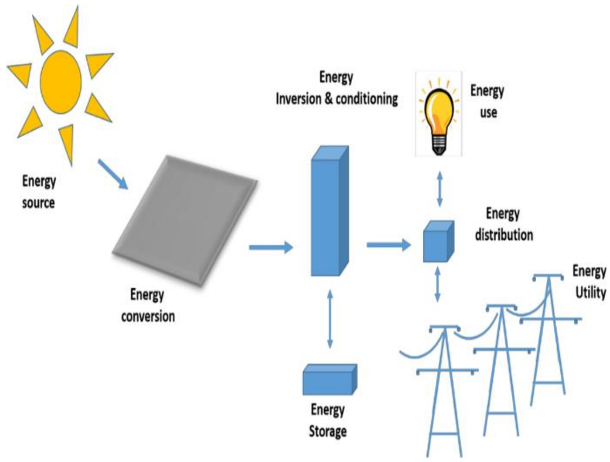

Figure 1.7: Technological Innovations in PV Systems

Additionally, innovations in power management can intelligently monitor and control photovoltaic devices, ensuring that energy is used efficiently and stored when not immediately needed. As these technologies continue to evolve, they are not only improving the performance of photovoltaic systems, but also the overall reliability and stability of hybrid energy solutions, making them an important part of the transition to clean transportation.

2. Literature Review

Isla Ziyat *et al* [2023] have proposed new concept charge curve and waveform (EV-CPW) data for AC electric vehicle charging. This file contains charge curves and high-resolution current/voltage AC waveforms for 12 different electric vehicles, including popular EVs and plug-in hybrids. Benchmarking was performed to compare EV charging behavior to new recommendations from the standard model. This includes measuring voltage, relative current and voltage, harmonic content, and behavior with line voltage and frequency. EV-CPW data can be used in many applications and research, including EV charging planning, demand management, EV charging and renewable energy research, fire electrical science, life sciences, and electrical engineering. Helps improve EV-CP system efficiency. However, when the charging power decreases, such as at the end of charging, the pulse current increases.

Yating Ding *et al* [2024] have proposed the new electric vehicle system (EV) has emerged as an important strategy to reduce carbon emissions. However, the inadequacy and inconsistency of charging stations have reduced consumers' willingness to purchase electric cars, leading to stagnation in the electric car market. Although many studies focus on the uncertainty problem in the electric vehicle market, there are few studies that investigate the charging strategy of service providers from the customer's perspective. Electric vehicles (EVs) have become an important strategy to reduce carbon emissions, enable charging service providers to make more efficient decisions, and thus increase revenue. However, as 2 increases, the demand for mobile payment will decrease. Although the cost of service is lower, the inflation period reduces the difference between fixed payment and mobile payment, making the advantage of mobile payment less obvious, causing demand to decrease.

Shahid Jaman *et al* [2023] have proposed a new framework using grid-tied modular Inverter with Integrated bidirectional charging points for residential applications are designed to increase grid reliability by providing uninterrupted services and ensuring grid security. The system includes a bidirectional electric motor that can be used as an electric vehicle (EV). It operates in different modes, such as charging and discharging electric vehicle batteries, storing excess energy from the grid when demand is low, and providing power to the grid when needed. Using grid-connected modular inverters with bidirectional charging, the system helps reduce demand while increasing overall energy efficiency. However, as the variable changes, the error rate will also increase.

G. Dhasharatha *et a*l [2024] have proposed a new frame uses a nine-stage quadrupole boost (NLQB) inverter that can measure the capacitor's own voltage, simplifying the working efficiency. More importantly, due to this self-measurement, there is no need for a power meter or a connected power meter to measure the power. A capacitor is connected to a voltage generator output stage with a suitable charge/discharge scheme. The advantage of the NLQB is to achieve high voltage gain. The inverter concept provides four times the power increase compared to conventional devices. An interesting aspect of this inverter is its ability to self-calibrate the voltage. However, the integration of these sensors introduces a certain level of loss into the overall circuit and as a precaution, the battery pack is disconnected when not in use.

Dong Sik Kim *et al* [2024] have proposed a use of new methods for EV charging time based on a combination of AC slow and DC fast chargers has been compared with the reduction of costs compared to various charging vehicles. AC payments have dynamic time of use (TOU) plans in addition to fixed-rate plans. For DC payment, there is also a subscription or membership fee plan driven by incentives such as car sales or the use of special payment facilities. Fixed plans and TOU plans are available for members and non-members. Assume that EV customers use both AC and DC chargers, and write and create various combinations of these charging plans. If the daily driving is long and the DC charging percentage is low, the AC charging cost is better. But their use is beyond a fixed problem.

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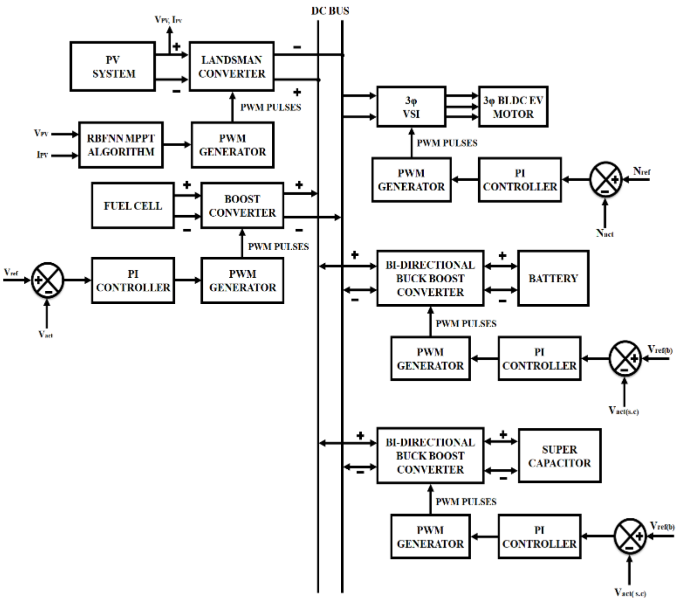

Figure 3.1: Block Diagram of Proposed System

4. Results And Discussions

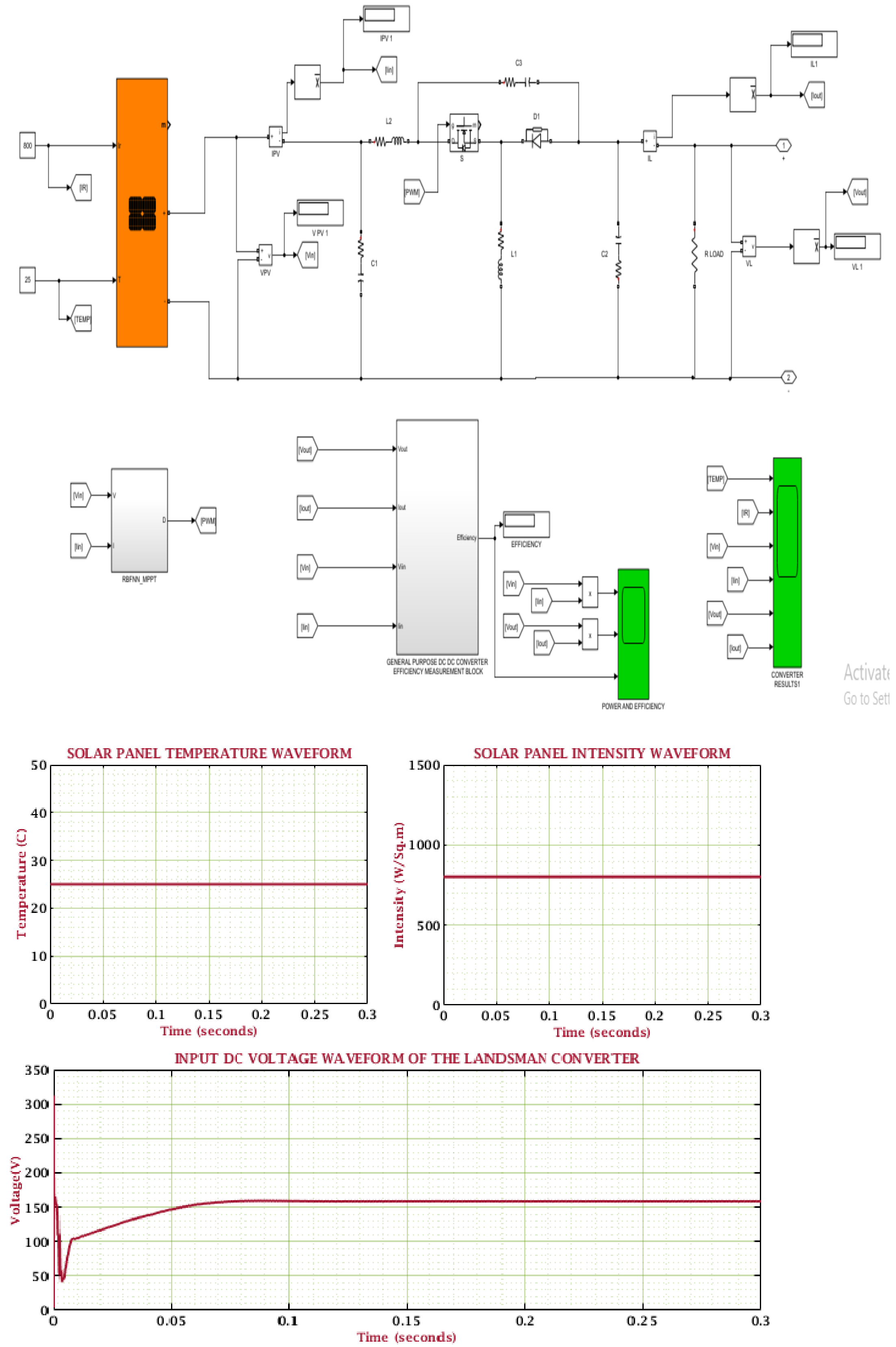

Figure 4.1: Solar Panel Landsman converter Waveforms

Figure 4.1 illustrates multiple waveforms associated with a solar power plant. The upper graph depicts the solar panel's temperature, demonstrating a constant value over time, signifying consistent thermal conditions. The central graph illustrates the solar panel's intensity, quantified in watts per square metre, which likewise seems stable, indicating consistent sunshine exposure throughout the measurement duration. The lower graph illustrates the input DC voltage waveform of the Landsman converter, which first ascends before stabilising at about 150 volts. This behaviour demonstrates that the converter effectively adjusts voltage output, which is crucial for optimum energy conversion from the solar panels. These waveforms illustrate the system's stability and performance under regulated settings.

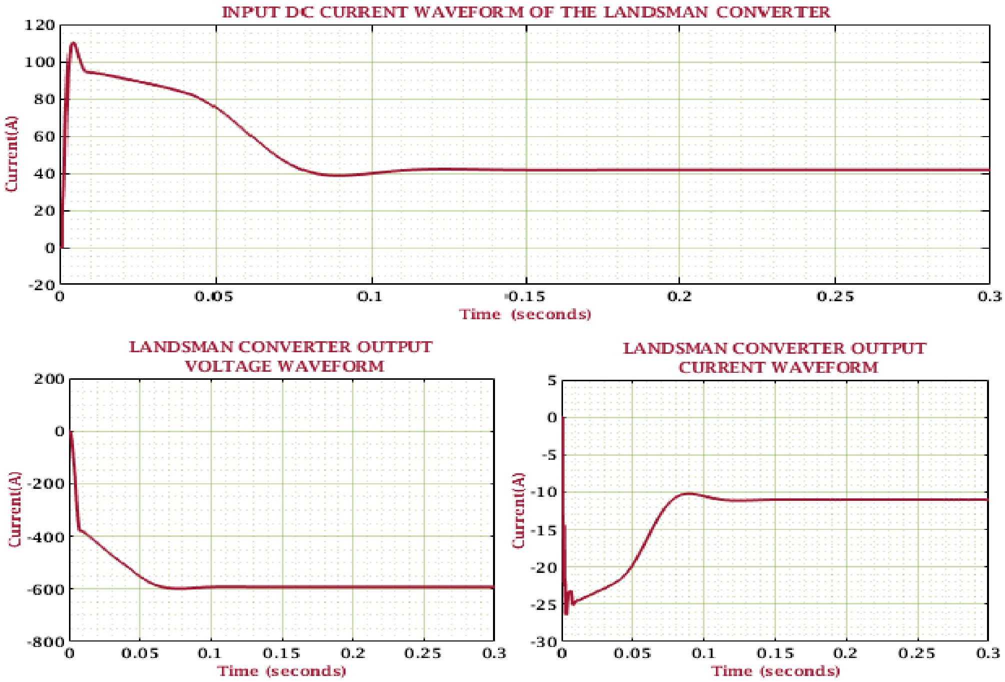

Figure 4.2: Landsman Converter Waveform

Figure 4.2 illustrates the current waveforms of a Landsman converter system. The upper graph illustrates the input DC current waveform, which first undergoes a rapid alteration before stabilising around 0 amperes. This behaviour indicates that the converter's input current rapidly adapts to operating circumstances. The central graph is the output voltage waveform of the Landsman converter, stabilising at around 200 volts. This signifies proficient voltage management, guaranteeing a stable output. The lower graph displays the output current waveform, exhibiting a consistent negative current value, which reflects the converter's output properties. Collectively, these waveforms illustrate the converter's proficiency in effectively regulating input and output currents and voltages, which is crucial for dependable energy conversion in solar power applications.

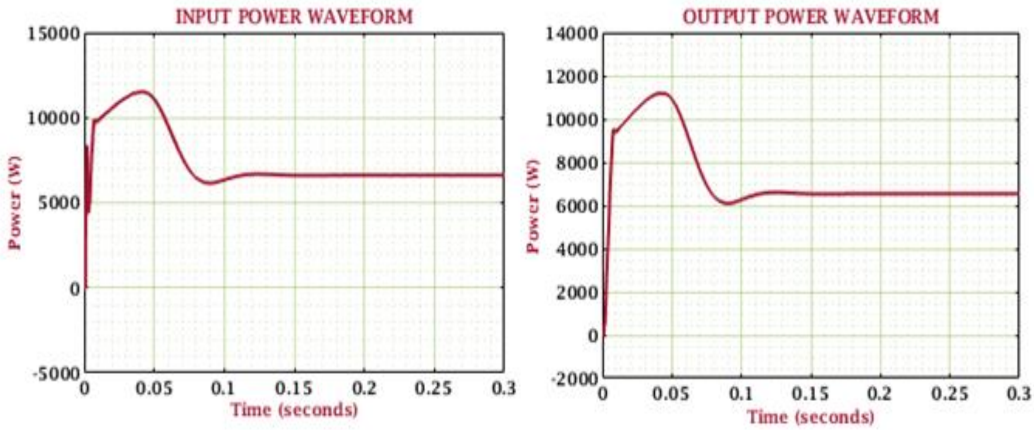

Figure 4.3: Input and Output Waveform

Figure 4.3 illustrates the power waveforms of a Landsman converter system. The left graph illustrates the input power waveform, which first reaches a peak of around 10,000 watts before stabilising close to zero, signifying a fast modulation in power flow. This indicates that the system rapidly adjusts to changing situations. In contrast, the right graph illustrates the output power waveform, which stabilises at around 6,000 watts after a short fluctuation. This steady output power illustrates the converter's efficacy in energy conversion management. Collectively, these waveforms underscore the converter's capacity to proficiently manage input and output power, crucial for optimum functionality in solar energy systems.

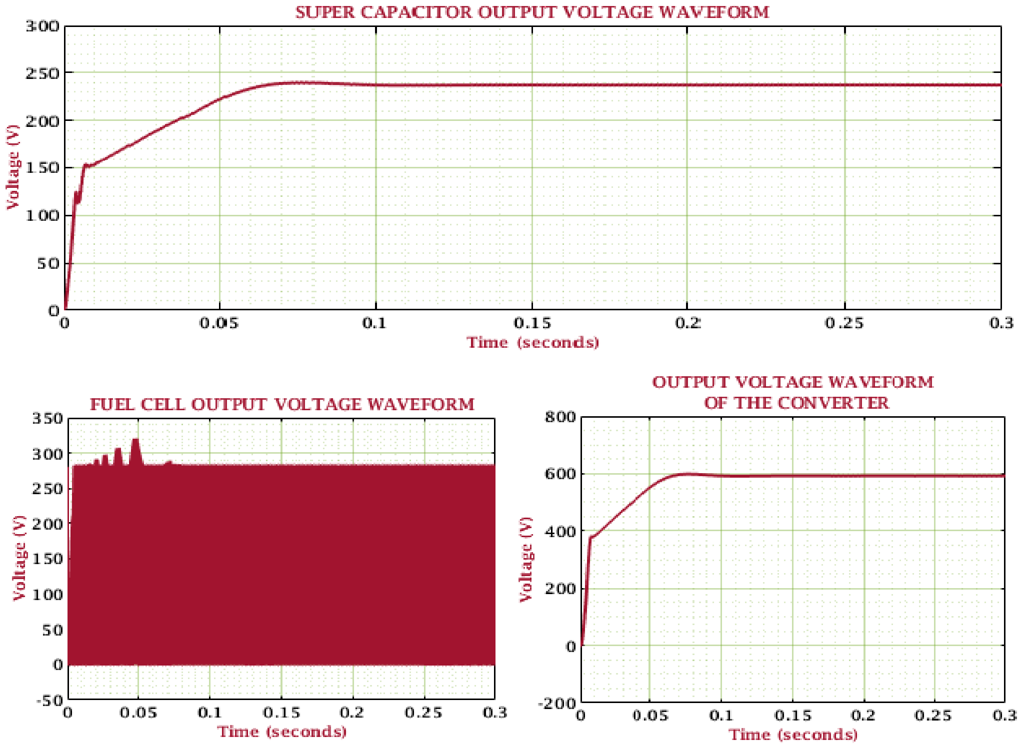

Figure 4.4: Super Capacitor, Fuel Cell and Converter Output Voltage Waveform

Figure 4.4 illustrates the voltage waveforms related to a Landsman converter system. The upper graph depicts the supercapacitor output voltage, which progressively increases and stabilises at about 250 volts, signifying efficient energy storage and transmission. The bottom left graph illustrates the fuel cell output voltage, first exhibiting a low voltage until achieving stability. This indicates that the fuel cell undergoes a transient adjustment phase prior to achieving stable functioning. The bottom right graph illustrates the converter's total output voltage, which stabilises at roughly 250 volts. Collectively, these waveforms illustrate the converter's capacity to sustain consistent voltage outputs from both the supercapacitor and the fuel cell.

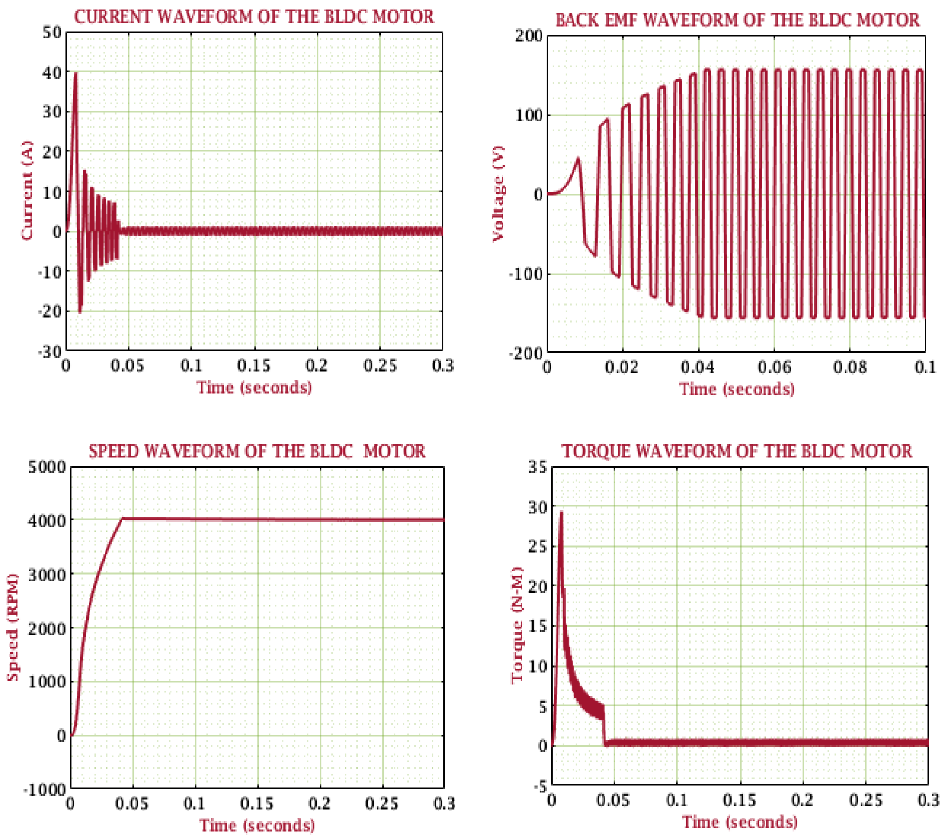

Figure 4.5: BLDC Motor Waveforms

Figure 4.5 illustrates the performance metrics of a Brushless DC (BLDC) motor. The upper left graph depicts the current waveform, with an early spike that rapidly stabilises, signifying the motor's efficient startup and subsequent consistent performance. The upper right graph illustrates the oscillation of the back electromotive force (EMF) waveform during motor operation, signifying the dynamic interplay between the motor's magnetic fields and electrical inputs. The bottom left graph illustrates the speed waveform, demonstrating the motor's swift attainment of a steady speed, indicative of efficient acceleration and performance. The bottom right graph illustrates the torque waveform, which stabilises at a uniform level, indicating the motor's capacity to provide constant torque production throughout operation. Collectively, these waveforms demonstrate the efficiency and performance attributes of the BLDC motor.

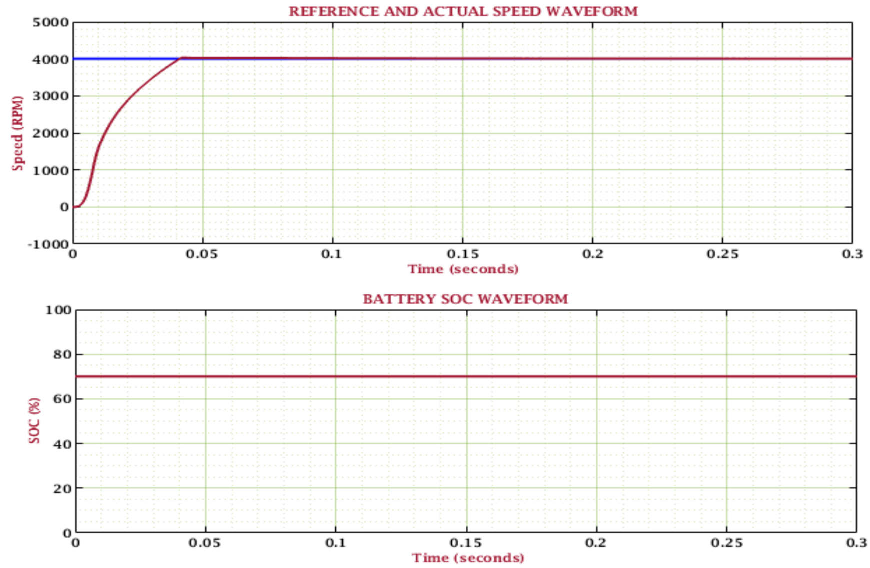

Figure 4.6: Reference and Actual Speed and Battery SOC Waveform

Figure 4.6 illustrates the critical parameters pertaining to motor control and battery performance. The upper graph displays the reference and actual speed waveforms of the motor. The real speed first increases swiftly, demonstrating good acceleration towards the reference speed of roughly 4000 RPM, which it thereafter sustains consistently. This indicates the motor's responsiveness to control inputs and its capacity to achieve required operating speeds effectively. The lower graph depicts the battery's state of charge (SOC) waveform, which stays stable at 60%. This signifies that the battery is neither charging nor draining during this interval, implying that it is in a stable condition while supplying power to the motor. Collectively, these waveforms provide information about the motor's efficacy and the battery's operating reliability.

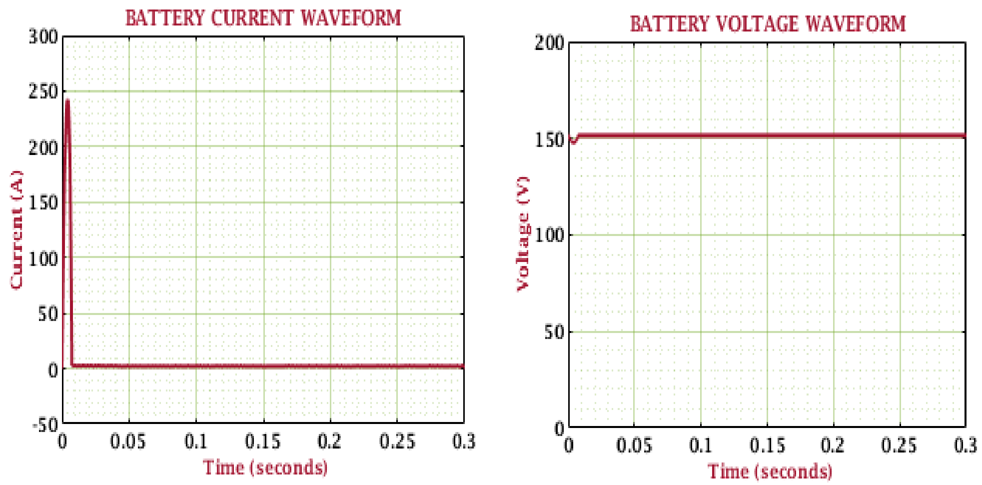

Figure 4.7: Battery Current and Voltage Waveform

Figure 4.7 illustrates the battery's current and voltage waveforms over time, offering insights into its functioning. The left graph illustrates the battery current waveform, exhibiting an early spike that signifies a substantial need for electricity during system activation. This increase rapidly stabilises at a lower, constant level, indicating the battery's capacity to provide a steady current to the load after the initial demand. Conversely, the right graph depicts the battery voltage waveform, which stays stable at roughly 150 volts. This stability signifies that the battery is proficiently sustaining its voltage output under load situations. Collectively, these waveforms underscore the battery's capacity to provide consistent current and sustain voltage, crucial for optimum system functionality.

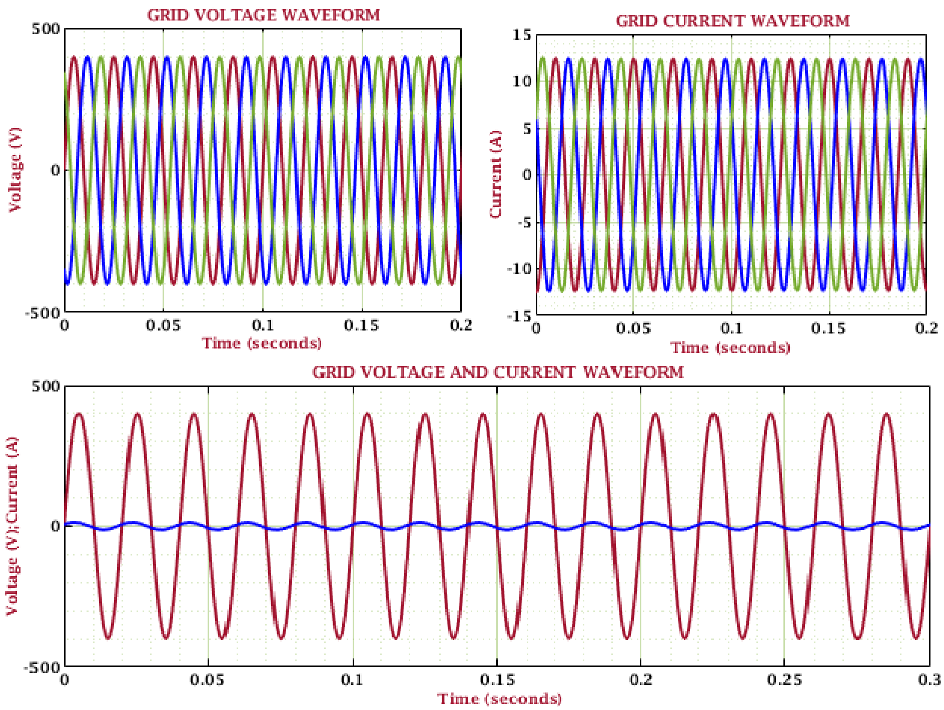

Figure 4.8: Grid Voltage and Current Waveform

Figure 4.8 depicts the voltage and current waveforms of a grid system over time, demonstrating the interaction between these two essential elements. The upper graph displays the grid voltage waveform, distinguished by a sinusoidal pattern that fluctuates around zero, signifying the alternating characteristic of the power source. The central graph displays the grid current waveform, which demonstrates a sinusoidal pattern with a phase shift in relation to the voltage. The phase difference is essential for comprehending power factor and energy efficiency inside the system. The lower graph amalgamates both waveforms, with voltage shown in blue and current in red. Examining these correlations facilitates the evaluation of grid stability, load characteristics, and overall system performance in electrical distribution.

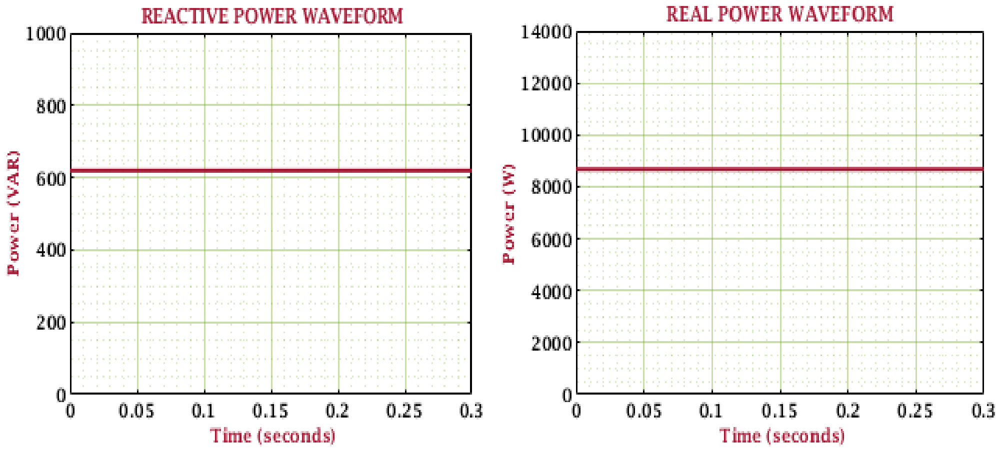

Figure 4.9: Real Power and Reactive Power Waveform

Figure 4.9 illustrates the waveforms of reactive power and actual power in an electrical system during a short time span. The left graph illustrates the reactive power, quantified in volt-amperes reactive (VAR), which remains consistently around 600 VAR. This steady level indicates the existence of inductive loads that need reactive power to generate magnetic fields. Conversely, the right graph illustrates the actual power, quantified in watts (W), which stays stable at about 8000 W. This figure denotes the real power used by the system to execute tasks. Examining these waveforms is vital for comprehending the equilibrium between reactive and actual power, which is essential for enhancing energy efficiency and maintaining stability in electrical systems.

5. CONCLUSION

This research illustrates that the incorporation of hybrid renewable energy systems (HRES) may enhance the efficiency and performance of electric cars (EVs). Integrating photovoltaic

(PV) generators with gas to power a brushless DC (BLDC) generator enhances energy efficiency and effectiveness, hence improving the performance of the electric vehicle. A maximum power point tracking is used to guarantee that solar systems function at peak efficiency and adjust to environmental variations, including exchange rates. Moreover, the use of Landsman converters guarantees an effective link between the photovoltaic system and the DC bus, facilitating steady power conversion and consistent voltage. The integration of batteries and supercapacitors, together with a bidirectional booster generator, enhances the system's flexibility by facilitating energy conservation and recovery. Maintaining energy balance is particularly crucial during heavy labour or recovery that requires a rapid surge of energy. The system's efficacy was validated by simulation using MATLAB 2021a Simulink, showing its capacity to enhance the performance and dependability of electric cars.

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