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An Advanced Dual-Input High-Gain DC-DC Converter for Solar-Assisted Electric Vehicle Charging Systems

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Abstract: This paper presents the design, modelling, and simulation of an advanced dual-input high-gain DC–DC converter for solar-assisted electric vehicle (EV) energy systems. The proposed system integrates two energy sources—solar panels and a battery—to ensure continuous and efficient power delivery under varying operating conditions. The converter is designed to achieve high voltage gain and provide a stable DC link voltage, which is essential for reliable motor drive operation. Simulation results demonstrate that the system successfully maintains a constant DC link voltage of approximately 350V with minimal fluctuations, ensuring a stiff and stable power supply. The inverter produces balanced line-to-line voltages, enabling efficient operation of the BLDC motor. The motor achieves a fast dynamic response, reaching the reference speed of 1500 RPM within a short time and maintaining steady-state operation with high precision. Additionally, the stator current and back-EMF waveforms confirm smooth motor performance and proper commutation, while the electromagnetic torque results indicate strong starting capability and stable operation under load conditions. Overall, the proposed converter system exhibits excellent performance in terms of voltage regulation, speed control, and energy management. The integration of solar and battery inputs enhances system reliability and efficiency, making it a suitable solution for next-generation electric vehicles.

Keyword: Electric Vehicle (EV), DC–DC Converter, Dual-Input Converter, Solar Energy, BLDC Motor, PWM Control, High-Gain Converter, Renewable Energy.

I. INTRODUCTION

The increasing demand for sustainable transportation and the depletion of fossil fuel resources have accelerated the development of electric vehicles (EVs) and hybrid electric vehicles (HEVs). These technologies offer reduced emissions, improved energy efficiency, and lower environmental impact compared to conventional internal combustion engine vehicles. However, the large-scale adoption of EVs depends on the availability of efficient charging infrastructure and reliable energy sources. In this context, solar energy emerges as a promising renewable solution due to its abundance, sustainability, and eco-friendly nature. Solar-powered EV charging systems integrate photovoltaic (PV) modules with power electronic converters to generate and supply clean energy. Since PV output varies with environmental conditions such as solar irradiance and temperature, Maximum Power Point Tracking (MPPT) techniques are employed to ensure optimal energy extraction. Additionally, grid-connected configurations enhance system flexibility by enabling bidirectional energy flow between the EV, solar panels, and the utility grid.

Efficient energy conversion and control in such systems are achieved using power electronic converters, particularly DC–DC converters like buck, boost, and buck–boost topologies, which regulate voltage levels based on load requirements while maintaining high efficiency. Advanced converters such as the Cuk converter further improve performance by reducing current ripple through capacitive energy transfer. In EV propulsion, Brushless DC (BLDC) motors are widely preferred due to their high efficiency, reliability, and superior dynamic characteristics, achieved through electronic commutation instead of mechanical brushes. Voltage Source Inverters (VSIs) are used to convert DC power into controlled AC output, enabling precise speed and torque control of the motor. Overall, the integration of solar energy systems, advanced power electronic converters, and efficient motor drives forms a strong foundation for next-generation EV technologies, significantly enhancing system efficiency while contributing to reduced carbon emissions and sustainable energy utilization.

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II. METHODOLOGY

The proposed system presents a solar-assisted electric vehicle (EV) drive architecture that integrates a photovoltaic (PV) source, battery storage, a dual-input DC–DC converter, and a BLDC motor drive. The methodology focuses on achieving efficient energy utilization, high voltage gain, and stable motor performance under varying environmental conditions.

The system employs a dual-source power configuration, where the PV array acts as the primary energy source and the battery serves as a backup. Due to the intermittent nature of solar energy, the battery ensures uninterrupted power supply during low irradiance conditions or sudden load variations. Both sources are connected to a common DC link, enabling continuous and stable energy delivery to the EV drive system.

A dual-input power management strategy is implemented to regulate energy flow between the PV system and the battery. Priority is given to solar energy to maximize renewable utilization and minimize battery discharge cycles. Controlled switching mechanisms and feedback-based control algorithms ensure smooth power sharing and prevent overloading of individual sources, thereby improving system reliability and lifespan.

To meet the high voltage requirements of the EV motor, a high-gain super-boost DC–DC converter is utilized. Unlike conventional boost converters, the proposed topology achieves high voltage gain at lower duty cycles by incorporating additional passive components and voltage multiplier techniques. This reduces switching stress and improves efficiency. Continuous input current operation minimizes ripple and enhances source performance, making the converter suitable for EV applications.

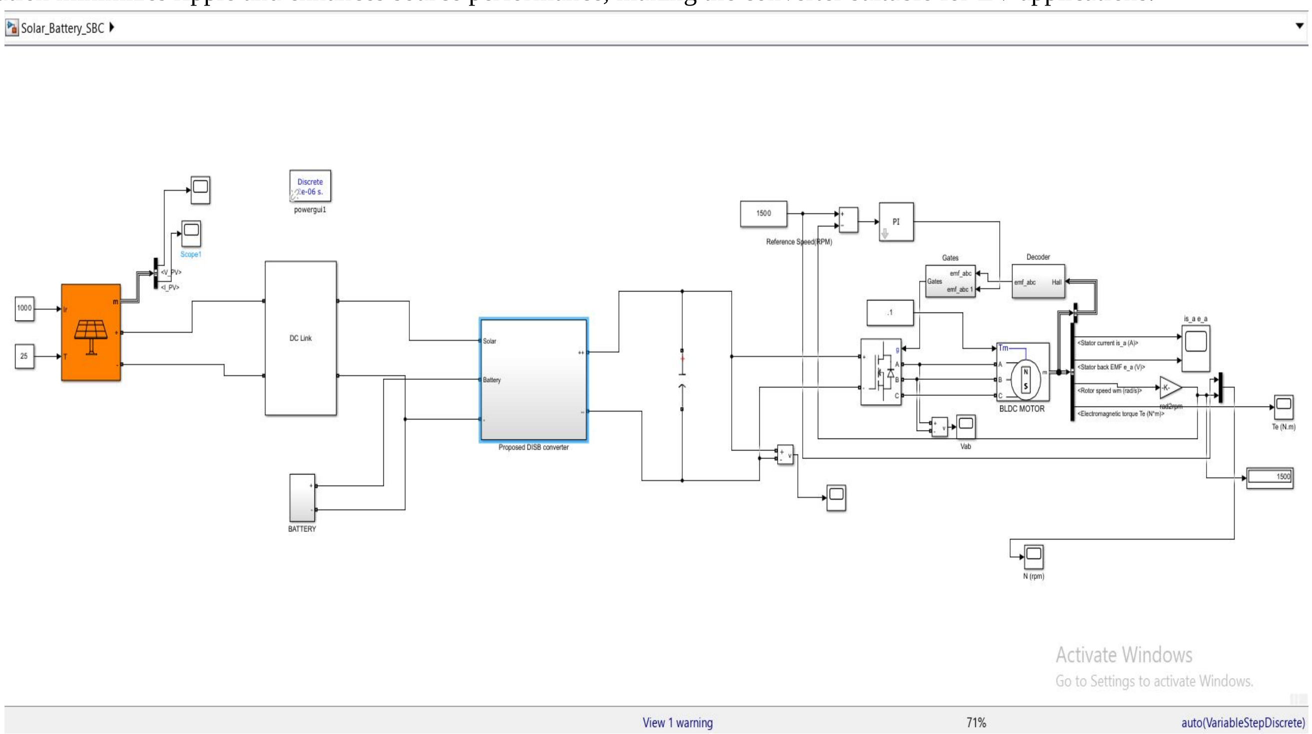

Figure:1 Simulation diagram of circuit. The picture illustrates a Simulink model of a solar-assisted electric vehicle power system

The system operates in adaptive modes based on solar availability. Under high irradiance, the PV source supplies the load and charges the battery if excess energy is available. During low irradiance or cloudy conditions, the system automatically switches to battery-assisted mode without interrupting the DC output. This seamless transition is achieved through real-time voltage and current sensing, ensuring uninterrupted operation.

A Pulse Width Modulation (PWM)-based control scheme is employed to regulate the converter output voltage. The duty cycle is continuously adjusted using feedback signals to maintain a constant DC-link voltage despite variations in input or load conditions. This ensures stable motor operation, minimizes voltage fluctuations, and provides smooth acceleration with reduced overshoot and undershoot. To enhance efficiency, power loss minimization techniques are incorporated, including the use of low-resistance switching devices, optimized switching frequency, and proper circuit design. Additional measures such as snubber circuits and thermal management reduce switching losses and improve system reliability. Reduced current ripple further minimizes conduction losses in passive components.

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The regulated DC output is supplied to a DC-link capacitor, which smooths voltage ripples before feeding a three-phase inverter. The inverter converts DC power into AC supply required for the BLDC motor. A closed-loop control system is implemented, where the motor speed is compared with a reference value (e.g., 1500 rpm), and a PI controller generates PWM signals for inverter switching. This ensures precise speed control, stable torque, and improved dynamic response.

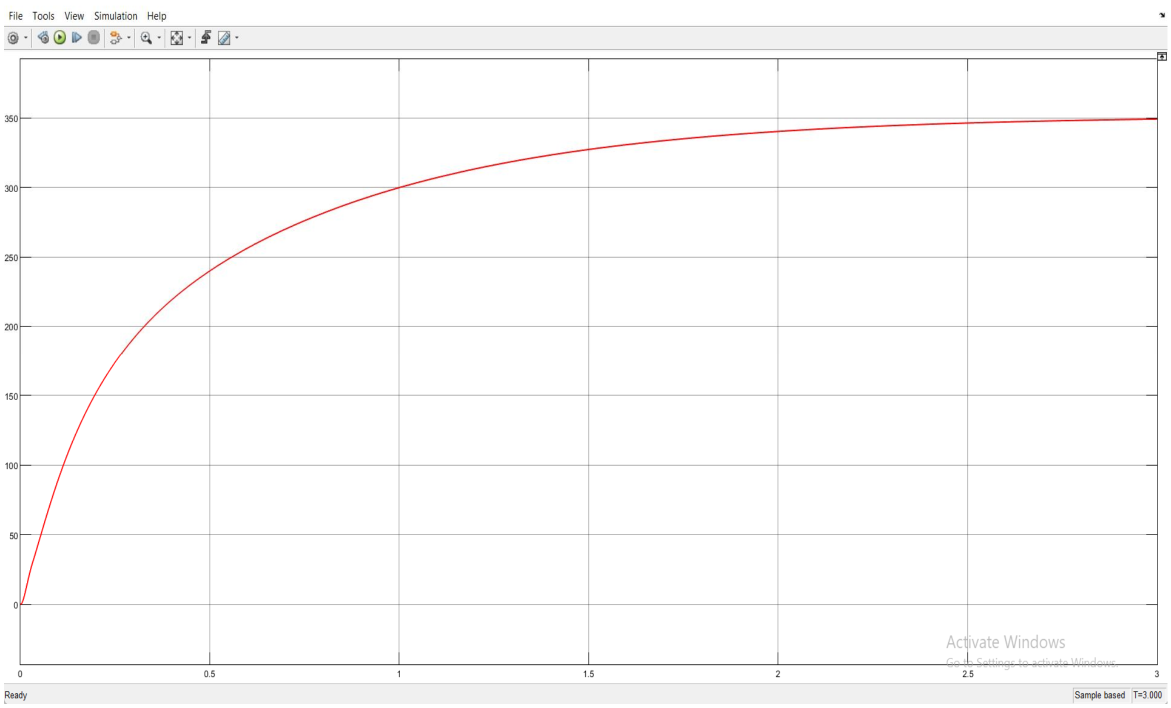
The complete system is modelled and simulated in MATLAB/Simulink to validate performance. Key parameters such as voltage regulation, current ripple, efficiency, and dynamic response are analysed under varying conditions. The results confirm that the proposed system provides stable DC output, efficient energy utilization, and reliable BLDC motor operation, making it suitable for solar-powered EV applications.

III. SIMULATION AND RESULTS

The performance of the proposed solar-assisted electric vehicle (EV) system is evaluated using MATLAB/Simulink under various operating conditions. The results demonstrate the effectiveness of the dual-input high-gain DC–DC converter, inverter, and BLDC motor drive in achieving stable voltage regulation, efficient energy utilization, and reliable motor performance.

A. DC-Link Voltage Response

The DC-link voltage waveform illustrates the dynamic behaviour of the system during startup and steady-state conditions. At the initial stage (t = 0), the voltage starts from zero and rises rapidly due to the charging of the DC-link capacitor and the action of the high-gain converter. This fast transient response indicates efficient energy transfer from both the photovoltaic (PV) source and battery.



Y-axis: DC Voltage
(volts)

X-axis: Time (seconds)

Figure: 2 The graph represents the DC-link voltage response of the system with respect to time

As time progresses, the voltage exhibits a smooth exponential rise and gradually approaches the desired steady-state value of approximately 350 V. The absence of oscillations or overshoot confirms the stability of the converter and the effectiveness of the control strategy. The settling time is observed to be around 2 seconds, indicating a well-damped system response. Such behaviour is highly desirable in EV applications as it ensures safe operation, prevents component stress, and provides a stable DC supply for the inverter stage.

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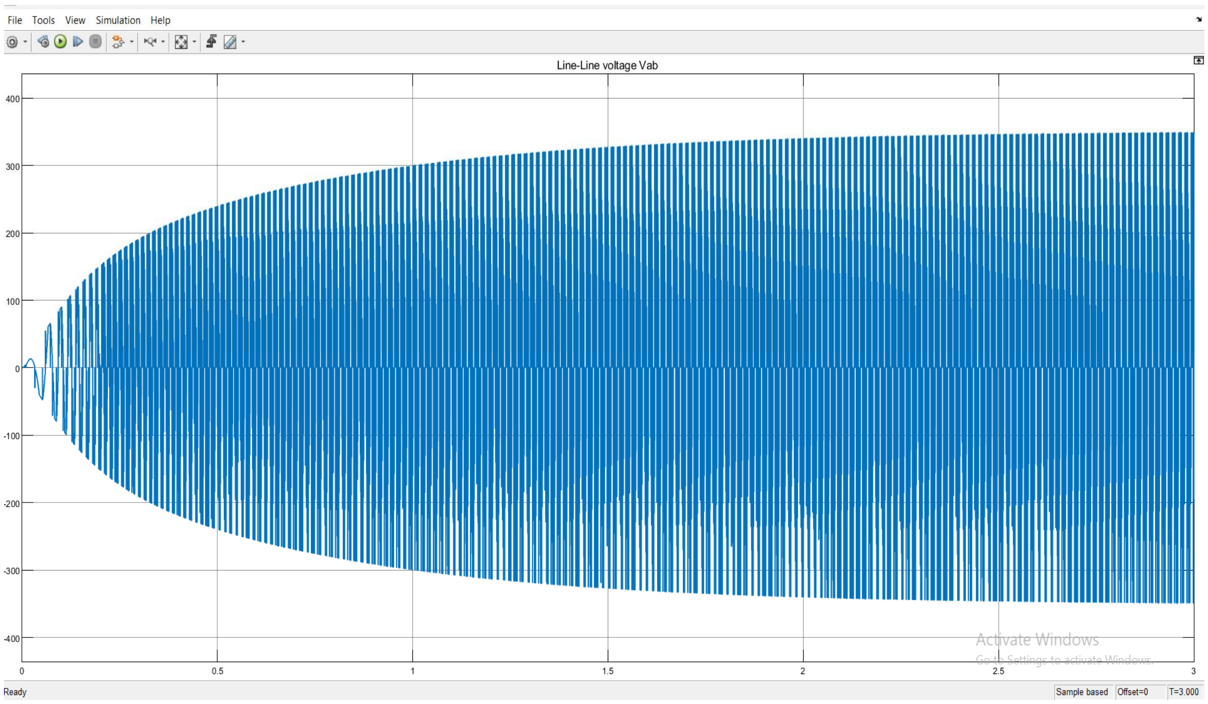
B. DC-Link and Inverter Output Voltage

The stabilized DC-link voltage serves as the input to the three-phase inverter, which converts DC power into AC voltage required for the BLDC motor. The line-to-line voltage (V_{ab}) waveform demonstrates a high-frequency PWM output with a peak-to-peak amplitude of approximately 700 V, consistent with the 350 V DC-link input. The waveform shows a gradual increase in modulation index during startup, representing a soft-start operation that minimizes electrical stress on the motor windings. The balanced and symmetrical nature of the inverter output confirms proper phase coordination and effective switching control. This ensures efficient power conversion and improved motor performance.

Y-axis: Voltage (Volts)



X-axis: Time (seconds)

Figure: 3 Line-to-line voltage V_{ab} of a three-phase inverter feeding a BLDC motor.

C. Speed Response and Closed-Loop Control

The rotor speed response under closed-loop control demonstrates excellent tracking performance. The motor accelerates rapidly and reaches the reference speed of 1500 RPM within 0.5 seconds. A small and controlled overshoot is observed during the transient phase, which is typical in high-performance systems designed for fast response.

After the transient period, the speed stabilizes precisely at the reference value with negligible steady-state error. The flat steady-state response indicates that the PI controller, along with Hall sensor feedback, effectively regulates the motor speed. This precise speed control is essential for EV applications, ensuring smooth operation, improved efficiency, and enhanced driving comfort even under varying load conditions.

D. Stator Current and Back-EMF Characteristics

The stator current waveform shows a high initial peak corresponding to the starting torque requirement. As the motor reaches steady-state operation, the current transitions into a stable periodic waveform, indicating balanced three-phase operation. The absence of significant distortions or fluctuations confirms that the DC-link voltage is well-regulated and free from excessive ripple.

The back electromotive force (EMF) waveform exhibits a trapezoidal shape, which is characteristic of BLDC motors. The amplitude of the back-EMF increases proportionally with motor speed, reaching approximately 70 V at rated conditions. The symmetry and consistency of the waveform indicate proper commutation and accurate rotor position sensing. This ensures efficient torque production and minimizes energy losses.

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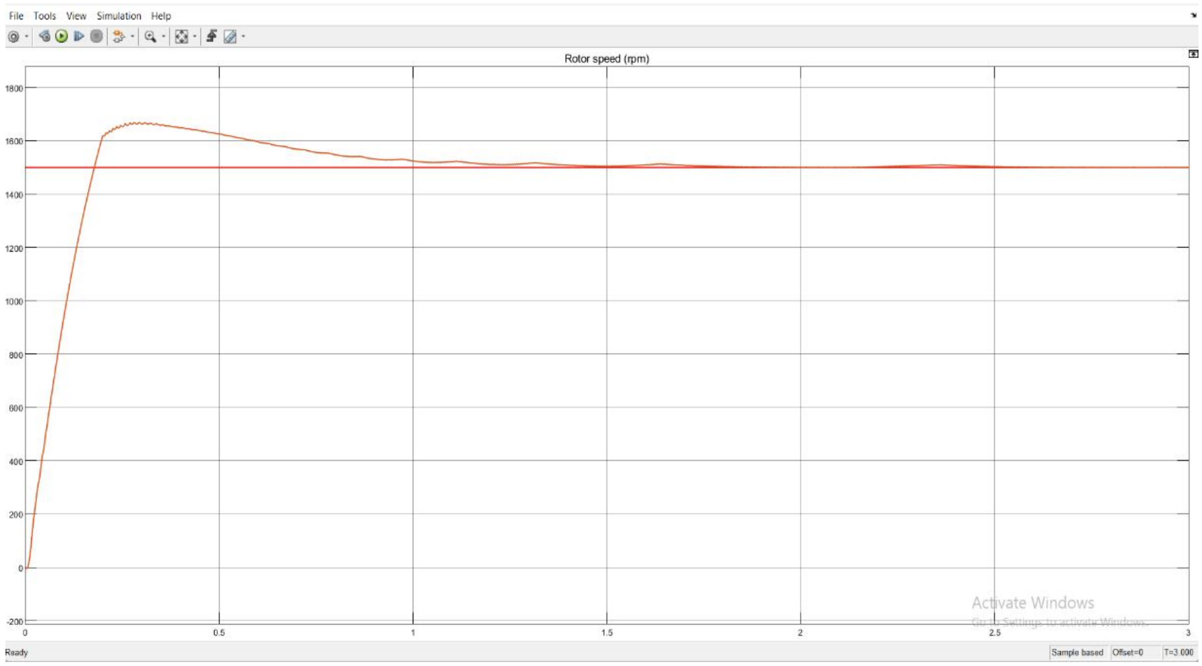
Y axis: Rotor Speed (RPM)



X axis: Time (seconds)

Figure :4Rotor speed (RPM) response vs time of your BLDC motor under closed-loop control.

- Red horizontal line → Reference speed (1500 RPM)
- Orange curve → Actual motor speed

E. Electromagnetic Torque Performance

The electromagnetic torque (T_e) waveform highlights the system's capability to handle dynamic load conditions. During startup, the torque reaches a peak value of approximately 1.0 Nm, providing sufficient force to accelerate the motor rapidly. Once the motor reaches the reference speed, the torque stabilizes within a range of 0.4–0.6 Nm.

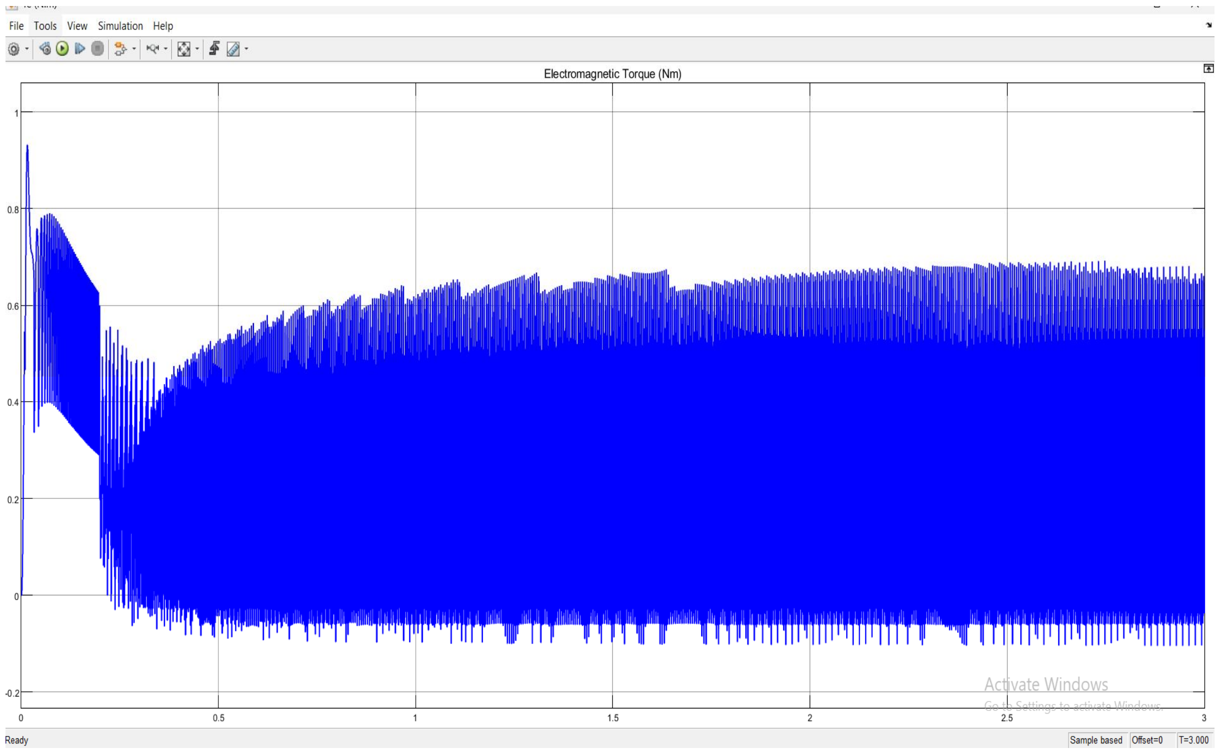
The steady torque output indicates that the system can maintain continuous operation under load without significant fluctuations. The high-frequency ripple observed in the torque waveform is due to PWM switching but does not affect the average torque value. This ensures smooth motor operation and enhances overall system reliability.

F. Overall System Performance

The simulation results validate the effectiveness of the proposed dual-input high-gain DC–DC converter in maintaining a stable DC-link voltage under varying input conditions. The seamless integration of solar and battery sources ensures uninterrupted power supply and efficient energy management.

The inverter and BLDC motor drive system demonstrate excellent dynamic response, precise speed control, and stable torque characteristics. The coordinated operation of all subsystems results in improved efficiency, reduced losses, and enhanced reliability. Compared to conventional systems, the proposed architecture provides superior performance in terms of voltage stability, energy utilization, and motor control .Overall, the results confirm that the proposed system is well-suited for solar-powered electric vehicle applications, offering a reliable, efficient, and sustainable solution for future transportation systems.

Y-axis: Torque/ (Newton-meter)



X-axis: Time (seconds)

Figure :5 This figure shows the Electromagnetic Torque (Te) waveform of a motor over time

IV. CONCLUSION

The proposed solar-assisted electric vehicle (EV) system integrating a dual-input high-gain DC–DC converter, battery storage, and BLDC motor drive demonstrates effective energy management and reliable performance. The system successfully combines solar and battery sources to ensure uninterrupted power supply under varying environmental conditions. The high-gain converter achieves stable DC-link voltage with minimal ripple and fast dynamic response, while the PWM-based control strategy maintains voltage regulation despite input and load variations. Simulation results confirm smooth startup characteristics, efficient voltage conversion, and stable inverter operation, validating the robustness of the overall architecture.

Furthermore, the BLDC motor drive exhibits excellent dynamic behaviour, including rapid speed tracking, minimal steady-state error, and consistent torque output. The integration of closed-loop control with Hall sensor feedback ensures precise commutation and efficient motor operation. Overall, the system improves energy utilization, reduces dependence on conventional energy sources, and enhances operational efficiency. These features make the proposed design a suitable and sustainable solution for future electric vehicle applications, with potential for further optimization and real-time implementation.

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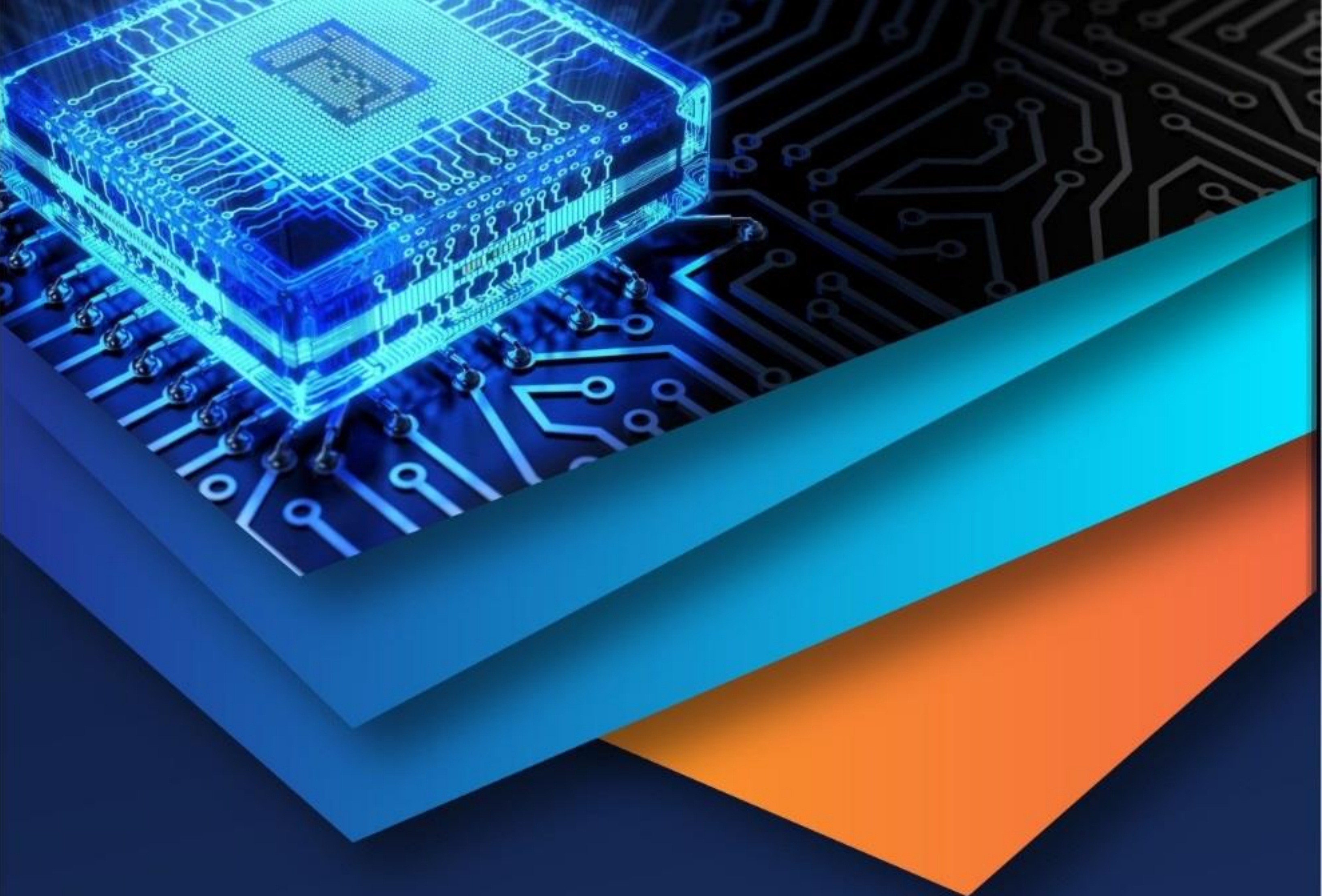

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