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REGENERATIVE BRAKING OF MATRIX CONVERTER UNDER SLIDING MODE CONTROL

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Abstract:

The growing demand for energy-efficient and environmentally friendly transportation solutions has spurred significant advancements in electric vehicle technology. Among the key innovations is regenerative braking, a technique that recaptures and stores energy during braking events. This report investigates the application of sliding mode control to the regenerative braking system of an electric vehicle utilizing a matrix converter. The matrix converter, known for its bidirectional power flow capabilities and efficiency advantages, is seamlessly integrated into the system to enable energy conversion between the electric motor and the energy storage system. Sliding mode control, renowned for its robustness against uncertainties and disturbances, is employed to orchestrate the matrix converter's modulation patterns during regenerative braking.The report presents a comprehensive overview of the electric vehicle system architecture, matrix converter operation, and the principles of sliding mode control. The proposed control strategy is validated through simulation/experimental results, showcasing the effectiveness of the approach in optimizing energy recovery during regenerative braking. Energy efficiency metrics are analyzed, and stability considerations are discussed to underscore the performance gains achieved through sliding mode control.The study contributes to the understanding of advanced control strategies in electric vehicle systems, offering insights into the synergistic combination of matrix converters and sliding mode control for enhanced regenerative braking performance. The results demonstrate the potential for increased energy savings and improved overall vehicle range, thus paving the way for greener and more efficient transportation solutions in the future.

Keywords — **Regenerative braking, matrix converter, sliding mode control, electric vehicle, energy efficiency, power electronics.**

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I. INTRODUCTION

The urgent need for sustainable and energy-efficient transportation solutions has led to remarkable advancements in electric vehicle (EV) technology. Electric vehicles offer numerous benefits, including reduced greenhouse gas emissions, decreased reliance on fossil fuels, and quieter operation. One of the crucial areas of innovation in the field of EVs is regenerative braking—a technology that enables the recovery and reuse of energy during braking events, thereby enhancing overall energy efficiency and extending vehicle range.

Regenerative braking involves the conversion of kinetic energy into electrical energy during deceleration, which is then stored for subsequent use, typically in the vehicle's energy storage system. This technology not only reduces wear on traditional friction-based braking systems but also contributes significantly to the overall energy balance of electric vehicles. However, efficient implementation of regenerative braking necessitates sophisticated power electronics and control strategies.

Matrix converters have emerged as promising candidates for controlling the power flow between different energy sources and loads in various applications, including EVs. A matrix converter is a power electronic device that offers advantages such as bidirectional power flow, reduced component count, and increased efficiency compared to traditional converters. Its direct AC-AC conversion capabilities make it particularly appealing for regenerative braking systems, as it allows seamless energy transfer between the electric motor and the energy storage system.

To harness the full potential of matrix converters in regenerative braking, advanced control strategies are crucial. Sliding mode control, renowned for its ability to maintain stability and performance under uncertain operating conditions, presents an attractive approach to tackle the challenges posed by regenerative braking control. Sliding mode control aims to drive the system state variables onto a predefined sliding surface, resulting in robust and efficient control, even in the presence of uncertainties and external disturbances.

This report delves into the integration of matrix converters and sliding mode control for optimizing regenerative braking in electric vehicles. It provides a comprehensive analysis of the electric vehicle system architecture, matrix converter operation, sliding mode control principles, and their combined application to achieve efficient energy recovery during braking events. The subsequent sections detail the methodology, simulation/experimental results, and insights gained from this study, shedding light on the potential benefits of this innovative approach for advancing electric vehicle technology.

In the following sections, we will explore the theoretical underpinnings of matrix converters, sliding mode control, and their harmonious integration in the context of regenerative braking systems. The experimental setup, results, and implications will be presented, ultimately contributing to the broader understanding of sustainable and energy-efficient transportation solutions.

II. MATERIAL

A. BLDC MOTOR

Regenerative braking is a method of braking in which the kinetic energy of the moving vehicle is converted back into electrical energy and stored or reused instead of being dissipated as heat, as in traditional friction-based braking systems.When the driver applies the brakes, the BLDC motor switches from its motoring mode (driving the vehicle) to its generating mode (acting as a generator). In this mode, the motor converts mechanical energy (the vehicle's kinetic energy) into electrical energy. In regenerative braking, the BLDC motor is controlled to act as a generator by adjusting the commutation of its windings.As the vehicle slows down, the wheels drive the motor, causing it to rotate. The motor generates electrical energy, which is typically in the form of three-phase AC power.The electrical energy generated by the BLDC motor needs to be converted into a form that can be stored or reused.In some advanced regenerative braking systems, a matrix converter can be used to directly convert the generated AC voltage to a form that can be fed back into the vehicle's electrical system, such as the battery or supercapacitors.

B. MATRIX CONVERTER

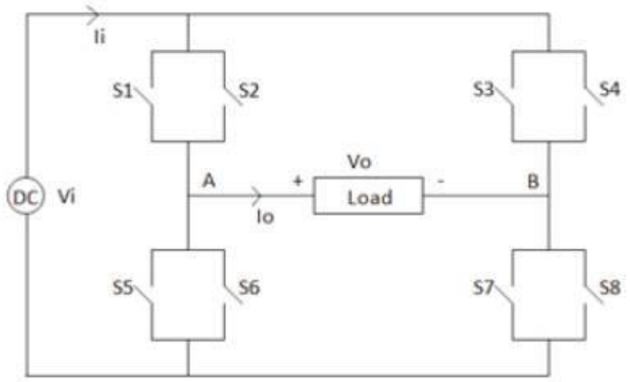
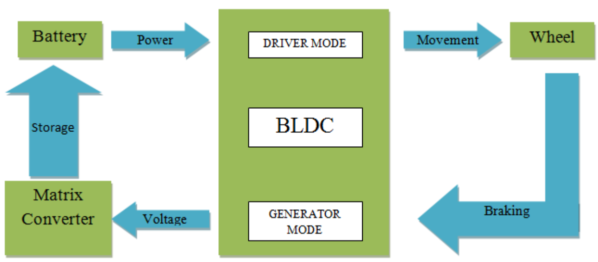


Fig.1.Matrix converter

The integration of matrix converters in electric vehicles goes beyond the realm of regenerative braking. Electric vehicles are not just energy consumers; they can also act as energy sources. Matrix converters facilitate bidirectional charging, allowing the EV to not only draw power from the grid but also feed excess energy back into it. This bidirectional capability supports vehicle-to-grid (V2G) and grid-to-vehicle (G2V) applications. In a V2G scenario, the EV becomes a mobile energy resource that can supply electricity to the grid during peak demand, thus contributing to grid stability. In a G2V setup, the vehicle can recharge during off-peak hours when electricity rates are lower, saving the owner money. The matrix converter's role in this context is to efficiently manage the bidirectional power flow, ensuring that energy conversion is optimal both ways.Matrix converters are not confined to the realm of energy recovery and storage—they also play a pivotal role in enhancing the efficiency of the EV's powertrain. Traditional powertrain architectures often rely on multiple converters, transformers, and DC-DC conversion stages, which can introduce power losses and increase complexity. Matrix converters offer a more direct and efficient solution by performing AC-AC conversion between different voltage and frequency levels in a single step. This streamlined approach minimizes power losses, reduces component count, and simplifies the powertrain architecture, all of which contribute to improved overall efficiency.With the global push towards renewable energy sources, electric vehicles are becoming part of a broader ecosystem that includes solar panels, wind turbines, and other forms of renewable energy generation. Matrix converters can efficiently integrate energy from these sources into the EV's power system. For instance, plug-in hybrid electric vehicles (PHEVs) can harness energy from solar panels on their roofs and convert it directly into the appropriate AC voltage and frequency for propulsion or charging. This integration not only reduces greenhouse gas emissions but also enhances the sustainability of electric vehicles.

The incorporation of matrix converters into electric vehicles represents a significant step forward in the quest for efficient, sustainable, and versatile transportation solutions. Whether through optimizing regenerative braking, facilitating bidirectional charging, improving powertrain efficiency, or integrating renewable energy sources, matrix converters have demonstrated their potential to elevate the performance and functionality of electric vehicles. As research and development in power electronics continue to advance, the role of matrix converters in EVs is expected to expand, driving the evolution of electric mobility towards greater efficiency and sustainability.

III. BLOCK DIAGRAM



C. Working

The process starts when the electric motor, typically a three-phase AC motor, transitions from motoring mode (where it's driving a load) to regenerative mode (where it acts as a generator during braking). When the vehicle or machinery needs to slow down or stop, the motor's controller changes its operation to generate electrical power instead of consuming it.As the motor operates as a generator, it produces electrical energy due to the mechanical energy of the load being converted back into electrical energy. This electrical energy initially exists as three-phase AC power. The electrical energy generated needs to be conditioned and converted into a form that can be utilized. This is where the matrix converter comes into play. The matrix converter is a power electronic device with a matrix of semiconductor switches that can be controlled to convert the input AC power into the desired output AC power. Sliding mode control continuously monitors the system's operating conditions and adjusts the matrix converter's switching states to maintain the desired control objective, which is typically to track a predefined sliding surface. The converted electrical energy can then be either fed back into the power supply grid or stored in batteries or capacitors for later use.

D. Simulation of matrix converter

The matrix converter is functional as a Rectifier-Inverter system, with precedence given to regenerative braking system for charging the battery as well as to meet the cargo and compensation via milage. Grounded on the conditions , both the operations could be incorporated in a single matrix conversion system with proper cargo insulation between the cargo and battery.

Let the force input to the matrix converter is AC. For the positive half cycle of the AC input the switches 1a and 4a are switched off and also for the negative half cycle of the input, the other two switches 2b and 3b are triggered such that the output from the matrix converter is DC.This is easily presented by the simulation of MATLAB/SIMULINK is shown in Fig 2. The output obtained from matrix converter is shown in Fig.3.

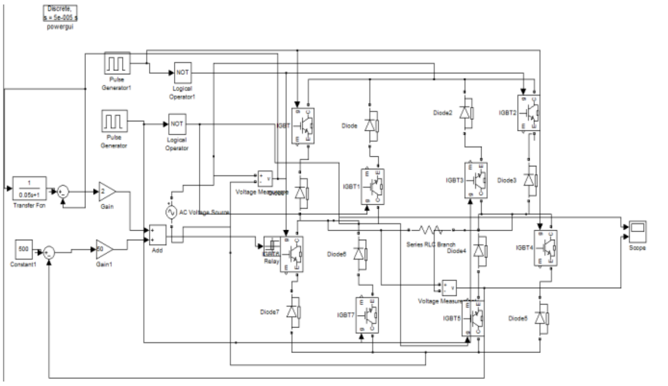


Fig.2 Simulation of matrix converter under sliding condition

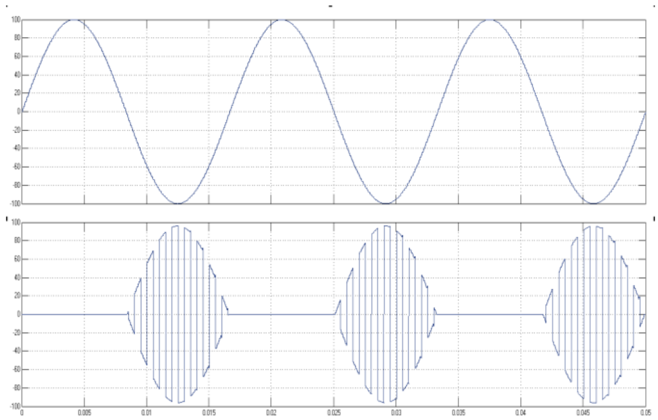


Fig. 3 .Simulation of matrix converter

E. Simulation of braking

The project focuses on applying a regenerative braking to the motor and to recover the energy when the motor run on its own inertia by giving a time delay in the MATLAB software. And then the recovered energy is given to the input of the motor which is again fed back to the battery for charging.In our project the battery acts both as source and load. The input current to run the motor is given via universal bridge to the Permanent Magnet Synchronous Machine which is operated as a BLDC motor with a help of a hall effect signals A time delay of 4 seconds is given to the torque input of the motor and also to the gate pulse of the universal bridge. It can be inferred from the simulation result that after 4 seconds the input to the motor is stopped. It rotates only on its own inertia. At this point of time the performance characteristics of the motor such as speed, torque, back emf and stator currents gradually decrease to zero.Here the motor acts as a generator and converts those energy into an electrical energy . This recovered energy is given to the converter input which boosts up the regenerative voltage and is again feedback to get required output using sliding moe control and the output voltage is given to the battery. At this time the battery acts a load. The current direction is from motor to the the load. In this way the regenerative braking is applied and analyzed in the MATLAB software.

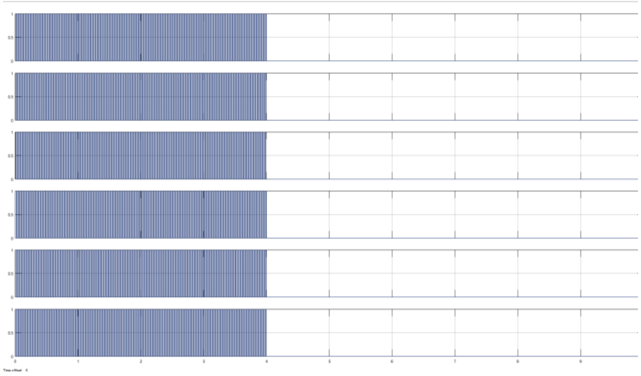


Fig.4.Gate pulses of MOSFET

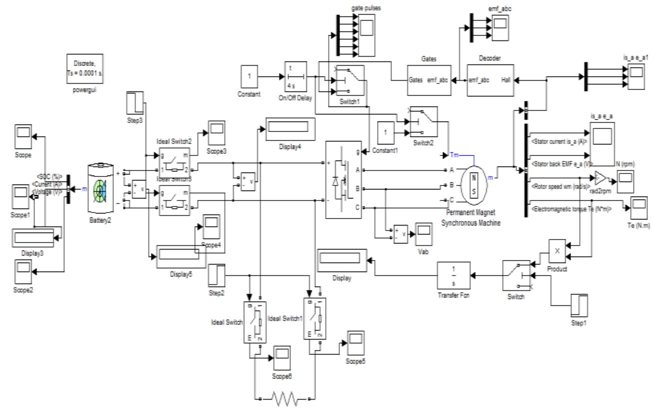
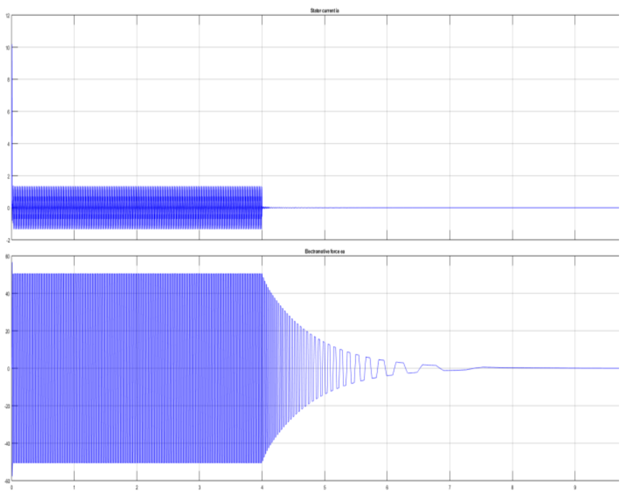


Fig. 2. Simulation of regenerative braking



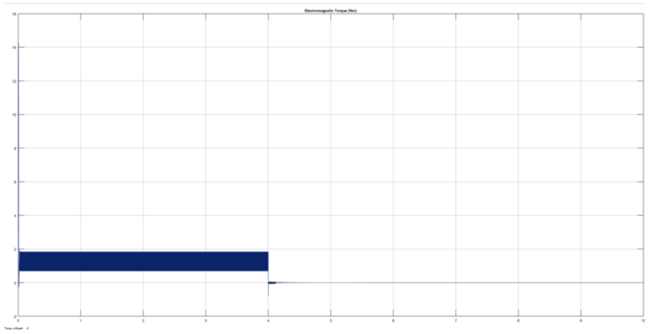


Fig.5.Waveform of electromagnetic torque

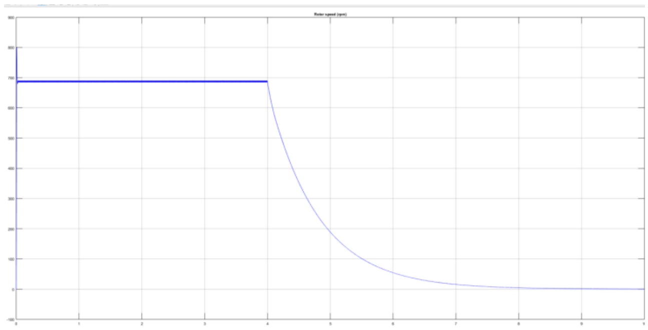


Fig.6.Waveform of Speed

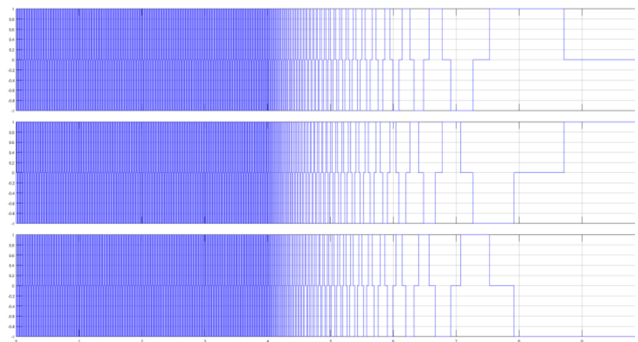


Fig.7.Signals from Hall sensor

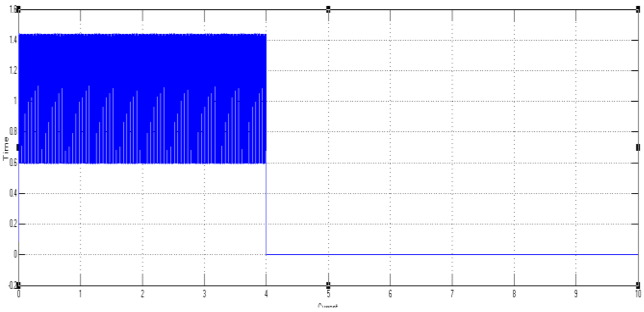


Fig.8.Waveform of battery current

IV. RESULTS AND DISCUSSIONS

In MATLAB, the energy for the PMSM motor is provided by battery.The motor is driven for the first 4 seconds. And then regenerative braking is applied, the motor starts to decelerate.

Fig.3. gives the clear explanation and working of the motor. For the first 4 seconds the voltage level of the motor is around 52V and then when the pulses are stopped, slowly it gets reduced. Within 8th second the emf gets reduced to zero. Thus from this it is clear that the motor gets stopped after the 4th second and the braking procedure is working as mentioned in the simulation of the braking circuit.

For the first 4 seconds the current is discharged and for the following seconds the battery gets charged due to regenerative braking.Fig.8. shows the graph between current-time of the battery.For the first 4 seconds graph is in the positive direction and for the next 4seconds graph is in negative direction which indicates that the battery is charged.

V. CONCLUSION

In conclusion, the project has successfully illustrated the potential of the "Regenerative Braking of Matrix Converter under Sliding Mode Control" system as an innovative solution for enhancing energy efficiency in electric vehicles. By seamlessly integrating matrix converters and sliding mode control, this approach offers a promising avenue to address the challenges associated with regenerative braking while contributing to the sustainability and performance of electric mobility.As electric vehicles continue to gain prominence in the automotive industry and the quest for energy-efficient transportation intensifies, the findings of this project hold relevance and significance. Future research and development efforts can build upon these results to further refine and optimize the proposed system, ultimately contributing to a more sustainable and energy-efficient future for electric transportation.

VI. FURURE SCOPE

As electric mobility continues to evolve and the demand for energy-efficient transportation solutions rises, the future scope for research and development in the field of matrix converters and regenerative braking is promising. Innovations in this area can contribute significantly to the sustainability, performance, and widespread adoption of electric vehicles.

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