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MATLAB Simulation of Regenerative Braking System in EV

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Abstract: This paper presents a comprehensive MATLAB/Simulink model for simulating a regenerative braking system in an electric vehicle (EV). Regenerative braking offers a significant advantage in EVs by converting the kinetic energy of the vehicle during deceleration into electrical energy, which is then fed back to the battery, thereby improving energy efficiency and extending the driving range. The developed simulation model incorporates key components of the regenerative braking system, including the vehicle dynamics, electric motor/generator, battery model, and the control logic that governs the transition between regenerative and mechanical braking. Different control strategies for distributing the braking torque between the regenerative and friction brakes are implemented and analyzed. The simulation results demonstrate the effectiveness of the proposed model in capturing the energy regeneration process under various driving conditions, including different deceleration rates and vehicle speeds. Furthermore, the impact of different regenerative braking control strategies on the energy recovery and overall braking performance is evaluated and compared. This study provides valuable insights into the design and optimization of regenerative braking systems in EVs, contributing to the development of more energy-efficient and sustainable transportation solutions.

Keywords: Electric Vehicle (EV), Regenerative Braking, MATLAB/Simulink, Simulation, Energy Efficiency, Braking Control Strategy.

I. INTRODUCTION

Regenerative braking is a vital feature in electric vehicles that significantly contributes to their efficiency and range. Instead of wasting the kinetic energy produced during deceleration as heat, like in traditional braking systems, EVs utilize their electric motor as a generator during these moments. When the driver releases the accelerator or applies the brakes, the motor's function reverses, and it captures the energy from the rotating wheels, converting it back into electricity. This generated electricity is then fed back into the vehicle's battery, effectively recharging it and extending the driving range. While regenerative braking handles a considerable portion of the deceleration, EVs are still equipped with conventional friction brakes for more forceful stops or when regenerative braking is less effective, with both systems working in tandem.

This energy recovery not only improves efficiency and range but also reduces wear and tear on the traditional brakes, leading to potential savings in maintenance and a smoother driving experience. Ultimately, regenerative braking is a key technology that underscores the environmental and practical advantages of electric vehicles. In addition to enhancing energy recuperation, this system minimizes wear on traditional braking components, reduces maintenance requirements, and contributes to a smoother, quieter braking experience. As regulatory pressures and environmental concerns drive the automotive industry towards greener technologies, regenerative braking stands out as a key innovation in electric vehicle design, representing not only a technical solution to energy wastage but also a crucial step towards achieving broader sustainability goals in transportation.

II. LITERATURE REVIEW

Regenerative braking in electric vehicles (EVs) is a crucial technology focused on recovering the kinetic energy produced during deceleration and converting it into electrical energy to recharge the battery, thereby increasing energy efficiency and extending driving range while reducing reliance on traditional friction brakes and minimizing brake wear and emissions. This energy recovery process, where the electric motor acts as a generator during braking, is influenced by factors like vehicle speed and battery state of charge, and its integration with conventional braking systems necessitates

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sophisticated control strategies (such as series or parallel braking and advanced techniques like fuzzy logic) to ensure optimal energy recapture and driving safety. Ongoing advancements in RB systems include integration with hybrid energy storage systems (like supercapacitors), improvements in motor and inverter technology, optimization algorithms, and the development of vacuum-independent braking, all aimed at maximizing energy recovery, enhancing vehicle performance, and further minimizing the environmental impact of EVs.

III. SYSTEM MODELLING

The MATLAB/Simulink model used in this study consists of several key components designed to simulate the behaviour of a nonlinear load under varying inductance and to analyze its effect on power factor and harmonic distortion.

1. DC Machine (Motor/Generator Mode): Acts as a motor during normal operation and as a generator during braking. Converts electrical energy into mechanical energy (motoring) and vice versa (regeneration).
2. DC Voltage Source: Provides power to the DC machine during motoring. Acts as a storage/load interface for regenerated energy during braking.
3. H-Bridge Inverter (MOSFETs): Controls the direction of current flow to allow both forward motoring and regenerative braking. Controlled by PWM signals from the pulse generator.
4. Pulse Generator: Generates PWM signals to control the switching of the inverter. Enables control of motor speed and braking torque.
5. NOT Gate: Inverts the signal for complementary control of switches (ensures safe and synchronized switching).
6. p_side and n_side (Goto/From Blocks): Used for transferring control and signal information between different subsystems. p_side and n_side control the H-bridge switching.
7. Inductor (L): Smoothens the current and reduces ripple in the DC link during operation. Stores energy temporarily and helps in current control during braking.
8. Capacitor (C): Filters voltage ripple and provides a stable DC voltage across the inverter terminals. Helps absorb the transient voltage during regeneration.
9. Torque Block: Applies mechanical load or braking torque to simulate real driving or braking conditions. Used to switch the motor to generator mode when deceleration is needed.
10. Bus Selector Blocks: Collects and distributes multiple signals like speed, current, voltage, torque, etc. Used for monitoring and analysis of system performance.
11. Powergui (in Continuous Mode): Essential block for running Simulink models using SimPowerSystems. Enables configuration of simulation type and solver options.
12. Scope: The Scope block is used to monitor and visualize signals in real-time during simulation.

IV. METHODOLOGY

1. Initially, the DC machine operates as a motor, converting electrical energy from the battery into mechanical energy to drive the wheels. The H-bridge inverter controlled by the PWM pulse generator, regulates the motor operation by switching the transistors appropriately to manage the current direction and motor speed.
2. When braking is required, a mechanical braking torque is applied to the motor shaft.This causes the DC machine to slow down, and due to the change in energy flow, the DC machine now starts to behave like a generator.
3. As the vehicle decelerates, the motor's rotation drives it to generate a back EMF, and current starts to flow in reverse through the system. The generated electrical energy flows back through the inverter bridge and passes through the inductor (L) and capacitor (C) for current filtering and voltage stabilization.
4. The recovered energy is then routed back to the battery, charging it. The Bus Selector and Scope blocks monitor key signals such as battery current, voltage, SOC (State of Charge), and confirm that the battery is indeed being recharged.
5. The Pulse Generator and NOT Gate generate gate signals to control the switches (S1–S4) dynamically during braking. These control pulses ensure the correct switching pattern is maintained whether the system is in motoring or regenerative mode.
6. The Scope block connected via the Selector1 allows real-time visualization of various performance parameters like motor speed, armature current, field current, and generated torque.
7. The powergui (continuous) block is essential for simulation. It provides solver configuration and enables real-time simulation of electrical systems under continuous-time operation.

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V. SIMULATION MODEL

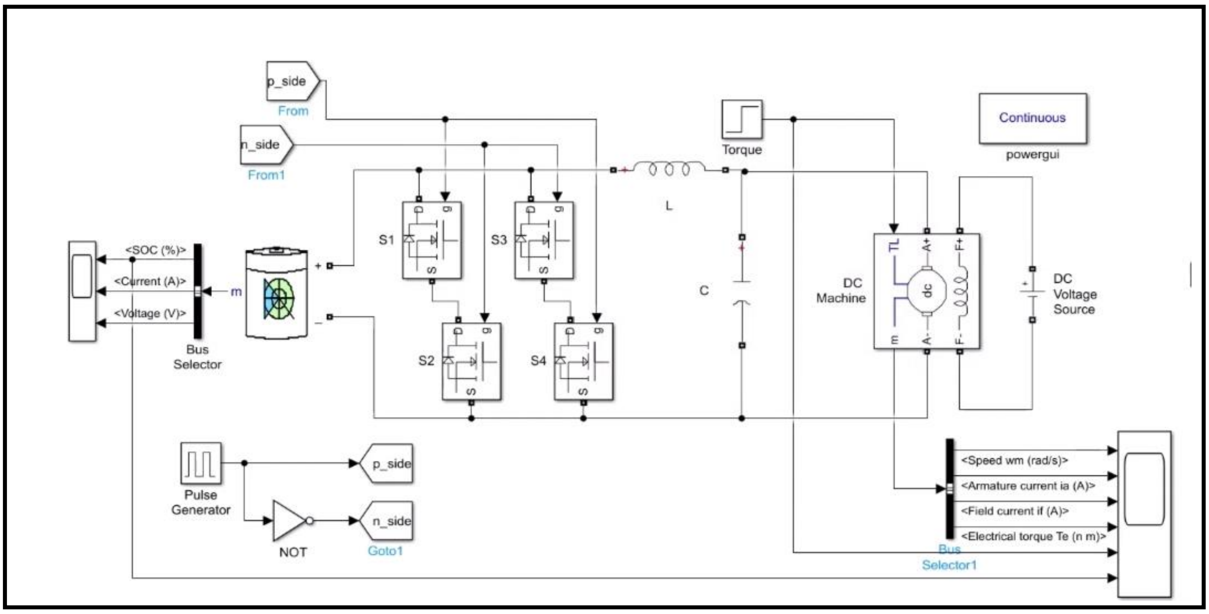

Fig 1. Block Diagram

RESULTS

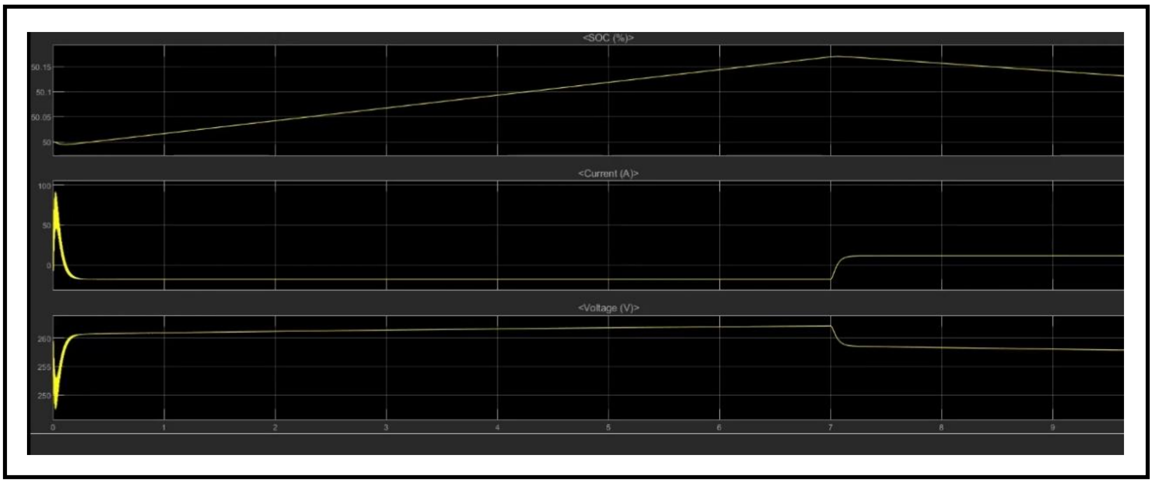

Fig 1.1 Charging of battery for 7 sec and after that discharges accordingly by changing current and voltage

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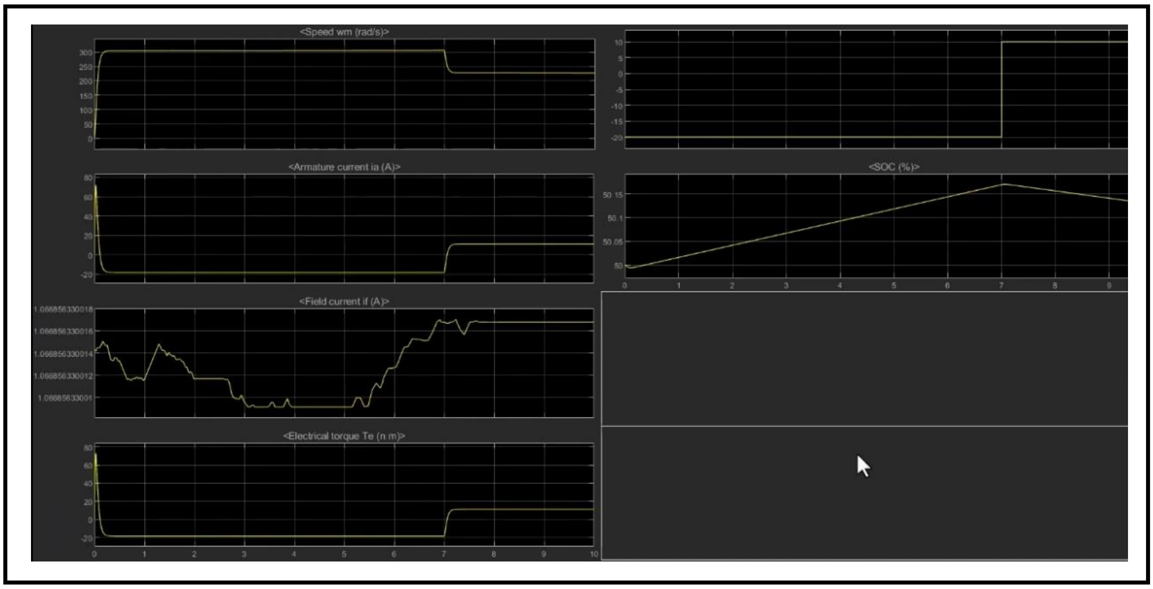

Fig 1.2 Waveform's of Parameters of DC Machine

VI. CONCLUSION

The MATLAB simulation of the regenerative braking system in an electric vehicle successfully demonstrates the feasibility and efficiency of energy recovery during braking. The results indicate that a significant portion of the kinetic energy can be converted back into electrical energy and stored in the battery, thereby improving the overall energy efficiency of the vehicle.

Through various driving and braking scenarios simulated in MATLAB/Simulink, the system showed effective power flow management between the motor and battery during deceleration. The integration of control algorithms ensured smooth braking performance while maintaining battery health and system stability. Overall, the simulation validates the importance of regenerative braking in enhancing the range and sustainability of electric vehicles, reducing energy consumption, and contributing to eco-friendly transportation.

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