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Regenerative Braking System: Why is Energy Regeneration System Required?

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I. INTRODUCTION

Our vehicle's Fundamental objective revolves around the incorporation of the Energy Regeneration System (ERS) designed to enhance energy efficiency. The ERS functions by capturing kinetic energy generated during braking and deceleration, effectively storing this energy in a high-capacity battery. Subsequently, the vehicle's powertrain converts this stored energy into electrical power to recharge the battery through the ERS. This innovative approach not only converges energy but also exemplifies the efficient transformation of energy from one state to another.

Indeed, the ERS system plays a crucial role in preventing energy wastage. The ERS minimizes reliance on external energy by converting braking kinetic energy into electrical energy, enhancing efficiency and sustainability while reducing the need for external energy. This system helps make the vehicle more environmentally friendly.

II. CONCEPT AND TECHNICAL FEATURES

The heart of electric vehicles lies in the Brushless DC (BLDC) motor, which serves as the main control of the inverter. Regenerative braking, a mechanical innovation in electric vehicles, tackles the challenge of energy recovery during braking, excelling in stop-and-go scenarios. Distinguished from traditional braking systems reliant on friction, it captures, converts, and stores a significant portion of kinetic energy in batteries or supercapacitors, marking a significant leap in energy efficiency and sustainability.

In the working principle of BLDC motors, the rotor, representing the rotating part, is a permanent magnet, while the stator, the fixed part, generates a stationary magnetic field. Controlled by adjusting current direction and magnitude, BLDC motors offer higher efficiency and durability, making them ideal for electric vehicles.

During acceleration, the current from the motor battery is reversed, and directed into the supply battery, enabling regenerative braking. Pulse Width Modulation (PWM) in independent switching is employed for effective brake control, maximizing energy recovery during the regenerative braking phase. The application of a PI controller in the current control mechanism ensures constant torque, and the entire setup facilitates regenerative braking through PWM control.

In conclusion, integrating BLDC motors and regenerative braking enhances the efficiency of electric vehicles and contributes significantly to sustainable transportation. This innovative approach, employing advanced motor control and regenerative braking systems, aligns with the evolving landscape of eco-friendly mobility solutions.

Fig.1 Represents Operational phase working of Electric Vehicle propulsion

A. Operational Phases of Electric Vehicle Propulsion

1) Acceleration

In the initial phase of operation, the electric vehicle undergoes acceleration, gradually reaching a steady speed determined by the applied torque. As the motor initiates its work, there might be brief current spikes that subsequently decrease. Positive current, conforming to standard conventions, is supplied from the battery to the motor during this phase, facilitating forward motion.

2) Braking

During forward motion, when the accelerator pedal is released, the motor generates reverse torque, inducing a slowing effect on the vehicle. This marks the activation of the regenerative braking system, where the energy produced during braking charges the battery. Due to the reversal in direction, the current flows back to the battery (acting like a generator) but with a negative sign. The motor initially accelerates under external input, and when braking is required, the regenerative system engages. Precise control of the braking operation is managed by a controller, in coordination with hall effect sensors for effective switching of the inverter/motor controller.

Electric vehicle dynamics encompass acceleration, with a positive current from the battery propelling the motor forward. Upon releasing the accelerator, regenerative braking engages, causing the motor to generate reverse torque.

This system, managed by a controller and hall effect sensors, converts braking energy into a charge for the battery. The intricate interplay of acceleration and regenerative braking optimizes efficiency, marking a sustainable approach to electric vehicle performance and energy management.

Components Specifications:-

- Battery:- It's for storing the energy recovered during the regenerative braking.

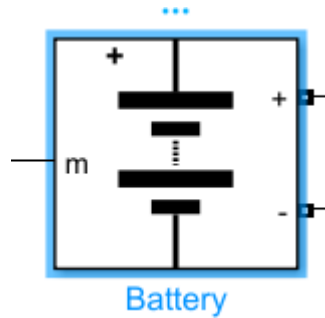


Fig 1.1 Battery Block

- Nominal Voltage=48V
- Initial SoC%=100%
- Rated capacity=50Ah

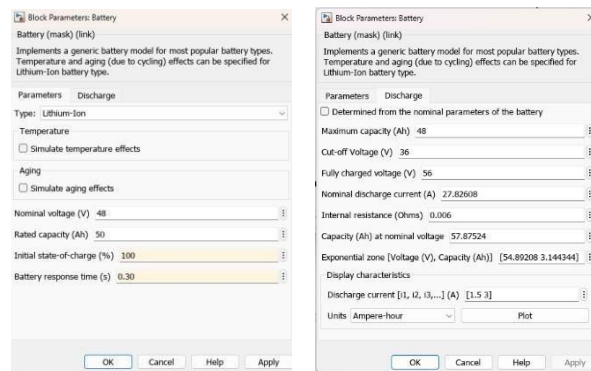


Fig 1.2 Parameters over Battery

- Universal Bridge Block:- It is used for the fast switching. Basically this block consists of two basic voltage boosting states such as

- Energizing
- Storing phase.

Current has been turned up to the battery by both of the diodes.

Universal Bridge

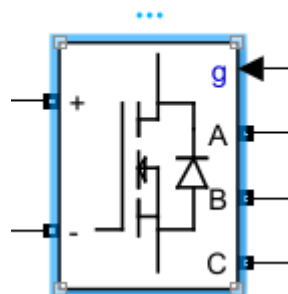


Fig 1.3 Universal Bridge Block

a) Motor:-

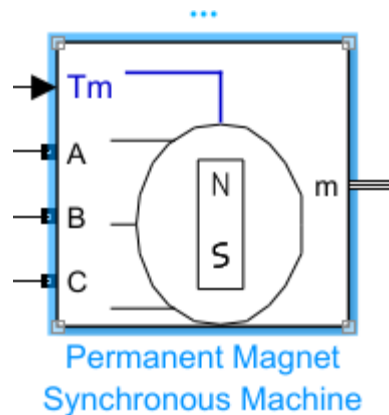


Fig1.4PMSMBlock

- In this System the PMSM block has been used as a BLDC Motor.
- For the Function the two required inputs are Torque and angular Velocity.
- The Mechanical torque as an input is given in the PMSM Block.
- The Motor will be connected to the bus selectors.

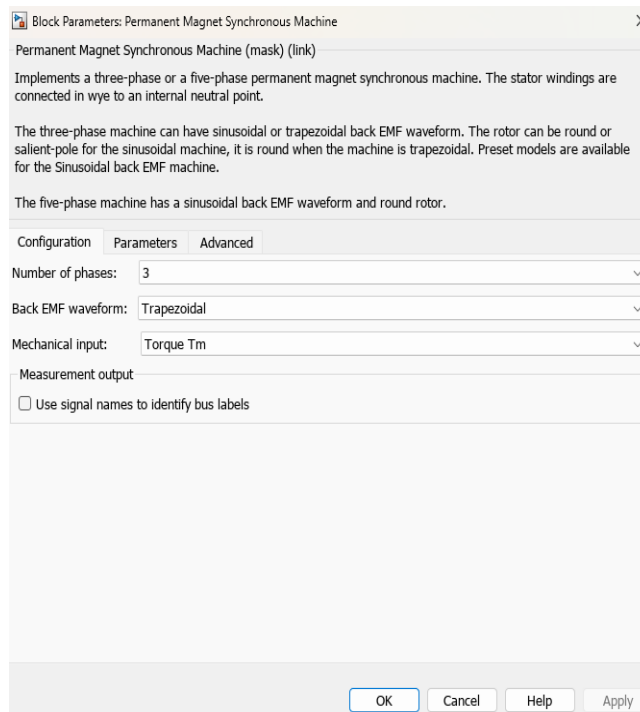


Fig1.5Parameters of PMSM

b) Controller:-

This is the controller which will be used in the system consisting of a hall sensor, rated speed, etc.

Specified Model Inside Controller:- Inputs in the Controller:-

- 3 Hall sensor points
- A Speed Controller

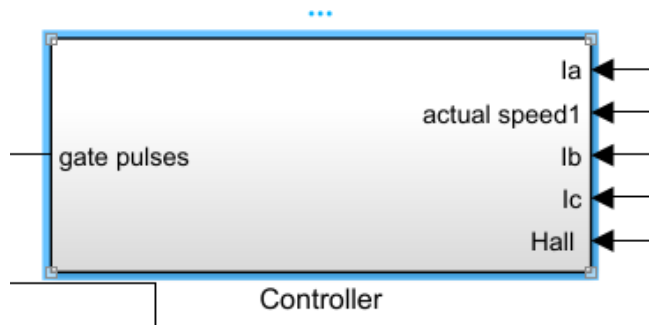


Fig1.6Controller

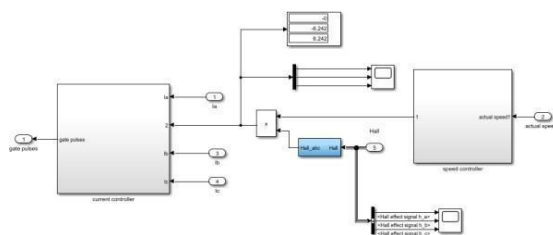


Fig1.7CircuitAnalysis

SpecifiedmodelunderspeedController:-

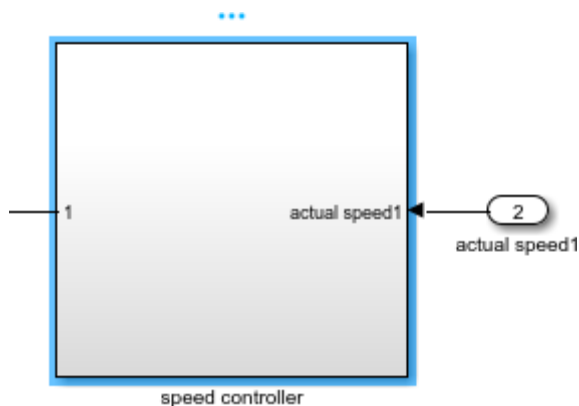
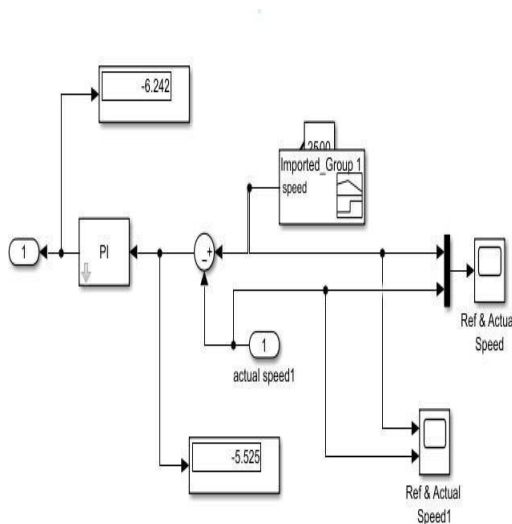


Fig1.8ControllerBox

It uses PI Controller that compares the Command setpointandtheactualvaluebasedonfeedback.



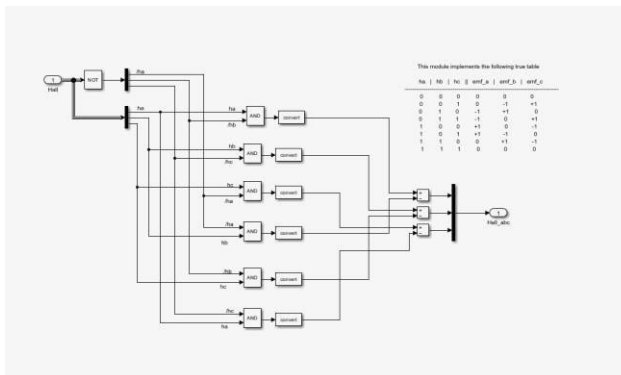


Fig1.9HallSensor Circuit

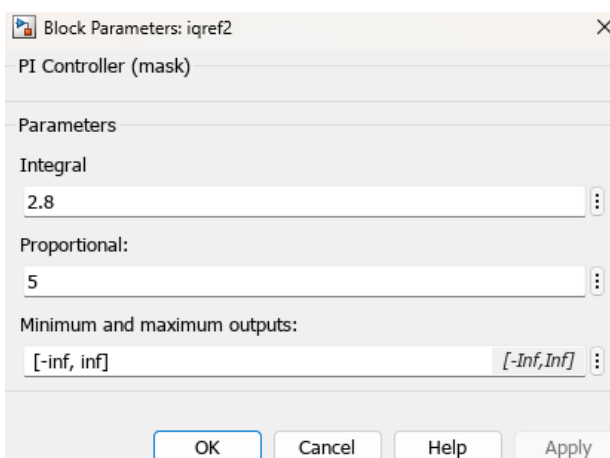


Fig1.10ParametersofPIController

The purpose of the hall sensor is to determine the rotor position to detect the energized winding after the energizing sequence.

c) Current Controller:-

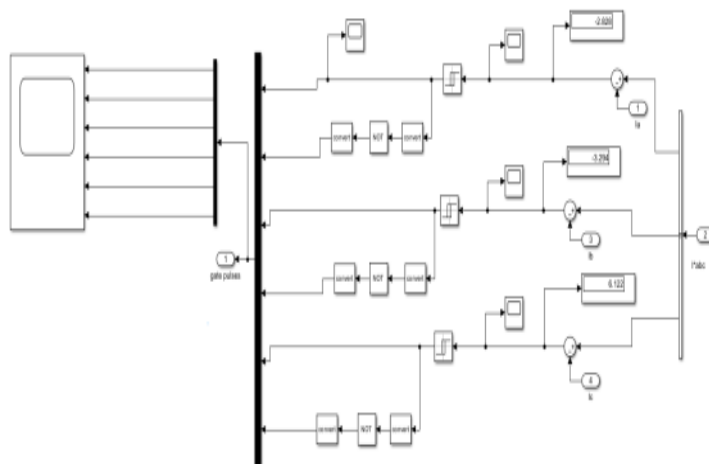
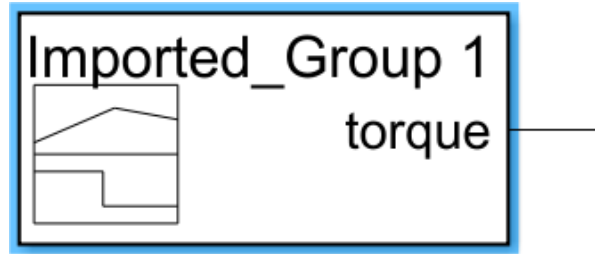


Fig1.11CurrentControllerCircuitDiagram

The output of the current controller will be the output of the whole controller block and it will be connected to the switching element MOSFET: the universal bridge block.

Concerning the torque of the brake pedal, a Simulink function called signalbuilder was used to generate torque values.



Signal Builder

Fig1.12SignalBuilderBox

III. CALCULATION AND ANALYSIS TARGET

1) Specifications:-

Parameters	Estimates
Weight	220kg
Initialvelocity	35km/hr.
brakingForce	1100N
stoppingdistance	4m
Regenerationefficiency	56%
Energyconversion efficiency	80%

2) Calculations:-

Efficiency

- KineticEnergy:-

$V_{in} = 35 \text{ km/hr.}$

$= 9.72 \text{ m/sec}$

$\text{KineticEnergy}(\text{initial}) = \frac{1}{2} * m * V^2(\text{initial})$

$= \frac{1}{2} * 220 * (9.72)^2$

$= 10392.624 \text{ J}$

- WorkDoneDuringBraking:-

$W = \text{BrakingForce} * \text{StoppingDistance}$

$= 1100 * 4$

$= 4400 \text{ J}$

- EnergyRegenerated:-

$\text{EnergyRegenerated} = \text{WorkDoneDuring Braking} * \text{Regeneration Efficiency}$

$= 4400 * 0.56$

$= 2464 \text{ J}$

- EnergyConvertedtoBattery:-

$\text{Energy to battery} = \text{EnergyRegenerated} * \text{Energy Conversion Efficiency}$

$2464 * 0.80$

1971.2 J

- StateofchargeChange:-

Stateofchargechange=Energyofbattery/Battery Capacity

BatteryCapacity=50Ah

SOCchange=1379.8/50

=27.59

- Deceleration

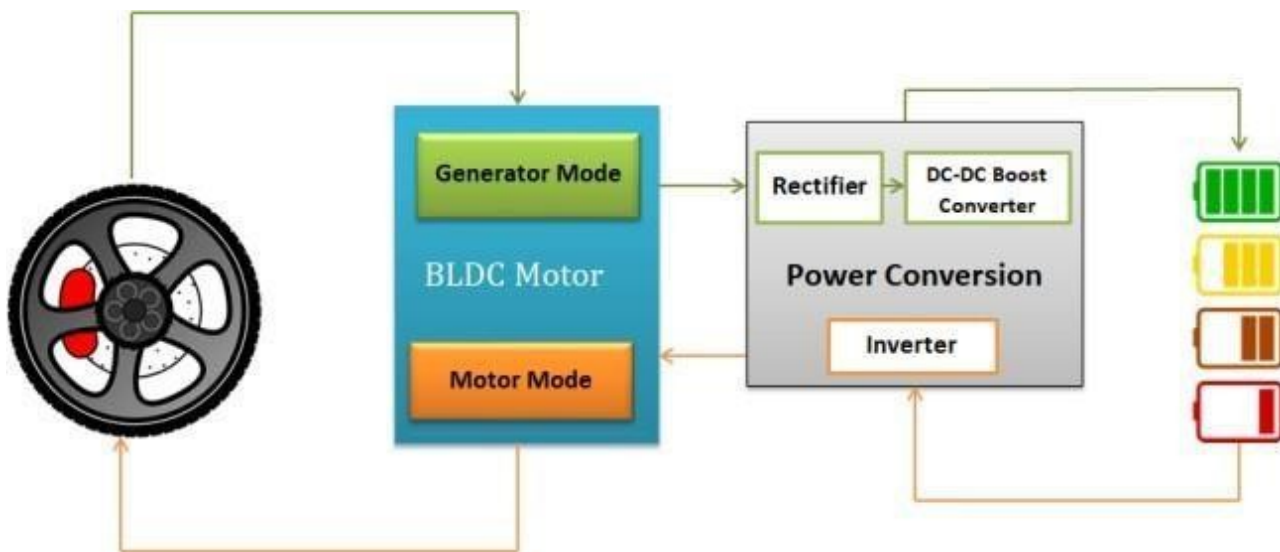
(d)=[V²(final)-V²(initial)]/2(StoppingDistance)

=0-(9.72)²/2(4)

=-94.4784/8

=11.8098m/sec²

IV. APPENDIX-1: DESIGN VIEWS AND PHOTOGRAPHS



A. Circuit Analysis:-

ThreePhaseStatorCurrent:-

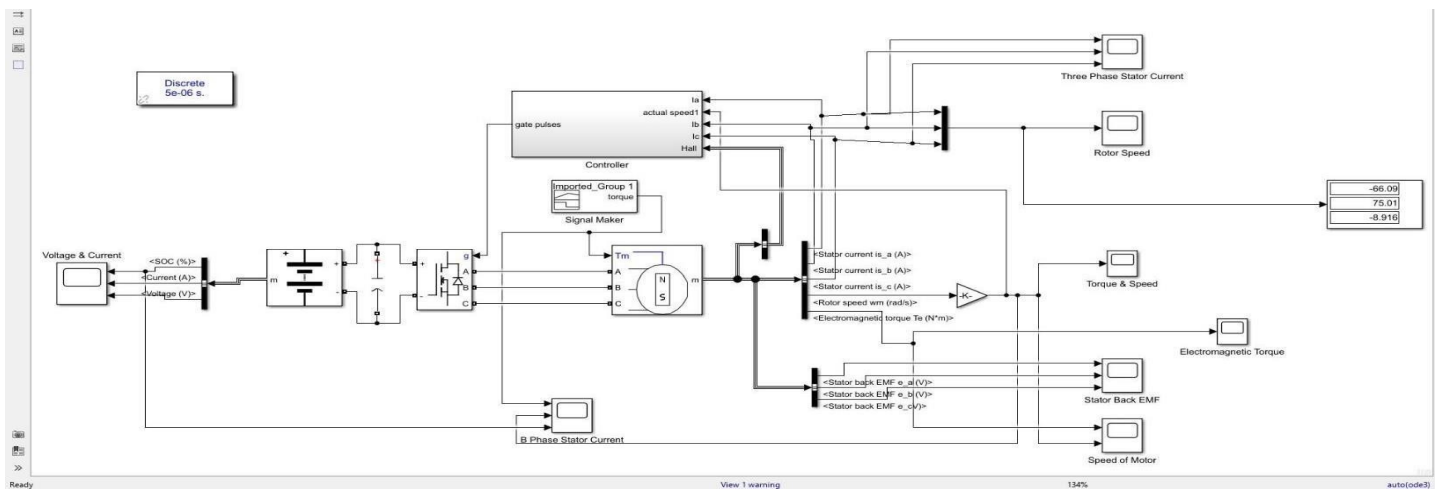


Figure-1(OperationalPhasesofElectricVehiclePropulsion)

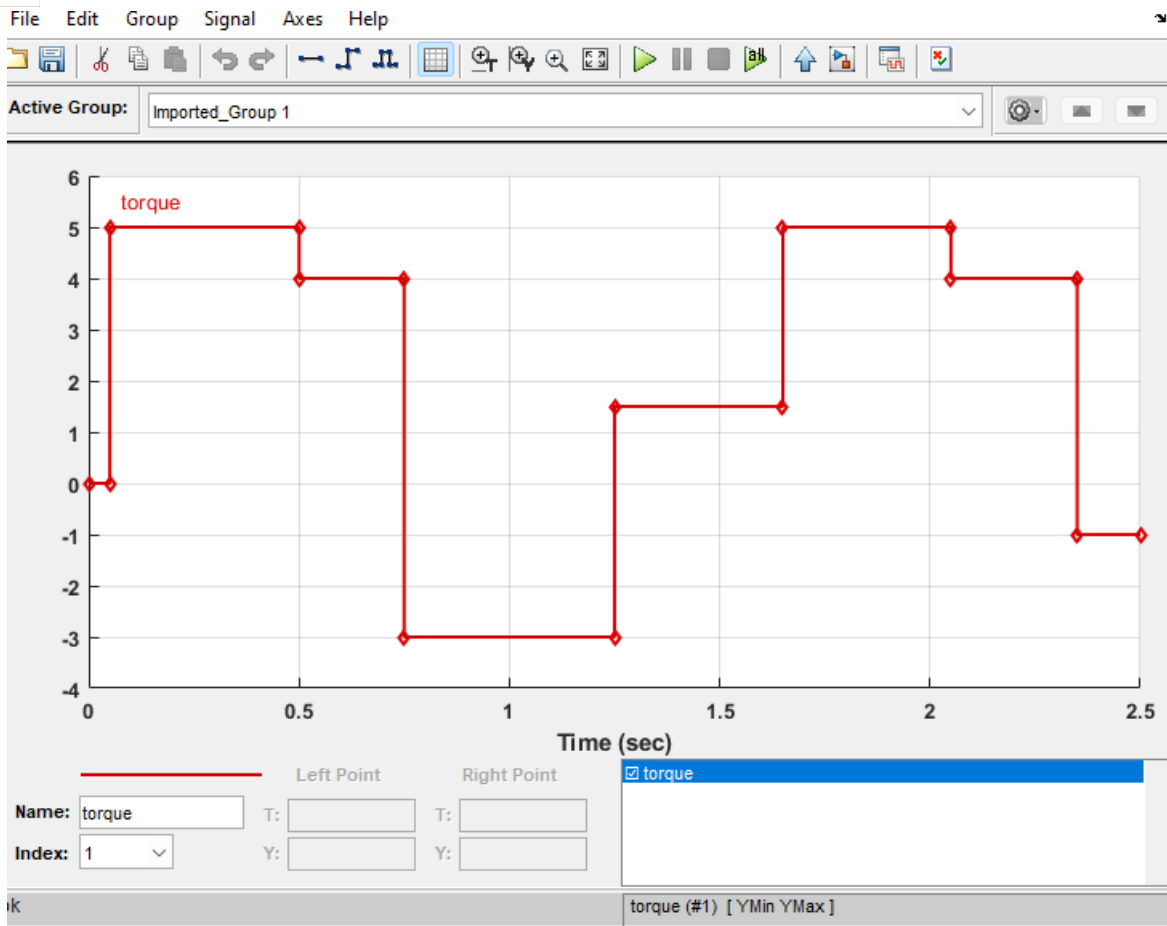


Figure-2(TorqueGenerated)

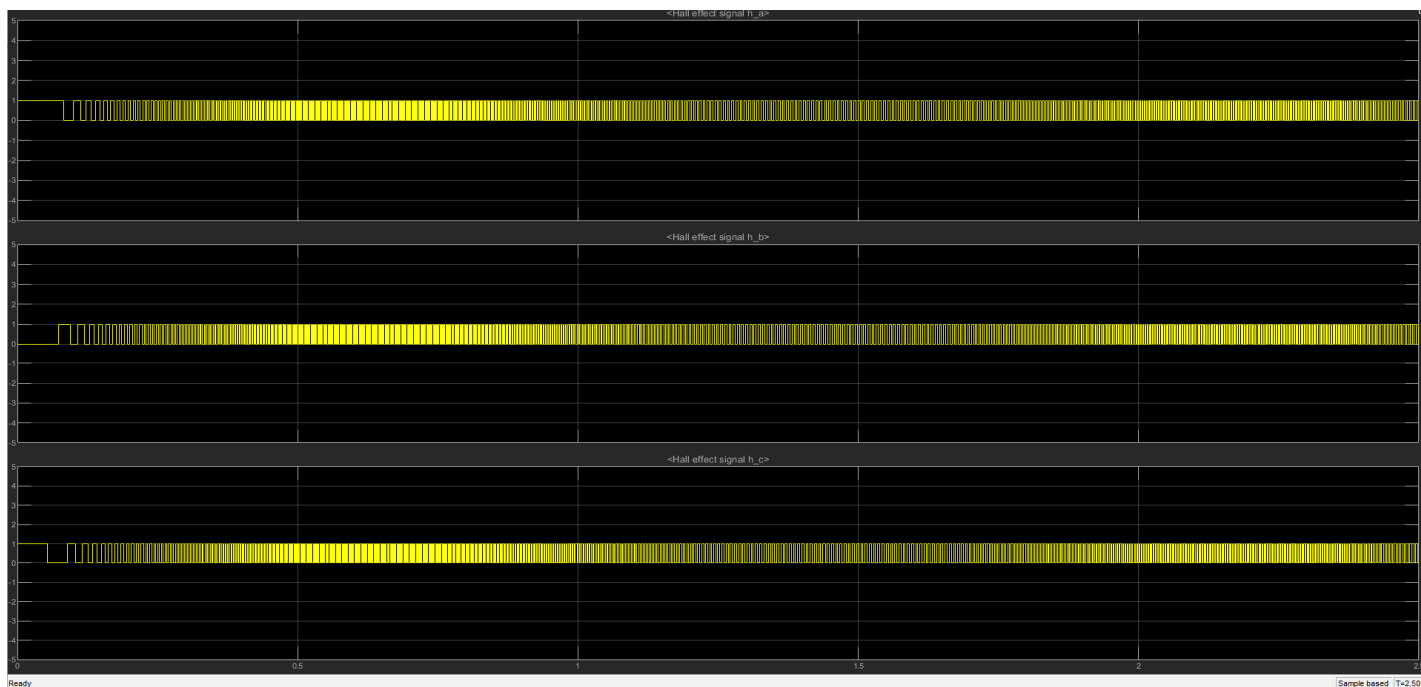


Figure-3(HallEffectSimulation)



Figure-4(SwitchScopeSimulation)

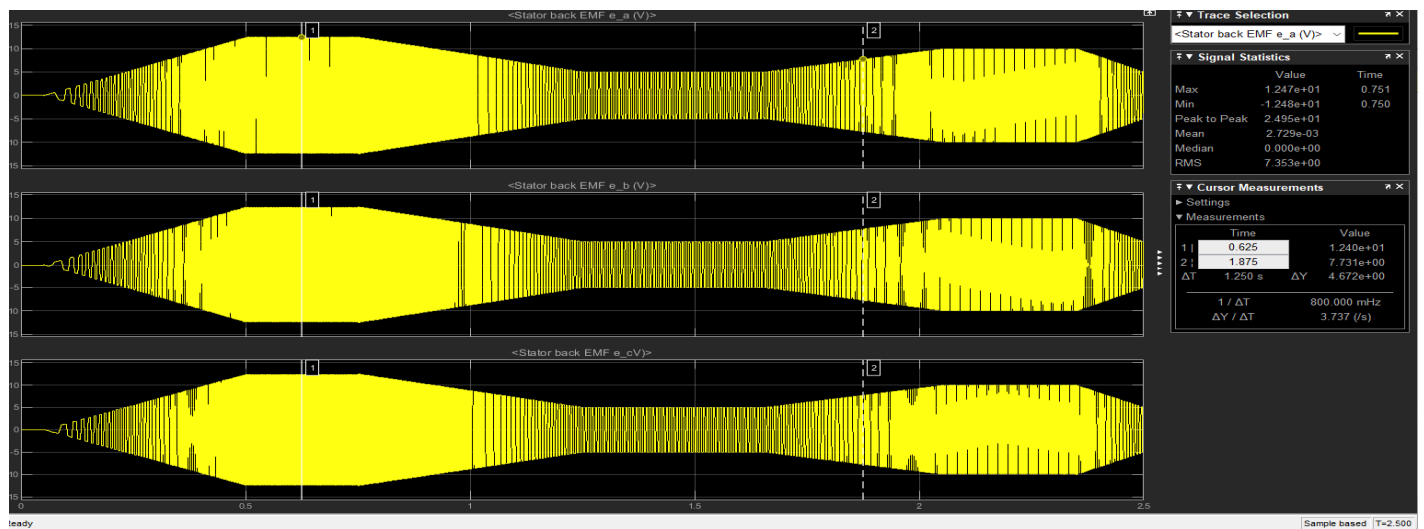


Figure-5(StatorBackemfSimulation)

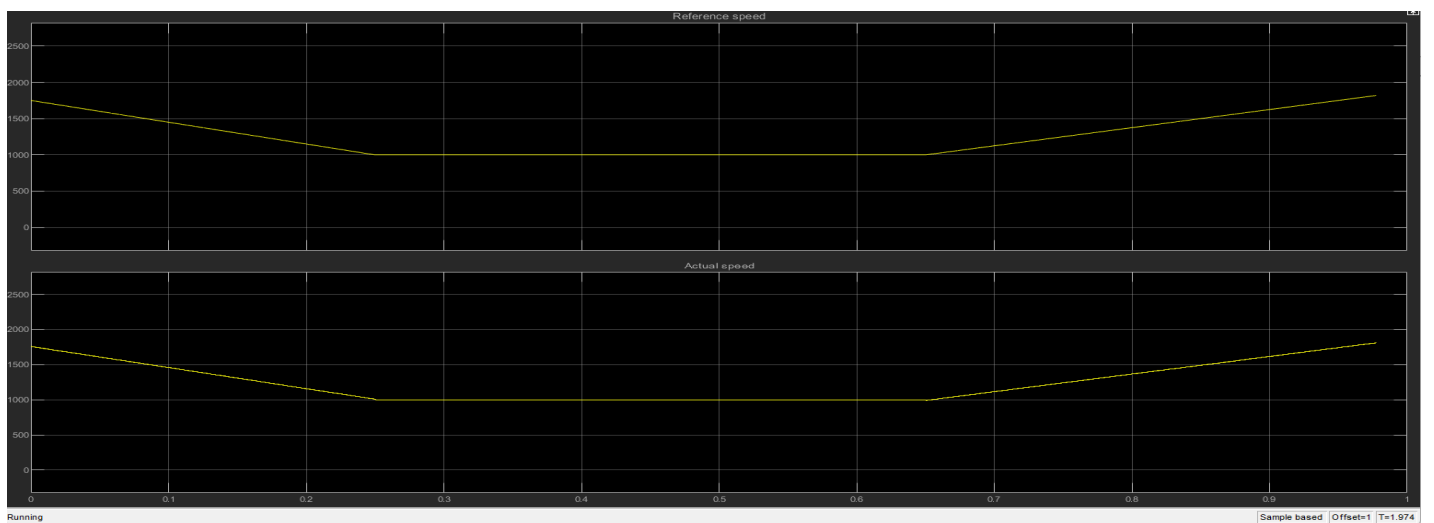


Figure-6(ReferenceVsMeasuredSpeed)

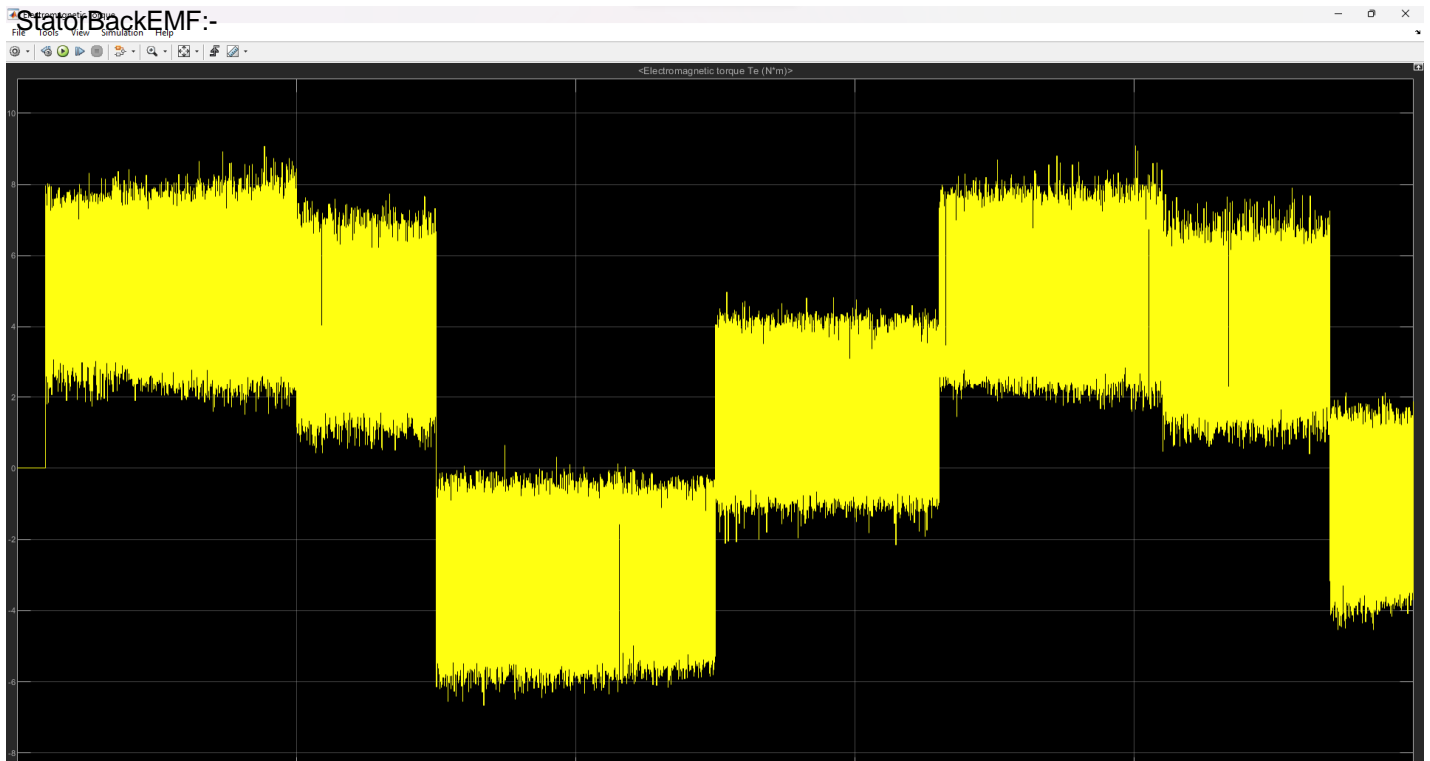


Figure-7(ElectromagneticTorque)

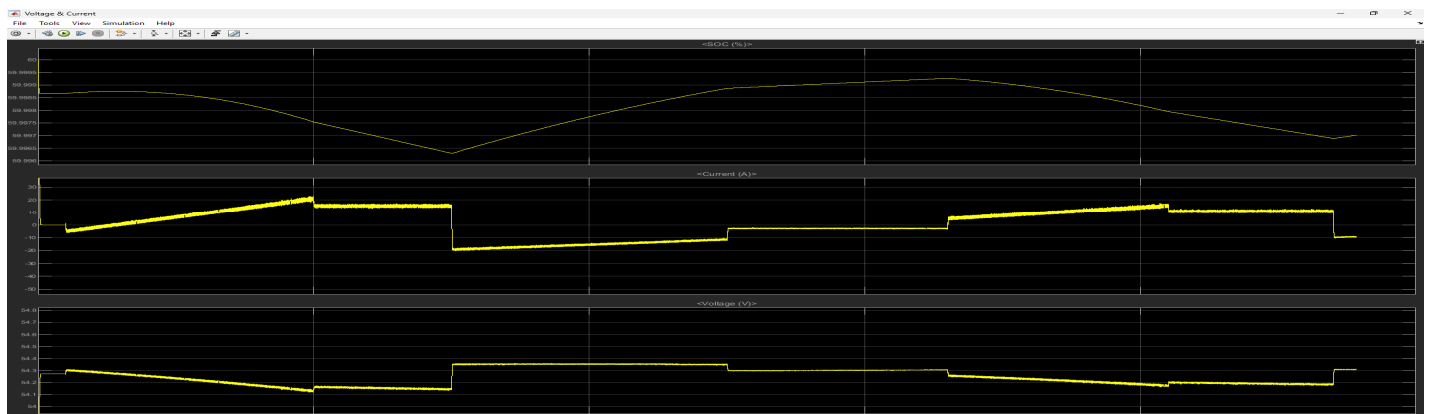


Figure-8(Voltage&Current)

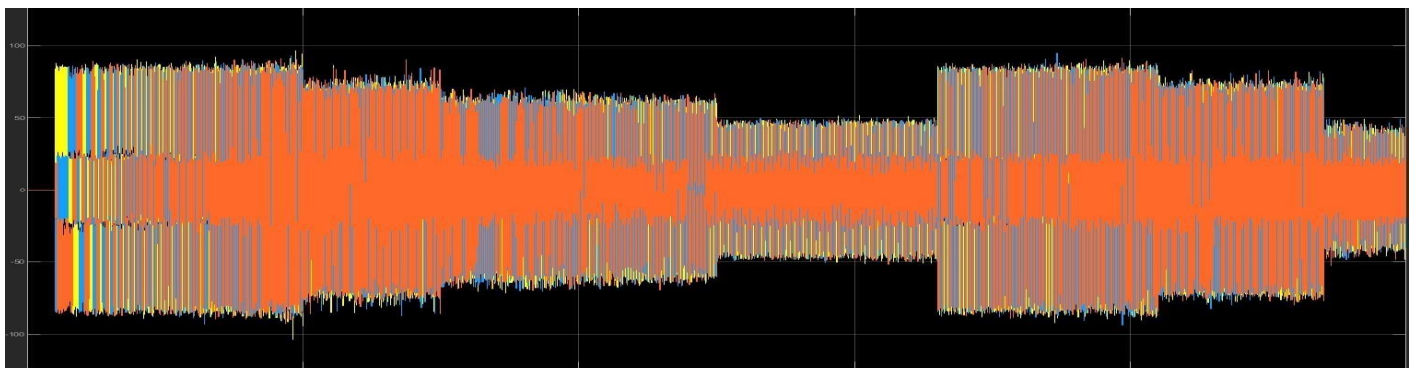


Figure-9(SpeedofMotor)

V. SOLAR PANEL REGENERATION SYSTEM

The system operates by converting solar energy into electrical power, regulating it through a solar charge controller. This controlled power is then utilized to charge a secondary battery while also supplying power to a connected load. The solar charge controller plays a pivotal role in adjusting voltage and current to meet the specific requirements of the battery and load.



B. Circuit Diagram

1) System Overview and Features:

- The solar charge controller is designed to handle a maximum power of 395W.
- A monocrystalline solar panel is employed, capable of generating power in varying weather conditions.
- Notably, the controller features a digital display for monitoring the status of all subsystems.
- Additionally, the controller is programmed to cease power supply to the battery when it reaches full charge.

2) Calculations and Solar Panel Size Selection:

- Secondary Battery: 12V 15Ah lead-acid type
- Solar Panel: 100W
- Solar Charge Controller Max Power: 390W
- Power Used: 93W

3) Calculations:

- Maximum Power Drawn from Battery (M_d): 92.76W (7.73A)
- Maximum Power from Solar Panel (M_s): 100W (8.3A)
- Maximum Power / Capacity of the Battery (M_b): 180Wh (15A)
- Battery Ah Rating: 15Ah
- Runtime without Charging: 1.9 hours (1 hour 45 minutes)
- Time Required to Charge the Battery: 1.8 hours (1 hour 40 minutes)



4) *AdditionalComments:*

- It is essential to ensure that the selected solar panel size meets the power requirements adequately for effective battery charging.
- The calculation offers valuable insights into system performance under specified conditions.
- Environmental factors and potential variations in solar radiation should be considered during the system's design and installation.



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