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The performance of the Optimisation and Regenerative Braking systems by using PI controlling technique for Electric Vehicle (EV)

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Abstract. Electric automobiles have lower fuel costs because electric motors are more efficient than internal combustion engines. These automobiles can only drive a certain distance because to insufficient batteries and the lack of charging stations. EVs, on the other hand, lack a short driving distance and require frequent charging and discharging of power batteries. EVs will benefit from the development of energy-saving technologies that will expand their reach and prevent battery damage caused by frequent charging and discharging. The goal is to improve the energy efficiency of braking system and its motor efficiency to generate current, as well as to improve regenerative braking (RB) efficiency in EV's. Using a Brushless DC (BLDC) motor by adding an LC filter is the method that will be applied. A significant addition of current and less ripple and spike in the torque and a quick dynamic interference is the desired result. The performance of the system optimisation and RB circuit systems by using PI controlling technique. The output from torque produced by a 2200 Rpm is 3 Nm and demonstrates that the BLDC motor is efficient when driven by an LC filter circuit. Finally, using the Matlab/Simulink tool, this research presents a thorough simulation of a BLDC motor's operation as a motor and a generator with RB to create more current in EVs.

1. Introduction

Electric vehicles (EVs) can save energy by converting kinetic energy into electrical energy while braking. The conversion process is known as regenerative braking (RB). Electric vehicles have aroused curiosity in these two fields, namely academia and industry. Feedback controllers must be designed to enhance regenerative brake energy recovery. However, some vehicle conditions, such as vehicle velocity, side slip angle, moment of mass inertia and so on, are difficult to obtain. As a result, a method for calculating the condition of a vehicle must be developed [1], [2].

EVs provide different ways to reduce transportation energy consumption. The gearbox can be placed between the electric engine and the drive wheel to increase EVs mileage, battery life and total cost. Two-speed gearboxes are more suitable for EVs in terms of dynamic performance, energy economy and price because electric motors have more desirable features than internal combustion engines (ICE). Automatic mechanical transmissions (AMT) have low cost, high transmission efficiency, better fuel economy and compatibility with electric car [3].

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One of the fundamental technologies of EVs' core competitiveness is RB, which can improve energy conversion efficiency and boost driving range. RB control technique is provided based on a novel braking intensity definition mechanism that may be applied to any braking circumstance [4]. The RB method expands the reach of electric vehicles while reducing maintenance costs. To regenerate electrical energy from kinetic energy and return it to the battery on the motor, a modified direct [5]. In comparison to conventional vehicles, EVs still have some disadvantages, such as battery pack, charging mechanism, and limited driving range due to battery charging capacity. As a result, automotive manufacturers have improved the capabilities of their vehicles in terms of standard quality and fuel efficiency in response to government directives and community demands. This technology, on the one hand may make EVs more sophisticated, while on the other hand, they may raise the entire cost of EVs production [6] – [10].

BLDC motor is a type of synchronous motor. The BLDC motor is ideal for EVs because of its high force density, strong speed torque characteristics, high efficiency, wide speed range and low maintenance [11]. It indicates that the magnetic fields produced by the stator and the rotor spinning have the same frequency. BLDC motors do not have the “slip” that induction motors have. A BLDC motor on the other hand need somewhat complicated electronics for control.

This indicates that the magnetic field generated by the stator and control of the magnetic BLDC motor by rotation is performed by changing the conduction sequence on the inverter bridge arm operating the electronic commutator (inverter). BLDC motor with a conventional H-bridge uses a DC power source to deliver energy. Each motor lead is connected to a low side and high side switch [12] – [15]. EVs, on the other hand, has a short -range disadvantage, which necessitates frequent charging and discharging of the power battery. Electric vehicles will benefit from the development of energy-saving technology that will extend their range and prevent battery deterioration caused by frequent charging and discharging [16].

As a result, the system is unable to reproduce current more effectively. The amount of current produced by the battery is greater. Researchers are trying to solve the problem by changing the RB system. The battery pack, motor drive system and converter controller are the three essential components in an EV [17]. This paper reviews and recommends the use of appropriate motors, as well as high -tech equipment such as sensors, auxiliary storage devices and inverter circuits.

According to [18], describe the advantages of a RBS over a conventional braking system are discussed in this article. When compared to conventional brakes RBS can function at high temperatures and are more efficient. They are more effective when the momentum is higher. The more frequently a car stops, the more this braking system can help. Large heavy vehicles that travel at high speeds accumulate a lot of kinetic energy making them more energy efficient. It offers a lot of potential for future advances and energy conservation.

In this paper [19], review how to make the regenerative braking system more efficient. The approach suggested was to lower the weight of the vehicle which increases performance. The energy conversion rate in an RBS is also improved by using a supercapacitors and keeping the vehicle small tends to enhance the system's efficiency.

In another recent study [20], the purpose of the RBS in automobiles is to reclaim part of the energy lost while braking and to recover part of the battery charge that is lost when the vehicle brakes. The energy is converted into heat by the friction brake, which is subsequently dissipated into the environment. This energy is utilised to spin the generator's rotor which converts mechanical energy from the wheels into a battery charge that may be used because it cannot bring the vehicle to a complete stop. The RBS cannot be used as the primary braking system. Experiments show that the RBS can recover at least 11% of the battery energy lost to heat in friction brakes. Consequently, when this RB technology is used in real automobiles, the distance travelled between two charging requirements can be extended by 10% to 15%.

In this paper [21], RB can save anywhere from 5% to 8% of wasted energy. The systems now include advanced power electronic components such as ultra-capacitors, DC-DC converters (Buck-Boost) and flywheels. Ultra-capacitors which assist enhance the car's transient state at beginning. Provide the battery a smoother charging characteristic and increase the electric car system's overall performance Buck-boost converters are used in regenerative braking systems to aid with power control and acceleration. Finally, flywheels are employed to enhance the power recovery procedure via automobile wheels.

The scope of this study that the project is in with the established objective. The main scope of this project consists of two parts which are studying and analysing RBS using BLDC motor with LC filter and without LC filter. Speed control of BLDC motor is done by designing a closed loop feedback control system using PI controller technique. Finally, the proposed control strategy's effectiveness was tested in MATLAB/Simulink, a modelling design application, and a theoretical study. The collected results are analysed and the results are used to conduct further research to evaluate the proposed system's regenerative power.

2. Methodology

The electronic controller circuit energises suitable motor windings by turning transistors or other solid-state switches to keep the motor rotating. A MOSFET bridge or inverter bridge, an electronic controller, a hall effect sensor, and a BLDC motor are all included in the simple BLDC motor driving circuit. illustrated in Figure 1.

Hall-effect sensors are utilised for location and speed feedback. These signals are received by the MOSFET driver circuit which analyses them and sends control signals to the controller. While the electric vehicle is operating in the force driving mode the magnetic field of the rotor is clockwise. The direction of the rotor magnetic field force becomes counterclockwise when the electric vehicle is operating in brake mode. The LC filter were added to Figure 2.

Using six switches (S1 to S6) including a freewheeling diode on the opposite. Explain the motor operating mode for BLDC motors. There is total six states of operation in one complete cycle of 360°. Each state is 60° shows one state of operation. When S1 and S4 are at ON state current flows from source to the motor. When S1 is at OFF state current circulates among the motor S4 and D2. In both the described transition conditions the current flows in the same direction Regenerative operating mode for BLDC motors when S3 and S2 are in the ON state current flows from the source to the motor. The energy stored in the inductor during the ON state of the switch is returned to the source via Dl and D4 in the OFF state of the switch (S3 and S2). The direction of the current is opposite in both modes of operation.

Using an EV with a BLDC motor drive with an identifier voltage of 400 V and a rated current of 5 A in the Matlab model. At a speed of 2200 rpm which is also the reference speed of the motor, we determined a power output of 2 HP. The stator resistance per phase and the stator inductance per phase are 2,875 Ω / phase and 0.0085 H / phase. In addition, the output torque is about 3 Nm. Using the Matlab simulation model, we were able to determine rotor speed, stator current, back-emf and electromagnetic torque.

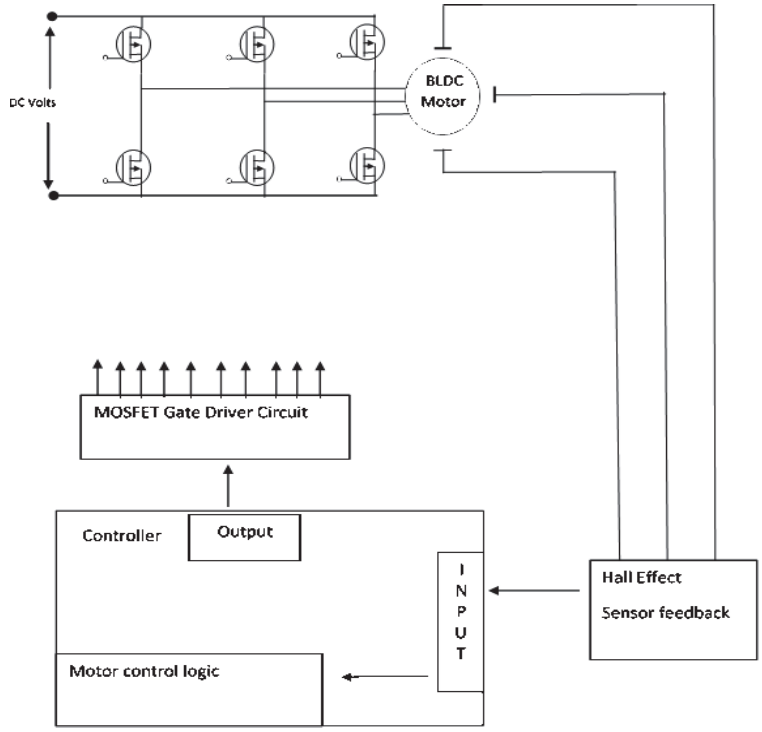

Figure 1 BLDC motor drive circuit

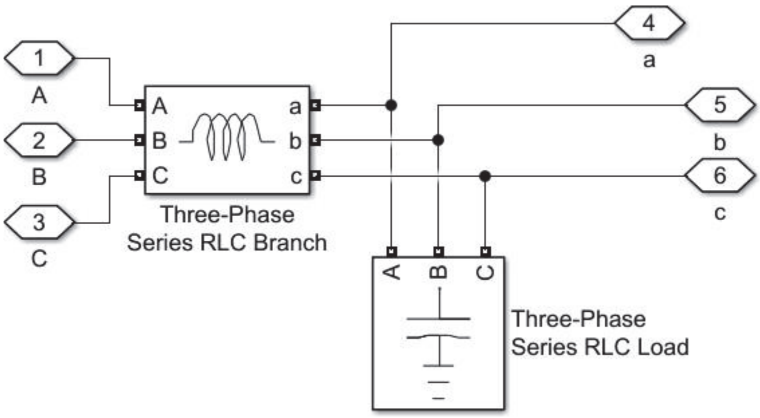

Figure 2 LC filter

The PI controller outputs an error signal. For PI regulating parameters, a manual tuning approach is used. The armature current is controlled using a PI controller. The torque of the motor is exactly proportional to the armature current. As a result, torque has a strong influence on armature current. The motor variable characteristics such as armature current, armature resistance, and armature inductance are used to determine the Kp and Ki values for current control of BLDC motors. The suitable Kp and Ki values for the speed control of BLDC motor obtained by manual technique are Kp = 0.015 and Ki = 17. By regulating processes using a controllable variable and preserving the desired output voltage, the controller aims to decrease error.

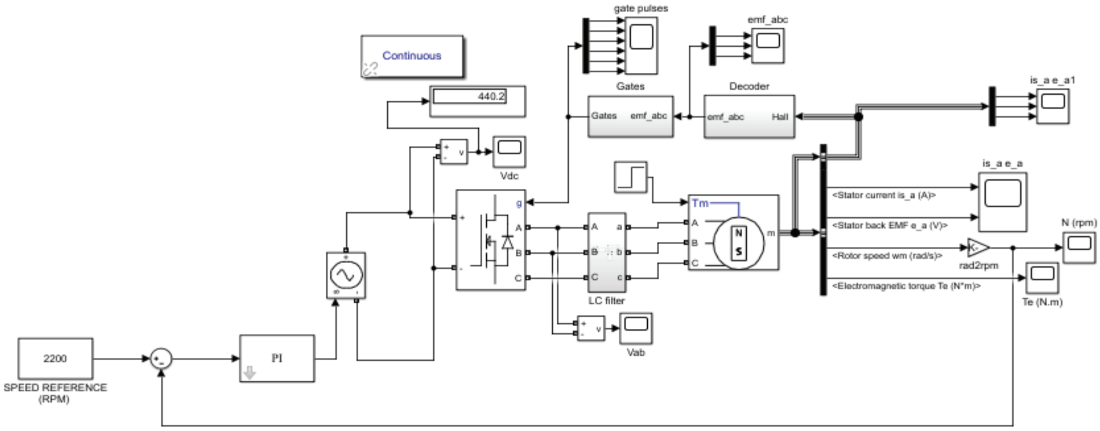

Figure 3 Overall circuit using BLDC motor with LC filter

This circuit contains three assemblies as in Figure 3. Inverter assembly, BLDC assembly and results. The inverter unit contains three circuits. Speed reference circuit, feedback controller and PI controller. The inverter unit receives feedback from the output BLDC motor and measures its output speed with a space sensor and plugs it back into the reference signal. It will generate an error signal that will be sent to the PI controller where it will produce the appropriate output that will control the speed of the BLDC motor. The switch guarantees that the BLDC motor rotor turns appropriately, with the motor speed governed solely by the provided voltage amplitude. The PWM method is used to change the amplitude of the applied voltage. The speed controller adjusts the required speed. The speed controller is implemented using a conventional PI controller. The discrepancy between real and required speeds is accepted by the PI controller. Based on this difference with the voltage amplitude required to maintain the target speed, the PI controller changes the PWM pulse duty cycle. The BLDC assembly receiving the output of this inverter will supply the input of the BLDC motor and then it will run and give some output and the result is the stator current, the EMF rotor speed behind the stator and the electromagnetic torque. The rotor speed will respond to the reference speed to improve and reduce the fault signal. This is the most important part because the entire control cycle is closed loop.

3. Result and Discussion

In Figure 4 displays the BLDC model's initial dynamics and the addition of a modest load. A 2200 rpm reference speed is utilized. The initial current is 15 A then drops to 3 A when no load is applied and the trapezoidal back-EMF is 358 V. The PI control is one of the most ideal ways for achieving a smooth transition between mechanical and electrical barking which have implemented in this system

Figure 5 and Figure 6 shows an electro-magnetic torque to start the engine, a Te of 0.1 N.m is produced. After 0.1s, the motor's speed stabilises. After 0.2 seconds, a fall in speed and back-EMF voltage is expected to occur when a modest load (Te = 3 N.m) is integrated. As the current rises to 21 A, the increased load must be met. All other parameters return to a no-load condition when the load is removed. High ripple and spike in the torque as a result.

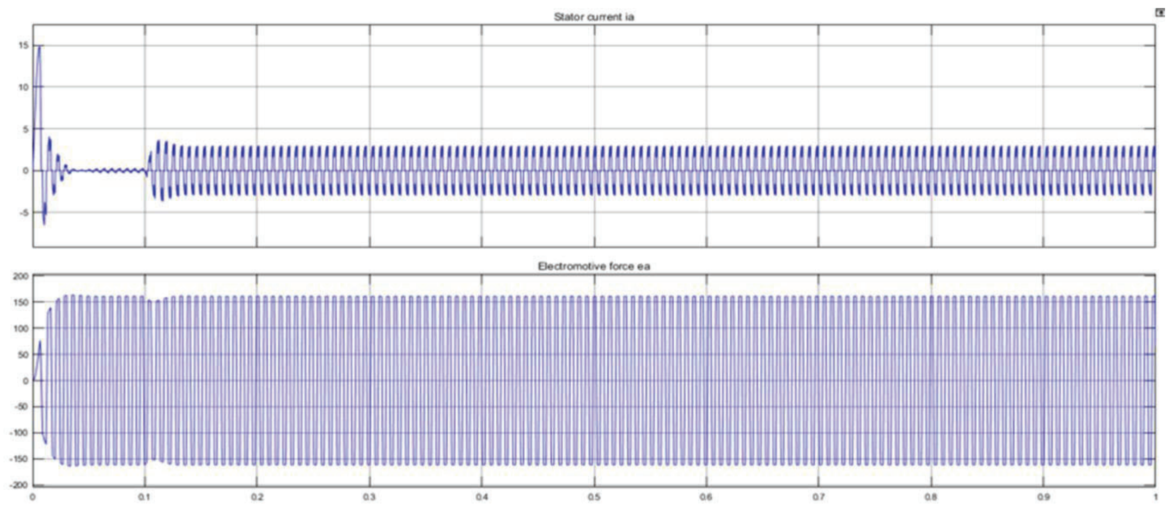

Figure 4 Result Stator Current and Back-EMF

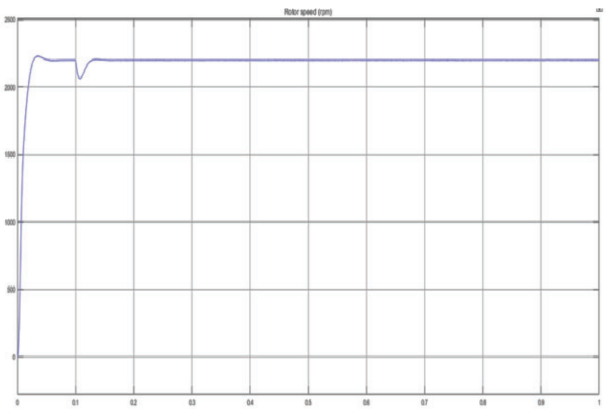

Figure 5 Rotor speed wm (rpm)

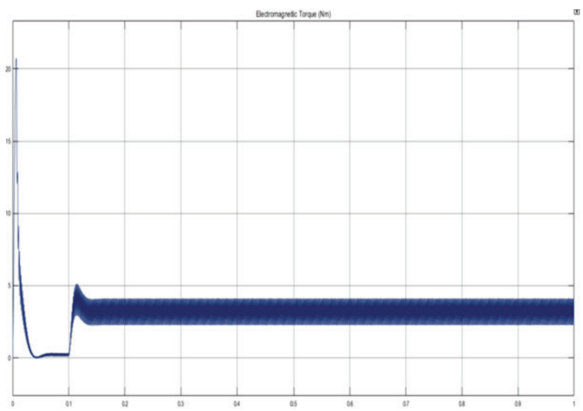

Figure 6 Result Electromagnetic torque Te(N.m)

Figure 7 displays the BLDC model's initial dynamics and the addition of a modest load. A 2200 rpm reference speed is utilized. The initial current is 15 A then drops to 12 A when no load is applied and the difference of the total current is doubled if compared before adding the LC and the trapezoidal back-EMF is 300 V. The PI control is one of the most ideal ways for achieving a smooth transition between mechanical and electrical barking which have implemented in this system

Figure 8 and Figure 9 show an electro-magnetic torque to start the engine, a Te of 0.1 N.m is produced. After 0.1s the motor's speed stabilises. After 0.2 seconds, a fall in speed and back-EMF voltage is expected to occur when a modest load (Te = 3 N.m) is integrated. As the current rises to 21 A the increased load must be met. All other parameters return to a no-load condition when the load is removed. The suggested technique has an excellent performance with less ripple and spike in the torque and a quick dynamic response. The new torque waveform that was created.

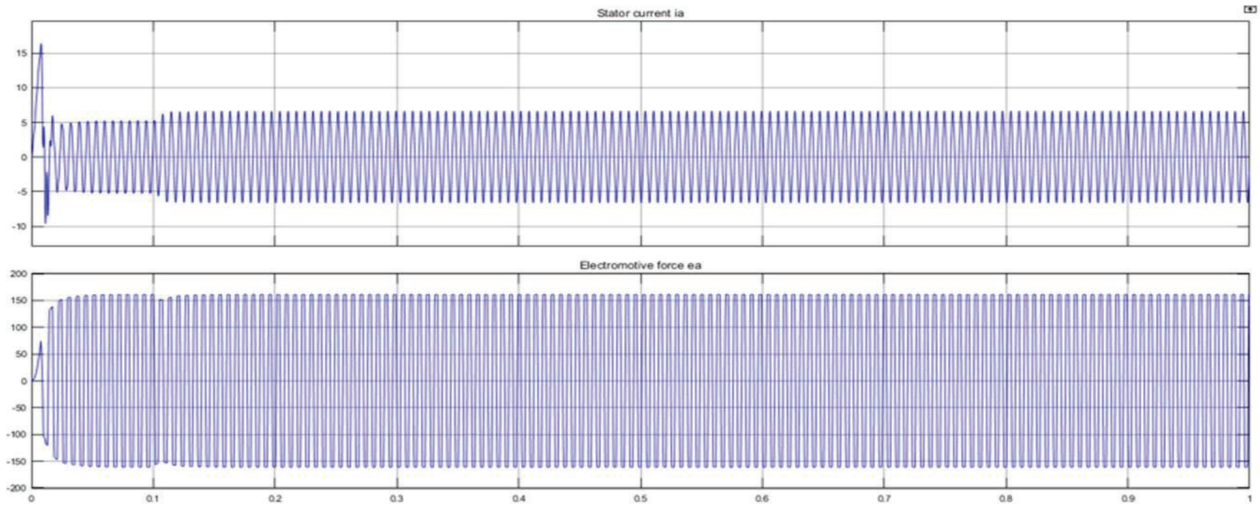

Figure 7 Result Stator Current and Back-EMF

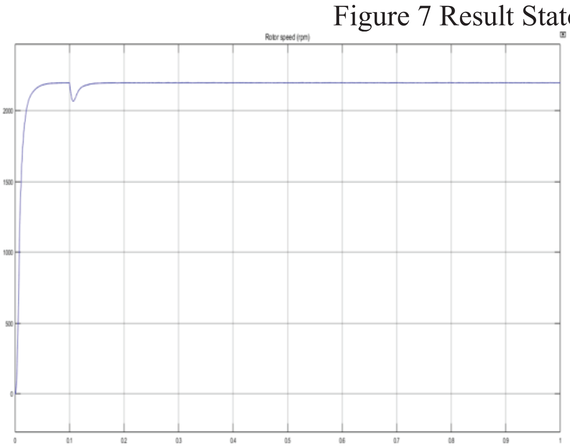

Figure 8 Result rotor speed wm (rpm)

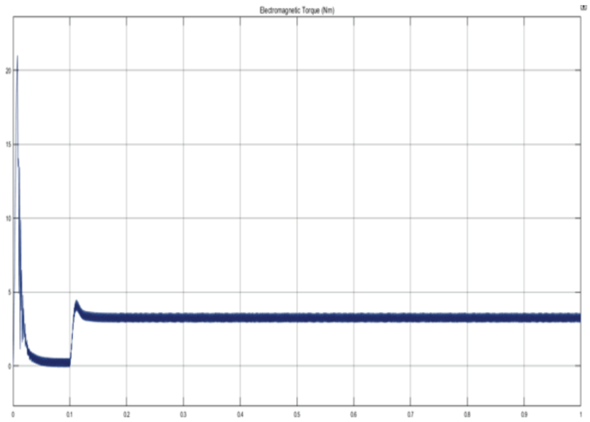

Figure 9 Result Electromagnetic torque Te(N.m)

From all the results, the performance of a BLDC motor is shown in Table 1. The BLDC motor improves when this LC filter is connected to it according to all the output findings. In steady-state circumstances all data demonstrate improved stator current, motor speed and electromagnetic torque waveforms with decreased ripple distortion and resulting in less pulsating electromagnetic torque on the rotor. When the BLDC motor is supplied without a LC filter the ripples are now decreased compared to the prior result. It is feasible to create a ripple-free output. The trigger pulse generated by a discrete six-pulse generator in an inverter with an LC filter has been confirmed now that the output values are as stated in the results and waveform. PI controller can process the current speed, compare this value with the set point, and define the frequency of the output signals that should be applied to the motor to stabilize its speed. The proportional plus integral (PI) controller is widely used for industrial applications. The input to the PI controller is the speed error. The output of the PI controller is used as the input of reference current block. The torque produced by a 2200 Rpm is 3 Nm and demonstrates that the BLDC motor is efficient when driven by an LC filter circuit.

Table 1 Result comparison

No	Part	BLDC without LC Filter	BLDC with LC Filter
1	Voltage	358V	440V
2	Stator current	3A	6A
3	Back EMF	300	300
4	Electromagnetic torque	Maximum harmonic	Minimum harmonic

4. Conclusions

The operation is carried out with the use of Brushless DC motors and the topic is RBS for electric vehicles. Conduct a comparative study using several motor drives and the conclusion can be made that BLDC motor is the best choice for performing regenerative braking operation. MATLAB is used to implement the suggested system. The acquired data are evaluated and further calculations are performed utilising the results to calculate the regenerative power derived from the proposed system. PI control is one of the most ideal ways to achieve a smooth transition between mechanical and electrical coatings that has been implemented in this system. To maintain consistent braking torque, the PWM method is used to the inverter via PI control. In the simulation, there are two potential outcomes. The results before and after the LC filter were compared. The performance of a BLDC motor improves when this LC filter is connected to it according to all of the output findings. Under steady -state conditions, all data show better stator current, motor speed and electromagnetic torque waveform with a decrease in ripple distortion and resulting in less pulsating electromagnetic torque on the rotor. Brushless DC motor drives are the most reliable and low maintenance option. The composition of DC motors without fixed magnetic force axial flux can provide higher performance when compared to other motors.

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