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BLDC MOTOR SPEED CONTROL BY THE INTELLIGENT CONTROL TECHNIQUES

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Abstract: In this study, we suggest using a bidirectional DC-DC converter to operate directions (forward, backward, driving, and braking). The motor is driven by (VSI), which receives its power from the DC-DC converter's output. A basic network with input and output nodes and hidden layers is (ANN). Since ANN more properly handles binary data, its implementation fulfills the desired outcomes. The BLDC motor is more widely used than its predecessors due to its fast speed, low maintenance requirements, and sufficient torque. The superior performance of this motor, along with the ease with which its speed can be modulated using Power Converters, makes it a popular choice. This article describes a technique for regulating the rotational velocity of a brushless DC motor by adjusting the DC input voltage to powers the motor. In the driving mode, the battery's bidirectional converter performs the buck operation, while in the regeneration mode, the boost operation is used to transform mechanical energy into electrical energy that may then becharged battery. The method suggests regenerative braking to collect energy at each stop for the electric car because of its frequent start/stop operation. Simulations of electromagnetic fields, pulse width modulation, and electromagnetic fields are achieved. Trained with the collected data, and their models provide parameter predictions that are quite near to the simulation findings.

I. INTRODUCTION

The generation technology around us is contributing to global warming, which is one of the chronic calamities associated with global climate change. Many efforts are being made, particularly in the area of transportation technology, to lessen the impact this sector has on global warming. Technologies like electric and driverless automobiles will have significant effects on global warming and fossil fuel conservation. The vast majority of electric cars nowadays use brushless DC motors are often used to propel an electric vehicle. In essence, BLDC motors are synchronous motors that are powered by direct current. To reliably detect the rotor's angle and operate the switches, BLDC motors have replaced the traditional mechanical commutator with an electronic servo system. To generate magnetic fields, direct current (DC) is switched to the motor windings through electronic closed loop controllers. The controller adjusts the DC pulses' amplitude and phase to regulate the motors' torque and speed. A bridge converter is a kind of direct current to direct current (DC-to-DC) converter that uses arrangement over a power transformer. A common setup that provides isolation and may step is a complete bridge converter. Bridge converters provide the added capabilities of reversing polarity and generating several output voltages concurrently. The function of speed regulation in BLDC motors in contemporary control systems is substantial. There are two main categories of control systems, open-loop and closed-loop. Torque or current loop constitutes the inner control loop of dual closed-loop control, while outside control loop. Pulse Width Modulation is used to adjust the motor's input voltage when its speed is below its rated operating range.

The system contains two energy sources, one operating the motor and the other storing while braking, similar to the method provided for conducting the four-quadrant operation in [4]. In this study, it is argued that a single battery may be used to power a motor in both the driving and regeneration modes. With this plan, you can avoid spending as much on a third rectifier and batteries. In [5], the four-quadrant operation is carried out without making use of the motor's kinetic energy. The system is very inefficient since the motor's kinetic energy is lost in resistive losses during braking. This method is not helpful in a future when fossil fuels are scarce. Without employing braking, [12] performs sensorless four-quadrant control of the electronically commutated motor. Electric vehicles' range is restricted by their batteries' capacities. One method of doing so is via the use of regenerative braking. the kinetic energy of the drive system may be utilised to charge the battery in regenerative mode [15], [17], and [18]. This research suggests a straightforward four-quadrant operating strategy in which the kinetic energy of the motor is converted into electrical current and used to recharge the battery during deceleration. There are two tools that may be used for this kind of power management. The VSI is used to charge kinetic energy of the motor, making this the only source of power. During braking, the VSI acts as a rectifier, boosting the rectified voltage to charge the battery.

As computers improve, electrical and electronics engineers are increasingly using AI to analyze simulation data. Some kind of computer model that has some of the properties of the human brain. These include a decentralized structure with several processing units working in parallel. The weights are the primary mechanism via which a neural network acquires new knowledge. In this article, we utilize MATLAB/Simulink to model BLDC motor speed regulation. An artificial neural network model is given the results of the simulation. The data needed to train ANNs is often trained using the TensorFlow library. For optimum results, it is suggested that several ANN architectures be used on various simulation data.

II. BLDC MOTORS

The BLDC motor's rotor has permanent magnets, while the stator features windings. The rotor's flux is created by permanent magnets. The rotor is rotated because it is attracted to the electromagnetic poles produced by the stator windings. Problems associated with connecting electricity to a moveable armature are avoided with a BLDC motor since the permanent magnets revolve around a stationary one. BLDC motors have an electronic controller that continuously swaps the winding phases. utilized in place of the conventional "brush and commentator" setup, the controller still generates the same timed power distribution. Because of its great efficiency, low torque, and precise control, the 3-phase BLDC motor is the most popular and widely used kind of BLDC motor.

Fig. 1 depicts the most typical three-phase BLDC motor. The VSI converts DC power to provide the inverter's three phases. (IGBT) switches with antiparallel diodes linked across them constitute the stage that follows the capacitor in the illustration. MOSFETs, which resemble switches, may be used instead of IGBTs since they include an antiparallel diode. However, the MOSFET's ON-state voltage drop is problematic. It is also possible to employ MOSFET for low-voltage applications. The back EMF waveform of a BLDC motor is typically trapezoidal. The current is supplied throughout to maintain a steady power output. The inverter's current injection is managed by a pair of switches that each connect to one of the two legs. So, only two switches may be on at once. In contrast to a here is managed by the switches. For optimum torque output, timed such that the angle between the rotor flux and the stator flux is close to 90 degrees. Fig. 2 depicts the forward and reverse switches. During regenerative braking, the dc voltage produced by these three phases is constant in all directions. In order to properly energize the stator winding, it is necessary to know where the rotor is in its rotation. Internal and exterior position sensors, as well as detection without sensors, may be used to ascertain the rotor's location, as shown in [6]-[8]. In order to determine where the rotor is, this article employs hall sensors. The stator has embedded sensors whose readings activate the associated switches. Since only two phases are conducting at any one time in a BLDC motor, the KVL may be applied at any time using the following equation:

$V_d = 2(E_b + I_c R_c)$ (1)

Where Vd is the voltage across the dc connection and is the back EMF of each phase of the motor.

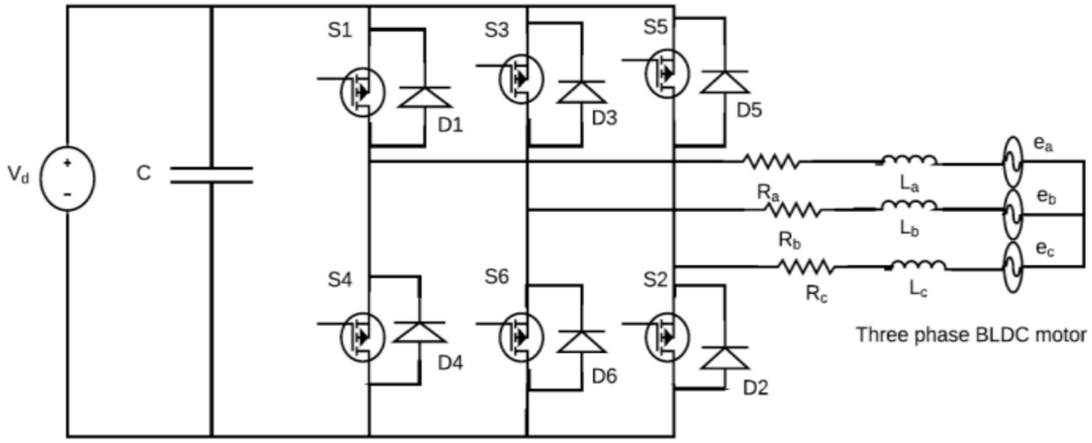

Fig. 1. Inverter based driving circuit of BLDC motor.

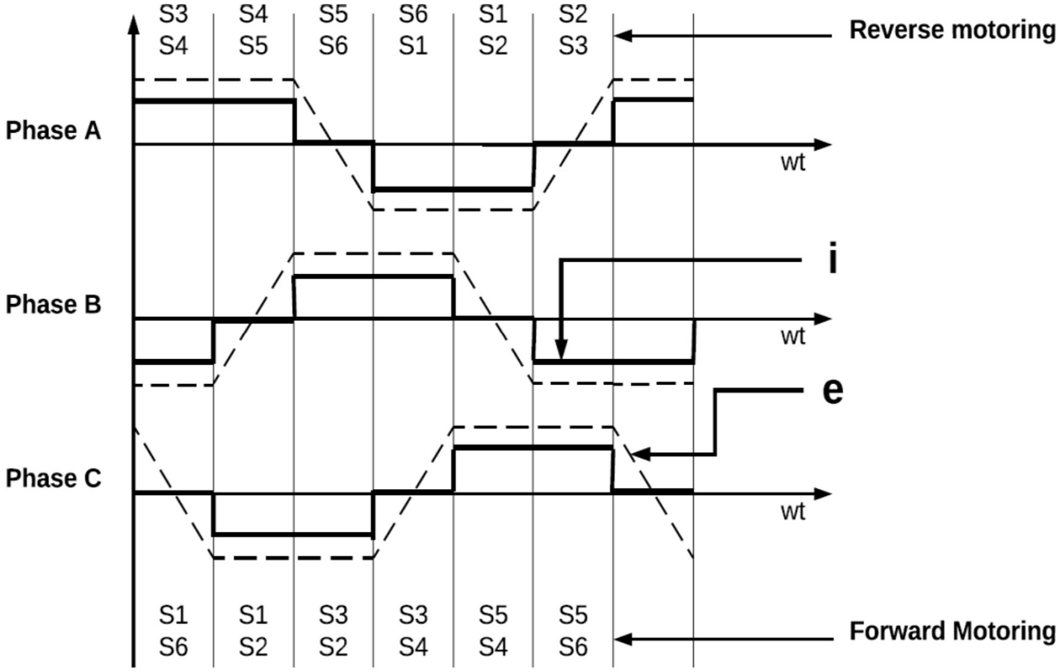

Fig. 2. Back EMF, phase current and switching sequence of switches with rotor electrical angle in degree.

III. ELECTRONIC CONTROLLERS

More often employed than its derivative, a kind of control system. The controller is essential regulation, but also for minimizing the deviation between the measured and set speeds. the whole controller is affected by the PI parameters, especially the gains, i.e., the Proportional and Integral gains. As a result, adjusting the parameters is a crucial yet challenging process. Non-integrating processes are ideal candidates for the PI controller since they share produce the same output. For the most part, PI controllers are tuned using either or Internal Mode Control (IMC) techniques. The data on measured current, voltage, and velocity.

$$U(t)K_pe(t)+K_i\int e(t) \qquad (2)$$

The PI controller relies on the aforementioned equation in order to function properly. In the controller, determined by comparing the observed data to the expected data. The in PI control multiply the mistake. Since the resulting number will be exponential, is used to normalize it so that it may be compared to other numbers. The PI controller then adjusts the DC voltage supplied to the motor winding through the bridge converter, so regulating the speed of the motor. When compared to a bridge rectifier, the efficiency of a DC-DC converter, such as a bridge converter, is much higher. Like a transformer, they allow for both stepped-up and stepped-down inputs, and they also provide isolation.

Bi-Directional DC-DC Converter

The schematic for the bidirectional converter, shown in Fig. 3 [9, 10], is as follows. In [13], we learn about the two-way performance evaluation. Two switches and diodes make up the whole thing. while switches T1 and D2 are on, the converter acts as a buck converter, which is used by the drive while in motoring mode; when switches T2 and D1 are on, the converter works in boost operation, increasing . Diodes may be used to restrict current flow to a single direction.

Ton is the time period during entire time period of operation, therefore the inverter side (Vd) voltage is reduced by a factor of the battery voltage (Vb) throughout the buck operation.

$$V_d = \propto V_b;\ \propto = \frac{T_{ON}}{T} \quad (3)$$

$$V_b = \frac{V_d}{(1-\propto)} \quad (4)$$

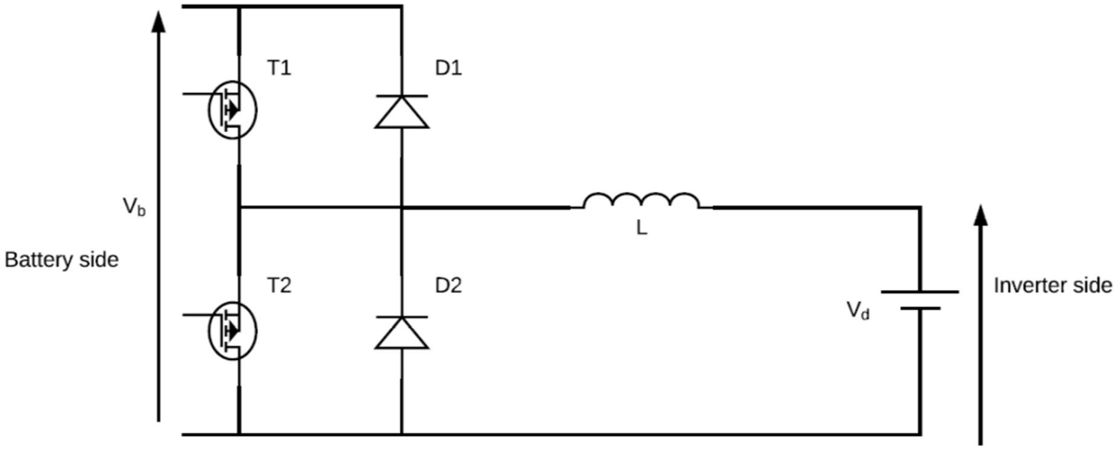

Fig. 3. Bi-directional Converter.

When switch T1 is activated in Fig. 4's buck mode (Stage I), (L), and then released when the gate pulse drops to zero (Stage II). T2 (Fig. 5) is active throughout the boost operation, allowing the inductor to store (Vd), and D1 (Fig. 5) provides a way for the current (Stage II) to return to the supply source Vd when the gate pulse becomes zero. The bidirectional converter's two switches, T1 and T2, are operated in two distinct ways, as shown in Fig. 3. In order to maintain a constant dc link voltage for motoring up to a given speed and to control during braking, switches T1 and T2 are triggered, respectively, using voltage control and current control techniques.

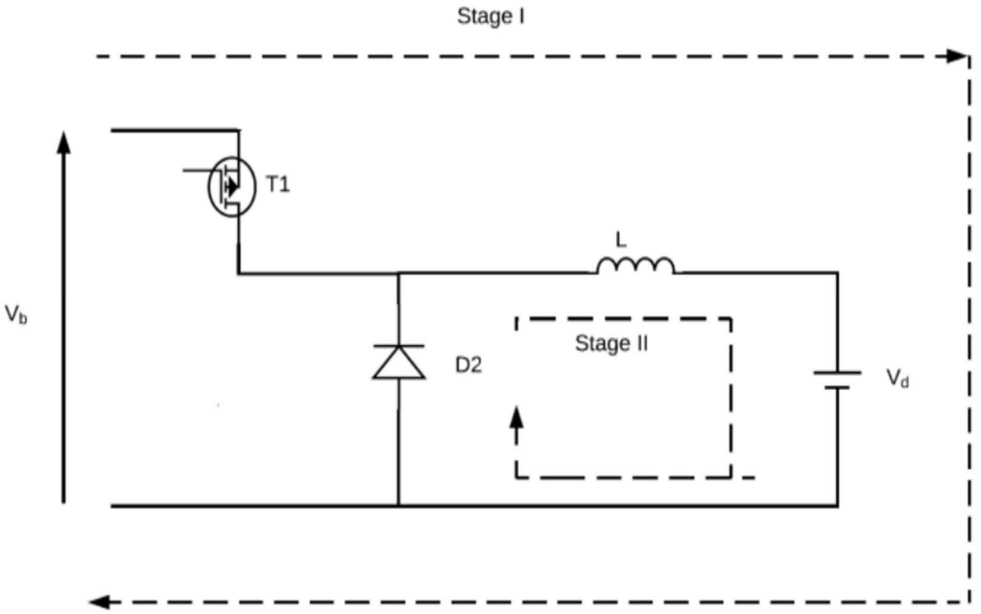

Fig. 4. Circuit diagram during forward motoring.

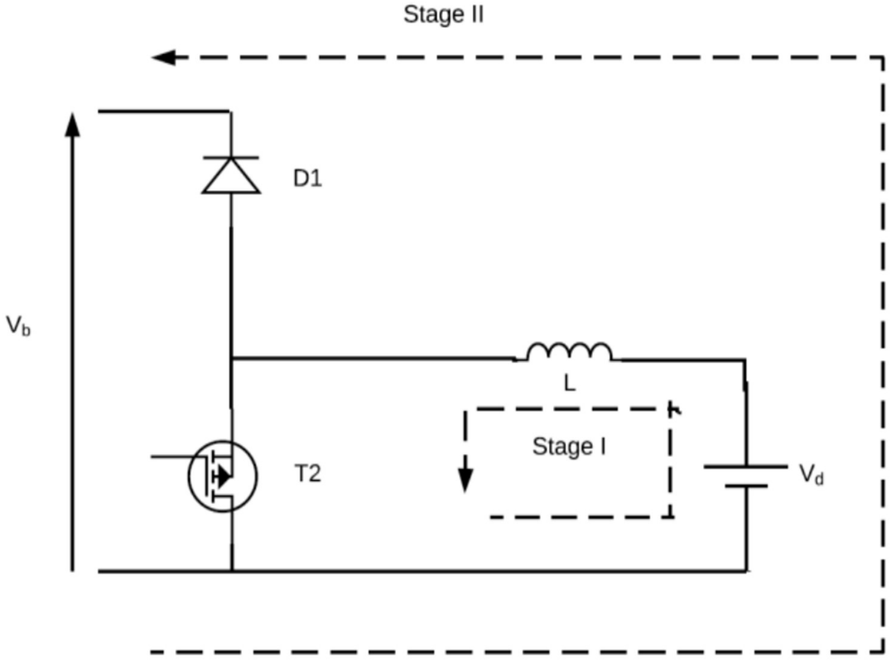

Fig. 5. Circuit diagram during regenerative braking.

Four Quadrant Operation

Figure 4 provides a good illustration of the four-quadrant functioning of a BLDC motor. Fig. 6 shows that the torque and the speed have the same sign quadrants. Since changing the rotational direction of a BLDC motor's four-quadrant operation requires more than just switching the dc link's voltage polarity, it differs somewhat from that of a DC motor. Since voltage across a positive, changing the phase sequence of a BLDC motor is required to reverse the direction of spin. Altering the BLDC motor's phase sequence allows it to function in the third quadrant. Altering the inverter's switching sequence (Fig. 2) might accomplish this.

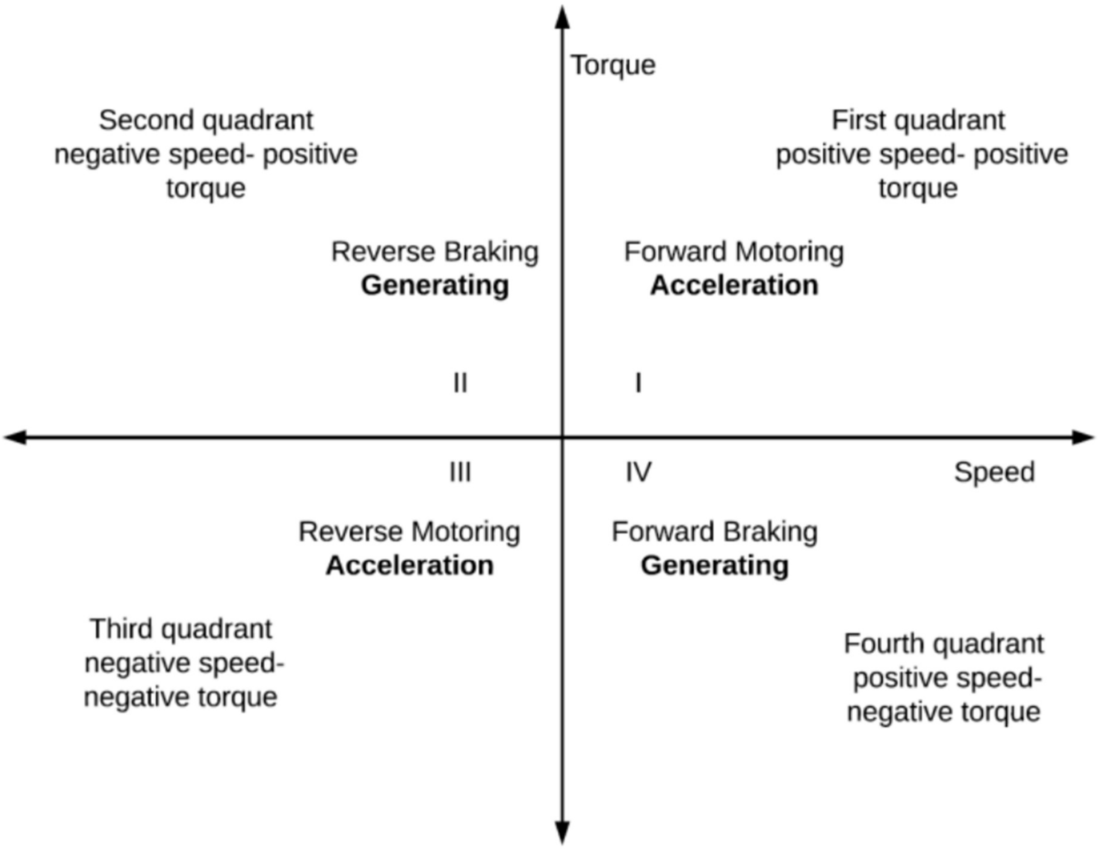

Fig. 6. Four quadrant operation.

Regenerative Braking

The DC-DC converter works both ways, providing braking. Both buck and boost modes are supported by the bidirectional converter. Buck action is used for driving and boost operation is used for stopping. Fig. 7 provides a description of the four-quadrant operation's logic diagram. When the need for regenerative braking is recognized, the gate pulses to the VSI switches are cut off. To convert (that emerges across the inverter DC supply), the VSI acts as a rectifier, with diodes linked across the anti-parallel switches. However, this only occurs in the forward biased state of the VSI diodes (D). The ideal scenario without phase resistance is 2) Fig. 2>, therefore to accomplish this, the dc-link voltage must be lowered such that it is lower than the voltage of the rectified back EMF.

$V_d = 2(E_b + I_c R_c)$ (5)

Switch T2 is activated as soon as increasing the voltage by a factor of four and charging the battery. Fig. 7 elaborates on the control logic. Switch T2 is controlled by current regulation. Downhill travel allows a vehicle to transform its stored potential energy into kinetic energy at a rate greater than the reference speed. As long as the reference speed is maintained, the motor's kinetic energy may be fed back into the battery to keep the speed constant.

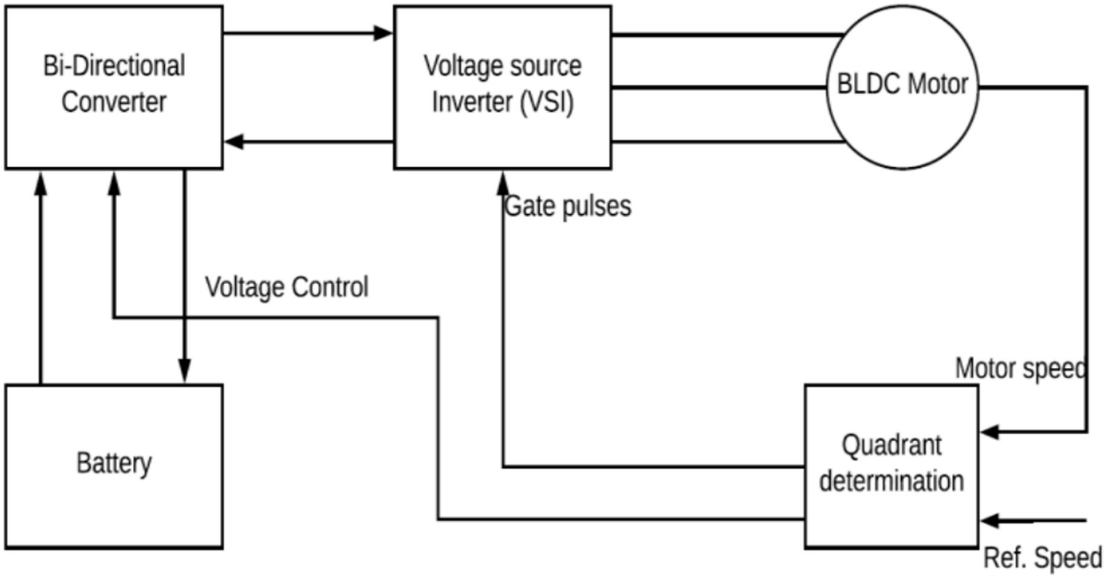

Fig.7. Block diagram representation of four quadrant operation.

CONTROL PARAMETERS

A. Hall Effect

In contrast to brushed motors, a BLDC motor's commutation is managed electronically. For the motor to spin, the stator windings must be energized sequentially. To determine which winding should be powered, rotor position is also required. The rotor's location is determined via Hall Effect sensors permanently installed in the stator. When magnetic poles of the rotor move closer to the sensor, the sensors respond with a high or low signal, respectively. Thus, the combination of Hall sensors establishes the commutation sequence. The Hall Effect Theory states that when a conductor carrying an electric current is put in a magnetic field, the charge carriers experience a transverse force that causes them to move. This is particularly obvious in flat, thin conducting materials. When the magnetic force is cancelled out by the buildup of charge on the conductor's sides, a voltage is generated across its width. The Hall Effect describes this occurrence.

B. Torque / Speed Characteristics

When specifying a BLDC motor, two types of torque are used: The motor may be continuously loaded up to the Rated Torque during operation. Torque is also unaffected by changes in speed up to the Rated speed, as was indicated before. The run up to 150% of its rated torque, however the torque drops down significantly after that. When the application involves rapid rotational reversals as well as frequent starts and stops when under load, greater is required. This occurs most often when the engine is first started and again during acceleration. Therefore, some additional torque is required to regulate the effect caused by the rotor's and load's inertia. The maximum torque that a motor is capable of producing is limited only by the speed-torque curve to which it must conform.

C. Pulse Width Modulation

Tuning the amount of electricity going to the load is a breeze with the help of Pulse Width Modulation (PWM). It's a method of gradually increasing speed without sacrificing initial thrust. Harmonics are eliminated as well. A DC motor's rotational speed may be precisely modulated by pulse width modulation (PWM). The motor is powered by a variable duty cycle.

Since PWM maintains a fixed frequency while varying the on and off period, the duty cycle is a function of the pulse width. Therefore, with PWM, a greater duty cycle corresponds to a higher power output. Hall signals are used to deduce the switching logic that ultimately triggers the inverter switches. The PID controller compares the current signal to a predetermined standard and uses the resulting error signal to adjust the current speed.

ARTIFICIAL NEURAL NETWORKS

Deep learning's secret weapon is an artificial neural network that takes its cues from nature. A neuron is a node in an artificial neural network. Data is processed and transformed in a manner analogous to how information is sent and processed in the human brain, i.e., through synapses and neurons. In addition to the obvious input and output layers, ANNs also have a series of hidden layers that play a crucial role in the overall structure. The input neuron takes in information (input) and multiplies it by predetermined weights. They are then combined and sent after an activation function has been applied. There is a recursive loop in play here. The model is able and take on challenging jobs because to this iterative approach. As was previously said, the process kicks off by giving information passing between neurons respective weights. Correctly setting the weights is crucial to the success of a neural network. Training a neural network using the training data modifies the weights. At each round of training, the model's weights are adjusted so that it can better comprehend the data and recognize its patterns. May make predictions based on fresh data that is put into it. The precision is conditional on a number of factors. Much rides on the specifics architecture, the dataset, the activation function, and the data at hand.

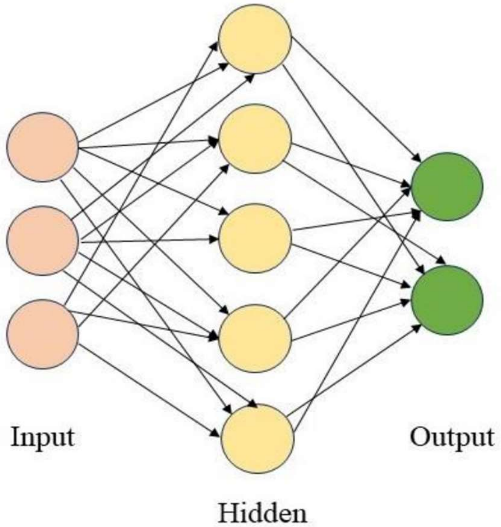

Figure 8 Structure of a basic Artificial Neural Network

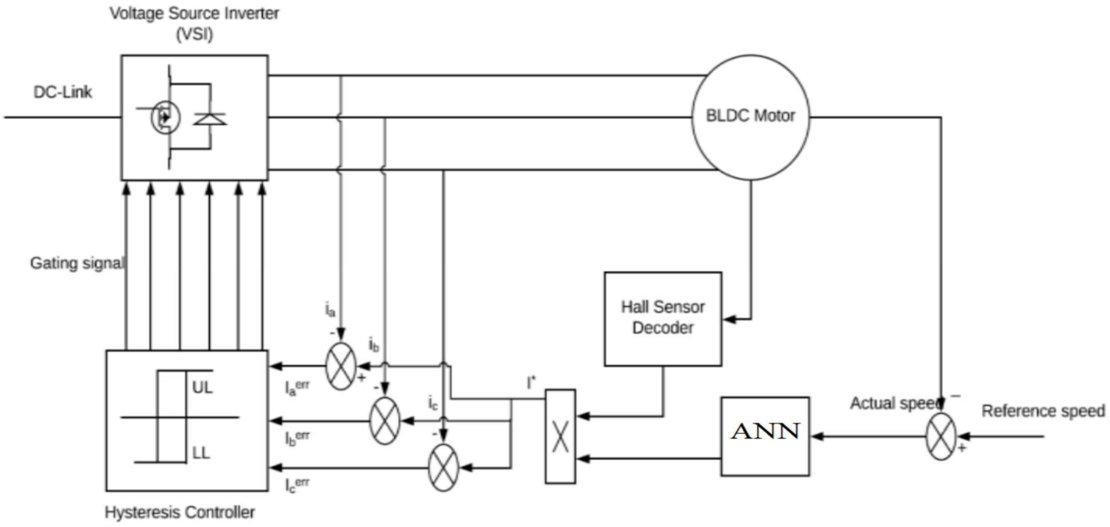

Fig9.Proposed block diagram

The neural network uses both forward and backward propagation to spread information. The information is passed forward in a forward propagation. It includes a sample with characteristics. The result depends on these factors. After that, it does a summing operation and an activating operation. In this procedure, the weights are added up. The information is then transferred to a deeper hidden layer, where applied. In the following formula, i represents the total represents the weights, and X represents the feature data.

$$Y = (W_i X_i + b) \qquad (6)$$

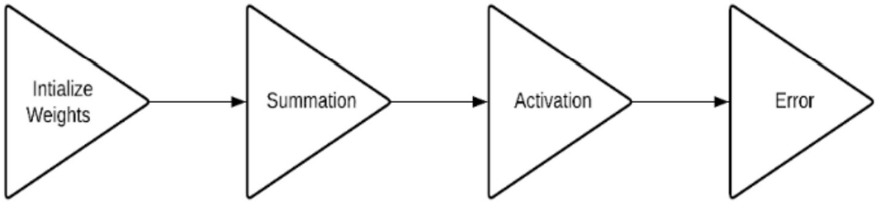

Figure 9 Flow Diagram of Forward Propagation

The major goal of the propagation is to lower the error as a whole. The term "backward propagation" refers to the process of measuring and then reducing error via tweaks to the activation function and weights. The chain rule is used in Backward Propagation to identify the incorrect weights that caused the mistake and to correct them.

$$\frac{dE}{dW_i} = \frac{dE}{dA} \times \frac{dA}{dS} \times \frac{dS}{dW_i} \quad (7)$$

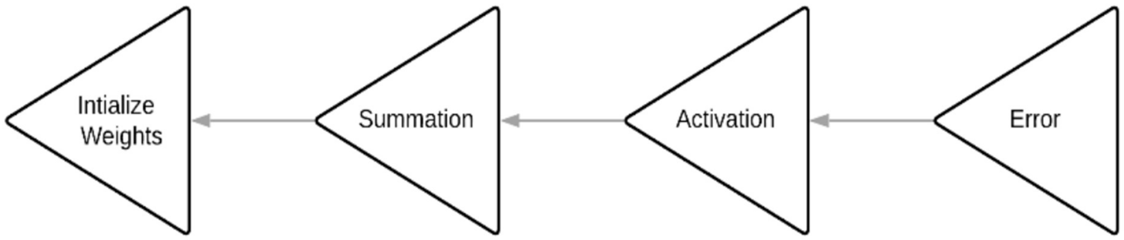

Figure 10 Flow Diagram of Backward Propagation.

RESULTS

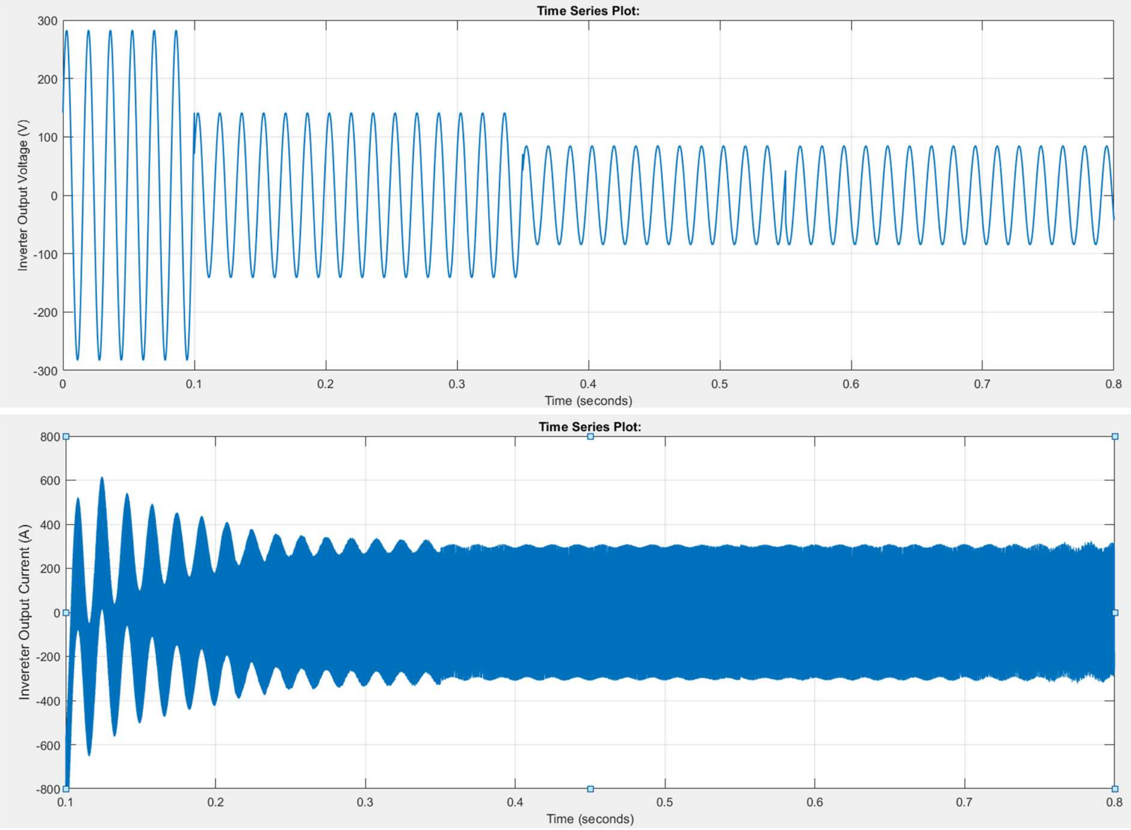

Fig. 10. Phase ‘A’ Voltage and current waveform of the inverter.

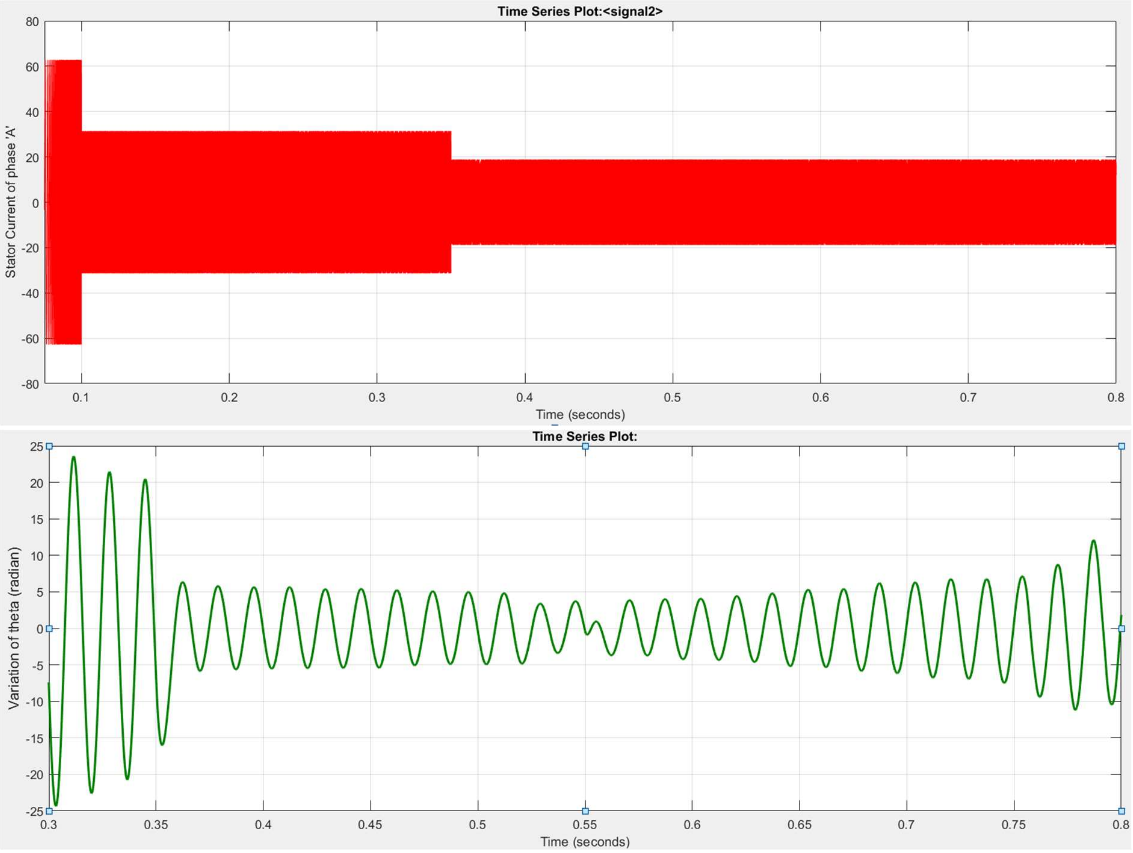

Fig. 11. Variation of theta during forward motoring to forward braking to reverse motoring.

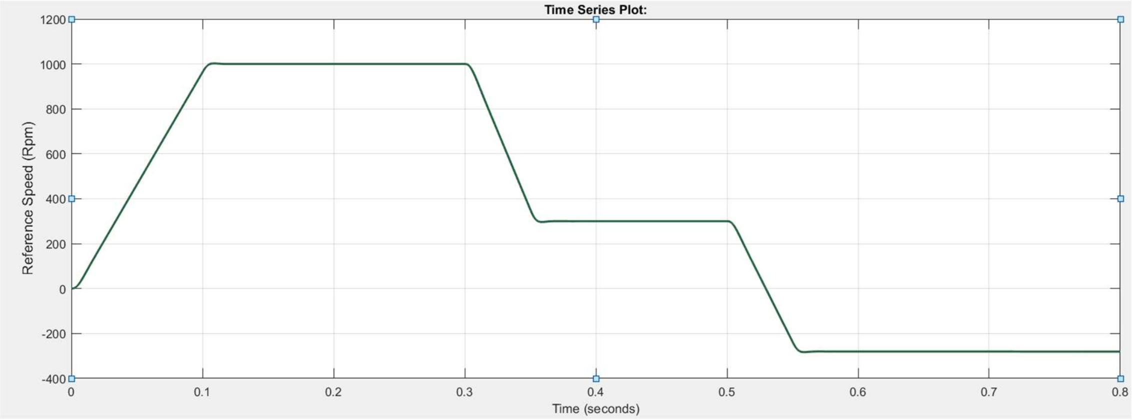

Fig. 12. Reference or the actual speed of the motor.

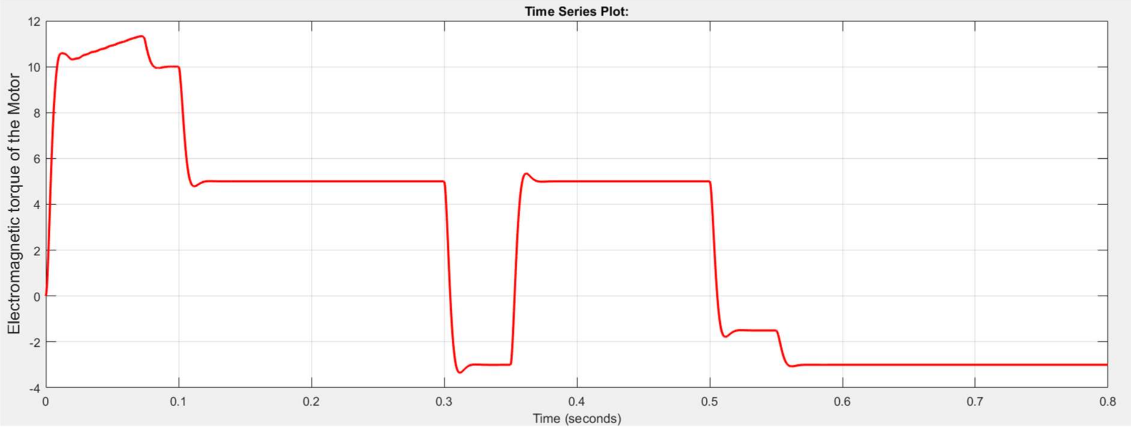

Fig. 13. Electromagnetic torque and load torque of motor.

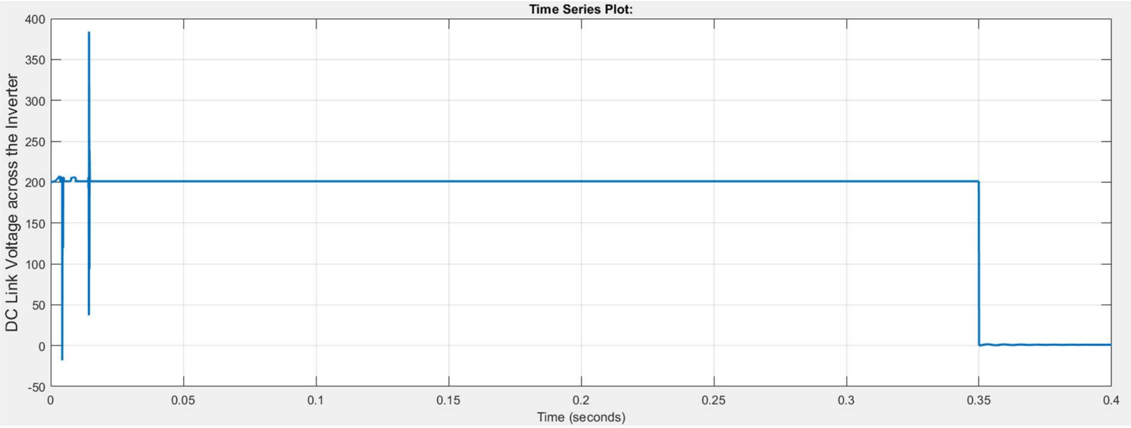

Fig. 14. Voltage across the inverter during forward motoring and braking.

Figure 14 shows the inverter model's voltage across circuitry. Voltage across the dc-link is acquired during forward braking by negative and decreases between 0.3 seconds and 0.35 seconds. This technology is energy-efficient because a bidirectional converter is used to increase the voltage before it is used (see Fig. 15). The necessary load torque varies with the kind of propulsion or braking being used. Figure 13 shows the combined electromagnetic and load torque that is generated. The process of switching the motor's rotational direction is shown in Fig. 11.

CONCLUSION

In this study, we offer a technique for efficient four-quadrant control of BLDC motors. For the electric drive, optimal efficiency is simulated throughout all four quadrants while still respecting the fuel restriction. During the regenerative mode, the battery is charged while closed-loop control is used to regulate the vehicle's speed. The suggested solution necessitates little hardware and allows for full four-quadrant operation control. The battery is charged when to it through the bidirectional converter during the regenerative mode. The suggested technique involves regulating the DC voltage sent into the bridge converter that supplies the motor's windings. A PI controller is used to regulate the input. For the suggested system, simulation results are used to inform the parameters of Network.

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