Ann Based Regenerative Braking System of Electric Vehicle

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Abstract **-** Regenerative Braking System (RBS) can increase energy usage efficiency and can extend the driving distance of Electric Vehicles (EVs). Brushless DC (BLDC) motors are ideally suitable for EVs. In the proposed work, BLDC motor control utilizes the Artificial Neural Network for the distribution of braking force. During the braking period, the proposed method only changes the switching sequence of the inverter to control the inverse torque for returning the braking energy to the battery. Since the braking kinetic energy is converted into the electrical energy and is returned back to the battery. Further the simulation results are analyzed under the environment of MATLAB and Simulink. In comparison to other solutions, the new solution has better performance in regard to realization, robustness, and efficiency because ANN gives high accuracy and better results.

Keywords **-** *Brushless Dc (BLDC) Motor, Artificial Neural Network (ANN), Regenerative Braking System (RBS), Electric Vehicles (Evs).*

I. INTRODUCTION

Now the EVs are attaining more attention than conventional Internal Combustion Engine (ICE) vehicles. The electric vehicles are hopeful substitute to ICE vehicles by the emerging technology of motor and battery. EVs performance is become comparably better than that of ICE vehicles. It is not possible to recycle the brake energy by RBS in ICE vehicles.

Regenerative Braking is the process of feeding energy from the drive motor back into the battery during the braking process, when the vehicle's inertia forces the motor into generator mode. In this mode, the battery is considered as a load, thereby providing a braking force to EVs. When the vehicle's brake is pressed, the motor will operate as generator and the electrical energy is fed back to the battery instead of being wasted.

II. BLDC MOTOR AND ITS CONTROL

A. *BLDC Motor*

BLDC motors also known as Electronically Commutated Motors (ECMs) are synchronous motors that are powered by a DC electric source via through an integrated inverter/switching power supply, which produces an Alternating Current (AC) electric signal to drive the motor.. Additional sensors and electronics control the inverter output amplitude waveform and frequency (i.e. rotor speed). BLDC motors are ideally suitable for EVs because of their high power densities, and low maintenance.

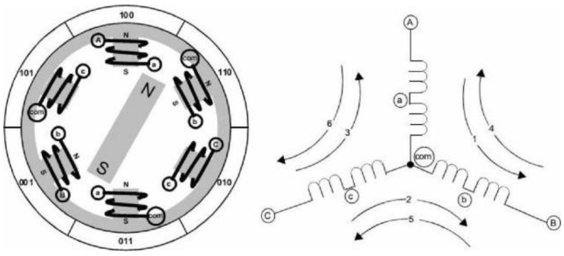

Figure 1: Y Connected BLDC Motor Construction

BLDC motor is a type of synchronous motor. It means that the magnetic field generated by the stator and the rotor rotation are at the same frequency. BLDC motors do not experience the "slip" which is normally seen in induction motors. As shown in Figure 1, in a BLDC motor, permanent magnets are mounted on the rotor, with the armature windings being fixed on the stator with a laminated steel core. BLDC motor parts as shown in Fig 2.

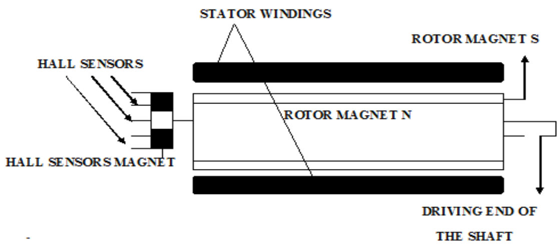

Figure 2: Parts of BLDC Motor

B. *BLDC Motor Control*

In brushless motor, the commutation is achieved electronically by controlling the conduction of switches in the arm of inverter bridge. To control the BLDC motor the position of rotor must be determined which decides the commutation. The voltage vector of BLDC motor is divided into six, which is an correspondence with the Hall Effect sensors signal, as shown in Figure 3. The corresponding hall signals are given to the controller which generates gate signals. These Pulse Width Modulation (PWM) signals are given to the switches in the inverter which supplies the stator winding.

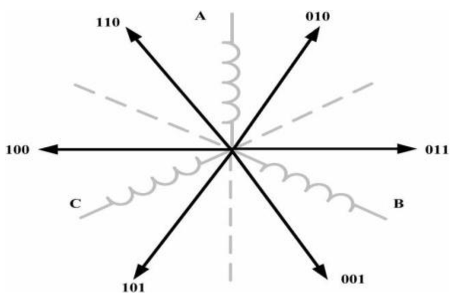

Figure 3: Six Sectors of the BLDC Motor Voltage Vector

The basic drive circuit for a BLDC motor is shown in Figure 4. Each motor lead is connected to high-side and low-side switches. The correlation between the sector and the switch states is noted by the drive circuit firing. At the same time, each phase winding will produce a back EMF.

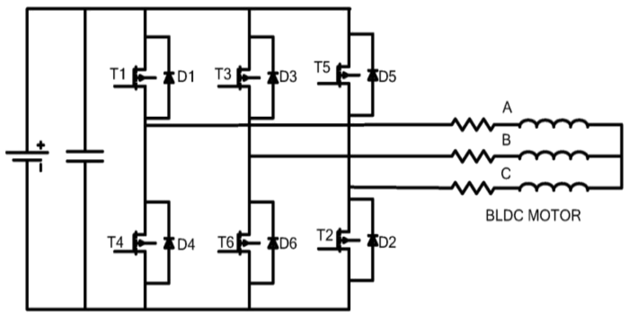

Figure 4: H-bridge Inverter Circuit

III. REGENERATIVE BRAKING

A regenerative braking is an energy recovery mechanism which slows a vehicle speed or object down by converting its kinetic energy into another form, which can be either used suddenly or can be stored. During "Regenerate," the wheels of a decelerating vehicle are still moving forward, that can be made to turn the electric motor, which can takes energy to the batteries for storage.

A. Control of Inverter For Regenerative Braking Mode

During deceleration the current in the circuit of motor-battery is reversed to achieve regenerative braking. Figure 5 shows the relation between armature current and back EMF for phase A, B and C. T1, T3, T5 are higher arm switches which are always kept off. T4, T6, T2 are lower arm switches which are controlled for the energy reversal during regenerative braking.

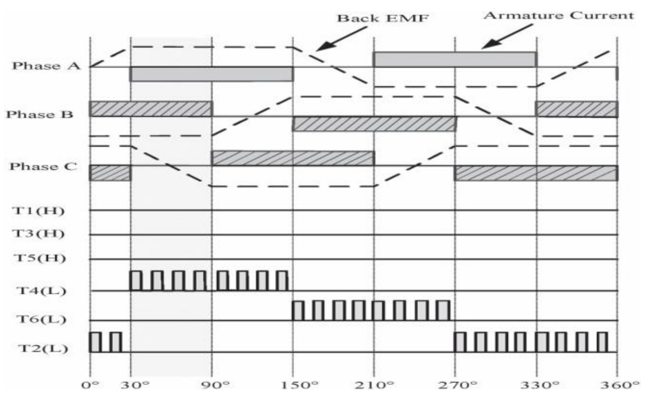

Figure 5: RB with single switch in lower arm of MOSFET based inverter

Table 1: Switching Pattern for the Motoring Mode

H1	H2	H3	S1	S2	S3	S4	S5	S6
1	0	1	1	0	0	1	0	0
1	0	0	1	0	0	0	0	1
1	1	0	0	0	1	0	0	1
0	1	0	0	1	1	0	0	0
0	1	1	0	1	0	0	1	0
0	0	1	0	0	0	1	1	0

During normal motoring mode both the upper and lower arm switches are used. Here, simultaneously both the switches in the single arm of the inverter cannot be operated as shown in table 1.

Table -2: Switching Pattern for the Regenerative Braking Mode

H1	H2	H3	S1	S2	S3	S4	S5	S6
1	0	1	0	1	0	1	0	0
1	0	0	1	1	0	0	0	0
1	1	0	0	0	0	1	0	1
0	1	0	1	0	0	0	0	1
0	1	1	0	1	0	0	0	1
0	0	1	0	1	1	0	0	0

During braking mode the motor acts as generator. Table 2 shows the switching pattern for the regenerative braking mode in accordance with the corresponding hall signals. Here only the lower arm switches are controlled all the upper arm switches of the inverter. The equivalent circuit of the single switch as shown in Figure 6.

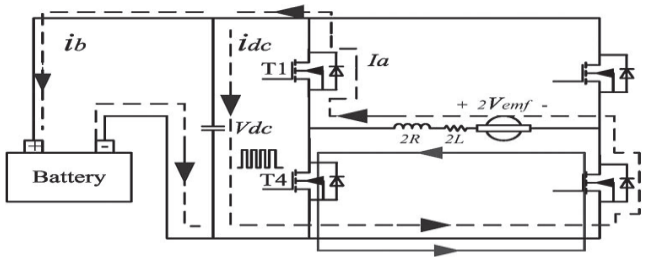

Figure 6: Equivalent Circuit of the Single Switch

IV. ARTIFICIAL NEURAL NETWORK

ANN is an efficient information processing system. Each neuron is connected with the other by a connection link and each connection link is associated with weights. It can perform several parallel operations simultaneously. The size and complexity is based on the chosen application and the network designer.

A. Execution Using ANN

ANN based regenerative braking system of electric vehicle using BLDC motor is achieved as shown in Figure 7.

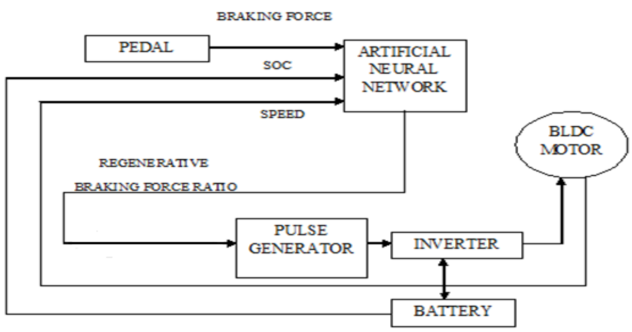

Figure 7: RBS OF Electric Vehicle Using ANN

B. GRBF Neural Network

A new model of ANN called the Generalized Radial Basis Function (GRBF) neural network. The GRBF allows different radial basis functions to be represented by updating the new parameter. The architecture for the GRBF as shown in Figure 8.

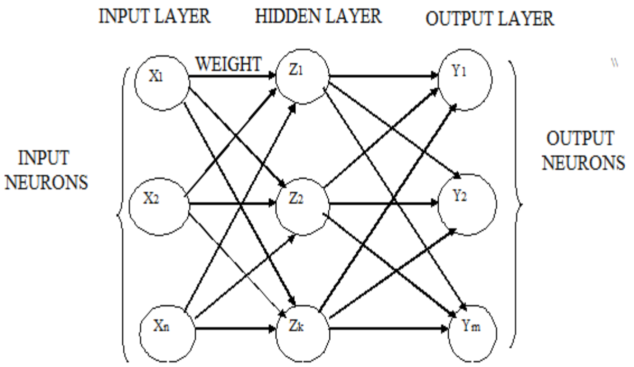

Figure 8: Architecture of GRBF

V. SIMULATION RESULTS

To simulate the system a closed loop ANN based RBS of EVs driven by BLDCM is constructed using Matlab/Simulink as in Figure 9. The output from the three phase inverter which is the supply voltage is given to the BLDCM. In a subsystem of control and inverter the source voltage is supplied to three phase bridge arm which consist of six MOSFET which is very effective for high frequency applications. The trigger circuit is used to generate the pulse as the input to inverter for turn off and on the switch as shown in Figure 10.

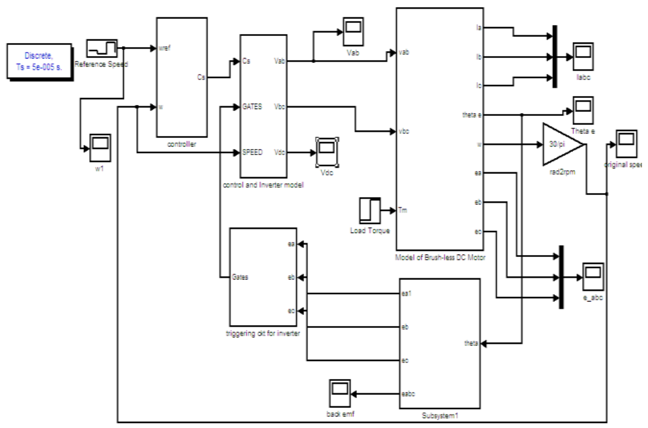

Figure 9: Simulink Model of Regenerative Braking using BLDCM

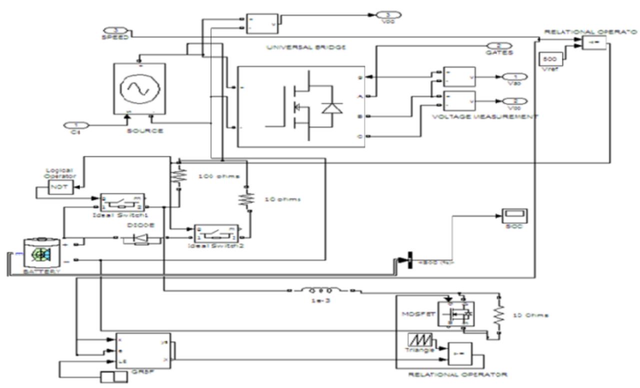

Figure 10: Subsystem of Control and Inverter Model

Figure 11 shows the battery State Of Charge (SOC). When the battery's SOC is below 10%, which is unsuitable for charging. When the SOC is between 10% and 90%, the battery can be charged with a large current. When the SOC is above 90%, the charging current is reduced to prevent the excessive charging of the battery.

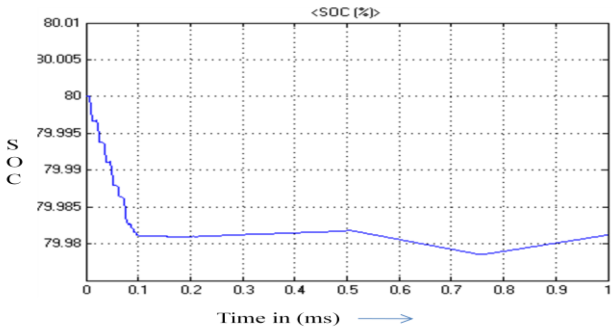

Figure 11: Battery SOC

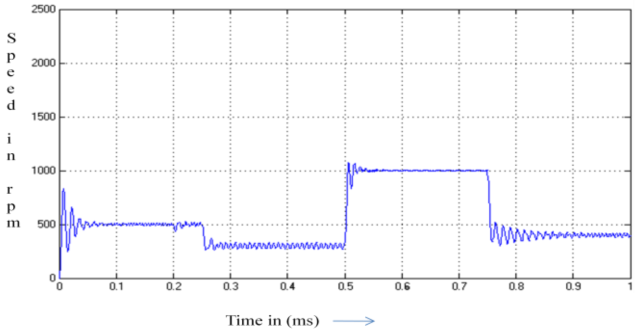

Figure 12: Speed of Motor

Vehicle speed plays an important role in ensuring the brake safety. Figure 12 shows the speed of motor. Therefore it reduces the back EMF induced in the armature. The generated back EMF is shown in Figure 13.

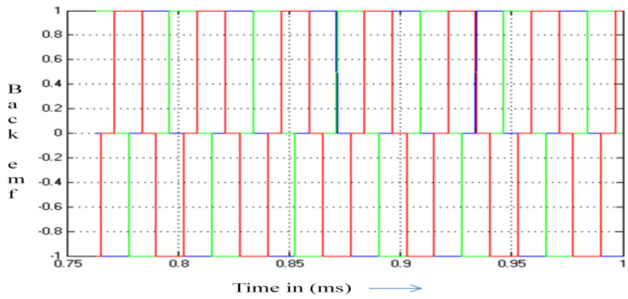

Figure 13: Back EMF

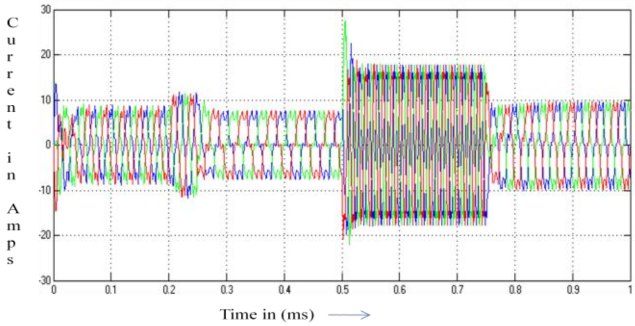

Figure 14: Current Waveform

In a Figure 14 and Figure 15 shows the variation of current with respect to the given voltage. In order to vary the speed of motor the reference speed is increased which in turn increases the input voltage for the motor.

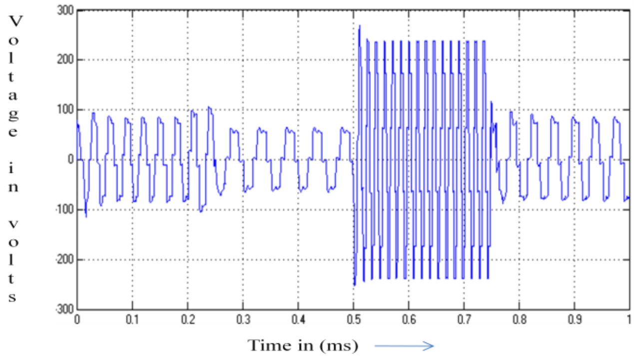

Figure 15: Voltage Waveform

CONCLUSION

RBS for electric vehicles which is driven by the BLDC motor has been presented in this thesis. The developed model is implemented in MATLAB/SIMULINK. The simulation results validate that the neural network control can realize the regenerative braking and can prolong the driving distance of EVs. The new solution has better performance in regard to realization, robustness, and efficiency.

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