International Journal of Multidisciplinary and Scientific Emerging ResearcH (IJMSERH)

IJMSERH

| ISSN: 2349-6037 | www.ijmserh.com ||Impact Factor: 9.274||Quarterly, Peer Reviewed & Refereed Journal|

|| Volume 12, Issue 1, January 2024 ||

# Regenerative Braking System of Electric Vehicle Driven By BLDC Motor Using Neuro-Fuzzy and PID

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**ABSTRACT:** Regenerative braking can improve energy usage efficiency and can extend the driving distance of Electric Vehicles. Innovative Regenerative Braking System of EV driven by BLDC motor is recommended. In this technique, Brushless DC motor is controlled by traditional Proportional Integral Derivative control, and the braking force distribution is done by ANFIS. This reasoning is quite sluggish compared to PID. Thus PID is used to control the negative torque of the motor when brake is pressed. This fresh elucidation has improved performance in regard to insight, strength, and efficiency. The suggested system grants the simulation results by analysing the speed of motor with its braking force and the vehicle's battery charge under the IDE of Simulink. The results illustrates that the Neuro-fuzzy logic and PID control can recognize the regenerative braking can prolong the driving distance of EVs under the condition of confirming quality of braking condition. Eventually, the proposed method is proved using MATLAB R2014a software.

**KEYWORDS**: Regenerative Braking System (RBS), Electric Vehicle (EV), Brushless DC (BLDC) motor, Adaptive Neuro-Fuzzy Inference System (ANFIS), ProportionalIntegral Derivative (PID)

## I. INTRODUCTION

Now a day EVs are attaining more attention than conventional Internal Combustion Engine vehicles (ICE). These ICE vehicles use fossil oil as fuel which leads to the focus of environmental aspects and economic anxieties. The electric vehiclesare hopeful substitute to ICE vehicles by the emerging technology of motor and battery. EVs performance features have become comparably better than that of ICE vehicles. It is impossible to recycle the brake energy by RBS in ICE vehicles. So the idea proposed is on Regenerative braking of BLDC motors used in electric vehicles. 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. During braking the vehicle's inertia pressures the motor into generator mode. The RBS applied to EVs can lengthen the driving distance of the vehicle to the range of 16% compared to the EVs without RBS. But the regenerative braking cannot be worked at all periods. Because when the battery is fully charged the energy is dissipated in resistive load so the braking is affected. Hence EV still needs mechanical brake for safety actions. Thus the smooth changeover from regenerative braking to mechanical is done in a single foot pedal which cannot attain by conventional ICE vehicles.

## II. LITERATURE SURVEY

EVs are becoming important, not only as an environmental measure against global warming but also as an industrial policy.Theproposed idea is simple and effective method of electric brake with energy regeneration for a brushless dc motor of an electric vehicle (EV). During the braking period, this only changes the switching sequence of the inverter to control the inverse torque so that the braking energy will return to the battery.In addition to the braking period, the duration of release throttle is also included in the energy-regenerative mechanism such that the EV is similar to engine vehicles having the engine brake [11].Regenerative braking can improve energy usage efficiency and can prolong the driving distance of electric vehicles (EVs). A creative regenerative braking system (RBS) is presented in this proposed. The RBS is adapted to brushless dc (BLDC) motor, and it emphasizes on the distribution of the braking force, as well as BLDC motor control. BLDC motor control utilizes the traditional proportional–integral–derivative (PID) control, and the distribution of braking force adopts fuzzy logic control [1]. Because the fuzzy reasoning is slower than PID control, the braking torque can be real-time controlled by PID control. In comparison to other solutions, the new solution has better performance in regard to realization, robustness, and efficiency.

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## III. BLDC MOTOR AND ITS CONTROL

### A.BLDC MOTORS

Brushless DC motors are inverter fed motors which perfectly suited for EVs due to their various characteristics such as high efficiency, wide speed ranges and good power densities. BLDC motor is one of the types of synchronous motor. Hence BLDC motors don't have slip i.e. the magnetic field produced by stator and rotor have same frequency.

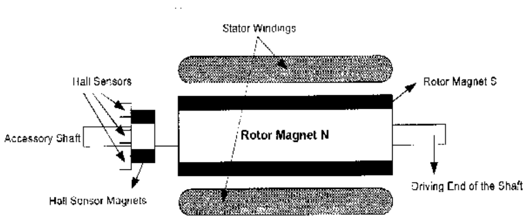



Figure 1 BLDC motor parts

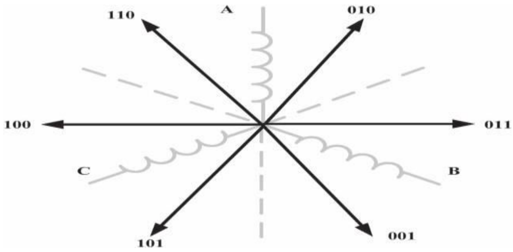



Figure 2 Six sectors of BLDC motor

To sustain the rotation the position of rotor is sensed with the help of Hall sensors which is mounted on the stator. In recent days sensor less control is applicable by measuring coil's back emf.

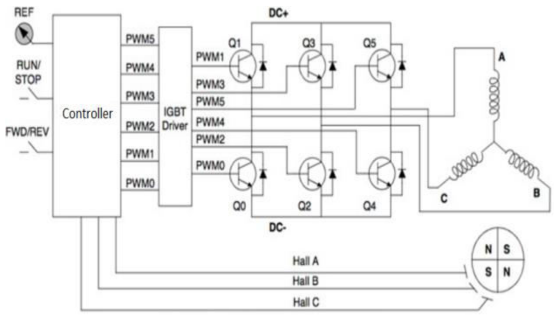



Figure 3 Schematic of BLDC motor

### B. BLDC MOTOR CONTROL

As the motor is brushless, the commutation is achieved electronically by controlling the conduction of switches in the arm of Inverter Bridge. The schematic of BLDC motor is shown in figure 3. DC power supply is given as input to BLDC motor. 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 in correspondence with the Hall Effect sensors signal, as shown in figure 2.As shown in figure 2 the corresponding hall signals are given to the controller which generates gate signals. These PWM signals are given to the switches in the inverter which supplies the stator winding. Thus with the help of Hall sensors the motor is controlled using any micro controller. Three phase motors use six switches, two in each arm of the inverter. MOSFET or IGBTs are most widely used. Due to its low output impedance IGBTs are commonly used in high power applications.

### C. CONTROL OF INVERTER SWITCHES FOR REGENERATIVE BRAKING MODE

During deceleration the current in the circuit of motor-battery is reversed to attain regenerative braking. Pulse Width Modulation (PWM) control is implemented for an active braking control. The back EMF of the stator winding is incapable to reach the voltage across battery when the speed of BLDC motor is low. The inductances in the stator of motor can establish a boost circuit. Through this inductor accumulator the dc bus voltage is upraised to accomplish the retrieval of brake energy. To achieve this all the switches in the higher arm of the inverter are turned off and the lower arm switches are only controlled throughout the regenerative braking mode.

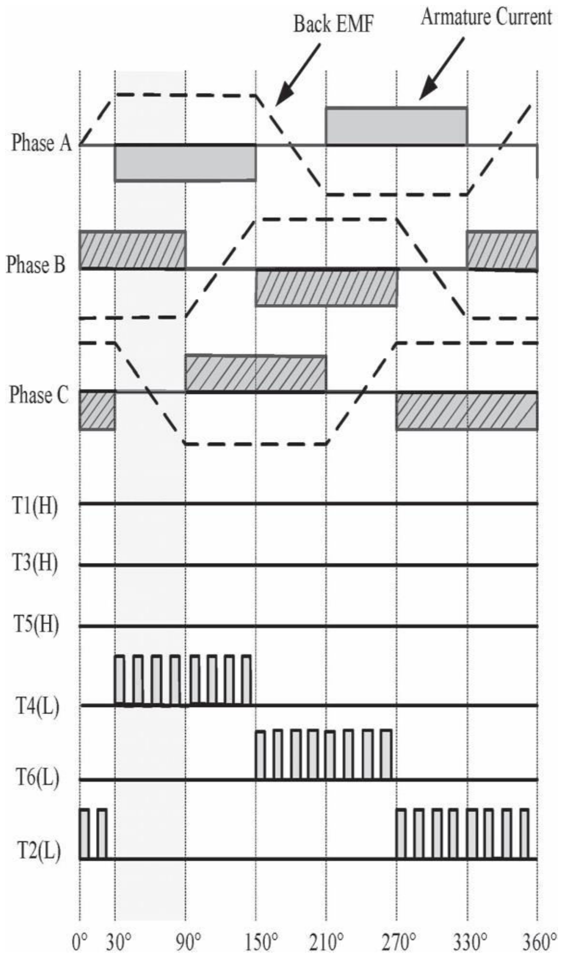



Figure 4 Regenerative braking with single switch in lower arm of MOSFET based inverter

Figure 4 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 power reversal during regenerative braking. The equivalent circuit of a single switch is shown is figure 5.

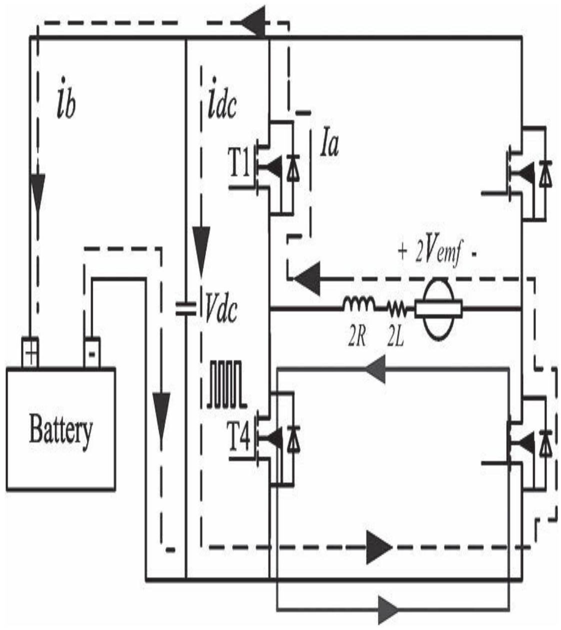



Figure 5 Circuit of single switch during regenerative braking

During normal motoring mode the control is done by operating the switches in accordance with the hall sensor signals as shown in the table 1(a). This table 1(a) shows that during motoring mode both upper arm and lower arm switches are used. The point to be noted here is simultaneously both the switches in the single arm of the inverter cannot be operated.

| 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 |

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

Table 1 Switching pattern of the switches corresponding to the hall sensors

During braking mode the motor operates as generator. The energy reversal between motor and battery can be done by operating only the lower arm switches. Table 1(b) shows the switching pattern for the regenerative braking mode in accordance with the corresponding Hall signals. We can see that in table 1(b) only the lower arm switches are controlled all the upper arm switches of the inverter are kept off for all Hall signals.

## IV. EXECUTION USING ANFIS

Using ANFIS and PID control the regenerative braking system of electric vehicle driven by BLDC motor is achieved as shown in figure 6.

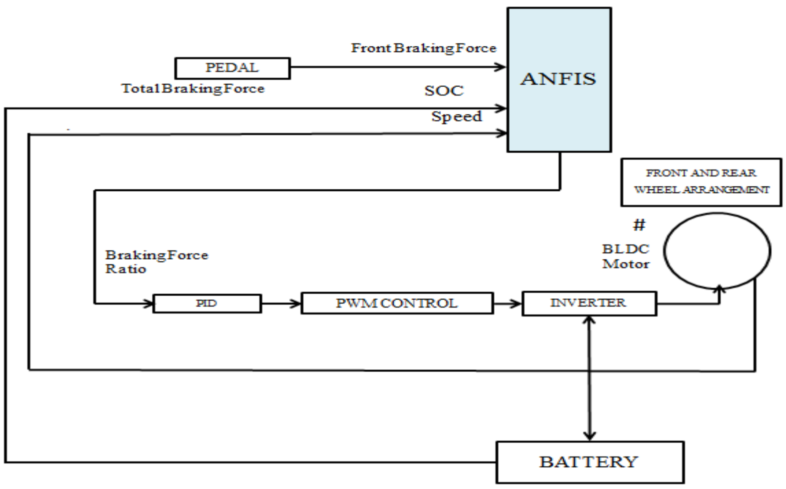



Figure 6 RBS of EV using ANFIS and PID

ANFIS is the hybrid intelligent control which combines the strength of neural networks and fuzzy logic.Using a given data set, the toolbox function ANFIS builds a fuzzy inference system (FIS) whose membership function parameters are tuned (adjusted) using either a back propagation algorithm alone or in combination with a least squares type of method. This modification allows our membership functions to learn from the data they are modelling.In this system ANFIS takes three input variables such as Distribution of braking force ($F_{front}$)battery's State Of Charge (SOC) and Speed of the motor. The output will be the braking force ratio.

Table 2 Fuzzy rules

| Speed | SOC | $F_{front}$ | MF |
|---|---|---|---|
| L | L | L | 0.2 |
| L | L | M | 0.1 |
| L | L | H | 0 |
| L | M | L | 0.4 |
| L | M | M | 0.2 |
| L | M | H | 0.3 |
| L | H | L | 0.3 |
| L | H | M | 0.1 |
| L | H | H | 0.2 |

| Speed | SOC | $F_{front}$ | MF |
|---|---|---|---|
| H | L | L | 0.5 |
| H | M | M | 0.5 |
| H | H | H | 0.4 |
| H | L | L | 1 |
| H | M | M | 0.9 |
| H | H | H | 0.8 |
| H | L | L | 0.5 |
| H | H | M | 0.3 |
| H | M | H | 0.1 |

The membership function chosen is Gaussian with the linguistic variables as Low (L), Middle (M) and High (H). With these the rules are formed.

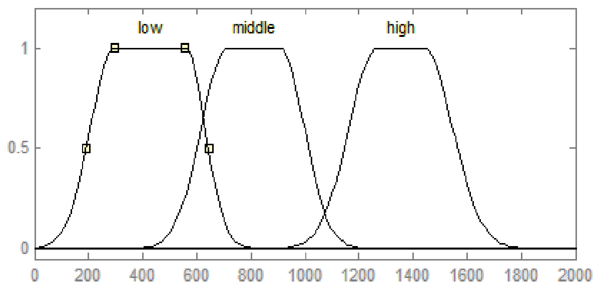



Figure 8a)

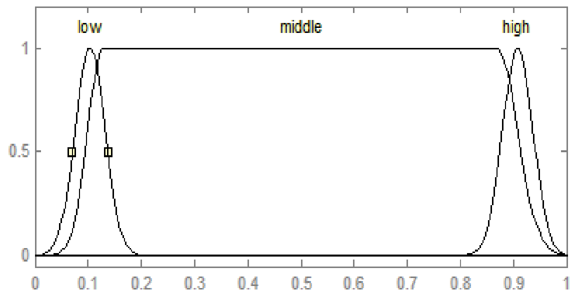



Figure 8b)

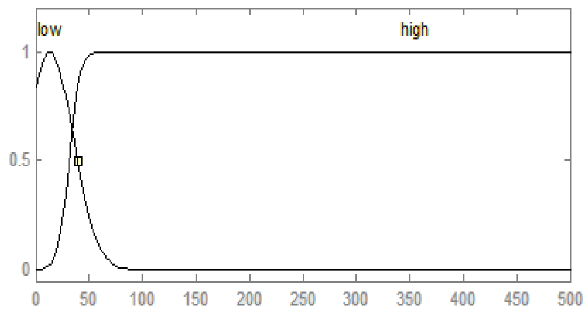



Figure 8c)

Figure8 a)Membership function of $F_{front}$b)Membership function of State of Charge c)Membership function of Speed

These membership functions are developed in MATLAB ANFIS editor. The sugeno model is used in the inference system. The output MF ratio is determined using various mechanical aspects such as friction of tire and uphill driving force etc. This ratio can be trained using any algorithm using the ANFIS editor.

## V. PID CONTROL

For the various braking force ratios the different values of PWM signals are generated. The PID is tuned in this method using Zeigler Nichols algorithm. The desired PWM is achieved by the PID control to have the braking torque constant. The output ratio is proportional to braking force.

## VI.SIMULATION RESULTS

Using the MATLAB R2014a software the RBS of EV driven by BLDC motor using ANFIS and PID control is implemented. ANFIS in MATLAB is executed using Graphic User Interface (GUI). Both linear and non-linear braking modes are analyzed.

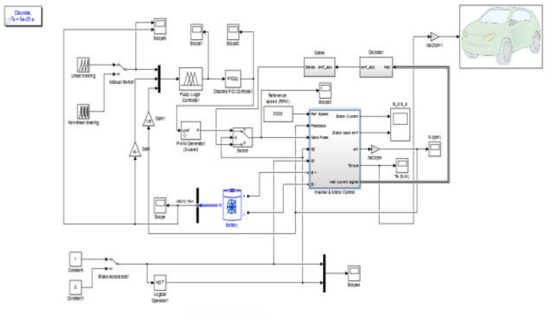
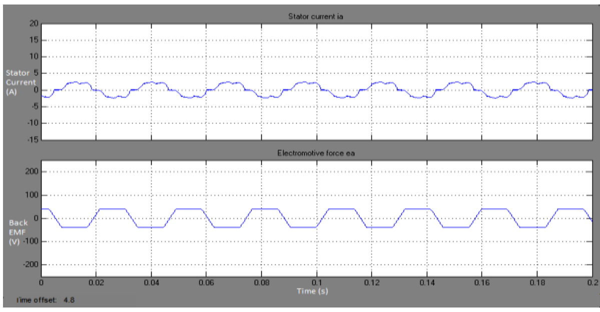


Figure 9 Simulation of RBS of EV using ANFIS and PID control   Table 3 BLDC motor specifications

| | | | |
|---|---|---|---|
| Rated Voltage | 300V | Rated Current | 5A |
| Rated Power | 2HP | Stator Resistance per phase (R) | 0.18Ω/phase |
| Rated Torque | 3Nm | Stator Inductance per phase (L) | 0.0085 H /phase |
| Rated Speed | 3000rpm | No. of Poles | 8 |

For the BLDC motor specifications shown in the table 3 below the simulation is carried out and the results are illustrated.



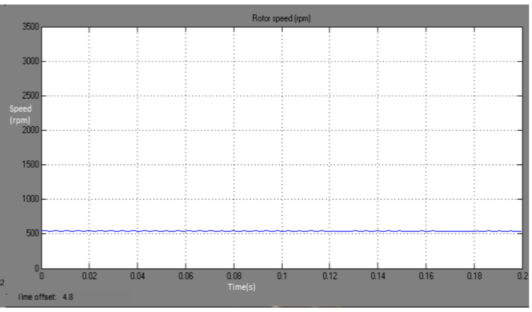
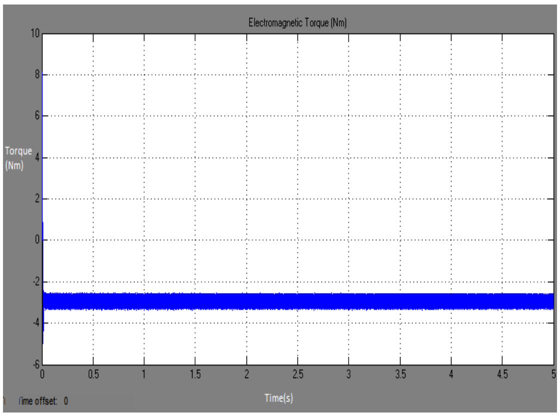




Figure 10 Stator current and back EMF of motor during braking

Figure 11 Speed of motor during braking



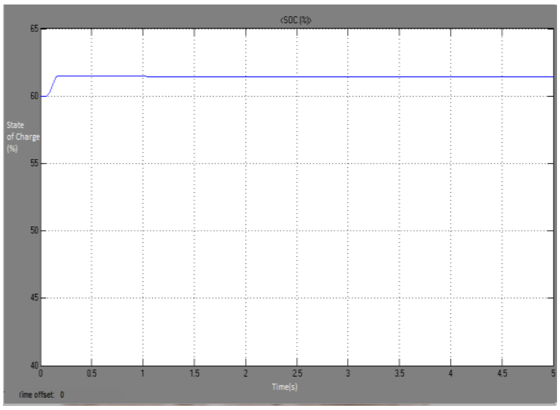



Figure 12 Braking torque of the motor

Figure 13 SOC of the battery when the brake is pressed

(The initial charge is taken as 60% of the battery)

Result shows that whenever brake is pressed linearly or non-linearly the battery gets charged about 2% to 3% of its charge. Thus a 300 V battery having one charge mileage of 280 Km, driving an electrical car of maximum speed 60Km/hr. Using the proposed RBS in this car around 30 Km distance can be prolonged. PID control is faster than fuzzy control, so the two methods combined together can realize the smooth transitions. Therefore, it can be concluded that this RBS has the ability to recover energy and ensure the safety of braking in different situations.

## VII. APPLICATION

This RBS can be implemented using ATMEGA64 microcontroller. The programs are implanted into the controller. Force sensor and Gate driver circuit is used to generate the gate pulses.

## VIII. CONCLUSION

This paper presented the advanced RBS of an electric vehicle driven by Brushless DC motor. The proposed scheme is implemented using MATLAB and the results are illustrated. PID control and ANFIS both are refined methods which are adapted in our scheme to have a fine transition between mechanical and electrical barking. ANFIS takes the input variables as State of charge, braking force and the speed of motor. The PWM technique is implemented to the inverter using PID control to maintain the constant braking torque. Thus it is proved that it is possible of recovering energy using our recommended RBS. By using the submitted RBS the safety of the vehicle is also ensured.

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