Analysis of Regenerative Braking In Brushless Dc Motor Drive Using Adaptive Neuro Based Fuzzy Inference System

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Abstract - *The electronically commuted Brushless DC motors are widely used in many industrial applications which increase the need for design of efficient control strategy for these motors. This paper deals with the efficient control mechanisms for these drives using meaningful fuzzy sets and rules. The proposed system includes Brushless DC motor control utilizing the PID control, and improved performance via adaptive neuro based fuzzy control. A simplified current controlled modulation technique for BLDC motor is presented so that one can evaluate the performance of the BLDC motor with PWM Control scheme and effective regenerative braking system has been implemented which has the ability to recover energy An adaptive neuro fuzzy inference system is developed using MATLAB. Simulation results shows that ANFIS reaches to the target faster and overcomes the complexity of the problem.*

Key Words: *Brushless DC (BLDC) motor, fuzzy control, Proportional-Integral-Derivative (PID) control, Adaptive neuro based fuzzy inference system (ANFIS), Regenerative Braking System (RBS).*

1. INTRODUCTION

With the emergence of energy crisis, waysf reducing the air pollution have become the great challenge. . Nowadays, fossil-fueled automobiles have become the major transportation tools. Automakers have made a great effort to find green, energy saving and zero pollution transportation tools. Thus, electric vehicles (EVs) have grown at an accelerated pace lately. However, some of the main difficulties for commercialization of EVs such as driving range still remain. Effective battery utilization and advanced motor control have become an important issue for EVs. A pure electric vehicle (PEV) contains three major parts: the power battery pack (usually in series as an energy-storage unit), the driving motor [can be induction motor (IM), brushless direct-current motor (BLDCM) and switched reluctance machine (SRM)], and the power converter Controller. Among all the driving motors, the brushless direct-current (DC) motor has many advantages over other brush DC motors, IMs and switch reluctance

machines. Brushless DC motors works similar to the conventional DC motor with the mechanical commutation replaced by an electronically controlled commutation system. These motors have the rotating permanent magnets and stationary armature. The BLDC motor that are utilized in this control design is star connected BLDC motor. The power distribution is achieved by the intelligent electronic controller. The electronic controller requires rotor position information for proper commutation of currents in the respective stator windings. The rotor position can be sensed using Hall effect sensors embedded in the stator and thus stator windings are energized accordingly. BLDC has the merits of simple structure, high efficiency, electronic commutating device, high starting torque, noiseless operation and high speed range, *etc.* Hence, the brushless DC motor has been widely used in EVs. Conventional EVs use mechanical brakes to increase the friction of the wheel for deceleration purposes. Thus, the braking kinetic energy is wasted. With this problem in mind, this paper will discuss how to convert the kinetic energy into electrical energy that can be recharged to the battery pack. As a result, regenerative braking can realize both electric brake and mechanical brake.

1.1 Regenerative Braking

Regenerative braking is defined as that in which the motor, which acts as a generator during braking turns the inertial energy generated in the process of moving into electrical energy that is stored in the storage devices for reuse. At the same time motor braking torque is applied to the driving wheels to brake the vehicle through the transmission system.

This paper is organized as follows. BLDC Motor and Control in section II. EV Modeling in section III and MATLAB simulation along with results are explained in section IV. Section V concludes the paper

2. BLDC MOTOR AND CONTROL

2.1 BLDC MOTORS

A brushless dc motor is defined as a permanent synchronous machine with rotor position feedback. The brushless motors are generally controlled using a three phase power semiconductor bridge. The motor requires a rotor position sensor for starting and for providing proper commutation sequence to turn on the power devices in the inverter bridge. Based on the rotor position, the power devices are commutated sequentially every 60 degrees. This eliminates the problems associated with the brush and the commutator arrangement, for example, sparking and wearing out of the commutator brush arrangement, thereby, making a BLDC more rugged as compared to a dc motor.As illustrated in figure 1 in a BLDC motor permanent magnets are mounted on the rotor, with armature windings being fixed on the stator with a laminated steel core.
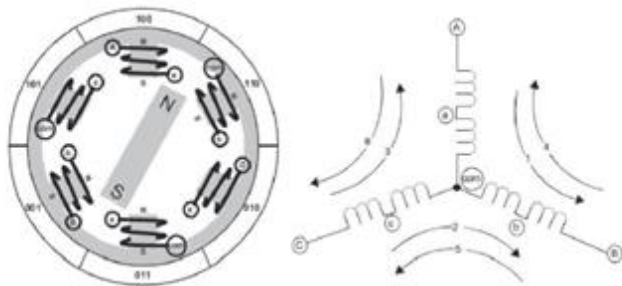

Fig -1: Y-connected BLDC motor construction

2.2 BLDC Motor Control

In Power Electronic Converter as shown in Figure 2, two switches are conducting at any instant of time. One switch is from upper side and one from lower side of the bridge. For a star connected system, only two phases are connected to the input and the third phase is left free. Each phase is conducting for a period of 120 electrical degree during flat portion of back EMF. For a period of 60 electrical degree commutation event occurs between phases. The details pertaining to rotor position are needed for proper commutation. By using Hall effect sensors, the position of rotor can be directly detected by observing back EMF of open phase. A BLDC motor uses a dc power supply which is required to provide energy. Hall Effect sensors provide the portion of information need to synchronize the motor excitation with rotor position in order to produce constant torque. It detects the change in magnetic field.. In the commutation system, one that is based on the position of motor identified using feedback sensors: two of three electrical windings are energized at a time.
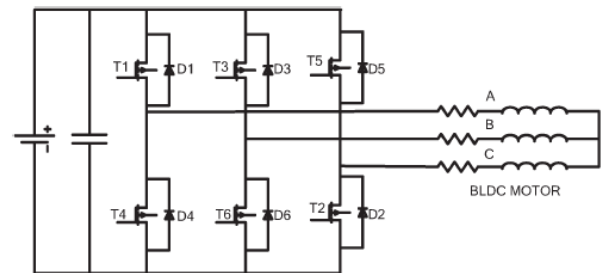

Fig -2: H bridge inverter circuit

2.3 MOSFET Control

The same power circuit in Fig. 2 can be used with an appropriate switching strategy. There are mainly two types of switching independent switching and complementary switching.
One simple and efficient method is to independently switch in conjunction with pulse width modulation (PWM) to implement an effective braking control. However, the back EMF of the winding cannot reach the battery voltage due to low speed of BLDC. Hence to raise the dc bus voltage for the energy recovery, a boost circuit is formed by the inductances in the winding. This is done by turning off all MOSFET on the high arms of H-bridge and control the low arms of H-bridge with PWM.

3. EV MODELLING

The modeling of the EV has been done in MATLAB/ Simulink . The torque request is made by the driver block which propagates through various power train system component and realizes vehicle motion.
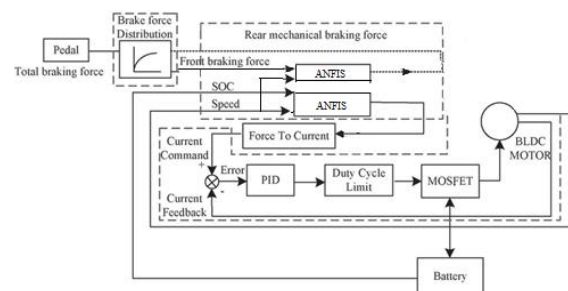

Fig -3: Structure of the control strategy

3.1 Driver Subsystem :
The desired drive torque and brake torque is delivered by the driver block through the activation of accelerator and brake pedal.

3.2 Proportional–Integral Derivative (PID) Control :
With PID control used primarily to ensure a constant brake torque, different braking force values will give dif-

ferent PWMs. A constant electrical braking torque can be achieved during the fuzzy inference.

3.3 Brake Strategy Subsystem

The structure of the control strategy system is shown in Fig 3. According to the fuzzy logic controller, we can obtain the value of the regenerative braking force. Then, the front mechanical braking force, the regenerative braking force, and the rear braking force can be attained.

3.4 Fuzzy Control

Braking force distribution in EVs with regeneration is influenced by many factors, and many parameters are constantly changing, so recycling strategy is difficult to be expressed. The fuzzy logic control strategy for EV braking force distribution can be easily demonstrated by the influence of different factors. The fuzzy control theory is applied to EV braking force distribution. In this control system, the input variables includes the front braking force, the SOC and the EV speed.

3.5 ANFIS

The advantage of a neural network is that it can be trained and so can self-learn and self-improve. Combining the two techniques, ANFIS has been proposed. The idea behind neural network and fuzzy inference combination is to design a system that uses a fuzzy system to represent knowledge in an interpretable manner and has the learning ability derived.
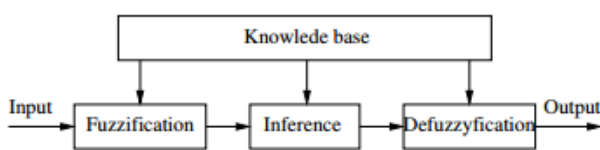

Fig -4: ANFIS

Adaptive Neuro based Fuzzy Inference System from a neural network that can adjust the membership functions parameters and linguistic rules directly from data in order to enhance the system performance. It implements a Sugeno fuzzy inference system for a systematic approach to generating fuzzy rules from a given input output dataset. The ANFIS architecture contains a five-layer feed forward neural network as shown.
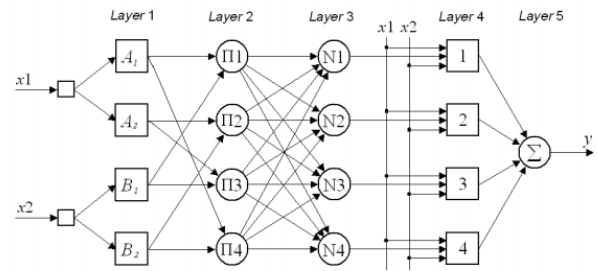

Fig -5: Five layer architecture

4. IMPLEMENTATION AND SIMULATION RESULTS

With the above design consideration the simulation has been done and the result is presented here. Speed is set at 1250 rpm and load torque disturbance is applied at 3 sec and the braking is obtained at the set speed

Table -1: BLDC MOTOR SPECIFICATIONS

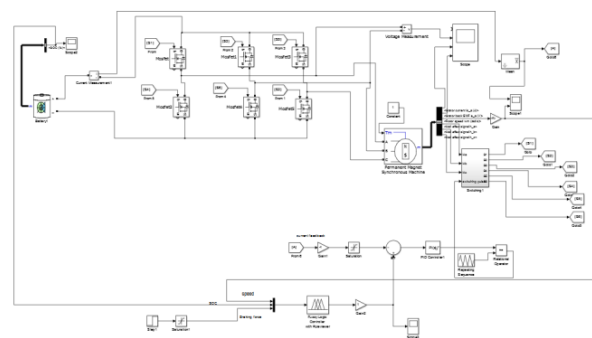| PARAMETER	VALUE	UNIT
Nominal voltage	72	Volts
Speed	2800	rpm
Current	200	amp
Rated power	7	KW

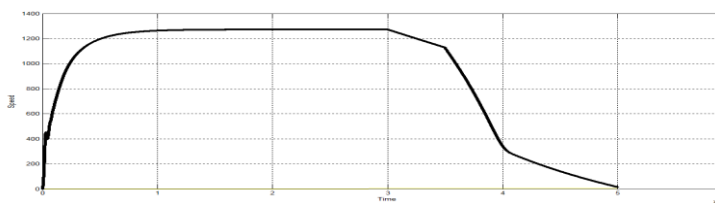**Fig -6**: MATLAB SIMULINK model with PID and fuzzy control

Fig -7: Controlled braking
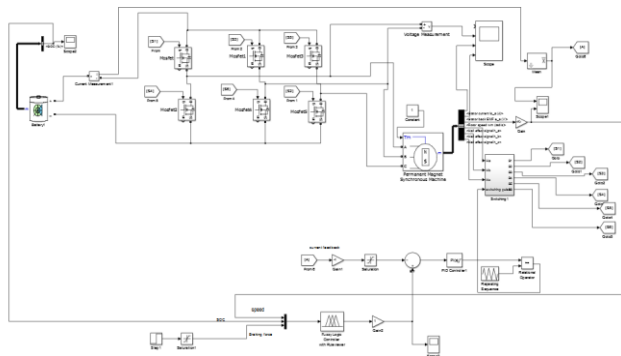

Fig -8:. MATLAB SIMULINK model with PID and adaptive neuro based fuzzy inference system
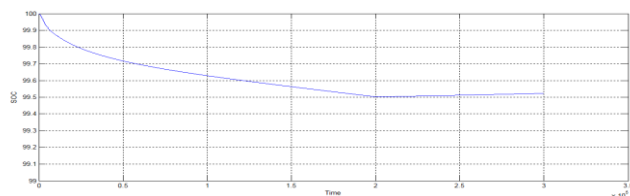

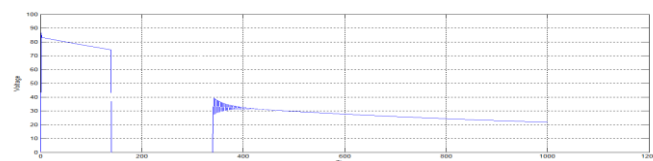**Fig -9**: State of charge of the battery

Fig -10: DC Bus voltage

The voltage waveforms during the regeneration state is shown. The dc bus voltage keeps a high value at the regenerative region. The EV will switch to mechanical braking if the speed is too low.
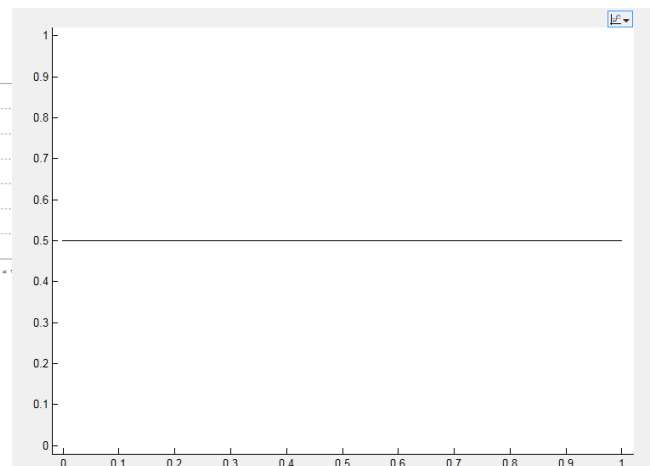

Fig -11: Fuzzy output

Using ANFIS errors have been reduced as maximum number of trials have been considered to get a fuzzy output of 0.5

As explained above, the PWM inverter modeling is based on the switching function concept. Fig 9 shows the battery SOC which reduces during the braking. A controlled braking as illustrated in Fig 7 is thus obtained by the distribution of braking forces by fuzzy control and current sensing control.

5. CONCLUSION

This paper has presented the RBS of EVs which are driven by the BLDC motor. The performance of the EVs' regenerative brake system has been realized by our control scheme which has been implemented both in the simulation. By combining adaptive neuro based fuzzy control and PID control methods which are both sophisticated methods, RBS can distribute the mechanical braking force and electrical braking force dynamically. PID control is has been adapted to adjust the BLDC motor PWM duty to obtain the constant brake torque. 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.

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