Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor

Submitted by

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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 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.

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 vehicle 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.

BLDC MOTOR:

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.

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

HALL SENSORS:

A Hall Effect sensor (or simply Hall sensor) is a type of sensor which detects the presence and magnitude of a magnetic field using the Hall effect. The output voltage of a Hall sensor is directly proportional to the strength of the field.

Two technologies offer a solution for positional feedback. The first and most common uses three Hall-effect sensors embedded in the stator and arranged at equal intervals, typically 60° or 120°. A second, ‘sensorless’ control technology comes into its own for BLDC motors that require minimal electrical connections.

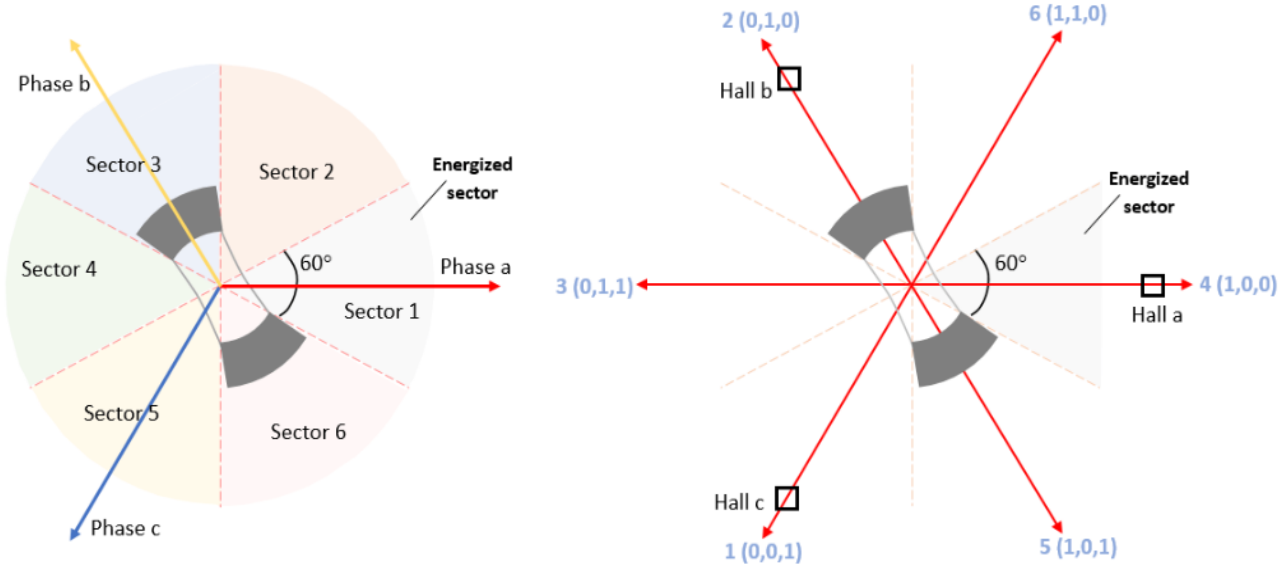
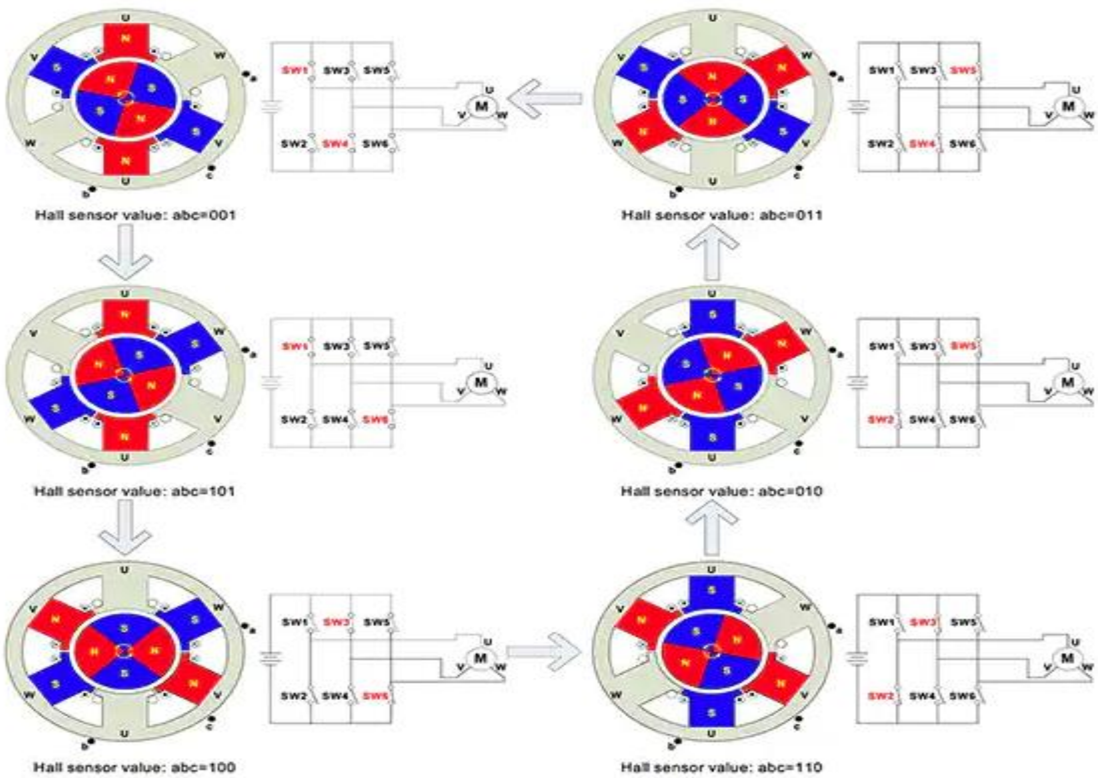


Fig 1.Six sectors of the BLDC motor voltage vector.

In a sensor-equipped BLDC motor, each Hall-effect sensor is combined with a switch which generates a logic “high” (for one magnetic pole) or “low” (for the opposite pole) signal. The commutation sequence is determined by combining the logic signals from the Hall-effect sensors and associated switches. At any time, at least one of the sensors is triggered by one of the rotor’s magnetic poles and generates a voltage pulse.



Above figure the commutation sequence of a three-phase BLDC motor driven anti-clockwise. The Hall-effect sensors are mounted at positions "a", "b" and "c". For each step in the commutation sequence, one winding (either "U", "V" or "W") is driven high by the MOSFET Bridge while one is driven low and the third is left floating. For example, at the top left of the figure, U is high (forming an N pole), V is low (S) and W is floating. The resulting magnetic field moves the rotor anti-clockwise as its permanent magnets are repelled by one winding and attracted by the next. The second stage (below) shows winding U remaining high while V switches to floating and W switches low thus maintaining the 'rotation' of the magnetic field and moving the rotor with it. The remaining commutation steps, one electrical cycle, completes half a mechanical rotation of the rotor.

A sensor less BLDC motor makes use of the electromotive force (EMF) that gives rise to a current in the windings of any DC motor with a magnetic field that opposes the original change in magnetic flux as described by Lenz's Law. The EMF tends to resist the rotation of the motor and is therefore referred to as "back" EMF. For a given motor of fixed magnetic flux and number of windings, the EMF is proportional to the angular velocity of the rotor.

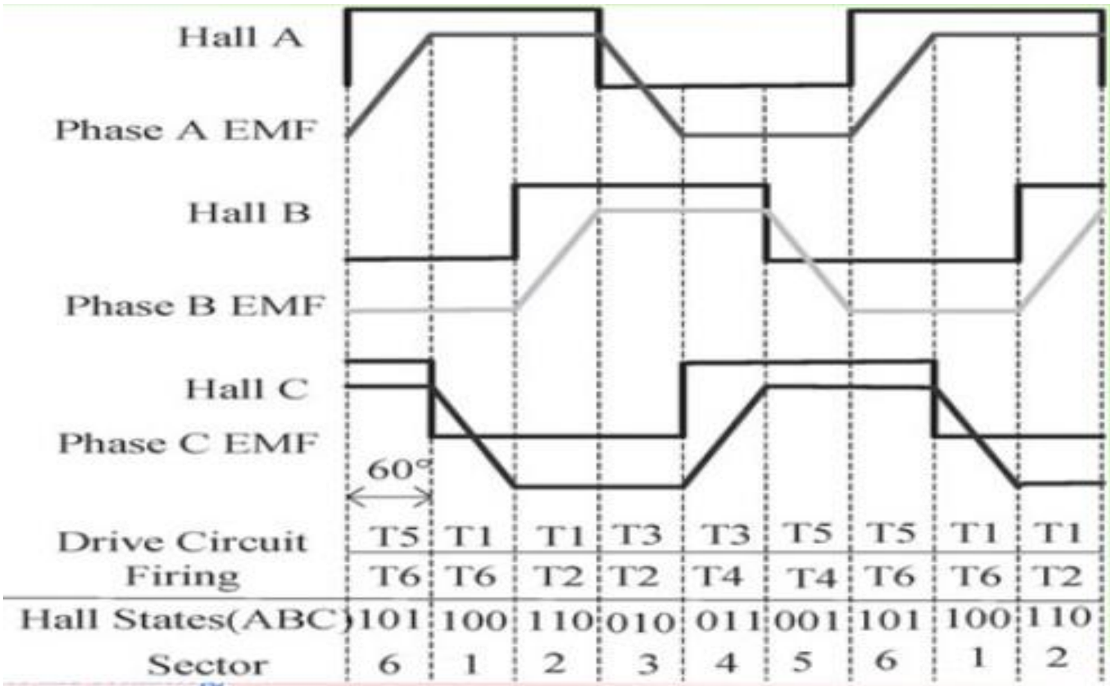


Fig 2. Back EMF BLDC motor phase

By monitoring the back EMF, a suitably programed microcontroller can determine the relative positions of the stator and rotor without the need for Hall-effect sensors. This simplifies motor construction, reducing its cost as well as eliminating the additional wiring and connections to the motor that would otherwise be needed to support the sensors, thus improving reliability.

However, because a stationary motor generates no back EMF, the controller is unable to determine the motor position at start-up. The solution is to start the motor in an open loop configuration until sufficient EMF is generated for the controller to determine rotor and stator position and then take over supervision. A more sophisticated control regime is used if the motor is used in an application where reverse rotation is forbidden.

The back EMF generated by each winding of the BLDC motor described above is shown in the bottom half of above figure .This is compared to the Hall-effect sensor logic switch output for a comparable BLDC motor equipped with sensors. It can be seen from the figure that the zero crossing points for the EMF generated in winding coincide with the switching status changes for the logic switches. It is this zero-crossing information that the microcontroller uses to trigger each stage of the commutation cycle in a sensor less BLDC motor.

EV MODELING:

The modelling of the EV has been done in MATLAB/ Simulink. The driver block makes a torque request which propagates through various powertrain system component and realizes vehicle motion. System-level simulators have been modelled by using empirical data that are based on measurements supplied by component manufacturers or extended from measurements obtained from literature sources. These are modelled in Simulink as look-up tables. Other component models are physical or analytical in nature and are modelled by mathematical equations.

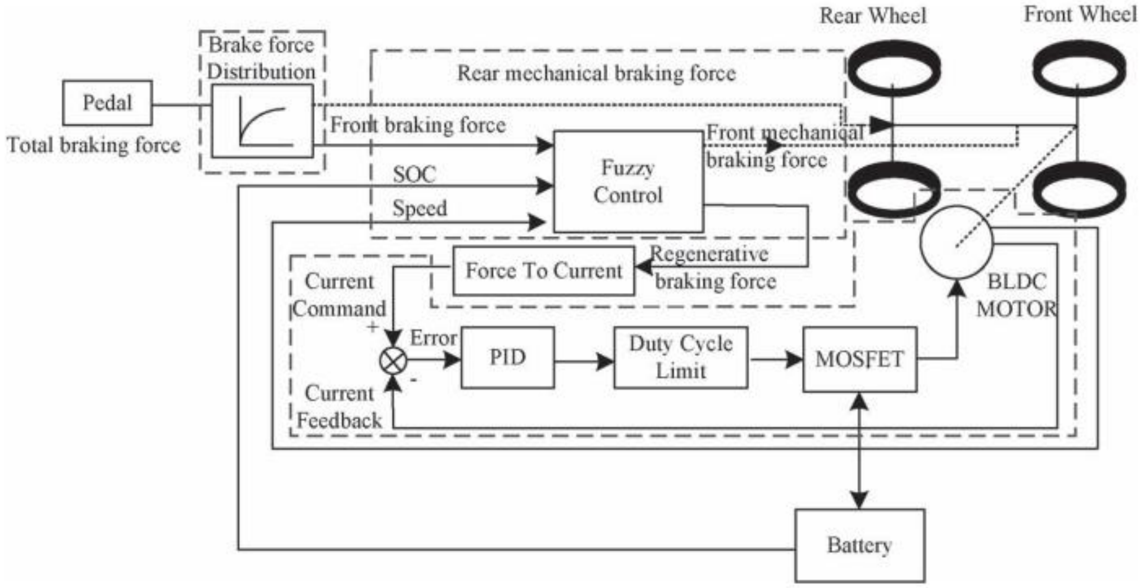
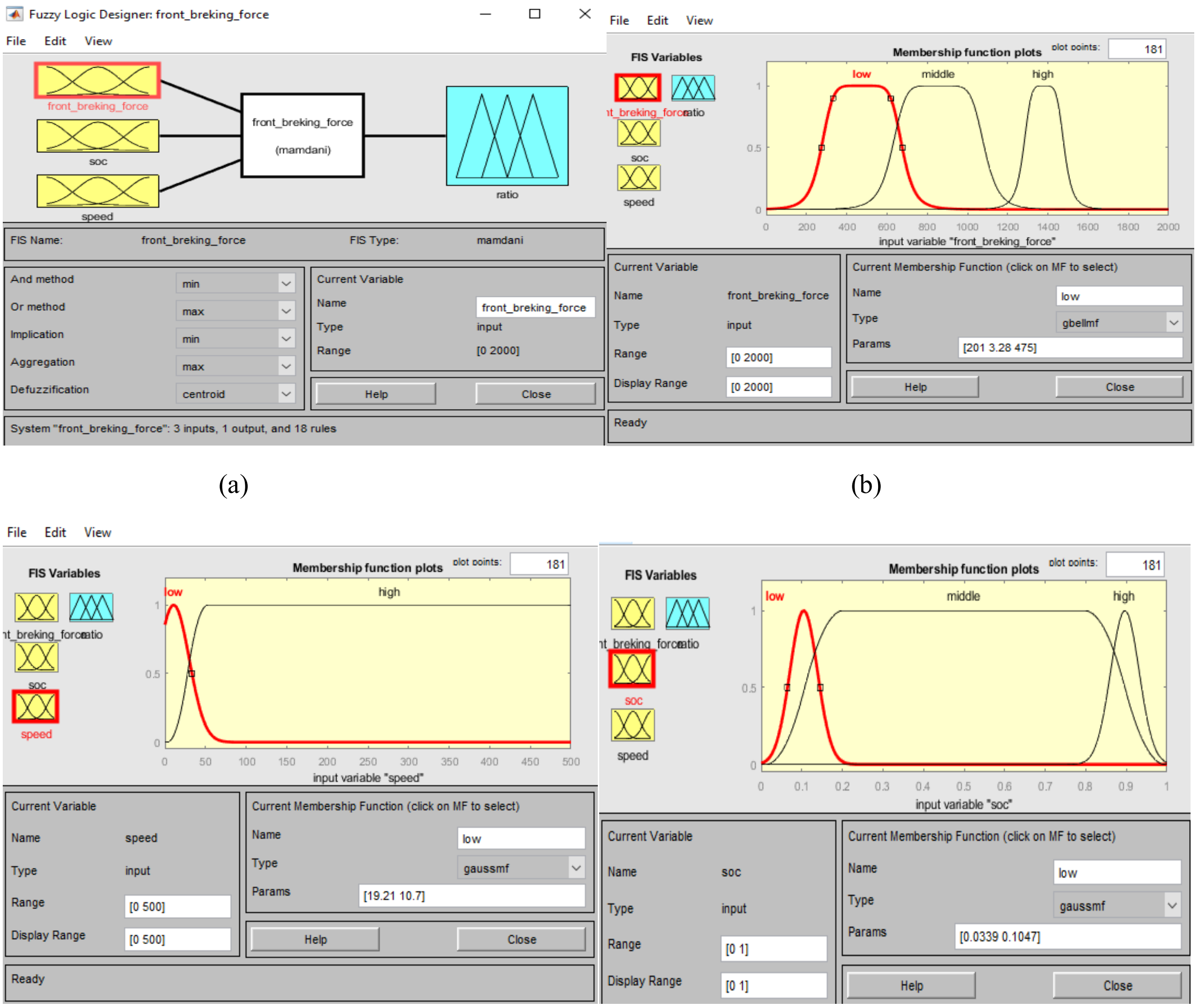


Fig.3 Structure of the control strategy system

FUZZY CONTROL

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. Therefore, the fuzzy control theory is applied to the EV braking force distribution. The fuzzy control strategy of the EV braking force distribution structure is shown in Fig. 8; the three inputs are the EV front-wheel braking force, speed, and battery charge state [state of charge (SOC)] [12]. In the fuzzy control system, the input variables include the front braking force, the SOC, and the EV speed. The output variable is the ratio which is proportional to the regenerative braking force taking in the front braking force. Front braking force: the driver braking requirements are concerned with the driving safety. The value of the braking force represents the braking distance and time the driver requires. We prefer the concourse of speed to be low, middle, and high, and the universe of discourse is [0, 2000]. The membership functions **are speed,force,soc,ratio.**



(a) (b)

(b) (d)

Fig .4 (a) Fuggy logic input output. (b) Membership function of the Force (c) Membership function of speed. (d) Membership function of SOC.

FUZZY LOGIC CONTROL RULES:

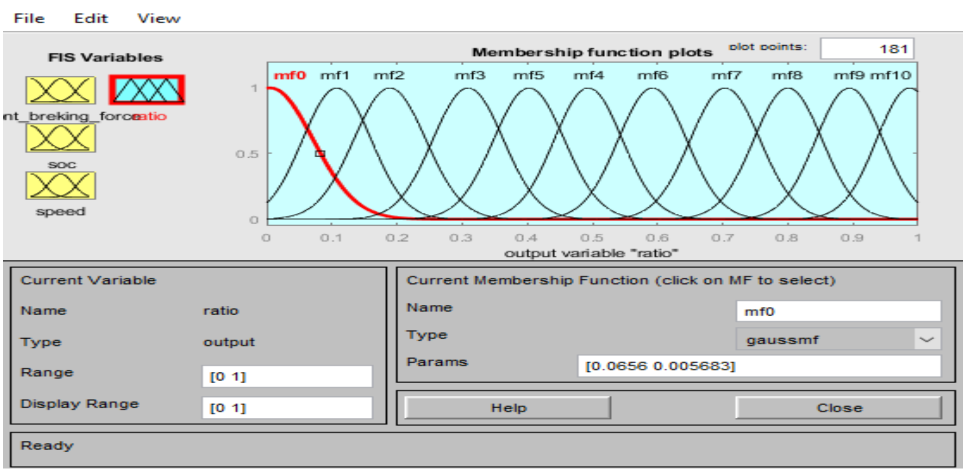


Fig .5 Membership function of ratio

SOC: when the battery's SOC is less than 10%, the internal resistance of the battery is high, unsuitable charging in this case; the regenerative braking force should be a smaller proportion. When the SOC is between 10% and 90%, the battery can be charging with a large current; the ratio of the regenerative braking force should be correspondingly increased. When the SOC is greater than 90%, the charging current should be reduced to prevent the excessive charging of the battery; the value of the regenerative braking force should be lower. We prefer the set of SOC to be low, middle, and high, and the universe of discourse is [0, 1]. The membership functions are shown in below figure.

Speed: vehicle speed plays an important role in ensuring the brake safety. To ensure the brake safety and to comply with the relevant legislation, the regenerative braking force should be a low proportion when the speed is low. The regenerative braking force can be increased to an appropriate level when the speed is intermediate. When speed is high, we can increase the ratio of the regenerative braking force to the biggest value. We prefer the set of speed to be low and high, and the universe of discourse is [0, 500]. The membership functions can be seen in below figure.

Output Variable:

The type of the fuzzy logic controller is Mamdani. Ratio = {MF0,MF1,MF2,MF3,MF4,MF5,MF6,MF7,MF8, MF9,MF10}=(0, 0.1, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.8, 0.9, 1.0). The membership functions can be seen

Speed	SOC	F_{front}	MF	Speed	SOC	F_{front}	MF
L	L	L	2	H	L	L	5
L	L	M	1	H	M	M	5
L	L	H	0	H	H	H	4
L	M	L	4	H	L	L	10
L	M	M	2	H	M	M	9
L	M	H	3	H	H	H	8
L	H	L	3	H	L	L	5
L	H	M	1	H	H	M	3
L	H	H	2	H	M	H	1

L=LOW M=MIDDLE H=HIGH

Fig.6 Fuggy Logic control rules

BRAKING FORCE DISTRIBUTION

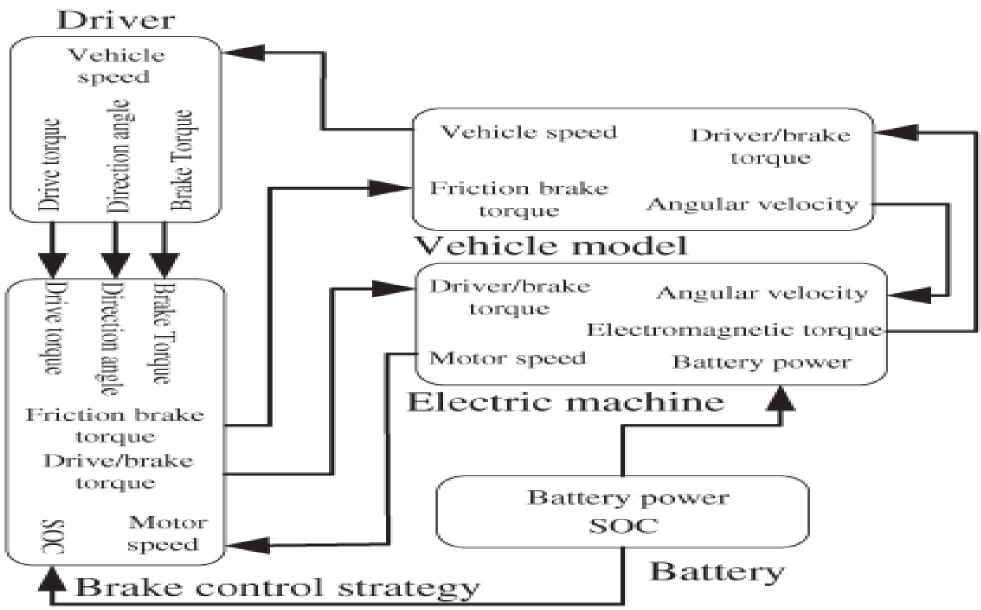


Fig.7 Braking force distribution

SIMULATION:

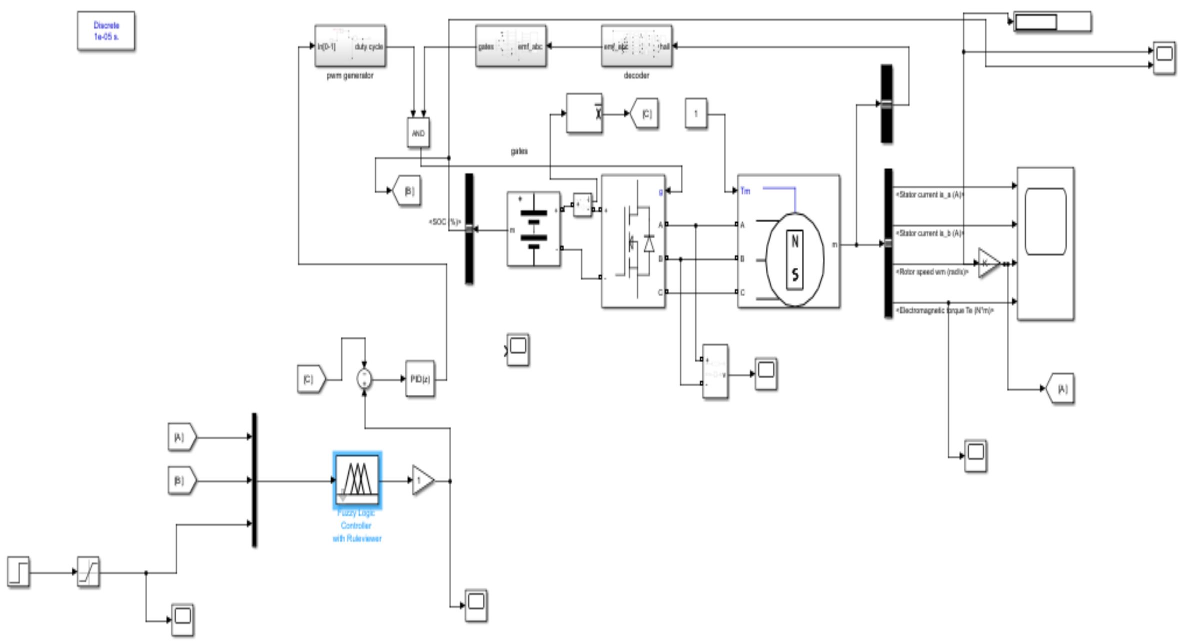
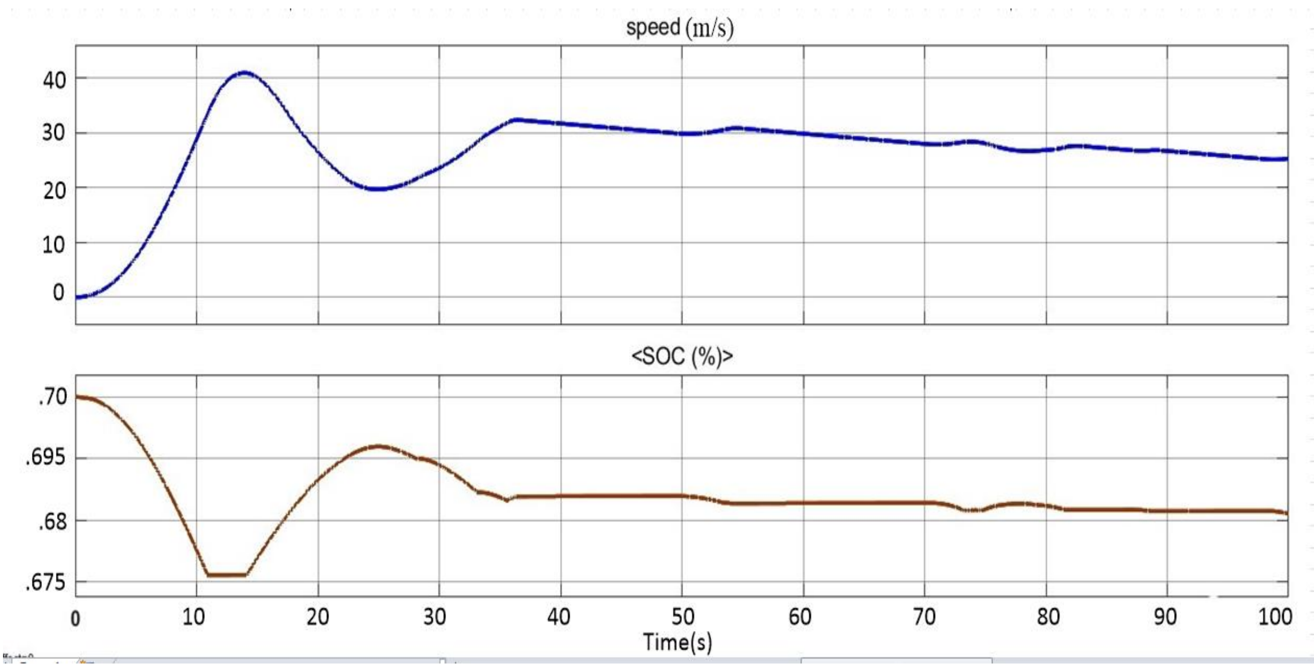
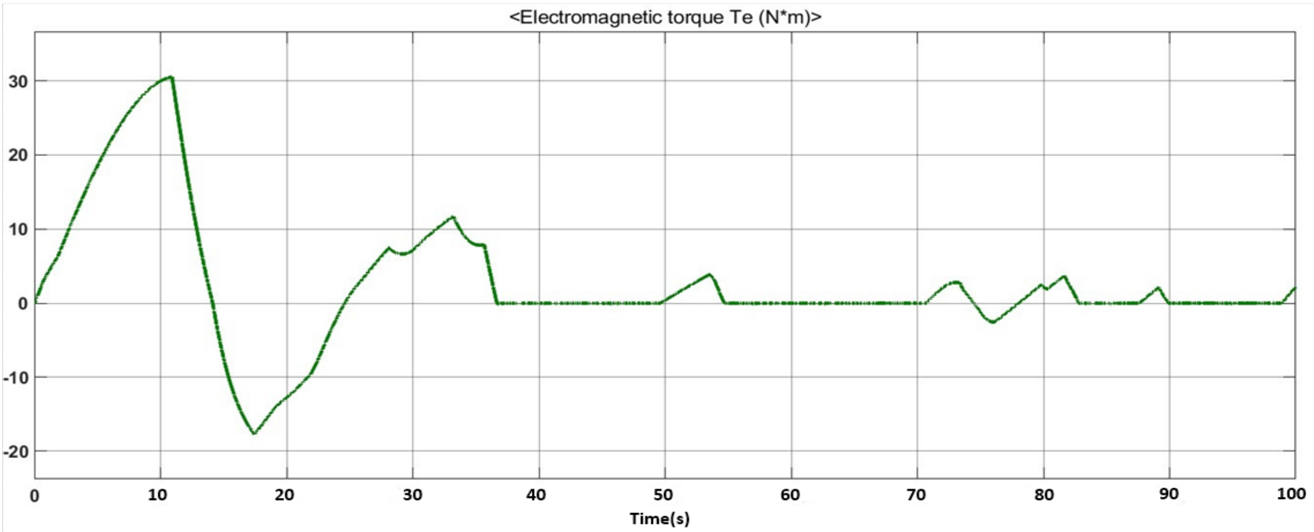


Fig.8 Simulation model

SIMULATION RESULTS





FUZZY LOGIC OUTPUT:

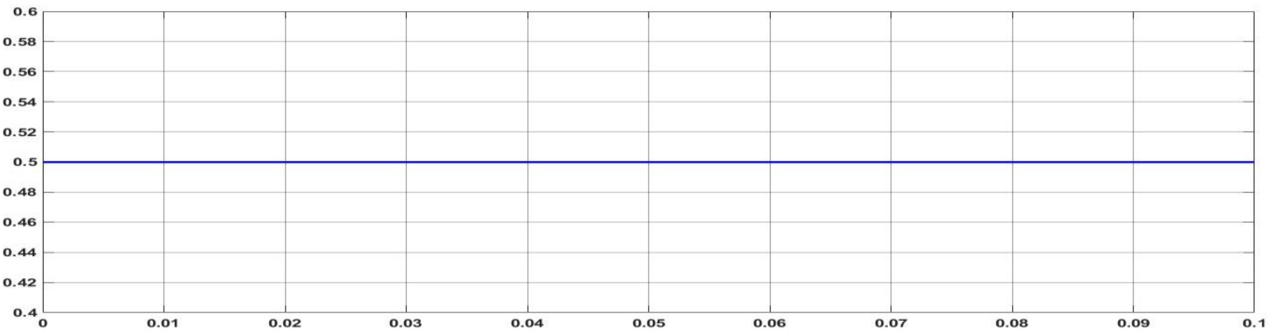


Fig 9 Simulation waveform

CONCLUSION:

This Report 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 and in the experiments. By combining 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 a very popular method in electric car control, but it is difficult to obtain a precise brake current. Braking force is affected by many influences such as SOC, speed, brake strength, and so on. In this paper, we have chosen the three most important factors: SOC, speed, and brake strength as the fuzzy control input variables. We have found that RBS can obtain appropriate brake current, which is used to produce brake torque. At the same time, we have adopted PID control 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. Similar results are obtained from the experimental studies. Therefore, it can be concluded that this RBS has the ability to recover energy and ensure the safety of braking in different situations.