BLDC Drive for EV Application

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Abstract. The purpose of this paper is to evaluate the efficiency of a BLDC motor in regenerative braking mode. The mode of operation of the BLDC motor using its torque-slip characteristics is taken into consideration to evaluate its performance. The simulation, characteristics and the tabular column are all got from the MATLAB simulation. The paper ends with a suggestion of using supercapacitors to compensate for the energy lost while the motor is in regenerative mode. The purpose of the supercapacitor has also been discussed to show the usefulness on the inclusion of the component. The motor and the supercapacitor compliment each other to increase the efficiency of the electrical vehicle.

Keywords: regenerative braking, supercapacitor, BLDC, torque-slip characteristics, electrical vehicles

1. Introduction

In current world the need for transportation is increasing day by day transportation has become an aspect for human beings to perform their day to day activities. Since the birth of technology till today the need for transportation is increased and will keep increasing.

We could see a drastic increase in the transportation technology. With increase in technology we could see increase in the amount of pollution caused by the automobiles. This has become a global concern, every country in the world today is striving towards pollution less economy by switching to electric vehicles and hybrid electric vehicles. The role of machines in commutation of humans and objects has significantly increased each year. No vehicle in this world, powered by an external substance runs without a motor. The types of motor may differ, but they still have to perform their function and fulfil their purpose. The BLDC motor has fairly been accepted to be superior to other motors in the field of electrical vehicles.

The highest efficiency of energy developed due to regenerative braking can go up to 88% approximately. The energy braking improvement efficiency of electric vehicles is considerably enhanced by the use of supercapacitors. The efficiency in regenerative braking differs along the behavior of the drivers being installed. [1]
2. Braking System

It is a device that reduces the motion by decreasing the energy of a moving system. It is used for deceleration or stop the motion by means of friction. It uses the friction between two surfaces to reduce the motion by converting the kinetic energy of the moving vehicle to other forms of energy. For example, eddy current brakes use magnetic fields to convert kinetic energy into electric current in the brake disc, which is converted into heat. Brakes are usually applied to a rotating wheel or axis. For example, in aircrafts, we use wheel brake and drag created by the flaps, etc.

- Electric Hydraulic Braking
- Servo Braking
- Mechanical Braking
- Electromagnetic Braking
- Regenerative Braking

3. Regenerative Braking

In the past few years, we have seen that electric vehicle (EV) are getting more attention than normal Internal combustion engine (ICE) vehicle. Regenerative braking can be used in EVs for reusing the brake energy which gets wasted in a normal ICEs. It can be considered as an energy recovery mechanism. When the motor detects braking, it comes into regenerative mode. Due to the force by vehicles inertia the motor goes into a generation mode. Rather than letting the kinetic energy being converted to heat energy we convert it into electrical energy and store it in battery and super capacitor. Brake controller monitors the speed of the wheel and the torque required by the brake. The extra energy is converted into electrical and send back to the battery. Due to regenerative braking the range of the EVs can increase up to 15% as compared to the vehicles without regenerative braking. Mechanical Braking is very important for EVs because of safety. In a EV we can have a combination of regenerative braking and mechanical braking. Both can be combined into a single brake pedal. [2]

In traditional combustion engine vehicles, we used a Hydraulic braking System. Its main issue was the loss of energy. When a car is moving it has a large amount of kinetic energy. When the driver applies brake a large amount of energy conversion takes place as the whole kinetic energy is converted into heat energy. Due to heavy weight cars produce a large amount of heat energy which is not used in a hydraulic braking system. Thus, a large amount of energy gets wasted which could have been used in other work. Moreover, heat also makes the brake weaker. This problem can be solved by the use of regenerative braking. It can easily overcome the major disadvantage of the hydraulic braking system.

Advantages and Disadvantages of Regenerative Braking

As 20%-30% of energy is returned back to the supply system the consumption of the energy is reduced. It reduces the operating cost and also increase the Battery Life. The wear and tear of the brake shoe of the wheel is also reduced thus their life is increased and the replacement cost is decreases. Vehicles can come to rest quickly and while going down the gradient more speed can be achieved as more energy will be obtained. Less amount of brake dust is produced when mechanical Brake are applied.

In Regenerative Braking System we must see that the rear wheel locking must not take place. When the rear wheels get locked under –steer value increases to a negative value resulting in infinite amount of over- steer. This cause loss of direction stability. In this case front axle is mounted with ABS. Due to this, it captures more energy as compared to the system with no ABS. This is because When the wheels get locked ABS will try to reduce the braking by the friction Brake. [3]

4. Supercapacitor

Supercapacitors are electrochemical capacitors with a re-markably high energy density as compared to the common capacitors available. Generally, they are thousand times greater than a high-capacity electrolytic capacitor. Supercapacitors are based on a structure which contains an electrical 2 layer (anode (Al foil) – active carbon – separator – active carbon – cathode (Al foil) and as a result,
they have this high capacity. The carbon nanotubes have a substantial surface area. One gram of this carbon presents surface area of about 2000 m²/g.

Fig. 1. Supercapacitor Modelling

A. Operation mechanism

Supercapacitor comprises in 2 porous electrodes dipped in an electrolyte. Using the electric field created between the electrodes and the electrolyte, the energy is stored. Positive charges are colored in blue while the negative charges are in yellow. Ionic charges are shown bigger than electronic charges, because their size is important for the performance of the supercapacitor. The two electrodes are separated by an ion-conductive membrane, which is the central part of the supercapacitor schematic. It allows ion throughout while taking care not to allow short circuits between the electrodes.

5. Simulation Working

The simulation of the BLDC drive has been divided into five blocks for better understanding. They

Fig. 2. Overall Simulation

A. Circuitry Block

The BLDC motor works with an AC supply. But the source we provide is DC. Hence, we have used a set of six MOSFETs (MOSFET, MOSFET1, MOSFET2, ..., MOSFET5) that operates in sequential order so as to provide a regulated AC supply. The trapezoidal back-EMF is considered as it provides mechanical input torque from the machine. This is used to check if the motor is operating in the forward direction or in the reverse direction. When we consider the torque-slip characteristics, we have four quadrants of working. The BLDC motor operates in the forward direction while the readings lie in the first and second quadrants. In the other two quadrants, the BLDC motor operates in regenerative mode.

The MOSFETs are short-circuited from source to drain. This provides a closed loop connection. A sub-block is added to measure the readings. Each current from each phase (MOSFET - MOSFET1, MOSFET2 - MOSFET5 and MOSFET3 – MOSFET4) is sent to the mux which is present in the sub-block. The output from the BLDC motor is fed to the control block.
B. Control Block

The rotor speed is converted from radian to rotations per minute by a simple formula. We use a hall sensor to measure the rotor speed and the magnetic effect produced by the PMSM. This is done with the help of a multiplexer and a de-multiplexer, which measures the hall effect. The output from the hall sensor is sent to the Hall decoder and control circuit. The hall decoder consists of a set of logic gates that help us in determining if the motor is in regenerative mode or not. There are three cases that have to be considered for this mode of operation.

\[
\omega = \frac{\text{R} \text{o} \text{t} \text{e} \text{r} \text{S} \text{p} \text{e} \text{e} \text{d}}{\alpha}
\]

- Stall Condition
- Reverse mode
- Higher amount of current is fed back to the DC source

If any one of these conditions is met, we can conclude that the output will be in reverse motoring condition.

The tabular column I, II gives us detailed information in when will the motor operate in regenerative braking mode.

![Fig. 3. Hall Sensor Decoder](image)

![Fig. 4. Speed of Motor In RPM and Current Drawn (A)](image)
Table I Initial Hall Sensor Outputs

| $H_a$ | $H_b$ | $H_c$ | $H_d$ | $H_e$ | $H_f$ |
|-------|-------|-------|-------|-------|-------|
| 0     | 0     | 0     | 1     | 1     | 1     |
| 0     | 0     | 1     | 1     | 1     | 0     |
| 0     | 1     | 0     | 1     | 0     | 1     |
| 0     | 1     | 1     | 1     | 0     | 0     |
| 1     | 0     | 0     | 0     | 1     | 1     |
| 1     | 0     | 1     | 0     | 1     | 0     |
| 1     | 1     | 0     | 0     | 0     | 1     |
| 1     | 1     | 1     | 0     | 0     | 0     |

Table II Outputs From And Gate

| $H_a$ | $H_b$ | $H_c$ | $H_d$ | $H_e$ | $H_f$ | $H_g$ | $H_h$ |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |
| 0     | 0     | 1     | 0     | 0     | 1     | 0     | 0     |
| 0     | 1     | 0     | 1     | 0     | 0     | 0     | 0     |
| 0     | 0     | 1     | 1     | 0     | 0     | 0     | 0     |
| 1     | 0     | 0     | 0     | 0     | 0     | 1     | 0     |
| 1     | 0     | 0     | 0     | 1     | 0     | 0     | 0     |
| 0     | 1     | 0     | 0     | 0     | 0     | 1     | 0     |
| 0     | 0     | 0     | 0     | 0     | 0     | 0     | 0     |

Fig. 5. Hall Signals Generated by Motor

The Hall decoder and the control circuit takes care of the hall sensor output and pulse control required to make the rotor to work in regenerative braking mode.

C. Firing Circuit

The output gate pulses from the Hall decoder, A, B, C, D, E, and F are fed back to the MOSFET to operate continuously and without any human interference. The duty cycle for each pulse ranges from 0 to 1.
D. Proportional Integral Control Block

We use a $\pi$ network to determine the stability of the system. In such a network, having a negative gain input maximizes the stability. A positive gain input will reduce the stability by half. We install a saturation point next to this so as to saturate the current flow to the motor and safeguard the internal components. The saturation is set as 5. This will result in a stability value of -5. This is given as a negative feedback. The step response is 5, which is given as a positive feedback. Hence the overall output is zero. Hence this indicates that the motor is in zero ampere state or regenerative mode.

We are using a PI controller for this system because the operation is linear and in much easier to understand. The value of P and I are 1.5 and 52 respectively. We include another saturation point of 0.8 so as to ensure that we don’t exceed the control limit.

E. Braking Circuit Block

A repeating sequence is added to the braking block. The time period of the repeater is 0.2 secs. The value shifts from 0 to 1 every 0.2 seconds and returns back to 0 the next 0.2 secs. This continues as long as the motor is switched on. The output from the saturation point doesn’t exceed 0.8. So, when we use the greater than comparator, the value coming from the PI controller must be greater than the value supplied by the repeater, so as to allow the current to flow. The tabular column given below shows when is the brake applied and when does the comparator pass the value.

We use another AND gate to make sure that the saturation of the PI controller doesn’t affect the efficiency of the motor. If we directly feed the result to the motor, then the slope will become much steeper and will give outputs with larger variation, that has to be avoided. Hence, we use the gate and a step response with a period of 5 secs to avoid this.

**Table III** Combination Of Braking And Ha $\cdot$ Hb

| Braking | Ha | Hb | MOSFET 4 |
|---------|----|----|----------|
| 0       | 0  | 0  | 0        |
| 0       | 1  | 1  | 1        |
| 1       | 0  | 1  | 1        |
| 1       | 1  | 1  | 1        |

**Table IV** Combination Of Braking And Hb $\cdot$ Hc

| Braking | Hb | Hc | MOSFET 5 |
|---------|----|----|----------|
| 0       | 0  | 0  | 0        |
| 0       | 1  | 1  | 1        |
| 1       | 0  | 1  | 1        |
| 1       | 1  | 1  | 1        |
6. Role Of Supercapacitor In Regenerative Braking

A supercapacitor was used as a system that stored energy in a process that tested the regenerative braking in order to traverse the various chances and obstacles of executing supercapacitors in regenerative braking through an automated path. Supercapacitors are preferred because of the appreciable power solidity that they retain and the recyclable characteristics that they possess. [4] At initial stages, the attributes of supercapacitor model were tested and concluded that the capacitance that the supercapacitor can withstand is highly depending upon the rate of charge or discharge with the total drop of about 9% noticed between the capacitance(rated) and the value(calculated) at a charge rate of 100 A. It was also observed that the decrease in capacitance was remarkably reduced when a varying rate of charge that represented the regenerative test was applicable. In spite of supercapacitors

Table V Combination Of Braking And Hc • Ha

| Braking | He • Ha | MOSFET 6 |
|-------|--------|----------|
| 0     | 0      | 0        |
| 0     | 1      | 1        |
| 1     | 0      | 1        |
| 1     | 1      | 1        |

having capability of absorbing high power, the state of charge remarkably effects the charged current and the absorbing capability of power in a supercapacitor based braking system that is regenerative in nature. This method predominantly owed to the current transmitting capacity of the convertors at power electronics that is necessary to control the charge gained and the charge dissipated in the supercapacitor model.

7. Conclusion

Nowadays everyone has started to understand the importance of our environment and they are also aware of the increase in pollution due to the conventional vehicles produced from automobile industry. This paves a way to create an awareness in usage of electric vehicles with is fuel efficient and pollution free compared to conventional vehicles. Lot of countries have started to research in hybrid electric vehicles as it has many advantages. Due to the increase in global warming everyone is pushed to use greener path for upcoming technologies. We can come to a conclusion that regenerative braking of the BLDC motor can significantly reduce the efficiency the vehicle. The usage of supercapacitors has proven to be useful for two reasons. Firstly, it helps in storing the charge that is wasted while the BLDC motor operates in regenerative mode. It also provides as a boost start for the motor since it requires multiple times the usual current it needs, to start rotating.
References

[1] Zou, Z.; Cao, J.; Cao, B.; Chen, W. Evaluation strategy of regenerative braking energy for supercapacitor vehicle. ISA Trans. 2015, 55, 234–240.

[2] X. Nian, F. Peng and H. Zhang, "Regenerative Braking System of Electric Vehicle Driven by Brushless DC Motor," in IEEE Transactions on Industrial Electronics, vol. 61, no. 10, pp. 5798-5808, Oct. 2014, doi: 10.1109/TIE.2014.2300059.

[3] P. Patel, H. Chandra and T. Sahoo, "Study on regenerative braking system, considerations of design, safety and associated effects," 2015 IEEE International Transportation Electrification Conference (ITEC), Chennai, 2015, pp. 1-8, doi: 10.1109/ITEC-India.2015.7386930.

[4] Partridge, Julius & Abouelamaimen, Dina. (2019). The Role of Supercapacitors in Regenerative Braking Systems. Energies. 12. 2683. 10.3390/en12142683.