Regenerative Braking Control Strategy Using Different Armature Voltage

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Abstract- *For an electric vehicle, energy saving is very important concerning factor. Regenerative braking plays an important role in electric vehicles to save the energy. There are a number of methods to control the regenerative braking characteristics. Permanent Magnet DC (PMDC) motor based regenerative braking is one of the solutions of improving the energy saving efficiency and improve the mileage of electric vehicles. In this proposed method, braking can be achieved by applying different armature voltage without any complex converter and switching techniques. The feasibility and effectiveness of this proposed method is proved with simulation results.*

Keywords- Regenerative braking, Armature voltage, PMDC motor, electric vehicle, efficiency.

I. INTRODUCTION

Due to global warming and rising cost of fuel, the battery operated electric vehicles have attracted the attention of the researchers in recent years. In electric vehicle energy saving is the most concerning factor. During the conventional braking system, most of the part of energy is lost in heat form due to friction between rotary brake pads. A regenerative braking is the process which not only created the braking torque but also recover the energy and feeding back to battery/ ultra capacitor. Hence during regenerative braking, electric motor acts as an electric generator.

Mostly in electric vehicles, AC motors are preferred because of its high efficiency. But for simple speed control operation, DC motors are more efficient and less expensive compare to AC motors. DC motor can provided high starting torque and variable speed as its versatile characteristics. In dc motor we can control the speed in wide range both below and above the rated values.

PMDC motor has the some advantages over the series-wound DC motors such as it has no field winding. No loss during excitation current, hence efficiency of PMDC motor is greater than the Series-wound DC motors. PMDC motor also small in size because of absence of field winding as compared to other types of dc motor. It creates less air noise as compared to other types of motors. In PMDC motor, speed can be controlled either the using variable resister at its armature or using power electronic switches to produce different armature voltage.

In PMDC motor based regenerative braking, braking torque is generated by applying different armature voltage. It can be achieved using a simple rotary mechanical switch with brake pedal without any complex convertor and switching techniques requirement.

To make an efficient system, each component of the system should be properly designed and efficient to achieve the maximum energy saving efficiency. Since energy density of battery is low and if we increase the energy density its size becomes very large. Hence to increase the capacity and lifespan of the battery, ultra capacitor is used along with the battery bank. Generally charging time of lead acid battery is about 1 to 5 hour whereas that of ultra capacitor is 0.3 to 30 sec. And discharging time of lead acid battery is about 0.3 to 3 hours whereas that of ultra capacitor is 0.2 to 30 sec. In order to improve the charging and discharging rate, ultra capacitor is used with battery bank. Ultra capacitor has high specific energy and power which reduced the size of battery and also reduced the braking time.

II. REGENERATIVE BRAKING USING DIFFERENT ARMATURE VOLTAGE

The PMDC motor is similar to DC shunt motor but its field winding is replaced by permanent magnets to reduce the excitation loss.

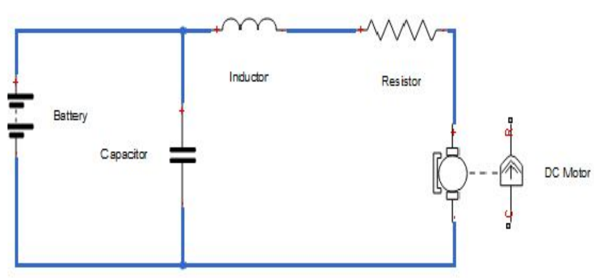


Fig.1. Equivalent circuit of PMDC motor

V= motor armature voltage (in volts)
Ia = Armature current (in amps.)
E= back emf (in volts)
Ra= Armature resistance (in ohms)
La= Armature inductance (in hennery)
ω= Angular speed (in rad /sec)
T= Torque (in N.m.)
Φ= Flux per pole (in Weber)

From the fig.(1), Armature current is given by

$$Ia = (V-E)/Ra \qquad (1)$$

We know that $E = K\Phi\omega$ (2)
And $T = K\Phi Ia$ (3)

Since flux can not be increased beyond the rated value, so regenerative braking is possible when speed of motor should be greater than the rated speed. And speed of motor is proportional to armature voltage (from eq. (2)) so we can control the speed by applying different armature voltage.

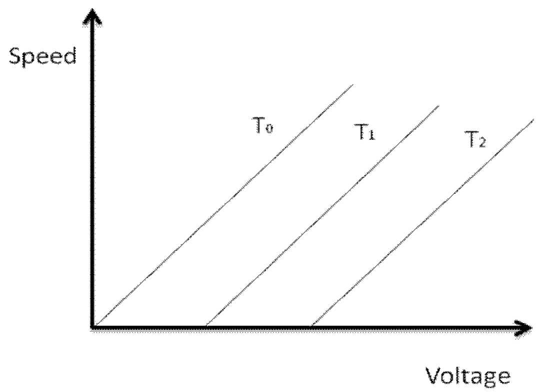


Fig. 2. Speed-voltage characteristics of PMDC motor

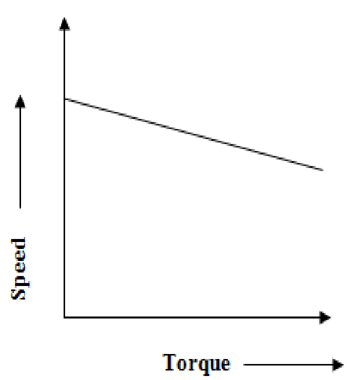


Fig. 3. Speed-Torque characteristics of PMDC motor

If V1 and V2 are two different armature voltage then corresponding speeds are N1 and N2 and corresponding back emf are E1 and E2, where V1>V2 and N1>N2 and E1>E2.

If we change armature voltage from V1 to V2 during running condition then that instant of time E1>V2 and from eq.(1) armature current will be negative that means electric motor acts as a electric generator and charge the battery/ultra capacitor until motor can not attain the speed N2 and back emf E2.

From eq. (3) during regenerative braking, torque will be negative that means motor will experience a braking torque which oppose the speed of motor. And this extra kinetic energy of motor converted into electrical energy and charge the battery which is used to build up the speed torque.

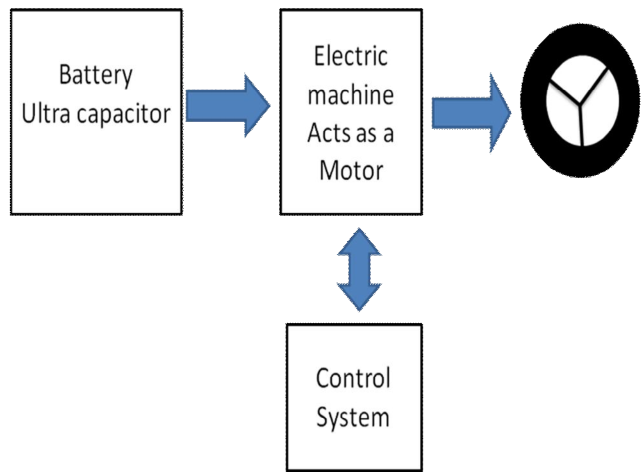


Fig. 4. Schematic diagram during driving mode

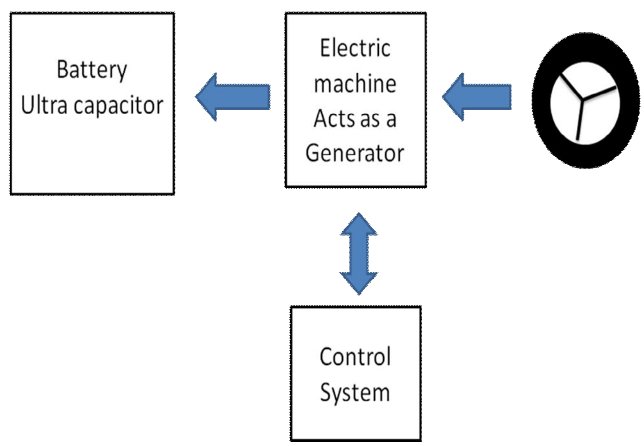


Fig. 5. Schematic diagram during braking mode

Hence as we reduce the armature voltage with rotary mechanical switch, the braking current and braking torque become higher. And higher braking torque produce higher deacceleration and taking less time to slow or stop the vehicle. Since this braking time is very small, hence to improve the energy saving efficiency and reduce the size of battery, we use ultra capacitor interconnected with battery because of its high rate of charging and discharging.

III. ARMATURE VOLTAGE CONTROL USING PWM TECHNIQUES

Pulse width modulation method is one of the best solutions for controlling the armature voltage. In this method output voltage is controlled with the help of simple power electronics switch like IGBT, MOSFET etc. Because of their higher power conservation efficiency, there is a no problem of heat dissipation and no requirement of cooling system. And there is a no need of any digital to analog converter.

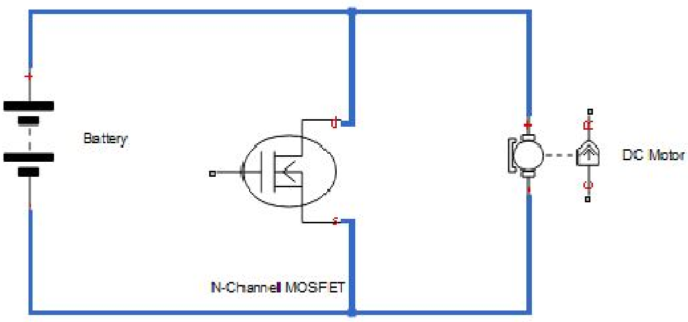


Fig.6. Armature voltage control using PWM techniques

The average voltage across the motor is given by

Vavg= D*Vs (4)

Where Vs = the supply voltage provided by the battery
and D = duty cycle

From eq.(4), we can easily control the voltage across the motor by varying the duty cycle(D) of PWM.

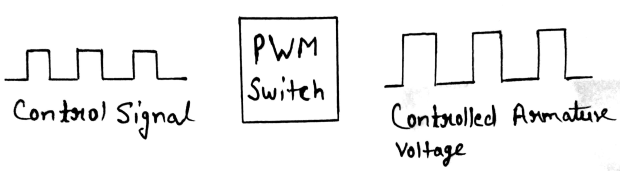


Fig. 7. Control topology of PWM techniques

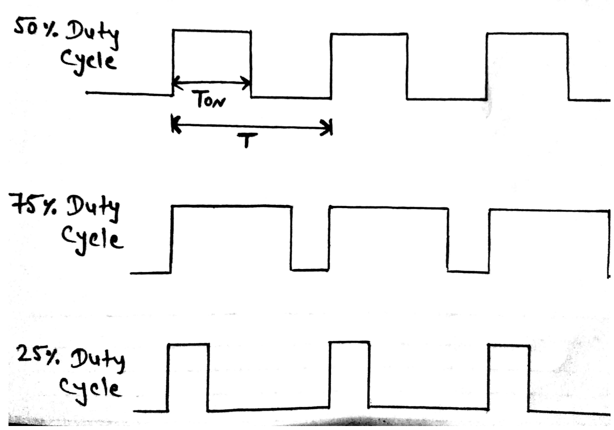


Fig. 8. Control signal with different duty cycles

For the 50% of duty cycle, the average output voltage is half of the applied input voltage hence the motor runs at half of its maximum speed. Similarly for 75% duty cycle, motor runs at ¾ of its maximum speed and for 25% of duty cycle motor runs with ¼ of its maximum speed.

IV. SIMULATION AND RESULTS

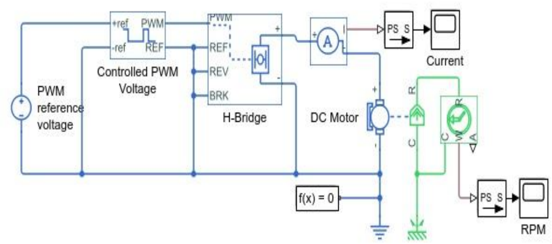
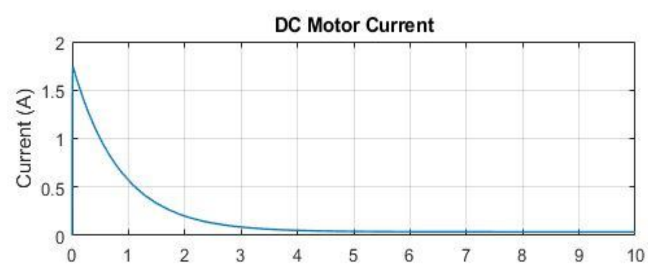
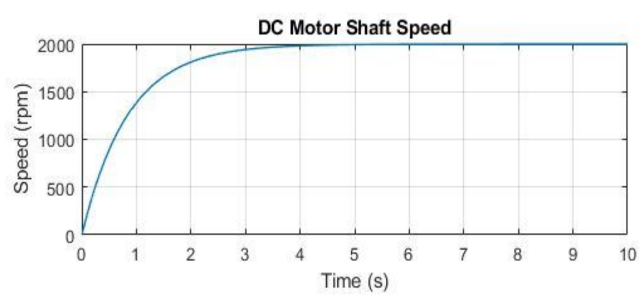


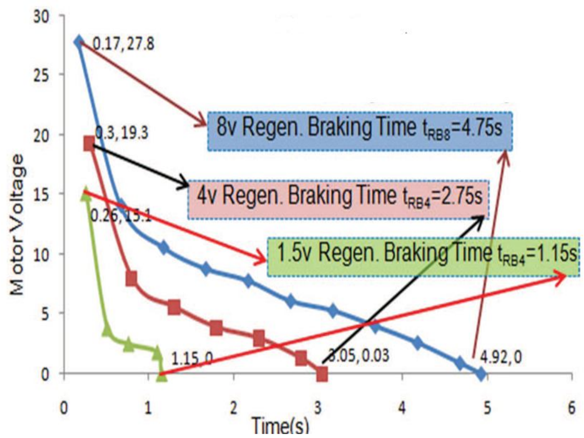
Fig.9. Simulation model of PMDC motor



(a)



(b)



(c)

Fig.10. Simulation results (a) speed of dc motor, (b) Armature current, (c) braking time curve with diff. armature voltages.

Simulation results show that during the drive mode armature current decrease from high starting current to zero and corresponding speed is increase from zero to rated speed. As we reduce the motor armature voltage, armature current becomes negative and a braking torque is experienced by the motor. Braking torque will be high with decreasing of motor armature voltage and also reducing the braking time.

V. CONCLUSION

The proposed PMDC motor based regenerative braking is a simple but very effective method for an electric vehicle. This paper shows that armature voltage control method is the very efficient for PMDC motor based regenerative braking rather than the other types of dc motors. With the help of this method a large amount of energy is saved during braking mode. Additionally ultra capacitor makes the operation fast as well as increase the battery lifespan. Further focus will be on designing of additional switch which can quickly and properly select the desired armature voltage from battery bank with the position of brake pedal.

REFERENCES

[1] LI Hua and ZHONG Meng chun “ Study on regenerative braking of hybrid electric vehicle drive system of Armord vehicle” 2011.

[2] Liang Chu and Tongbo wu “ Stability coordinated control algorithm for hybrid electric vehicle” 2011.

[3] Destiny Loukakou and Patrice Chetangny “ Regenerative braking in a small low cost plug-in hybrid electric vehicles” 2013.

[4] Yan Qun, Xu Peng and Ya Da Tai “micro synthesis robust control on regenerative braking of hybrid electric vehicles” 2013.

[5] Barcelona and Spain ” Development of regenerative braking co-operative control system” 2013.

[6] Maxime Boisvert and Philippe Micheau “ Wheel slip controller for the regennerative braking of electric vehicles” 2015.

[7] Khaled Itani and Alexandre De “ Energy management of a battery flywheel storage system used for regenerative braking” 2016.

[8] Jeongwoo Lee and Douglas J. Nelson “ Rotating inertia impact on propulsion and regenerative braking” 2010.

[9] S.M. Baque Billah and Dr. Khazi Khairui Islam “ Regenerative braking char. Of PMDC motor by applying diff. Armature voltages” 2016.

[10] Amrit Anand Mahapatra and S. Gopalakrishna “ Regenerative braking in induction motor drives “2014.

[11] Bin Wang , Xiaoyu Huang and Junmin Wang “ A robust wheel slip control design for In- Wheel-motor-driven electrical vehicles with hydraulic and regenerative braking system” 2014.

[12] Wei Xu, Haiyan Zhao and Bingtao Ren “A regenerative braking control strategy for electrical vehicle with four in wheel motors” 2016.

[13] Xiaohong Nian, Fei Peng and Hang Zhang “ Regenerative braking system of electrical vehicle driven by brushless dc motor” 2014.

[14] Khaled Itani, Alexandre De and Ahmad Jammal “ Control strategy for extreme conditions regenerative braking of a hybrid energy storage system for an electric vehicle” 2016.

[15] Rigoberto Jimenez T. And Juan M. Ramirez “Main motor controller and regenerative braking of an electric vehicle” 2016.