IJARSCT
ISSN (Online) 2581-9429
International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Impact Factor: 7.67
Volume 5, Issue 2, February 2025

A Systematic Review of Recent Trends and Developments of Regenerative Braking in Electric Vehicles

Subathra Devi C
Assistant Professor
T J Institute of Technology, Chennai, India
csubathradevi111@gmail.com

Abstract: *Hydraulic braking system is employed in normal conventional vehicles. The regenerative braking method is implemented in Electric Vehicles (EV) which converts friction braking energy into electrical energy which results in an increase of the output energy for a given actual energy input to a vehicle thereby efficiency of the vehicle is improved. Aside from energy conservation, minimal wear, less consumption of fuel and more efficient braking are the merits of regenerative braking over mechanical braking. Energy recovery depends on the control strategies applied to electric motors used in the EV. In this paper, the various motors employed in EVs and their efficiency of energy conservation, and speed regulation are analyzed.*

Keywords: Regenerative Braking, Electric vehicle, BLDC Motor, PMSM motor, Induction motor

I. INTRODUCTION

In modern life, transport is the necessity of the people. Conventional vehicles use natural resources which are being depleted day by day. Petrol and diesel automobiles are polluting the environment as well as leading to global warming. The environmental impact of petroleum-based transportation led to renew the interest in electric vehicles. Conventional vehicles are generally powered only by fossil fuels, whereas EVs can run on the power generated from solar energy, wind energy, fossil fuels or even nuclear energy. The energy, thus harvested from these sources is stored in batteries or supercapacitors. Regenerative braking, an energy-efficient method is the key advantage of Electric Vehicles which cannot be applied to IC engines. Electrical energy is recovered from the braking energy and stored in the onboard battery. The kinetic energy produced in the wheel during deceleration is converted into reverse power flow. Energy recovery happens at two conditions 1. When the driver releases the accelerator pedal, 2. When the brake pedal is pressed. The range of driving of EVs is extended to 16.2%. [1] Though regenerative braking extends the range of EVs, if fully charged batteries are used, it is not possible to charge the battery further. The harvested energy is stored in the supercapacitor or along with regenerative braking, mechanical braking is also used.

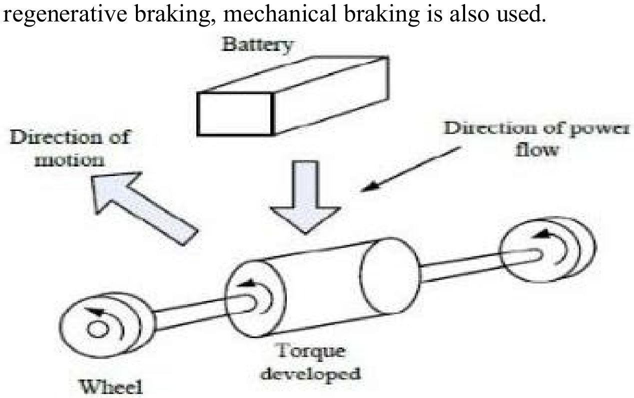

Fig. 1. Driving Mode

While the vehicle is in the acceleration mode, electric motor produce positive forward torque [2] and wheels are in the driving condition. Fig 1 shows the driving mode of vehicle. The back emf generated in this mode opposes the motion of vehicle in accordance to Lenz law.

As per diagram, battery deliver power to the motor and gradual rise in speed increase the magnetic field strength.

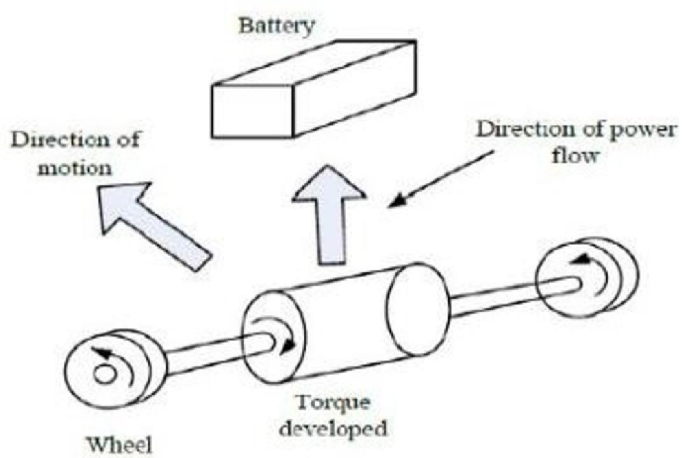

Fig. 2. Braking Mode

The motor acts as a generator during the braking mode and the braking energy in the wheel becomes mechanical input and this mechanical input in turn transforms into electrical output [2]. Fig 2 represents the braking mode of the EV. The speed of the motor and the magnetic field strength are directly proportional to each other. When there is a reduction in the speed of the motor, the magnetic field strength also reduces and the torque is reversed, which makes the driving machine to act as a dynamo and supply energy to the battery. A vehicle comes to a halt at less time when regenerative braking is applied.

II. TYPES OF MOTORS USED IN EV

There are five major types of motors used in EV applications, which are as follows: -

1. DC series Motor (Brushed DC Motor)
2. Brushless DC Motor (BLDC Motor)
3. Permanent Magnet Synchronous Motor (PMSM Motor)
4. Switched Reluctance Motor (SRM Motor)
5. Three phase induction motor (IM Motor)

1. DC SERIES MOTOR (BRUSHED DC MOTOR)

Commutators and brushes are important parts of these motors. The starting torque is high. Easy speed control methods are adopted. It has a high bearing capacity when there is a sudden change in load. The major drawback of this motor is maintenance of commutators and brushes is tedious. DC series motors are commonly employed for traction purposes. Energy regenerated is enhanced by applying an eddy current brake during regenerative mode when fully charged battery is available. [3]

2. BRUSHLESS DC MOTOR (BLDC MOTOR)

BLDC motors have high power density. It has high starting torque. The BLDC motor (Fig.3.) and DC motor share a similar design except the BLDC motor uses a permanent magnet in place of the commutator and brushes. Low maintenance is needed due to the absence of a commutator and brushes. [4] 'M.Athira & P.S.Shenil' analyze the sliding controller and adaptive PID controller methods for efficient braking control and conclude the earlier one produces the best results

The stator and rotor magnetic field rotate at the same frequency. So, BLDC is said to be a of synchronous motor. It does not have slip like induction motor [5]

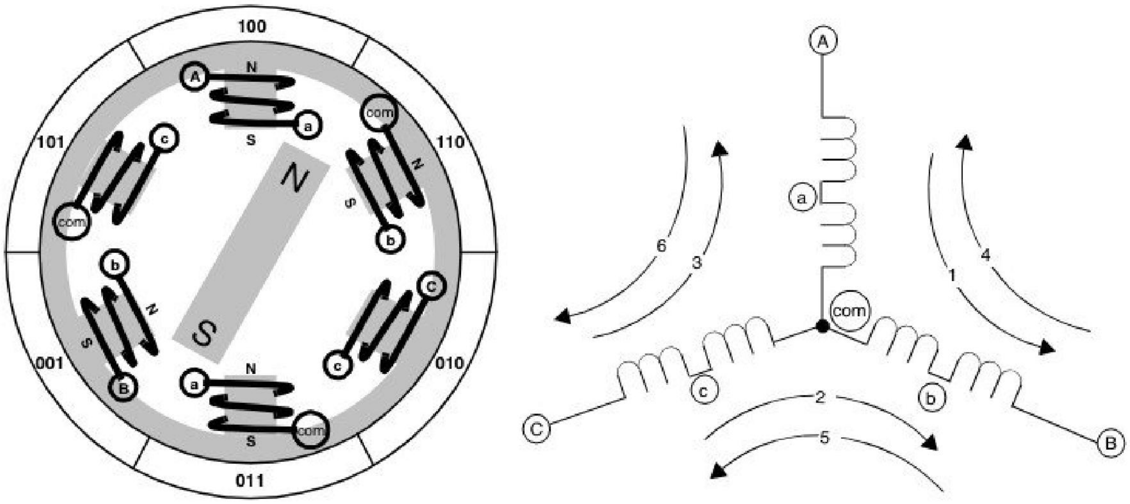

Fig. 3. BLDC motor construction

For fully charged battery, regenerative braking is not efficient. So super or ultra capacitor must be implemented along with battery (Fig.4). [6]

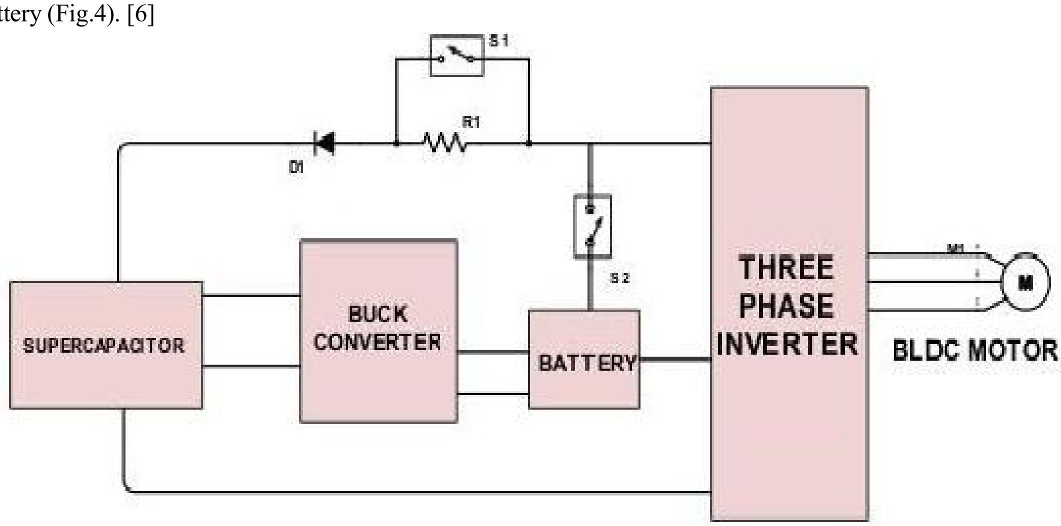

Fig.4. Basic Block Diagram for RBS in BLDC motor

3. PERMANENT MAGNET SYNCHRONOUS MOTOR (PMSM)

BLDC and PMSM motors have like designs. PMSM has a large power density, larger torque weight ratio, and greater efficiency. The difference between BLDC and PMSM lies in the shape of the back emf. PMSM has the waveshape in the form of a sinusoidal shape whereas BLDC has a trapezoidal shape Reactive power is necessary for the induction motor to operate as a generator. But PMSM has a permanent magnet to produce the required flux so a simple buck converter is sufficient to recover the energy [7].

The three armature windings in the PMSM are predominantly star-connected. This is fed with the three-phase AC supply. The permanent magnet is used in the construction of the rotor. The stator and rotor magnetic field interact with each other to produce the necessary rotational torque which makes the rotor rotate [8].

U. Gupta, 'D. K. Yadav and D. Panchauli' suggested the field-oriented control otherwise called vector control for the controlling of regenerative braking operation. The stator current is split into two components called magnetizing and torque current which control the amplitude and phase. This reduces the cost and gives good control and maximum energy recovery,

4. SWITCHED RELUCTANCE MOTORS (SRM MOTOR)

By changing the reluctance of the path, the torque of SRM can be changed. SRM is preferred because of its simple structure, high efficiency, ability to withstand high temperatures, and the absence of a permanent magnet (Fig.5).

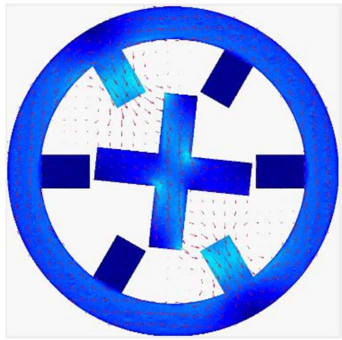

Fig.5. Structure of Switched Reluctance Motor

When the stator is supplied with electric power, the rotor tries to get aligned with the energized stator poles thereby decreasing the magnetic reluctance. The major problems faced in SRM motors are vibrations, high noise, and ripples in torque. SRM has complications in controlling its torque due to non-linear characteristics

5. THREE PHASE INDUCTION MOTORS

Three-phase induction motors are low-cost, highly efficient, better speed regulation machines. It is suitable for all environmental conditions (Fig.6).

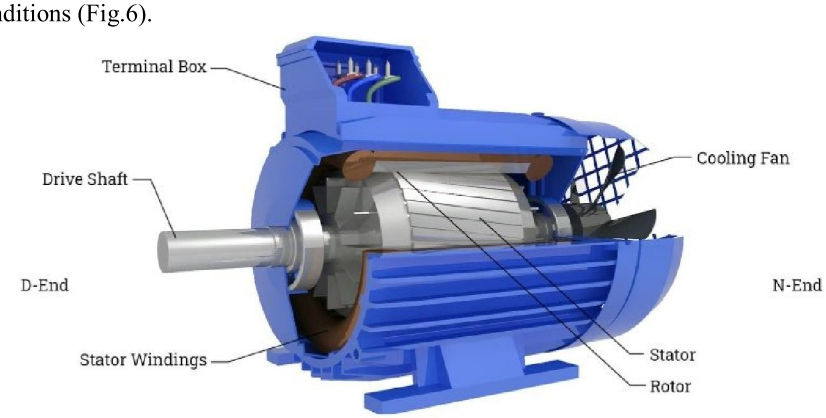

Fig.6. Induction Motor

Various controlling methods are employed in induction motors for achieving better performance and enhancing the regenerative power. Some of the braking methods employed in three phase Induction motor are,

1. Regenerative braking
2. Plugging Braking
3. Dynamic braking

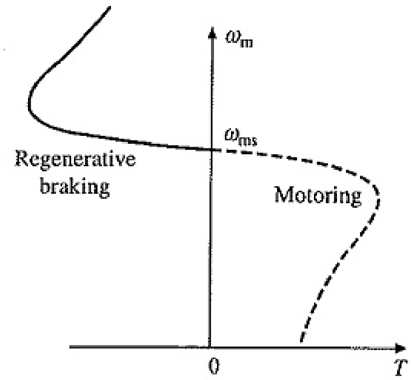

Fig.7. Regenerative braking

At the time of braking, plugging is efficient but for energy conservation regenerative braking is better [10]. If rotor speed is more than the synchronous speed at a constant supply frequency regenerative braking can take place. Regenerative braking occurs if the rotor speed is greater than the synchronous speed when the supply frequency is unchanged. When the variable supply frequency is available then regenerative braking can happen at a speed less than the synchronous speed. Similarly, regenerative braking takes place when its speed is less than that of the synchronous speed given the supply frequency is variable.

Synchronous speed $Ns = 120\ f/p$____

Where f- supply frequency & P- Number of poles

By varying the number poles in induction motor speed range is varied widely [11]. Thereby improving the efficiency of regenerated energy to 19.6% using the pole-changing method. Energy regeneration is controlled by controlling the stator voltage and stator frequency [9][11]. By maintaining the V/F ratio the machine operates in a constant torque region. Since the speed and electromagnetic torque of the induction motor are inversely proportional to frequency, braking torque is improved by reducing the frequency.

[14] The author juxtaposes the functioning of the DC motor, permanent magnet DC motor, and AC induction motor in both the driving and braking periods. The analysis of the performance of both motors ends with that AC Induction motors have better performance in both cases.

III. CONCLUSION

In this paper, the characteristics which govern in the selection of electric motors applied to EV are analyzed. Controlling of BLDC motors is complicated. But the power electronic components made it easier. Weakening of permanent magnets can happen in PMSM motors. As comparing all the factors induction machine has numerous controlling methods, high efficiency, wide speed variation. These methods are used to obtain maximum conversion of wasted power to useful energy

REFERENCES

[1]. Kuo- Kai Shyu, Hong-Lin Jhou, Ming-Ji Yang, Bin-Yen Ma, “A CostEffective Method of Electric Brake with Energy Regeneration for Electric Vehicles”, IEEE Transactions on Industrial Electronics, Vol.56,

[2]. S. S. Bhurse and A. A. Bhole, "A Review of Regenerative Braking in Electric Vehicles," 2018 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC), Chennai, India, 2018,

[3]. M. T. Guneser and A. Ridha Othman, "Enhancement of Regenerative Power Utilization for Electric Vehicle by Using Eddy Current Brake," 2021

[4]. International Aegean Conference on Electrical Machines and Power Electronics (ACEMP) & 2021 International Conference on Optimization of Electrical and Electronic Equipment (OPTIM), Brasov, Romania, 2021, pp. 254-258,

[5]. M. and S. P. S., "Novel Regenerative Braking Controllers for Electric Vehicle Driven by BLDC Motor," 2021 Fourth International Conference on Electrical, Computer and Communication Technologies (ICECCT), Erode, India, 2021,.

[6]. R. G. Chougale and C. R. Lakade, "Regenerative braking system of electric vehicle driven by brushless DC motor using fuzzy logic," 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), Chennai,

[7]. E. R. Aswathi, P. K. Prathibha and J. R. Nair, "Regenerative Braking of BLDC Motor using Fuzzy Control for Electric Vehicles," 2018 Second International Conference on InventiveCommunication and Computational Technologies (ICICCT), Coimbatore, India, 2018,.

[8]. A F. N. Esfahani and A. Darwish, "Regenerative Braking for EVs Using PMSM with CHB as Bidirectional Traction Converter," 2022 IEEE 16th International Conference on Compatibility, Power Electronics, and Power Engineering (CPE-POWERENG), Birmingham, United Kingdom,2022,

[9]. U. Gupta, D. K. Yadav and D. Panchauli, "Field Oriented Control of PMSM during Regenerative Braking," 2019 Global Conference for Advancement in Technology (GCAT), Bangalore, India, 2019,

[10]. A A. Mahapatra and S. Gopalakrishna, "Regenerative braking in induction motor drives in applications to Electric Vehicles," 2014 IEEE Students' Conference on Electrical, Electronics and Computer Science, Bhopal, India, 2014, pp. 1-5, ,

[11]. M. Chandrakanta, A. A. Mahapatra and A. Sahoo, "Comparative analysis of electrical braking performance for induction motor drive," 2018 Technologies for Smart-City Energy Security and Power (ICSESP), Bhubaneswar, India, 2018,

[12]. S. Dabral, S. Basak and C. Chakraborty, "Regenerative Braking Efficiency Enhancement using Pole-Changing Induction Motor," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022, pp. 1-6,

[13]. P. Binesh Mohan and V. R. Bindu, "Energy Regeneration in Induction Machine Drive During Braking," 2018 2nd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, 2018,

[14]. K. Rahane and R. Hardas, "Induction motor braking using Discrete Frequency Control," 2015 International Conference on Energy Systems and Applications, Pune, India, 2015, pp. 782-784,

[15]. K. Sedef, A. Maheri, A. Daadbin and M. Yilmaz, "A comparative study of the performance of DC permanent magnet and AC induction motors in urbanelectric cars," 2012 2nd International Symposium On Environment Friendly Energies And Applications, Newcastle Upon Tyne, UK, 2012, pp. 100-105,