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RESEARCH ARTICLE

REVIEW OF REGENERATIVE BRAKING FOR ELECTRIC TWO-WHEELER

Ankush S. Pujari[1], Ajay R. Joshi[1] , M. M. Wagh[2] and N. N. Shinde[3]

[1,2,3]Energy Technology, Department of Technology, Shivaji University, Kolhapur, Maharashtra, India

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ABSTRACT

This paper presents how electric Two-wheelers are environmental friendly. Paper also shows main drawback of the electric vehicles is the low travelling range; the distance covered between two charging. Regenerative braking gives a green source of energy with help of which one can improve the fuel efficiency of electric Two-Wheeler and the range of vehicle. The design of electric Two-wheelers is more suitable for regenerative braking than that of IC engine powered Two-wheeler. To improve the recovered energy one has to consider the various components of the electric Two-wheelers; such as battery system, control system, transmission system, drive system. With a comparative study of various types of these components the energy recovery in the vehicle can be improved. Paper also explains why BLDC motors and Ni-MH batteries are suitable for electric vehicle. The limitations of ETW, such as low voltage can overcome by using various techniques explained in paper.

INTRODUCTION

The transportation sector is responsible for 24% of the global CO_2 production, and road transport contributes roughly 73% of it. Electrical vehicle is an environment friendly option for IC engine powered vehicles. And regenerative braking helps to overcome the drawback of electric vehicle such as lower travelling range by energy recovery.

By various studies it is found that with electric two-wheelers, the annual CO_2 emission reduction is 3.25 million metric tonnes for 2011/2012 and rising to 54.29 million in 2020/2021.The annual gasoline saving with electric two-wheelers has shown 2.25–37.59 billion litres in the span of 10 years. [2]

Electric Two-Wheeler

The **Electric two-wheelers** have three main parts energy storage, energy control unit, and motors. Diagram shows circuit for ETW. This contains Ni-MH batteries as energy storage and BLDC motors to drive the wheels

The Regenerative Braking system includes generator system which uses kinetic energy of vehicle to produce electrical energy. This energy produced can be stored and used to accelerate the vehicle.

Construction of Electric vehicle with generator assembly for regenerative braking is shown in figure 1.

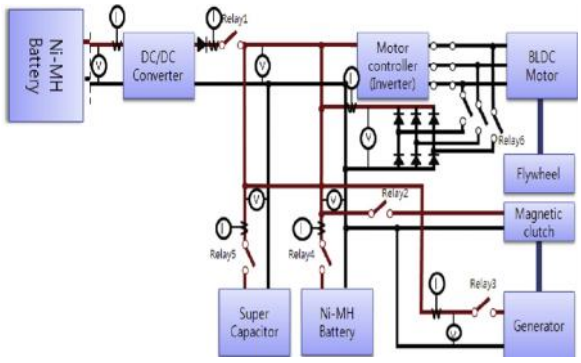

Fig 1 Electric TWH circuit diagram having regeneration with generator circuit

BLDC motor acting in generator mode- eliminates the generator, flywheel and clutch. Thus use of BLDC motor reduces weight of regenerative braking system. Super capacitors are used to absorb the sudden reverse current produced during regenerative braking, and to protect the battery from over current.

BLDC motors

BLDC motors are the type of synchronous motors. It experiences zero slip and produces stator and rotor magnetic

Corresponding author:* **Ankush S. Pujari
Energy Technology, Department of Technology, Shivaji University, Kolhapur, Maharashtra, India

field with same frequency. A BLDC motor comes in 1-phase, 2-phase and 3-phase configuration. Out of which 3-phase motors with trapezoidal waveform of back EMF are most used. Motors with sinusoidal waveform are also available but they are more costly [3].

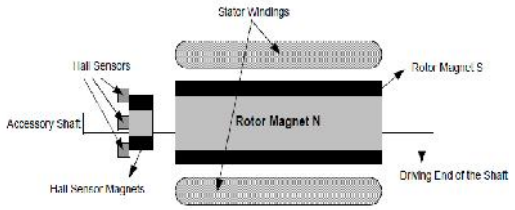

Fig 2 BLDC motor transverse section

One of the causes why BLDC motors are used is speed-torque characteristics. Two characteristic parameters are used two define a BLDC motors, peak torque (T_P) and rated torque (T_R). Figure 3 gives the speed-torque curve for BLDC motors. It is a straight line states that torque varies linearly with inverse of speed.

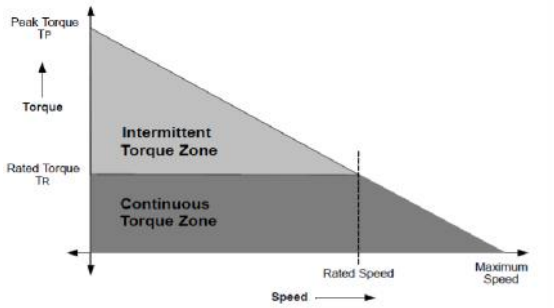

Fig 2 Speed- Torque characteristics of BLDC motor.

Ni-MH batteries

From studies it is known that Li-ion batteries weights 50% less than Ni-MH batteries consuming 5-10% less energy. And also in case of investment cost Ni-MH batteries has much higher cost than Li-ion and lead-acid batteries. But on the basis of Annual cost which depends upon the cycle-life, Ni-MH batteries are less costly. Annual cost of Ni-MH batteries is 62% lower than lead-acid batteries and 33% lower than Li-ion batteries. Thus Ni-MH batteries are proved more economical for electric two wheelers [1].

Braking techniques for ETW

ETW uses electric motors as prime movers so braking of electric can be of electrical or mechanical or of both types. Friction brakes are normally used mechanical type of braking. In mechanical braking motion of vehicle is restricted by friction applied to the shaft of the wheel. Thus mechanical braking dissipates its kinetic energy into the heat. Thus heating of brake pads and wearing of pads are the main drawbacks. Also it wastes kinetic energy of vehicle in the form of heat reducing range of ETW.

In case of electrical baking there are three types which are Dynamic Braking, Plugging, and Regenerative Braking. In Plugging a reverse current is made to flow through motor, producing magnetic field in opposite direction reducing vehicle speed. In dynamic and regenerative braking the kinetic energy is converted to electrical energy by separate generator assembly or by running same motor as generator (Especially in case of BLDC motors). In dynamic braking produce energy is wasted in form of heat by using resistance. Energy produced Regenerative braking is stored in batteries or in ultra capacitors for further use. Thus regenerative braking gives a green source of energy to charge the batteries of vehicle and increases range of vehicle. Regenerative braking is mainly explained in this paper. It recovers the Kinetic energy of ETW and feed it back to battery system.

Controls of BLDC Motors and Regeneration

BLDC motors normal operations

To run the three-phase BLDC motor a three phase inverter circuit is used. This circuit supply the DC current to any two of its three coils. Thus three phase BLDC motors run by energizing two of its three coils. The energizing sequence is decided by the hall sensors. The pair which is to be energized is decided by the position of the shaft. Hall sensors used to sense the position of the shaft. The dependence of phase winding energization on rotor position lies in the fact that the rotor magnet of the motor induces voltages in the phase windings during rotation, and efficient motor operation is accomplished when the energized windings are experiencing their steady or non-varying back emf. Hence, knowledge of the back emf of each phase winding as a function of rotor position is necessary in the determination of the phase winding energization sequence. Figure-3 gives the inverter and control circuit for three phase BLDC motor.

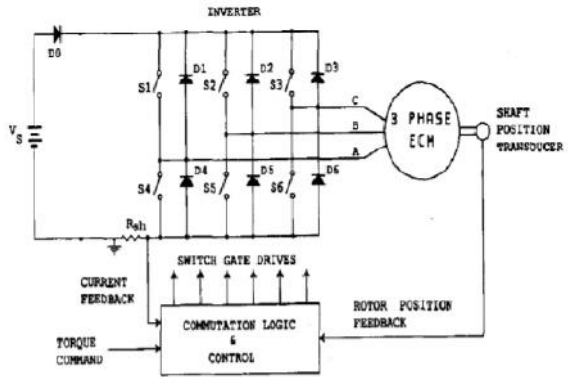

Fig 3 BLDC Motor during normal operation

Regenerative braking of BLDC motors

Normally mechanical breaking is applied to the vehicles. In mechanical brakes kinetic energy of vehicle is wasted in the form of by friction. Thus the energy used to accelerate the vehicle is wasted during this type of brake. In regenerative braking the kinetic energy is converted to electrical energy and is stored in the batteries or capacitors. The motor works as generator and it produces braking toque to oppose the motion of vehicle simultaneously generated energy charges the battery. Regenerative braking may be of following types:

1. Electrical regenerative braking
2. Flywheel regenerative braking

3. Hydraulic regenerative braking
4. Elastomeric regenerative braking

Last three types of the above mentioned types are mainly useful for vehicle with IC engine powered or having mechanical drive system. These types also have lower efficiency than electrical regenerative braking. Electrical type of braking is mainly applied in case of electric vehicles. It is easy to implement in electric vehicle because storage system for electrical energy is already present in the vehicle. Also in case of BLDC motor the motor itself can act as generator and recovers energy and also eliminates need of additional wiring required.

To charge battery during regenerative braking two conditions must be satisfied. First is that the voltage produced or the back EMF must be greater than the supplied voltage. And second is that the current must change its direction and flow from motor towards the battery.

To achieve the above condition either the flux field has to be increased or the motor must run at the speed greater than the rated speed. In case of BLDC motors as 1st condition is not possible the motor must run at speed greater than rated speed to charge the batteries. This can be achieved only if the vehicle running down a downhill gradient. Thus if one have to control or reduce speed of vehicle on a downhill we can use the regenerative braking system. The figure given below explains the working of BLDC motors during regenerative braking.

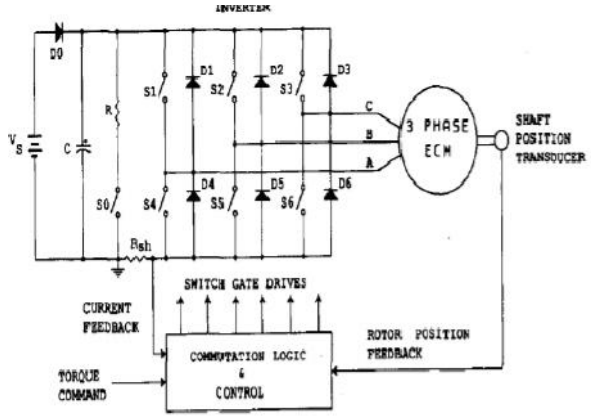

Figure 4 BLDC motor drive during Regenerative braking.

Electrical and Kinematics

Electrical

To run the BLDC motor two of its three coils are energized but with apposite polarity. One coil is connected to positive. Second coil is connected in series to 1st coil and at other end to negative pole of battery. Thus a same current (*i*) flows through both coils. Then the torque (*Te*) produced is given by the formula,

$$\bar{T}_e = \lambda_m \left| \bar{i}_{xy} \right| Sin\alpha \, \bar{k} \qquad \text{----- (1)}$$

In above equation k represents the unit vector perpendicular to both field flux and the current flowing through coil. If we change the direction of current apposite to its original direction, direction of torque also changes. Thus it produces a braking torque reducing the speed of vehicle or apposing motion of vehicle. λ_m represents the field flux of the motor which depends on magnetic flux density(Ø) and number of poles N.

$$\lambda_m = N\text{Ø} \qquad \text{\_ \_ \_ \_ (2)}$$

Kinematics of Braking Performance

When vehicle runs down a downhill gradient a torque in direction apposite of axel motion is required to stop or control the vehicle. This torque required is called as braking torque. The general equation for braking performance can be given by Newton's law as following equation.

$$Ma_x = (W/g)\, D_x = - Fxf – Fxr - Da - W\sin\theta \qquad \text{\_ \_ \_ \_ (3)}$$

W = Vehicle weight + riders weight
g = Gravitational acceleration
Dx = -ax = Linear deceleration
Fxf = Front wheel breaking force
Fxr = rear wheel breaking force
Da = Aerodynamic drag
θ= Uphill grade (Negative for Downhill)

A detailed analysis of braking performance depends upon values of various forces as explained above.

From the kinematic calculation gives the breaking torque to be produced by motor required to run the motor at constant speed. Using this value of torque it leads to find out the value of current flowing through coils. If the speed is known we can calculate the back EMF produced in the coils. Thus one can calculate the energy that can be generated if the braking torque and speed are known. The generated energy depends upon the speed and braking torque of the vehicle. Means generated energy depends upon the gradient of the vehicle. When the vehicle is running on the straight road the generated energy is less.

Limitations and Techniques to Improve

Limitations

As explained regenerative braking is mainly applicable for downhill gradient to brake or to control the vehicle at speed greater than rated speed. This is the main limitation of regenerative braking. We cannot use the regenerative braking system in case of slow speed braking of vehicle. If we use it, the generated voltage will not be sufficient to charge the battery.

Thus regenerative braking requires an additional mechanical friction break to control the vehicle at lower speed. Regenerative braking depends on the state of charge (SOC) of battery, percentage charge of battery. If the battery is fully charged the regenerative braking will not work. Thus it's not reliable and requires additional braking system.

More complications in electronic control increase the cost of the control circuit to some extent. Thus increases initial cost of

vehicle. Also this will cause to increase the maintenance cost of vehicle. Frequent charge and discharge of battery may cause to reduce battery cycle life. Added weight bulk of system may reduce the efficiency of the vehicle.

Boost Converter

This is the electronic device which can be used to step up the DC voltage. Boost converter can help to overcome some of main drawbacks of the regenerative braking. Boost converter takes the current from lower DC voltage stores it to a capacitor again during next step current is taken and energy in capacitor increases thus the capacitor voltage increases. This increased voltage can use to charge the battery. Thus one can use boost convertor to boost up the voltage generated by motor during slow speed regenerative braking. Thus the regenerative braking can be used at slower speed and at normal working also. The output voltage depends upon the input voltage and the duty cycle of the boost convertor. By reducing duty cycle the output voltage may be increased if required (6).

Ultra-capacitor

Ultra-capacitor is the device used to store the electrical energy for few seconds. While regenerative braking instead of using regenerated energy to charge the battery ultra-capacitor is charged and this energy used either to charge the battery or to accelerate the vehicle. This type of system reduces damage to battery which may occurs due to frequent charging and discharging. Also it can avoid the damage to system due to over current. Charge density of ultra-capacitor is high to absorb the sudden current produced in braking.

Advantages of Regenrative Braking

Improved travel range of vehicle is the most important advantage of regenerative braking. System such as ultra capacitor can provide extra current required during frequent acceleration after braking. If we use regenerative braking as supportive for friction braking, it helps to reduce the friction of brake pads. It is a green source of energy thus we can reduce the energy consumption by improving overall efficiency and operating cost will reduce to some extent.

CONCLUSIONS

The regenerative braking is a green source of energy; which recovers the energy lost during the braking. It is a best way to improve the travel range of the ETW.

BLDC motors and Ni-MH batteries are more compatible for ETW due to their performance characteristics.

Use of BLDC motor gives opportunity to use regenerative braking with more flexibility. Control unit of BLDC motor is can be easily change to regenerative braking control. With the help of boost convertor and Ultra-capacitor one can make regenerative braking more efficient and can overcome its limitations.

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BIOGRAPHIES

1.	Ankush Shankar Pujari, Research Student
2.	Ajay R. Joshi Research Student
3.	Mahesh Wagh is currently Assistant professor Nilkanth Shinde Coordinator
4.	Energy Technology Department, Department of Technology, Shivaji University, kolhapur, Maharashtra, India.

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