Regenerative Braking of Electric Vehicle using Piezoelectric Material

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ABSTRACT

In Automobile industries Hybrid & Electric Vehicles (EV's) are going to be more popular due to energy efficiency fuel saving and zero emission. Brushless DC Motor (BLDCM) plays a significant role in EV's. These motors can run through battery energy. This paper describes the application of BLDCM technology in EV's with an importance of Regenerative Braking. Regenerative Braking it conserves energy during braking by charging the battery and extends the efficiency and driving range of EV's. There are number of ways to implement Regenerative Braking. This paper demonstrates the application of Piezoelectric Material in regenerative braking for EV's. The Piezoelectric material provides electric feedback due to stress produced by applying brakes. The Electric Vehicle using BLDC motor and piezoelectric material is Modelled and Simulated in MATLAB / SIMULINK.

Keywords: Electric Vehicle (EV), Conventional Braking, BLDC Motor, Piezoelectric material – Quartz Crystal, Energy Regeneration.

1. INTRODUCTION

Due to the increasing environmental pollution and reduction of fuel sources, many industries move towards the electric systems. Therefore in automobile industries electric vehicles are come forward than the traditional vehicles. Most electric vehicles including electric cars, electric scooters, electric bicycles, electric wheelchairs etc., are driven by electricity stored in battery. Hence how to use batteries' energy efficiently is an important issue for developing EV's. [1] EV's run on Brushless DC Motor, due to benefits like, simple and robust construction, high efficiency, high dynamic response, higher speed range, large starting torque, noiseless operation etc. [1] BLDCM been applied in many fields, because of its most advantages such as reduced hardware size and weight, no reduction gear, high efficiency of driving system etc . Hub type of BLDCM is widely used in EV's. Normally mechanical brakes are used to stop EV's, mechanical brakes dissipate much energy, that the EV's kinetic energy is converted into the heat loss. Hence in this paper we see that how the conversion of kinetic energy into electrical energy that can recharge the battery. Thus both the braking and regeneration can be achieved. Piezoelectric material in conventional / mechanical braking system is the best suited material for producing electricity. The pressure applied on piezoelectric material at the time of braking produces electricity. The electricity that produced is given back to recharge the batteries, and the discharging rate of batteries decreases, and increases vehicle running capacity. In this paper a new and effective charging method is developed to solve batteries discharging problems. This circuit does not consist of any complexity. The whole charging process is depending on the quantity of pressure applied to the piezoelectric material.

1.1 BLDC MOTOR

Permanent Magnet Brushless DC (PMBLDC) Motors are the latest choice of researchers due to their high efficiency, silent operation, compact size, high reliability and low maintenance requirements [5]. Conventional DC Motors are highly efficient and their characteristics make them suitable for use as servomotors. However, their only drawback is that they need a commutator and brushes which are subject to wear and require maintenance. When the functions of commutator and brushes were implemented by solid-state switches, maintenance-free motors were realized. These motors are now known as Brushless DC Motors [6]. Brushless DC motors are widely used in applications such as laser printers, floppy and hard disk drives, robotic drives and machine tools, etc. There are mainly two types of BLDC Motor: Trapezoidal type and Sinusoidal type. In The Trapezoidal motor the back emf induced in the stator winding has trapezoidal shape and its phases must be supplied with quasi-square currents for ripple free torque operation.
The Sinusoidal Motor on the other hand has a sinusoidally back emf and requires sinusoidal phase currents for ripple free torque operation. The shape of the back emf is determined by the shape of the rotor magnets and stator winding distribution [7].

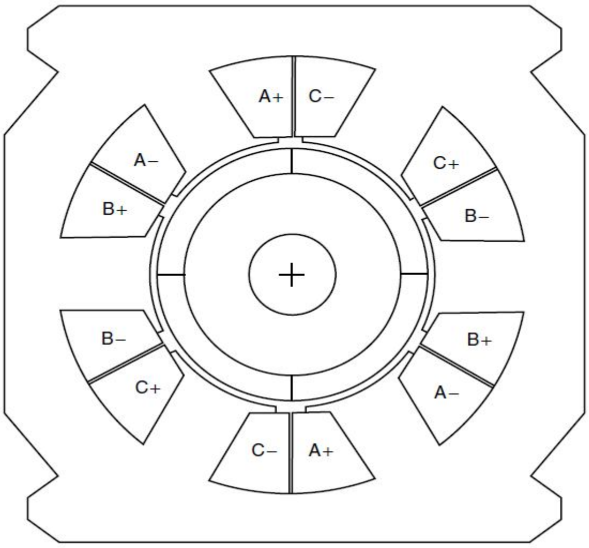

Fig (1) Three phase BLDC Motor with six slots and four poles

1.2 REGENERATIVE BRAKING

A regenerative brake is an apparatus, a device or system which allows a vehicle to recapture part of the kinetic energy. Regenerative braking is the process of feeding energy from the drive motor back into the battery during the braking process, when the vehicle's inertia forces the motor into generator mode. In this mode, the battery is seen as a load by the machine, thus providing a braking force. Regenerative braking is used on hybrid electric automobiles to regain some of the energy lost during stopping. This energy is saved in a storage battery. Here in this paper we regenerate electricity by the application of piezoelectric material.

1.3 PIEZOELECTRIC MATERIAL

Since piezoelectricity discovery in 1880, piezoelectric materials have found their way into many scientific and commercial applications. By definition, A piezoelectric material cannot be isotropic, or identical in all directions. If there was symmetry in the material there would be no electric polarization yield. So if you exert pressure on certain crystals, the molecules will re-align and produce a charge across the crystal. A charge can be read as a voltage. A piezoelectric crystal is like a capacitor that is pressure-sensitive.
Piezoelectricity is the ability of some materials (notably crystals and certain ceramics) to generate an electrical potential in response to applied mechanical stress. This may take the form of a separation of electric charge across the crystal lattice. If the material is not short circuited, the applied charge induces a voltage across the material. The word is derived from the Greek word piezien, which means to squeeze or press [3]

Therefore: Pressure ➔ Crystal ➔ Voltage

Types of Piezoelectric Materials:

➢ Naturally-occuring crystals
- Quartz, tourmaline, sodium potassium tartarate, Rochelle salt, etc.

➢ Ceramics
- Sintered form of finely ground powdered mixture made of ferroelectrics of the oxygen-octahedral type
- PZT: Pb (Zr, Ti) O3
- PT: PbTiO3
- PLZT: (Pb, La) (Zr, Ti) O3

➢ *Polymers*
- PVDF: polyvinylidene fluoride

1.4 THE MATHEMATICAL MODEL OF BLDC MOTOR [2]

$$V_a = R i_a + (L - M)\frac{d i_a}{dt} + E_a \quad (1)$$

$$V_b = R i_b + (L - M)\frac{d i_b}{dt} + E_b \quad (2)$$

$$V_c = R i_c + (L - M)\frac{d i_c}{dt} + E_c \quad (3)$$

$$\begin{cases} E_a = K_e \omega_m F(\theta_e) \\ E_b = K_e \omega_m F\left(\theta_e - \frac{2\pi}{3}\right) \\ E_c = K_e \omega_m F\left(\theta + \frac{2\pi}{3}\right) \end{cases} \quad (4)$$

$$\begin{cases} T_a = K_t i_a F(\theta_e) \\ T_b = K_t i_b F\left(\theta_e - \frac{2\pi}{3}\right) \\ T_c = K_t i_c F\left(\theta_e + \frac{2\pi}{3}\right) \end{cases} \quad (5)$$

$$T_e = T_a + T_b + T_c \quad (6)$$

$$T_e - T_l = J\frac{d^2\theta}{dt^2} + \beta\frac{d\theta_m}{dt} \quad (7)$$

$$\theta_e = \frac{P}{2}\theta_m \quad (8)$$

$$\omega_m = \frac{d\theta_m}{dt} \quad (9)$$

Where k = a, b, c
V_k : k_{th} Phase voltage applied from inverter to BLDC
I_k : k_{th} Phase current
R : Resistance of each Phase of BLDC
L : Inductance of each Phase of BLDC
M : Mutual Inductance
E_k : kth Phase back – EMF
T_k : Electric torque produced by k_{th} Phase
T_e : Electric torque produced by BLDC
K_e : Back – EMF constant
K_t : Torque constant
ω_m : Angular speed of rotor
θ_m : Mechanical angle of rotor
θ_e : Electrical angle of rotor
$F(\theta_e)$: Back EMF reference as function of rotor position

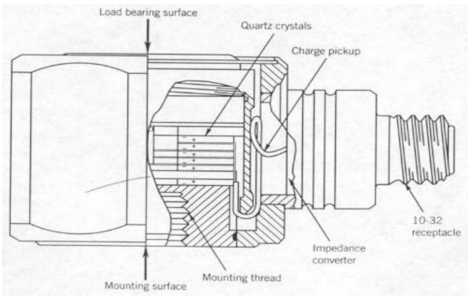

Fig (2) A Piezoelectric Load Cell [4]

2. EQUATIONS

The generated voltage from a piezoelectric material can be calculated from the following equation.

$$V = Sv * P * D \quad (i)$$

where
V = Piezoelectric generated voltage (Volts)
Sv = Voltage sensitivity of the material (Volt *meters / Newton),
P = Pressure (N/m2),
D = thickness of material (meters),

Voltage sensitivity values are provided with the material when received from the manufacturer. Different materials and different geometry cuts give different sensitivities. [3]

Here the pressure is directly related to the Force and Area of the material used

$$P = \frac{F}{A} \qquad (ii)$$

and the torque is directly related to force

$$T = F*d \qquad (iii)$$

from equations (ii) & (iii) we get,
d = Distance from axis to point of applied force

$$P = \frac{T}{dA} \qquad (iv)$$

where
F = Force applied by braking
A = Area of the piezoelectric material used
put equation (iv) into equation (i) we get

$$V = Sv*\frac{T}{dA}*D \qquad (v)$$

where
V = Generated voltage
from equation (v) we see that the Generated voltage (volts) is directly proportional to the Sensitivity of the material (Volt *meters / Newton), Torque developed (Newton meters), Thickness of the material (meters), and inversely proportional to the, Area of the piezoelectric material (meter^2) and Distance from axis to point of applied force (meters). [4]
From equation (v) we calculate the value of voltage generated.

Table 1: Sensitivity of Several Piezoelectric Materials [8]

S.No.	Material	Charge Sensitivity S_q (pC-N^{-1})	Voltage Sensitivity S_v (mV-m-N^{-1})
1	Lead Zirconate Titanate (PZT)	110	0.01
2	Barum Titanate	140	0.006
3	Quartz	2.5	0.05
4	Rochelle Salt	275	0.09

Here i am using a piezoelectric material Quartz Crystal and the dimensions are Sv = 0.05 Vm/N, D = 0.002 m, d = 0.01 m.

3. SIMULATION

In order to examine the output voltage the above equations have been input to a Matlab Simulation model. The result is shown in figure 3.The simulation time is 5secands and the breaking period is at 3rd secand where the output voltage is to be examined.

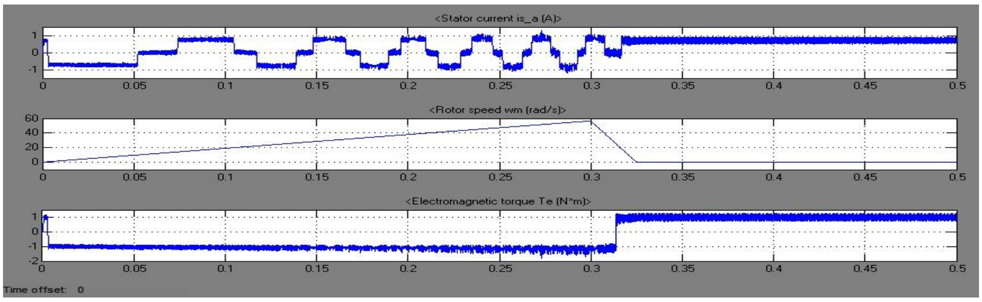

Fig (3) Speed and Developed Torque at the time of braking

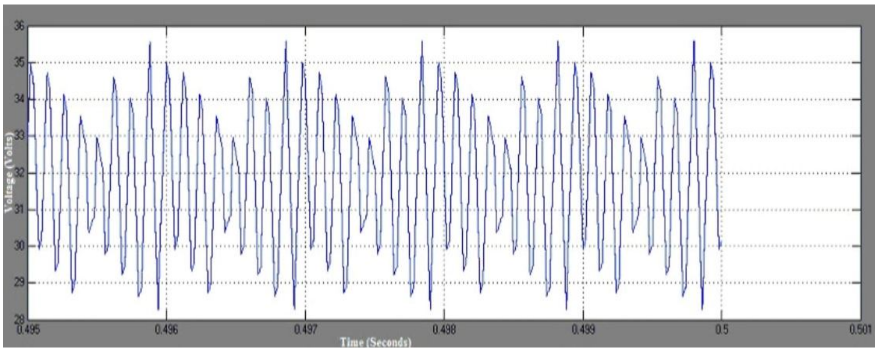

Fig (4) Voltage Generated by applying pressure on piezoelectric material at the time of braking.

4. CONCLUSION

A new and effective method of Regenerative braking of electric vehicle by the use of piezoelectric material quartz crystal and their simulation results has been observed, which highly reduces the discharging rate of batteries used in EVs. From the above observation we conclude that the driving range of EV can be increased up to 30% to 40%.

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