ENERGY REGENERATION REPORT

1.INTRODUCTION

Despite good control characteristics and ruggedness possessed by DC Machines, their performance and applications in wider areas is inhibited due to sparking and commutation problems. Induction motors do not possess such problems, they have their own limitations such as low power factor and nonlinear speed torque characteristics. A Brushless DC motor is able to overcome the limitations mentioned above and satisfy the requirements of a variable speed drive. The commutator and brush system in conventional DC machine is replaced with electronic Switches in BLDC motor which is the reason for its distinct characteristics. The main parts of BLDC Motor are: stator, rotor, hallsensor.

Stator:

Similar to an Induction motor, the BLDC motor stator is made up of laminated steel, stacked up to carry poly phase windings. These windings are fed with rectangular voltages and distributed so as to produce trapezoidal back emf. Windings can be arranged in two patterns : star or delta.

Rotor:

The rotor in a BLDC motor consists of an even number of permanent magnets. The flux density of the rotor is high due to the construction of permanent magnet, hence there are no losses in rotor because of no winding present in core.

Hall sensors:

The commutation in BLDC Motor is by means of electronic switches. To operate these switches the rotor position sensing mechanism is required. Hall sensors are used for this purpose. They are based on the principle of hall effect.

Hall effect :

The development of a transverse electric field in a solid material when it carries an electric current and is placed in a magnetic field that is perpendicular to the current.The electric field, or Hall field, is a result of the force that the magnetic field exerts on the moving positive or negative particles that constitute the electric current.

For the estimation of the rotor position, the motor is equipped with three hall sensors. These hall sensors are placed every 120^0. Phase commutation depends on hall sensor values. Power supply to the coils changes when hall sensor values change. With right synchronized commutations, the torque remains nearly constant and high.

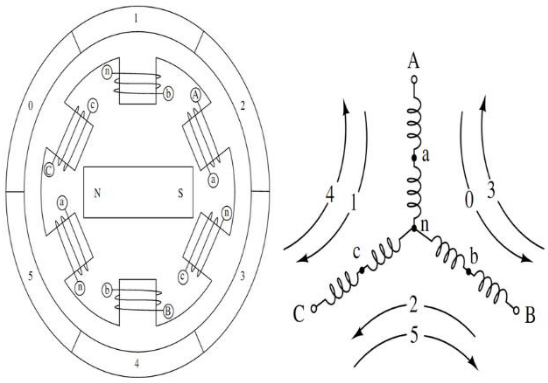

Fig 1.Crossection of BLDC Motor

Phase commutation:

Consider a typical BLDC motor with only three coils. As stated earlier phases commutation depends on the hall sensor values. When motor coils are correctly supplied, a magnetic field is created and the rotor moves. The most elementary commutation driving method used for BLDC motors is an ON-OFF scheme, a coil is either conducting or not conducting. Only two windings are supplied at the same time and the third winding is floating.

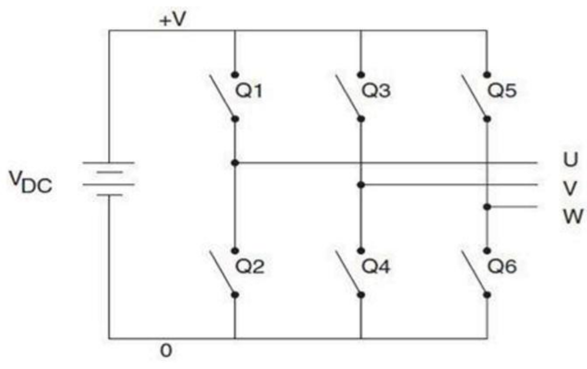

Fig 2.Three phase inverter supplying power to the motor windings.

The supply given to the windings is controlled by the electronic switches. Using pulse width modulation the average voltage supplied by the inverter bridge can be controlled. This way the average current and hence the motor torque can be controlled. The following table represents the operation sequence of bldc motor.

Hall Sensors Values	Phase	Switches
101	U-V	Q1;Q4
001	U-W	Q1;Q6
011	V-W	Q3;Q6
010	V-U	Q3;Q2
110	V-W	Q5;Q2
100	W-V	Q5;Q4

Fig 3. Hall sensor truth table

This way hall sensor senses the rotor position and corresponding signal is given to the inverter to operate the switches accordingly, supplying power to the windings. Continuous operation of the switches ensures uniform rotor rotation.

2.EQUATIONS OF BLDC MOTOR

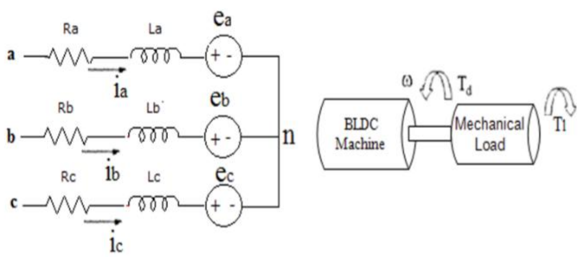

Fig 4.Dynamic model of BLDC Motor.

Voltage equations of the stator phases are given as:

$$V_{an} = R_a i_a + L_a \frac{di_a}{dt} + e_a$$
$$V_{bn} = R_b i_b + L_b \frac{di_b}{dt} + e_b$$
$$V_{cn} = R_c i_c + L_c \frac{di_c}{dt} + e_c$$

where,
V_{an}, V_{bn} and V_{cn} : phase voltage in volts
i_a, i_b and i_c : phase current in amps
e_a, e_b and e_c : phase voltage back-emf in volts
Ra, R_b and R_c : phase resistance in ohms
L_a, L_b and L_c : phase inductance in henry

The torque equations of motor are given as:

$$T_{em} = T_L + \omega B + J_m \frac{d\omega}{dt}$$
$$T_{em} = k_t i_a$$
$$e_a = k_e \omega$$

where,
T_{em} : developed electromagnetic torque in Nm

ω: rotor angular velocity in rad/sec

B : viscous friction constant in N-m/rad/sec

J_m: rotor moment of inertia in Kg-m^2

T_L: load torque in Nm

k_e : back emf constant

Taking Laplace transform and solving the above equation the following results are obtained,

$$T_{em}(s) = k_t \frac{V_{an}(s) - k_e \omega(s)}{R_a + sL_a}$$

$$\frac{\omega(s)}{V_{an}(s)} = \frac{\frac{k_t}{J_m L_a}}{s^2 + \left(\frac{J_m R_a + BL_a}{J_m L_a}\right)s + \left(\frac{BR_a + k_t k_e}{J_m L_a}\right)}$$

The desired performance of the motor can be easily achieved from the transfer function.

3.ADVANTAGES OF BLDC MOTOR

- Due to the absence of commutator and brushes the maintenance is less and life is more.
- The rotor is permanent magnet and sparks in brushes are absent. Due to the reduction in losses the efficiency is more.
- Rotor inertia is less due absence of windings thus the dynamic performance is improved.
- Speed torque characteristics are flat and speed range is higher.

4.ENERGY REGENERATION

Generally the motor in electric vehicles runs on a battery. During the braking, the kinetic energy of the motor is converted into heat energy due to friction and is subsequently lost. Regenerative Braking is an energy recovery system which tries to recover this energy before it is converted into heat. There are various methods by which regenerative braking can be implemented. One of the ways is to store the energy at the time of braking in a battery or energy storage device like capacitor .The energy regeneration here is being implemented using a capacitor .

The circuit for regeneration is shown in Fig 5. Here, battery of 48v supplies the motor with required power. The motor circuit is connected using inverter and hall sensor feedback. At the time of brake application, the breaker 1 is cut-off and braker 2 is connected.Thus battery is replaced with capacitor and the capacitor charges.

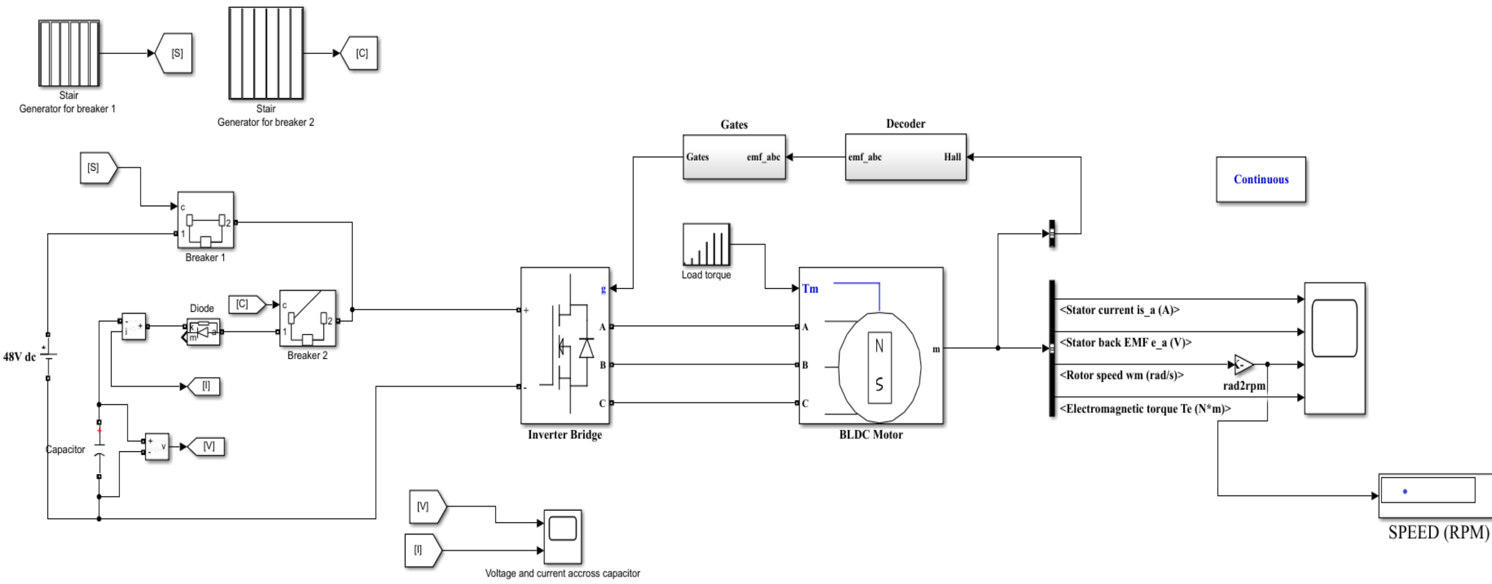

Fig 5: circuit for energy regeneration

Let us consider a scenario where brake is applied about five times as the vehicle travels a distance of 100m. The braking torque will be acting on the vehicle at the moment of brake application and during rest of the time it is assumed that load torque/rated torque will be acting on the motor. Using a stair generator the torque acting on the motor is varied accordingly. As battery is replaced by capacitor when each time brake is applied ,we are using a stair generator to turn on and off the breakers respectively. Thus the charge accumulates cumulatively on the capacitor and voltage builds up. Using capacitance value of 68000µf the voltage results have been simulated .

Simulation results:

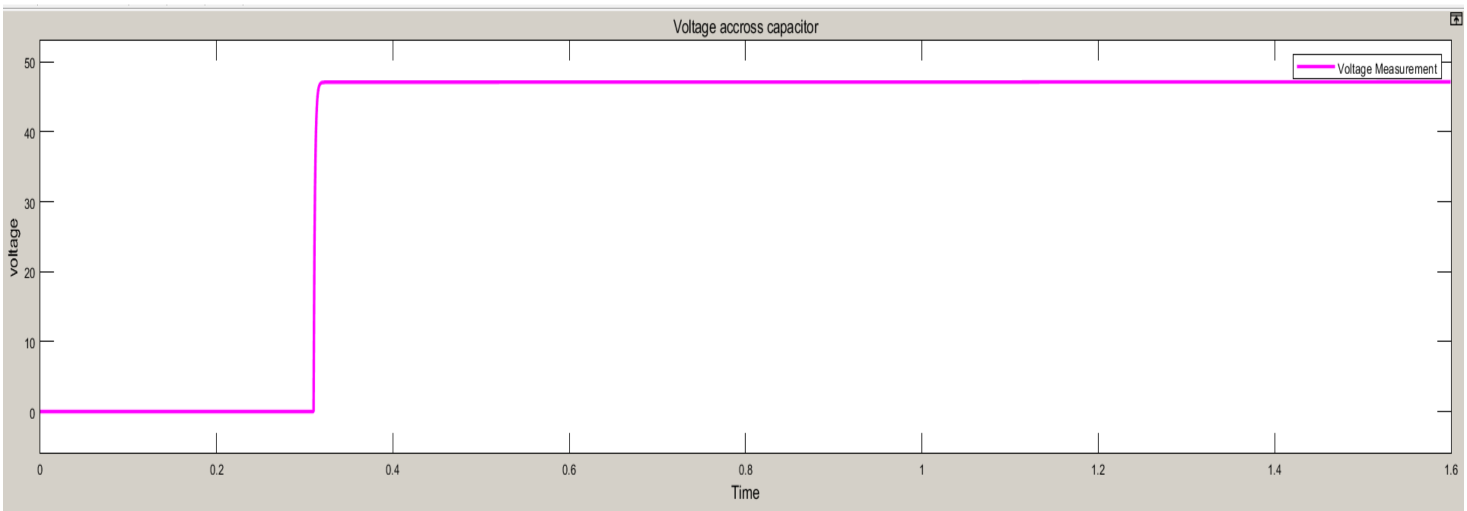

Fig 6:Cumulative rise in voltage across capacitor:

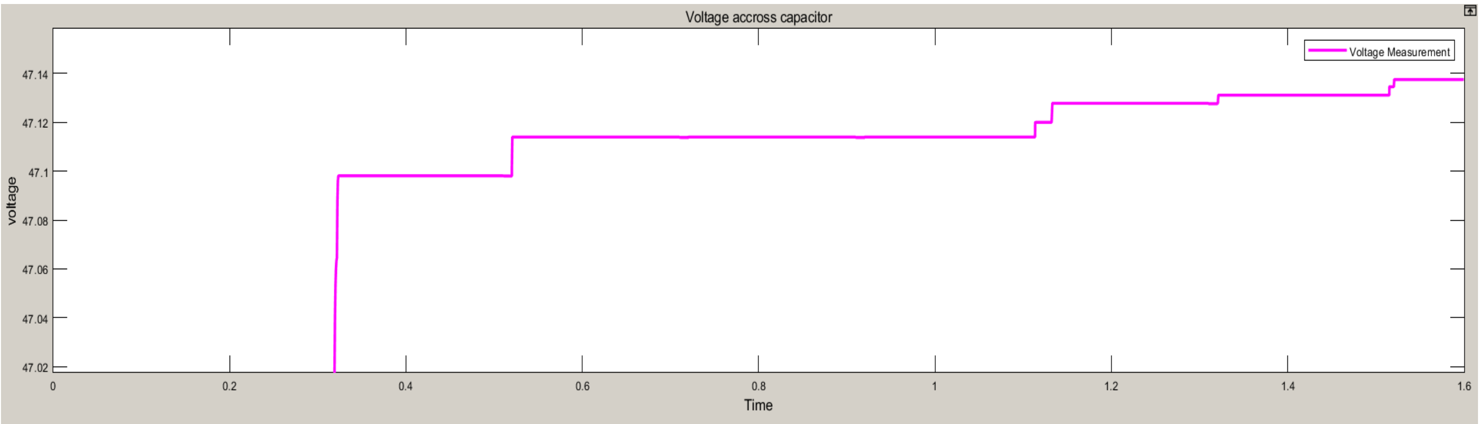

Fig: The above figure shows the cumulative increase in voltage across the capacitor due to gradual increase in stored charge. By this method we can increase the energy regenerated each time we apply the brake.

5.CALCULATION

Assuming that the vehicle moves with maximum velocity, the kinetic energy of the vehicle at the time of brake application is:

$$KE = \frac{1}{2}mv^2$$

M= mass of the vehicle= 280kg

V= velocity of the vehicle= 8.65 m/s^2

KE= 0.5*280*8.65^2=10,475 J

Energy stored in capacitor = $\frac{1}{2}cv^2$
C=68000µf
V=47v
Energy stored in capacitor =0.5*68000*47^2*10^{-6}
=75.1 J

Efficiency of regeneration
= Energy stored in capacitor/ KE of the vehicle
= 75.1/104=0.71%

6.APPLICATIONS OF BLDC MOTORS

- They are used in fans, pumps, blowers where variable speed is more important than maintaining speed accurately at set value.
- Washers, dryers, compressors, centrifuges pumps, robotic arm controls, gyroscope controls etc which require high speed control accuracy.
- They are also used in positioning application in which accurate control is required. Closed loop torque and speed control is involved in such applications.