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# Comparative analysis of Speed control of BLDC motor using PWM and Current Control Techniques

Gopal Gupta
*Dept. of Electrical Engineering*
Delhi Technological University
gopalgupta_2k20pes09@dtu.ac.in

Mini Sreejeth
*Dept. of Electrical Engineering*
Delhi Technological University
minisreejeth@dce.ac.in

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***Abstract*—BLDC Motors are among the many possible solutions employed in electric vehicle applications. Brushless DC motor are featured in 2-wheeler segment and light load vehicles catering to majority of courier industry and ride hailing providers. This research paper focuses on such solutions based on BLDC motors specifically. In the paper presented, PWM and current control techniques are implemented for speed control of Brushless DC motor using MATLAB Simulink environment. The performance in both the cases are compared in terms of drive response, stator current, electromagnetic torque. Further, the stator current ripples and electromagnetic torque ripples are elaborately discussed and results analyzed for further improvements.**

***Keywords*—BLDC Motor Control, Pulse Width Modulation, Current Control Techniques, Torque Ripples**

## I. INTRODUCTION

Indian government is making a massive shift in policies to make electric vehicle countrywide acceptable and affordable. Initiatives are being taken to encourage courier industry and ride hailing providers to switch to electric vehicles [1]-[4]. Brushless DC motor being featured in 2-wheeler segment and light load vehicles due to which we are witnessing an exponential growth in its demand and controlling techniques. Efficiency and solidarity are increasing with the development in motor drives. Brushless DC motor has high electromagnetic torque at lower speeds and has higher power density as compared to other motors [5]-[7]. Other advantages include silent operations and reliability. Controlling of BLDC must be efficacious for having a lower cost, silent and efficient operation.

The algorithm for controlling speed of brushless dc motor is quite complex. The Brushless DC motor drive control technique utilizes the rotor position information for giving the proper commutation scheme implementation [9]-[10]. Broadly there are two main techniques namely sensored and sensorless techniques. Sensored techniques relies on the information provide by three hall sensors that are placed 120 degree apart whereas the sensorless method requires tracking of back EMF wave shape and its zero crossing is detected [11] considering overall advantage of sensorless technique. Sensorless doesn't require the rotor position lowering the operation cost but the main disadvantage of using sensorless techniques are (a) sensorless techniques tracks back emf wave for which a minimum speed is mandatory to get detected making it incompatible for low speed applications. (b) When the load and speed varies rapidly, it may misinterpret the driving loop and cause lock. Therefore electric vehicle uses sensored technique.

A trapezoidal drive approach [13] is used to switch the Brushless DC motor using Hall Effect sensors. The initial rotor position data detection and management of commutation after switching to closed loop control are handled by Hall Effect sensors [14]-[16]. The current is measured via the shunt resistor, with conversion occurring in the midst of the PWM duty cycle. Because the difference in mechanical degrees between two commutation signals is 60 degrees, it is easy to compute the speed of the motor with the passing mechanical degrees per time-interval using the position feedback from Hall Effect sensors. The PI controller receives feedback from the speed information.

The simulation model of speed control of Brushless DC drive is developed and carried out using MATLAB SIMULINK. The Simulink model consists of star connected BLDC motor, 3-phase inverter, 3-phase PWM based inverter and controller. The specification of motor used is provided below. For speed control loop, European-15 driving speed cycle is given as the reference speed.

## II. BLOCK DIAGRAM OF BLDC MOTOR

The basic block diagram of brushless dc motor is as shown Fig.1. The brush less dc motor drive basically consists of four main parts which are power converter for feeding power to motor, brushless DC motor, sensors like hall sensors and speed sensor to give inputs to the controller, and control algorithm to give switching pulse to power converter in accordance to the desired speed and power.

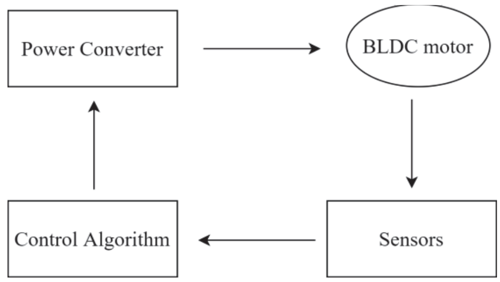



Fig.1: Block Diagram of Brushless DC Motor

## III. MODELLING DRIVE SYSTEM

### *A. Modelling of BLDC Motor*

The equivalent circuit diagram of BLDC motor shown in fig.1, is connected to a battery via 3-Φ inverter which consists of six MOSFET switches. The rotor of BLDC motor is mounted with the permanent magnet making the rotor's flux linkage dependent on the magnet making saturation of magnetic flux linkage typical for BLDC. Assumptions made are as following:

1. Motor is operated within rated current to avoid saturation.
2. Three phases are balanced out

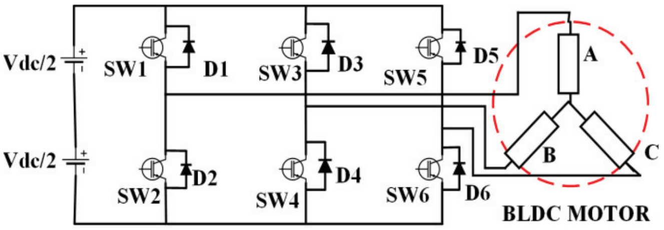



Fig.2: Equivalent Circuit Diagram of Brushless DC Motor

The stator windings of BLDC motor is star connected. The voltage equations are represented below:

$$v_a = Ri_a + L_a \frac{di_a}{dt} + e_a \quad (1)$$

$$v_b = Ri_b + L_b \frac{di_b}{dt} + e_b \quad (2)$$

$$v_c = Ri_c + L_c \frac{di_c}{dt} + e_c \quad (3)$$

Or in the compact matrix form as follows.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} R+\rho L & 0 & 0 \\ 0 & R+\rho L & 0 \\ 0 & 0 & R+\rho L \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4)$$

Where $L_a = L_b = L_c = \mathrm{L} = L_S - L_M$ [H]

$L_S$ is self-inductance of armature, $L_M$ is mutual-inductance, whereas $R_a = R_b = R_c = R$ are resistances of armature in ohm. $v_a$, $v_b$ and $v_c$ are terminal phase voltages of motor in volts. $i_a$, $i_b$ and $i_c$ are motor input current in amperes. $e_a$ , $e_b$ and $e_c$ are the motor's back emf in volts

The expression of back emf are represented as

$$e_a(\mathrm{t}) = K_E * \emptyset(\theta) * \omega(\mathrm{t}) \quad (5)$$

$$e_b(\mathrm{t}) = K_E * \emptyset(\theta - \frac{2\pi}{3}) * \omega(\mathrm{t}) \quad (6)$$

$$e_c(\mathrm{t}) = K_E * \emptyset(\theta + \frac{2\pi}{3}) * \omega(\mathrm{t}) \quad (7)$$

The produced torques are given by:

$$\tau_E(\mathrm{t}) = (e_a i_a + e_a i_b + e_c i_c)/\,\omega \quad (8)$$

$$\tau_a(\mathrm{t}) = K_T * \emptyset(\theta) * i_a(\mathrm{t}) \quad (9)$$

$$\tau_b(\mathrm{t}) = K_T * \emptyset(\theta - \frac{2\pi}{3}) * i_b(\mathrm{t}) \quad (10)$$

$$\tau_c(\mathrm{t}) = K_T * \emptyset(\theta + \frac{2\pi}{3}) * i_c(\mathrm{t}) \quad (11)$$

Where $K_T$ is the torque constant.

$$\tau_c(t) = \tau_c(t) + \tau_c(t) + \tau_c(t) \quad (12)$$

$$\mathrm{T_E(t)} - \mathrm{T_L(t)} = \mathrm{J}\frac{\mathrm{d}\omega(\mathrm{t})}{\mathrm{dt}} + \mathrm{B} * \omega(\mathrm{t}) \quad (13)$$

Where $\mathrm{T_L}$ is load torque in N-m.
J is rotor inertia in [kgm$^2$], B is damping constant.

## B. Modelling of Current Control Loop

Fig.3 shows the block diagram for speed control of BLDC motor using current control. The stator current is measured and compared with this reference current to generate an error signal which is fed to a comparator with a predetermined hysteresis band. Switching of MOSFET depends on the comparison of the stator current w.r.t reference current. Switching pattern for the MOSFET is given as:

If ΔIa >H, SW1 is on and SW2 is off.
If ΔIa <L, SW1 is off and SW2 is on.
If ΔIb >H, SW3 is on and SW4 is off.
If ΔIb <L, SW3 is off and SW4 is on.
If ΔIc >H, SW5 is on and SW6 is off.
If ΔIc <L, SW5 is off and SW6 is on.

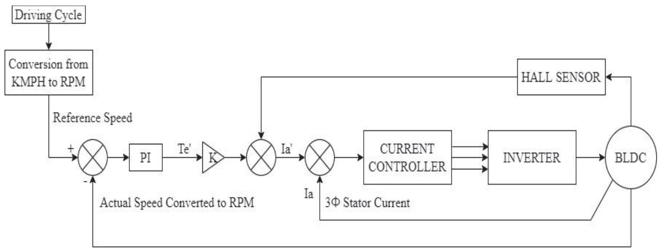



Fig.3: Schematic of Speed Control of BLDC motor using current controller

Quasi-square waveform is obtained by regulation the desired current. ΔIa = Ia* - Ia, where 'H' and 'L' are the high and low limit for the predetermined hysteresis band.

# IV. Simulation and Results

## A. Simulink Models

Simulink Model for the Speed Control of BLDC motor using PWM and current control are shown in fig.4 and fig.5 where a battery of 72V, 3.6 kWh is chosen. The BLDC motor is fed by a three phase PWM based inverter. Motor specifications are given above in the Table 1. The switching of the inverter is based on the switching pulses generated by the controller which uses the rotor speed and the hall sensor signals to know the correct position of the rotor. A driving cycle pattern is giving as reference. The rotor speed is in rad/sec so this is converted to rpm. After this error speed is fed to PI controller. Kp and ki values are are selected and output from PI is fed to PWM to generate pulses [17]. These pulses are compared with the hall sensor pulses generated to give the switching to the inverter.

TABLE I. Specification of Motor

| Motor Parameter | Value |
|---|---|
| Input DC Voltage | 72V |
| Stator Resistance | 2.875 ohm |
| Stator Inductance | 8.5e-3 H |
| Rated Torque | 2.5 N-m |
| Pole Pair | 4 |
| Moment of Inertia | 0.12 Kg-m$^2$ |
| Damping | 0.005 N-m-s |

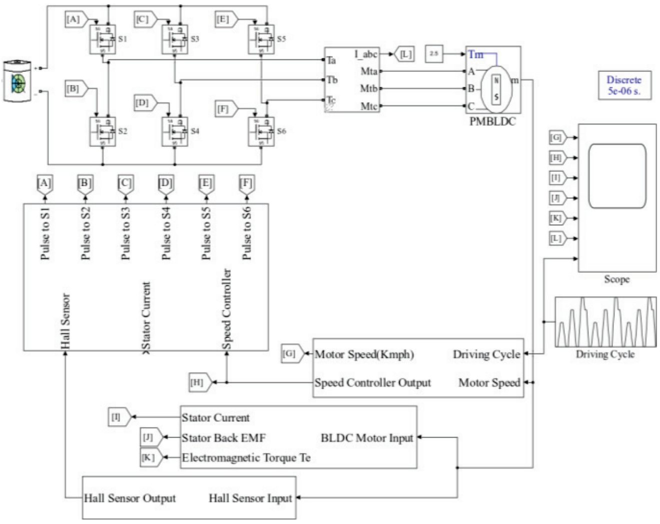



Fig.4: Simulink Model for Speed Control of BLDC using PWM

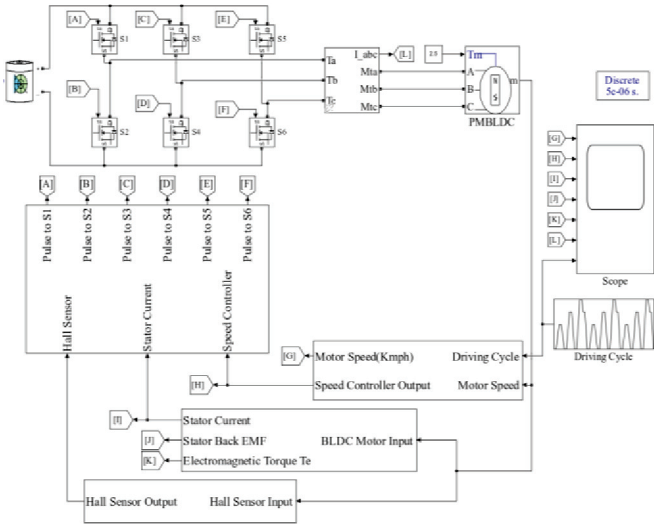



Fig.5: Simulink Model for Speed Control of BLDC using Current Controller

### B. *Results*

At European-15 driving cycle, the simulation is done and the results obtained were satisfying. Fig.6 shows the driving speed given and the speed we obtained.

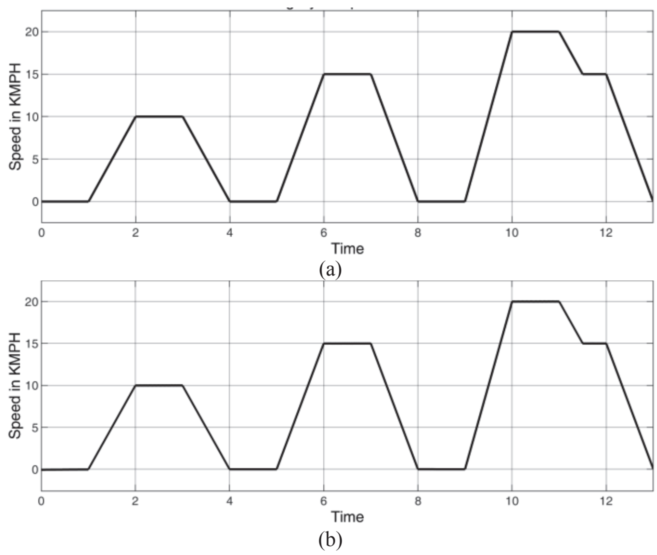



Fig.6: Comparison of (a) Driving speed and (b) Achieved speed

Fig.7 shows stator back EMF for phase A. It can be clearly see the variation in EMF with reference to the speed. Since the back EMF is directly proportional to back EMF of motor, with the increase in speed, back EMF rises proportionally. Since this is a BLDC motor back EMF has to be trapezoidal. On zooming the plot for the Stator back EMF, it can be observed that a perfect trapezoidal shape is obtained which is shown in Fig.8.

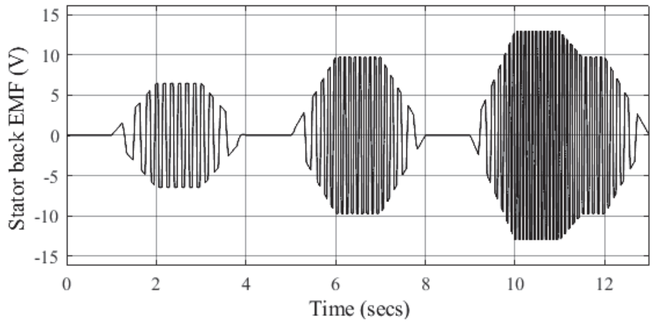



Fig.7: Stator Back EMF response for Speed Control of Brushless DC

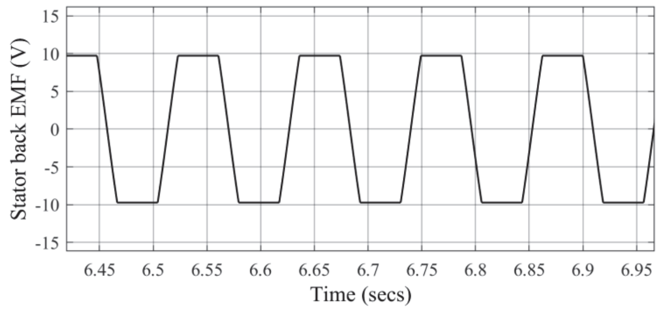



Fig.8: Zoomed Stator Back EMF response for Speed Control of Brushless DC

Fig.9. shows the electromagnetic torque and stator current for the BLDC motor using controller. But here we can observe the ripples in the stator current. Since torque is directly proportional current, ripple in torque can be observed. Because of these ripple, this will not deliver us a smooth driving experience.

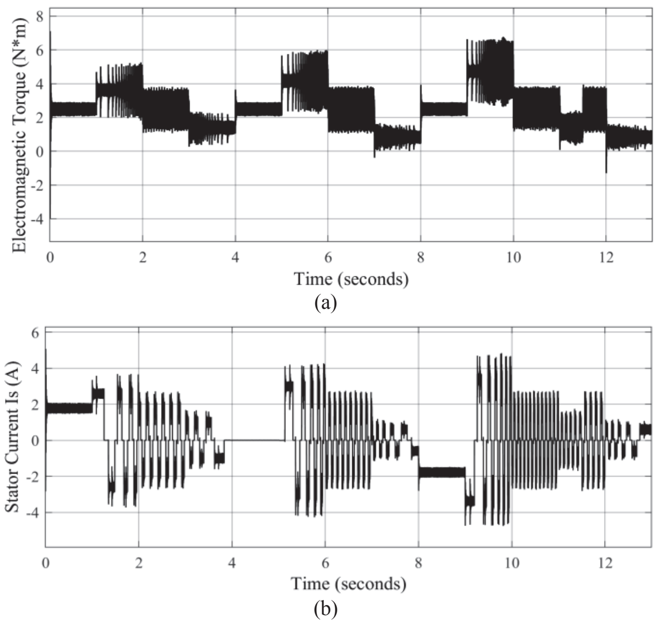
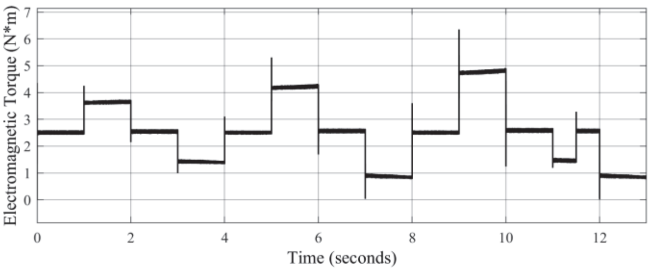
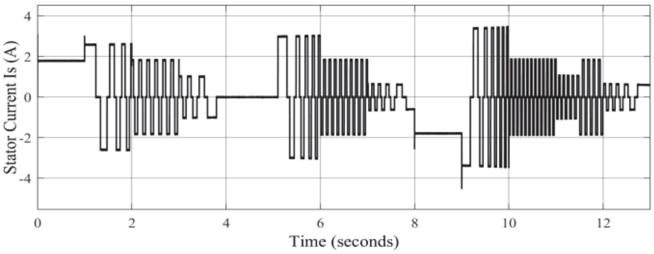



Fig.9: (a) Electromagnetic Torque and (b) Stator Current of Brushless DC motor using PWM

The electromagnetic torque and stator response obtained from the hysteresis current control of Brushless DC motor is shown in Fig.10. where it can be see the ripples are more smoothened out. With the rise in torque, current rises sharply to meet the demand and decreases when the torque becomes flat. The shape of current is quasi-square as can be seen from the Fig.10.




(a)

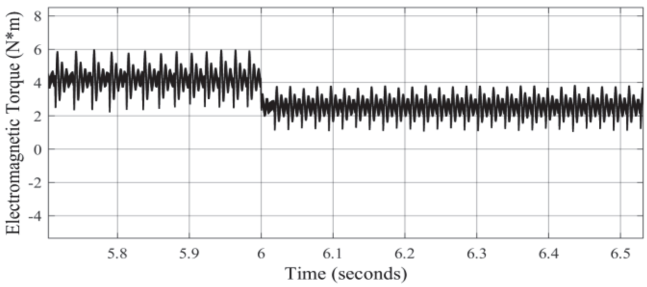



(b)

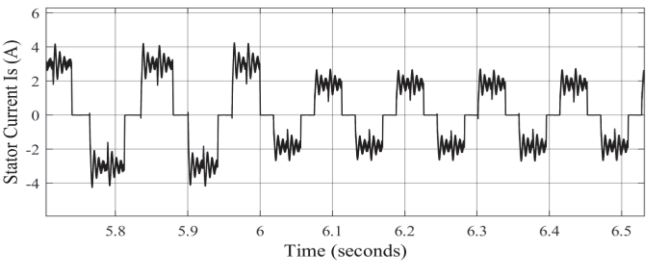
Fig.10: (a) Electromagnetic Torque and (b) Stator Current Response for Brushless DC motor using Current control

### C. Discussion

To show the proper outcome of the control strategies used, curve of both the techniques used are shown. Zoomed up curves in Fig.11 show the ripples in the electromagnetic torque and stator current for speed control using PWM controller. These need to be rectified so moved towards hysteresis current control. Fig.12 clearly shows ripples are quite smoothened out and looks good.

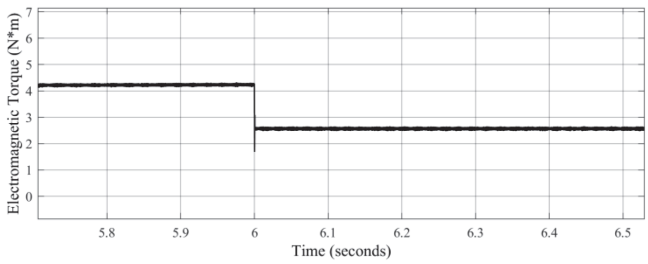



(a)

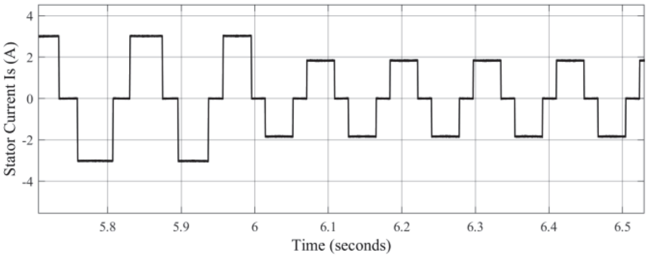



(b)

Fig.11: (a) Electromagnetic Torque and (b) Stator Current response for Brushless DC motor using PWM




(a)




(b)

Fig.12: (a) Electromagnetic Torque and (b) Stator Current Response for Brushless DC motor using current control

## V. CONCLUSION

Electric 2-wheeler requirement is going to rise exponentially in order to curb pollution level due to which BLDC motor will be in high demand. They are also being used for other high performance application because it has high torque in low speed range and less noisy as compared with other motors as well as their efficiency is high whereas requirement basis for maintenance is quite low. It can be observed from the MATLAB simulation that the estimated speed calculated from rotor is similar to the actual driving cycle. A clear observation can be made that the current controller was able to minimize the ripple in the torque and stator current which in turn enhances the overall performance. The shape of back EMF traced from the stator was trapezoidal which shows the operation was successful. The results show that the dynamic performance of the motor is quite satisfactory.

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