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Comparative Analysis of BLDC Motor Drive with & Without Back EMF Controller Technique

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***Abstract**: Brushless DC motors are widely used in variable speed drive application. The torque produced by the Brushless DC (BLDC) motors with trapezoidal back Electromotive force (BEMF) is constant under ideal condition. However in practice the torque ripple appears on the delivered output torque. Smoothness of variable speed drive operation is critical due to this torque ripple. The brushless DC motors uses power electronic switches for the commutation purpose, it creates the Harmonics in armature current. The brushless dc motor will have many reasons for having ripples in output torque. The ripples in the torque are mainly due to commutation. Here a variable dc link voltage to control the torque ripples has been used. Basically the current present in the inductor after switching the phase will produce ripples in the current. These can be reduced by supplying sufficient voltages at the regions by mathematical analysis of the circuit. The power quality is maintained to get an efficient output. This power quality control can be done by maintaining good power factor. This can be done by using a boost converter. The boost converter circuit is added to the brushless dc motor circuit after adding the dc link voltage control. This can give an effective load to the power system.*
***Keywords:** Brush less dc motor, dc link, hysteresis current controller,sensored bldc motor.*

I. Introduction

A Brushless dc (BLDC) motor is a rotating self-synchronous machine. Whose stator is similar to that of an induction motor and the rotor has surface mounted permanent magnet. In BLDC motor, winding is placed on stator which is stationary and permanent magnets are placed on rotor which is rotating. In the dc motor, the current polarity is altered by commutaor and brushes. However in brushless dc motor there are no brushes and commutator. The current polarity reversal is controlled by switches (MOSFET, IGBT) in synchronization with rotor position. Therefore sensoredBLDC motor uses position sensors to sense the actual rotor position or the position can be detected without sensors. Brushless dc motors are preferred over conventional dc motor due to their high efficiency, silent operation, compact form, reliability and low maintenance. But the speed control of these motors is not an easy task, the advancements in microcontroller, power electronics and electrical drives over the decade have made reliable and cost effective solution for adjustable speed application. The BLDC motors are used in home appliances, replacing the conventional motor applications, everywhere there is a fast growing market for BLDC motors for several years to come because everyone wants reliable and cost effective solution.

The major application includes washing machines, room air conditioner, refrigerator, vacuum cleaner, dish washer etc. House hold appliance have traditionally relied on classic electric motortechnology such as single phase AC induction, induction split phase, capacitor start, capacitor run types and universal motor. There is demand for low operating cost, high performance, reduced acoustic noise and more convenience features. Those conventional technologies cannot provide cost effective solution. One of the ways to get higher efficiency is by selecting the right hall sensor which can significantly affect reliability and performance of many critical applications including robotics, medical equipment, heating, ventilation and air conditioning (HVAC) system fans. These applications all call for a highly efficient and quiet motor. BLDC motors are electronically commutated motors, also known as synchronous motors because stator flux and rotor flux both rotate at same frequency that are powered by a DC supply through an inverter .

Comparative analysis of bldc motor to permanent magnet synchronous machine:

BLDC	PMSM
1.Torque generated will have more ripples	1. Torque generated will have less ripples compare to bldc motors.
2. Coil span is less than 180 degrees electrical and coil pitch is 1.	2. Coil span is 180 degrees electrical and coil span is greater than 1.
3. Two phases are conducting at a time.	3. Three phases are conducting at a time.
4. Concentrated winding.	4.Distributed winding
5. Back EMF is of trapezoidal fashion	5.Back EMF is of sinusoidal fashion

In BLDC the commutator assembly is replaced by an intelligent electronic controller. The advantages of BLDC motors are summarized below:
a) High dynamic response
b) High efficiency
c) Long operating life
d) Noise less operation
e) Higher speed range
f) High output power
g) Low maintaines
h) Compact volume

The major disadvantage of BLDC motor is higher cost because of permanent magnet and electronic commutator. The permanent magnet synchronous motor (PMSM) and the brushless dc (BLDC) motor have many similarities.

II. Literature Survey

V.Vijaya Kumar, V.Udayakumar, J. Muruganandham [1]:

In this modern world the power demand and wastage is one of the major problems over the home appliance and small scale industries. In this paper speed control of three phase BLDC motor for four quadrant operation with reduced power loss is proposed. Using Hall sensors, the position of Rotor is determined and then individual stator windings are energized in order to make the rotor to rotate. The

Power generated during the Braking mode of BLDC motor is stored in the Battery. Thus the speed control of four quadrant operation of three phase BLDC motor has been done without loss of power using MATLAB Simulink and also battery is charged during regenerative mode of operation under the application of conventional PI controller.

Jianwen Shao, Dennis Nolan, and Thomas Hopkins [2]:

A novel back EMF detection method for Sensorless BLDC motor drives without the motor neutral point voltage information is presented in this paper. The true phase back EMF signal can be directly obtained from the motor terminal voltage by properly choosing the PWM and sensing strategy. As a result, the method proposed is not sensitive to switching noise,No filtering is required, and good motor performance is achieved over a wide speed range. The detailed circuit model is analysed and experimental results verify the analysis and demonstrate advantages of the new technique. In this paper they have discussed Inverter configuration and currentcommutation sequence for BLDC motor for Back EMF zero crossing detection.

The true back EMF can be detected during off time of PWM because the terminal voltage of the motor is directly proportional to the phase back EMF during this interval. Also, the back EMF information is referred to ground without any common mode noise. Therefore, this back EMF sensing method is immune toswitching noise, and suitable for high voltage or low voltage, and high speed or low speed applications.

Ahmad Faiz Noor Azam, AuzaniJidin, Nor AzaziNgatiman, M.H Jopri,MustafaManap, Adeline LukarHerlino, Nor Faezah Alias [3]:

This paper presents a current blocking strategy of brushless DC (BLDC) motor drive to prolong the capacity voltage of batteries per charge in electric vehicle applications. The BLDC motor employs a simple torque hysteresis control (THC) that can offer a robust control and quick torque dynamic performance. At first, a mathematical modelling of BLDC motor and principle of torque hysteresis control will be described, so that the benefit offered by the proposed current blocking strategy can be highlighted. It can be shown that the current control method naturally provides current limitation, in which the current error (or ripple) is restricted within the pre-defined band-gap furthermore provide current protection. The control scheme is validated and verified by the simulation and experimental results. This paper presented the modelling and experimental result of THC for BLDC motor. The current controller has been applied to a BLDC drive.

NorhazilinaBintiBahari, Auzani bin Jidin, Abdul Rahim bin Abdullah, MdNazribin Othman,Mustafa bin Manap [4]:

This paper presents modelling and simulation of a torque hysteresis controller for brushless DC motors. Brushless DC (BLDC) motors can offer great advantageous compared to other machines used in industrial applications due to its compactness, high torque density, simpler controller and lower maintenance. This paper has also presented the modeling and simulation of torque hysteresis controller for BLDC motor. Moreover, a new current blocking strategy to prevent the energy wastage from the batteries such that it can prolong the capacity ofvoltage battery is proposed .From the simulation results obtained, itshowed that the hysteresis controller can offer inherent current protection/limitation and robustness in controlling the motor torque.

Kirankumarvadlamudu,BhanuPrakeshAdangi [5]:

The BLDC (brushless DC) motor is characterized by linear torque to current and speed to voltage. However, at variable-speed operation, torque and speed response characteristic is deteriorated by the motor inductance components in stator windings. A simplified current controlled modulation technique for brushless DC motors is presented. It is based on the generation of pulses, using PI and Fuzzy logic controllers under fixed and variable speeds. The advantages of this strategy are: (a) very simple control scheme; (b) effective controlling in wide speed range of operations; and (c) the difficult of reducing the error between reference and actual signals is avoided. These characteristics allow using the triangular carrier as a current control strategy for the switches, which is simpler and better than other options. Simulations analysis has done with Mat lab/Simulink to show the good characteristics of this solution, and its simplicity. A BLDC drive system, controlled with PI and Fuzzy based current controller compared to the conventional motor without current control technique at fixed and variable speeds, the proposed current control system is to increase the speed response of the motor and effective controlling.

III. Mathematical Modelling Of BLDC Motor

Assumptions:

1. The motor's three phase are symmetric, including their resistance, inductance and mutual inductance.
2. There is no misalignment between each magnet and the corresponding stator winding.
3. All three phases have an identical back-EMF shape.
4. There is no misalignment between each magnet and the corresponding stator winding

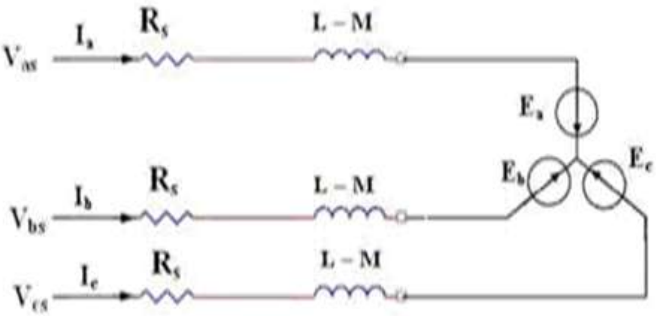


Figure 3.8.1 Equivalent Circuit for Stator Windings

Z = $2\{R\_S + S(L - M)\}$

$$R_a = 2\,R_s$$

2(L-M) =L_a

Z = $2\{R_s + S(L - M)\}$

Z = $R_a + SL_a$

The mathematical equation of phase a, phase b, phase c, are follows as

$$V_{an} = R_s + L\frac{di_a}{dt} + M\frac{di_b}{dt} + M\frac{di_c}{dt} + e_a$$

Similarly for phase b and phase c

$$V_{bn} = R_S + L\frac{di_b}{dt} + M\frac{di_c}{dt} + M\frac{di_a}{dt} + e_b$$

$$V_{cn} = R_s + L\frac{di_c}{dt} + M\frac{di_b}{dt} + M\frac{di_a}{dt} + e_c$$

Where

L is self-inductance [H]

M is mutual inductance per phase [H]

R is the resistance per phase in bldc motor [Ω]

V_{an} , V_{bn} and V_{cn} are the phase voltage [V]

i_a, i_b and i_c are motor input current [A]

e_a, e_b and e_c are motor back -EMF [V].

Since the rotor is not having any winding it will not having any equations the stator will have 3 equations which can be written in the form of matrix.

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \text{P} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

Where $L_{aa} = L_{bb} = L_{cc} = L$
And

$$L_{ab} = L_{ba} = L_{ac} = L_{ca} = L_{bc} = L_{cb} = M, H$$

Substituting these L&M in main coupling circuit equations

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = R_s \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} + \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix}$$

Under balanced condition the currents in the stator is

$$i_{as} + i_{bs} + i_{cs} = 0$$

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} R_s & 0 & 0 \\ 0 & R_s & 0 \\ 0 & 0 & R_s \end{bmatrix} \begin{bmatrix} i_{as} \\ i_{bs} \\ i_{cs} \end{bmatrix} +$$

$$\begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} P \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_{as} \\ e_{bs} \\ e_{cs} \end{bmatrix}$$

It shows that voltage equation of the phase is similar to the voltage equation of armature of DC machine and reflects to a dc machine having no brushes and mechanical commutator are the root cause for the name of permanent magnet dc machine.
The magnitude of developed electromagnetic torque is given as

$$T_e = [e_{as} i_{as} + e_{bs} i_{bs} + e_{cs} i_{cs}] \frac{1}{w_m} (N.m)$$

The induced emfs of the rotor in the bldc motor is given by

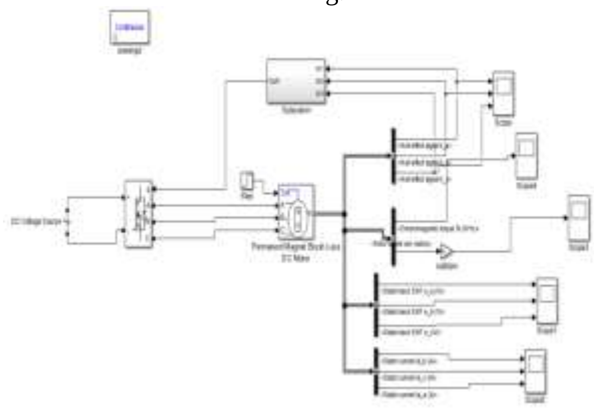
$$e_{as} = f_{as}(\theta_r)\lambda_p w_m$$
$$e_{bs} = f_{bs}(\theta_r)\lambda_p w_m$$
$$e_{cs} = f_{cs}(\theta_r)\lambda_p w_m$$

Where the functions $f_{as}(\theta_r)$, $f_{bs}(\theta_r)$, $f_{cs}(\theta_r)$ have the same shape as e_{as}, e_{bs}, e_{cs}.

IV. Simulation Results

Without controller:

In bldc motor the actual position of the rotor can be sensed by using hall sensors. Therefore the actual position of the signals is feed to the inverter. In inverter through proper switching sequence bldc motor can be controlled the basic block of bldc motor as shown below fig.1



In this without any controller the obtained outputs are ,speed and torque back emf of an BLDC motor as shown below.

Fig.2 Hall signals of a BLDC motor drive without any controller

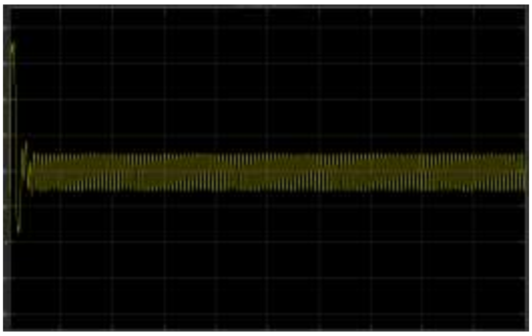


Fig.3 Torque of an BLDC motor drive without any controller

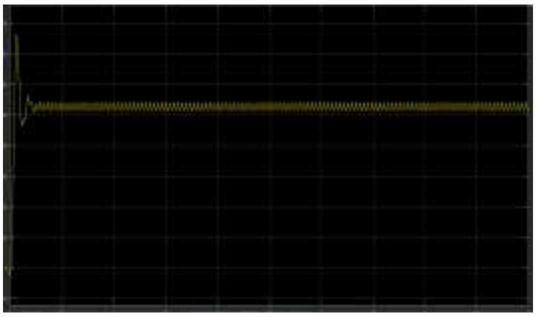


Fig.2 Speed response of a BLDC motor drive without any controller

With current controller:

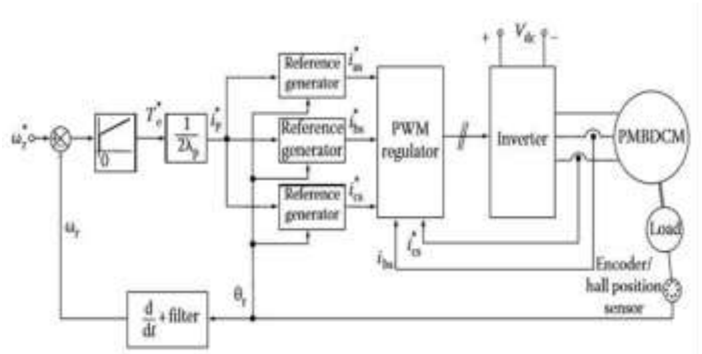


Fig.9 Hysteresis current controller

It is desirable to provide current limitation and fast dynamic control of many electrical applications. A simple method that offers these requirements is the use of Torque Hysteresis controller (THC) technique. The control of torque can be established by controlling the three phase current at its reference current provided by the speed controller. The motor currentsneed to be controlled satisfying to their references (Ia*, Ib*, Ic*).From the above block diagram, the rotor speed is compared to its reference and the rotor speed error is amplified through the speed controller. The output of the speed controller provides the reference torque Te*.Thecurrent magnitude command Ip*is obtained from the torque expression.

The obtained outputs of current control technic are speed,torque,stator currents are as shown below

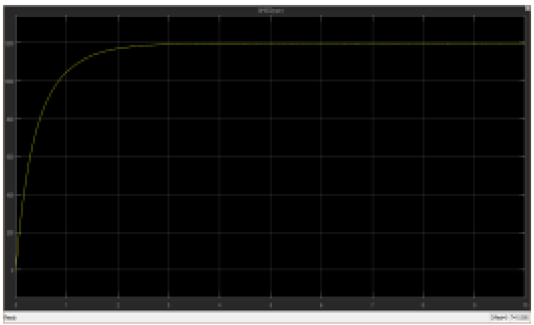


Fig.6 Speed response of a back emf control technique

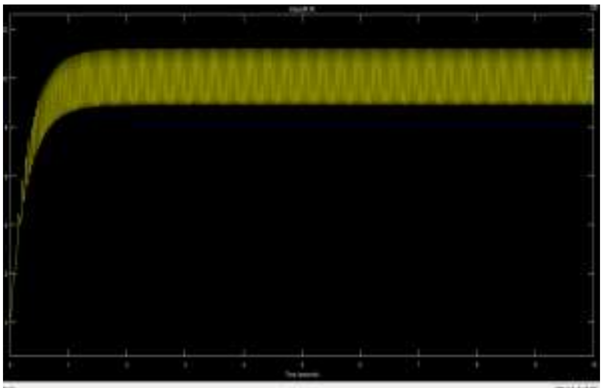


Fig.7 Torque of a Bldc motor drive with current controller

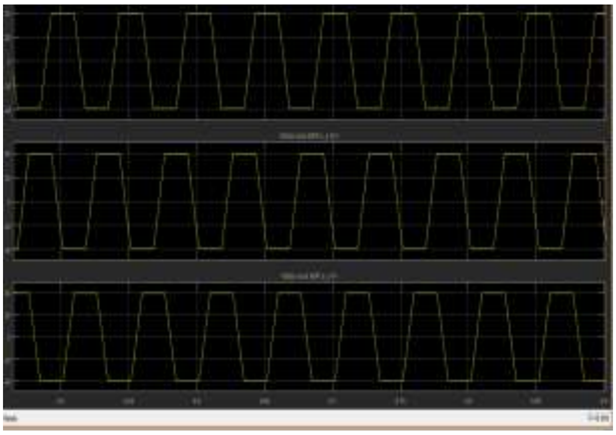


Fig.8 back emf of a bldc motor drve with current controller

V. Conclusion

In above simulations results we observed that Back EMF controller and their performance in comparison to the without controller is obtained. In this the man aim was to make a model that would be simple, accurate, and easy to modify and fast running. It is believed that these goals have been reached. Based on the application we have to choose the controller which give satisfactory performance. From this Back EMF current controller Torque and speed responses was implemented using sensor less controlled strategies.

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