ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
Vol 4, Issue 3, March 2018

Comparative Analysis of BLDC Motor and Induction Motor using MATLAB/Simulink

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***Abstract*: -- This paper proposes a comparative analysis of the performance of BLDC motor and induction motor. The BLDC motor can act as an alternative for traditional motors like Brushed DC motor, induction motor, switched reluctance motors etc. Due to over-weighing merits of the BLDC motor, modeling is done in order to enhance the performance of the system. The torque characteristic of BLDC motor plays a very important factor in the design of BLDC motor drive system, so it is necessary to predict the precise value of torque, which is determined by the waveform of back EMF. After the development of the simple mathematical model of the three-phase BLDC motor with trapezoidal waveforms of back EMF, the motor is simulated in the MATLAB/Simulink environment. Based on the analysis, a comparative study of the result of both the motors is presented in Graphical User Interface of MATLAB environment.**

***Index Terms* – BLDC motor, induction motor, motor equation, back emf, simulation of motor.**

I. INTRODUCTION

Induction motor are most widely used motor drive in the industry and BLDC motor also rapidly gaining popularity due to its utilization in various industries. The Brushless DC Current motor have been used in various industries, such as Appliances, Automotive, Aerospace, Medical, consumer, Induction Automation Equipment and Instrumentation. As the name implies, the BLDC motor do not use brushes for commutation process instead, they are electronically commutated.
The BLDC motors have many advantages over brushed DC motors and induction motor. A few of these are:

- Better speed verses torque characteristics
- High dynamic response
- High efficiency
- Long operating life
- Higher speed ranges
- Noiseless operation

The torque of the BLDC motor is mainly influenced by the waveform of back-EMF (the voltage induced into the stator winding due to rotor movement). The ratio of torque delivered to the size of the motor is higher, making it useful in applications where space and weight are critical factors.
Ideally, the BLDC motors have trapezoidal back-EMF waveforms and are fed with rectangular stator currents, give a theoretically constant torque. In practice, torque ripple exists, mainly due to back emf waveform imperfections, current ripple and phase current commutation. Electronic commutation technique and permanent magnet rotor cause BLDC to have immediate advantages over traditional motor like brushed DC motor and induction motor in electric vehicle application. BLDC has more difficult control algorithm compare to other motors such as Brushed dc motor, induction motor, due to electronically commutation. Therefore accurate model of motor is required to have complete and precise control scheme of BLDC motor. To design BLDC motor drive system, it is necessary to have motor model gives precise value of torque which is related to current and back-EMF. Induction motors are the most widely used motors in industry because of its simple and robust construction and other advantages such as reliable operation, low initial cost, easy operation and simple maintenance, high efficiency and having simple control gear for starting and speed control.

II. COMPARISON OF BLDC AND INDUCTION MOTOR

Ac motors are classified as synchronous motor and asynchronous motor. They are also classified based upon the flux density distribution , current excitation, etc.
BLDC motor has rectangular shaped flux density, current variation and back EMF while the induction motor has sinusoidal current variation, flux density and back EMF.

Property	BLDC Motor	Induction Motor
Phase current excitation	Trapezoidal	Sinusoidal
Flux density	Square	Sinusoidal
Phase back EMF	Trapezoidal	Sinusoidal
Power and Torque	Constant	Constant

III. BLDC MOTOR MODEL

In this paper, 3 phases, 4 poles, star connected trapezoidal back-EMF type BLDC motor is modeled. Trapezoidal back-

EMF is referring that mutual inductance between stator and rotor of a motor has trapezoidal shape. Therefore abc phase variable model is more applicable than d-q axis. With the intention of simplifying equations and overall model the following assumptions are made:

- Magnetic circuit saturation is ignored.
- Stator resistance, self and mutual inductance of all phases are equal and constant.
- Hysteresis and eddy current losses are eliminated.
- All semiconductor switches are ideal.

The electrical and mechanical mathematical equations of BLDC motor:

$$V_a = Ri_a + (L - M)\frac{di_a}{dt} + E_a \qquad (1)$$

$$V_b = Ri_b + (L - M)\frac{di_b}{dt} + E_b \qquad (2)$$

$$V_c = Ri_c + (L - M)\frac{di_c}{dt} + E_c \qquad (3)$$

$$E_a = K_e\,\omega_m\,F(\theta_e)$$

$$E_b = K_e\,\omega_m\,F\left(\theta_e - \frac{2\pi}{3}\right) \qquad (4) \qquad E_c = K_e\,\omega_m\,F\left(\theta_e + \frac{2\pi}{3}\right)$$

$$T_b = K_t\, i_b\, F\left(\theta_e - \frac{2\pi}{3}\right) \qquad (5)$$

$$T_c = K_t\, i_c\, F\left(\theta_e + \frac{2\pi}{3}\right)$$

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

$$T_e - T_l = J\frac{d^2\theta m}{dt^2} + \beta\,\frac{d\theta m}{dt}$$

$$\theta_e = \frac{p}{2}\,\theta_m \qquad (7)$$

$$\omega = \frac{d\theta m}{dt} \qquad (8)$$

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 : K_{th} phase back emf
T_k :Electric torque produced by k_{th} phase
T_e :Electric torque produced by BLDC
$F(\Theta_e)$:Back - EMF reference as function of rotor position
Θ_e:Electrical angle of rotor
Θ_m:Mechanical angle of rotor
ω_m :Angular speed of rotor
K_t :Torque constant
K_e :Back EMF constant

Hence it is assumed that back-EMF signals have 120 degree phase shift with respect to each other and phase zones are distributed symmetrically to different phase windings. For convenient implementation of equation in MATLAB / SIMULINK, most of references are used state space equations. Hence most of motor manufacturers do not wire motor neural point, phase to phase voltage equations are used like in [9]. State space form of equations (1), (2), (3) and (7) can be derive as:

$$V_{ab} = R(i_a - i_b) + (L - M)\frac{d}{dt}(i_a - i_b) + E_{ab} \qquad (10)$$

$$V_{bc} = R(i_b - i_c) + (L - M)\frac{d}{dt}(i_b - i_c) + E_{bc} \qquad (11)$$

Where $i_a + i_b + i_c$, therefore after modifying equations (10) and (11) and neglecting mutual inductance,

$$\frac{di_a}{dt} = -\frac{R}{L}i_a + \frac{2}{3L}(V_{ab} - E_{ab}) + \frac{1}{3L}(V_{bc} - E_{bc}) \qquad (12)$$

$$\frac{di_b}{dt} = -\frac{R}{L}i_b - \frac{1}{3L}(V_{ab} - E_{ab}) + \frac{1}{3L}(V_{bc} - E_{bc}) \qquad (13)$$

Then the state space modal of BLDC motor is :

$$\begin{bmatrix} \dot{i_a} \\ \dot{i_b} \\ \dot{\omega_m} \end{bmatrix} = \begin{bmatrix} -\frac{R}{L} & 0 & 0 \\ 0 & -\frac{R}{L} & 0 \\ 0 & 0 & -\frac{R}{L} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ \omega_m \end{bmatrix} + \begin{bmatrix} \frac{2}{3L} & \frac{1}{3L} & 0 \\ -\frac{1}{3L} & \frac{1}{3L} & 0 \\ 0 & 0 & \frac{1}{J} \end{bmatrix} \begin{bmatrix} V_{ab} - E_{ab} \\ V_{bc} - E_{bc} \\ T_e - T_l \end{bmatrix} \qquad \ldots\ldots\ldots.(14)$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \\ \omega_m \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -1 & -1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ \omega_m \end{bmatrix} \qquad (15)$$

Implementing of final state space equations (14) and (15) will make model more difficult. Although neutral point of motor is not accessible but almost it is possible to estimate it with zero crossing point of back-EMF. Also for linear an zero initial condition systems, State space to Laplace transform and vice

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ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)
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versa can be written. Therefore final state space equation is divided to two simple and separate electrical and mechanical Laplace equations applied by phase to neutral voltages. It makes the BLDC model more simple and convenient for understanding and various control techniques implementation.

IV. SIMULINK MODEL

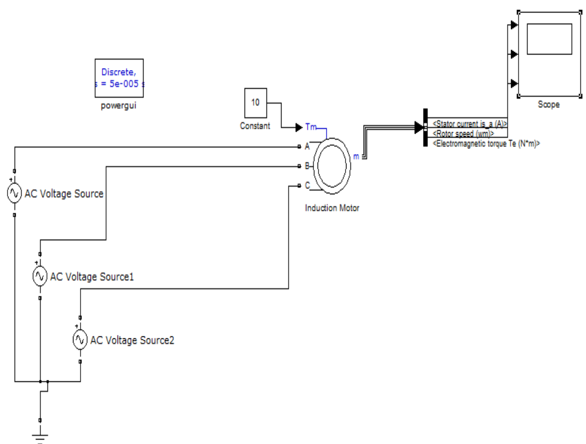

Fig:1 Induction motor model

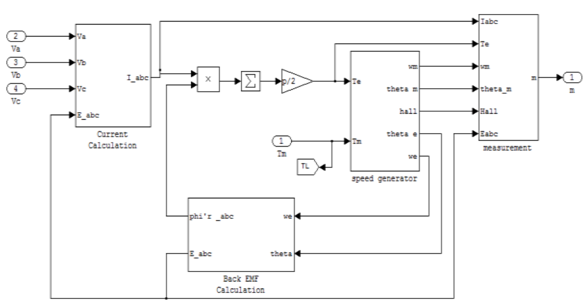

Fig:2 BLDC Motor Model

V.SIMULATION RESULT

TABLE I BLDC MOTOR SPECIFICATION

Description	Value	UNIT
Power	5	hp
DC voltage	220	volt
Phase resistance (R)	1.43	ohm
Phase inductance (L)	9.4e-3	H
Inertia(J)	1.5e-3	Kg/m
Damping ratio	2e-3	
Poles	4	

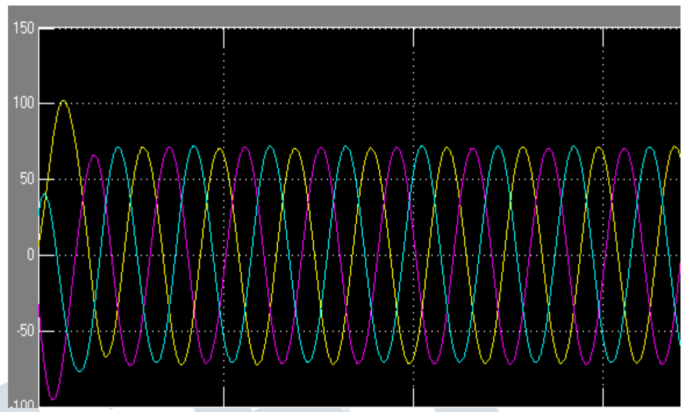

Fig :3 Stator Current Of BLDC Motor

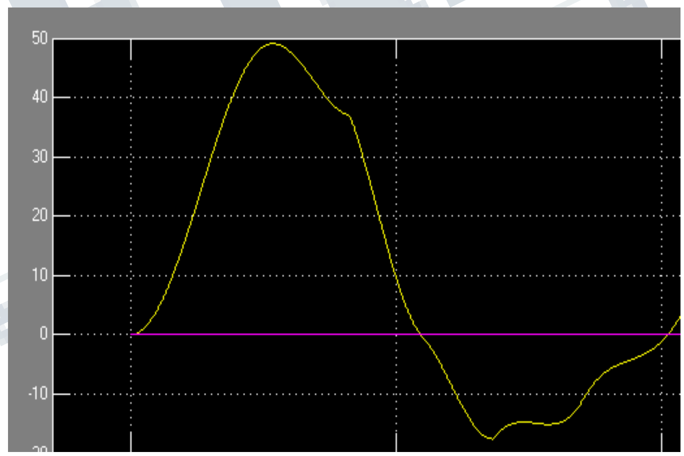

Fig :4 Torque of bldc motor

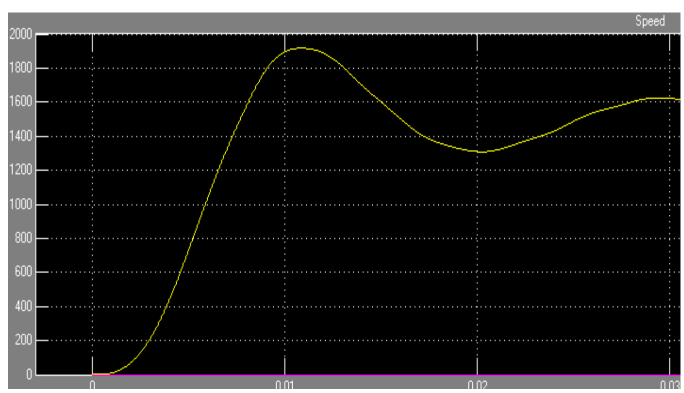

Fig:5 Speed of bldc motor

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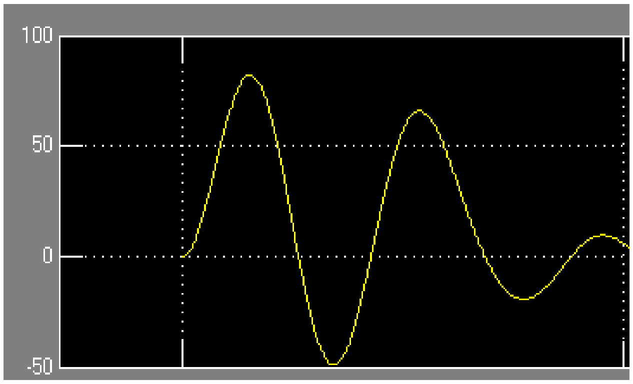

Fig :6 Current of induction motor

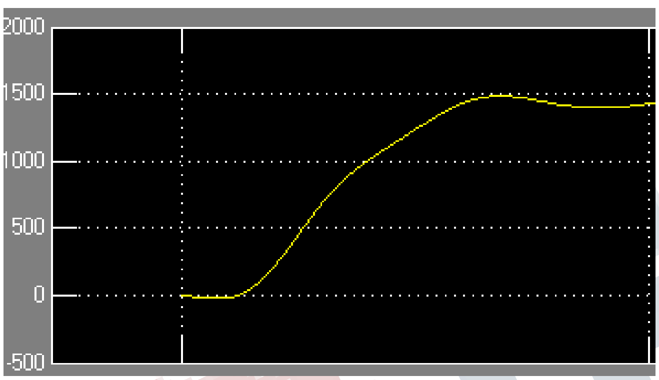

Fig 7: Speed of induction motor

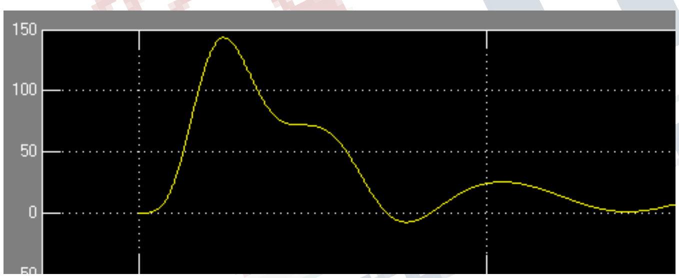

Fig : 8 Torque of induction motor

VI. EDUCATIONAL USE OF MODELS

The entire set of electrical machines virtual models developed in MATLAB/SIMULINK Environment have been successfully integrated in electric machinery courses, they helps for easier understanding operation principle and after performing virtual experiments the student enter the laboratory to work on real devices.

VII. CONCLUSION

Different performance aspect of both BLDC and induction motor have been seen and it is clear that permanent-magnet brushless dc motors is more accepted used in high-performance applications because of their higher efficiency, higher torque in low-speed range, high power density, dynamic response, low Maintenance and less noise than induction motors. The only disadvantage of it is that BLDC motor is costlier than induction motor. In this paper BLDC motor mathematical model is developed. Finally the performance of BLDC motor is analyzed by using Matlab/Simulink and simulation results are presented. The torque characteristics of BLDC motor plays a very important factor in design of the BLDC motor drive system.. All the simulation results are of theoretical aspect and can be utilized for practical implementation of motors.

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