International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-8 Issue-5, March 2019

Analysis of Recent developments in Brushless DC motors controlling techniques

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Abstract: ***BLDC motors are the latest option for research people due to their inherent features like high efficiency, constant flux density low maintenance requirements there by it acquire greater reliability. These motors are best suited for many applications, but it needs developments in sensorless control methods to overcome the draw backs of the sensor-based techniques. Within the available control strategies, the flux linkage function-based control strategy is certainly appropriate for BLDC motor even at low-speed range. This paper presents working and behavior of BLDC motor with various controlling techniques with closed loop operation, the function of sensors and its importance, different sensor based and sensorless control techniques were discussed. The modeling of BLDC machine done under MATLAB environment. Closed loop operation of BLDC drive using PI controller helped to analyze the dynamic behavior of drive.***

Index Terms:Permanent magnet brushless DC motor (PMBLDCM), hall sensors, shaft-encoders, zero crossing back electromotive force (EMF), flux linkage based sensorless technique.

I. INTRODUCTION

Over the Decades, there is a rapid development in using of power Electronic switches, control strategies and special machines. The initial era of time, DC drives played a vital role in industrial applications later AC drives were coming to force. As compared to DC drives, AC drives didn't have smooth and flexible controlling techniques. [1] The bulkiness of Dc machines, availability of AC power made the application of dc machines to limited areas. later industry concentrated on effective, smooth speed controlling of drives there the special machines like PMSM, BLDC, SRM are introduced. Today over the 90% of applications are adopted these special machines only. growth of variable speed PM drives brings the great revolution in this category. Since, PM drives are very compact in nature and it's controlling strategy is easy when compared to conventional drives [2]. The overall speed controlling of PM drives is provided on primary side through power electronic switches in order to minimize the rotor side losses. In the year 1950, The adoption of permanent magnets in place of electromagnets brought tremendous changes in machines design.PM machines became compact by eliminating bulky rotor winding, external energy source. In synchronous machines, the field excitation on the rotor side is replaced by permanent magnets excitation. on other side PMSM and PMBLDC have many resemblances. Both have permanent magnets on their rotors and involve stator currents to produce persistent torque. The modification in these two machines is that PMSM develops sinusoidal Back EMF and PMBLDCM develops trapezoidal back emf. BLDC motor can produce 15% more torque than PM synchronous motor with the same frame size by considering the core losses are equal and the complete analysis is given in [3]. Based on the constructional design of rotor, BLDC motors are categorized into two types, they are Conventional radial field and axial field motors. However, the Power density of axial field machines is high compared to radial. The detailed performance comparisons for radial and axial field were given in. Applications like robotics and aerospace actuators, it is superior to have a low weight to torque ratio as possible for given output power. The current flowing pattern in BLDCM as it is conducting for 120° and staying at zero for 60° this 60^0 (electrical degrees) time period is called non-conducting mode. During this time transitions happens therefore, it is essential to notify these instants on the periphery of the motor to commutate the currents. So that, rotor position sensing is needed for every 60° (electrical degrees); other important aspect is that, during operation only two phases conduct current at a given time the and Third phase goes into isolation. On the other hand, PMSM needs sinusoidal currents, the magnitudes of these currents rely the instant rotor position. For PMSM a high-resolution rotor position transducer is essential where as a low position transducer is enough for PMBLDCM. This makes the PMBLDC superior than PMSM drives. BLDC motor consists of 3-ϕ concentric form of winding on stator and permanent magnets on rotor. A BLDC motor is conventionally operated by 3-ϕ full bridge inverter engaging a 2-ϕ conduction method. This motor doesn't experience a "slip'' which is typically seen in Induction motors [4]. They are wound with concentrated non-overlapped stator windings fractional pitched in space. which results in high efficiency and torque density in motors. The air gap in these motors equals the summation of actual air gap length and permanent magnets radial thickness which says that small armature field reaction, and subsequently small stator winding Inductance [5]. The assortment of the magnet explained in [6], the choice slot-fragmentary, winding laying procedure and the arranging of a magnetic position discussed in [7].

Manuscript published on 30 March 2019.
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To detect the rotor position information even at low speed range, hysteresis characteristics of the stator iron at standstill is also one of the sensorless control techniques explained in [8]

II. WORKING PRINCIPLE

In BLDC motor the most commonly used sensors are hall sensors and optical encoders. The Electronic commutation in the BLDC motor is achieved using smart 3 Hall Effect sensors which detects the rotor position and feedback this signal for switching the inverter [9]. These three sensors outputs are digital in nature. Each one detects when it comes under north or south pole, there by sending HIGH or LOW signal respectively. Table 1 indicates the six states of hall sensors with the equivalent inverter switches Fig.1 shows the basic block diagram, fig.2 shows simulation diagram of 3-phase BLDC drive [10].

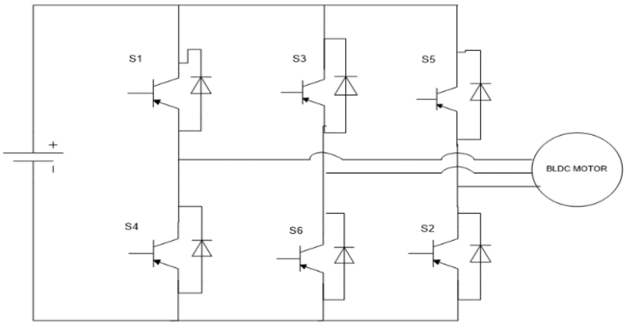

Fig.1 Block Diagram of 3-Phase BLDC motor

TABLE 1
SIX STATES OF SMART HALL EFFECT SENSORS

State No	Hall sensor A	Hall sensor B	Hall sensor C	Switches to be on	The active lines of the stator winding
I	1	0	0	S_1,S_4	RY
II	1	1	0	S_1,S_6	RB
III	0	1	0	S_3,S_6	YB
IV	0	1	1	S_3,S_2	YR
V	0	0	1	S_5,S_3	BR
VI	1	0	1	S_5,S_4	BY

In sensor-based control method, these hall sensors are driven by Digital motor control kit. In this method, The PWM applied on top switches (S_1,S_3,S_5) and bottom (s_4,s_2,s_6)switches. The PWM duty period (δ) controls the quantity of current to the digital controller. The modeling equations of BLDC motor are derived in equations [1-8 and 15].

III. III.MODELLING OF BLDC MOTOR

Stator phase voltages

$$V_a = RI_a + L\frac{di_a}{dt} + E_a \qquad (1a)$$

$$V_b = RI_b + L\frac{di_b}{dt} + E_b \qquad (1b)$$

$$V_c = RI_c + L\frac{di_c}{dt} + E_c \qquad (1c)$$

Three phases back EMF's

$$E_a = K_e f(\theta_a)\omega \qquad (2a)$$

$$E_b = K_e f(\theta_b)\omega \qquad (2b)$$

$$E_c = K_e f(\theta_c)\omega \qquad (2c)$$

Line voltages

$$V_{ac} = R(I_a - I_c) + L\frac{d}{dt}(I_a - I_c) + E_{ac} \qquad (3a)$$

$$V_{cb} = R(I_c - I_b) + L\frac{d}{dt}(I_c - I_b) + E_{cb} \qquad (3b)$$

By solving equations 3a,3b. Phase currents becomes

$$i_a = \int (\frac{1}{L_s}V_{ac} + \frac{1}{3L_s}V_{cb} - \frac{1}{L_s}i_a R - \frac{2}{3L_s}E_{ac} - \frac{1}{3L_s}E_{cb}) \quad --- (4a)$$

$$i_b = \int (-\frac{1}{3L_s}V_{ac} - \frac{2}{3L_s}V_{cb} - \frac{1}{L_s}i_b R + \frac{1}{3L_s}E_{ac} + \frac{2}{3L_s}E_{cb}) \quad --- \quad (4b)$$

In a balanced three phase circuit

$$I_a + I_b + I_C = 0$$
$$i_c = -(i_a + i_b)$$

Electromagnetic torque

$$T_e = k_t[(f(\theta_a)I_a) + (f(\theta_b)I_b) + (f(\theta_c)I_c)] \qquad (5)$$

Rotor speed

$$\omega_r = \frac{T_e - T_L}{Js + B} \qquad (6)$$

Back EMF

$$E = \int k_b \omega \quad (7)$$

Flux linkages

$$\varphi = \int E_b \qquad (8)$$

Mechanical equation:

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$$J\frac{d\omega_m}{dt} + B\omega_m = T_e - T_L \qquad (9)$$

IV. IV.DRAWBACKS OFSENSOR-BASED TECHNIQUES

The sensor-based BLDC motor has many complications like it needs a special placement for mounting the sensors [11] and they are temperature susceptible which results the errors in position detection of rotor. The cost of the system also increases due to usage of sensors [12]. So, it isn't always preferable to use the position sensors for all applications. Where reliability is the most important parameter sometimes a sensor failure may also reason for instability [13].

V. V.REVIEW ON SENSORLESS TECHNIQUES OF BLDC MOTOR

Sensorless speed control of BLDC motor has been a research area for the last several years. Many authors and patents were published on this topic discussed in [14]. Some of the important methods published in literature are discussing here. The trapezoidal back-EMF Zero crossing,Back-EMF integration method, Freewheeling Diode Conduction method, Flux estimation methods are categorized under sensorless controlling methods. All these methods work based on speed of the drive except flux linkage based. Hence this method has more accurate method to find the position of rotor even at low speeds.

5.1. BACK EMF DETECTION METHODS:

Speed control of BLDC motor can be explained in two ways: (i) Direct back-EMF detection (ii) Indirect back-Emf detection. To understand the direct back-EMF sensing strategy, machines needs a neutral point [15]. The unpowered phase back-EMF will be sensed and compared with neutral point voltage. There is a difficulty included in this method i.e., speed range is not much wide Here, The zero crossing of isolated back emf phase detection is easy method and it depends on tracking the point quickly at which the back-EMF in floating phase while crossing zero [16]. Meanwhile, the phase whose BEMF voltage is stated to be the neutral point of the motor, is not typically accessible. So, by creating virtual neutral point we can access the back EMF raised through to neutral point .The draw back with this technique is low signal/noise ratio at low speed, because the amplitude of BEMF is directly proportional to speed of the machine and there is one more problem comes into existence i.e., we have to use low pass filter to create phase delay for zero crossing point of the back EMF ,it leads to too much phase delay when motor rotate at high speeds. So, this virtual neutral point method is applicable for narrow speed range only. we can access the back EMF voltage(E) w.r.t ground can be obtained directly from motor terminal voltages [17].

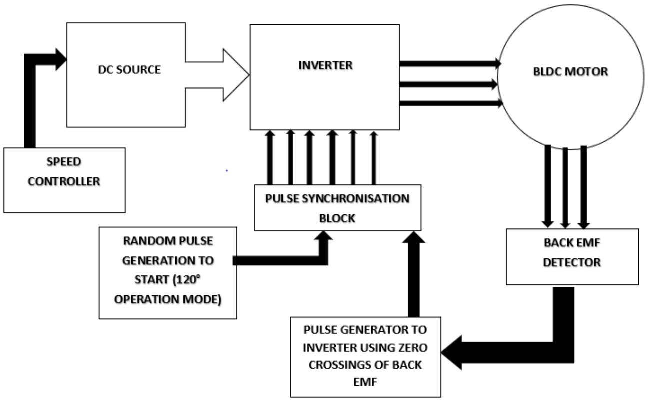

Fig.3. Block diagram of Zero Crossing of back emf sensorless control method

5.2 TERMINAL VOLTAGE SENSING:

BLDC motor consists of trapezoidal distribution of flux density in air gap, and thus trapezoidal shaped back-EMF will generate. By monitoring the specific phase current zero (the silent phase), we must detect zero crossing instants and decode it with appropriate time shift to get switching patterns. While starting, the motor's back EMF is zero. Since, the back EMF of motor is directly proportional to speed, it is not possible to sense the terminal voltage at that low speeds. The average terminal voltage gets increases while the motor speed gets increase parallelly the excitation frequency also increases; this whole function introduces a speed independent delay in switching instants. It leads to the misalignment of back emf voltage and current which causes an error to switching patterns. Normally it happens at higher speeds. This is the major drawback of terminal voltage sensing method.

5.3 BACK-EMF INTEGRATION METHOD:

In back EMF integration, the position information of rotor is obtained by integrating the back-EMF of the unexcited phase. During working of machine, the Integration of back EMF starts and stops at threshold value which resembles to commutation instant. As the trapezoidal back EMF's transition changes linearly from positive to negative and the slope is assumed to be speed insensitive. While the integrated value met the threshold voltage, a reset signal is injected to get zero integrators output and the commutation is going to be done at this time. When compared to back EMF zero crossing detection technique, back EMF Integration is not much sensitive to noise it may introduce the offset voltage problems. This method is effective at low speeds and at high speeds its operation is poor. [18]

5.4. FREEWHEELING DIODE CONDUCTION METHOD:

Freewheeling diode conduction is type of Indirect sensing of zero crossing to get the switching sequence for continuous operation of BLDC motor . In BLDC, one of the phases is open circuited. After a particular phase gets open circuited, a phase current flows through the freewheeling diode for a very short period. The current flowing in the diode becomes zero at the mid part of commutation interval i.e.

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where back EMF crosses zero. So, using the freewheeling diode current sensing we can detect the rotor position. But the isadvantage of this method is we need to setup six isolated power supplies to protect the comparator circuitry while sensing the current position at six freewheeling diodes. But this technique performs better when compared to above techniques.

5.5 FLUX ESTIMATION METHOD:

There are many sensorless control methods has been proposed till now but few of them can work well at low speed range [19]. This paper presenting a novel sensorless strategy which predicts the stator position at every instant of time with more accuracy[20][21]. The basic idea of flux estimation technique is the estimation of flux linkage values by integrating the voltage and current magnitudes throughout a complete rotation [when compared to back-Emf detection method the flux linkage-based method works on speed independent variables. So, this method gives rotor position consistently. DC kick start method is used for initial starting of the drive .after alignment of any two phases the drive continue with the flux linkage based switching sequence. The algorithm was explained in table 2 .the modeling equations are explained in equations [9 to 12].fig.4 shows the block diagram of sensorless controlling method.

For flux linkage based algorithm

$$E \propto \frac{d\varphi}{dt} \qquad (9)$$

Where

$$E = V - I_a R_a - L\frac{di_a}{dt} \quad (10)$$

$$\frac{d\varphi}{dt} = V - I_a R_a - L\frac{di_a}{dt} \qquad (11)$$

$$\varphi = \int (V - I_a R_a - L\frac{di_a}{dt} \qquad (12)$$

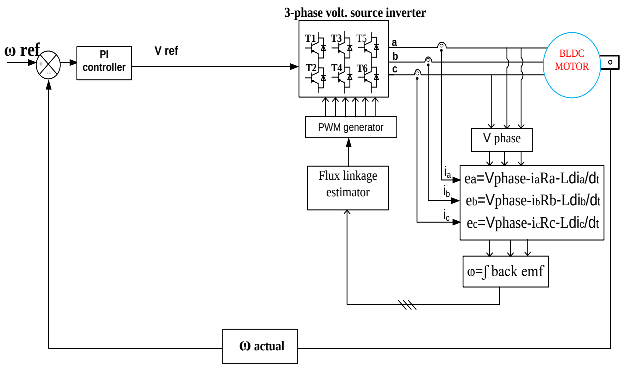

Fig.4 Block diagram of flux linkage-based algorithm

ψ_a	ψ_b	ψ_c	S1	S2	S3	S4	S5	S6	E1	E2	E3
+Ve	-Ve	+Ve	1	0	0	0	0	1	1	0	-1
+Ve	-Ve	-Ve	0	0	1	0	0	1	0	1	-1
+Ve	+Ve	-Ve	0	1	1	0	0	0	-1	1	0
-Ve	+Ve	-Ve	0	1	0	0	1	0	-1	0	1
-Ve	+Ve	+Ve	0	0	1	1	0	0	0	-1	1
-Ve	-Ve	+Ve	1	0	0	1	0	0	1	-1	0

Table.2. Flux linkage-based algorithm

VI. RESULTS

The simulation diagrams of Speed (ω) shown in fig.5.where step change of reference speed has been taken to find the performance of drive. a three-phase quasi squared wave forms are shown in fig.7. the torque developed in the machine are shown in fig.6. Three phase flux linkages are shown in fig.8.

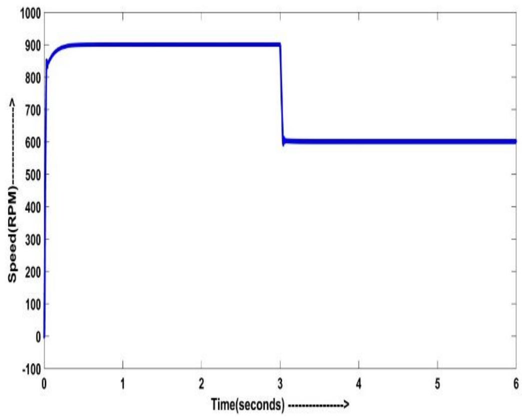

Fig.5.simulation wave form of speed in (rpm)

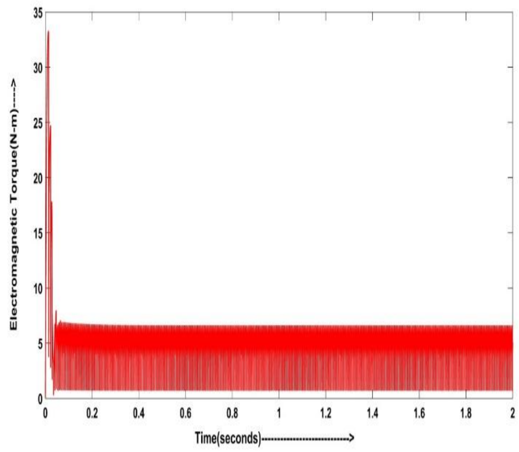

Fig.6.simulation wave form of Torque in (N-m)

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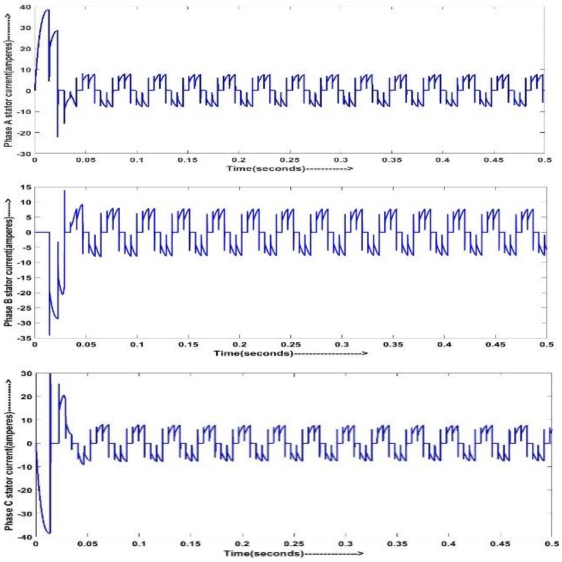

Fig.7.simulation wave form of 3-phase currents in (amp)

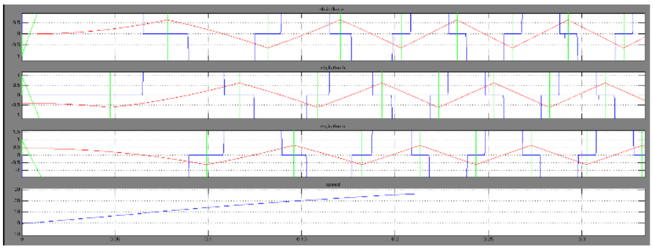

fig.8. Three phase flux linkage-based wave forms

VII. CONCLUSION

BLDC motor usage made tremendous revolution in industrial and commercial applications in these days. The electronically controlled bldc drives has the complete command over the switching states of inverter which could give a smooth and accurate voltage control there by the speed of the drive too. As research goes on increased there are various controlling techniques were adopted based on application of drive. To avoid the usage of hall sensors industry adopted the sensorless controlling techniques. Similarly, to overcome the speed dependent back-emf based sensorless technique, the flux linkage based sensorless technique is developed. The last section proposing the flux estimated algorithm which has less assumptions and less complexity.

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