A Review: Sensorless Control of Brushless DC Motor

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Abstact:

Having known the negative consequences of global warming so many efforts are being implemented in various areas. The diesel engine being one of the substantial causes of global warming, efforts are being made to replace it. This becomes the reason for the evolution of electric driven vehicles. Electric driven vehicles use high efficient motors. In order to use electric motors in electric vehicles their performance should be controlled. To avoid the use of these sensors we can adopt many senseless schemes for the control of motor. Here in this paper we are studying three techniques which are 1) Direct EMF detection scheme, 2) Phase current sensing Scheme and 3) Detection of conducting interval of freewheeling diode, through which we can control the motor without applying a hall sensor. Because the hall sensor is suitable only for high temperature environment and it loses its sensing capability at temperature above 120 degrees.

II. Direct Back EMF Sensing

In direct back EMF sensing method the phase back EMF voltage is referred to, the neutral point of the motor. The methods which are generally used for the direct back EMF sensing reconstruct the neutral voltage information because of the unavailability of centre point of the motor. Figure 1 shows the circuit for direct EMF detection which is based on virtual neutral point. For the proper processing of signals low pass filters and detection dividers are necessary to be used. The phase back EMF voltage is referred to neutral point of the motor. Since the center point of In this scheme the function of low pass filter is to provide a phase delay for phase back EMF's zero crossing [3], [4], [11-13]. There are following limitations with the direct back EMF sensing scheme:

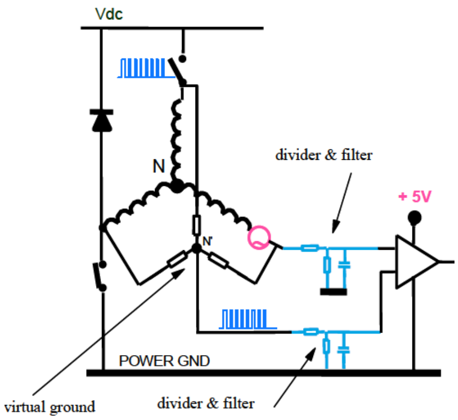


Figure1: Back EMF sensing based on virtual neutral point

1) Since the amplitude of the back EMF is directly proportional to the speed of the motor, the signal/noise ratio is low at lower speeds. 2) A large phase delays is introduced by the low pass filter at higher speeds.

In this way the direct back EMF methodology can be used only for a specified range of speed which is very narrow.For the proper working of this scheme appropriate PWM technology must be implemented. If the selection of PWM strategy is appropriate the back EMF voltage, referred to the ground will be obtained directly from the terminal voltage of the motor. At any instant of time the excitation is given only to two of the three phases. The third phase is left floating. This arrangement can be made in three different ways:

-On the high side- In this case the only on the high side switch PWM is being applied and the low side is kept on during the completion of the step.

-On the low side- In this case the only on the low side switch PWM is being applied and the high side is kept on during the completion of the step.

-On both sides-In this case the switches on the high side and low side are switched On/off simultaneously.

In our analysis we have considered the first case i.e. PWM is applies on the high side switch [2], [3]. Figure 2 shows a circuit to conduct the analysis. For a specified step we have considered that phase A and phase B are energized and phase C is floating. The current will be conducted by phase A and phase B. The PWM is applied to the upper switch of phase A and the lower switch will be kept on during the complete step. The measurement of terminal voltage Vc is done. As the upper switch of the phase A is turned on by the application of PWM, the flow of current starts through the switch to winding A and B. The freewheeling action takes place when the upper transistor of the half bridge is turned off. The current freewheels through the diode which is paralleled with the bottom switch of phase A. During this freewheeling period, there is no current in phase C, at this moment the terminal voltage Vc is detected as Phase C back EMF .

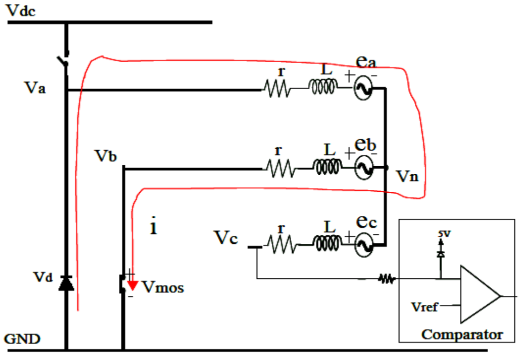


Figure2: Back EMF detection during the PWM off time moment

From the above circuit, we have $V_c = e_c + v_n$, where Vc is the terminal voltage of the floating phase C, ec is the phase back EMF and Vn is the neutral voltage of the motor. From phase A, if we ignore the forward voltage drop of the diode, we get

$$v_n = 0 - ri - L\frac{di}{dt} - e_a \qquad (1)$$

From phase B, if we ignore the voltage drop on the switch, we get

$$v_n = ri + L\frac{di}{dt} - e_b \qquad (2)$$

Adding (2.1) and (2.2), we get

$$v_n = \frac{e_a + e_b}{2} \qquad (3)$$

Assuming it to be balance three-phase system, we have

$$e_a + e_b + e_c = 0 \qquad (4)$$

From (3) and (4),

$$v_n = \frac{e_c}{2} \qquad 5)$$

So, the terminal voltage Vc,

$$v_c = e_c + v_n = \frac{3}{2}\, e_c \qquad (6)$$

On observing above equations we can infer that terminal voltage of phase C which is the floating phase is directly proportional to the back EMF during the freewheeling period i.e. during the off-time of the PWM. Also there is no superimposed switching noise The important point to keep in mind is that the instead of floating neutral point terminal voltage is referred to ground. So the information regarding the neutral point voltage not required for the detection of the zero crossing of the back EMF. The phase back EMF zero crossing is very precisely detected because the actual back EMF is being extracted from the motor terminal voltage. From the above study of the direct EMF sensing techniques we can infer that this technique has several advantages, which are as follows: 1) The back EMF zero crossing can be very precisely detected without the low pass filtering and voltage dividing. 2) In this technique of sensing scaling of voltage is needed regardless of whether high volage or low voltage system is being used. 3) The precise detection of BEMF zero crossing facilities the fast motor start-up. 4) It is Simple to be implemented and cost effective

III. Phase Current Sensing:

For the speed control of brushless dc motor the information regarding rotor position signal is required. In traditional methods of rotor position sensing the matter of concern is phase shift occurring due to variation speed. To avoid this matter of concern the phase crrent sensing scheme is being used. The detected phase current signals can be converted to near exact rotor postion signals same as hall sensor output by the signal processing unit given in fig 3 and there is no phase difference between them. In phase current sensing scheme the rotor position is detected by sensing the phase current of the motor [1], [5], [13-17]. To implement this technique the motor must first be started in order to induce current in the stator winding. The initial rotor position cannot be determined without starting the motor because there will be no induced current in the stator at standstill For starting the motor special starting techniques are used. By sending six inverter drive pulses and the brushless dc motor is started as a separately controlled synchronous motor. A substantial amount of current should available in order to detect the rotor position. To induce sufficient amount of current in the stator winding of the brushless dc motor the frequency of drive pulse is lept on accelerating by degrees until enough current is induced in the stator winding. After enough current is induced in the stator winding it is detected by phase current sensing methodology. The output processed signal of the phase-current sensing circuit is used for the controller of the brushless DC motor.

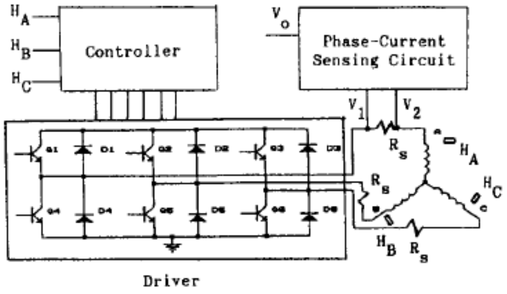
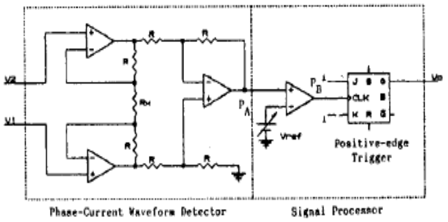


Figure3: System block diagram of brushless DC moto r with phase-current sensing circuit.



Figur4: Phase Current Sensing Circuit

For the experimental three-phase, four-pole brushless DC motor the termima1 voltage of i-th phase in steady state is

$$V_i = RI_{i+}\frac{dI_i}{dt} + \frac{K_0 w}{2}\sin(\theta - \theta_{0i})$$

Where $\theta = \frac{2\pi i}{3}$

$\theta =$ Electrical angular position of the motor,
w = electrical angular frequency,

Owing to existing of R and L in the stator winding, the phase shift variation of the terminal voltage is obtained as

$$\theta_p = \tan^{-1}\frac{wL}{R} \qquad (7)$$

From the above equation, as the brushless DC motor speed increasing, the phase-shift variations will be introduced into the terminal voltage Vi. Therefore,

the position signals sensed and processed from the terminal voltage by using low-pass filters have nonlinear phase-shift variations due to the increase in speed of the motor. The relation between induced EMF in stator coil, v, and the flux, ∅, produced by rotor magnets is:

$$v = -N\frac{d\emptyset}{dt} \qquad (8)$$

which implies :

$$V = Ns\emptyset$$
$$V = Njw\emptyset$$

This relation shows that the flux,∅, and the induced EMF, v**,** are not in-phase. For only the self-inductance of the stator windings, the relation between induced EMF, v, and the induced current, i, of the stator windings is:

$$v = L\frac{di}{dt}$$

From equation (B) and equation **(A) ,** the following equation can be obtained as :

$$N\frac{d\emptyset}{dt} = L\frac{di}{dt}$$

By finite-integrating the above equation during one period, the above equation becomes

$$N\emptyset = Li \qquad (9)$$

which reveals that both of ∅ and i are in-phase, i.e.

$$\emptyset = i \qquad (10)$$

However, in fact, the rise time of the stator winding current waveform will get affected with the values of resistor and inductance values of brushless DC motor. A fast comparator must be implemented in the phase current sensing circuitry in order to obtain the near exact rotor position signal without concerning phase-shift of brushless DC motor. Therefore just by processing the phase current waveforms near exact rotor position signals can be obtained. This phase current waveform can then be converted into the required rotor signal without any phase differences with the aid of signal processor in the phase-current sensing circuit. Moreover, the torque generated by phase i is

$$T_i = K\emptyset I_i \sin\theta \qquad (11)$$

The above equation signifies the the proper excitation of stator winding with accurate shaft position signal is required for better torque operation. Thus, the better torque operation can be obtained with the near exact rotor position signals from phase current sensing circuit.

IV. Detection of the Conducting Interval of Free-Wheeling Diodes

In this technique of rotor position detection the position of the rotor is detected based on the conducting state of the freewheeling diode. The freewheeling diodes are connected in antiparallel with the power transistors. The basis for this method of detection is that when no drive signal is applied to either to positive or negative side transistor still the current is flowing in that particular phase

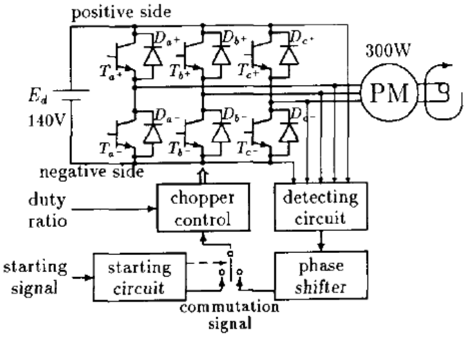
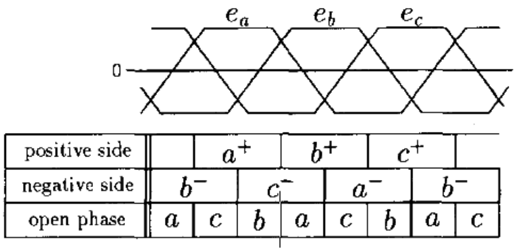


Figure5: System configuration of the proposed position sensorless drive.



positive side		a^+		b^+		c^+		
negative side	b^-		c^-		a^-		b^-	
open phase	a	c	b	a	c	b	a	c

Figur6: Relationship between drive signals and back emf

. Then this flow of current in that particular phase is due to the back EMF produced in the motor winding. The rotor positions over wide range of speed can be obtained using this method, specially at lower speed [1], [7], [17], [18] . This technique is relatively simpler

The assembly of brushless dc motor is generally including magnet synchronous motor which converts electrical energy into mechanical energy. It also consists of an inverter corresponding the commutator and brushes and a position sensor is used. The configuration circuit for this detecting scheme has been shown in figure 5. Figure 6 illustrates the output of the three phase permanent magnet synchronous motor used in figure2.5 which is trapezoidal in nature [7]. A conventional three phase voltage source inverter is used corresponding to the commutator and brushes. For the voltage source inverter 120 degree conduction mode has been used that is why only two transistors are on at a time i.e. a positive side transistor in one phase and negative side transistor in the other phase. The phase remaining is an open phase because in this phase active drive signal is not given to either of the transistor, i.e. neither positive nor positive side transistor is on. The inverter should be commutated every 60 degree with the proper commutation sequence in order to produce the maximum torque. The conducting state of the freewheeling diode which is connected in antiparallel with the power transistors is observed every 60 degees, through which the rotor position is detected

The position signal which is being detected leads the next commutation signal by an angle of 30 degree. Therefore the inverter is given the commutation signal through a phase shifter shown in fig. 5.

The rotor position signal cannot not be detected at motor standstill position because the back EMF is directly proportional to the rotor speed. Therefore for detecting the rotor position with this method it is necessary to apply suitable starting procedure. The commutation signal for starting is given by the starting circuit.

Fig. 7 shows a circuit which is specially designed to detect the conducting state of the freewheeling diode. To clamp the voltage a resistor and a diode are connected to the comparator of the detection circuit

The reference voltage applied to the comparator is slightly less than the forward voltage drop of the freewheeling . Isolated power supplies are needed for the detecting circuit. It has no influence of the dc ling voltage variation.

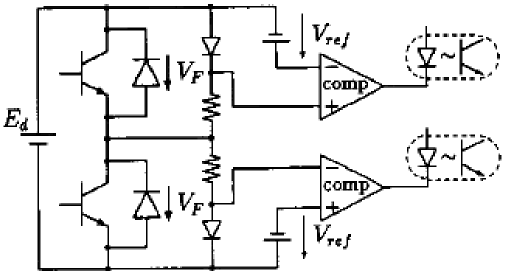


Figure7 Detecting circuit for conduction of free-wheeling diodes.

The speed of the motor can also be controlled using chopper control by adjusting the duty cycle if the one of the transistors which is in on-state is turned on and off at chopper frequency. Fig.8 Shows the waveforms of alternate chopper control.

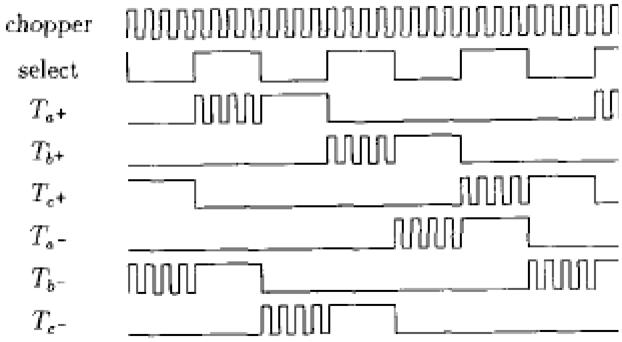


Figure8: Drive signals under alternate chopper control

Alternate chopper control is implemented in order to obtain symmetrical line currents. In this way switching losses are distributed in positive and negative side transistors.

CONCLUSION:

This paper presents a review on sensorless control schemes of a brushless dc motor. In all the three schemes the control is achieved without the use of sensor. In back EMF sensing technique the information regarding the back EMF is referred to ground without any common mode noise. That is why, this sensing scheme is immune to switching noise and suitable for high voltage, low voltage and high speed and low speed drives. The phase current sensing scheme senses near exact rotor position therefore provides better torque operation. The third scheme is based on the conduction interval of freewheeling diode which are connected in antiparallel with power transistors, this approach makes the detection possible for a wide range of speeds specially lower speeds. In this way we have compared different sensing schemes with their advantages in different ranges of speed.

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