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Indirect Back-Emf Detection Methods for Sensorless Speed and Position Control of BLDC Motors

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Abstract: Brushless DC (BLDC) motors are widely used for many industrial applications because of their high efficiency, high torque and low volume. Sensorless means fewer parts, i.e. the omission of the position sensors and auxiliary decoding circuitries. High reliability, cost reduction and compactness are main advantages of sensor less strategies. The only reliable way to utilize the BLDC machine drives in harsh environments is sensor less techniques. For sensor less control Direct back-EMF detection and Indirect back-EMF detection methods are used, in this paper we will discuss Indirect back-EMF detection methods like back-EMF Integration, Third Harmonic Voltage Integration, Free-Wheeling Diode-Conduction/Terminal Current Sensing methods, for detecting rotor position signal accurately and reliably, so that BLDC motor can commute and run correctly.

Keywords: BLDC motor, sensorless, back-EMF, Terminal Current Sensing, Third Harmonic, Integration, speed and position control.

I. INTRODUCTION

Brushless DC Motor uses electronic commutation to replace the electro-brush in DC motor. It not only keeps the advantages of DC motor, but also avoids the disadvantages of DC motor caused by electro-brush. Because of its advantages such as good mechanical characteristic linearity, wide speed range, long service life, easy to maintain, high reliability, low-noise, no commutation spark, etc. it was widely used in electrical and household appliances, industrial equipment, automotive and military equipment is widely applied in the field. In DC commutator motor, current polarity is altered by commutator and brushes. In the BLDC motor polarity reversal is performed by power transistors switching in synchronization with the rotor position. To accomplish this, BLDC motor is inverter fed. Inverter is designed in such a way that, its output frequency is function of instantaneous rotor speed and its phase control will correspond to actual rotor position.

In the Indirect back-EMF detection, back-EMF Integration, Third Harmonic Voltage Integration, Free-Wheeling Diode-Conduction/Terminal Current Sensing methods used for detecting rotor position signal accurately and reliably, so that BLDC motor can commute and run correctly.

Third Harmonic Voltage Integration method uses the third harmonic of the back-EMF to determine the commutation instants of the BLDC motor. The main benefits of this technique are simplicity of implementation, low susceptibility to electrical noise, and robustness. Signal (back-EMF) detection at low speeds is possible because the third harmonic signal has a frequency three times higher than the fundamental back-EMF, allowing operation in a wider speed range (100-6,000 rpm) [1].

Free-wheeling Diodes Conduction Detection (Terminal Current Sensing) is indirect back-EMF sensing method in which the position information can be detected on the basis of the conducting state of free-wheeling diodes connected in antiparallel with power transistors because a current flows in a phase.In this phase any active drive signal is given to the positive and negative side transistors and the current results from the back-EMFs produced in the motor windings.This method makes it possible to detect the rotor position over a wide speed range, especially at a lower speed, and to simplify the starting procedure [2]. In back-EMF Integration Method, the commutation instant is determined by integration of the silent (unexcited) phase's back-EMF. The concept is that the integrated area of the back-EMFs is approximately the same at all speeds.The integration approach is less sensitive to switching noise and automatically adjusts for speed changes, but low speed operation is poor due to the error accumulation and offset voltage problems from the integration [3].

II. MATHEMATICAL MODEL

In the figure 1 [3], three inverter phases are shown in a different colour: red phase A, green phase B, blue phase C, and pink neutral point N. The initial position of the rotor is determined by non-linear magnetic saturation characteristic of stator iron. The inductance of stator winding is a function of the rotor position because when the stator winding is excited, applying a DC voltage for a certain time, a magnetic field with a fixed direction will be established. Then, the current responses are different due to the inductance difference, and this variation of the current responses contains the information of the rotor position. The study of the circuit shown in Figure 1 is based on the BLDC motor model for phase A, shown in Figure 2 and the following assumptions are considered [4]:

1. The motor is not saturated
2. Iron losses are negligible
3. Stator resistances of all the windings are equal (Rs)
4. Self-inductances are constant (Ls)
5. Mutual inductances (M) are zero
6.

Now, voltage function of the conducting phase winding might be expressed as indicated in Equation (1):

VDC = I.Rs + Ls.dI/dt + e (1)

Where, VDC = DC voltage.
Rs & Ls = equivalent resistance and inductance of stator phase winding respectively.
e = trapezoidal shaped back-EMF.

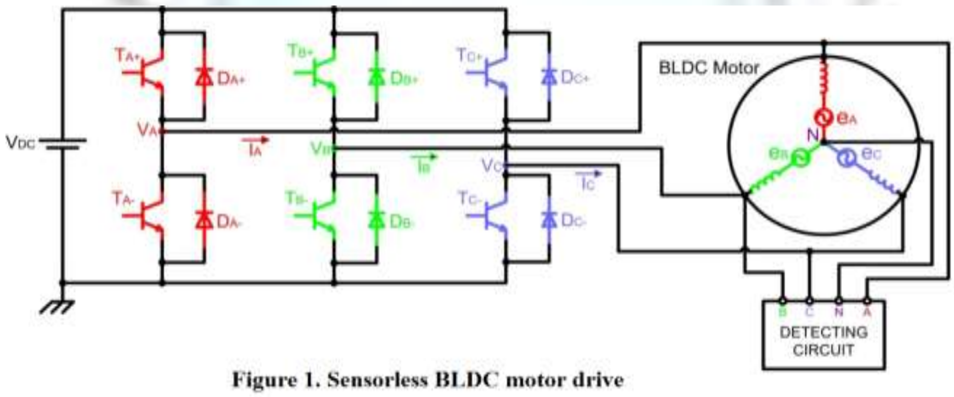

Figure 1. Sensorless BLDC motor drive

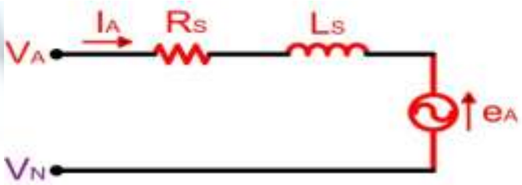

Figure 2. BLDC motor model for phase A

III. THIRD HARMNIC VOLTAGE INTEGRATION METHOD

The method of Indirect sensing the rotor fluxposition is applicable to trapezoidal back-EMF typeof BLDCmotors. The open circuit stator phase voltages, also called back-EMF, have a trapezoidal shape that contains a fundamental and higher order frequency harmonics This method is based on the fact that in a symmetrical three phase Y-connected motor with trapezoidal air gap flux distribution, the summation of the three stator phase voltages results in an elimination of all poly-phase components (fundamental and all the characteristics harmonics components like 5th, 7th, etc.); only the zero sequence components are left from the summation [5].The resulting sum is dominated by the third harmonic component that keeps a constant phase displacement with the fundamental air gap voltage for any load and speed. An appropriate processing of the third harmonic signal allows the estimation of the rotor flux position and a proper inverter current control. In contrast with indirect sensing methods based on the back-EMF signal, the resulting third harmonic signal is practically free of noise that can be introduced by the inverter switching; only a small amount of filtering is necessary to eliminate the switching frequency and its side bands. As a result, this method is not sensitive to filtering delays, achieving a high performance for a wide speed range. A superior motor starting performance is also achieved because the third harmonic can bedetected at low speeds.

Figure 3 shows the idealized air gap flux density distribution for a BLDC motor with surface mounted magnets [6]. The resultant trapezoidal air gap flux density has a dominant third harmonic component that links the stator phase windings inducing a third harmonic voltage component in each one of the phases. The summation of the three stator phasevoltages results only in the third harmonic plus other high frequency components. This summation, however, requires access to the neutral point connection of the stator. This extra wire connection to the neutral carries only signal currents. Two possible implementations for acquisition of the third harmonic voltage signal, one using the neutral connection (4-wire method) and another without neutral connection (3-wire method).

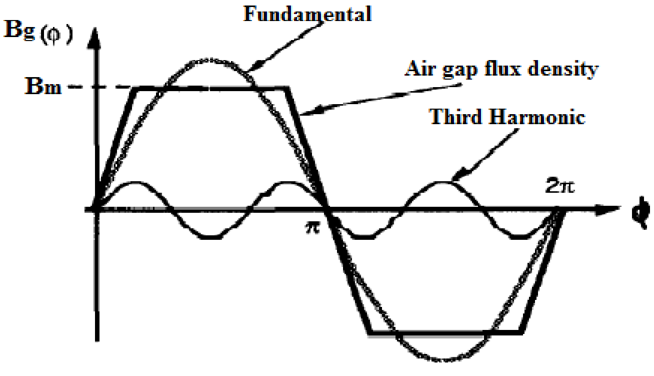

Figure 3. Air gap flux distribution and its fundamental and third harmonic components

The stator voltage equation for phase A, for instance, is written in Equation 1. Similar expressions canbe written for the other two stator phases. Where VDC=VA, I=IA, and e=eA

The harmonic content of the motor air gap or internal voltages eA, eB and eC is a function of the rotor magnets and stator winding configurations [7].For a full pitch magnet and full pitch stator phase winding, the internal voltages can be represented using the Fourier transform, obtaining many voltage harmonic components. From the summation of three-terminal to neutral voltages, the third harmonic of the back-EMF can be measured by Equation (2) [3]:

$$\begin{aligned} Vsum=V3 &= VAN+VBN+VCN \\ &=(eA+eB+eC) \\ &=3*E3*\sin(3*We*t) \qquad (2) \end{aligned}$$

The summed terminal voltages contain only the third and the multiples of the third harmonic due to the fact that only zero sequence current components can flow through the motor neutral. To obtain switching instants, the filtered voltage signal which provides the third harmonic voltage component is integrated to estimate the rotor flux linkage, as it is shown in Equation (3):

$$\lambda_{r3} = \int v_3 \, dt \qquad (3)$$

Figure 4 gives the motor internal voltage corresponding to phase A, eA, the third harmonic signal, VSUM, obtained from the summation of the stator phase voltages, the rotor flux third harmonic component λr3, the rotor flux λr, and the stator phase currents [7]. In order to obtain maximum torque per ampere, the stator current is kept at 90 electrical degrees with respect to the rotor flux. In addition, the zero crossings of the rotor flux third harmonic component occur at 60 electrical degrees, exactly at every desired current commutation instant.

This sensing method requires access to the neutral connection of the stator phases. It also requires a stator winding pole pitch and rotor pole pitch different of 2/3, otherwise the third harmonic rotor flux component does not link the stator winding and no third harmonic voltage is induced in the stator phases. The important advantage of this technique, besides its simplicity, is its low susceptibility to noise.

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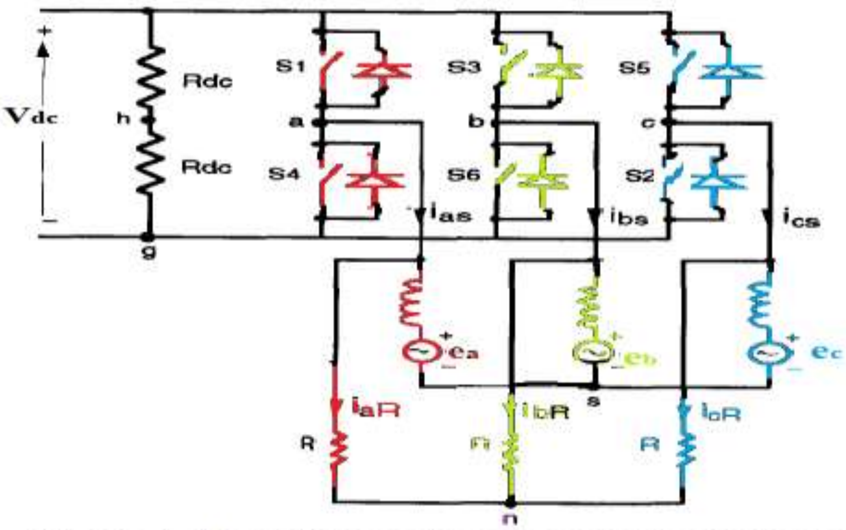

Figure 4. Third Harmonic sensing registor interface connected to an inverter bridge

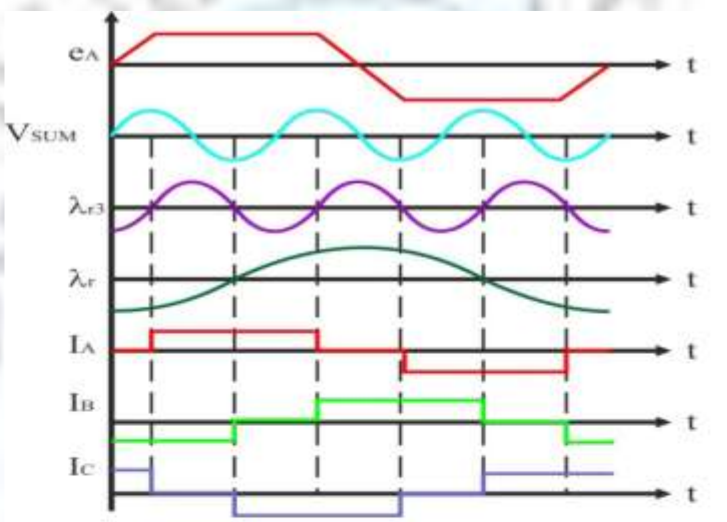

Figure 5. Back-EMF, third harmonic voltage, rotor flux and rotor flux fundamental components, and motor phase

Figure **4** shows a generic three phase inverter used to drive, a three phase BLDC motor. A star network of resistors of same value R is connected across the motor terminals and its common point labelled, n.Two other resistors, Rdc,are connected across the dc-link bus, forming a reference point labelled **h.** Note that the stator neutral point is labelled **s** and each one of the stator terminals labelled **a, b**, and **c**. Since the stator is star connected, so the summation of the stator currents reduces to zero. Similarly, the summation of the three voltages across the star resistor network is zero, so that the summation above taking into account equation 2 reduces toVns =1/3(V3).

It is interesting to note that the third harmonic voltage is obtained directly from the voltage across the two neutral points and no electronic summation means is necessary to add the three phase voltages [8]. In summary, the third harmonic stator voltage component can be obtained either from the voltage between the resistor network neutral and the motor statorneutral, VNNorfrom the resistor network neutral and the mid-point reference at the dc bus, VHN,in spite of the switching method used for the inverter bridge. A filter is necessary to eliminate the high switching frequency components. It is clear, then, that the stator third harmonic signal can be obtained without a direct access to stator neutral, eliminating the need of a fourth wire connection to the motor if desired.

IV. BACK-EMF INTEGRATION METHOD

In this indirect back-EMF sensing technique, the commutation instant is determined by integration of the silent (unexcited) phase's back-EMF. The main characteristic is that the integrated area of the back-EMFs shown in Figure 5 is approximately the same at all speeds. The integration starts when the silent phase's back-EMF crosses zero. When the integrated value reaches a pre-defined threshold value, which corresponds to a commutation point, the phase current is commutated. If flux weakening operation is required, current advance can be achieved by changing the threshold voltage. The integration approach is less sensitive to switching noise and automatically adjusts for speed changes, but low speed operation is poor due to the error accumulation and offset voltage problems from the integration [3]. As the back-EMF is assumed to vary linearly from positive to negative (trapezoidal back-EMF assumed), and this linear slope is assumed speed-insensitive, the threshold voltage is kept constant throughout the speed range.Once the integrated value reaches the threshold voltage, a reset signal is asserted to zero the integrator output. To prevent the integrator from starting to integrate again, the reset signal is kept on long enough to insure that the integrator does not start until the residual current in the open phase has passed a zero-crossing.

The use of discrete current sensors for each motor phase will provide complete current feedback, but the cost associated with individual current sensors (e.g., current transformers or Hall-effect sensors) is often prohibitive. An appealing alternative is the use of current sensors which are integrated into the power switches, such as power MOSFET'S and IGBT's, which are available from several device manufacturers with ratings up to several hundreds of volts and several tens of amps. However, embedded current sensors impose their own constraints; for example, the current sensing terminal is not electrically isolated from the associated power device. Also, the availability of new power integrated circuits makes it possible to take more complete advantage of these sensors for the combined purposes of current regulation and overcurrent protection [9].

Finally, the back-EMF integration approach provides significantly improved performance compared to the zero-crossing algorithm. Instead of using the zero-crossing point of the back-EMF waveform to trigger a timer, the rectified back-EMF waveform is fed to an integrator, whose output is compared to pre-set threshold. The adoption of an integrator provides dual advantages of reduced switching noise sensitivity and automatic adjustment of the inverter switching instants according to changes in rotor speed [10].

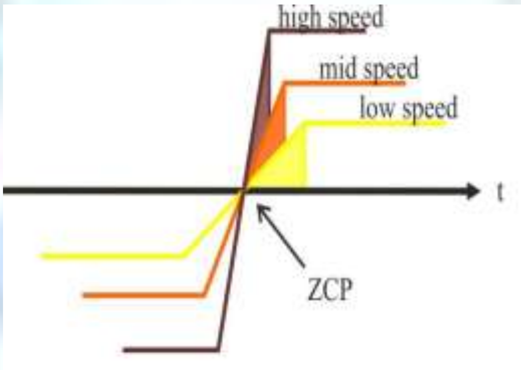

Figure 6. Integrated areas of back-EMF signals at various speeds

V. FREE-WHEELING DIODES CONDUCTION DETECTION METHOD (TERMINAL CURRENT SENSING)

In this technique the position information is detected on the basis of the conducting state of the free-wheeling diodes connected in antiparallel with power transistors, because a current flowing in a phase, in which no active drive signal is given to the positive or negative side transistor, results from the back-EMF's produced in the motor windings. The three-phase permanent magnet synchronous motor has the trapezoidal back-EMFs shown in Figure 7. The inverter used here is shown in Figure 1, but the conducting interval is 120" by electrical angle as shown in Figure 7.

Therefore, only two transistors, i.e. a positive side transistor in one phase and a negative side transistor in another phase, are ON-state at a time. The other phase, in which no active drive signal is given to the positive or negative transistor, is called the "open phase". To produce the maximum torque, the inverter commutation should be performed every 60º so that the rectangular-shaped motor line current is in phase with the back-EMF signal. A starting circuit is needed to give a commutation signal for starting. This approach makes it possible to detect the rotor position over a wide speed range, especially at a lower speed, and to simplify the starting procedure [2].

Therefore, the conducting condition of DC- is given by Equation (4), taking into account that VCE and VF are much smaller than the back-EMFs. Then, when the back-EMF of phase C (eC) becomes negative, the open-phase current flows through the negative-side diode DC:

$$V_{CE},V_F \ll e_A,e_B,e_C \Rightarrow e_C < -\frac{V_{CE}+V_F}{2} \approx 0 \Rightarrow e_C < 0 \quad (4)$$

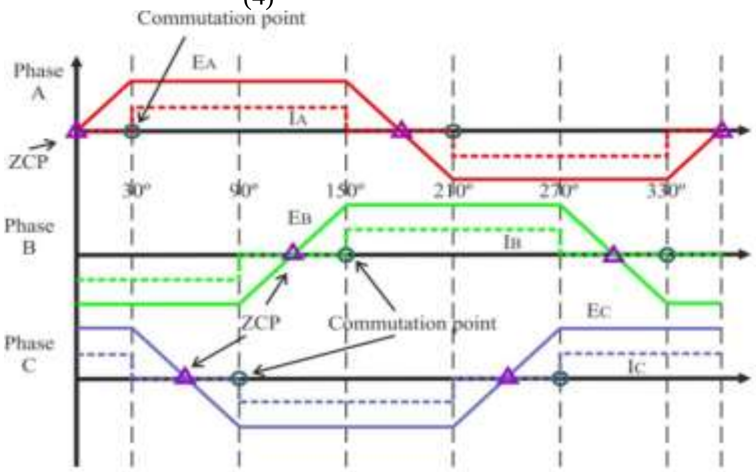

Figure 7. Zero crossing points of the back-EMF and phase current commutation points

Since the open-phase current results from the back-EMFs, it is impossible to detect the rotor position at a standstill. Therefore, a suitable starting procedure is necessary to the position sensorless BLDC motor drive. The procedure starts by exciting two arbitrary phases for a pre-set time. The rotor turns to the direction corresponding to the excited phases. At the end of the pre-set time, the open-loop commutation advancing the switching pattern by 120° is done, and the polarity of the motor line current is altered. After the starting procedure, the motor line current indicates that satisfactory sensorless commutations are performed by the free-wheeling diode conduction method [2]. This method has a position error of commutation points in the transient state as other back-EMF based methods. But, the most serious drawback of this method is the use of six isolated power supplies for the comparator circuitry to detect current flowing in each freewheeling diode, which prohibits this method from practical applications. However, this technique outperforms the previous back-EMF methods at low-speeds.

VI. CONCLUSIONS

A complete review of indirect back-EMF detection for sensorless control of BLDC motors is presented with their advantages, drawbacks and application.

REFERENCES

[1]. Moreira, J.C. Indirect Sensing for Rotor Flux Position of Permanent Magnet AC Motors Operating Over a Wide Speed Range. IEEE Trans. Ind. Appl. **1996**, 32, 1394-171.
[2]. Ogasawara, S.; Akagi, H. An Approach to Position Sensorless Drive for Brushless DC Motors. IEEE Trans. Ind. Appl. **1991**, 27, 928-933.
[3]. Kim, T.; Lee, H.W.; Ehsani, M. Position Sensorless Brushless DC Motor/Generator Drives: Review and Future Trends. IET Electr. Power Appl. **2007**, 1, 557-564.
[4]. Lee, B.K.; Kim, T.H.; Ehsani, M. On the Feasibility of Four-Switch Three-Phase BLDC Motor Drives for Low Cost Commercial Applications: Topology and Control. In Proceedings of the Sixteenth Annual IEEE Applied Power Electronics Conference and Exposition (APEC 2001), Anaheim, CA, USA, March 2008; pp. 428-433; Volume 1.
[5]. Brushless DC (BLDC) Motor Fundamentals Application Note; AN885, Microchip: AZ, USA. 2003.
[6]. Bianchi, N.; Bolognani, S.; Jang, J.H.; Sul, S.K. Comparison of PM Motor Structures and Sensorless Control Techniques for Zero-Speed Rotor Position Detection. IEEE Trans. Power Electron. **2007**, 22, 2466-2475.
[7]. Moreira, J.C. Indirect Sensing for Rotor Flux Position of Permanent Magnet AC Motors Operating Over a Wide Speed Range. IEEE Trans. Ind. Appl. **1996**, 32, 1394-1401.
[8]. Shen, J.X.; Zhu, Z.Q.; Howe, D. Sensorless Flux-Weakening Control of Permanent-Magnet Brushless Machines using Third Harmonic Back EMF. IEEE Trans. Ind. Appl. **2004**, 40, 1629-1636.
[9]. Jahns, T.M.; Becerra, R.C.; Ehsani, M. Integrated Current Regulation for a Brushless ECM Drive. IEEE Trans. Power Electron. **1991**, 6, 118-126.
[10]. Becerra, R.C.; Jahns, T.M.; Ehsani, M. Four-Quadrant Sensorless Brushless ECM Drive. In Proceedings of the Sixth Annual Applied Power Electronics Conference and Exposition (APEC 1991), Palm Springs, CA, USA, March 1991; pp. 202-209.

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