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Indirect Position Detection and Speed Control of PMBLDC Motor using LABVIEW

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Abstract

The brushless dc motors are used in various applications such as defense, industries, robotics, etc. In these applications, the motor should be precisely controlled to give the desired performance. This paper describes a position sensorless operation of permanent magnet brushless direct current (PMBLDC) motor and its speed control using LABVIEW. The Sensorless position detection proposed in this paper is based on the detection of zero crossing points of the line voltage difference measured at the terminals of the motor using Virtual Instrumentation. It is shown in the paper that this line voltage difference provides an amplified version of an appropriate back-EMF at its zero crossings. The speed control of the motor is obtained by pulse width modulation of the pulses given to the MOSFET inverter circuit using PIC micro controller. The effectiveness of the proposed method is demonstrated through simulation and experimental results.

Keywords: Brushless machines, Inverters, Zero- crossing Detection, Virtual Instrumentation, LABVIEW.

Introduction

Permanent magnet (PM) motors have been widely used in a variety of applications in industrial automation and consumer appliances because of their higher efficiency and power density. BLDC motors, with their trapezoidal EMF profile, require six discrete rotor position information's for the inverter operation. These are typically generated by Hall Effect switch sensors placed within the motor. However it is a well known fact that these sensors have a number of drawbacks. They increase the cost of the motor and need special mechanical arrangements to be mounted. Further, hall sensors are temperature sensitive and hence limit the operation of the motor. They could reduce the system reliability because of the extra components and wiring. Furthermore, sensorless control is the only reliable way to operate the motor for applications in harsh environments. The BLDC motor without position and speed sensors has attracted wide attention and many papers have reported work on this.

These methods are based on using back-EMF of the motor [1]-[3], detection of the conducting state of freewheeling diode in the unexcited phase [4], back-EMF integration method [5],[6], Detection of stator third harmonic voltage components [7],[8].Back-EMF estimation methods typically rely on the zero crossing detection of the EMF waveform. The technique of estimating back-EMF by sensing the terminal voltages with respect to a virtual neutral point is proposed in [1]. The neutral point will not be stable during PWM switching. Low pass filters have been used to eliminate the higher harmonics and to convert the terminal voltages into triangular waveform signals. Delay is introduced in the sensed signal due to heavy filtering, which also varies with the operating speed. Therefore this method is well suited only for a narrow speed range. Indirect back-EMF sensing technique is proposed by [2] without the need of neutral or virtual neutral potential. The back-EMF zero crossing is sensed with respect to the negative dc bus potential. In [3], the authors define a function depending on the measured voltages, currents and the derivative of the currents which indicates the switching instants. After pre- positioning, the authors in [3] advance the switching pattern by 60 electrical degrees and let their sensorless algorithm take over. Since their functions are dependent on the computation of derivatives of currents, the method requires digital implementation and could be affected by sensor noise.

Detecting the free-wheeling diode conduction in the open phase gives the zero crossing point of the back-EMF waveform [4].This approach of rotor position sensing works over a wide speed range, especially at lower speed. The main drawback of this scheme is the requirement of six additional power supplies for the comparator circuits to detect current flowing through the free- wheeling diode. Integrating the back-EMF waveform of the unexcited phase is another method to extract the position information for the phase commutation [5].Integration starts when zero crossing of the back-EMF occurs and the integration stops when the threshold set value is reached which gives the commutation instant. This approach is less sensitive to switching noise but low speed operation is poor. Further, this scheme needs the neutral potential and suffers from the offset error due to integration. Based on this technique a low cost sensorless scheme has been proposed [6]. Only one terminal voltage is sensed to detect the switching instant of a phase. Due to interpolation of the switching instants for other two phases from the sensed phase switching instants, frequent, rapid acceleration or deceleration is not possible.

Switching instants of starconnected BLDC motors have also been estimated from the third harmonic of the back-EMF waveform [7],[8]. Summation of the terminal voltages gives the third harmonic voltage. The third harmonic voltage component is then integrated to find the third harmonicflux linkage whose zero crossing corresponds to the commutation instants [7].The approach based on the inherent third harmonic voltage components [7] has the limitation that the amplitude and phase of harmonic components vary with magnetic saturation, and it is not suited to the low speed range owing to the relatively low amplitude of harmonic component voltages. Authors in[8] proposes integration of third harmonic of back-EMF instead of terminal voltages using ASIC for ultrahigh speed operation, however access to motor winding neutral potential is required. A detailed review of the recent literature on sensorless methods is given by authors in [9].Direct commutation instant detection from line voltages is proposed by authors in[10] along with a fine tuning technique to further improve the accuracy of the detected commutation instant. In [11], the authors implement sensorless operation by using the average line to line voltage, which is obtained by filtering the PWM waveforms. Filtering introduces a delay, which to be minimized, requires a high switching frequency. Further, [11] does not discuss the details of sensorless starting of the motor. Authors in [12] designed and implemented an integrated circuit for the sensorless operation of BLDC motor by sensing the motor terminal voltages. Frequency independent phase shifter is proposed by authors in [13] for sensorless control of BLDC motor which can shift the zero crossing point of input signal with a specified phase delay.

An extended kalman filter estimator for a brushless dc motor has been developed by authors in [14] for speed and rotor position estimation. An obstacle to applying the extended kalman filter algorithm to rotor position estimation is the need to set appropriate values for the covariance matrix parameters, which reflect the uncertainties in modeling and measurements. The parameter values are often chosen by trial and error. Advancing the commutation instantincreases the torque production particularly at high speed operation of BLDC motor as proposed and analyzed by authors in [15],[16]. However direct commutation instant detection technique proposed by [10],[11] lacks this flexibility to advance the commutation instant, which is possible to implement using the back- EMF zero crossing detection techniques.

This paper proposes a novel method of detecting the back- EMF zero crossings, by making use of line voltage differences. It is shown that the difference of line voltages provides an amplified version of the back-EMF in appropriate phase near the zero crossing. The line voltage difference is fedto the virtual instrument developed in LABVIEW throughserial communication and the zero crossing points are detected. These details are given through serial port to the micro controller. The pulses Generated and the pulse width modulation is done according to the set speed in the microcontroller. The method is simple, reliable and does not involve any integration. Further, since line voltages are used, the requirement of neutral potential has been eliminated. The Zero crossing instants are done using virtual circuits developed in LABVIEW. This also eliminates the common mode noise. Device drops and their variations would also not play a part since line voltages are used. Unlike the method of [3] this scheme is easy to implement. No derivative operations are involved. The organization of this paper is as follows. Section II describes the proposed back-EMF zero crossing estimation method. Section III presents hardware implementation of the proposed method. Section IV presents the virtual instrument and results that validate the proposal and section V presents the conclusion.

The Proposed Back-EMF Zero Crossing Estimation Method

Consider a BLDC motor having three stator phase windings connected in star. PMs are mounted on the rotor. The BLDC motor is driven by a three phase inverter in which the devices are triggered with respect to the rotor position as shown in Fig. 1. The phase A terminal voltage with respect to the star point of the stator Van, is given in (1)

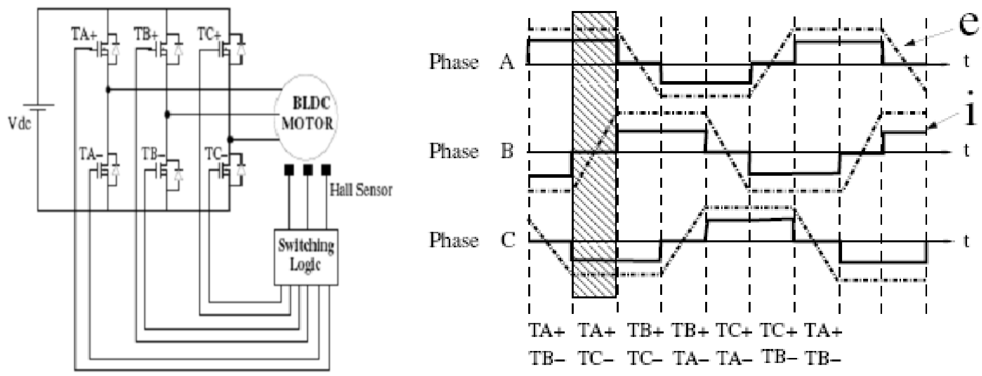

Figure 1: PMBLDC drive and typical phase current and back-EMF waveform.

$$Van = Raia + La\ (dia/dt) + ean \quad (1)$$

Similar equations for the other two phases are,

$$Vbn = Rbib + Lb\ (dib/dt) + ebn \quad (2)$$

$$Vcn = Rcic + Lc\ (dic/dt) + ecn \quad (3)$$

From equation (1),(2),(3) the line voltage Vab and

Vbc may be determined.

$$Vab = Van - Vbn$$

$$= R\ (ia - ib) + L\ (d\ (ia - ib)\ /dt) + ean - ebn \quad (4)$$

$$Vbc = Vbn - Vcn$$

$$= R\ (ib - ic) + L\ (d\ (ib - ic)\ /dt) + ebn - ecn \quad (5)$$

A similar expression can be written for Vca also. These line voltages can however be estimated without the need for STAR point by taking the difference of terminal voltages measured with respect to the negative DC bus.

Subtracting (5) from (4) gives

$$Vabbc = R(ia - 2ib + ic) + L\ d(ia - 2ib + ic)/dt + ean - 2ebn + ecn \quad (6)$$

In the interval when phases A and C are conducting and phase B is open, phase A winding is connected to the positive of the DC supply, phase Cto the negative of the

DC supply and phase B is open.

Therefore ia = -ic and ib = 0.

Therefore in this interval the equation is simplified as,

$$Vabbc = Vab - Vbc = -2\ ebn \quad (7)$$

The line voltage difference waveform is thus an inverted representationof the back-EMF waveform. The error between the line voltage difference and back EMF, also shown in Fig. 2 is negligible at the zero crossing instant. Therefore the operation

Vab-Vbc (Vabbc) enables detection of the zero crossing of the phase B EMF. Similarly the line voltage difference Vbcca enables the detection of zero crossing of phase C back-EMF. The line voltage difference Vcaab waveform gives the zero crossing of phase A back-EMF. Therefore the zero crossing instants of the back-EMF waveforms may be estimated indirectly from the line voltage differences. While the discussion above used an ideal trapezoidal waveform, the practical induced emf deviates from this wave shape due to slot ripples. The validity of (7) for a practical machine is verified from experimental waveforms. Real back- EMF waveforms are measured and the line voltage difference Vabbc is evaluated from the expression ea+ec-2eb using the measured back-EMF waveforms in order to verify the ZCP match. Fig. 2 shows the Vabbc waveform along with the back- EMF waveform (multiplied by gain two, 2eb) and the error between the two. It is evident from the Fig. 2 that the Vabbc waveform matches well with the back-EMF waveform -2eb in the zero crossing region. The error between the two, also shown in Fig. 2 is negligible at the zero crossing instant.

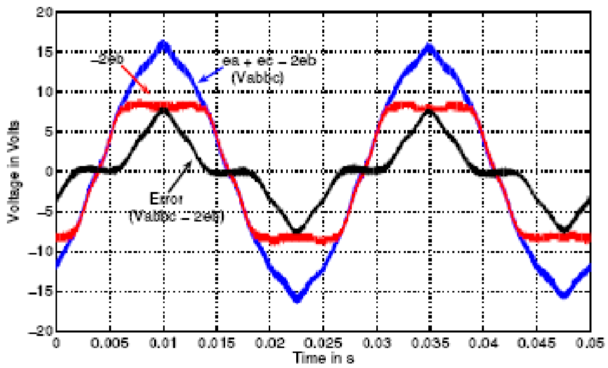

Figure 2: Line voltage difference and back –EMF.

The line voltage difference waveform is fed in to the virtual instrument developed in using RS232 serial communication. Using the LABVIEW the zero crossing of Line voltage difference is determined and the switching signals are generated. The switching signals are further fed to the PIC 16F877A micro controller through the same Serial port. In the micro controller the pulse width modulation of the particular signals are performed and fed to the MOSFET inverter circuit. The set speed is given by the user in the VI developed in LABVIEW and its fed to the PIC micro controller using serial communication.

Hardware Implementation

Fig. 3 shows the block diagram of the proposed sensorless BLDC motor drive. Three phase bridge inverter fabricated using n – channel MOSFET is operated in 120 degree mode to provide square wave current excitation to the stator windings. PWM techniques use to produces the switching pulses for the 120 degree inverter. Inverter switches are triggered in a sequence provided by the high performance digital controller IC MC 33035. The IC contains all the functions required to implement a full featured open loop control.

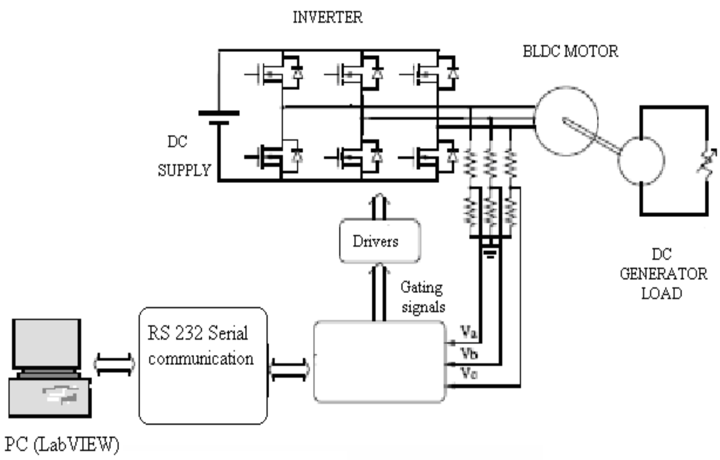

Figure 3: Block Diagram of proposed method.

The output of MC 33035 is ideally suited for driving power MOSFET's of low ratings. For isolation4N35 optocoupler are used. The regulators 7812 and 7805 in the control circuit give the DC supply required by the driver and microcontroller chips respectively. The driver chip amplifies 5V pulse to 10V level. DC output from the rectifier is ripple free due to the filter. The Atmel microcontroller 16F877A is used to generate the pulses. Port 1 of the microcontroller is used for generating the gate pulses. Timer 0 is used for producing the delay required for the duration Ton and Toff. The microcontroller operates at a clock frequency of 12 MHz.

Virtual Instrumentation and its Results

LABVIEW is a graphical programming language that uses icons instead of lines of text to create applications. LABVIEW program facilitates Virtual Instrumentation (VI), which imitates the appearance and operation of physical instruments. VI is defined as a process of combining hardware and software with industry standard computer technology to create a user-defined instrumentation solution. Several other add-on toolsets can be incorporated for developing the specialized applications. The voltage is measured and actual speed is determined.

Using this data and according to set speed the gating signals are produced using LABVIEW software. The voltage waveform and speed waveform is also displayed using LABVIEW. The line voltages are measured using RS232, Which is used to measure the voltage from motor and used to send the commutation instants to the microcontroller. The pulses produced by the microcontroller are amplified using the driver IC IR 2110. Three driver ICs are used to amplify the gate pulses. The results are also displayed in LABVIEW Front panel diagram easily. Figure 4 shows the experimental setup using LABVIEW. Fig 5 shows the results for the speed control of brushless dc motor using LABVIEW. The set speed and the actual speed of the motor is also displayed in front panel of LABVIEW.PMBLDC motors drives are used in a wide range of commercial and residential applications due to their highest possible efficiencies. The speed control ability of compressors and blowers is able to provide operation at their high efficiency. The physical integration of controller in the motor body itself is able to make them most suitable for low power (0.5hp) blowers and low power (50W) tube axial fans for cooling the electronic equipment.

Figure 4: Experimental Setup for speed control using Labview.

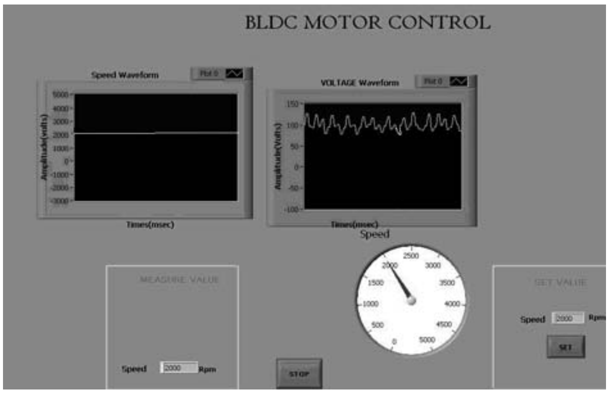

Figure 5: Voltage waveform and Speed for set speed of 2000 rpm.

Conclusion

Speed control of PMBLDC motor is achieved using virtual instrumentation. This proposed method controls the speed for various ranges. The speed control is achieved for different speed using this method is tabulated in table1 for the motor having specifications given in appendix –1. When Compared with the conventional back EMF zero crossing sensorless control, the proposed new sensorless control methods for brushless DC technique is more robust, easier to implement, and cost Effective because of virtual instrumentation and micro controller.

Table 1: Speed obtained for different Set speed.

S.No.	Set speed RPM	Actual speed RPM
1	1500	1500
2	2000	2005
3	3000	3000
4	4000	4000
5	5000	5000

The hardware system used in the present work has obvious advantage of using single-phase supply. Theoretical analysis and experimental results verified that satisfactory performance is achieved with the motors with the proposed method. This drive can be used for variable speed applications like Electrical vehicles, Robotics etc.,

Appendix 1

PMBLDC Motor Specifications

Number of poles	4 poles
LINE TO LINE RESISTANCE	0.2ohms
LINE TO LINE INDUCTANCE	0.45mH
NOMINAL VOLTAGE	24V
NO LOAD SPEED	11500RPM
NO LOAD CURRENT	0.8A
RATED TORQUE	0.05N.m
RATED SPEED	10000RPM
BACK EMF	2V/KRPM
TORQUE CONSTANT	0.02N.m/A
WEIGHT	0.5Kg

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