

DSP Based Sensorless Control of A BLDC Motor with Direct Back EMF Detection Method

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Abstract

This paper proposes a scheme for sensorless control of brushless dc (BLDC) motor by a direct back EMF detection method. The terminal voltage of the motor is proportional to the phase back EMF on the floating phase, the DSP ADC feature can be utilized to sense the back EMF. Digital control of the system ensures the detection of rotor electrical position when the open terminal voltage equals half the applied voltage. A mathematical model of the drive system is analyzed. The simulated and experimental results from a prototype BLDC drive system using a digital signal processor are verified. Experimental waveforms of phase back EMF and current from a 3-phase, 200 W, 4-pole, BLDC drive system are validated with simulation results.

1. Introduction

Large, medium, small as well as micro BLDC motors are extensively used for applications in many types of motion control apparatus and systems. The availability of smart power electronics devices and their optimal topologies has accelerated unprecedented growth of cost effective and reliable power electronic controllers. This improvement brings greater efficiency in materials and functionality to the point of making the BLDC a preferred solution in a broad range of applications using adjustable speed drives [1-3].

The high performance of digital signal processors (DSPs) allows the BLDC drive to perform high-resolution control and minimize control loop delays. An efficient digital controller reduces torque ripples,

harmonics and improves dynamic behavior in all speed ranges of BLDC motor. Overall, these improvements resulted in a reduction of system cost and better reliability [4].

The BLDC motor is inherently electronically controlled and requires rotor position information for proper commutations of current. Many sensorless drive solutions have been offered to eliminate the costly and fragile position sensor for BLDC motors with trapezoidal back-EMFs. The virtual neutral point sensing [5], third harmonic back-EMF sensing [6], back-EMF integration [7], flux estimation [8], and detection of the freewheeling diodes conduction [9], are the main categories of past sensorless solutions for BLDC motors. A virtual neutral point sensing method of back EMF requires both filtering and attenuation, and tends to have poor signal to noise ratio at low speeds, such as at startup, and significant commutation delays at high speeds.

The back EMF integration, and third harmonic voltage integration approaches have the advantage of reduced switching noise sensitivity but accuracy problem at low speed. An indirect sensing of phase back EMF zero crossing by detecting the conducting state of the freewheeling diodes in the unexcited state is complicated and expensive, while the low-speed operation continues to be a problem.

2. Sensorless BLDC motor control

A three-phase star connected BLDC motor is normally driven by a three-phase inverter using 6-step commutation. In order to produce maximum torque, the inverter should be commutated every 60 electrical degrees so that current is in phase with the back EMF.

The conducting interval for each phase is 120 electrical degrees, or two steps. The commutation timing is determined by the rotor position, which can be determined every 60 electrical degrees by detecting when the back EMF on the floating phase crosses the zero potential point, or “zero crossing.” As only two phases conduct current at any step, one phase is always available to measure back EMF as shown in Fig.1[10, 11].

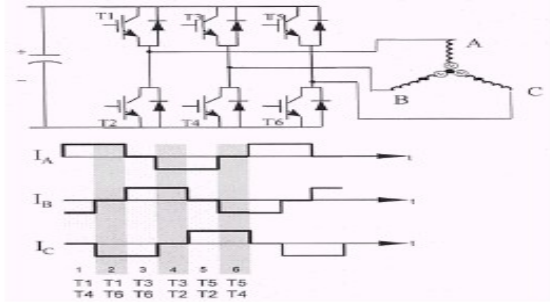


Fig. 1. Commutation sequence for BLDC Motor.

3. Back EMF detection method

The proposed back-EMF detection method successfully avoids using the neutral point voltage. The back-EMF voltage can be extracted directly from the motor terminal voltage referred to ground. An inverter motor-drive model shown in Fig. 2 is used in this paper to conduct the analysis and simulation.

The back-EMF sensing technique is based on the fact that only two phases of a BLDC motor are connected at a time, and the third phase is available to sense the back-EMF voltage. Assuming at a particular step, phase C as floating, from Fig. 2

$$U_C = U_{IC} + U_o \quad (1)$$

where U_C is the terminal voltage of the floating phase C, U_{IC} is the phase back EMF and U_o is the neutral voltage of the motor. From phase A, the expression for neutral voltage is given as,

$$U_o = V_{DC} - V_{MOS} - R_i - L \frac{di}{dt} - U_{IA} \quad (2)$$

From phase B, the equation become,

$$U_o = V_{MOS} + R_i + L \frac{di}{dt} - U_{IB} \quad (3)$$

Where V_{MOS} is the voltage drop on MOSFET.

From Equations (2) and (3),

$$U_o = \frac{V_{DC}}{2} - \frac{(U_{IA} + U_{IB})}{2} \quad (4)$$

Assuming a balanced three-phase system, and neglecting the third harmonics,

$$U_{IA} + U_{IB} + U_{IC} = 0 \quad (5)$$

From Equations (4) and (5),

$$U_o = \frac{V_{DC}}{2} - \frac{(U_{IC})}{2} \quad (6)$$

and the terminal voltage U_C ,

$$U_C = U_{IC} + U_o = \frac{3U_{IC}}{2} + \frac{V_{DC}}{2} \quad (7)$$

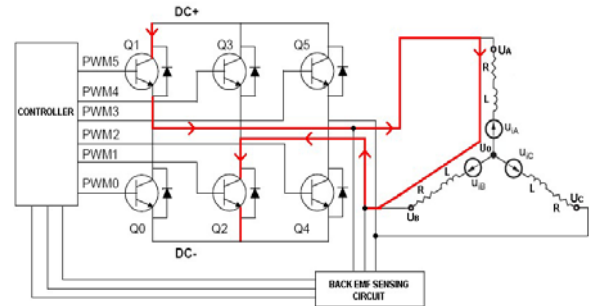


Fig. 2. Inverter motor-drive model.

As observed from equations (1) to (7), the PWM the terminal voltage of the floating phase is directly proportional to the back EMF voltage plus the half of dc bus voltage. By comparing U_{IC} with $\frac{V_{DC}}{2}$, the

zero crossing of the back EMF can be achieved. It is also important to note that this terminal voltage is not referred to the floating neutral point. So, the neutral point voltage information is not needed to detect the back EMF zero. As a result there are no common-mode voltage issues. Since the true back EMF is extracted from the motor terminal voltage, the zero crossing of the phase back EMF can be detected very precisely.

4. Hardware Implementation

The motor drive is powered from a standard wall socket and controlled by a digital signal processor utilizing pulse width modulation to control the speed of the motor. The circuit board has three sections:

control, power inverter and power supply. The power circuit for the drive is an MOSFET based inverter with gate driver circuit. The control section consists of dsPIC30F3010, protection circuit, and back EMF signal conditioning circuit. The dsPIC30F3010, has specialized hardware peripherals, like the power control PWM, high-speed ADC, motion control feedback, integrated EEPROM and the power supervisory function, that are required for efficient motor control [12].

For the over current protection circuit a shunt resistor connected in the DC return path converts the combined three-phase motor current into voltage. In addition to this, the amplified voltage is compared to a voltage reference using an op amp comparator. The voltage reference is set using a potentiometer. Back EMF (BEMF) signals are used for the sensorless control of the BLDC motor speed. Based on zero crossing of BEMF signals, motor commutation is decided in the firmware. The dsPIC30F3010 device uses its fast ADC to sense the zero-cross point. Having sensed the zero-cross point, it can predict the time required for the next commutation phase.

5. Software Implementation

Remaining parts of the drive system are implemented in the assembly language of dsPIC30F3010. The software design, consist of few blocks such as speed module, speed controller, current controller, PWM generator, and fault monitoring [13]. Each block in the diagram represents a separate module to be implemented. It consists of reference speed magnitude and direction sensing. Actual speed magnitude and direction are calculated from zero crossing of BEMF signals. Pulse width of these signals is proportional to the speed of the motor. The error in reference and actual speed is processed in PI speed controller and output of speed controller is termed as reference torque and is limited to a set value. The dsPIC30F3010 device uses its fast ADC to sense the zero-cross point, and also predicts the time required for the next commutation phase. The current controller compares the actual and reference currents and generates the switching signals to MOSFET devices.

6. Results and discussion

The simulation of the proposed BLDC motor controller shown in Fig. 3 was implemented in MATLAB software [14].

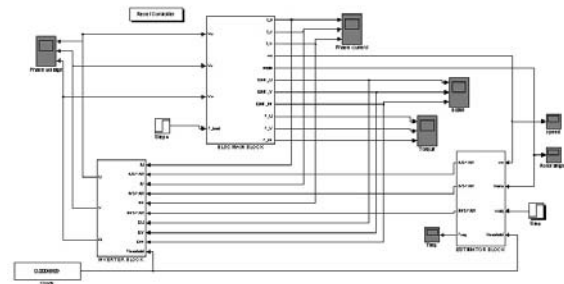


Fig. 3. MATLAB simulation circuit.

The simulated operating waveforms of the BLDC drive system are presented in Figs. 4 to 7. The rotor speed from standstill to a speed of 500 rpm is shown in Fig. 4, while Fig. 5 shows the rotor speed at 1500 rpm. The PI speed controller comes into action and tracks the reference speed.

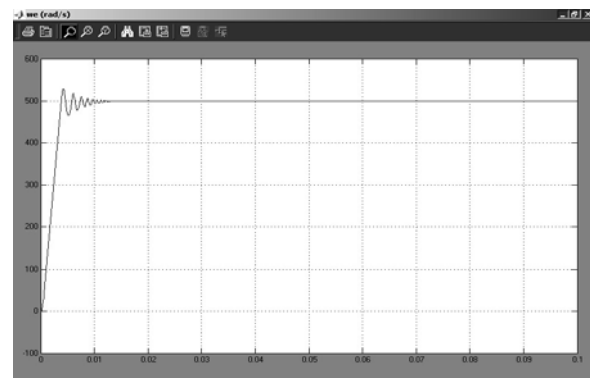


Fig. 4. Motor speed waveform at low speed (500 rpm).

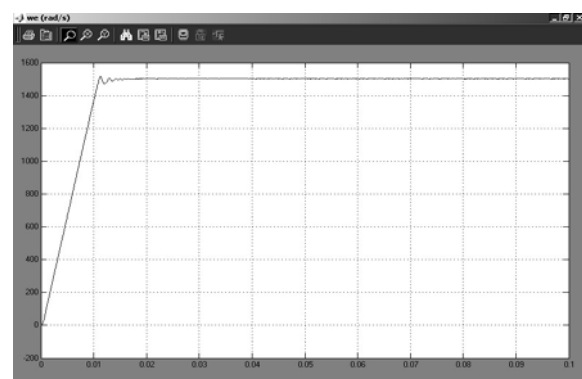


Fig. 5. Motor speed waveform at high speed (1500 rpm).

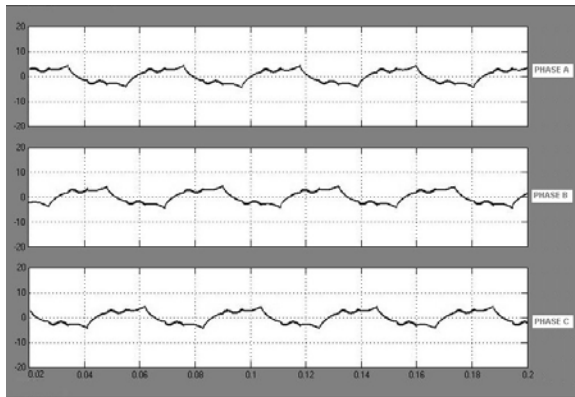


Fig. 6. Phase current waveforms.

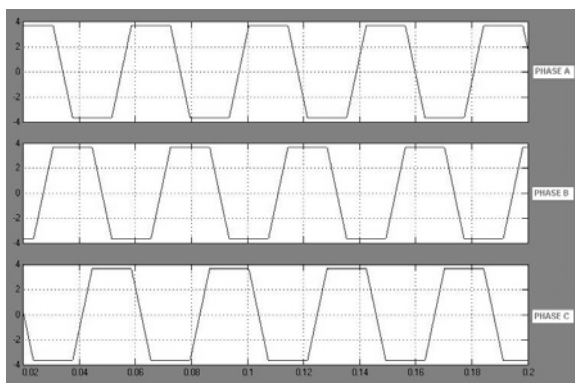


Fig. 7. Phase back EMF waveforms.

The simulated three-phase current and generated back EMF signals are presented in Figs. 6 and 7, respectively. Comparing Figs. 6 and 7, the sequence from back EMF zero crossing to commutation is clearly demonstrated. It is observed that the commutation takes place approximately 30 electrical degrees after zero crossing of the back EMF.

A prototype control driver circuit is constructed for a 200 W BLDC sensorless motor, and some key experimental waveforms are presented in this section. The experimental waveforms for back EMF waveforms and comparison between the phases are shown in Figs. 8. The phase back EMF of the floating winding is extracted from the winding of the terminal voltage.

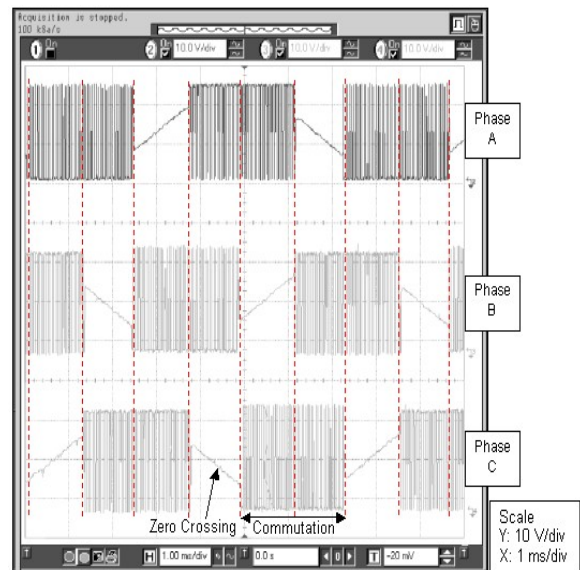


Fig. 8. Back EMF waveforms for phases A, phase B and phase C.

The experimental output phase currents of the prototype BLDC drive are shown in Fig. 9.

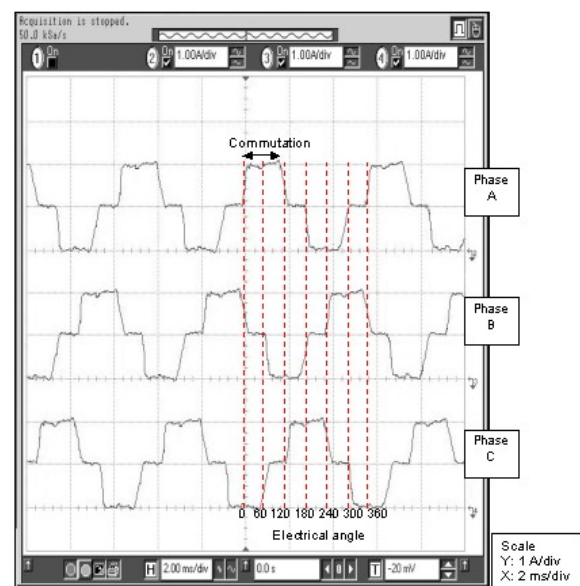


Fig. 9. Phase current waveforms for phase A, phase B and phase C.

The sequence from back EMF zero crossing to commutation is clearly demonstrated in Fig. 10. To avoid clutter, only the terminal A waveform, as would be observed on an oscilloscope is displayed and is denoted as back EMF. It is observed that the terminal voltage waveform is flattened at the top and bottom

because at those points the terminal is connected to the drive voltage or ground.

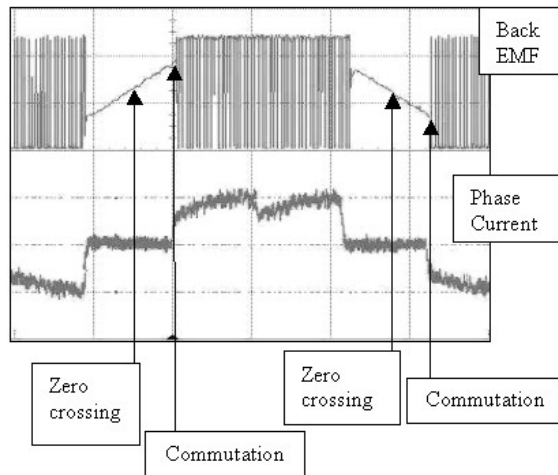


Fig. 10. Sequence of zero crossing of back EMF and phase commutation.

It may be noticed that the BEMF waveform passes through a voltage that is exactly half of the applied voltage, which coincides with the zero crossing of the BEMF waveform. This implies that it is possible to determine the rotor electrical position by detecting when the open terminal voltage equals half the applied voltage. Also it is shown that the commutation takes place approximately 30 electrical degrees after zero crossing of the back EMF. Thus it is clearly demonstrated that the hardware and software digital control of the system results obtained match the theoretical as well as the simulation results.

7. Conclusion

The experimental results obtained using the proposed BLDC drive system has proved the simplicity of the application of dsPIC30F3010 microcontroller for sensorless speed control. In general, the back EMF sensing technique which does not depend on actual or simulated neutral voltage for BLDC drives was successfully implemented. The implemented back EMF sensing method has superior performance and provided much wider motor speed range with low cost. The validity of the developed sensorless BLDC drive system using back EMF

detection is verified successfully as shown from the simulation and experimental results on a 3-phase, 200 W, 4-pole, BLDC motor.

8. References

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