Sensor less BLDC Motor Control with Back EMF Zero Crossing Detection using PIC 18F2431 MCU

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***Abstract:* From Mid 19th Century Brushless Direct Current (BLDC) motors are one of the motor types that are rapidly gaining popularity. These motors are being utilized in many of the industrial, commercial appliances such as in Automotive, Aerospace, Medical Instruments, Industrial automation equipment's & Instrumentation. These motors do not use brushes for commutation; instead, they are electronically commuted which is having complex control circuitry. For this electronic sensor circuits like Hall Effect sensor & Rotary encoders were used to directly measure the rotor's position. But with Sensorless control a BLDC motor calls for commutation based on the Back-EMF which is produced in the stator windings. Sensorless control has two distinct advantages: 1. Lower system cost & 2. Increased reliability. Hall Effect sensors are not required for this type of control of BLDC motors.**

***Index Terms:* Sensorless BLDC motor control, BLDC motor, 3-phase bridge inverter circuit, IGBT driver.**

I. INTRODUCTION

Brushless DC motors also known as electronically commutated motors are actually Synchronous motors which are powered by a DC electric source via an integrated inverter, which produces an AC electric signal to drive the motor; additional sensors & electronics control the inverter output. When BLDC motor rotates, each winding generates Back EMF which opposes the main voltage supplied to the winding's according to Lenz's law. The polarity of Back EMF is in the opposite direction of the energizing voltage. This Back EMF depends mainly on 3 factors.

1. Angular velocity of the rotor.
2. Magnetic field generated by rotor magnets.
3. The number of turns in the stator windings.

The motor part of a Brushless DC motor is often permanent magnet synchronous motor, but can be a switched reluctance motor, or induction motor. BLDC motors can be described as stepper motors; however, the term stepper motor tends to be used for motors that are designed specially to be operated in a mode where they are frequently stopped with the rotor in a defined angular position.

The easiest way to know the correct moment to commutate the winding currents is by means of a position sensor. Many BLDC motor manufacturers supply motors with a three-element Hall Effect position sensor. Each sensor element outputs a digital high level for 180 electrical degrees of electrical rotation, & a low level for the other 180 electrical degrees.

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The three sensors are offset from each other by 60 electrical degrees so that each sensor output is in alignment with one of the electromagnetic circuits.

Whereas in **Sensorless BLDC control,** we need not have Hall sensors to sense the position of rotor. It is done by the analysis of Back EMF that is generated at the stator of the motor windings. By using this this method, the reliability of the control system is enhanced. The setback of this method is that the algorithm & control circuit to detect the Back EMF is complex, hence requiring more powerful micro-controller & software knowledge.

II. BLOCK DIAGRAM

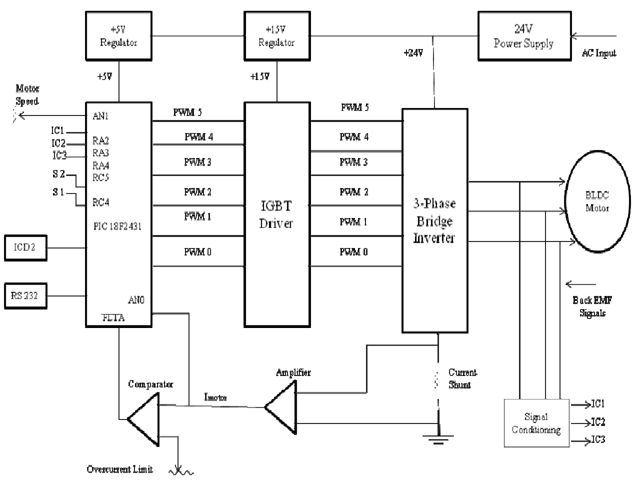

Fig 1: Block Diagram of Technique implemented here.

III. WORKING

The methods discussed here are applicable only to 3-phase motors of standard construction (no search coils or deliberate asymmetries). It is also assumed that conventional 120^0 blocks of energization are used such that there are periods of time when one phase has zero current flowing & is not being actively driven. The driven phases must be switched or commutated; at periodic intervals to run the motor.

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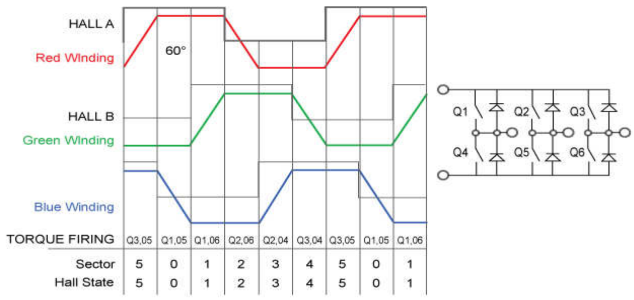

Fig 2: Hall Effect sensor output with corresponding Back EMF voltage waveform [1]

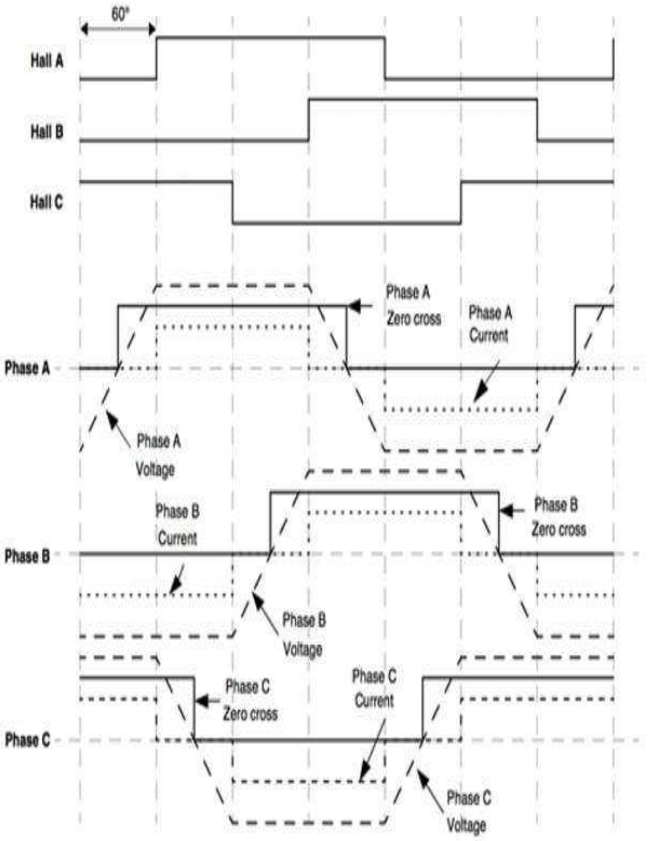

Fig 3: Controlling of sensorless BLDC with zero current detection.[2]

To allow correct commutation of the motor, the absolute position within an electrical cycle must be measured. For conventional energization, six equally spaced commutations are required per electrical cycle. This is usually implemented using three hall-effect or optical switches with a suitable disk on the rotor. Continuous position information is not required, just detection of the required commutation instances. Figure 1 shows the three sensor outputs along with the corresponding Back EMF voltage waveform for each phase. To detect rotor position by monitoring a property of the motor, clearly this property must vary with position. Furthermore, it is desirable if the property establishes a unique position within an electrical cycle, which adds robustness to the sensorless technique.

The variation in phase flux-linkage with position produces torque. This effect can be dissected into reluctance and Back EMF components, both of which may vary with current, as well as position. Back EMF also varies linearly with speed. The variation of the reluctance or Back EMF can either be monitored directly or their effect on a secondary quantity can be used instead.

$R = MMF / \Phi$

In this equation,

R = Reluctance

MMF = Magneto-Motive Force

Φ = Flux.

A. *Reluctance Variation Method*

Reluctance is the magnetic equivalent to electrical resistance in the magnetic Ohm's law. Since reluctance varies with position, it can be used as the basis for sensorless operation. In all BLDC motors, there will be some variation in reluctance with angle. But unfortunately, the reluctance variation with position is too small to be measured reliably for many BLDC motors. This characteristic is especially true of motors with surface mounted magnets because the effective air-gap is large.

B. *Back EMF Methods*

The Back EMF waveform of the motor varies as both a function of position and speed. Detection of position using Back EMF at zero and low speeds is, therefore, not possible. Nevertheless, there are many applications (e.g., fans and pumps) that do not require positioning control or closed loop operation at low speeds.

For these applications, a Back EMF method is very appropriate. There are many different methods of using the Back EMF. The majority of these methods can be summarized as follows:

- Machine terminal voltage sensing:- Either by direct measurement or inference (knowledge of switch states and DC bus voltage).
- Mid-point voltage sensing:-
  - Only works for Y connected motors with particular Back EMF properties.
  - 4^{th} wire not actually required. Can re-create star point using resistor networks and difference operation.
- Bus current gradient sensing:-
  - Relies on characteristic bus current shape due to commutation changing as rotor leads/ legs.
  - Can't use fast bus current control.

IV. IMPLEMENTATION OF CHOSEN SENSORLESS TECHNIQUE

The particular method implemented here is based on detecting the instances when the Back EMF of an inactive phase is zero. Apart from amplification of the bus shunt signal, which is optional and the power switch gate drivers, the implementation is single-chip with the dsPIC30F providing all of the control functionality. The so called Back EMF "Zero Crossing" technique was chosen because:

1. It is suitable for use on a wide range of motors.
2. It can be used on both Y and delta connected 3-phase motors in theory.
3. It requires no detailed knowledge of motor properties.

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4. It is relatively insensitive to motor manufacturing tolerance variations.
5. It will work for either voltage or current control.

The zero crossing technique is suitable for a wide range of applications where closed-loop operation near zero speed is not required. Its application on Fans and Pumps is particularly appropriate. Provided the speed is greater than zero, there are only two positions per electrical cycle when the Back EMF of a phase is zero, and these positions can be distinguished by the slope of the Back EMF through the zero crossing as shown in figure 3. Each sector corresponds to one of six equal 60^0 portions of the electrical cycle. Commutations occur at the boundary of each of the sectors. Therefore, it is the sector boundaries that need to be detected. There is a 30^0 offset between the Back EMF zero-crossings and required commutation positions, which must be compensated for to ensure efficient and smooth operation of the motor.

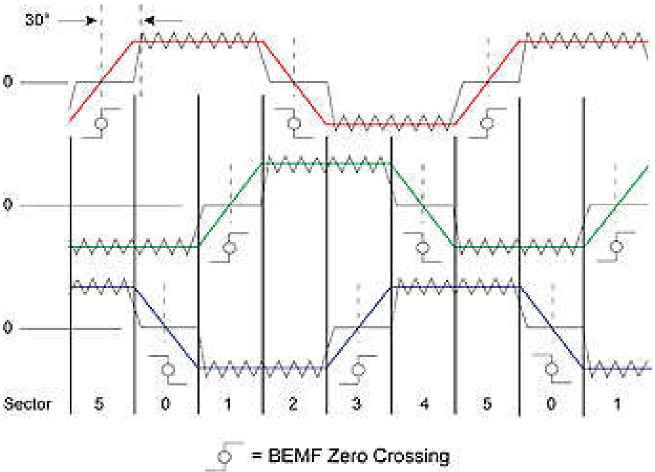

Fig 4: Back EMF zero crossing [3]

Fig 3 also shows the individual idealized phase Back EMF waveforms. Assuming only the three motor leads are available for sensing the Back EMF, then the voltage of the star point of the motor must be determined because the Back EMF waveform will be offset by the star point voltage.

V. ADVANTAGES AND DISADVANTAGES

A. Advantages

1. BLDC Vs. Sensorless BLDC motor control.

In BLDC control, a few Hall sensors are placed on the stator of the motor to detect the position of the rotor during the operation of the motor. The sensors are normally build into the printed circuit board and mounted onto the enclosure cap of the non-driving end of the motor. The setback of this method is that the sensors and PCB need to be placed in a location where the temperature of the motor will not build up and thus affect the lifetime and operation of the PCB.

2. Hall sensor signals Vs. Back EMF.

Hall sensor signals are out of phase by 120 degrees to each other. At every 60 degrees, one of the Hall sensors makes a transition.

The Back EMF generated in the windings are also at 120 degrees out of phase to each other, but they are asynchronous with the hall sensor signals. In every energizing sequence, two phases are connected across the power supply and the third winding is left open. The Back EMF voltage is monitored on the winding that is left open. With this, the Back EMF voltage in windings increases when it is connected to power supply and reduces when it is connected to the return path.

The transition takes place when the winding is left open in sequence. The combination of all 3 zero cross over points are used to generate energizing sequence. The phase difference between the Hall sensor and the Back EMF signal is 30 degrees.

Another aspect to be considered is very low-speed operation. Because Back EMF is proportional to the rotation speed, it would be at very low amplitude at very low speeds, making it difficult to detect the zero crossovers.

In addition, since the commutation itself is derived based on Back EMF zero crossovers, it is impossible to start the motor from standstill. To overcome this difficulty, the motor has to be started from standstill in open loop. When sufficient Back EMF is built to detect the zero crossover point, control is then shifted to the Back EMF sensing. The minimum speed at which the Back EMF can be sensed is calculated from the Back EMF constant of the motor.

B. Disadvantages

- The motor must be moving at a minimum rate to generate sufficient Back EMF to be sensed.
- Abrupt changes to the motor load can cause the Back EMF drive loop to go out of phase.

VI. APPLICATIONS

The BLDC motor is used for both consumer and industrial applications owing to its compact size, controllability and high efficiency. Increasingly, it is also used in automotive applications as a part of strategy to eliminate belts and hydraulic systems, to provide additional functionality and to improve fuel economy. The continuing reduction in cost of magnets and the electronics required for the control of BLDC motors has contributed to its use in an increasing number of applications and at higher power levels.

VII. CONCLUSION

This paper describes a fully working, highly flexible and reliable application for using the dsPIC18F to control BLDC motors without position sensors.

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