Sensorless Control of a Brushless DC Motor

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Digital signal controllers make it possible to meet motor torque and speed demands without employing rotor position sensors.

This article discusses a sensorless technique to control brushless direct current (BLDC) motors using a majority filter implemented on a digital signal controller (DSC). It is intended for the developer who wants to drive a sensorless BLDC motor using a new motor-control technique.

The technique, called sensorless trapezoidal control, eliminates the use of discrete, low-pass filtering hardware or off-chip comparators, while providing high efficiency and excellent performance. The algorithm utilises a majority function for digitally filtering the back-electromotive force (BEMF). Each phase of the motor is filtered to determine when to commutate the motor drive voltages.

Sensorless trapezoidal control has five parts:

- Sampling trapezoidal BEMF signals using the analogue-to-digital converter (ADC) peripheral on a DSC;
- Reconstructing the motor virtual neutral point;
- Comparing the trapezoidal BEMF signals to the reconstructed motor virtual neutral point to detect the zero-crossing points;
- Filtering the signals coming from the comparisons, using a majority-function filter; and
- Commutating the motor driving voltages.

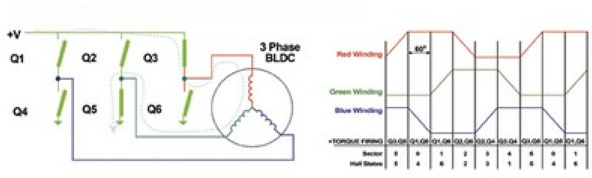

Fig 1. Six-step trapezoidal commutation process

Sensored vs. sensorless control

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 part of a strategy to eliminate belts and hydraulic systems, to provide additional functionality and improve fuel economy. The continuing reduction in the cost of magnets and the electronics required for the control of the BLDC motor has contributed to its use in an increasing number of applications, and at higher power levels.

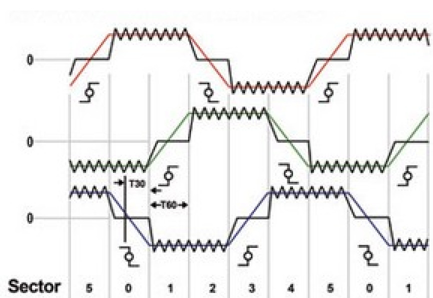

Fig 2. Ideal BEMF waveforms and zero-crossing points

The BLDC motor is usually operated with one or more rotor-position sensors, since the electrical excitation must be synchronous to the rotor position. For reasons of cost, reliability, mechanical packaging and especially if the rotor runs immersed in fluid, it is desirable to run the motor without position sensors, which is known as sensorless operation.

It is possible to determine when to commutate the motor-drive voltages by sensing the BEMF voltage on an undriven motor terminal during one of the drive phases. The obvious cost advantage of sensorless control is the elimination of the Hall position sensors. If low cost is a primary concern and low-speed motor operation is not a requirement, and the motor load is not expected to change rapidly, sensorless control may be the better choice for your application.

Six-step (trapezoidal) commutation

The method for energising the motor windings in the sensorless algorithm described in this article is called six-step trapezoidal, or 120 degree, commutation. Each step, or sector, is equivalent to 60 electrical degrees. Six sectors make up one electrical revolution. Figure 1 shows the commutation process.

For every sector, two windings are energised and one winding is not energised. The fact that one of the windings is not energised during each sector is an important characteristic of six-step control that allows for the use of a sensorless control algorithm. When a BLDC motor rotates, each winding generates BEMF, which opposes the main voltage supplied to the windings according to Lenz's Law. The polarity of this BEMF is in the opposite direction of the energising voltage. Figure 2 shows ideal BEMF waveforms and the zero-crossing points.

The BEMF waveform of the motor varies as both a function of the rotor's position and its speed. Detection of rotor position using the BEMF at zero and very 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. Likewise, there are many different methods of using the BEMF. The majority of these methods can be summarised as follows:

- Motor-terminal voltage sensing
- Mid-point voltage sensing
- Bus-current gradient sensing

The selected technique utilised the Mid-point voltage reconstruction and it is based on detecting the instances when the BEMF of an inactive phase is zero. The sensorless zero-crossing technique is suitable for a wide range of applications where closed-loop operation near zero speed is not required.

Assuming that only three motor leads are available for sensing the BEMF, the voltage at the star point of the motor must be determined because the BEMF waveform will be offset by the star-point voltage.

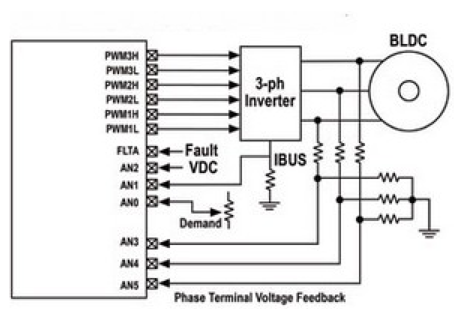

Fig 3: Digital signal controller

Most of the time, motor manufacturers do not wire the motor neutral point. However, it can be generated by software. Three networks are connected in parallel with the motor windings to sense the voltage at each phase. The neutral voltage is equal to the average of the phase signals. Figure 3 shows how the voltage is measured at each phase, using six resistors.

The reconstructed motor neutral voltage is compared to each BEMF signal to determine the zero-crossing events. A zero-crossing event exists when the BEMF signals are equal to the motor neutral point.

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