

# BLDC Motor Control

## Trapezoidal back EMF BLDC motor control techniques

### Three-Phase BLDC Motor

The brushless DC (BLDC) motor is also referred to as an electronically commutated motor. There are no brushes on the rotor, and commutation is performed electronically at certain rotor positions. The stator magnetic circuit is usually made from magnetic steel sheets. Magnetization of the permanent magnets and their displacement on the rotor are chosen in such a way that the back EMF (the voltage induced into the stator winding due to rotor movement) shape is trapezoidal. This allows a rectangular shaped three-phase voltage system (see figure 1) to be used to create a rotational field with low torque ripples.

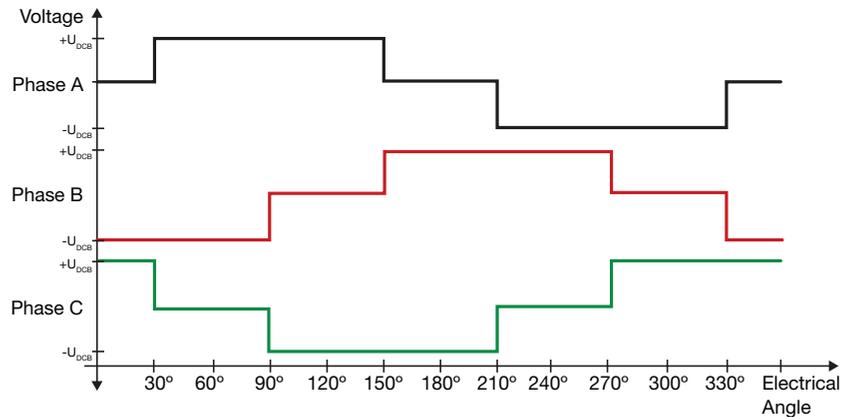
### Six-Step BLDC Motor Commutation

The rectangular shape of applied voltage ensures the simplicity of control and drive. The BLDC motor rotation is controlled by a six-step commutation technique (sometimes called 60, 120 degree control). The six-step technique creates the voltage system with six vectors over one electronic rotation as shown in figure 1. The applied voltage needs to have amplitude and phase aligned with the back EMF. Therefore, the BLDC motor controller must:

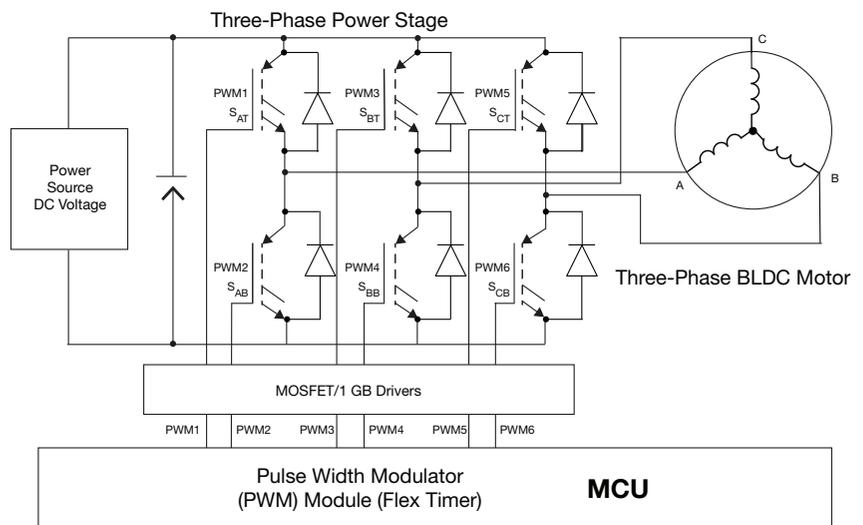
- Control the applied amplitude
- Synchronize the six-step commutation with the rotor position

The rotor position must be known at certain angles in order to synchronize the applied voltage with the back EMF (voltage induced due to movement of the PM). Under that condition, the BLDC

**Figure 1: Six-Step Commutation**



**Figure 2: Power Stage Topology**



motor is controlled with minimal torque ripple and maximal power efficiency.

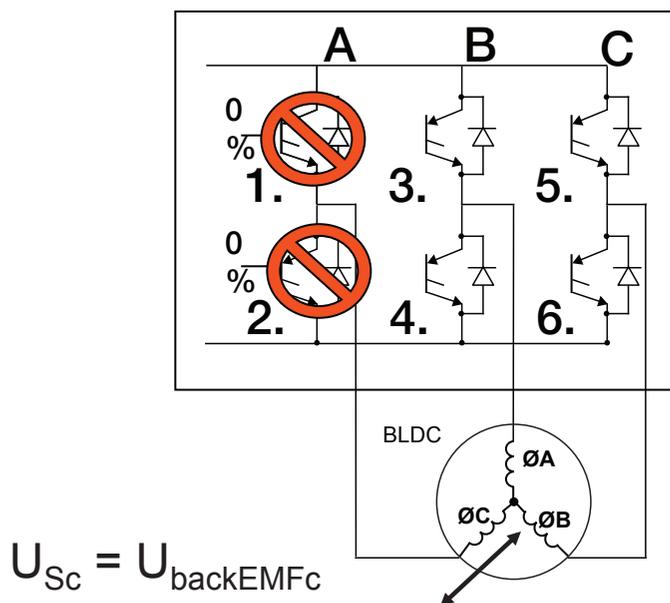
### Three-Phase Power Stage

The three-phase six-step voltage system is created by a three-phase power stage with six IGBTs (MOSFET) power switches controlled by the MCU on-chip PWM module.

### Voltage Amplitude Controlled by PWM

One possibility to control the three-phase six-step voltage amplitude is to have a variable power source DC voltage. This solution requires DC bus voltage controlled with quite complex topology. The benefit of such a solution is the lack of high-frequency current

**Figure 3: Six-Step Commutation Specifics**



ripples in the BLDC motor windings, resulting in lower loss (especially the motor magnetic circuit loss).

For the majority of the motors and applications, this is not critical and a constant power source DC voltage is used. The three-phase average voltage amplitude is then controlled by a PWM technique on the top and bottom transistors of two conducting motor phases (the third phase is off). The six-step controller uses one of two PWM techniques:

- Bipolar PWM switching
- Unipolar PWM switching

There are a few derivatives of the two PWM switching techniques. According to the operating quadrants of the power stage voltage and current:

- Four quadrant power stage control for motoring and generating mode
- Two quadrant power stage control with motoring mode only

The bipolar/unipolar switching and the operating quadrant control is

determined by all six transistors (Sat to Scb) switching as shown in Figure 2.

The four quadrant control requires complementary PWMs. The complementary PWM means that the bottom switch (transistor) is controlled with a signal inverted to the top switch transistor of the same phase. The two quadrant control does not require complementary control of the inverter switches. The unipolar PWM complementary switching is more popular due to lower loss. The applied voltage vector at one PWM cycle has the same polarity. The vector amplitude changes from DC bus voltage and zero. In the case of the bipolar PWM switching, the applied voltage vector polarity changes during the PWM cycle, so the applied amplitude changes from positive DC bus voltage to negative DC bus voltage.

The PWM frequency is usually constant at >10 kHz. However, a derivative of the PWM switching technique is a technique which can be used for very high motor speed

ranges. In that case, one PWM pulse per motor commutation is introduced. This also means the PWM frequency varies according to motor speed.

### Position Feedback

The rotor position must be known in order to drive a BLDC motor. This is provided with:

- Position sensors, or
- Sensorless

The solution with position sensors usually utilizes hall sensors. The main disadvantages are:

- Necessity for additional connections between position sensors and the control unit
- Cost of the sensors and wiring

Therefore, sensorless techniques are much more widespread today. There are two main groups for the sensorless techniques:

- Those based on back EMF sensing
- Low-speed techniques

The sensorless techniques based on back EMF sensing are dedicated for medium (>5 percent of nominal speed) to high-speed range because they require significant value of the induced back EMF voltage. This voltage is proportional to rotor speed.

The low-speed techniques are based mainly on motor inductance alteration on rotor position, so this does not require the back EMF and can be used at low-speed, or zero-speed control range. Some of these techniques require complex hardware which increases system cost. At high speed, the back EMF is more significant than the inductance alteration, so most of the controllers use a combination of a low-speed control technique with the back EMF based technique. Or, they use the back EMF techniques only.

## Sensorless Technique Based on Back EMF Zero Crossing

The rotor position estimation is based on the back EMF voltage induced in the stator phases due to rotor flux (permanent magnet) rotation. The back EMF voltage phase corresponds with the rotor position relative to stator position.

The six-step commutation specific feature is that one of the three phases is off at a time.

After the commutation transient (current recirculation, the fly-back diodes conduct the decaying phase current), the current of phase x:

$$I_{Sx} = 0 \text{ and so } U_{Sx} = BEMFC$$

The phase back EMF voltage zero crossing can be measured.

The back EMF zero crossing sensing can be provided using ADC or comparators that usually build inside the controller devices.

## Speed Controller

The motor rotation speed is usually controlled using the rotor position feedback provided to the speed regulator. The speed regulator controls the three-phase power stage PWM (applied voltage amplitude).

## BLDC Motor Control with PLL Commutation

One advantage of BLDC motor control compared to standard DC motors is that the speed can be exactly determined with the six-step commutation frequency. This allows for very accurate speed control. One of the benefits of accurate BLDC motor speed control is that the commutation period is constant and the six-step amplitude feedback is based on the phase difference between estimated back EMF zero crossing and the required zero crossing instant.

## Freescale Enablement

BLDC controllers usually require MCU or DSC devices with PWM, ADC, PDB and other modules supporting BLDC motor control. Freescale motor control devices support the BLDC motor control.

Reference designs, application notes and software solutions for BLDC motor control applications are available at [freescale.com/motorcontrol](https://www.freescale.com/motorcontrol).

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Document Number: BBCNTRLBLDCART REV 0