MM32 SPIN MCU non-inductive square wave **BLDC** motor drive principle article

Application Notes

AN6301

Non-inductive square wave **BLDC** motor driving principle

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1 Introduction

Brushless DC motors (BLDC) are widely used in

Popular areas such as robots, instrumentation, drones, and power tools. Square wave control has simple control algorithm, good speed regulation performance,

Cheap price and other advantages.

2. Principle of non-inductive square wave **BLDC** motor drive technology

1.1 BLDC motor

The full name of BLDCM is Brushless Direct Current Motor, which is a brushless DC motor and is a permanent magnet synchronous motor.

A type with permanent magnets mounted on the surface of the rotor and three-phase windings on the stator. The permanent magnets generate the rotor flux, while the energized stator

The winding creates the magnetic poles. The rotor (equivalent to a bar magnet) is phase attracted to the energized stator. by using the appropriate sequence

Powering the stator phases creates and maintains a rotating magnetic field on the stator. The natural magnetic poles of the rotor follow the rotating magnetic field of the stator

Orderly rotation to achieve the normal operation of BLDCM.

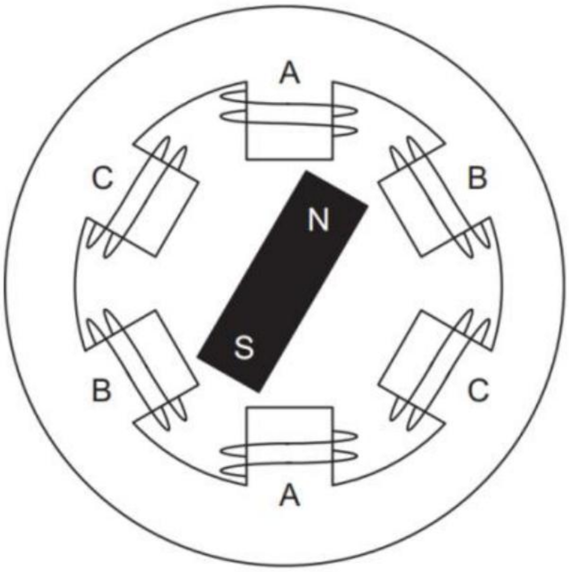


Figure 1. One-pole three-phase BLDC motor

A distinctive feature of the BLDC motor is that the back electromotive force characteristic is a trapezoidal wave, as shown in Figure 2. This makes the BLDC motor more

Suitable for six-step commutation control method to obtain greater output torque.

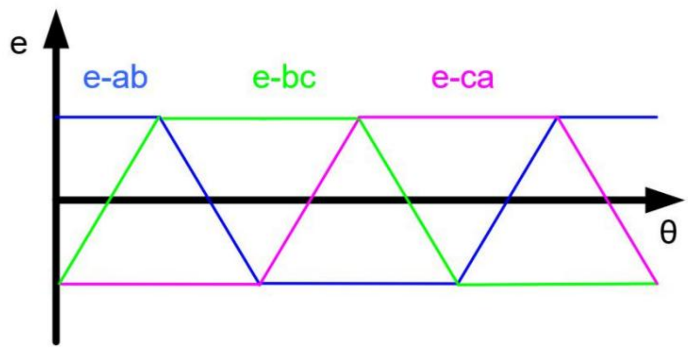


Figure 2. Three-phase BLDC motor back electromotive force

1.2 BLDC motor mathematical model

The three-phase stator voltage equation of the brushless DC motor is expressed in a matrix as follows:

$$\begin{bmatrix} in_A \\ in_B \\ in_C \end{bmatrix} = R_s \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L_{aa} & L_{ab} & L_{and} \\ L_{not} & L_{bb} & L_{bc} \\ L_{that} & L_{cb} & L_{cc} \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} It is_A \\ It is_B \\ It is_C \end{bmatrix} \quad (1\text{-}1)$$

Among them, , is the self-inductance of the phase winding, , , is the difference between the corresponding phase windings

Mutual induction, , , is the three-phase stator back electromotive force.

Under ideal conditions, the mutual inductance between the three-phase windings is also constant, regardless of the rotor position. Right now:

$$L_{aa} = L_{bb} = L_{cc} = L_s \quad (1\text{-}2)$$

$$L_{ab} = L_{ba} = L_{bc} = L_{cb} = L_{ac} = L_{ca} = L_M \quad (1\text{-}3)$$

The three-phase star connection structure derived from no neutral point can be obtained:

$$i_A + i_B + i_C = 0 \quad (1\text{-}4)$$

Substituting the above conditions into the three-phase stator voltage equation 1-1 and simplifying it, we can get:

$$\begin{bmatrix} in_A \\ in_B \\ in_C \end{bmatrix} = R_s \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + L \frac{d}{dt} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} It is_A \\ It is_B \\ It is_C \end{bmatrix} \quad (1\text{-}5)$$

in $L = L_s - L_M$;

The electromagnetic torque equation is, where is the mechanical angular speed of the motor (rad/s):

$$T_{It is} = \frac{eyes_{AABBCC}}{\omega_m} \quad (1\text{-}6)$$

The flat top of the trapezoidal wave back electromotive force is divided into 120° electrical angle, so the control of the brushless DC motor should be conducted in pairs.

The control method is a six-step commutation control scheme.

Considering that only two-phase windings are conducting at any time, the electromagnetic torque equation can be converted into Equation 1-7, where *E* m is the conducting phase

Amplitude of back electromotive force, *I* m is the amplitude of the conduction phase current:

$$T_{e} ÿ \frac{2 NQ_m \; m}{ÿ_m} \qquad ÿ1\text{-}7ÿ$$

According to Faraday's law of electromagnetic induction, the back electromotive force amplitude of the brushless DC motor is formula 1-8, where is the back electromotive force coefficient, N

is the equivalent number of turns of the phase winding, ÿ *m* is the main magnetic flux of the rotor permanent magnet, is the number of pole pairs of the motor, $nÿ \; ÿ_m /2ÿ$ is the motor speed:

$$I n_m ÿÿ \; {}_{in} ÿ \qquad ÿ1\text{-}8ÿ$$

Substituting equation 1-8 into electromagnetic torque equation 1-7, we can get:

$$\text{The } ÿKe \; ÿÿ_m \; ÿIm /ÿ \qquad ÿ1\text{-}9ÿ$$

It can be seen from Equation 1-9 that the electromagnetic torque of the brushless DC motor is proportional to the rotor permanent magnet flux and conduction phase current amplitude.

Proportional, so controlling the current amplitude of two conductive phases can control the torque of the brushless DC motor.

1.3 Motor drive principle

The brushless DC motor is a type of permanent magnet synchronous motor, with permanent magnets mounted on the surface of the rotor and three-phase windings on the stator.

The permanent magnets generate the rotor flux, while the energized stator windings generate the magnetic poles. The rotor (equivalent to a bar magnet) is energized to set

Sub-phase attraction. By using an appropriate sequence to power the stator phases, a rotating magnetic field is created and maintained on the stator.

The inherent magnetic poles of the rotor rotate in an orderly manner following the rotating magnetic field of the stator to achieve the normal operation of the BLDCM.

The core device of the non-inductive BLDC motor (three-phase) square wave drive is an inverter circuit composed of 6 MOS tubes. The structure is "

Up N Down N" or "Up P Down N", it converts direct current into alternating current and changes the amplitude and frequency of the alternating current to control the motor's

operation. The principle of the three-phase inverter circuit is shown in Figure 3.

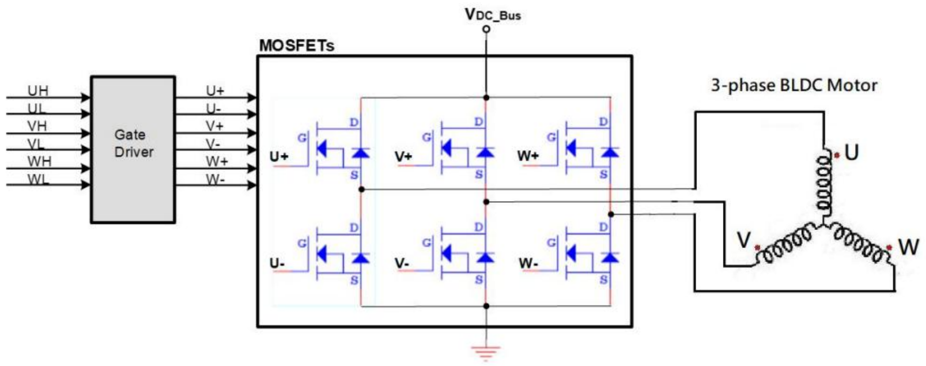


Figure 3. Three-phase inverter circuit

How can I make the motor run normally? Figure 4 is the schematic diagram of the six-step commutation control method. Through six-step commutation control, the total

A total of six possible stator flux vectors can be obtained. When the stator flux vector is changed at a specific rotor position, the motor can

Rotate it once so that the motor runs normally.

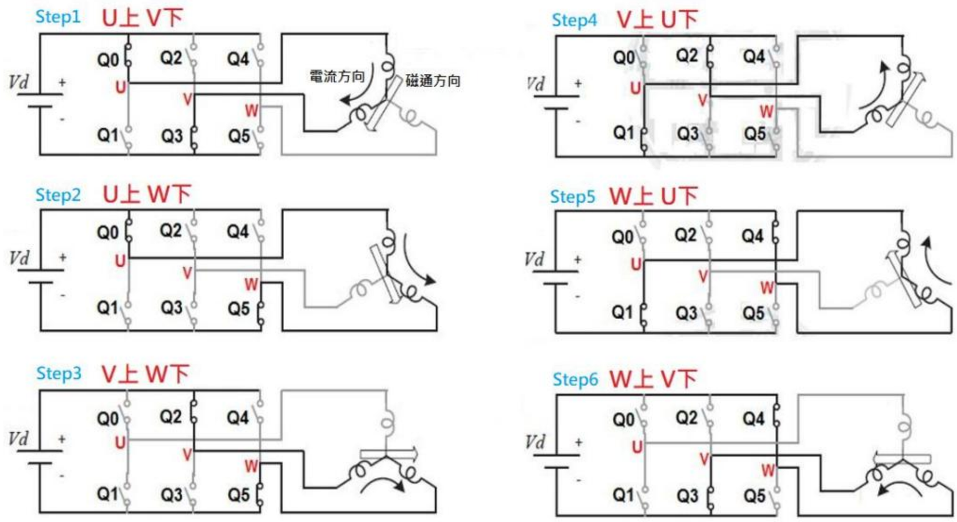


Figure 4. The six switching states of three-phase BLDC correspond to the magnetic flux direction.

1.4 Rotor position detection

1.4.1 Rotor position acquisition method

The core of brushless DC motor control is to obtain the commutation moment, that is, to obtain the rotor position.

There are two types: position sensor and position sensorless.

Control with position sensors will bring certain disadvantages to the application of brushless DC motors:

1) Increases the size and cost of the motor;

2) The addition of sensors reduces the reliability of the brushless DC motor, and the installation accuracy of the sensor will also affect the brushless DC motor.

machine performance;

3) Position sensors are not suitable for some special applications.

Therefore, research on position sensorless brushless DC motor control has become mainstream.

1.4.2 Position sensorless method

The control strategies of brushless DC motors can be mainly divided into back electromotive force method, freewheeling diode method, inductance method, flux linkage function method, and fixed

Sub-third harmonic method, etc. Among them, the back electromotive force method is the most widely used and technically mature solution.

As long as the zero-crossing point of the back electromotive force of each phase winding can be detected, six key positions of the rotor can be obtained within one electrical cycle. non-guided

The commutation point is delayed by 30° electrical angle from the zero-crossing point of the reverse potential. This method is achieved by detecting the zero-crossing point of the phase winding back electromotive force.

The algorithm of sensorless six-step commutation control of brush DC motor is the back electromotive force method.

Simply put, the back electromotive force method is to detect the terminal voltage of the non-conducting phase and compare it with the neutral point voltage of the brushless DC motor.

Compare. Generally, the neutral point of a brushless DC motor cannot be drawn out, and in some PWM modulation methods, the voltage at the neutral point and the motor terminal changes with the

PWM modulates regular pulsations, so special processing is required to detect back-EMF zero crossings. Current back electromotive force zero crossing point check

There are three main methods of testing:

1) Detect the non-conducting opposite potential at the moment when PWM is turned on, and compare it with half of the bus voltage to find the zero-crossing point.

This method is only suitable for certain PWM modulation methods.

2) Use a three-phase symmetrical star resistor network to construct a virtual neutral point and perform low-pass filtering on the motor terminal voltage that needs to be detected.

The zero crossing point is found by comparison with the comparator. The principle and method of this method are simple and do not require synchronization with PWM modulation.

Therefore it is widely used. Because this solution filters the motor terminal voltage, it will cause phase delay, thus affecting the feedback

The accuracy of potential zero-crossing detection requires software processing.

3) Use ADC sampling to convert the motor terminal voltage into a digital signal, calculate it, and compare it with the analog neutral point voltage.

This solution saves the cost of the analog comparator, but requires the ADC sampling accuracy and speed of the microcontroller as well as the computing power.

There are requirements for strength. When the motor speed is high, the zero-crossing point cannot be accurately detected.

No matter which solution is used, special attention needs to be paid to avoid the impact of commutation freewheeling on back electromotive force detection and avoid freewheeling.

This leads to inaccurate zero-crossing point detection, leading to commutation failure.

1.4.3 Brushless motor terminal voltage detection

Ideally, the mathematical model of the brushless DC motor terminal voltage is as follows:

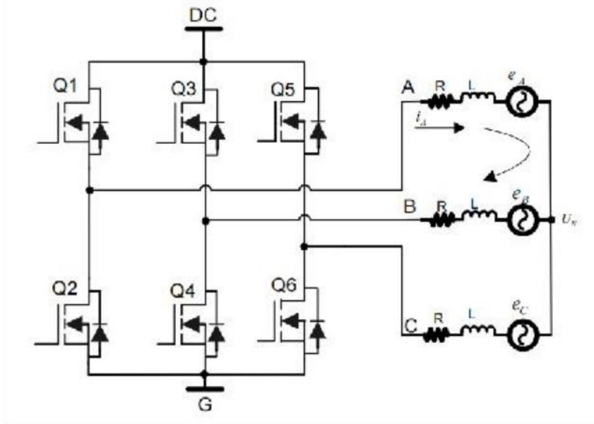
$$\begin{cases} U_{AG} = Ri_A + L\dfrac{di_A}{dt} + e_A + U_N \\ U_{BG} = Ri_B + L\dfrac{di_B}{dt} + e_B + U_N \\ U_{CG} = Ri_C + L\dfrac{di_C}{dt} + e_C + U_N \end{cases} \quad (1)$$

U_{AG}、U_{BG}、U_{CG}：端电压

U_N：中性点电压

e_A、e_B、e_C：三相反电动势

R、L：绕组的等效电阻和等效电感



AB相导通，C相浮空电流回路示意图

Figure 5. Mathematical model of brushless motor terminal voltage

When detecting the zero-crossing point of phase C (floating phase i = 0), the relationship between winding back electromotive force and current:

$$\begin{cases} e_A + e_B + e_C = 0 \\ i_A + i_B = 0 \end{cases} \quad (2)$$

(1) Add the voltages at the two phase terminals of Formula AB to get:

$$U_{AG} + U_{BG} = R(i_A + i_B) + L\left(\frac{di_A}{dt} + \frac{di_B}{dt}\right) + (e_A + e_B) + 2U_N \quad (3)$$

Substituting equation (2) into equation (3), we get:

$$U_N = \frac{U_{AG} + U_{BG}}{2} - \frac{e_A + e_B}{2} \quad (4)$$

Substituting equation (2) and equation (4) into equation (1), we get:

$$e_C = U_{CG} - U_N = U_{CG} - \frac{U_{AG} + U_{BG}}{2} + \frac{e_A + e_B}{2} \quad (5)$$

1) When phase C crosses zero point, eC = 0, UCG = UN , UN = (UAG + UBG)/2;

2) When phase C crosses zero, eC > 0, and UCG > UN ;

3) When phase C crosses zero, eC < 0, and UCG < UN .

UAG, UBG, and UCG are the A, B, and C phase terminal voltages respectively ; UN is the virtual neutral point voltage.

1.4.4 ADC sampling to detect zero crossing point

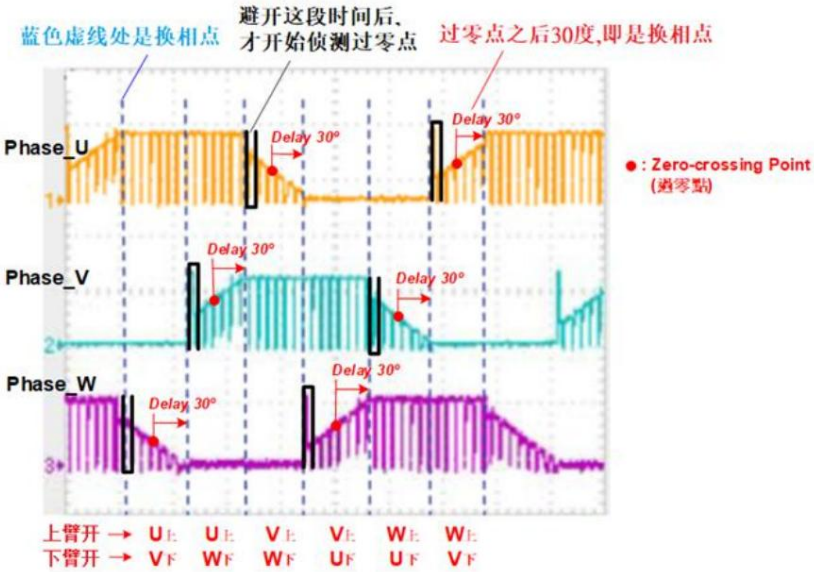


Figure 6. Zero-crossing detection and delayed commutation

Before using the MCU's ADC to detect the zero-crossing point, the phase voltage must be divided first and then low-pass filtered to obtain a voltage lower than

5V voltage. The threshold for judging the zero-crossing point is set to 1/2 of the DC voltage amplitude. As the motor speed and load vary,

The amplitude of the DC voltage will change. Therefore, the threshold of the zero-crossing point is also adjusted, which can be sampled and calculated by the MCU in real time.

And the schematic diagram is as follows:

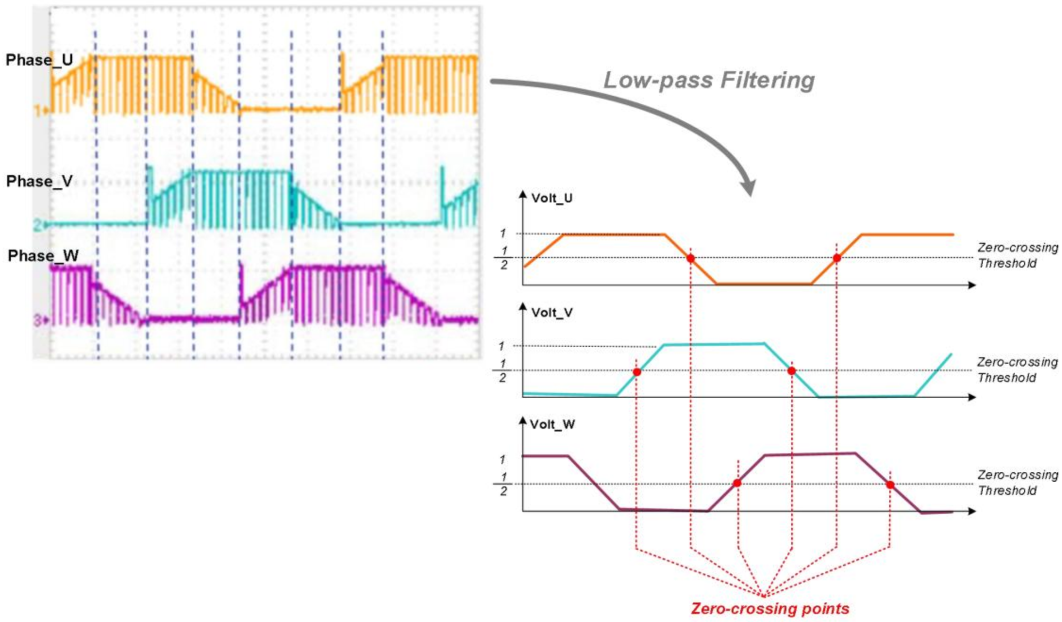
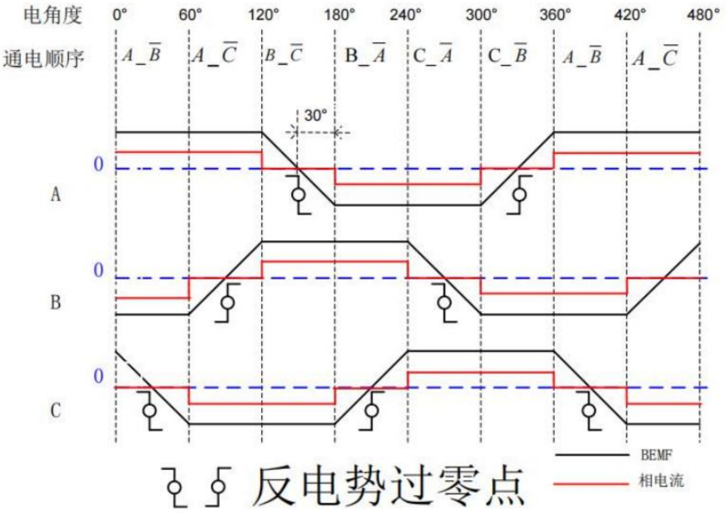


Figure 7. Implementation of zero-crossing detection

1.4.5 Comparator detects zero crossing point

Using a comparator to compare the floating phase terminal voltage and the virtual neutral point signal, the back electromotive force zero-crossing signal can be obtained, which

The timing is shown in the figure below.



Electrical angle	0ÿ60°	60ÿ120°	120ÿ180°	180ÿ240°	240ÿ300°	300ÿ360°	360ÿ420°
Power-on sequence	A_ B	A_ C	B_ C	B_ A	C_ A	C_ B	A_ B
floating air phase	C	B	A	C	B	A	C
Trigger edge	falling edge	rising edge	falling edge	rising edge	falling edge	rising edge	falling edge

Figure 6. Corresponding relationship between zero-crossing state and switching tube

3.Abbreviations and symbols

the term	meaning
MM32	Smart Microelectronics
BEMF	Counter electromotive force
BLDCM	Brushless DC motor
PMSM	Permanent magnet synchronous motor
DC	direct current
GPIO	General purpose input/output
ADC	Analog to Digital Converter

OPA	Operational Amplifier
ISR	interrupt service routine
CMP	Comparators
PWM	pulse width modulation
DCBus	DC bus

Table 1 Abbreviations

symbol	definition
R_s	Stator phase resistance
L_s	Stator phase inductance
P_p	Number of motor pole pairs
T_e	Electromagnetic torque

Table 2 Symbol index list

Modify records

Version	content	date
V1.0	Initial issueÿ	2022/3/31