The Control System Design of BLDC Motor

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Abstract. According to the existing theory, the control scheme of square wave BLDC motor is designed. The scheme mainly includes the single closed-loop speed control part, the PWM signal control part and the gate control signal calculation part. The simulation program was established according to the control scheme. The simulation program mainly consists of four modules: speed control module, inverter bridge module, brushless DC motor module, detector and gate signal conversion module. The simulation results show that the proposed control scheme has the advantages of high stability, fast response capability and low complexity.

1. Introduction

With the continuous expansion of brushless dc motor applications, various control algorithms and control strategies are emerging. In order to facilitate theoretical analysis and verification of various control algorithms and strategies, it is very important to establish a model of dc brushless motor control system. At present, the scheme of brushless dc motor is divided into sine wave and square wave control. In this paper, the control scheme is designed based on the square wave control theory. The control system of brushless dc motor is modeled and simulated with the "Simulink" simulation toolbox from the software "MATLAB". The simulation results show that the simulation model is consistent with the theoretical analysis.

2. Design and Simulation

2.1 Brushless DC Motor Control System Design

The single closed-loop speed control brushless DC motor control scheme can be divided into three parts, namely single closed-loop speed control part, PWM signal control part, and gate control signal calculation part. The complete control scheme is as follows:

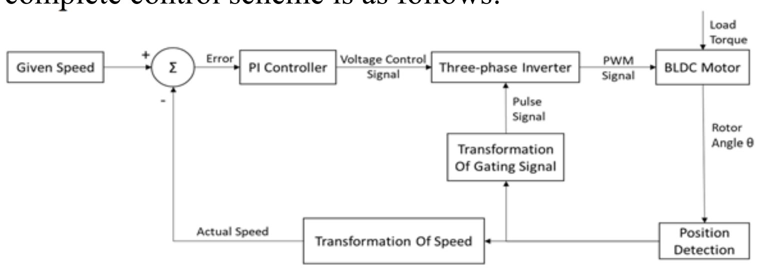

Figure 1. Complete flow chart of BLDC Motor Control System

The error is calculated by the difference between the given rotation speed and the actual rotation speed of the motor, and then calculate the voltage control signal through the PI controller. The three-phase inverter combines the gated pulse signal and voltage control signal to give the actual PWM voltage signal waveform. Based on the generated magnetic field of the PWM voltage signal waveform, the permanent magnet rotor is driven to move. During the rotation of the motor, the mechanical angle is obtained by the position detection device when the rotor is rotating. After the angle is converted into the degree measure, it is sent to the speed conversion module and the gate signal conversion module respectively, and the actual speed is sent back to the comparator in the speed conversion module. The gating pulse signal is calculated according to the six commutation rules in the gate signal conversion module.

2.2 Single Closed-Loop Speed Control Section Design

The speed control part adopts PI controller. The error obtained after the difference between the given speed and actual speed is obtained through proportional enlargement/reduction and integral summation, respectively, to calculate the current error and past accumulation. Errors are finally passed to the process for control improvement.

2.3 PWM Signal Control Section

To change the phase and amplitude of the applied voltage across the motor, it can be achieved by inputting pulse voltages with different duty cycles. This is Pulse Width Modulation. The theoretical basis is the principle of area equivalence, that is, when the narrow pulse with equal impulse and different shape is added to the link with inertia, the effect is basically the same. Impulse refers to the area of a narrow pulse. The effect is basically the same, which means that the output response waveform of the link is basically the same. The low frequency band is very close, only slightly different in the high frequency band. Therefore, if you want to change the phase and amplitude of the voltage across the motor to generate a rotating magnetic field, you can achieve this by equating the sine wave with voltage pulses of different duty cycles.

The voltage pulses of different duty ratios will be obtained by using an inverter bridge as shown in the structure diagram of the three-phase inverter bridge in Figure 2.

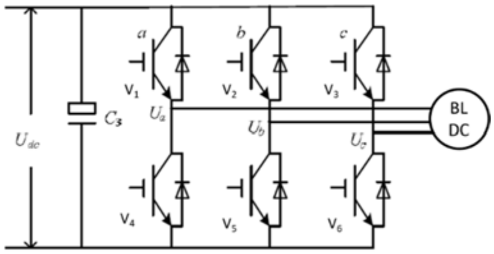

Figure 2. The structure diagram of the three-phase inverter bridge

That is, by inputting different gating signals, different switch tubes are controlled to be turned on and off to generate pulse voltages with different duty ratios. The inverter bridge has a total of three groups of six, which are used to control the voltages of the three phases and finally synthesize a rotating magnetic field. It is worth noting that the input of the inverter bridge is not only the gating signal, but also the terminal voltage UDC. The size of the UDC is provided by the front part of the PI controller. To sum up, the terminal voltage determines the speed of the motor. The gate signal determines that the motor can continue to operate.

2.4 Gating Signal Calculation Section

The rotation of the rotor of Brushless DC motor depends on a rotating magnetic field, while the rotation of the magnetic field relies on the constant change of the three-phase alternating voltage to the stator.

The three-phase ac voltage of different phases can produce magnetic fields in different directions.

Therefore, in order to determine if a moment to give what the direction of the magnetic field, rotor must first know the position of the rotor, which is the Angle of the mechanical rotor, then according to the Angle of conversion, determine a set of exact door switch control signal to control the inverter bridge, corresponding to the magnetic field generated to guide the rotor continues to rotate.

In this study, a six-step commutation method was used. The principle is shown in Figure 3.

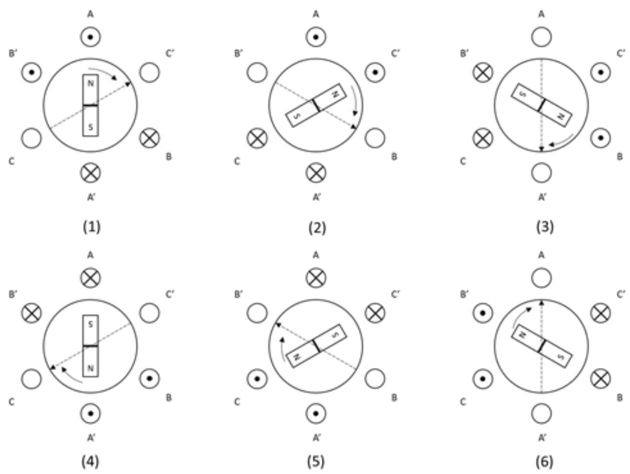

Figure 3. The six-step commutation method.

The rotor is replaced by a permanent magnet. When the stator is energized, it uses a two-pass and one-floating method. The first step is shown in (1) in the figure. The AB phase is energized, the current enters from phase B, flows from phase A, and phase C is vacant. Corresponding to Figure 2, the V2 and V4 switches in the three-phase full-bridge inverter bridge structure are opened and the others are shut down. A magnetic field in the direction of the CC' leads to the rotation of the rotor. As shown in (2) in the second step, the AC phase is energized, the current enters from the C phase, flows out of the A phase, and the B phase floats. Corresponding to Figure 2, the three-phase full-bridge inverter bridge structure has V3 open, V2 is off, and the rest remains unchanged (including V4 does not change), resulting in a magnetic field guided rotor rotation in the B'B direction. The same applies to other steps. It is called six-step commutation. As can be seen from the above, the six-step commutation can ensure that only one switch is turned on and one switch is turned off at a time, which reduces the frequency of the switch, prolongs the service life of the inverter, and enhances the safety.

From the above derivation, the gated switch sequence of Table 1 can be derived. From this table it is possible to calculate the output of specific gating signal pulses.

Table 1. The gated switch sequence

Rotor Angle θ	**Current of the Stator**			**Switch of the Inverter**					
	A	**B**	**C**	**V1**	**V2**	**V3**	**V4**	**V5**	**V6**
0°-60°	Out	In			On		On		
60°-120°	Out		In			On	On		
120°-180°		Out	In			On		On	
180°-240°	In	Out		On				On	
240°-300°	In		Out	On					On
300°-360°		In	Out		On				On

3. The Design of the Simulation Program of BLDCM

The simulation of this research is based on MATLAB R2017a software and adopts Simulink simulation system. It is divided into four modules for the construction of a brushless DC motor control system. They are respectively the speed control module; inverter bridge module; brushless DC motor module; detector and gate signal conversion module. The complete simulation system flow chart is as follows:

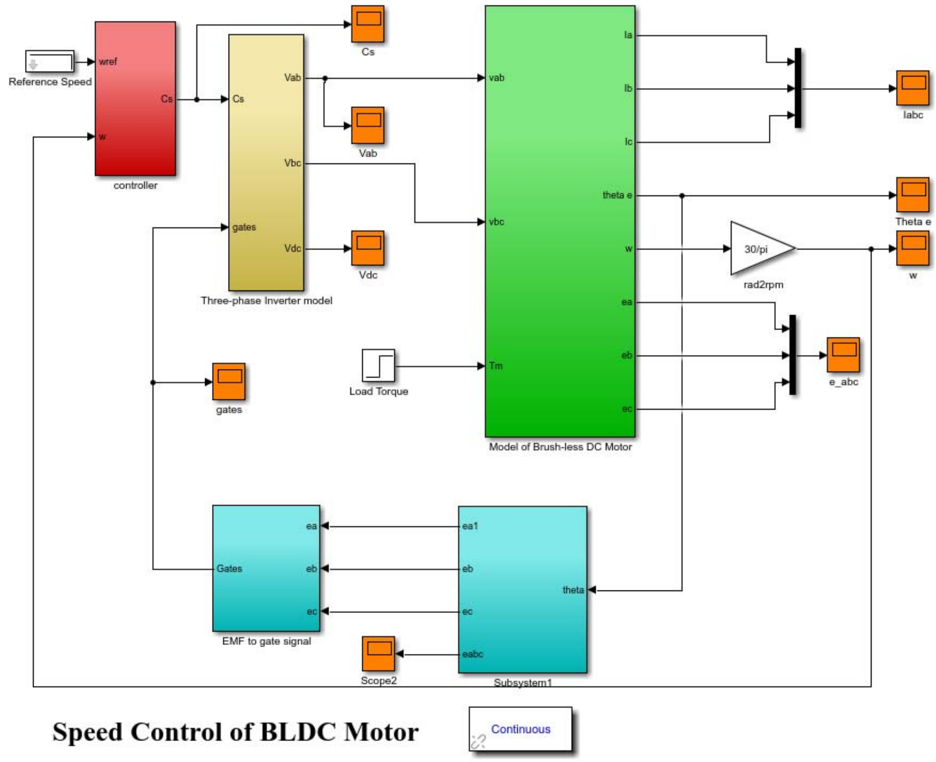

Figure 4. The complete simulation system flow chart

The red square in the figure is the PI speed controller module, the input is the given speed and actual speed, the output is the correction signal of the speed difference; the yellow box is the three-phase inverter module, the input is the correction value and gate of the speed difference The signal, the output is the supply voltage and the three-phase voltage PWM value; the green box is the BLDC motor module, the input is the three-phase voltage PWM signal and the given load torque, the input is the armature current value, the back EMF, the actual speed and the rotor in real time The position signal; The cyan square is the detector and the gating signal conversion module, the input is the radian value of the real position of the rotor, the output is the gating signal.

The running time of the entire simulation system is 1 second, and the given speed is 2000 revolutions in the first 0.5 seconds and 1000 revolutions in the next 0.5 seconds. Given speed parameter changes from 2000 rpm to 1000 rpm.

3.1 PI Speed Controller Module

At the PI speed controller module, the wref is a given speed signal, w is the actual speed signal. The difference between these two signals is then divided into two parts. The proportional part is given a gain factor K (take 0.15). The larger the proportional gain factor, the more sensitive the feedback, but if it is too large, it will result in significant fluctuations. It may even cause oscillations. The integral part is given a gain factor of 75, which is then integrated over time. The integral part is mainly used to collect the cumulative error of the past, ensuring a smoother feedback signal. The addition of the proportional signal P and the integral signal I results in the feedback signal CS of the system.

3.2 Three-Phase Inverter Module

The CS signal in the figure controls the voltage magnitude of the controllable AC voltage source, which can be measured by the output Vdc of the voltmeter. The green square is a three-phase inverter bridge, which receives a voltage value and a gating signal, and generates a corresponding PWM modulation voltage signal V_a, V_b, V_c according to the gating signal, which can be measured by a voltmeter V_{ab}, V_{bc}.

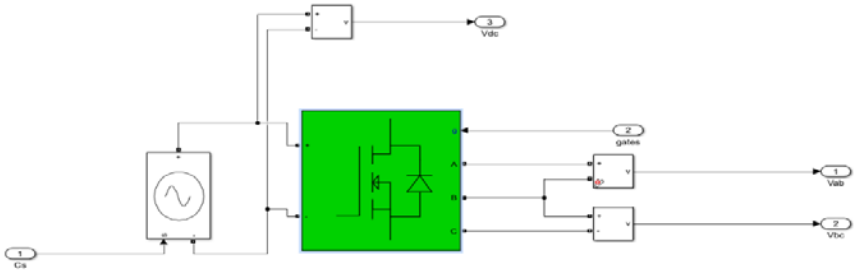

Figure 5. Three-phase inverter module

3.3 BLDC Motor Module

BLDC motor module can be divided into three parts, which are current generation module, speed generation module and back-EMF generation module. The speed output can be detected that the motor can run smoothly at 2000 and 1000 rpm after the initial fluctuations according to the given speed.

Since the parameter simulation of the motor does not belong to the motor control system design, it will not be elaborated here.

3.4 Detector and Gate Signal Conversion Module

In the detector module, firstly, the radian value of the real-time position of the collected rotor is converted into an angle value, and then a discriminant function is provided to output different signals for different angle values. Rotor real-time position of the radian and angle values see figure 6:

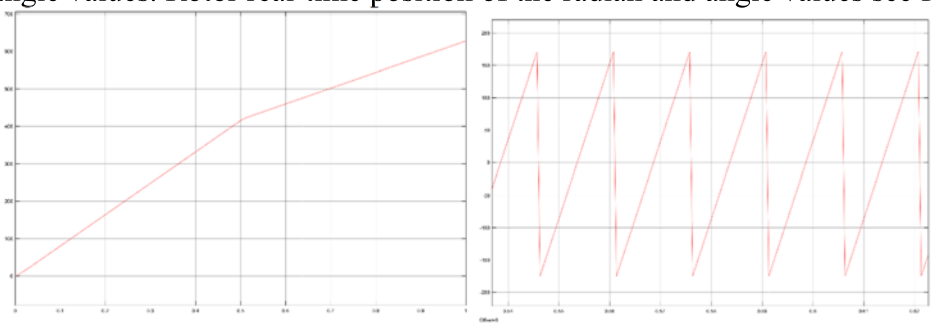

Figure 6. Rotor real-time position of the radian (left) and angle values (right)

It can be seen from the figure that under the radian system, the radian of the rotor is continuously increasing, and since the speed is faster in the first 0.5 s, the radian value is also increased faster. In the angle system, the interception is part of the time and the angle can be seen. Always change from -180 degrees to 180 degrees. The changing angle value will be based on the following (1) discriminant function to obtain the corresponding step model. The u is the input angle value and the y are the output step signal.

$$y=\begin{cases} [-1 \quad 0 \quad 1] & -180<u\leq-120 \\ [0 \quad -1 \quad 1] & -120<u\leq-60 \\ [1 \quad -1 \quad 0] & -60<u\leq0 \\ [1 \quad 0 \quad -1] & 0<u\leq60 \\ [0 \quad 1 \quad -1] & 60<u\leq120 \\ [-1 \quad 1 \quad 0] & 120<u\leq180 \end{cases} \tag{1}$$

The output image of the signal y is shown in figure 7. The more dense the signal, the faster the rpm change. From the right figure, we can see that the commutation signal is a commutation, a total of 6 steps, so called six-step commutation.

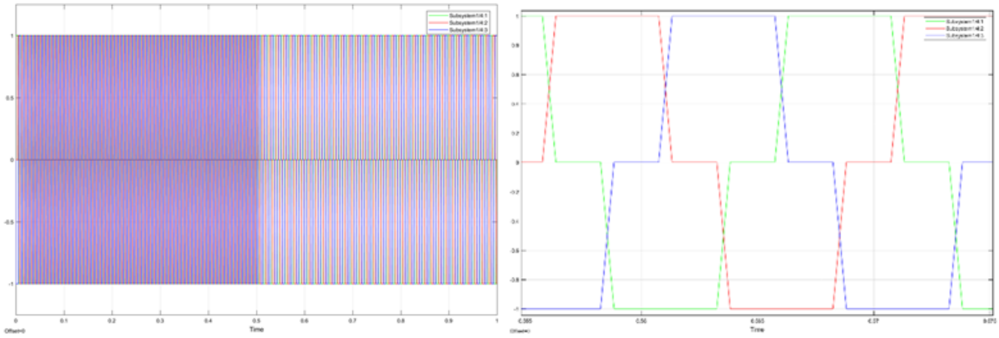

Figure 7. The output of the signal y (left) and detail view (right)

Since the step signal has a positive and negative signal, it is required to transform. Through the gated signal conversion module, all the signals become binary signals. This signal can control the output PWM modulation voltage of the three-phase inverter module to control the motor rotation.

4. Conclusion

Through the above simulation experiments, the rotor rotation Angle and the counter electromotive force are the same as the theoretical waveform and will change with the change of the given speed. The actual speed also changes synchronously with the given speed. In this case, the actual motor speed of the motor is reduced from 2000rpm to 1000rpm. On the other hand, the jitter of the motor is also small, and the speed is stable. In the case of low accuracy of motor speed, it is only necessary to meet the performance of variable speed, such as small electric fan, electric tool, etc. This theoretical model has a quick response, simple algorithm and stable control, which can satisfy the control of brushless dc motor in these situations.

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