A New Type Hi-Speed BLDC Control System Base on Indirect Current Control Strategy

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Abstract. High speed BLDC has the characteristic as larger air gap smaller armature inductance, traditional PWM modulation will produce a great number of high frequency current harmonics which led problem like large torque ripple and serious motor heat. In the meantime traditional PWM modulation use the diode rectifier which cause harmonic pollution in electric power net. To solve the problem above, proposes a new motor controller topology. Using the IGBT device to replace the diode on frequency converter rectifier side, apply the power factor correction technology, reduce the pollution on the grid. Using busbar current modulation on the inverter, driving bridge-arm use 3-phase 6-state open as driving Mode, realize the control on a 10000r/min,10kw BLDC. The results of Simulation on matlab show the topological structure as proposed can effectively improve the network side power factor and reduce the motor armature winding harmonic and motor torque ripple.

1. Introduction

Compare with general motors, high speed BLDC has smaller volume; smaller inertia, faster dynamic response; higher efficiency of the transmission system and precision, which make it widespread used in the area of servo control, numerically-controlled machine tool, robotics, etc. High speed BLDC get few number of turns which led very small terminal inductance [1]. When use the traditional PWM modulation will produce the great number of high frequency current PWM harmonics which led a great number of non-conducting phase follow current and motor torque ripple. Literature [2] use motor drive circuit based on the buck converter PAM modulation to solve this problem, which can effectively suppressed forward and reverse follow current cause by terminal voltage zero-crossing which cause by lagging commutation conducting phase shut-before winding current peak, but because of traditional PWM modulation use the diode rectifier, the grid side current will produce harmonic and reduced the power factor, that will cause the pollution of the grid. Literature [3] proposed a PWM rectifier base on 3-phase VSR and BUCK circuit, it has the advantage of current waveform sinusoidal, little harmonic, high power factor, but it has further research on the applicability of high speed motor. Given on the basis, proposed a motor drive circuit topological structure base on 3-phase controlled rectifier bridge indirect current modulation method and then computer simulation is obtained [4].

2. The foundation of BLDC mathematical model

Take the example of the 3-phase 6-state square-wave motor BLDC with two mosfets, to analyze BLDC mathematical model and electromagnetic torque characteristic, suppose [5]:

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In the equation:

Mechanical movement equation is:

Electromagnetic torque equation is:

Simultaneous equation

Three-phase winding voltage balance equation can be expressed as:

In the equation: \( U_a, U_b, U_c \) is the phase winding of the stator voltage; \( i_a, i_b, i_c \) is the phase winding of the stator current; \( e_a, e_b, e_c \) is the stator winding back emf; \( L \) is the one phase winding inductance; \( M \) is the mutual inductance between every two phase winding; \( p \) is the differential operator \( p=d/dt \).

Suppose 3-phase winding is wye-connected and there is no central line, there are:

Simultaneous equation (1) (2) (3), get voltage equation:

Electromagnetic torque equation is:

In the equation: \( T_e \) is electromagnetic torque; \( \omega \) is electrical machinery rotational speed.

Mechanical movement equation is:

In the equation: \( T_L \) is the load torque; \( J \) is the rotational inertia of motor.

Basic on the equation (4) (5) (6), the BLDC mathematical model can be found. At the same time the parameters of motor used in this paper is given: rotational inertia \( J=0.0018164 \text{kg} \cdot \text{m}^2 \), damping coefficient \( B=0 \), back EMF coefficient \( K_e=0.021 \), winding single-phase resistance \( r=0.02 \Omega \), one phase winding inductance \( L=245 \mu \text{H} \), mutual inductance between every two phase winding \( M=40 \mu \text{H} \), number of pole-pairs \( p=2 \), rated speed \( \omega=10000 \text{r/min} \), rated power \( P=10 \text{kW} \). The carrier frequency of system is 10kHz, input load torque 10N·m launch after 0.01 seconds input.

3. traditional PWM control

PWM control is the technique that modulated the pulse width, it means through a series of pulse width on modulation, to equivalent to obtain waveform needed [6]. Figure 1 is the typical low speed double closed-loop BLDC control block diagram.
According to literature [7], when carrier frequency of system is 10kHz, the inverter output voltage waveform show up significant harmonic function, not only appear the burr, but also amplitude will change over time in constant ups and downs, thus the output current and electromagnetic torque of the motor will show greatly influence. According to the parameters of BLDC show in the first quarter, the figure 2 (a) (b) (c) is the motor single-phase current waveform, the electromagnetic torque waveform and the current/voltage waveform on the grid side can be created [8].

Figure 1. Double closed-loop BLDC control block diagram

Figure 2. BLDC waveform under the traditional PWM control
4. A new type of BLDC control system

4.1. The competition of CSR and VSR
According to the difference of topological structure, rectifier could be divided into voltage source rectifier (VSR) and current source rectifier (CSR) [9]. If using 3-phase VSR, in order to realize voltage matching between the motors, general increase one level of BUCK circuit in the rectifier output. Compare with this, 3-phase CSR can directly control the DC current, and the output voltage from 0-1.5Vm is controllable. According to literature [10] calculation, When the rated output is 10.5Kw and below, from the point of system efficiency and power density, 3-phase CSR circuit structure has an advantage over 3-phase VSR, and VSR-BUCK is two stage topological structure, which more complex on the control system. In conclusion, choose current source rectifier as frequency converter rectifier part.

4.2. topological structure principle
Converter topological structure shown as Figure 3, add 3-phase current source rectifier to the front of the 3-phase inverter bridge. Different from the traditional inverter topology, using IGBT to replace the diode-bridge rectifier, thous to realized the controllable on rectifier can greatly improve the power factor of netside. Because of use CSR, filter capacitance is added on the AC side, composite with the filter inductance on the netside become LC filter which can effectively suppressing The high frequency harmonic components on the netside current [11]. 3-phase inverter apply on 3-phase 6-state open, by this time the sampling current value on DC bus in every conduction zone, the impulse will not appear, could truely reflect the reality of the conduction phase current [12].

![Figure 3. Topological structure](image)

4.3. The analysis of simulation result
Show the validity of this method by comparing the simulation result. Figure 4 is the current/voltage waveform on the grid side by using new BLDC control system. Figure 5(a) (b) is the motor single-phase current waveform and the electromagnetic torque waveform. From the figures show the system can realizes the operation of unity-power factor and the current on grid side sinusoidal. Compare with traditional PWM modulation show it has the advantage of low harmonic distortion and fine torque ripple suppression.

![Figure 4. Current/Voltage waveform on the grid side](image)
5. Conclusion
On the basis of analyze the character of the high speed BLDC and traditional control method, improve the traditional control method and the topological structure, and made then appropriate simulation investigations. The result show when use the proposed topology can effectively improve the network side power factor and reduce the motor armature winding harmonic and motor torque ripple.

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