Comparative analysis of the performance influence of isolated bus open-end winding BLDCM and star-end winding BLDCM

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Abstract: The open-end winding motor (OEWM) system is a hot spot of current scholars' research due to its advantages of large output power, wide speed range, and strong fault tolerance. Through Maxwell and Simploer software co-simulation, the open-end winding brushless direct current motor (OEWM-BLDCM) and the star-end winding BLDCM under three-phase six-state control mode are compared and analyzed, including conduct current, torque, speed and mechanical characteristics. The simulation results show that: OEW-BLDCM has faster response speed, smaller torque ripple, and doubled the maximum speed.

1. Introduction:
The OEWM system is a motor system that only opens the neutral point of the stator winding of the traditional motor without changing the electromagnetic design of the motor, and the two ends are connected to the converter. Compared with the traditional motor system, it uses two inverters for power supply, with higher output voltage, higher utilization of DC bus voltage, wider speed range, greater freedom of control of each phase winding current, stronger fault tolerance, and application in the field of high safety, wide speed range and high power [1-2].

Isolated bus open-end winding motor topology, double-ended inverters are powered by independent power sources, which can achieve Multi-source hybrid application without zero-sequence current. Literature [3] proposed a unified space vector modulation algorithm to modulate an open-end winding permanent magnet synchronous motor with an isolated bus topology to improve the output performance of the system, and mentioned it as a drive motor for electric vehicles. Literature [4] mentions the application of an open-end winding motor topology with a dual-power isolated bus structure to dual-energy source electric drive vehicles. Literature [5] studied the problem of overcharging of the low-voltage side Z-source capacitor of an open-end winding permanent magnet synchronous motor with an isolated bus structure based on the Z-source network.

Researches on the control methods of OEWM, including a large number of researches are carried out on the basis of traditional star-end winding motor control methods. Literature [6] uses space voltage vector modulation that does not generate zero sequence voltage to reduce the zero sequence current of the system; Literature [7] uses 60°decoupling space voltage vector to eliminate the instantaneous value of zero sequence voltage; Literature [8] uses shift Phase 120°decoupling the space voltage vector to obtain a wider output range and smaller zero-sequence voltage; Literature [9] studied the direct torque control of an open-winding motor; In the conduction mode of two-by-two conduction, three-phase and six-state, there are few research literatures on open-end winding motors, and it is of certain significance to compare the performance of star-end winding motors.
2. Two-by-two conduction three-phase six-state control mode of OEW-BLDCM

Figure 1 shows the isolated bus open-winding motor topology. The neutral point of the traditional motor is opened, and the x, y, and z terminals are connected to the converter respectively, and the converters at the a, b, and c ends form three H bridges. The three H bridges are independent of each other, and the three-phase stator winding voltage and current can be controlled separately. Inverter 1 (VSI1) and inverter 2 (VSI2) provide power in coordination.

![Figure 1. Isolated bus topology of OEW-BLDCM](image)

In the three-phase six-state conduction mode of OEW-BLDCM, the phase sequence for realizing forward energization is AB→AC→BC→BA→CA→CB, and the realization of each state requires four IGBTs to be turned on at the same time. Figure 1 shows the direction of current flow when the AB phase sequence is turned on. The current flowing from VSI1 into VSI2 is regarded as flowing out. At this time, the current flows from phase A out of phase B and flows back, turning on T1, T10, T8, and T5.

3. Comparative analysis of OEW-BLDCM and star-end winding BLDCM

In the simulation analysis, establish the motor model in RMxprt, import it into Maxwell software, and generate Maxwell 2D finite element model, further import and generate ECE model, import ECE model into Simplorer, and establish motor control model in Simplorer. Finally, the joint simulation of Maxwell and Simplorer is realized by accessing the connection port in Simplorer.

3.1. Current comparative analysis

![Graph](image)

(a) Phase A current of star-end winding BLDCM
Figure 2 is a comparison diagram of phase A current. Figure 2 (a) is the A-phase current of the star-end winding BLDCM, and Figure 2 (b) is the A-phase current of OEW-BLDCM. It can be seen from the figure that from the perspective of the commutation time, OEW-BLDCM commutation time is earlier than the star-end winding BLDCM, indicating that the rotor of OEW-BLDCM reaches a certain position first, that is, it can be inferred that it rotates faster than the traditional star-end winding BLDCM; because the simulation analysis here is limited to 1000rpm in speed, the size has no reference value and will be analyzed in the subsequent mechanical characteristics simulation part; from the perspective of the current size, after stability, the current in OEW-BLDCM is smaller than the current in the star-connected winding BLDCM. Therefore, the current in OEW-BLDCM is smaller, the current that the IGBT needs to withstand is small; from the current fluctuation, the current fluctuation in OEW-BLDCM is small.

3.2. Torque comparison analysis

(a) Torque of star-end winding BLDCM
Figure 3. Torque comparison chart

Figure 3 shows the torque comparison between OEW-BLDCM and star-connected winding BLDCM. Figure 3 (a) is the torque of the star-end winding BLDCM, Figure 3 (b) is the torque of OEW-BLDCM. It can be seen from the figure that when starting, the starting torque of OEW-BLDCM is large, the starting time is short, and the response is more rapid; after starting, the torque ripple in OEW-BLDCM is smaller.

3.3. Comparative analysis of speed

Figure 4 shows the speed comparison chart. The solid line is the rotational speed of the star-connected winding BLDCM, and the dashed line is the rotational speed of OEW-BLDCM. It can be seen that OEW-BLDCM responds faster. Under the same control setting, OEW-BLDCM starts faster and reaches the reference speed earlier, but it has a certain overshoot.

3.4. Comparative analysis of mechanical characteristics

Figure 5. Mechanical characteristic curve of star-end winding BLDCM
Maxwell was used to build the BLDCM used in the above analysis, and two external circuit control models corresponding to the star-connected winding and the open winding were built respectively, and the average steady-state torque at different speeds were analyzed parametrically, and two mechanical characteristic curves were obtained. Figure 5 shows the mechanical characteristic curve of the star-connected winding BLDCM. The overall trend is that the torque decreases as the speed increases. When the speed reaches 25000 rpm, the torque is 0. When the speed is greater than 25000 rpm, the torque becomes negative, and the motor turns from the motor state to the generator state. Figure 6 shows the mechanical characteristic curve of OEW-BLDCM. The overall trend is similar to that of star-connected windings. However, when the motor speed is 25000 rpm, the torque is 6.2 N·m, which does not reach zero. When the speed reaches 50,000 rpm, the torque is zero. Comparative analysis shows that the maximum speed of OEW-BLDCM is twice that of the star-connected winding BLDCM. OEW-BLDCM has a larger field weakening acceleration zone.

4. Conclusion

The results show that: compared with star-end winding motor system, open winding motor system has larger starting torque, shorter starting time and faster response speed, but it has certain overshoot and smaller torque ripple. The maximum speed is twice that of the star-connected winding, and the magnetic field weakening speed-up zone is larger.

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