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A Zero-sequence Current Suppression strategy for Five-phase Open-end Winding PMSM with Vector Proportional Integral Controller

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CENTRAL MESSAGE

The model of a five-phase OEW-PMSM is built in this paper, which contains the zero-sequence component and a VPI controller is designed to suppress the ZSC in the system.

INTRODUCTION

The industrial applications need higher requirements for permanent magnet motor (PMSM) system, especially for the demand of power density and high reliability. Five-phase OEW-PMSM has stronger adaptability for this area. It not only has the advantages of high power density, small torque ripple, but also has the advantages of high bus voltage utilization, large speed range and output three-level.

The conventional model of the multiphase PMSM has been reported in [12]. in the conventional model of the five-phase PMSM, the zero-sequence component is neglected because of the neutral point. However, as to the five-phase OEW-PMSM, the zero-sequence cannot be neglected and the model has not been established in existing studies. Therefore, in this paper, the five-phase OEW-PMSM model is established first. The self-inductance and mutual inductance are expressed. The electromagnetic torque is also expressed. In order to suppress the ZSC, a modified vector proportional integral controller is designed.

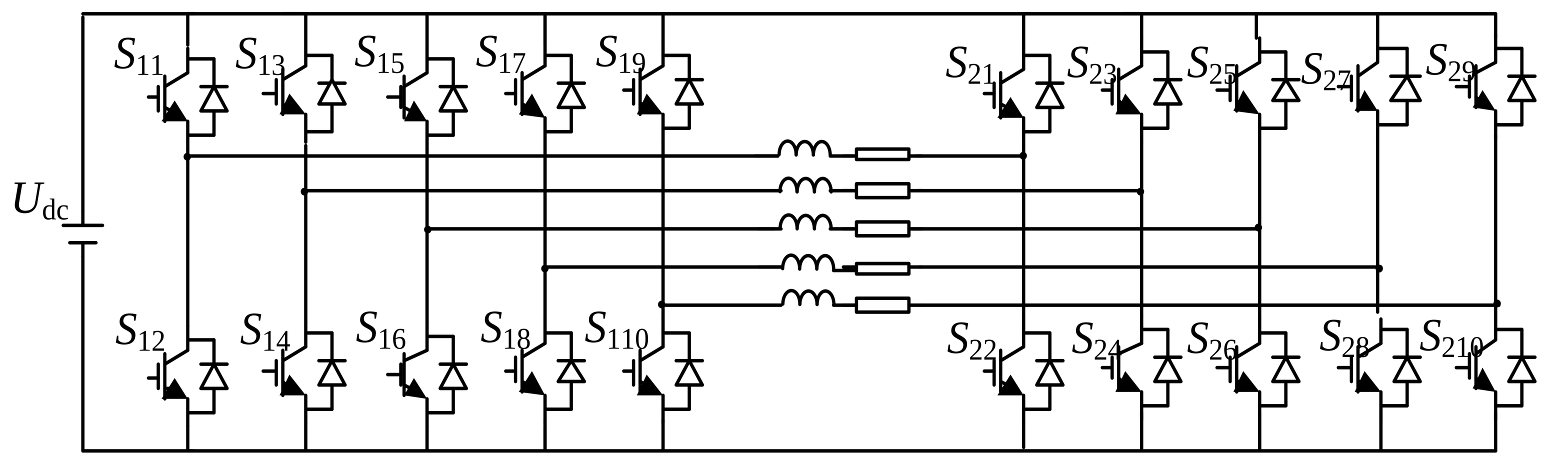

Fig.1 The five-phase OEW-PMSM drive.

CONTROL STRATEGY

In this section, the five-phase OEW-PMSM math model is built. First the assumptions in [12] should be made in the process of modeling. According to the winding function theory, the reciprocal curve of phase a winding air gap function of five phase motor considering the zero-sequence component is analyzed. the model of five-phase OEW-PMSM in the rotating coordinate axis can be obtained as follows

$$\begin{bmatrix} u_{d1} \\ u_{q1} \\ u_{d3} \\ u_{q3} \\ u_0 \end{bmatrix} = R_s \begin{bmatrix} i_{d1} \\ i_{q1} \\ i_{d3} \\ i_{q3} \\ i_0 \end{bmatrix} + \begin{bmatrix} L_{d1} & 0 & L_{13} & 0 & 0 \\ 0 & L_{q1} & 0 & 0 & L_{13} \\ L_{13} & 0 & L_{d3} & 0 & 0 \\ 0 & L_{13} & L_{d3} & 0 & 0 \\ 0 & 0 & 0 & 0 & L_s \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_{d1} \\ i_{q1} \\ i_{d3} \\ i_{q3} \\ i_0 \end{bmatrix}$$
$$+\omega \begin{bmatrix} 0 & -L_{q1} & 0 & -L_{13} & 0 \\ L_{d1} & 0 & L_{13} & 0 & 0 \\ 0 & -3L_{13} & 0 & -3L_{q1} & 0 \\ 3L_{13} & 0 & 3L_{d1} & 0 & 0 \\ 0 & 0 & 0 & 0 & L_s \end{bmatrix} \begin{bmatrix} i_{d1} \\ i_{q1} \\ i_{d3} \\ i_{q3} \\ i_0 \end{bmatrix} + \omega \begin{bmatrix} 0 \\ \psi_1 \\ 0 \\ 3\psi_3 \\ 5\psi_0 \end{bmatrix}$$

Electromagnetic torque is the deviation of magnetic co-energy to rotor position, it can be expressed as

$$T_e = \frac{5P}{2}[\psi_1 i_{q1} + 3\psi_3 i_{q3} + i_{q1} i_{d1}(L_{d3}\text{-}L_{q3}) + 3 i_{d3} i_{q3}(L_{d3}\text{-}L_{q3}) + 10\sqrt{2}\omega i_0 \psi_0 \cos(5\omega t)]$$

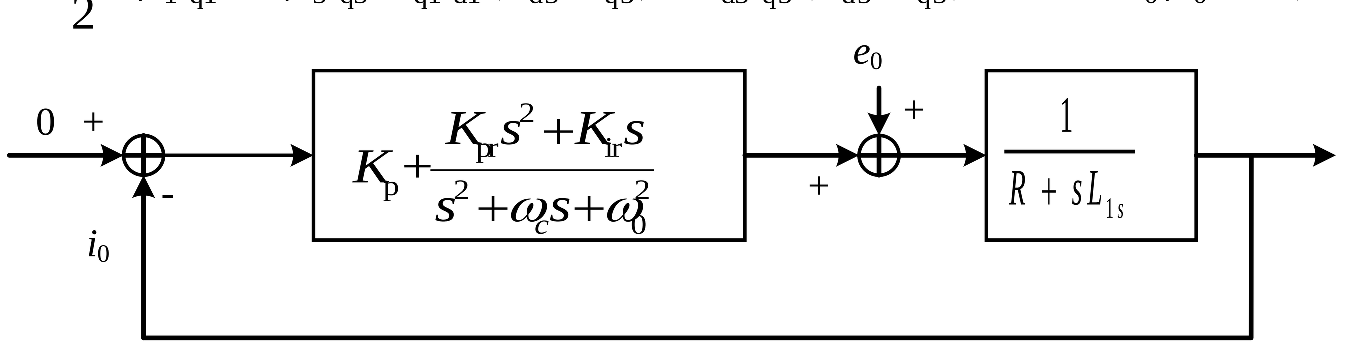

Fig. 2 control diagram of zero-sequence circuit.

To better suppress the ZSC, the resonant frequency of vector proportional integral controller should be the same as the zero-sequence frequency. Since the zero sequence current changes with the motor speed, the resonant frequency should be changed in real time with the motor speed. Since there may be a slight offset between the measured speed and the actual speed, there will be a possibility of rapid gain reduction near the resonance frequency point, thus reducing the ability of ZSC suppression. In order to ensure the ZSC suppression ability in the presence of measurement deviation, compared with the traditional vector proportional integral controller, w_c is added to improve the system bandwidth and enhance the robustness of the system to resonant frequency offset. The block diagram of suppressing the ZSC is shown in Fig. 3.

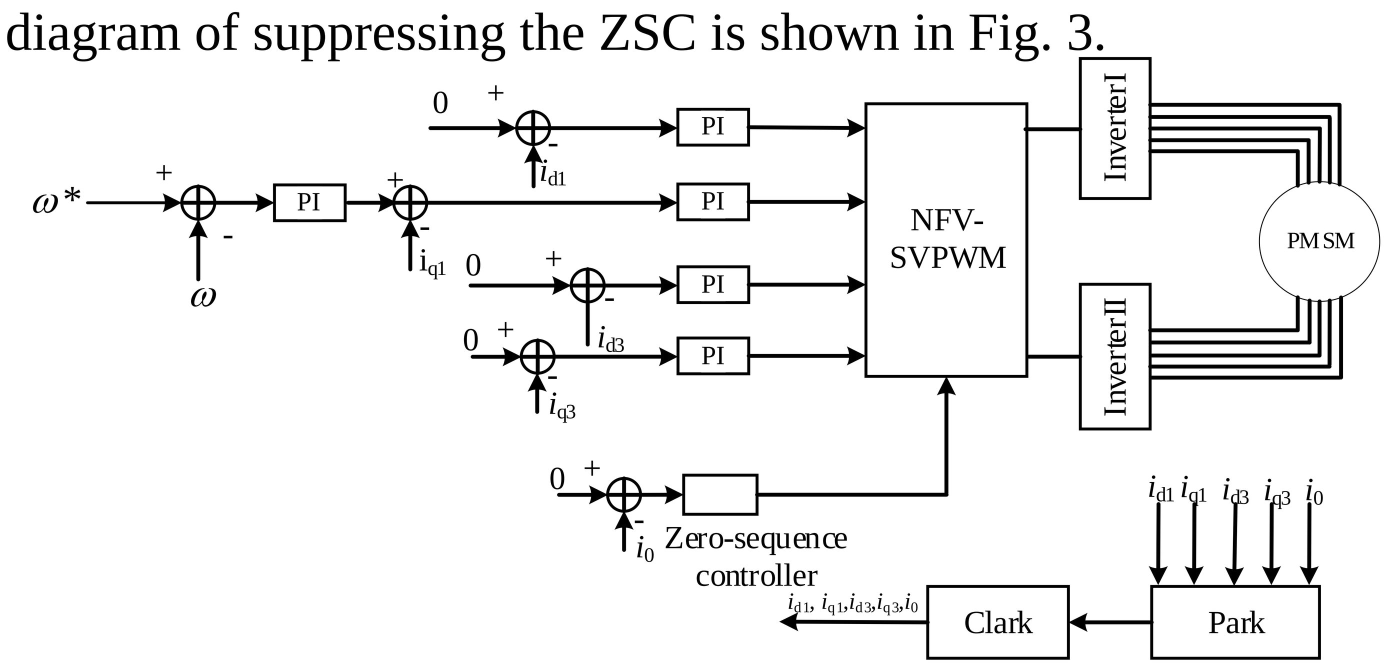

Fig. 3 Control diagram of the five-phase OEW-PMSM drive.

VERIFICATIONS

To verify the vector proportional integral controller, a simulation and experiment for dual inverter with common DC bus is carried out. The DC bus voltage is 100V. The switching frequency and dead time is 10 *k*Hz and 2μs respectively. The pole pairs number is 2. The d_1-axis inductance is 7.34mH. the q_1-axis inductance is 9.18mH. The fundamental flux linkage is 0.5155Wb. The third harmonic flux linkage is 0.0247Wb. The resistance is 1.1 Ω. The simulation is first carried out.

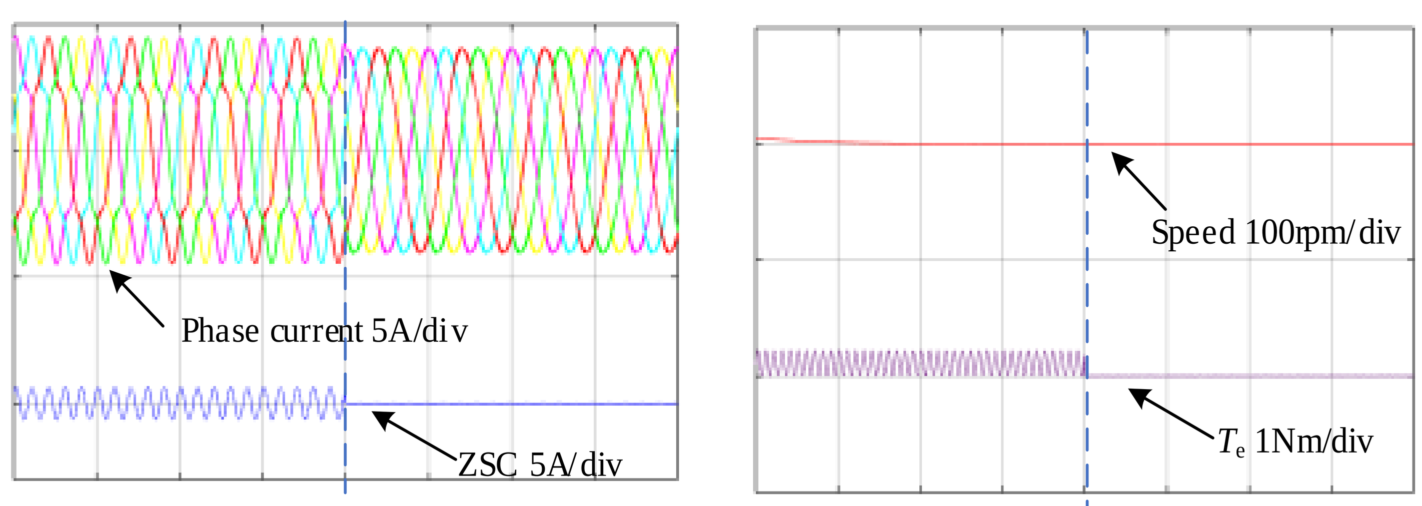

Fig. 4 simulation results under the speed is 300rpm.

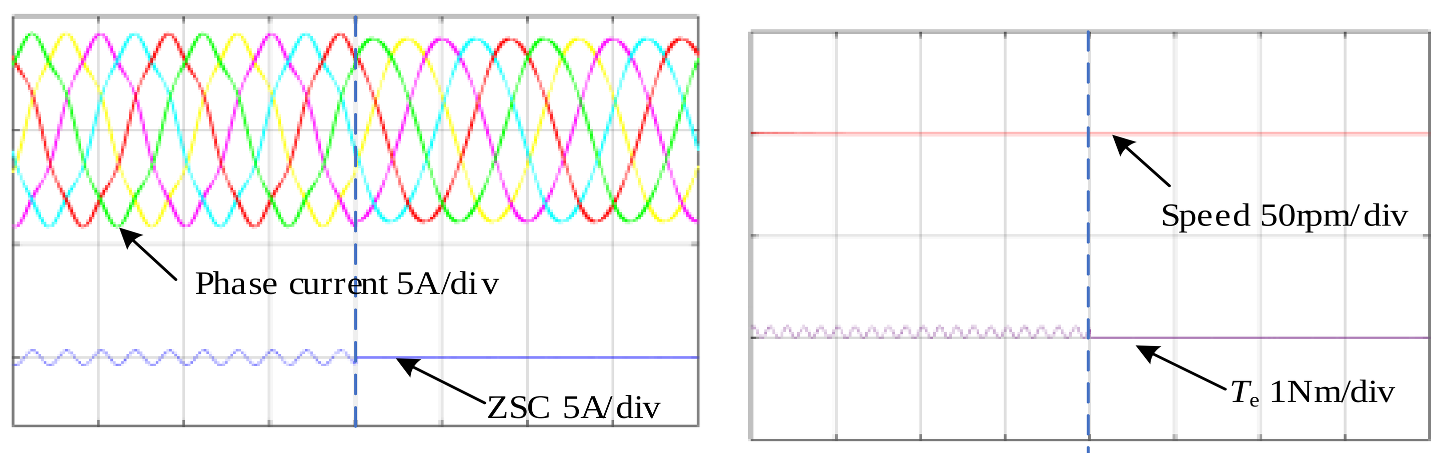

Fig. 5 simulation results under the speed is 150rpm.

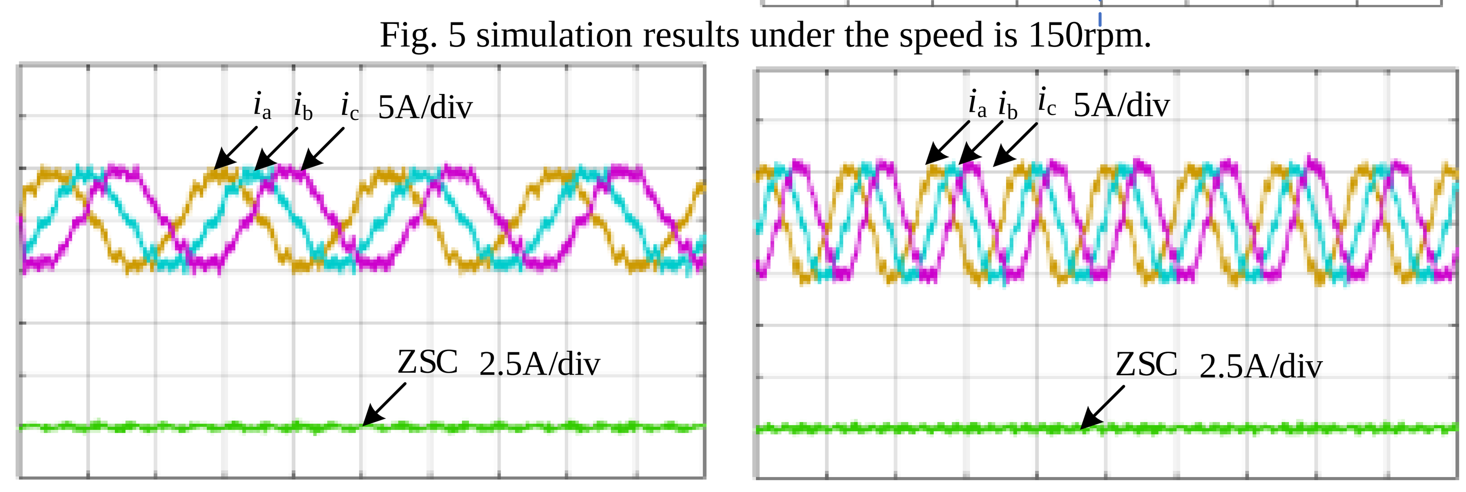

Fig. 6 Experimental results of proposed method.

CONCLUSION

In this paper, the model of the five-phase PMSM fed by the dual inverter with common DC bus is built. Compared with conventional model of five-phase PMSM, the zero-sequence component is considered in this paper. To improve the performance of the closed loop controller, the vector proportional integral controller is applied and the bandwidth is extended in this paper. The simulation and experimental results show the zero-sequence controller has a good performance of suppressing the ZSC.