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INFLUENCE OF THIRD SPACE HARMONIC WAVE OF MAGNETIC DENSITY ON CURRENTS AND TORQUE OF INDUCTION MOTOR

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Abstract: Influence of the third space harmonics of stator current layer and field density on properties of induction motors is discussed in the paper. The rise of these waves in connection with zero-sequence component in stator currents is shown. It is proved that the flux corresponding to the third wave of the field density passes through the air gap and can give rise to rotor currents in dependence of rotor winding configuration. Symmetrical component corresponding to the third space waves of current layer results in increasing of machine currents and additional losses. The additional torque is produced by interaction of these components.

Keywords: Induction machine, higher space harmonics, symmetrical components.

1 Introduction

Induction motors are frequently used as drive units in driven systems with variable seed. The reason is their relatively low price and high reliability. Feeding converters are however rather liable to rise of failures. In case of necessity to sustain the drive in operation till the driven equipment is laid up without damage, additional precautions are adopted after the failure of the converter. An example of a serious defect is the failure of one leg of the converter or break-down of one phase winding of the stator of the electric motor. One of possible ways to maintain drive in operation is reconfiguration of the inverter, so that the damaged leg is disconnected and the stator winding neutral is connected with the midpoint of the bank of capacitors of the dc link (see [1]

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and [2]). The winding fed from the failed converter leg is kept open. The failed phase winding can be isolated in the same way. Connection of the stator neutral with the source of the feeding voltage results in the rise of the zero-sequence component of stator currents. This component may affect properties of the induction motor considerably. The presented paper deals with analysis of the zero-sequence component of the currents and torque of induction machines.

2 Rise of third space harmonic waves

At first, the rise of the third space harmonics waves of the current layer of stator currents, of the flux density along the air gap, and of the flux in the stator yoke will be shown experimentally. Let us consider a three-phase induction motor with the cage rotor fed in the way shown in Fig. 1. All three phase windings are fed by identical voltages, which represents the zero-sequence component in this case. This voltage contains neither the positive component nor the negative component evidently. When the voltage is connected to the stator terminals of the mechanically no-loaded induction motor at a low initial speed, the machine may start to accelerate. Some results of such an experiment are in Fig. 2. A two-pole induction motor of nominal power 1.1 kW has been used. Figure 2 shows the voltage and current of one stator phase during starting from the low speed. The rotor reached speed about 975 rpm in steady state after starting. The time of starting depends especially on the amplitude of the zero-sequence component and on the moment of inertia [3]. Currents of the remaining phases have been identical with the current in Fig. 2.

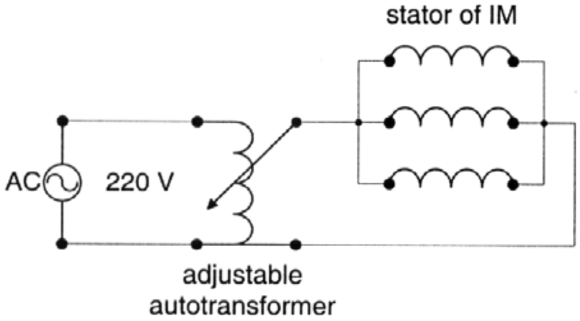

Fig. 1. Rise of zero-sequence component

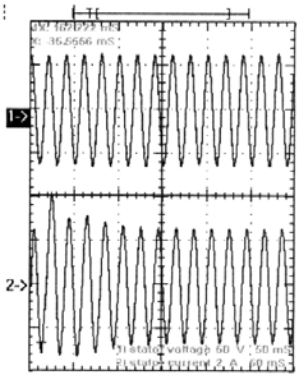

Fig. 2. Measured voltage and current

The ability of the motor to accelerate proves the rise of the electromagnetic torque. Therefore, the stator currents give rise to flux, which passes across the air gap and reacts with the rotor winding. The fact that the speed in the steady state is approximately 1/3 of the nominal speed of the considered experimental machine indicates rise of the third harmonic wave of the flux instead of the first harmonic wave in this case. The three-phase machine fed only by the zero-sequence voltage component may be considered as an equivalent of a one-phase machine with three times greater number of poles. It is evident that the zero-sequence component of the three-phase current system is associated with the three space harmonic of the current layer, which gives rise to the third waves of the magnetic flux density. The connection between the zero-sequence component and the third space harmonics is in detail described in [4].

3 Emergency operation

Emergency operation with one stator phase open after inverter reconfiguration owing to the failure of one leg may be according to [5] described by equations

$$\frac{u_B - u_C}{2\sqrt{3}} = R_S i_{1S\beta} + L_{1S}\frac{di_{1S\beta}}{dt} + L_{1m}\frac{di_{1R\beta}}{dt} \tag{1}$$

$$\frac{u_B + u_C}{2} = \frac{3}{2}R_S i_{3S} + \left(\frac{L_{1S}}{2} + L_{3S}\right)\frac{di_{3S}}{dt} + L_{3m}\frac{di_{3R\alpha}}{dt} - L_{1m}\frac{di_{1R\alpha}}{dt} \tag{2}$$

$$0 = R_{1R}i_{1R\alpha} + L_{1R}\frac{di_{1R\alpha}}{dt} - \frac{1}{2}L_{1m}\frac{di_{3S}}{dt} + \frac{d\rho}{dt}\left(L_{1R}i_{1R\beta} + L_{1m}i_{1S\beta}\right) \tag{3}$$

$$0 = R_{1R}i_{1R\beta} + L_{1R}\frac{di_{1R\beta}}{dt} + L_{1m}\frac{di_{1R\beta}}{dt} - \frac{d\rho}{dt}\left(L_{1R}i_{1R\alpha} - \frac{1}{2}L_{1m}i_{3S}\right) \tag{4}$$

$$0 = R_{3R}i_{3R\alpha} + L_{3R}\frac{di_{3R\alpha}}{dt} + L_{3m}\frac{di_{3S}}{dt} + 3\frac{d\rho}{dt}L_{3R}i_{3R\beta} \tag{5}$$

$$0 = R_{3R}i_{3R\beta} + L_{3R}\frac{di_{3R\beta}}{dt} - 3\frac{d\rho}{dt}\left(L_{3R}i_{3R\alpha} + L_{3m}i_{3S}\right) \tag{6}$$

where u_B and u_C are voltages across the fed phases. Symbol i represents current and symbols R and L are resistance and inductance respectively. Subscripts S and R denote stator and rotor quantities respectively. Subscript m represents main inductances. Positive components are denoted by subscript 1, zero-sequence component of stator currents is denoted by 3 owing to its connection with the third space harmonics. In case of the rotor, subscript 3 means space phasor of the third harmonic. Further, α and β represent the real and imaginary parts of space phasors in stator co-ordinates. Symbol ρ represents mutual shift of the stator and rotor. Based on these equations supplemented by equations for torques and by motion equation numerical model has been developed. Formal analogy of this model with the feeding of induction motors from the mains with one phase winding open and with neutrals of the machine and the mains connected together may be used for further analysis and experimental verification with advantage. Examples of simulation results are in Fig. 3 and Fig. 4. Connection of a no-loaded motor fed in the investigated way on voltage at synchronous speed has been modelled. The motor with main parameters in per unit system $R_S = R_{1R} = 0.02$, $L_{1S} = L_{1R} = 0.00955$, and $L_{1m} = 0.00923$ has been considered. The voltages of phases B and C were chosen $u_{SB} = \sqrt{2}\cos(100\pi t)$ and $u_{SC} = \sqrt{2}\cos(100\pi t + 2/3\pi)$. The stator phase currents and their zero-sequence component are in Fig.3. This component influences the magnitudes of these currents considerably. The torque T_1 generated by the fundamental harmonic, the torque T_3 generated by the third harmonic, the resulting torque T, and the mechanical speed are in Fig. 4. The resulting torque is distorted by ripples due to the considerable zero-sequence component. Torque pulsations also arise due to the unbalanced feeding [6].

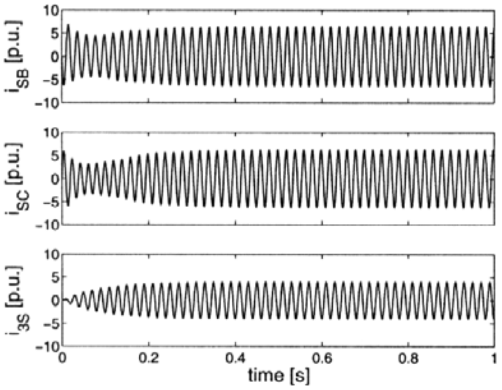

Fig.3. Phase currents and zero-sequence component

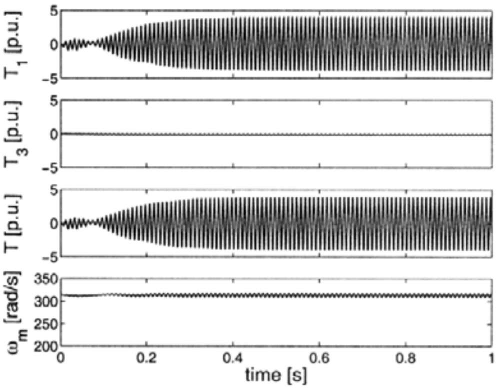

Fig.4. Torque components and mechanical speed

4 Conclusion

A rise of the third harmonic along the air gap and its relation to the zero component were presented. The presented equations can be applied for optimization of converter control and for analysis of qualities of the whole drive in the investigated failure state.

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