Fault tolerant vector control of induction motor drive

G Odnokopylov[1, a], **A Bragin**[1, b]

[1] Tomsk Polytechnic University, Tomsk, Russia
[a]OGIz@yandex.ru, [b]lflenylol@gmail.com

Abstract. For electric composed of technical objects hazardous industries, such as nuclear, military, chemical, etc. an urgent task is to increase their resiliency and survivability. The construction principle of vector control system fault-tolerant asynchronous electric. Displaying recovery efficiency three-phase induction motor drive in emergency mode using two-phase vector control system. The process of formation of a simulation model of the asynchronous electric unbalance in emergency mode. When modeling used coordinate transformation, providing emergency operation electric unbalance work. The results of modeling transient phase loss motor stator. During a power failure phase induction motor cannot save circular rotating field in the air gap of the motor and ensure the restoration of its efficiency at rated torque and speed.

1. Introduction

The use of vector-controlled induction motor drives system is closely connected with increasing their resiliency and survivability in hazardous industries (nuclear, military, chemical, etc.). Induction motor vector control drives has a wide control range (up to 1:10,000), an extremely high speed.

Typically this drives are controlled by scalar control system in two phase operate mode [1, 2]. The purpose of this paper is development of vector-controlled induction motor drives.

2. Formation of failure-free vector control algorithm

Vector control of induction motor drive is based on a constant orientation of the coordinate system in the direction of a vector that allows the projection of this vector equate to another axis Cartesian coordinate system to zero. The control system produces control signals in a two-phase rotating coordinate system then this signals converted into three-phase coordinate system for controlling the frequency converter. Consider in detail the process for coordinate transformation in two-phase operate mode.

To derive the required expressions use the notion of a generalized space vector [3]. Denote the vectors arbitrarily shifted relative to the real axis coordinate angles λ, μ, ν, in the three-phase stator the coils A, B, C as IA, IB, IC and sum them, write the expression for the current space vector as:

$$\boldsymbol{I} = \frac{2}{3}(\boldsymbol{I}_A + \boldsymbol{I} \quad + \boldsymbol{I}_C) = \frac{2}{3}(I_A e^{j\lambda} + I_B e^{j\mu} + I_C e^{j\nu}),$$

$\boldsymbol{I}_A = I_A e^{j\lambda}$, $\boldsymbol{I}_B^B = I_B e^{j\mu}$, $\boldsymbol{I}_C = I \;\; e^{j\nu}$ vectors of the phase currents, I_A, I_B, I_C - their instantaneous values.

Denoting the real and imaginary axis as *a* and *b*, write the expression for the generalized current vector:

$$\boldsymbol{I} = i_a \quad ji \; .$$

Taking into account space shift of the currents angles λ, μ, ν and separating the real and imaginary parts, we obtain:

$$i_a = \mathrm{Re}(\boldsymbol{I}) = \frac{2}{3}(I_A \cos\lambda + I_B \cos\mu + I_C \cos\nu);$$
$$i_b = \mathrm{Im}(\boldsymbol{I}) = \frac{2}{3}(I_A \sin\lambda + I_B \sin\mu + I_C \sin\nu).$$

Denoting the component of zero sequence current as $i_0 = \frac{1}{3}(I_A + I_B + I_C)$ write expressions for the currents in the matrix form:

$$\begin{bmatrix} i_a \\ i_b \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\lambda & \cos\mu & \cos\nu \\ \sin\lambda & \sin\mu & \sin\nu \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \cdot \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix}.$$

The inverse transform of the two-phase stationary coordinate system a, b, 0 in the three-phase A, B, C will be as follows:

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \frac{3}{2}\begin{bmatrix} \cos\lambda & \cos\mu & \cos\nu \\ \sin\lambda & \sin\mu & \sin\nu \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} i_a \\ i_b \\ i_0 \end{bmatrix}.$$

In general, if the drive is running in a symmetrical three-phase mode angles λ, μ, ν are 0 °, 120 ° and -120 °, respectively, and the transformation can be written in the form [3]:

$$\begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} & 1 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} & 1 \end{bmatrix} \cdot \begin{bmatrix} i_a \\ i_b \\ i_0 \end{bmatrix}.$$

Then the transformation from the fixed coordinate system a, b to a three-phase coordinate system A, B, C given the absence of the neutral wire is carried by the expressions [4]:

$$I_A = i_a,$$
$$I_B = -\frac{i_a}{2} + \frac{\sqrt{3}}{2} i_b, \quad (1)$$
$$I_C = -\frac{i_a}{2} - \frac{\sqrt{3}}{2} i_b,$$

where I_A, I_B, I_C - three-phase stator currents in the fixed coordinate system, i_a, i_b - a two-phase stator currents in the fixed coordinate system.

Expressions (1) are valid for a three-phase mode of operation when the phase currents are symmetrical and are offset from each other by 120 °, but in case of emergency situations such as phase loss their use is not justified, because in case the motor circuit with decoupled phases appears in the neutral wire current i0.

Condition for the existence of a circular rotating field in an electric machine with two arbitrarily shifted in space windings is knew [5]:

$\delta + \beta = \pi$; $F_{AM} = F_{CM}$, (2)

F_{AM}, F_{CM} - the amplitude values of magnetomotive forces, δ - angle spatial shift coils, β - angle timeshift winding currents asymmetric biphasic electrical machine. Spatial angle shift winding is constant and equal to $\delta = 2\pi/3$ in the 3-phase electric machine, the time phase shift can be specified as $\beta = \pi / 3$. In this case, the amplitude values of magnetomotive force of asymmetric two-phase motor are equal $F_{AM}=F_{CM}=F_M$ and circular rotating field is formed in the air gap of the motor.

Consider the algorithm of current vectors shift in two-phase operate mode. Fix the current vector I_A, taking the angle λ = 0. Current vector will be displaced by an angle-π / 3 and π / 3, respectively, upon the occurrence of an emergency phase B or C. Current vector IC is shifted to meet IB current vector by an angle π / 3 at phase loss A. Work of considered algorithms current vectors shift is shown in Fig. 1.

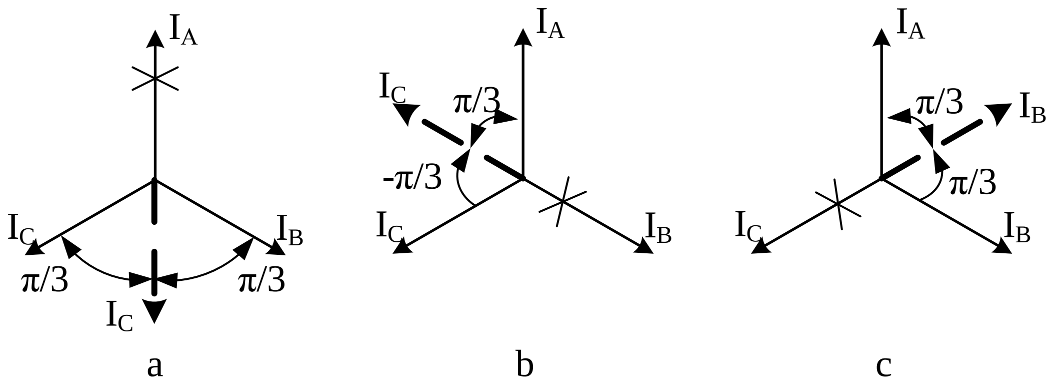

Figure 1. Current vectors shifts in an emergency two-phase mode: a - accident in phase A; b - an accident in phase B; in - an accident in the C phase

Having regard to the above conditions for the existence of a circular rotating field, we can write a general expression for coordinate transformation that takes into account the drive operate mode:

$$\begin{bmatrix} \bar{a} & 0 & 0 \\ 0 & \bar{b} & 0 \\ 0 & 0 & \bar{c} \end{bmatrix} \cdot \begin{bmatrix} I_A \\ I_B \\ I_C \end{bmatrix} = \frac{3}{2} \begin{bmatrix} 1 & \cos(\frac{2\pi}{3} + c \cdot (-\frac{\pi}{3}) + a \cdot \frac{\pi}{6}) & \cos(-\frac{2\pi}{3} + c \cdot \frac{\pi}{3} + a \cdot (-\frac{\pi}{6})) \\ 0 & \sin(\frac{2\pi}{3} + c \cdot (-\frac{\pi}{3}) + a \cdot \frac{\pi}{6}) & \sin(\frac{2\pi}{3} + c \cdot (-\frac{\pi}{3}) + a \cdot \frac{\pi}{6}) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}^{-1} \cdot \begin{bmatrix} i_a \\ i_b \\ i_0 \end{bmatrix},$$

a, b, c - bit of failure phase A, B, C respectively $\bar{a}$, $\bar{b}$, $\bar{c}$ - inverted bit of failure.

Vector control system is shown in Fig. 2. It comprises a flux, speed and three current regulators. The reference signal on the current from the speed and the flux regulator flows in a coordinate converter which converts from the rotating coordinate system x, y to the fixed coordinate system a, b. Further, depending on the operating mode is converted according to the expression (3).

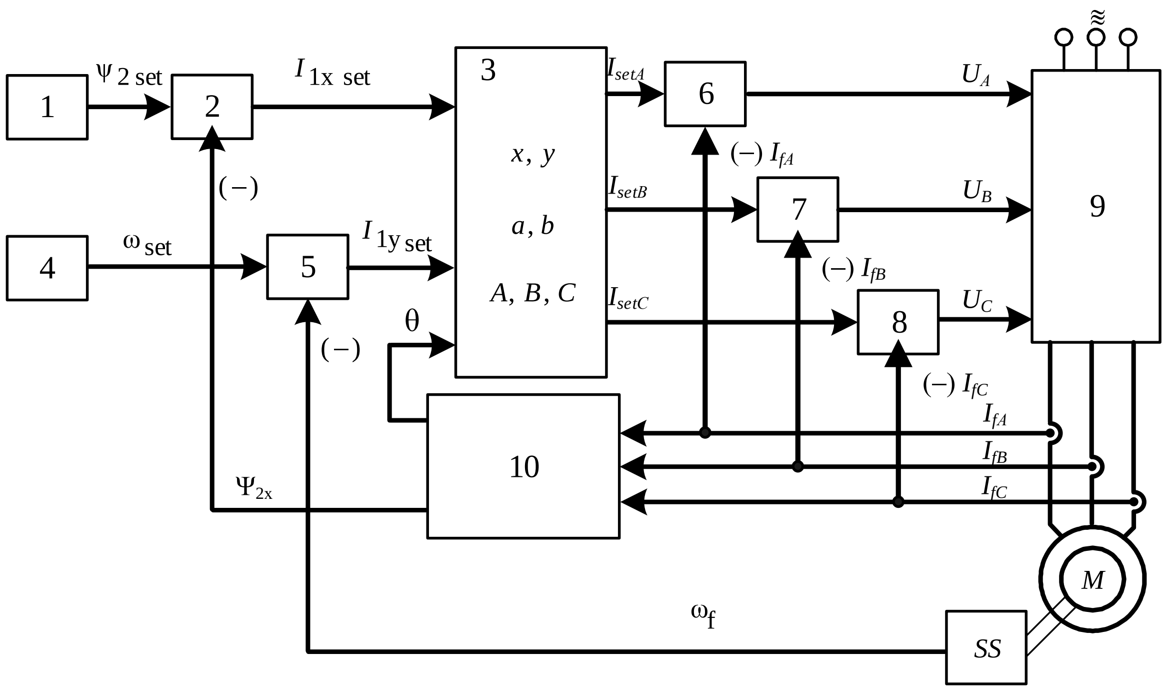

Figure 2. Vector control system of fault-tolerant induction motor drive: 1 - dial rotor flux linkage; 2 - the rotor flux linkage regulator; 3 - coordinate converter; 4 - speed dial; 5 - speed regulator; 6, 7, 8 - stator current regulators; 9 - frequency converter; 10 - calculating unit flux.

Induction motor AIR63A2 was chosen for the simulation. Loops were optimized by the method presented in [6]. Simulation was conducted among Matlab Simulink. Presented transient process of current, speed and torque occurring in the motor in the event of an accident with use of the fault tolerant vector control algorithm and without it fig. 3-4.

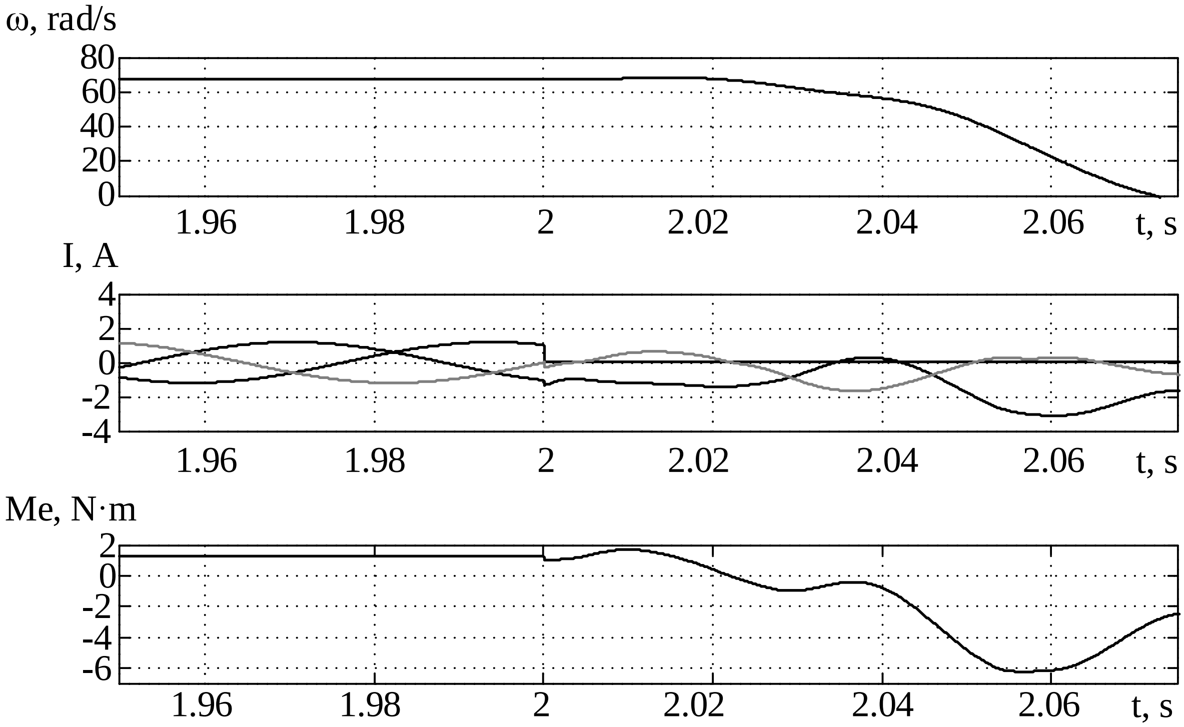

Figure 3. Transients process in the drive with vector control in stator phase loss case

Figure 4 shows the transient process stator B phase loss using recovery algorithm, represented by the expression (3).

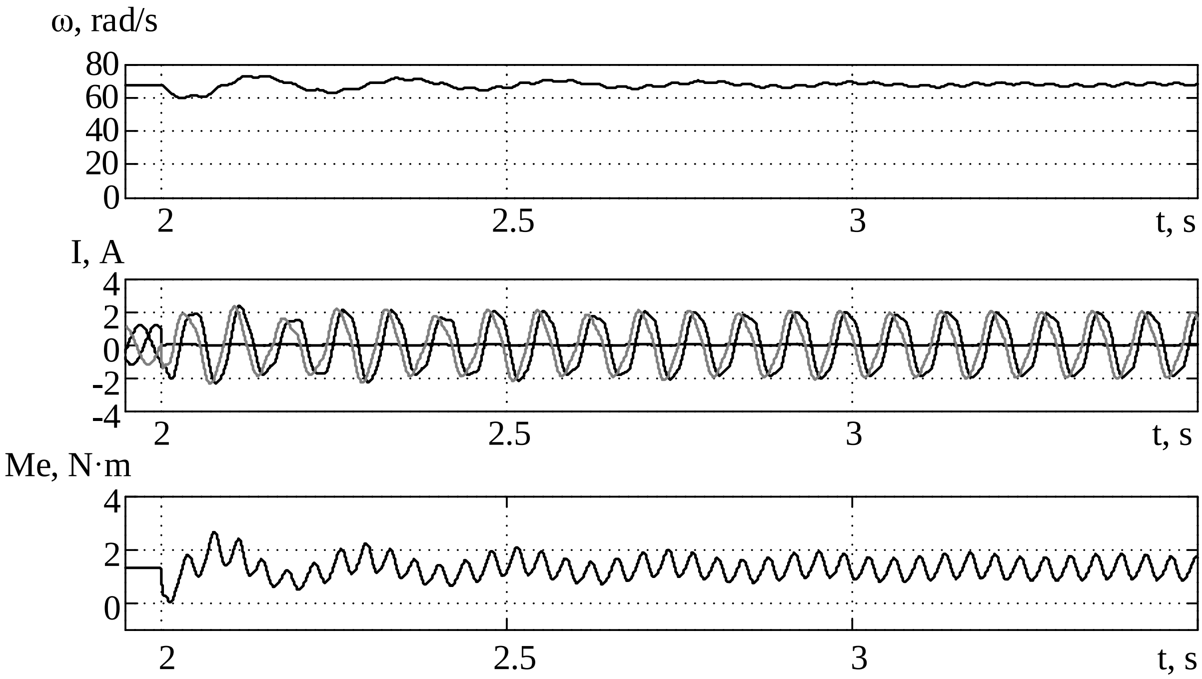

Figure 4. Transients process in the drive with vector control in stator phase loss case with using of recovery algorithm

The transients process (Fig. 3) shows that in the case of an emergency there is an increase of stator currents, and stalling of the motor. The electromagnetic torque changes its sign and becomes inhibitory. Elliptic field arises in the induction motor air gap. This field provides additional inhibitory torque and reduces the overload capacity of the motor. Upon transition to a two-phase operate mode when the motor circuit with decoupled sum of phase stator currents becomes zero, which leads to incorrect coordinate transformation coordinate in the forward converter. All of this features lead to inoperable of the electric drive in two-phase operation mode.

Amplitude of current increase when using recovery algorithm (Fig. 4), because of the need to compensate the lack of power has occurred due to loss of phase stator. Speed is oscillatory and the amplitude of the oscillations does not exceed 2.9% of the set speed, with the failure of the frequency of rotation of the transient time reaches 15.5% of the set frequency.

3. Conclusions:

1. A method of coordinate transformation that takes into account the shift of current vectors and the reconstruction algorithm allows to advance the vector control system. It allows you to keep a circular rotating field in the air gap and provide disaster recovery motor rated torque and speed after on of the motor phase falling.
2. A simulation model of three-phase induction motor drive with vector control system is developed in Matlab Simulink. It allows to investigate the drive in an emergency two-phase operation mode.
3. In a two-phase operating mode speed fluctuations in the steady state does not exceed 2.9% of the set speed when using fault tolerant vector control algorithm.

References

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