

Stator Winding Fault Diagnostic of Induction Motor Using Instantaneous Currents' Space Phasor Approach

Abstract. The paper introduces a new approach, based on the computer-aided monitoring of the motor instantaneous current space phasor (ICSP), for diagnosing the occurrence of inter-turn short circuits in the stator windings of operating three-phase induction motors. The proposed diagnostic technique generates the motor ICSP, whose modulus through time ripple increases with the severity of the fault and whose phase ripple is associated to the faulty phase. It generates also the angular speed of the ICSP that is more sensitive to the stator-winding fault.

Streszczenie. W artykule zaproponowano nowy sposób diagnozowania zwarć międzyswojowych stojana na podstawie analizy chwilowej wartości fazowa na płaszczyźnie prądowej. (Diagnozowanie uszkodzeń stojana w silniku indukcyjnym na podstawie analizy chwilowej wartości fazora na płaszczyźnie prądu).

Keywords: Induction Motor, Stator Winding Fault Diagnosis, Space Phasor.

Słowa kluczowe: silnik indukcyjny, uszkodzenia stojana, diagnostyka.

Introduction

In recent years health monitoring of three-phase induction motors, which is considered the workhorse of the modern industrial drive systems, has become very important to reduce the unscheduled downtimes of the appropriate production lines. Almost 40% of all reported induction motor failures are caused by insulation damage between two adjacent turns in stator coils, therefore many research activities has been addressed on the subject of on-line detection of inter-turn short circuits in the stator winding. Several techniques for health monitoring and fault diagnosis of induction motors are based on the processing of the stator line currents. Among these, the fault detection method based on the stator currents' Park's vector representation has been demonstrated to be sensitive to motor internal faults [1]-[3].

In the literature, the current Park's vector approach is based on the correspondence between the ellipticity of its two-dimensional representation (geometric locus of the vector) with the three-phase induction motor malfunctions, such as, single-phasing, stator-winding inter turn short-circuits and rotor faults. The ellipticity of the Park's vector geometric locus increases with the severity of the fault and its major axis orientation is associated to the faulty phase [5]-[9].

Another way of finding fault in Park's vector approach consists in watching the influence of the value that the modulus of the vector takes through time on the motor current frequency spectrum. The existence of an inter-turn short circuit in the motor stator winding manifests by the presence of a spectral component at twice the fundamental supply frequency. The amplitude of this spectral component is directly related to the severity of the fault [4].

The present paper introduces a new approach, based on the computer-aided monitoring of the motor instantaneous current space phasor (ICSP), for diagnosing the occurrence of inter-turn short circuits in the stator windings of operating three-phase induction motors. The proposed diagnostic technique generates the motor ICSP, whose modulus through time ripple increases with the severity of the fault and whose phase ripple is associated to the faulty phase. It generates also the angular speed of the ICSP that is sensitive to the stator-winding fault. The investigative study for stator winding fault monitoring by using the modulus ripple fault sensitivity and angular speed sensitivity of the ICSP was made on a simulated induction motor in *Simplorer* programming medium.

ICSP'S Modulus and Speed Approach

As a function of the line currents i_a , i_b and i_c of a three-phase motor with isolated neutral point, the ICSP is given by the following equation:

$$(1) \quad \underline{i} = i_a + i_b e^{j120} + i_c e^{j240}$$

which can take the shape:

$$(2) \quad \underline{i} = i_\alpha + j i_\beta$$

where

$$(3) \quad \begin{aligned} i_\alpha &= i_a - \frac{1}{2}i_b - \frac{1}{2}i_c \\ i_\beta &= i_b \frac{\sqrt{3}}{2} - i_c \frac{\sqrt{3}}{2} \end{aligned}$$

The *Simplorer* simulation scheme for ICSP modulus and phase calculation is shown in Figure 1.

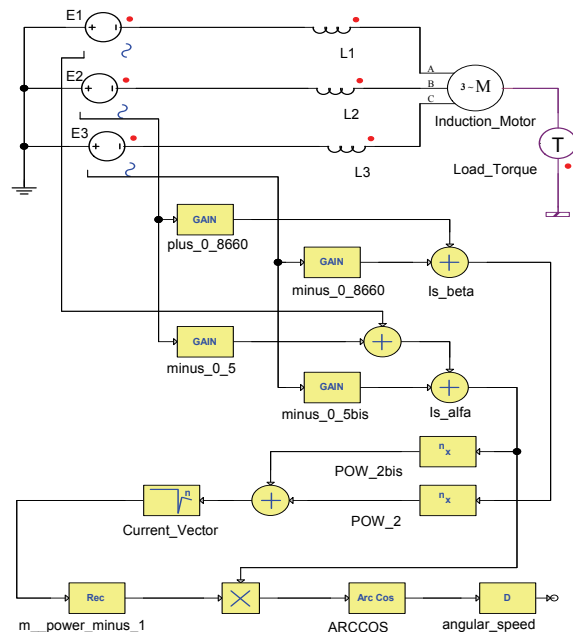


Fig.1. The *Simplorer* simulation scheme for ICSP modulus and phase calculation

The following relations give the modulus $m(t)$ and the angular speed $\gamma(t)$ of ICSP:

$$m(t) = \sqrt{i_\alpha^2 + i_\beta^2}$$

$$(4) \quad \gamma(t) = \frac{d}{dt} \left(\arccos \frac{i_\alpha}{m} \right)$$

In normal conditions, when a healthy three-phase induction motor works through a system of balanced sinusoidal currents, the geometric locus of ICSP is a circle centered in the origin of the plane $i_\alpha-i_\beta$ with a constant radius, as it is shown in Figure 2.a. As a consequence, the ICSP modulus is constant and its angular speed is also constant, as it is shown in Figures 3.a and 4.a, respectively.

In the case of a short circuit in one of the stator windings, the current of affected phase will be increased and the geometric locus of ICSP turns into elliptical shape, as it is shown in Figure 2.b. The ICSP modulus will vary with a frequency twice the fundamental of supply voltage frequency and with a maximum of that ripple centered on the maximum of current in faulty phase, as it is shown in Figure 3.b. The ICSP angular speed will vary also, as it is shown in Figure 4.b.

Taking into account the above-mentioned ICSP modulus and angular speed changes with the stator winding short circuits' severity, we propose to use these variables as detection tools of the stator inter-turn short circuits of induction motor.

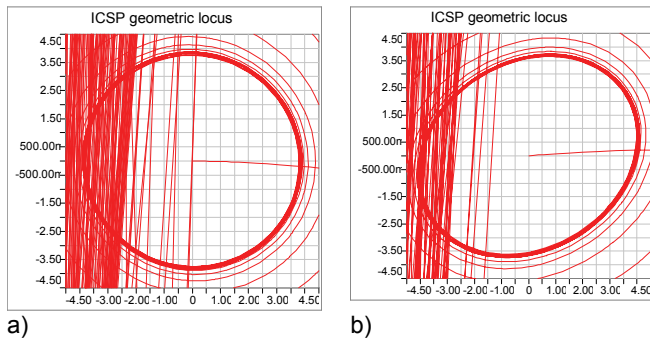


Fig.2. ICSP geometric locus for a healthy induction motor (a) and for a fault induction motor with a short circuit in phase "c"

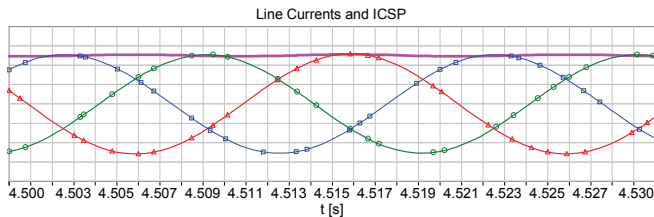


Fig.3.a. Line currents and ICSP for a healthy induction motor

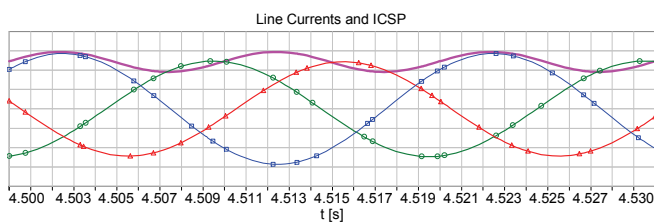


Fig.3.b. Line currents and ICSP for a fault induction motor with a short circuit in phase "c"

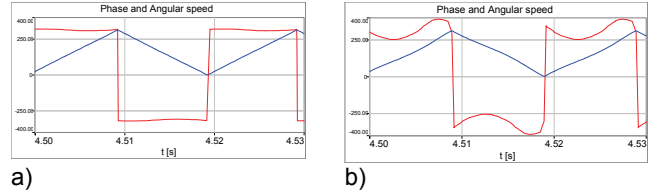


Fig.4. Phase and angular speed of ICSP for a healthy induction motor (a) and for a fault motor with a short circuit in phase "c"

Analyze of new stator winding fault detection tools

By using *Simplorer* simulation scheme of Figure 1, has been investigate stator winding fault for an 400 V, 50 Hz, 4-pole induction motor with the following parameters:

- Stator resistance: 1 Ohm,
- Stator leakage inductance: 20 mH,
- Rotor resistance: 0.88 Ohm,
- Rotor leakage inductance: 13 mH,
- Main inductance: 0.4 H.

As short-circuit detection tools have been considered the following variables:

- The increasing of faulty phase current amplitudes in respect with the healthy phase current amplitudes,
- The ICSP modulus ripple amplitudes,
- The quadratic ICSP modulus ripple amplitudes,
- The ICSP angular speed ripples amplitudes.

The short circuits' severity was varied in 9 steps of 5%, from 0% until 40%.

The increasing of faulty phase current amplitudes

In figure 5 it is shown the short circuits' severity dependences of the faulty and healthy phases current amplitudes, for no loaded and loaded induction motor. The increasing of the faulty phase current amplitudes is direct proportional with the short circuits' severity.

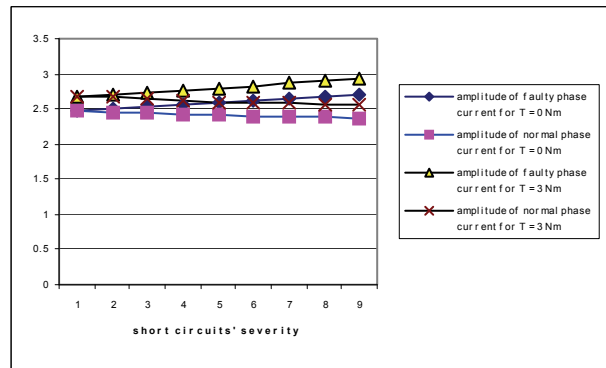


Fig.5. The short circuits' severity dependences of phase current amplitudes for two extreme torque values

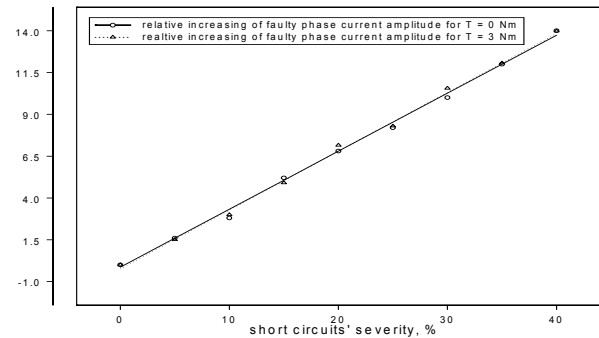


Fig.6. The relative increasing of faulty phase current amplitudes

In figure 6 it is shown *the relative increasing of faulty phase current amplitudes*. The relative increasing is defined as the ratio between the absolute increasing and the current amplitude of a healthy phase for the same short circuits' severity. It has to note that the load torque has a very small influence on the relative increasing.

The slope of the relative increasing can be considered as a *merit number* of the faulty phase current amplitudes detection tool. In our case its value is $M_{CA} = 0.33$.

The ICSP modulus ripple amplitudes

In figure 7 it is shown the short circuits' severity dependences of the maximum and minimum of ICSP modulus ripple amplitudes for two extreme values of the load torque.

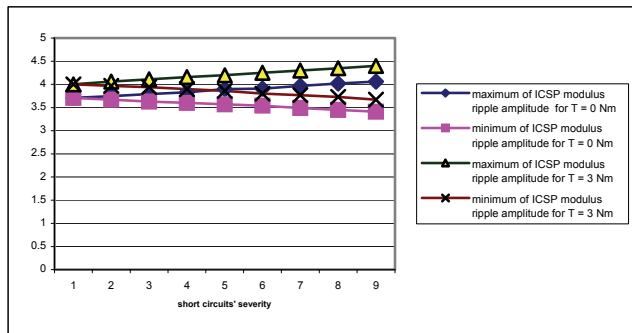


Fig.7. The short circuits' severity dependences of the extreme values of ICSP modulus ripple

The short circuits' severity dependences of the relative amplitudes of ICSP modulus ripple are shown in figure 8. The average value of the ICSP modulus, for a given torque, is adopted as the reference value for the relative dependence. As it is shown, the load torque has a small influence on this dependence. The merit number of this detection tool has the value $M_{I1} = 0.44$.

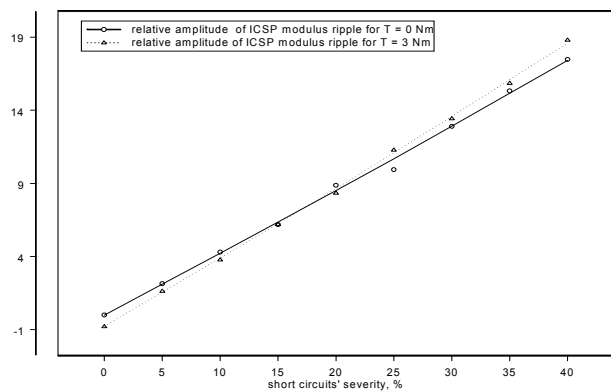


Fig.8. The short circuits' severity dependences of the relative amplitudes of ICSP modulus ripple

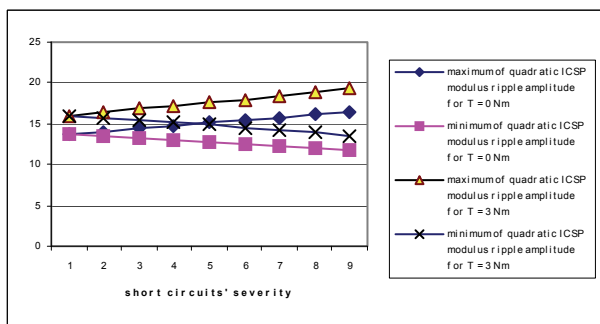


Fig.9. The short circuits' severity dependences of the quadratic ICSP modulus ripple

The quadratic ICSP modulus ripple amplitudes

In figure 9 it is shown the short circuits' severity dependences of the maximum and minimum of quadratic ICSP modulus ripple for two extreme values of the load torque. Its corresponding relative dependence is shown in figure 11.

The ICSP angular speed ripple amplitudes

In figure 10 it is shown the short circuits' severity dependences of the maximum and minimum values of ICSP angular speed ripple amplitudes for two extreme values of the load torque. These dependences have two positive characteristics: the linearity and the lack of the load torque influence.

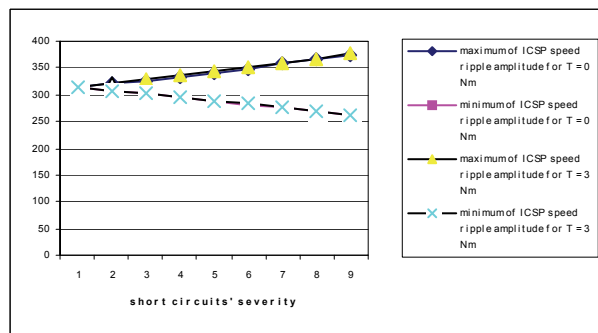


Fig.10. The short circuits' severity dependences of the ICSP angular speed ripple amplitudes

The short circuits' severity dependences of the relative ICSP angular speed ripple amplitudes are shown in figure 11. The reference value for this relative dependence is the average value of the angular speed for various short circuits' severity percent. The linearity of these dependences is high and the lack of the load torque influence is also an advantage. The merit number of the last two detection tools are the same and has the value $M_{I2S} = 0.86$.

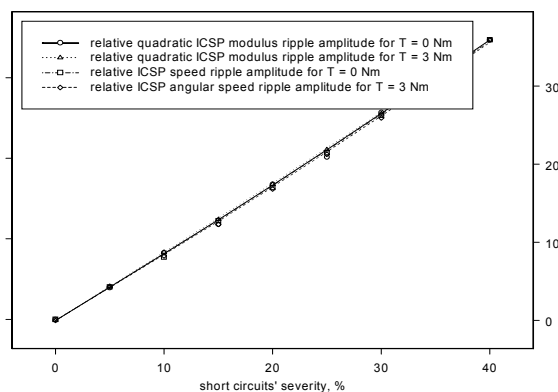


Fig.11. The short circuits' severity dependences of the relative ICSP angular speed ripple amplitudes

Conclusions

This paper introduces a new approach, based on the computer-aided monitoring of the instantaneous current space phasor (ICSP), for online diagnosing the occurrence of inter-turn short circuits in the stator windings of three-phase induction motor.

The online diagnosis is based on the identifying the modulus and the angular speed of the ICSP, whose ripples increase with the fault severity and whose phases are associated to the faulty phase.

Four stator short circuit detection procedures, which use the following variables, have been analyzed:

- The increasing of faulty phase current amplitudes in respect with the healthy phase current amplitudes,
- The ICSP modulus ripple amplitudes,
- The quadratic ICSP modulus ripple amplitudes,
- The ICSP angular speed ripples amplitudes.

The efficiency of these procedures has been appreciated with merit numbers, defined as the slope of its relative short circuits' severity characteristics. The merit numbers evaluate the diagnosis sensitivity of procedures. The last two procedures have the highest merit numbers and can be recommended as online short circuits' detection tools.

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