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# Phase-Modulus Diagram of Instantaneous Current's Space Phasor as Diagnosis Tool of Induction Motor's Stator Windings

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**Abstract.** The paper introduces a new approach for induction motor stator's windings inter-turns short circuits diagnosis, based on the computer-aided monitoring of the stator Instantaneous Currents Space Phasor (ICSP). Between the stator's windings short circuits severities and the shape of the permanent geometrical loci of ICSP, as it appears in the polar coordinates modulus-phase, are identified the appropriate correspondences which are used as on-line induction motor fault identifiers. It is shown the new short circuit identifier is insensitive to induction motor load variations. The investigative studies of this new stator windings inter-turns fault identifier are made on a simulated induction motor in *Simplorer* programming medium.

## Key words

Induction motor, stator winding diagnosis, current's space phasor, phase-modulus diagrams.

## 1. Introduction

Nowadays, induction motor is the workhorse of the modern industrial drive systems, therefore its health monitoring, which can contribute to the shortage of the unscheduled downtimes, has a great economic importance. According to some statistics, almost 40% of all reported induction motor failures are caused by insulation damage between two adjacent turns in stator coils. In technical literature can be find several techniques for induction motor health monitoring and fault diagnosis based on its stator line currents processing. Among these, there are methods based on the stator currents' Park's vector in Cartesian representation due to the sensitivity of this vector to motor internal faults. The currents' Park's vector approach is based on the correspondence between the ellipticity of its Cartesian representation with the induction motor malfunctions – the ellipticity increases with the severity of the fault and its major axis orientation is associated to the faulty phase [1]-[8].

The present paper introduces a new approach for induction motor stator's windings inter-turns short circuits diagnosis, based on the computer-aided monitoring of the stator ICSP in polar coordinates modulus-phase. By using a simulated model of induction motor with various severities of inter-turns short circuits in stator coils, the correspondences between these internal faults and the shape of the permanent geometrical loci in polar representation of ICSP are identified. In this new coil short circuit diagnosis approach, the modulus width of the ICSP trigonometric geometrical locus increases with the severity of the fault and its shape is associated to the faulty phase *a* or *b* and *c*, therefore the ICSP polar geometric locus can be used as an induction motor fault identifier. Also by simulation it is shown as this new fault identifier is insensitive to induction motor load variation.

## 2. The ICSP's phase-modulus approach

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

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

which can be write in Cartesian coordinates as:

$$\underline{i} = i_\alpha + j i_\beta \tag{2}$$

where the real and the imaginary components are:

$$i_\alpha = i_a - \tfrac{1}{2} i_b - \tfrac{1}{2} i_c$$
$$i_\beta = \tfrac{\sqrt{3}}{2} i_b - \tfrac{\sqrt{3}}{2} i_c \qquad (3)$$

In polar coordinates, the stator ICSP is:

$$\underline{i} = m \cdot e^{j\varphi} \qquad (4)$$

where the modulus $m$ and the phase $\varphi$ are given by

$$m = \sqrt{i_\alpha^2 + i_\beta^2}$$
$$\varphi = \arccos \frac{i_\alpha}{m} \qquad (5)$$

The *Simplorer* simulation scheme of the stator faulty induction motor with computer-aided monitoring of the stator ICSP according to the equations (3) and (5) is shown in Figure 1.

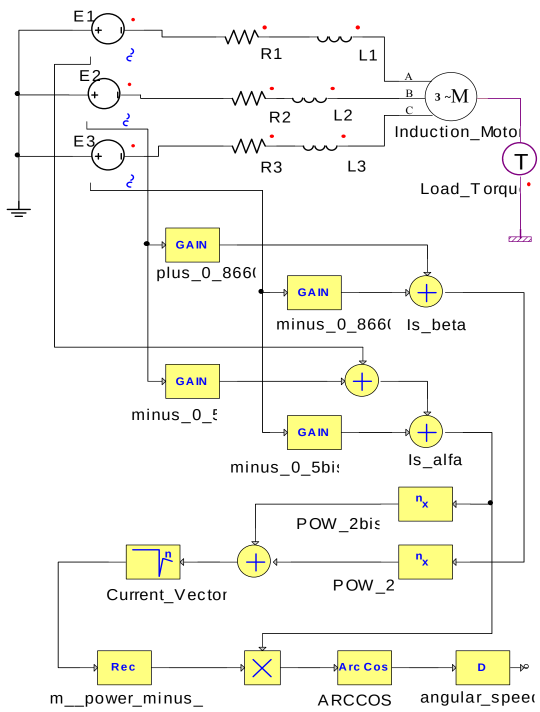



Fig. 1. The *Simplorer* simulation scheme of the faulty induction motor with the monitoring of the stator ICSP

The simulated induction motor parameters are the stator resistance of 1 ohm and the stator inductance of 10 mH. The specified stator resistance of 1 ohm and the stator inductance of 10 mH where divided in two, one half inside the motor and another half outside. An inter-turns short circuit in a stator phase was simulated by a proportional reduction of the values of the external stator phase parameters.

For a starting process of the induction motor, the modulus-time diagram of the stator ICSP is shown in Figure 2 and the phase-modulus diagrams of the stator ICSP for a short circuit in phase $a$ and in phase $b$ are given in Figure 3.a and 3.b, respectively. A phase-modulus diagram of ICSP is named also geometrical locus of the phasor.

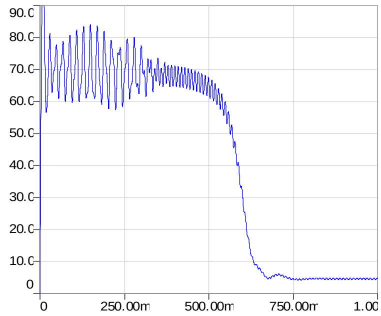
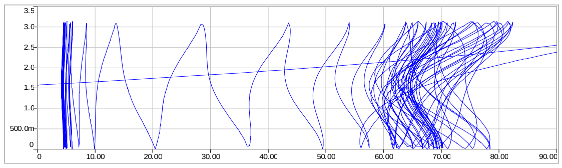
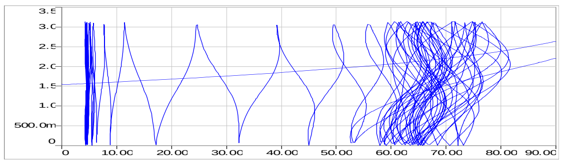


Fig. 2. The modulus-time diagram for a starting process of the stator ICSP of induction motor



a)



b)

Fig. 3. The phase-modulus diagrams for a starting process of the stator ICSP of induction motor for a short circuit in phase $a$ and $b$, respectively

The phase-modulus diagrams of Figures 3 contain two distinct thick zones – the modulus high values thick zones and the modulus low values thick zones. The high values thick zones are created at the beginning of the starting process of the motor and the low values thick zones are created after the end of the starting process, namely in permanent regimes. Both of these zones configurations are sensitive to the inter turns coils short circuit but the configurations of the low values thick zone are more accurate as those of the high values thick zone and therefore it is recommended as a fault identifier for stator coils short circuits. In addition, due to the fact that the low values zones are created in permanent regimes make this configuration – geometrical loci of ICSPs' in permanent regimes – recommendable for on-line short circuit diagnosis. In the following section we will shown the correspondences between coils inter turns short circuits severities and modulus low values thick zones configurations.

## 3. Short circuits identifiers

By using the simulation scheme given in Figure 1, the configurations of geometrical loci of the stator ICSP in permanent regimes for various single phases inter turns short circuits were determined. The simulation results are shown in Table 1, in the case of short circuits in phase *a*, and in Table 2, in the case of short circuits in phase *b*.

As a quantifier of the geometrical locus of the ICSP in permanent regimes we introduce the relative width of the configuration, defined as:

$$\Delta m_{rel} = \frac{\Delta m}{m_{med}} \qquad (6)$$

where the absolute with of the geometrical locus is:

$$\Delta m = x_{\max} - x_{\min} \qquad (7)$$

with $x_{\max}$ and $x_{\min}$ defined in Figure 4, and

$$m_{med} = 2 \cdot \frac{x_{\max} - x_{\min}}{x_{\max} + x_{\min}} \qquad (8)$$

As it shown in Tables 1 and 2, the values of $m_{\text{med}}$ are the almost same for all the geometrical loci configurations ($m_{\text{med}}$ = 4.575), and the widths $\Delta m$ of the configurations generated by short circuits in any phase but with the same severity are identical.

Table 1. – Geometric loci of the stator ICSP for short circuits in phase *a*

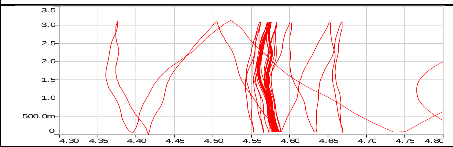
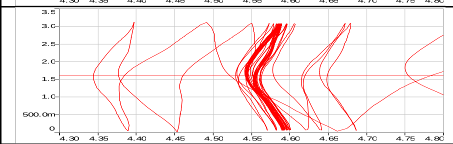
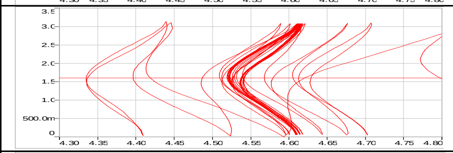
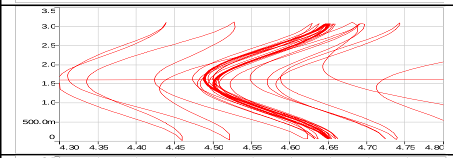
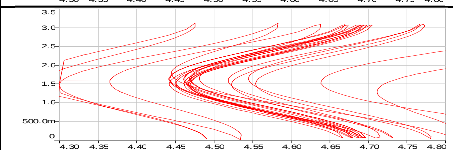
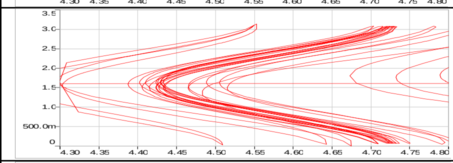
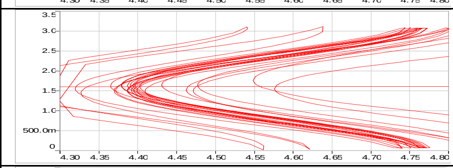
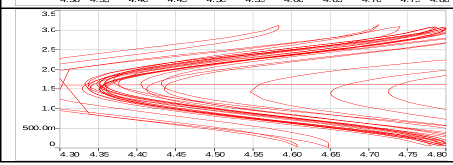
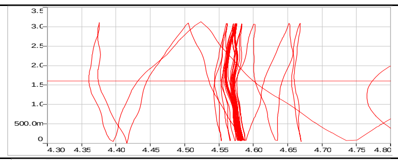
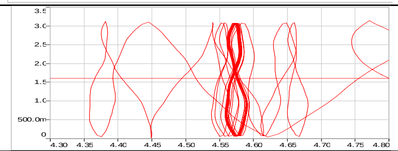
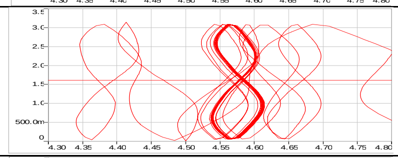
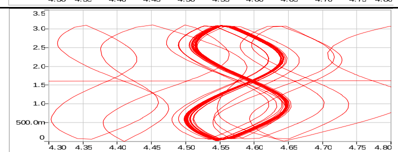
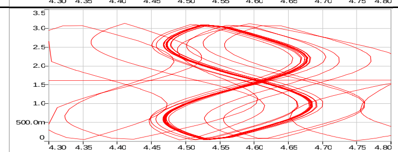
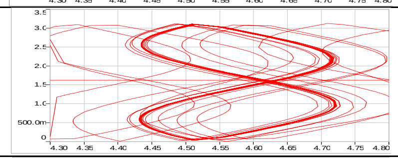
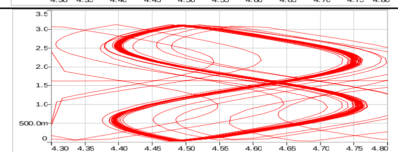
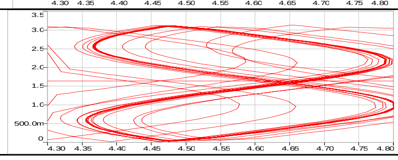
| Fault severi ty | Geometric loci of stator ICSP in permanent regimes | $\Delta m$, $m_{med}$, $\Delta m\%$ |
|---|---|---|
| 0% |  | 0<br>4.575<br>0% |
| 2% |  | 0.035<br>4.575<br>0.76 |
| 5% |  | 0.08<br>4.575<br>1.74% |
| 10% |  | 0.15<br>4.575<br>3.28@% |
| 15% |  | 0.21<br>4.575<br>4.59% |
| 20% |  | 0.30<br>4.58<br>6.55% |
| 25% |  | 0.36<br>4.575<br>7.87% |
| 30% |  | 0.43<br>4.575<br>9.39% |

Table 2. – Geometric loci of the stator ICSP for short circuits in phases *b* or *c*

| Fault severi ty | Geometric loci of stator ICSP in permanent regimes | $\Delta m$, $m_{med}$, $\Delta m\%$ |
|---|---|---|
| 0% |  | 0<br>4.575<br>0% |
| 2% |  | 0.035<br>4.575<br>0.76 |
| 5% |  | 0.08<br>4.575<br>1.74% |
| 10% |  | 0.15<br>4.575<br>3.28@ % |
| 15% |  | 0.21<br>4.575<br>4.59% |
| 20% |  | 0.30<br>4.58<br>6.55% |
| 25% |  | 0.36<br>4.575<br>7.87% |
| 30% |  | 0.43<br>4.575<br>9.39% |

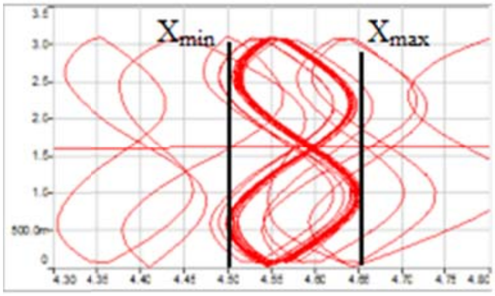



Fig. 4. How it is defined the absolute width of the geometrical locus of ICSP

The established dependence between single phase short circuits severities (Fault Severity – F.S.) and the relative width of the geometrical locus of the stator ICSP, considered as a fault identifier (F.I.), is given in Table 3.

Table 3. – The dependence between short circuit severities and the fault identifier

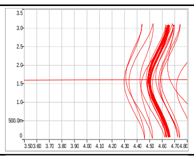
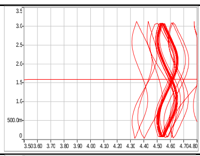
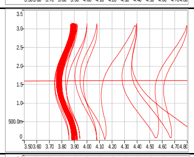
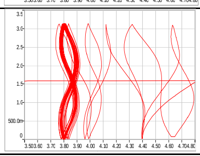
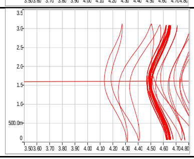
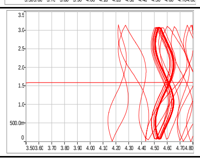
| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| F.S.% | 0 | 2 | 5 | 10 | 15 | 20 | 25 | 30 |
| F.I.% | 0 | 0.76 | 1.74 | 3.28 | 4.59 | 6.55 | 7.87 | 9.39 |

The sensitivity of the fault identifier, defined as the ratio between the average increases of the F.I. and the average increases of F.S. is about 33%.

## 5. Load influence

The results obtained by simulations and given in Tables 1 and 2 where obtained for the induction motor with rated load ($T_N$ = 5 Nm and $J_N$ = 75 kgm$^2$). In order to establish the load influence on the shapes of geometrical loci of the ICSP, stator winding short circuits with 10% severity where simulated and for non-rated loads ($T_1$ = 1 Nm, or $J_1$ = 150 kgm$^2$). The obtained results are given in Table 4

Table 4. –Load influence on the ICSP geometrical loci

| Load parameters | Geometric loci for non-rated loads | | $\Delta m$ |
|---|---|---|---|
| $T_N$, $J_N$ |  |  | 0.17 |
| $T_1$, $J_N$ |  |  | 0.17 |
| $T_N$, $J_1$ |  |  | 0.17 |

## 5. Conclusion

The stator winding inter turns short circuits on-line identification can be made by using a new identifier – the geometrical locus of the ICSP in permanent regimes, defined in polar coordinates. The width of the ICSP polar geometrical locus, defined in Figure 4, can be used as quantifier of the fault severity.

The shape of the ICSP polar geometrical locus for the phase *a* is not the same as the shape of the ICSP polar geometrical loci for the phase *b* or *c*, but its widths are the same, as one can remark from the Tables 1, 2 and 4.

The dependence between short circuit severities and fault identifier is almost linear and has a sensitivity of 33%, as one can see from the Table 3.

The load variations have no influence on the new short circuits identifier, as one can remark from the Table 4.

The computer-aided monitoring of the stator ICSP needs a minimal calculus power, as it is shown in Figure 1.

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