ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2012. No. 7(123)
ELEKTRONIKA IR ELEKTROTECHNIKA

AUTOMATION, ROBOTICS
AUTOMATIZAVIMAS, ROBOTECHNIKA

Using Clarke Vector Approach for Stator Current and Voltage Analysis on Induction Motors with Broken Rotor Bars

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crossref http://dx.doi.org/10.5755/j01.eee.123.7.2368

Introduction

Condition monitoring and diagnostic of induction motors has become an important issue for companies and industries whose production depends on the reliability of electrical drives. As the number of induction motors is growing in time, so is the importance of their diagnostics.

The majority of all stator and rotor faults are caused by a combination of various stresses, which can be thermal, electromagnetic, residual, dynamic, mechanical or environmental [1]. Broken rotor bars of squirrel-cage induction motors can be classified as one of the most common faults along with bearing faults and gearbox failures. Broken rotors bars can lead to vibration problems, but more likely, in severe cases, the bar pounds out of the slot and makes contact with the stator core or winding [1]. If not detected and treated in time, fault such as cracking or broken rotor bars will propagate until the whole rotor cage is destroyed.

During the last years many papers have been written about condition monitoring of induction machines. However, even though thermal and vibration monitoring have been utilized for decades, most of the recent research has been directed toward electrical monitoring of the motor with the emphasis on inspecting the stator current [2]. It has been suggested that stator current monitoring can provide the same indications as vibration based monitoring, but it can be done without requiring access to the motor. This is a very important benefit of such diagnostic approach, as the motors that are diagnosed will not suffer any changes in their working cycle and all the processes can be continued completely undisturbed.

As stator current pattern is highly dependent from the supply quality and load conditions of the motor, authors of this paper have tried to find solutions for improving the diagnostic possibilities of induction motors using simple mathematic methods such as Clarke vector approach. To lessen the impact of the factors mentioned before, implication of Clarke vector approach on stator voltage is proposed. Using voltage as an indicator for detection of broken rotor bars can have its own advantages which are described latter in this paper.

Measurements

To test the broken rotor bars detection possibility using Clarke vector approach sets of laboratory measurements and analysis were conducted. Two different motor states were used for the measurements. First series of measurements were done with a healthy rotor and the second series with a faulty rotor, containing seven broken bars, situated under the same magnetic pole next to each other (Fig. 1). Thus, the measurements provided two sets of results: one healthy set and one set with a faulty rotor in a very bad shape. Technical data of the tested induction motor used in the experimental setup (Fig. 2) is brought in Table 1.

Table 1. Technical data of tested induction motor INDRAMAT AD100B

Parameter	Symbol	Value
Nominal voltage	U_n	177 V
Nominal current	I_n	14.8 A
Speed	n_n	1456 rpm
Nominal torque	T_n	20 Nm
Frequency	f	50 Hz
Power factor	cosφ	0.785

During all the tests current and voltage of two phases was measured. Third phase current and voltage was calculated. Tests were performed in no-load and full-load conditions at steady state performance.

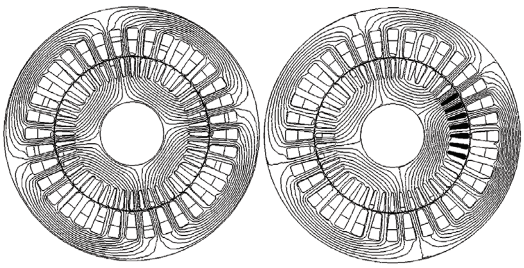

Fig. 1. Magnetic field distribution in the cross section of a 3 kW induction motor at nominal load operating condition: left – healthy rotor cage, right – faulty rotor cage with seven broken bars (shaded) [3]

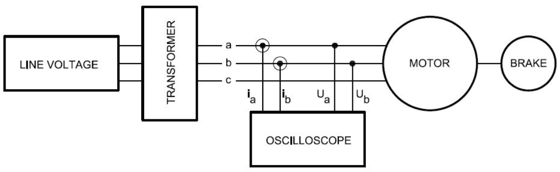

Fig. 2. Experimental setup for motor testing

Analysis

Clarke transformation. Clarke transformation is an easy way to decide if the motor is healthy or not [4]. It means that the phase currents (i_a, i_b, i_c) are to be transformed into current alpha and beta components (i_α, i_β) and placed on d-axis and q-axis respectively. In other words, transforming a three-dimensional system into a two-dimensional one:

$$\begin{cases} i_\alpha = i_a, \\ i_\beta = \sqrt{2/3}\left(i_b + i_c\right). \end{cases} \tag{1}$$

Its representation is a circular pattern centered at the origin of the coordinates. This is a very simple reference figure, which allows the detection of an abnormal condition due to any fault of the machine by observing the deviations of the acquired picture from the reference pattern [5].

The healthy pattern differs slightly from the expected circular one, because supply voltage is generally not exactly sinusoidal [6]. Pattern of the rotor with broken bars is however more like an ellipse shaped one [7].

Exactly the same transformation can be used to transform the three-phase voltage into a two-dimensional system:

$$\begin{cases} u_\alpha = u_a, \\ u_\beta = \sqrt{2/3}\left(u_b + u_c\right), \end{cases} \tag{2}$$

where u_a, u_b, u_c are the phase voltages and u_α, u_β are the voltage alpha and beta components. This gives the opportunity to monitor the stator voltage as well as current and make the decisions upon the analyses of the obtained graphs [5].

Stator current. To perform analysis on the data received from the measurements, MATLAB software was used. This makes it very simple to perform Clarke transformation on the gained data.

It should be taken into account however, that the supply voltage during those tests was not exactly sinusoidal, which affects the graphs and can result in some unexpected curves, peaks and deviations in the resulting figures. But as different loads, voltage and current, as well as both healthy and faulty motor conditions are observed, can those deviations due to non-ideal sine wave be discarded at the moment.

At the first two figures (Fig. 3 and Fig. 4) Clarke vector pattern of the stator current can be seen. It should be noted that these graphs have been plotted with the motor running with no torque applied to the rotor.

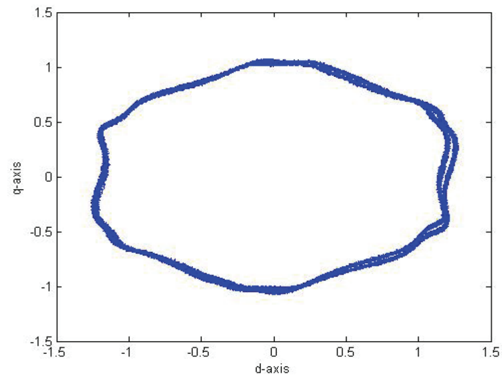

Fig. 3. Stator current Clarke vector pattern of healthy motor on no-load conditions

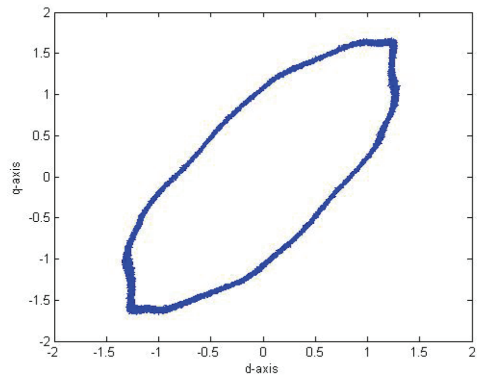

Fig. 4. Stator current Clarke vector pattern of faulty motor on no-load conditions

As seen in these graphs, the healthy motor figure is indeed in a more or less circular shape and the faulty one more close to an ellipse as referred to in the literature concerning this method. In addition, it was found that the absolute value of current is higher in the figure of the faulty motor.

Next graphs (Fig. 5 and Fig. 6) are plotted when the motor is running on its nominal torque, meaning that 20 Nm of torque is applied to the rotor.

As seen from the graphs of nominal load operation, faulty case of the motor is again traceable. Clarke vector pattern in the healthy cases is drawn in more or less as a circle, whereas graphs turn ellipsoidal, when the faulty case with seven broken rotor bars is viewed.

As more torque has been applied to the rotor, the current amplitude rises. It can be seen when both healthy and faulty state graphs of no load and nominal load situations are compared to each other.

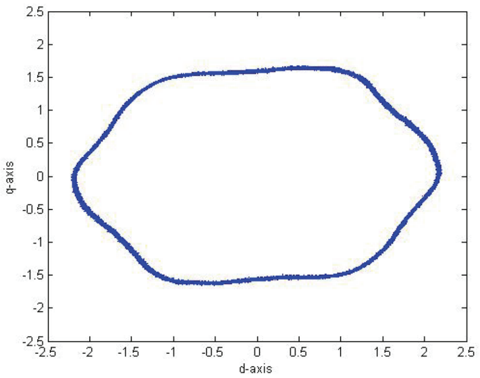

Fig. 5. Stator current Clarke vector pattern of healthy motor on nominal load conditions

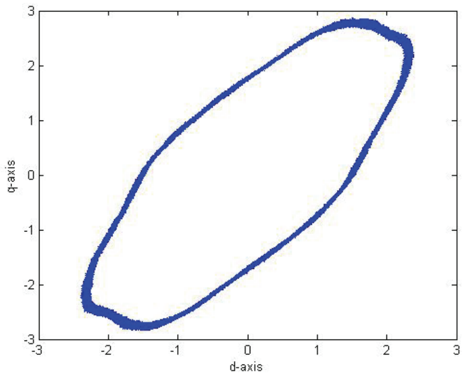

Fig. 6. Stator current Clarke vector pattern of faulty motor on no-load conditions

Stator voltage. The next graphs (Fig. 7 and Fig. 8) are plotted using the Clarke transformation on stator voltage at the same time moment as the current data was gathered. Using stator voltage should yield better results and no-load condition is observed first.

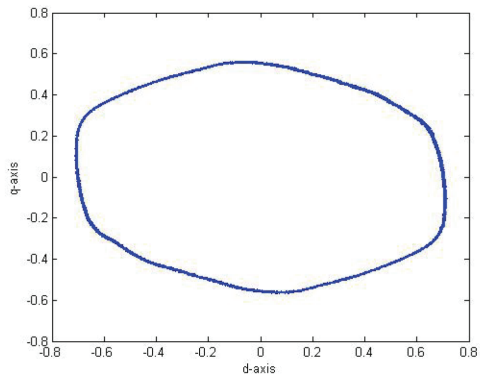

Fig. 7. Stator voltage Clarke vector pattern of healthy motor on no-load conditions

From these graphs it can be seen that in case of voltage the healthy motor pattern looks again more as a circle and in case of faulty motor more like an ellipse. However changes in scale are more drastic and better traceable in case of the voltage graphs. Additionally, from the healthy case graph it can be seen that deviations due to the not ideal sine voltage supply are not so vivid in the voltage case.

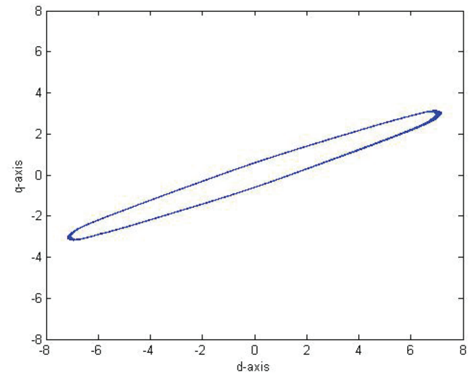

Fig. 8. Stator voltage Clarke vector pattern of faulty motor on no-load conditions

Next set of graphs (Fig. 9 and Fig. 10) are from the nominal load test, again taken in the same moment as for the current figures.

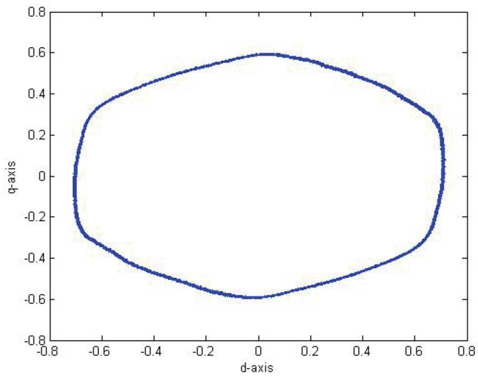

Fig. 9. Stator voltage Clarke vector pattern of healthy motor on nominal load conditions

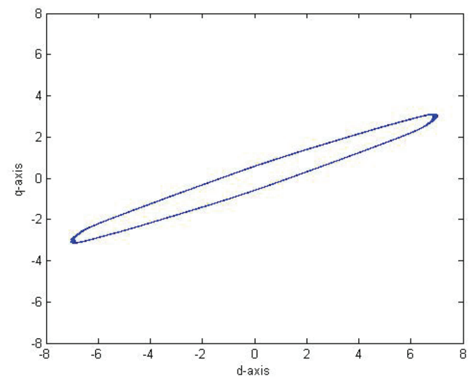

Fig. 10. Stator voltage Clarke vector pattern of faulty motor on nominal load conditions

When no load situation and nominal load situation are compared, it can be seen that they match in a very large amount, which means that most of the changes in the patterns are due to the voltage unbalance caused by the seven broken rotor bars in the induction motor and not any other deviations in the grid or other variables. More importantly, as load does not affect the voltage pattern and the supply voltage is held constantly at a 177 V margin, it gives the opportunity to set a hypothesis that broken rotor bars in three-phase squirrel-cage induction motors are more traceable, when stator voltage Clarke vector pattern is viewed.

Conclusions

Conducted experiments and analyses show that although traditionally used for transformation of current data, Clarke transformation (or Park's transformation) can be very effectively used for transformation of three-phase voltage. For diagnostic purposes this might be a better use of the method, as in the case of voltage, load conditions, as well as deviations of supply voltage do not have as high effect on the outcomes as in the case of current.

If the figures of stator current and voltage patterns in both load conditions are observed, it can be seen that voltage graphs do not have alterations in amplitude when load is changed. In current cases the change is about 1.5 times. This peculiarity of voltage patterns gives the opportunity for better and more precise decisions as healthy and faulty case data can be compared without any changes or recalculations of amplitudes.

When diagnostics via the comparison of induction motor performance models is desired, the described method could be used in a sufficiently effective way to decide upon the state of the motor. The needed information is the model or figure of the healthy case of the motor, which would also be the master model, to which other graphs would be compared to. It could prove to be a very good way for performing diagnostics also in the sense that no disturbance in the working cycle of the motor is needed in order to perform the needed measurements and analysis.

These tests and analysis that are presented in this paper are based on the measurements performed on a healthy motor and a motor in a very bad shape. For future tests it is necessary to analyze similar diagnostic possibilities on motors with smaller faults as well. This would show if such diagnosis is relevant in cases not as severe as described here and whether predicting possible faults using the described method is possible.

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Received 2011 10 27
Accepted after revision 2012 02 07

T. Vaimann, A. Kallaste, A. Kilk. Using Clarke Vector Approach for Stator Current and Voltage Analysis on Induction Motors with Broken Rotor Bars // Electronics and Electrical Engineering. – Kaunas: Technologija, 2012. – No. 7(123). – P. 17–20.

This paper presents the possibilities of using Clarke vector approach for stator current and voltage analysis for induction motors with broken rotor bars. The equations for performing Clarke transformation on three-phase stator current and voltage are presented. Since this method is generally used for transforming current signals, benefits for using it on voltage signals is presented. Described method can be used for effective detection of broken rotor bars in three-phase squirrel-cage induction motors. Necessity for further study is proposed. Ill. 10, bibl. 7, tabl. 1 (in English; abstracts in English and Lithuanian).

T. Vaimann, A. Kallaste, A. Kilk. Indukcinių variklių su sulūžusiais rotoriaus strypais statoriaus srovės ir įtampos analizė naudojant Klarko vektorių // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 7(123). – P. 17–20.

Pateikiama indukcinių variklių su sulūžusiais rotoriaus strypais statoriaus srovės ir įtampos analizė, atliekama naudojantis Klarko vektorių galimybėmis. Pateikiamos trifazio statoriaus srovės ir įtampos Klarko transformacijos išraiškos. Kadangi šis metodas daugiausiai taikomas srovės signalams transformuoti, pateikiami įtampos signalų naudojimo privalumai. Aprašytasis metodas gali būti taikomas trifazių indukcinių variklių sulūžusiems rotoriaus strypams efektyviai detektuoti. Il. 10, bibl. 7, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).