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Application of Radial Basis Neural Network to diagnostics of induction motor stator faults using axial flux

Abstract*. The paper presents diagnostics of induction motor stator faults. The decision on stator winding condition has been taken using the axial flux and based on artificial neural network with radial basis transfer function. The axial flux has been measured for different configuration of stator winding. On the basis of research it can be concluded that the axial flux can be successfully used in detection of faults in induction motor stator.*

Streszczenie*. W artykule przedstawiono zastosowanie radialnej sieci neuronowej do diagnostyki maszyny indukcyjnej. Do uczenia sztucznej sieci neuronowej wykorzystano pomierzony strumień osiowy. Pomiaru strumienia osiowego dokonano za pomocą cewki pomiarowej nawiniętej wokół połączeń czołowych stojana. Uszkodzenia symulowano za pomocą wyprowadzonych zaczepów uzwojenia stojana. Przedstawione wyniki podań potwierdzają skuteczność zaproponowanej metody.* ***(Zastosowanie radialnej sieci neuronowej z wykorzystaniem strumienia osiowego w diagnostyce silnika indukcyjnego)***

Keywords: axial flux, artificial neural network, diagnostics, induction machine.
Słowa kluczowe: strumień osiowy, sztuczna sieć neuronowa, diagnostyka, maszyna indukcyjna.

Introduction

The induction machines (IM) are widely used in many industrial applications. There is a need for non-invasive diagnostic methods which are able to indicate the condition of the machine. The monitoring process includes condition of stator and rotor windings, asymmetrical position of rotor, condition of bearings. The artificial neural network (ANN) may draw inferences about condition of IM on the basis of spectrum of stator current [3]. The other signals such as a value of power, vibrations and axial flux can be used in diagnosis process [1].

The main target of diagnosis is detecting any asymmetry in IM structure. In general, the machine is working in asymmetry state when even one phase has different conditions than any other. The asymmetry can be caused by faults in electrical system such as break in phase, turn to turn shortcuts, phase to phase shortcuts, phase to corpus shortcut. The asymmetry in magnetic circuit can be caused by air gap, anisotropy of magnetic material, inaccuracy during manufacturing process. The asymmetry can be observed as pulsation in phase current and torque, losses and overheating. Using the positive, negative and zero sequence analysis it can be concluded that asymmetry has influence in followings: power consumption, increasing of phase current, decreasing of torque (by negative sequence of torque), decreasing of power on shaft (by negative sequence of phase current).

Axial Flux

A. The measurement of the axial flux

In the ideal three-phase induction machine supplied by ideally symmetrical source in steady-state the axial flux should not occur. Unfortunately the real machines are not perfect therefore the axial flux occurs even for symmetrical supply. It is an effect of imperfection in a production process. Moreover, the symmetry supply is not a trivial task. The negative effects of incidence of axial flux are eddy current losses in elements near end-turn area and bearings damages. Therefore, the axial flux could be a good indicator of IM health.

To measure the axial flux the search coil was wound around end-turn in front of the machine (Fig.1). The coil is perpendicular to machine and shaft. It can be seen in Fig.1 that the search coil measures the sum of flux from stator winding and flux from rotor winding. In real machines this sum is not equal to zero because of asymmetry in electric and magnetic circuits. The frequency spectrum of EMF induced in the coil includes frequency of stator current and rotor current. Influence of asymmetry in rotor can be observed in spectrum by frequencies f_{nw} which can be calculated as follows [4]

(1) $$f_{nw} = (1 \pm 2s) f_s$$

where: s – slip, f_s – supply frequency.

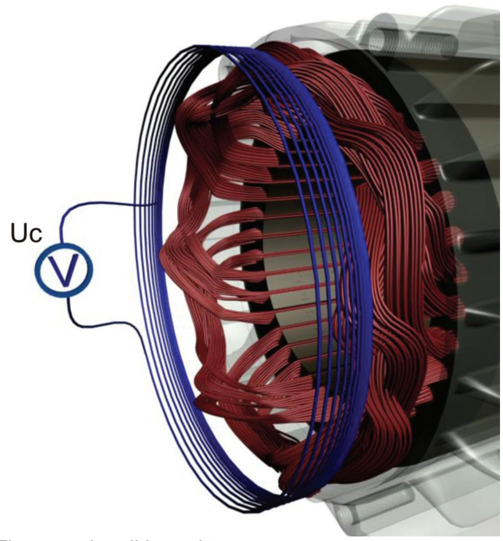

Fig.1. The search coil in end-turn area

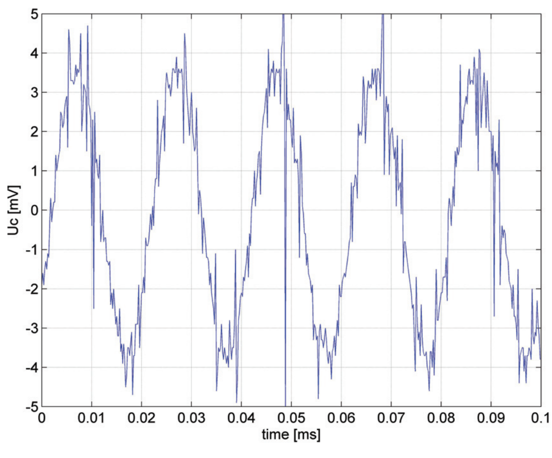

Fig.2. The waveform of EMF induced in the coil

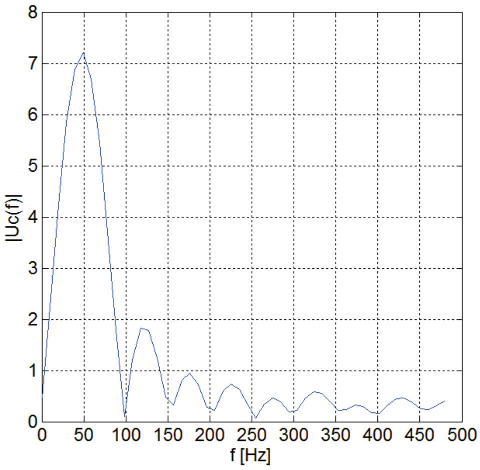

Fig.3. Spectrum of EMF induced in the coil

The waveform of the EMF induced in the coil, at symmetrical supply without rotor is presented in Fig.2. The spectrum of EMF, in only the low frequency band, is shown in Fig.3. The supply frequency (50 Hz) can be observed.

B. Formation of asymmetry in stator winding

In order to model the faults in stator windings, each phase has been dived into separate parts (Fig.4). The ends of coils have been got out of the machine. The asymmetry in stator winding has been formed as shortcutting of a coil.

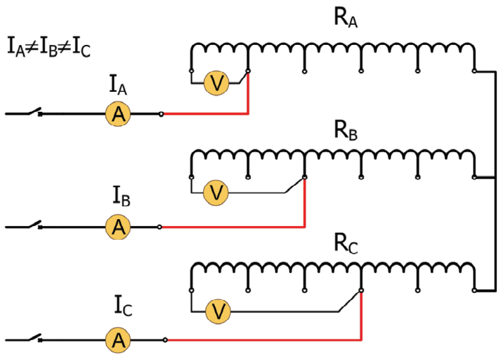

Fig.4. Formation of asymmetry in stator winding

Artificial neural network

The numerical technique in signal analysis, classification problems and deduction is a difficult task. The artificial neural network (ANN) could be very helpful and stand in for this task.

A. Structure of ANN

For the problem under consideration the ANN has two layers. The neurons in first layer have radial basis transfer function and linear transfer function in the second layer. This type of the ANN is Radial Basis Neural Network (RBNN). The structure of RBNN is presented in Fig. 5 [5]. The radial basis transfer function can be expressed as follows

(2) $$\varphi(\mathbf{x})=\varphi(\|\mathbf{x}-\mathbf{c}_i\|)=\exp\left(-\frac{\|\mathbf{x}-\mathbf{c}_i\|^2}{2\sigma_i^2}\right)$$

where $\mathbf{c}_i$ – center, σ_i – spread. The plot of radial basis transfer function is presented in Fig. 6.

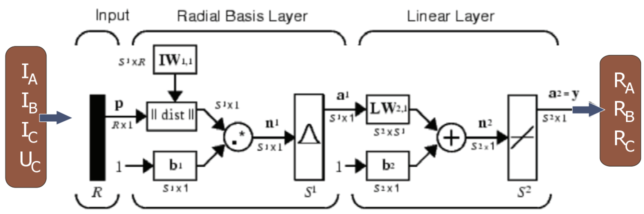

Fig.5. The structure of RBNN

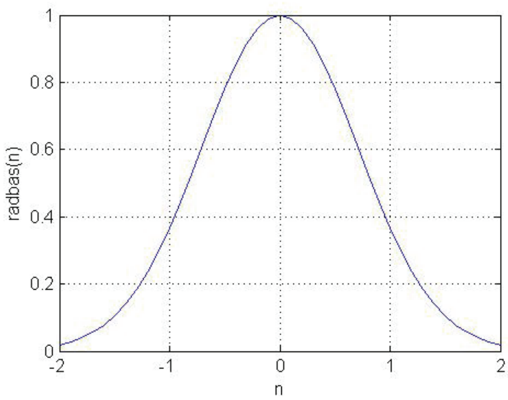

Fig.6. The plot of radial basis transfer function

B. Training of RBNN

The classification problem is realized as a sum of radial basis functions. This sum can be expressed as follows

(3) $$f(x)=\sum_{i=1}^{n} w_i\varphi(\|\mathbf{x}-\mathbf{c}_i\|)$$

The training process of RBNN is a procedure of modifying the weights and biases of each neuron in the network. The procedure ends when the minimum of the objective function of the following form

(4) $$E=\sum_{i=1}^{p}\left[\sum_{j=1}^{n} w_j\varphi(\|\mathbf{x}-\mathbf{c}_i\|)-d_i\right]^2$$

is achieved.

The application of RBNN in diagnosing faults in rotor of electrical machines can be found in [2].

The selected results

The developed RBNN has been used for detection of faults in a three phase P_N=2,2 kW, n_N=1420 rpm induction motor.

For training RBNN the set of measured data has been used. The set of data for training consists of 31 samples. One sample includes RMS value of the phase current and RMS value of the voltage in a search coil. The training process has been shown in Fig. 7.

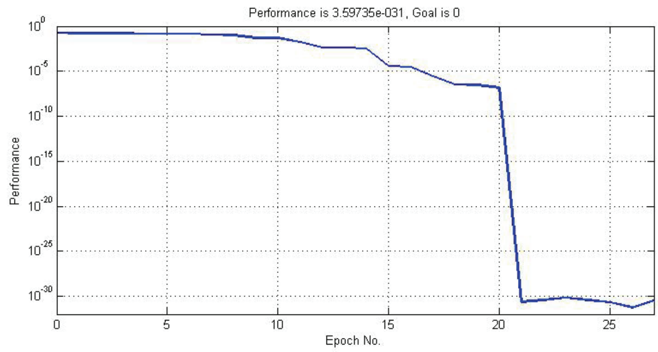

Fig. 7. Training process

The trained RBNN has been used in detection of faults in stator windings. The target value was the resistance of the phase which depends on the number of shorted turns. If more turns are shorted then resistance is smaller. The error as a difference between the answer of the RBNN and the real value indicates how RBNN has been trained. The results have been shown in Fig.8.

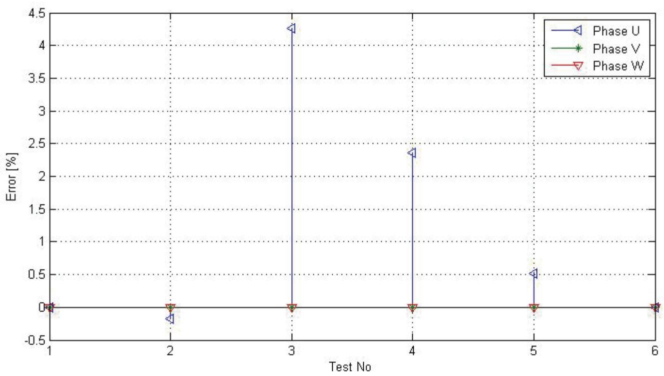

Fig.8. Answer of RBNN

Summary

In the paper the proposition of application of axial flux in diagnosis of faults in induction motor stator winding has been presented. The artificial neural network with radial basis transfer function has been developed. On the basis of obtained results it can be concluded that RBNN can be successfully used in detection of faults in induction motor. The main disadvantage is training process of the RBNN which needs the set of measured data.

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