Park's Vector Approach to detect an inter turn stator fault in a doubly fed induction machine by a neural network

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ABSTRACT

An electrical machine failure that is not identified in an initial stage may become catastrophic and it may suffer severe damage. Thus, undetected machine faults may cascade in it failure, which in turn may cause production shutdowns. Such shutdowns are costly in terms of lost production time, maintenance costs, and wasted raw materials. Doubly fed induction generators are used mainly for wind energy conversion in MW power plants. This paper presents a detection of an inter turn stator fault in a doubly fed induction machine whose stator and rotor are supplied by two pulse width modulation (PWM) inverters. The method used in this article to detect this fault, is based on Park's Vector Approach , using a neural network s.

KEYWORDS

Doubly fed induction machine, PWM inverter, inter turn stator fault, Park's vector approach, neural network.

1. INTRODUCTION

The rational use of electrical energy implies having transportation networks capable of transmitting large quantities of electrical energy over long distances as well as adequate storage plants. Nearly all the pump turbine groups operating today consist of synchronous motor-generators working at the network frequency and therefore at constant speed. The performance and efficiency of such groups can be significantly improved by using variable speed motor – generators and more specifically doubly fed asynchronous motor –generators (DFIM); nowadays there is a strong demand for their reliable and safe operation. The manufacturers and users of such machines initially relied on simple protections such as over-current, over-voltage, earth fault ,etc.., to ensure safe operation. However, as the tasks performed by these machines grew increasingly complex, improvements were also sought in the field of fault diagnosis.

In the industry, methods based on analytical models of the motor systems are still the most common choices for condition monitoring of electrical machinery. However, during the last decade also applications of different kinds of data- based modes such as Neural Network (NN) have established a firm position.

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We propose in this article to detect an inter turn stator fault in a doubly fed induction machine, based on Park's Vector Approach, using a Neural Network.

Neural networks are the object of many researches nowadays thanks to their capacity of training, approximation and generalization.

The proposed method shows a good results to classify safe and damaged machine using this method.

2. DESCRIPTION AND MODELING OF THE DFIM

The proposed system is shown on figure 1, it is constituted by two pulse width modulation inverters supplying separately the stator and the rotor of the machine [1] [2]

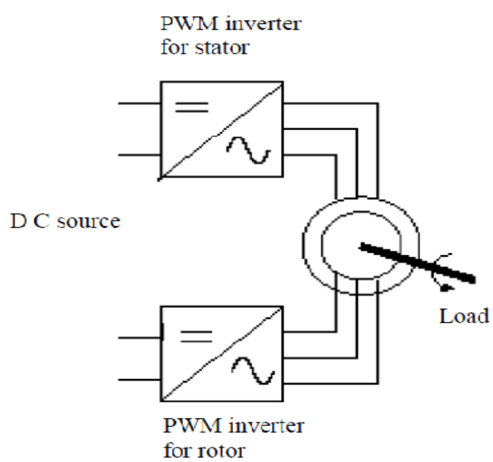

Figure 1. DFIM supplied by two PWM inverters

We choose a three levels PWM for both stator and rotor inverters, it is constitute of three arms, every one has four switches formed by a transistor and a diode as shown in figure 2.

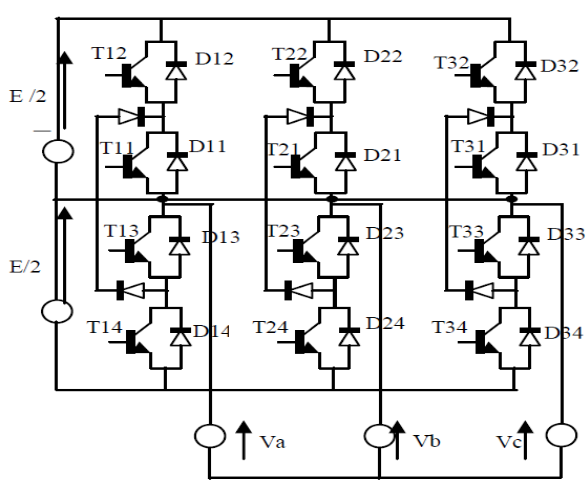

Figure 2. General diagram of a three level PWM inverter

The simple voltages are obtained starting from the following conditions:
If ($V_{réf} = V_p$) and ($V_{réf} > 0$)
$=> V_K = + E/2$

If $V_{réf} = V_p => V_K = 0$
With
$V_{réf}$: reference voltage standard;
V_p: carrying;
V_K: potential of the node K.

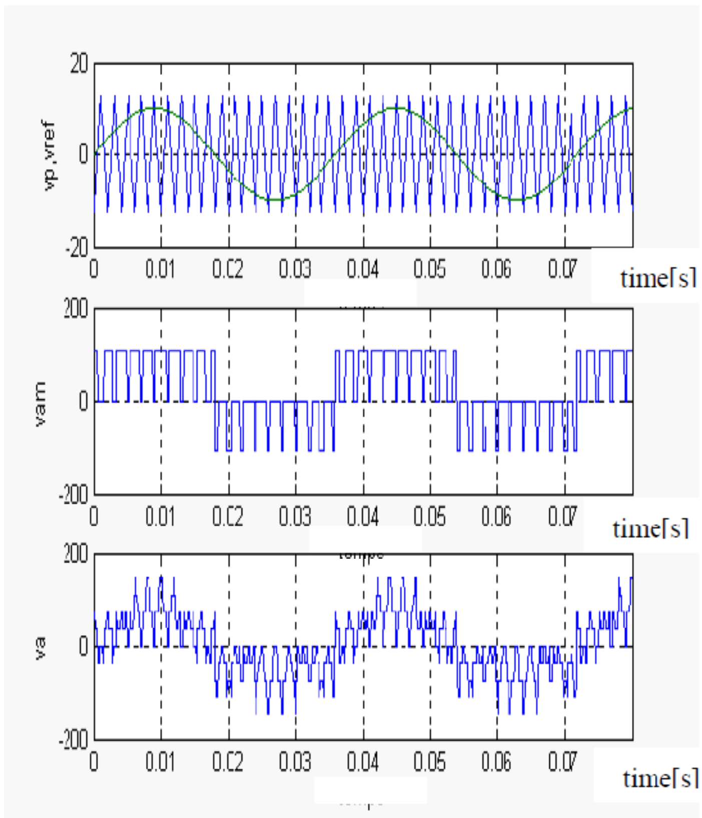

Figure 3 Carrying voltage, simple voltage and phase voltage

Stator and rotor voltages of the machine after Park transformation are given by [3]:

$$\begin{cases} Vds = RsIds + \frac{d}{dt}\psi ds - \frac{d\theta s}{dt}\psi qs \\ Vqs = RsIqs + \frac{d}{dt}\psi qs + \frac{d\theta s}{dt}\psi ds \end{cases} \quad (1)$$

$$\begin{cases} Vdr = RrIdr + \frac{d}{dt}\psi dr - \frac{d\theta r}{dt}\psi qr \\ Vqr = RrIqr + \frac{d}{dt}\psi qr + \frac{d\theta r}{dt}\psi dr \end{cases} \quad (2)$$

Stator and rotor fluxes are given by:

$$\begin{cases} \psi ds = LsIds = MIdr \\ \psi qs = LsIqs + MIqr \\ \psi dr = LrIdr + MIds \\ \psi qr = LrIqr + MIqs \end{cases} \quad (3)$$

Mechanic equation is given by:

$$Cem = Cr + J\frac{d\Omega}{dt} + f\Omega \quad (4)$$

3. PARK'S VECTOR APPROACH

The Vector's Park Approach is a relatively new diagnostic technique, which has been successfully applied in the diagnosis of rotor faults, inter turn stator faults and unbalanced supply voltage [4] [5].

The instantaneous line currents of the stator are transformed into Park's vector using (5). An undamaged machine theoretically shows a perfect circle as shown in figure 4. An unbalance due to turn faults results in an elliptic representation of the Park's vector as shown in figure 5.

$$\begin{bmatrix} ids \\ iqs \end{bmatrix} = \begin{bmatrix} \sqrt{\frac{2}{3}}ia & \frac{-1}{\sqrt{6}}ib & \frac{-1}{\sqrt{6}}ic \\ 0 & \frac{1}{\sqrt{2}}ib & \frac{-1}{\sqrt{2}}ic \end{bmatrix} \quad (5)$$

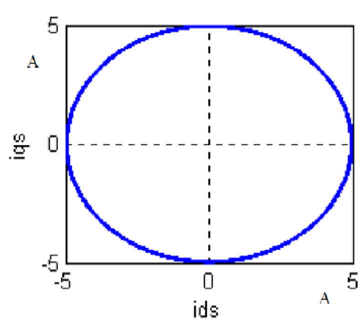

Figure 4. Park's vector of healthy machine

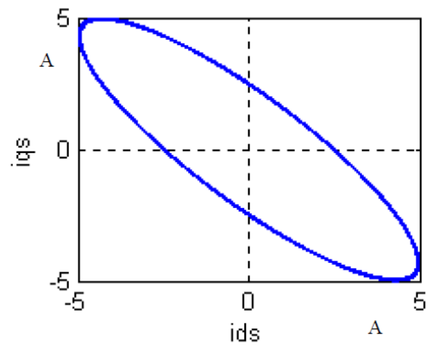

Figure 5 .Park's vector of faulty machine

4. NEURAL NETWORK ALGORITHM

We choose to use a neural network to classify the state of the machine (safe or faulty).

We attribute for every shape of the Park's vector a label describing the operating state of the machine:

-The state "Safe machine" is classified by a label "0" at the neural network output.
-The state "faulty machine" is classified by a label "1" at the neural network output.

For the construction of the multiple coatings network [6] we adopt the error retro propagation method which is based on the gradient descent algorithm.

The calculation stages of the neural network can be resumed like this:

a- The output of the latent layer

$$y_i = f_j^c\left(\sum_{i=1}^{n} w_{ji}^c x_i + b_j^c\right) \quad (6)$$

b- The outputs of the output layer

$$o_k = f_k^s\left(\sum_{j=1}^{m} w_{kj}^s y_j + b_k^s\right) \quad (7)$$

c- The error terms of the output units

$$\delta_k^s = (t_k - o_k) f_k^{s'}\left(\sum_{j-1}^{m} w_{kj}^s y_j + b_k^s\right) \quad (8)$$

d- The error terms of the latent layer

$$\delta_j^c = f_j^{c'}\left(\sum_{i=1}^{n} w_{ji}^c x_i + b_j^c\right) . \sum_{k=1}^{l} \delta_k^s w_{kj}^s \quad (9)$$

e- Weight and bias adjustment of the output layer

$$w_{kj}^{s}(t+1)=w_{kj}^{s}(t)+\eta\delta_{k}^{s}y_{j} \qquad (10)$$
$$b_{k}^{s}(t+1)=b_{k}^{s}(t)+\eta\delta_{k}^{s} \qquad (11)$$

f- Weight and bias adjustment of the latent layer

$$w_{ji}^{c}(t+1)=w_{ji}^{c}(t)+\eta\delta_{j}^{c}x_{i} \qquad (12)$$

$$b_{j}^{c}(t+1)=b_{j}^{c}(t)+\eta\delta_{j}^{c} \qquad (13)$$

The procedure is repeated until the performance criterion is satisfied.
When the learning procedure is finished , the synaptic coefficients take an optimal values and the network can be operational.

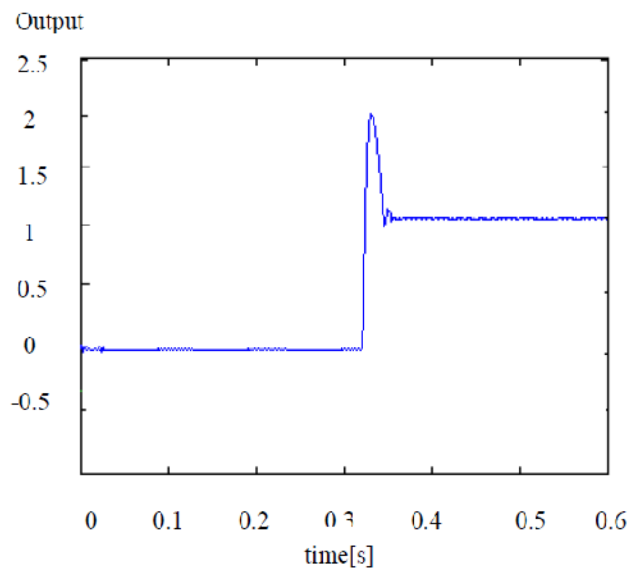

Figure 6. Neural network test

5. RESULTS ANALYSIS

Figure 3 shows the carrying voltage, simple voltage and phase voltage of the three levels inverters used. Figure 4 presents the diagram of Park’s vector in the case of a healthy machine , and figure 5 shows the elliptic shape of Park’s vector in the case of a faulty machine. Figure 6 presents the response of the neural network constituted, at time equals to 0.32s we induce an inter turn stator fault and the test grows automatically to label “1”, before this time the test was stabilized on label “0” which constitute a healthy machine.

6. CONCLUSION

Neural network based on Park's Vector Approach has been successfully applied to the detection of stator turn faults in doubly fed induction generator. This method of detection works well if the machine being diagnosed operate only in steady state. It can be said that this method in addition of its simplicity, shows good results.

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Nomenclature

Vds: active stator voltage
Vqs: reactive stator voltage
Vdr: active rotor voltage
Vqr: reactive rotor voltage
Rs: stator resistance
Rr: rotor resistance
Ls: stator inductance
Lr: rotor inductance
Ids: active stator current
Idr: active rotor current
Iqs: reactive stator current
Iqr: reactive rotor current
ψds, ψsd : active stator flux
ψdr, ψrd : active rotor flux
ψqs, ψsq : reactive stator flux
ψqr, ψrq : reactive rotor flux
M, Msr : mutual inductance
ωs : stator pulsation
ωr : rotor pulsation
J : inertia
f: viscous rubbing ratio
Cem: electromagnetic torque

Cr: resistant torque
x_i : The learning vector value
w_{jic} : The connection weight between the input layer and the latent layer
w_{kjs} : The connection weight between the latent layer and the output layer
b_{jc} : The bias of the latent layer
b_{ks} : The bias of the output layer
η : The learning gain

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