Designing Artificial Neural Networks for Fault Detection in Induction Motors with the TMS320C30 DSP

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Abstract

Artificial Neural Networks (ANN) is succesfully used in many areas such as fault detection, control and signal processing in our daily technology. Artificial Neural Networks have nonlineer structure and this is an effective feature that it approaches to the results of learning phase. Then, it gives results in test phase in short time (the degree about 10^{-3} second). It is a very preferable according to the other approaching methods.

In this paper, feedforward network and error backpropagation training algorithm is used to perform the motor fault detection. The values which were used for ANN were taken from a split-phase squirrel-cage induction motor in Türk Electric Motors A.S. as a prototip. So, it was done a new application with the values.

Motor fault detection with ANN, as the inputs I (stator current) and w (angular velocity depending on rotor speed), as the outputs N_c (insulation condition) and B_c (bearing wear condition) are made and discriminated with success rate above 95% for 30000 iterations. It is considerably important to success the fault detection with e=0,8% error for N_c.

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Introduction

Although ANN are generally used robotics, biomedical engineering and telecominication areas, it is a very preferable improvement to perform to electric machines (for all rotating ones) under control event-Digital Signal Proccessor (DSP). An iterational approach to the solution of the problems which are done by formules based on the model that we currently have the projects, despite having many iteration numbers, as it quickly gives results in test phase to the inputs of the system with very few error rate, that is very high straightness, ANN can be accepted one of the best working techniques.

It is pay attention for fault detection on single-phase squirrel-cage induction motors as a prototip one in this paper. Fault detection subject can easily be performed all rotating machines after we do necassary modifications [1]. We usually meet insulation condition (N_c) and bearing wear condition (B_c) as types of faults in induction motors. In the paper, the values taken from the motor have used the design based on ANN simulation. It was practically reached to the results by feed-forward network and error backpropagation algorithm under some conditions.

In addition, it is considerably important to success the fault detection with e=0,8% error for N_c and e=3,5% error for B_c. This is very good to see low error of N_c especially.

Artificial Neural Networks and the Analysis of Faults in Induction Motors

The first using of ANN can be taken away to the 1940's. However. the main works in this area (ANN) have been done recent ten years. One of the major paradigms of it is feed-forward networks. Kohonen network, Hamming network, Hopfield network, adaptive resonance theory like this workks are good examples of the other networdk paradigms. Each paper about the ANN has its own network structure. appropriatenesses and training algorithms. If we pay attention for engineering areas to this subject like firstly computer and electric-electronic engineering, ANN have found plenty of practical application ones, under biological and physical subjects.

ANN is an information processing system on which information spreads parallel. It is accepted one of the best working techniques, because it has got very short reply time and very high straightness of results, although there are many iteration numbers. It can do a working under the support of the fundamental sciences-biology, physics and mathematics.

It isn't necessary for ANN the relationship between input-output variables and its effectiveness and approaching to the results in short time is a preference reason for it. These features are doing plenty of facilities in the matter of time for solution to the problems that we are face to face. There is a big effect of Fast Learning Rules for the features above [2][3]. It was used some chareceristics of Fast Backpropagation Algorithm in the program to train the learning set. So, the result of the experiment gives a satisfied idea how and why we use ANN for all rotating machines in fault detection. It is depicted a general model of ANN in Figure 1.

Thus, it was used 3-layer feed-forward ANN and error backpropagation algorithm. It was done necessary variations on the algorithm from getting Fast Error Backpropagation Algorithm [8].

It was taken the monotonous increasing sigmoid function in the algorithm in equation1 classically.

$$f(x) = 1/(1 + e^{-x}) \tag{1}$$
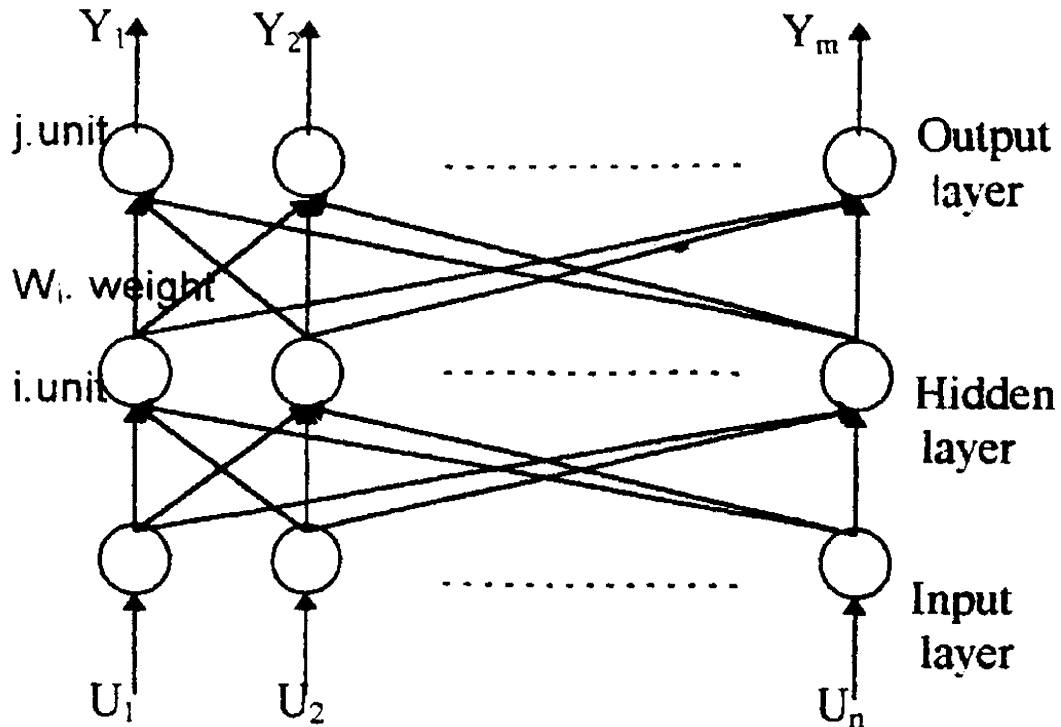
The output O_j for each ij unit in the ANN,

$$O_j = f(netij) = \sum_i W_{ij}O_i + \theta_j \tag{2}$$

where the output of i. unit is O_j, wij is the weight from I. unit to j. unit and θ_j is threshold of j. unit. The squared error function E_p for a pattern p is defined by,

$$E_p = \frac{1}{2}\, j \in \overset{\Sigma}{output}\left(t_{pj} - O_{pj}\right)^2 \qquad (3)$$

The purpose is to make $E = \sum_p E_p$ small enough by choosing appropriate w_{ji} and θ_j.

Figure 1. Ordinary Type Neural Network

{$t_p = (t_{pl},\ldots.,t_{pm}$);$p \in P$} are n-dimension real output values, O_{pj} are the output values of the simulation by a determined rate as well as [9].

The short explanation of the importance of fault detection, it can be defined the cost functions by controlling unsuccessfulnesses of machine before they occur. Machines need to protect by circuit breakers or fuses to cut sudden line currents. The firing elements which ensure a protection to extreme current load and the switches which are put in system are made motor establish as safety elements. These, in real, can protect an element that is very close to motor from possible damage. But they don't give warning before faults occur. We can meet a question at this point: Do not rotating machines completely found to meet kinds of problems?, although they are usually well constructed and robust, the possibility of incipient faults is inherent in the machine due to the stresses involved in the conversion of electrical energy to mechanical energy and vice versa [2]. For example. the condition of stator windings are related to insulation faults which are caused by mechanical vibration, heat, period damage for loading time and also dirtyness from lubricating. In addition, the bearings of the machine are influenced by extreme wearing or insufficient lubricating, extreme lubricating more than necassary quantity for the motor, incorrect loading and incorrect adjusting.

It is generally an incorrect and unpractical situation to use serious mathematical formulation to mean the condition which cause fault, such a fault comment recently. Because of being ANN an information processing system on which one spreads parallel to many input values, they are spreadly used for real-time applications. In spite of increasing the number of the input nodes the calculation time of the network remains same. The increasing of input nodes make the robustness of ANN rise, despite the effect that comes from measurement noise.

After we said to all things above. it is easily done necassary changes and additions on ANN which was designed one time, if we want to do anything [2][3].

The Experimental Working and Simulation

It was shown stator winding current with I and rotor speed with w. In steady-state situation.

$$\frac{dl}{dt} = \frac{dw}{dt} = 0 \tag{4}$$

by moving the equation. input values I and w can be shown by,

$$f_1 = (I, w) \tag{5}$$

output values can be defined by,

$$f_2 = (N_c, B_c) \tag{6}$$

Stator winding is very important lement of squirrel-cage induction motor. It shows its importance with short circuit winding and extreme heat, growing old (yearly) or fault because of vibration [5][6][7]. It is strictly necessary the control of motor internal condition to follow with computer the stator windings one. This kind of control is made by heat control elements which are settle down the motor windings. Unfortunately, the type of working has very high cost for the motors that have smaller than 100 HP. Heat measurement elements and etc. are expensive and physically application difficulties for small power motors.

It is depicted the experiment diagram in Figure 2. The motor type is a 5KC97C100 single-phase squirrel-cage induction motor. The label values are 0,75 kW , 220V, 7,2A, 1400 rpm. It was also used a dc motor which has 0,75 kW power and mechanically connected to the ac motor. The induction motor has a 2p=4 pole main-winding and other (helping) winding. The resistance of the main-wainding is 2,54 Ω , the movement condencer of the motor is 130-156 μF and the environment temperature is 24 ^{0}C. As to be seen from the diagram, a tachometer records period numbers. Then, they are used to calculate w values. This is one of the input values of ANN. Similarly, I current values are taken by a current sensor. This is the other input value for ANN There is a big effect of Fast Learning Algorithms for the application of ANN to all engineering areas with small changes in their structure. It was used the advantage of the mathematical equation of Fast Backpropagation Algorithm for the software of ANN [8].The program language is Turbo Pascal and IBM compatible 486-DX 2*66 computer was used to train ANN.[9]

It is possible to follow stator winding faults by doing short circuit a pair or more than one of input connection. While motor is working normal, the determination of relationship between windings involve voltage measurement between input connection points. The important thing we pay attention for that it should not be used multi-winding short circuits because of the high level of current measurements. That is, short circuits should only be used for a winding of stator winding. If it is not these events, that is high current levels are harmful for stator winding.

There is two aims using dc motor in the experiment. One of them, it is to give a fixed load moment to ac motor by working dc motor as a generator type. Second of them, it is to ensure a changable load moment by rising the fixed load current at normal working point, to see additional load which are caused by a worn bearing in ac motor. It is appropriate to use TMS320C30-DSP (Digital Signal Processor). There is asyncronous data transmitting, here, to detect insulation and bearing condition because of winding short circuits and extinction coefficient respectively.

Figure 2. The Experiment Set for Fault Detection of Induction Motor
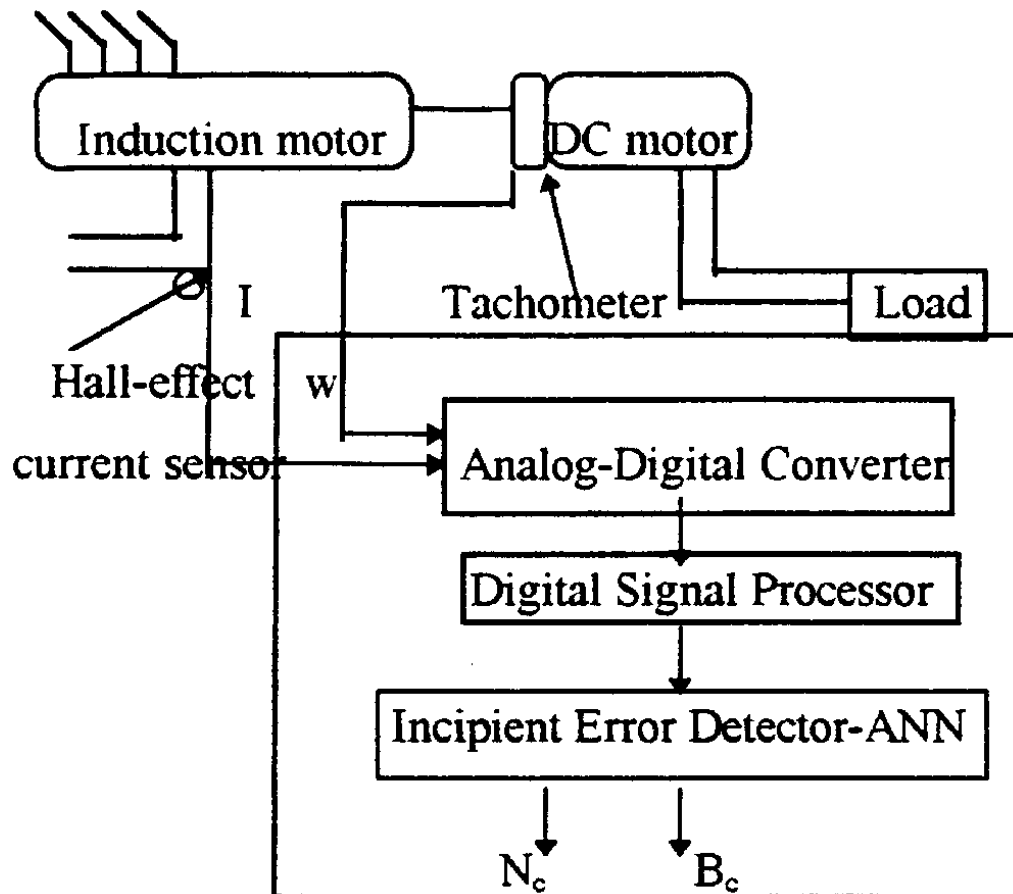
In Figure 2, it was used a fault detector to check insulation and bearing conditions of the motor. At the same time, it has got a strong structure for parasites and noises from the motor mile. The experimental results to train ANN are shown in Table 1. Table 2 shows test phase results of it.

Table 1. Experimental Results to Train ANN

I (Amper)	w (rpm)	N_c (Insulation con.)	B_c (Bearing wear con.)
1,5	535,45	0,900	0,500
2	920,05	0,500	0,900
3	461,55	0,500	0,100
5,6	309,12	0,500	0,100
6	307,45	0,100	0,900
6,6	303,26	0,100	0,900
7,3	296,14	0,100	0,500
7,4	298,66	0,100	0,500
7,7	300,12	0,100	0,900
8,4	292,79	0,100	0,500

Table 2. Numerical Results in Test Phase of ANN

I (Amper)	w (rpm)	Nc (Insulation con)	Bc (Bearing wear con)
2,5	640,45	0,496	0,482
4,5	247,51	0,494	0,096
8,5	307,65	0,099	0,098

Network architecture for Nc and Bc was given in Figure 3 as 5:5:2. Learning rate is $\varepsilon = 0,7$ and momentum rate is $\alpha = 0,9$. The results are e=0,8% for N_c, e=3.5% for B_c for 30,000 iterations. It is depicted training error related to the number of iterations in Figure 4 and training error related to the number of nodes in hidden layer in Figure 5. The error rates of the values which are in Table 2 are respectively 0,4%, 0,6%, 0,1% for N_c and 1,8%, 4%, 2% for B_c with degree of 10^{-3} seconds for fault detection.

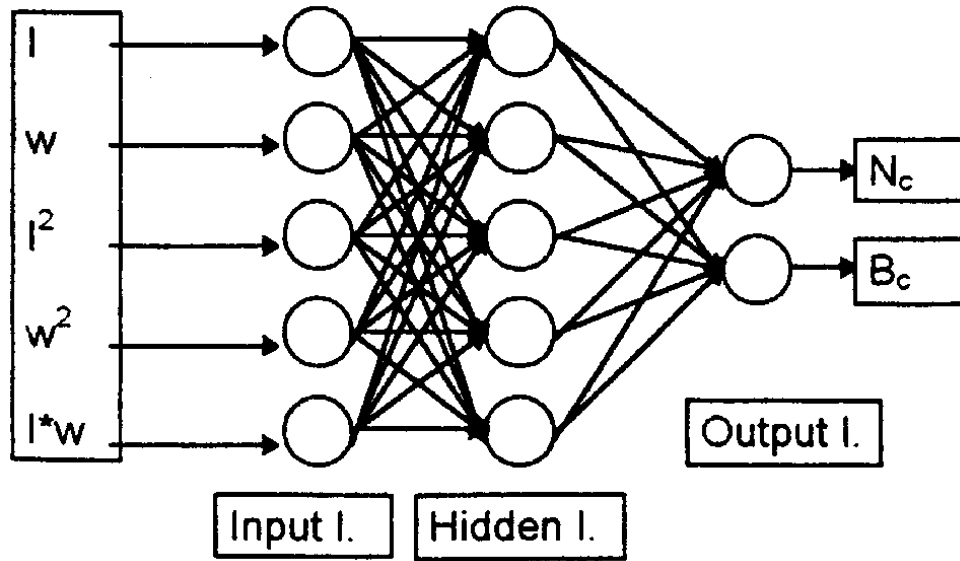Figure 3. Multi-layer Perceptron According to 5:5:2 Network Architecture

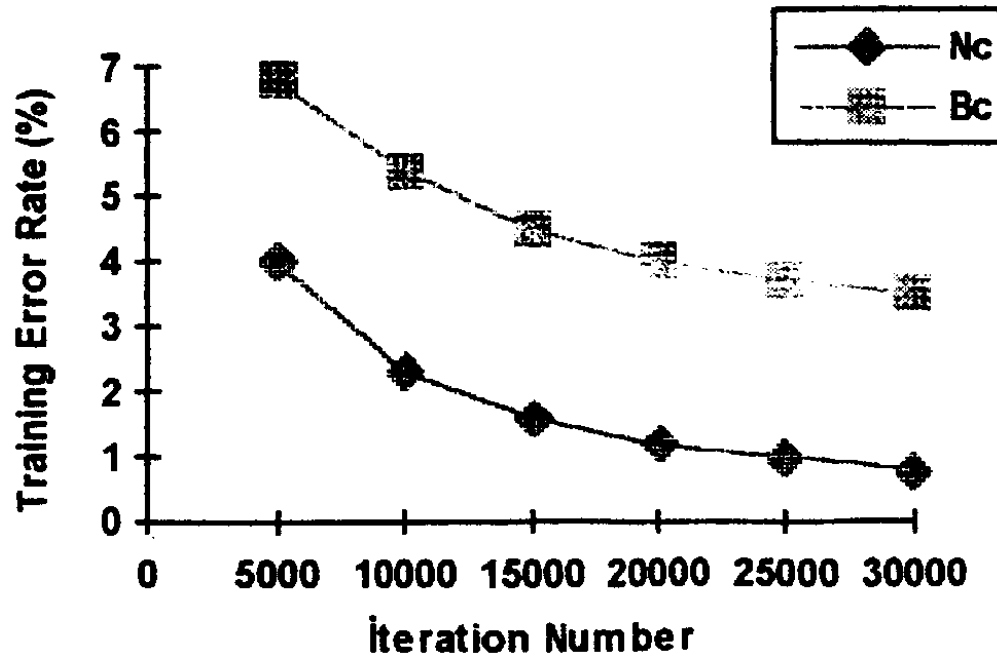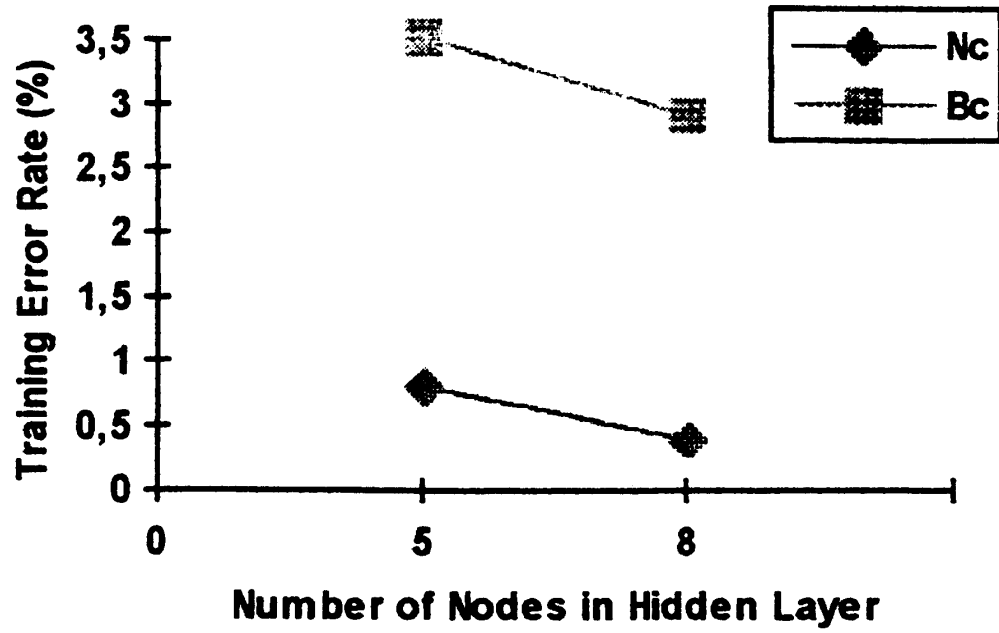Figure 4. The Change of Number of Iteration With Error Rate for 5:5:2 Architecture

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*Figure 5. The Change of the Increasing of Number of Nodes in Hidden Layer
With Error Rate for N_c ve B_c*

Conclusions

It was taken good results of the experiment and the simulation for fault detection of Nc (insulation condition) and Bc (bearing condition) with small rate error percentage by using multi-layer perceptron-ANN (Artificial Neural Networks) for high-order network and DSP (Digital Signal Processor) according to the output nodes.

DSP was used to take digital values from the output of ADC (Analog-Digital Converter). Thus, it was rarely seen better results than workings in literature.

Fast Learning Algorithms ensured a good effect approaching to the target values.

ANN which is designed by the movement from nouron cells in human brain easily performs motor fault detection subject. This shows that it can solve many problems that have mathematical and time difficulties.

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