

# Inter-turn Short Circuit Fault Diagnosis using Adaptive Neuro-Fuzzy Interface System

Sindu.P\*, Aarthi\*, Aravindh.E\* and Raj Thilak.K#

\*PG Scholar, #Assistant Professor, Department of Electrical and Electronics Engineering, Sri Eshwar College of Engineering, Coimbatore, TamilNadu, India.

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## Abstract

Because of its robustness and low maintenance Induction motors have found many applications in various industries. The Induction motors are used for various control process in industries. And they are about to operate in different environmental conditions. These different operating conditions may cause various stress factors on the windings of the Induction motor. And which in turn causes short circuit faults in the motor. In this paper the short circuit faults are identified using adaptive neuro-fuzzy interface system (ANFIS).

**Keywords:** Induction motor, Stator short circuit faults, ANFIS.

## 1. Introduction

In order to analysis the fault produced in induction motor, the motor should be modeled using any one of the modeling techniques. The stator current will produce disturbances in the total flux distribution and these effects are ignored under normal conditions. A network is modeled with a equivalent winding resistance and winding inductance, a back emf source and an induction motor connected all together in series is obtained by considering that the current through all phases will be equal and the self and mutual inductances are constant. The voltage equation can be given by

$$\begin{pmatrix} V1 \\ V2 \\ V3 \end{pmatrix} = \begin{pmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{pmatrix} \begin{pmatrix} i1 \\ i2 \\ i3 \end{pmatrix} + \begin{pmatrix} L & 0 & 0 \\ 0 & L & 0 \\ 0 & 0 & L \end{pmatrix} \frac{d}{dt} \begin{pmatrix} i1 \\ i2 \\ i3 \end{pmatrix} + \begin{pmatrix} e1 \\ e2 \\ e3 \end{pmatrix} \rightarrow (1)$$

Here V1,V2,V3 are the phase voltages; R is winding resistance; i1,i2,i3 are line currents, L is equivalent winding inductance; and e1,e2,e3 are produced back emfs of three phases. The electromagnetic torque is given by the expression:

$$T_e = \frac{1}{wr} (e1i1 + e2i2 + e3i3) \rightarrow (2)$$

Here wr is angular speed of the rotor.

$$T_e - T_l = J \frac{dwr}{dx} \rightarrow (3)$$

Here Tl is load torque and J is inertia of connected load and motor. Is the winding is balanced and symmetrically displaced, the back emf equations are given by

$$\begin{pmatrix} e1 \\ e2 \\ e3 \end{pmatrix} = \begin{pmatrix} Em \sin(\Theta_e) \\ Em \sin(\Theta_e - 2\pi/3) \\ Em \sin(\Theta_e - 4\pi/3) \end{pmatrix} \rightarrow (4)$$

The maximum value of back emf is given by Em and is given by

$$Em = K_e wr \rightarrow (5)$$

Where ke is back emf constant and  $\Theta_e$  is the electrical rotor position is given by,

$$\Theta_e = p\Theta_r = p \int wr dt \rightarrow (6)$$

Here  $\Theta_r$  is the mechanical rotor position and p is number of pole pairs of the motor.

$$V1 = Va - Vb \rightarrow (7)$$

$$V3 = \left( \frac{Va+Vb+Vc}{3} \right) - \left( \frac{e1+e2+e3}{3} \right) \rightarrow (8)$$

connected motor, the summation of current will be zero and the star-point voltage of the motor can be derived easily by this condition.

$$V3 = \left( \frac{Va+Vb}{3} \right) - \left( \frac{e1+e2}{3} \right) \rightarrow (9)$$

$$T_e - T_l = J \frac{dwr}{dx} \rightarrow (10)$$

**Table 1:** Parameters under normal conditions

Sl.No	Rs (ohm)	Rr (ohm)	Ls (Henry)	Lr (Henry)	Lm (Henry)
1	5.9	8.03	0.425	0.425	0.389

**Table 2:** Parameters under inter-short circuit conditions

Sl. No	No. of shorted turns	Stator Resistance (ohm)			Rotor Resistance (ohm)	Fault Inductance (Henry)			Rotor Inductance (Henry)	Magnetizing Inductance		
		Rsa	Rsb	Rsc	Rr	Lfa	Lfb	Lfc	Lr	Lma	Lmb	Lmc
1	1-3	2.1	7.8	3.9	6.2	0.015	0.05	0.024	0.452	0.400	0.49	0.39
2	3-5	2.01	7.99	3.6	6.2	0.0149	0.058	0.0234	0.452	0.391	0.48	0.37
3	5-7	1.98	8.65	3.33	6.2	0.0136	0.059	0.0221	0.452	0.385	0.51	0.36
4	7-9	1.89	9.0	3.09	6.2	0.0123	0.061	0.0198	0.452	0.382	0.52	0.35
5	9-11	1.72	9.49	2.88	6.2	0.0119	0.065	0.0187	0.452	0.375	0.53	0.34
6	11-13	1.69	9.99	2.79	6.2	0.0102	0.067	0.0177	0.452	0.367	0.54	0.32
7	13-15	1.50	10.20	2.69	6.2	0.00956	0.069	0.0163	0.452	0.356	0.55	0.30
8	15-17	1.39	11.4	2.45	6.2	0.00844	0.072	0.0159	0.452	0.342	0.56	0.29
9	17-19	1.30	11.95	2.36	6.2	0.00784	0.076	0.0135	0.452	0.339	0.57	0.28
10	19-21	1.21	12.85	2.29	6.2	0.00712	0.085	0.0123	0.452	0.331	0.58	0.25
11	21-23	1.10	18.55	2.18	6.2	0.00698	0.098	0.0114	0.452	0.329	0.59	0.22
12	23-25	1.05	13.99	2.10	6.2	0.00623	0.108	0.0109	0.452	0.325	0.60	0.21
13	25-27	0.93	14.30	2.09	6.2	0.00598	0.114	0.0099	0.452	0.319	0.62	0.20
14	27-29	0.88	14.96	1.85	6.2	0.00432	0.123	0.0087	0.452	0.307	0.67	0.19
15	29-31	0.75	15.90	1.50	6.2	0.00339	0.115	0.0078	0.452	0.298	0.69	0.17

If only two phases of the three phase winding conducts current, then the star-point voltage of the motor can be given by the expression,

**3. Induction Motor Parameters**

The parameters of the Induction motor are find out using no load test, blocked rotor test and DC test under healthy and inter-short circuit fault condition.

**3.1 Normal Operating Condition**

From the no load test, blocked rotor test and DC test, the Induction motor parameters are find out under healthy operating condition and are listed below.

**3.2 Under Inter-Short Circuit Condition**

From the no load test, blocked rotor test and DC test, the Induction motor parameters are find out under inter-short circuit fault in any one of the phases of the Induction motor and are listed above.

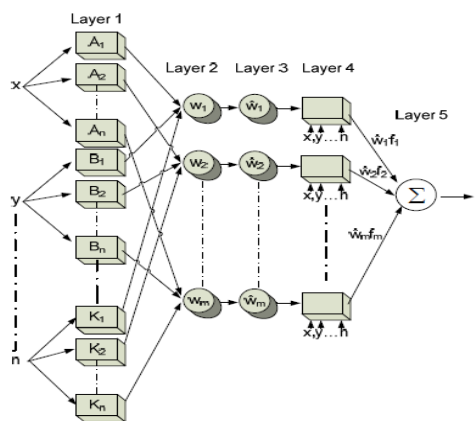
**4. Adaptive Neuro-Fuzzy Inference System**

ANFIS had gained popularity over other soft computing techniques due to its knowledge extraction feasibility, domain partitioning, rule structuring and modifications. Neural network and fuzzy logic techniques have their own short comings and thus a combination of these two techniques, called Adaptive Neuro-Fuzzy Inference System(ANFIS) and they have better alternative solution

for various problem. ANFIS is a hybrid controller structure using a fuzzy logic inference system and architecture of a neural network having five-layer feed-forward structure. And ANFIS have many advantages of learning capability of neural networks and inference mechanism of fuzzy logic. A typical architecture of ANFIS having n inputs, one output and m rules.

The IF-THEN rules have the following form:

- Rule 1 : If x is A1 and y is B1,....n is k1 then f1 = (p1x + q1y + r1z + .....u1)
- Rule 2 : If x is A2 and y is B2,....n is k2 then f2 = (p2x + q2y + r2z + .....u2)
- Rule m : If x is Am and y is Bm,....n is km then fm = (pmx + qmy + rmz + .....um)



**Figure 1:** Typical ANFIS structure

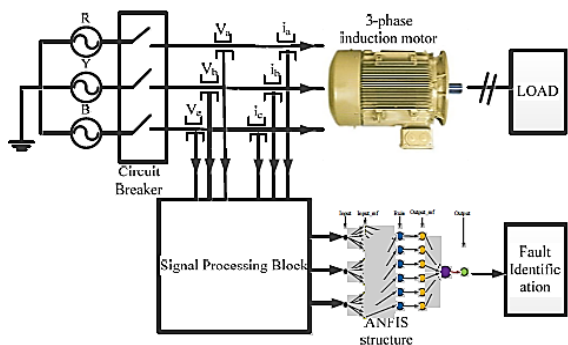


Figure 2: Block diagram of fault diagnosis system

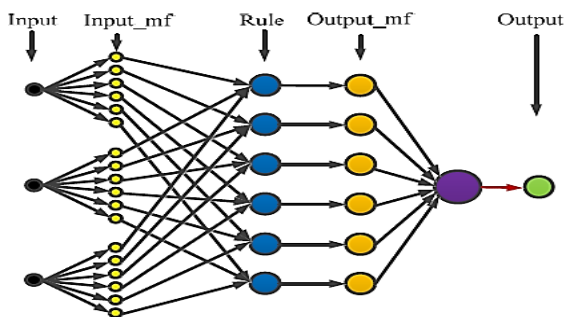


Figure 3: ANFIS structure

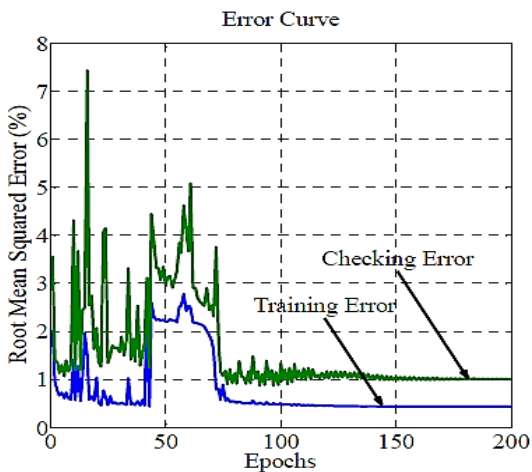


Figure 4: Error curve of ANFIS controller

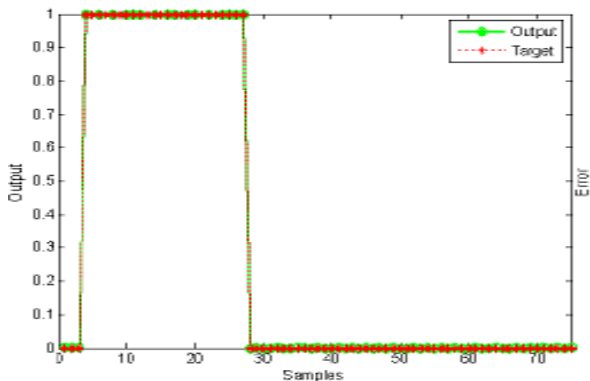


Figure 5: ANFIS output for fault in Phase-A

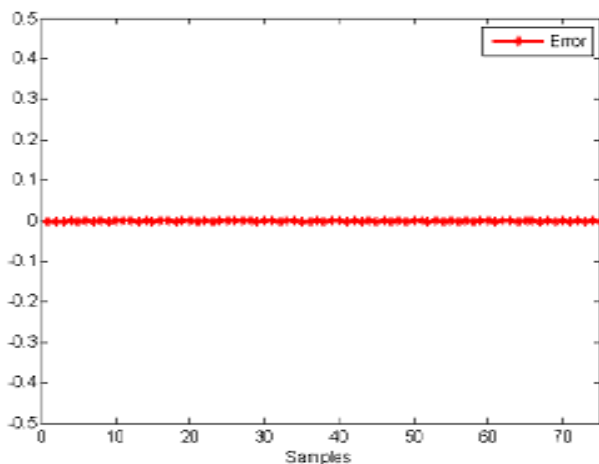


Figure 6: ANFIS error for fault in Phase-A

The initial model for ANFIS training is generated by applying subtractive clustering on the parameters of the Induction motor. Subtractive clustering is a fast one-pass algorithm for estimating the number of clusters and the clusters centers in a set of data. The ANFIS model generates input membership functions of Gaussian structure by subtractive clustering method.

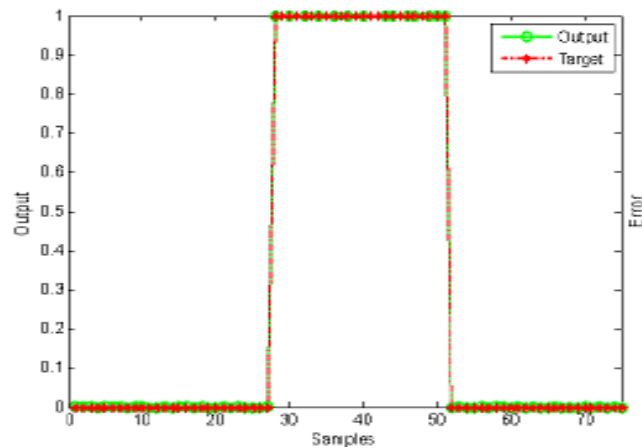


Figure 7: ANFIS output for fault in Phase-B

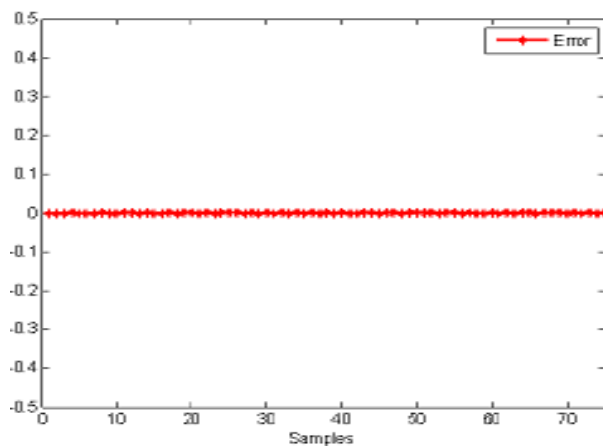


Figure 8: ANFIS error for fault in Phase-B

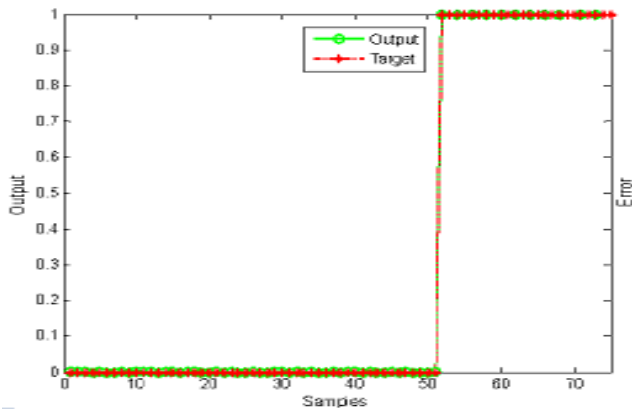


Figure 9: ANFIS output for fault in Phase-C

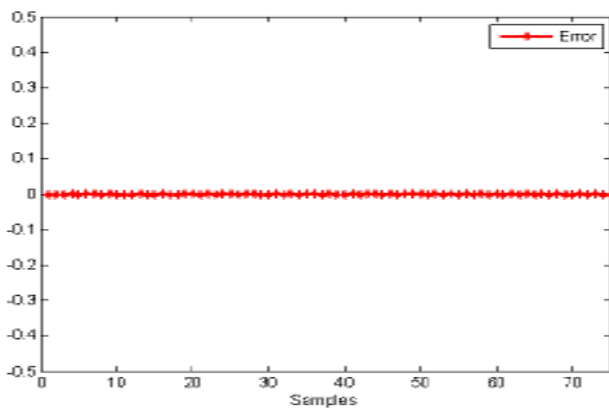


Figure 10: ANFIS error for fault in Phase-C

### 3. Simulation Results

The model of the Induction motor is derived by using the parameters obtained by conducting no load test, blocked rotor test and DC test. The ANFIS fault indicator will indicate the fault by analyzing the magnitude of the positive, negative and zero sequence voltages. The performance of the ANFIS controller is 99% accurate for fault diagnosis. The input and output mapping in ANFIS is not in a Black box like Neural Network. The stator currents under normal and fault conditions are given below.

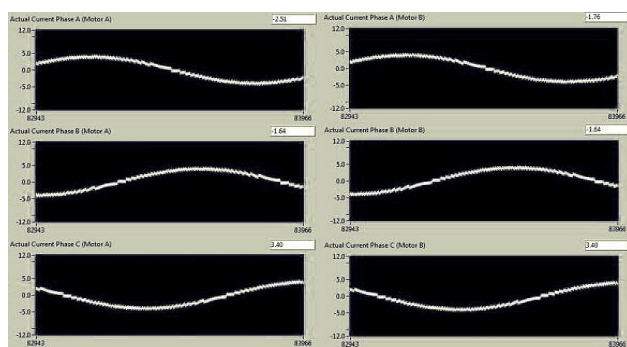


Figure 11: Stator currents under normal operating conditions

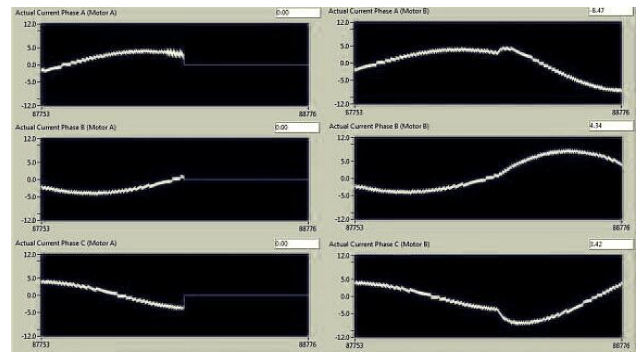


Figure 12: Stator currents under inter-turn short circuit faults

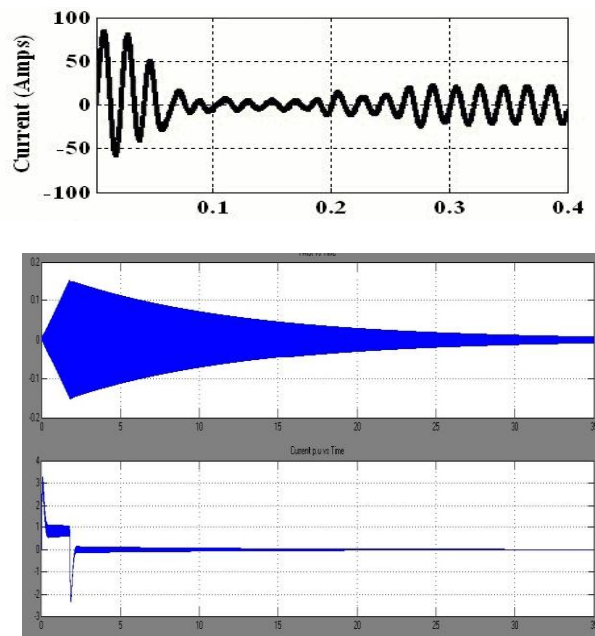


Figure 13: Simulation results of stator current using ANFIS Controller

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