Neuro Fuzzy Approach for Broken Bar Detection in Induction Machines Using Vibration Signals and its Application in Biotechnology

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Abstract
In Biotechnology and life sciences industry, centrifugal pumps play a crucial role in controlling the flow of fluids. Continuous monitoring of the centrifuge pumps play a crucial role in maintenance. As a set up and proven technology with a far reaching knowledge base, vibration examination offers a complete technique for recognizing an assortment of problems. For condition monitoring on multiple levels it is utilized. It can be utilized as a basic gage to figure out whether equipment running inside of a worthy vibration range with general readings. It can likewise decide the reason for expanded vibration with extra readings like ranges, time waveforms, and so forth. A good condition-monitoring program, utilizing vibration investigation, detects approaching problems, decides the reason and permits time for proper remedial corrective action– before equipment failure. By using vibration signal this paper accentuates the need of a soft computing based softened bar detection in induction motor. The vibration spectrums for variable and also for steady load conditions in induction motor are separated. By using extracted vibration spectrum this work proposes the neuro-fuzzy broken bar detection in induction motors. It has been accepted utilizing 1 HP, 3 phase, 50 HZ, 415V induction motor and results were presented.

Index terms: induction motor, broken bar, fault diagnosis, fuzzy logic, neural networks.

Introduction
Because of their ruggedness and versatility the induction motors are the base tools of a wide range of industrial applications. The essential subjects in the engineering domain include the monitoring, diagnosing, as well as detecting of faults in motors. With appropriate machine monitoring as well as error detections strategies, early warnings may be provide for preventive action, enhanced security, as well as dependability of various engineering system functions. The significance of error detection is present in the expense reserve funds acknowledged by identifying potential machine disappointments before they happen. The induction motor is subject to electromagnetic as well as mechanical forces. Design of motors is so that the cooperation between the forces during normal or good conditions results in stable operations with lease noise as well as vibrations. As the point when faults happen, balance between the interactive forces is diminishes, prompting improvement of the error[1]. These include: 1) bearing 2) stator 3) eccentricity as well as 4) broken bar and end ring faults of induction motor that are the most transcendent ones and in this way, need monitoring[2]. The innermost component of the induction motor is the rotor that is turned by an electromagnetic field prompted in its loops from the stator field. The rotational force is connected to the external equipment. An induction motor rotor is extremely tough, yet at the same time, rotor defects, for example, broken bar, cracked end-ring, bent shaft as well as unconventionality do happen.

Around 10% of induction motors errors are because of broken rotor bars. There is various routines for online rotor faults diagnoses have been presented in literature. Reviews on a few of the methodologies are spoken to in[3]. In a few studies, utilization of search coils are suggested to gauge the fluxes identified with rotor faults[4]. Harmonic analyses of speed changes [5], motor variable estimation, frequency investigation of quick power Park's Vector technique[6], as well as machine current signature analysis (MCSA) [7] are amongst the suggested methodologies spoke to in writing. These strategies have a few imperfections because of 1 or a greater amount of the accompanying prerequisites:

1-Connection to live electric components
2-More than one sensor
3-Pre-introduced sensors, for example, search coils or tachometers
4-High exactness sensors, on the grounds that estimations got by various sensors ought to be joined scientifically (computations might increase the faults.)
5- Knowledge of motor internal structure, (for example, motor slots) for motor slots estimations.

The presence broken rotor bar was identified and the hardware is displayed, where a faulty 1 HP, 3 phase, 50 Hz, 415V induction motor was inspected. It doesn't require an excess of investment. The technique proposed in this exploration depends on spectrum analysis of signal acquired by a vibration sensor. Utilizing vibration spectrum the neuro fuzzy based methodology for broken rotor fault are disregarded as a part of previous works. Accurate determination of the quantity of broken rotor bars is found. The extent of this paper is deciding the quantity of broken rotor bars with lessened time.

Broken Bar Detection Scheme Using Vibration Signal

Rotor bars may be incompletely or totally cracked amid the functioning of induction motor, because of stresses, incorrect rotor geometry design or imperfections in materials or rotor creation procedure. The bar breakage is the significant error in the induction motor rotors. When a bar breaks, the state of the neighbouring bars likewise decays continuously because of the increased stress. To counteract the cumulative destruction, the issue ought to be identified earlier, i.e, the point at which the bars are starting to crack [8]. Vibration signal investigation is an error detection method that is by and large utilized for mechanical faults analysis, for example, bearing problems, gear mesh defect, rotor mis-alignment as well as mass unbalance [9].

On the other hand, it can likewise be effectively connected to distinguish broken rotor bar, subsequent to this deficiency energizes the electromagnetic field unsettling influence and in this way escalates the torque adjustments as well as the vibrations of the motor that could be assessed by setting vibration sensors on motor housing [10-11]. A 3-phase, 1HP squirrel cage induction motor is considered for fault detection and accepted that the motor is working at unfaltering state condition. It is additionally accepted that the m.m.f circulation is sinusoidal and the stator is supplied with symmetrical three-phase voltage system. The broken bars up the rotor yield asymmetry in the rotor circuit. Because of the asymmetry in the rotor circuits, there will be a corresponding result in reverse pivoting field at slip frequency s_f concerning the rotor. Cooperation of rotor in reverse turning field with the stator field yields oscillating torque as well as oscillating velocity, the frequency of this oscillation being 2sf. The frequency of the rotor currents is **'2sf'**, wherein **'f '**represents the supply frequency while„s" represents the slip, the frequency of the positive-sequence rotor m.m.f with respect to the stator is:

$$f_{brbl} = f_m + 2sf \quad (1)$$

and the frequency of the negative-sequence rotor m.m.f with respect to the stator is:

$$f_{brb2} = f_m - 2sf \quad (2)$$

The vibration spectrum contains a left side-band frequency component at '2sf' left side of the supply frequency „f" because of rotor asymmetry. However there is also a right side-band frequency component at '2sf' right side of the supply frequency. The reason for this is that, due to rotor asymmetry, pulsating torques are produced in the electromagnetic torque (Peter Vas 1993, Mohamed EI Hacheni Benbouzid 2000). Due to speed oscillations, e.m.fs at frequencies $f_{brb} = (f_m \pm 2sf)$ **Hz** are induced, which are super imposed on the fundamental voltage. This speed oscillation functions as a frequency modulation on rotation frequency as well as 2-side band frequencies $f_m \pm 2sf$ appear around f_m in vibration spectrum. The frequency components give predominant variation in their amplitudes and these two components are taken for the analysis under different broken bar conditions [12]. Furthermore, the broken bars result in a sequence of other sidebands expressed as follows:

$$F_{brb} = (f_m \pm 2ksf) \text{ Hz } k = 1,2,\ldots,k_n \quad (3)$$

and are depicted conceptually in figure 1.

Because of broken rotor bar the harmonics are induced at both upper and lower sideband frequencies as given by:

$$F_{brb} = (f_m \pm 2sf) \quad (4)$$

In a squirrel cage induction motors with rotor asymmetry, the vibration spectrum will contain harmonic components f_{brbl} at frequency (f_m -2sf) and f_{brbr} at frequency (fm + 2sf). The amplitudes of the consonant parts f_{brbl} and f_{brbr} are alluded to the amplitude of fundamental component in dB and are signified as A1 and A2 individually. These components are dependent on induction motor operating conditions, i.e. load and inertia. The greatness of A1 and A2 increments if the quantity of broken bar increments. The broken bars can be distinguished monitoring the magnitudes of A1 and A2. It is likewise conceivable to decide the quantity of broken rotor bars. In this theory, neural/fuzzy fault detection schemes are displayed to distinguish broken rotor bars utilizing A1 and A2 as inputs. The schematic of fault identification procedure is appeared in figure 2.

Experimental setup

To exhibit the fault detection scheme, investigations were led on a 1 HP, 3 phase, 50 Hz, 415V induction motor used in centrifuge is used in the experiments. The motor has 24 rotor bars. A hole is drilled on the rotor bar to simulate the broken rotor bar fault as appeared in figure 3. With one bar broken, the motor is made to keep running at evaluated speed without load as well as load. The vibration example is persistently recorded. For information securing the experimental setup is appeared in figure 4 in which an accelerometer is set on the motor and figure 5 gives photographic perspective of trial setup. Utilizing the Fast Fourier Transformation (FFT) analyzer, the extents of A1 and A2 are measured. The comparative strategy is rehashed up to seven broken bars. The machine with broken bars for no load and load conditions and the vibration spectrum of healthy machine and faulty machine are appeared in figures 6 to 13. The extents of vibration spectrum of induction machine for different broken bar conditions are surrendered table 1(a) and (b).

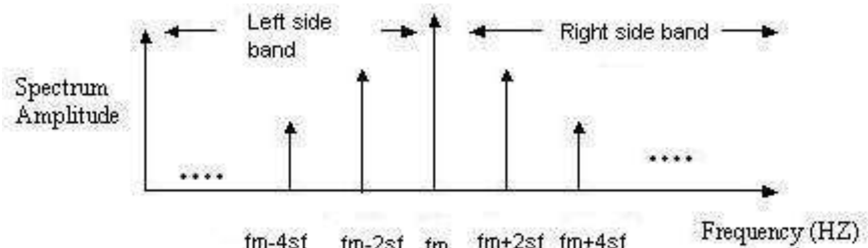


Figure 1: Sideband frequencies around the fundamental line frequency

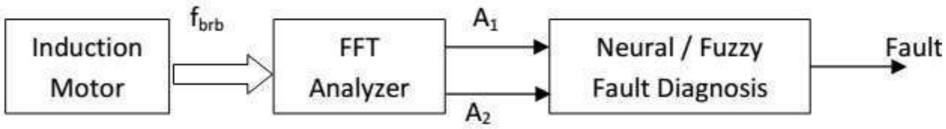


Figure 2: Schematic of fault detection process

Figure 3: Photographic view of broken rotor bar

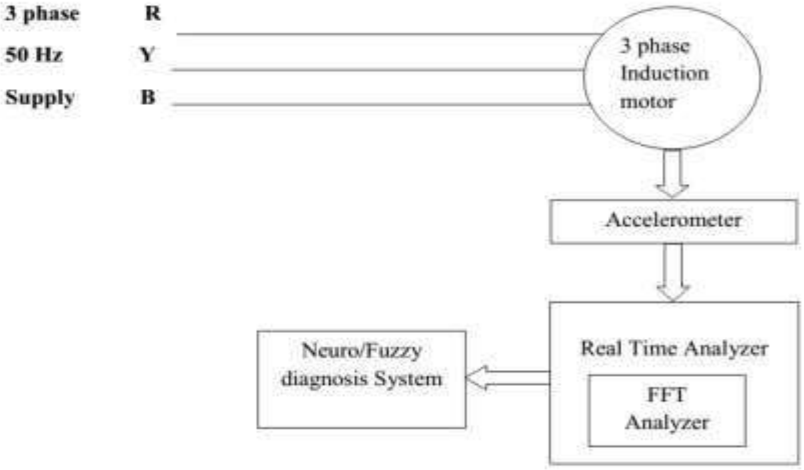
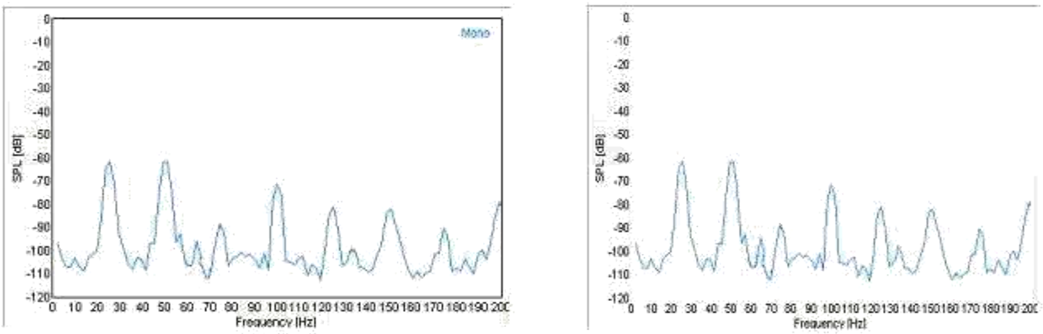


Figure 4: Experimental setup for data acquisition

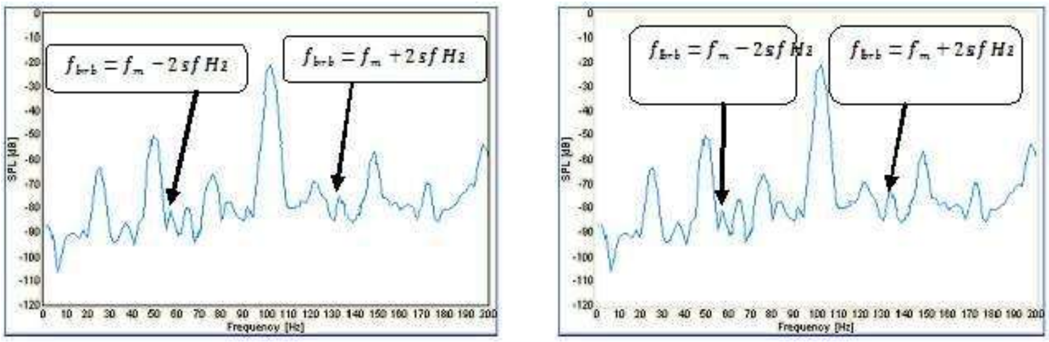
Figure 5: Photographic view of Experimental Setup and Accelerometer

The above procedure is repeated for various load conditions, while to study the effect of load on fault diagnosis.



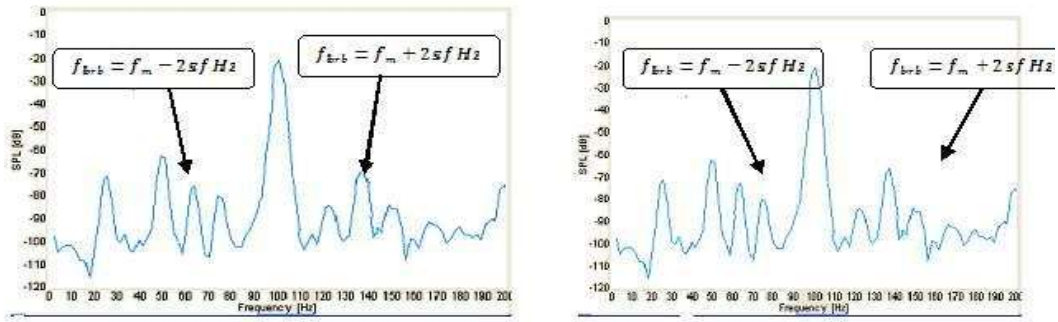
(a) at no load **(b) at load**

Figure 6: The vibration spectrum of healthy machine



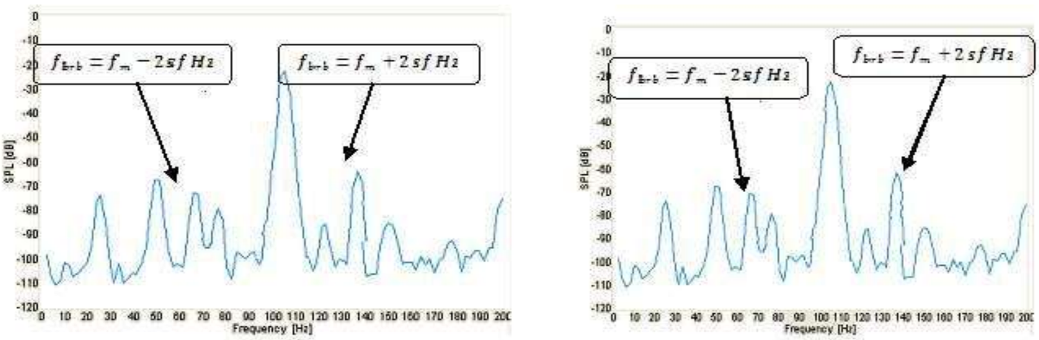
(a) at no load **(b) at load**

Figure 7: The vibration spectrum of faulty machine with one broken bar



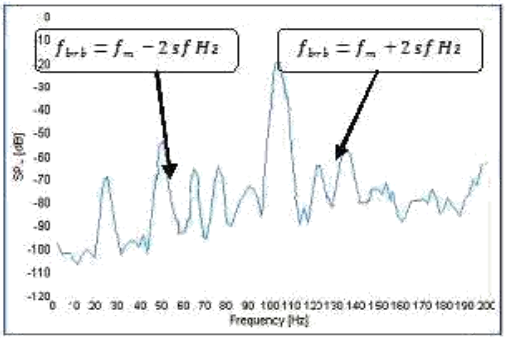
(a) at no load **(b) at load**

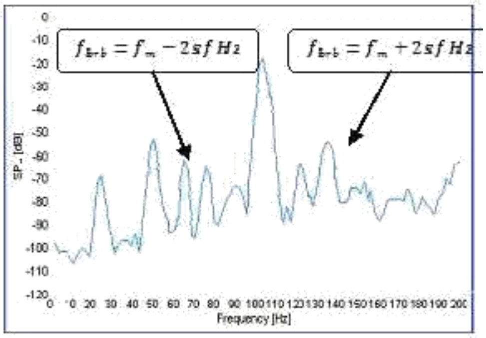
Figure 8: The vibration spectrum of faulty machine with two broken bars



(a) at no load **(b) at load**

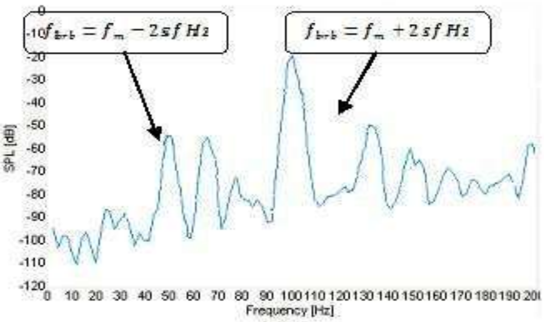
Figure 9: The vibration spectrum of faulty machine with three broken bars

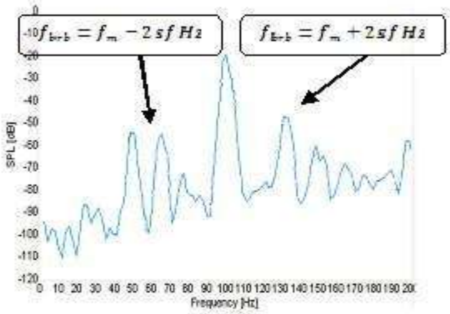




(a) at no load **(b) at load**

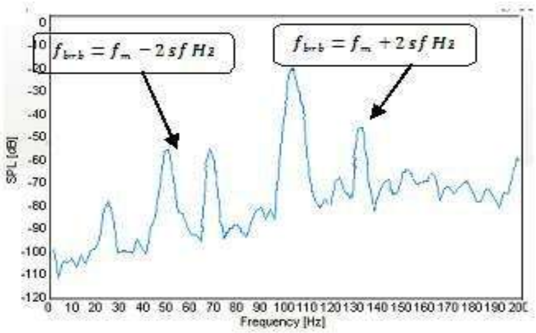
Figure 10: The vibration spectrum of faulty machine with four broken bars

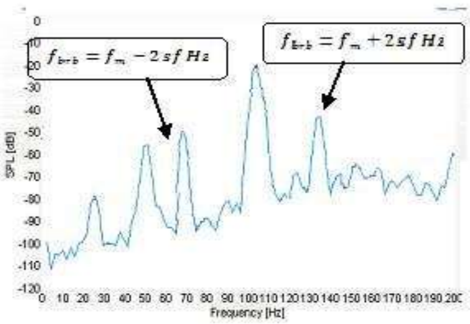




(a) at no load **(b) at load**

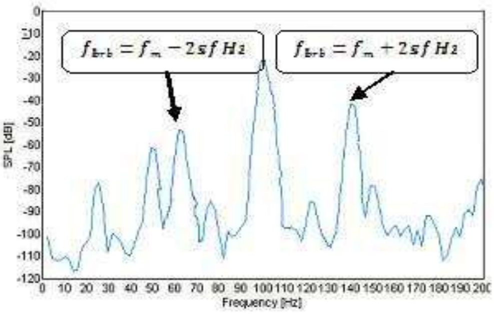
Figure 11: The vibration spectrum of faulty machine with five broken bars

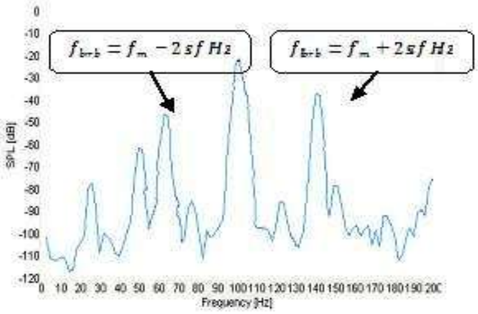




(a) at no load **b) at load**

Figure 12: The vibration spectrum of faulty machine with six broken bars





(a) at no load **(b) at load**

Figure 13: The vibration spectrum of faulty machine with seven broken bars

Table 1
The magnitudes of A_1 and A_2 for various broken bars
(a) at no load

S.N.	A1 in db	A2 in db	No of Broken bars
1	-95.3	-99.4	0
2	-80.3	-73	1
3	-76.4	-70.2	2
4	-72.3	-63	3
5	-65.4	-57.3	4
6	-59.2	-50.4	5
7	-53.3	-46.5	6
8	-50.6	-40.3	7

(b) with load

S.N.	A1 in db	A2 in db	No of broken bars
1	-93.2	-97.8	0
2	-78.4	-71.4	1
3	-73.62	-69.2	2
4	-70.5	-60.5	3
5	-62.2	-54.4	4
6	-58.1	-48.7	5
7	-49.7	-42.2	6
8	-46.8	-38.2	7

Soft Computing Based Fault Diagnosis: In many engineering applications such as fault detection, control and optimization of dynamic systems the soft computing tools like Neural Network (NN) and Fuzzy Logic (FL) have been utilized. The NN can be delegated feed forward NN and repetitive NN as per their structure. It is surely understood that a feed forward neural network is equipped for approximating any continuous function nearly. The utilization of FL in control applications has massively expanded throughout the most recent decade. Hypothetically established by Zadeh and investigated by Mamdani in the early 1970s the wide modern utilization of FL started right around 10 years after the fact. With the commercial accessibility of FL control advancement apparatuses and the better comprehension of investigation techniques, more mechanical organizations have effectively utilized this innovation for their particular applications. Main advantages of fuzzy controllers are effortlessness, low cost and possibility to design without knowing the accurate mathematical model of the process or system[13,14].

Neural Network Based Fault Diagnosis: An artificial neural network is made out of neurons with a deterministic enactment capacity. The neural network is prepared by modifying the numerical estimation of the weights will contain the non-linearity of the wanted mapping, so that troubles in the mathematical modeling can be stayed away from. The numerical estimations of the weights and the inner edge of every neuron have adjusted by utilizing BP training algorithm. The network is trained by, at first selecting little arbitrary weights and interior edge and afterward displaying all training data. Weights and edges are balanced after each training case is displayed to the network; until the weight joins or the errors is decreased to worthy quality. Figure 14 demonstrates BP Network's structure for Faults Detection. Fig 15 shows the Epoch Vs Error characteristics for the BP network.

Simulation Results

The difference between the measured and the predicted number of bars is an estimate of fault severity. The trained network is tested for various broken bar conditions. The test results are shown in table 2 (a) and (b).

Fuzzy Logic Based Fault Diagnosis

Problems in this present reality the entire time and up being complicated because of uncertainty in the variables that characterized the issue, or in the circumstances within which the issues happens. It is in those circumstances that fuzzy set hypothesis could potentially comprehend the uncertainty in the issue effectively. For handling the uncertainty that emerge because of vagueness the Fluffy set hypothesis is a mathematical tool.

In the current work, the Mamdani fuzzy derivation is a system utilized for finding faults. For both the inputs as well as the outputs while triangular membership functions are utilized. Three membership functions for the input parameters as well as four membership functions for the output parameter are utilized. The fuzzy rules utilized for simulations are noted as a part of table 3.

The membership functions used for simulation are given in figures 16 as well as 17.

For different input-output pattern the difference between the target as well as the actual has been computed. The outcomes of the simulations of fuzzy fault diagnosis system for broken bar detection with and without loads are given in table 4.

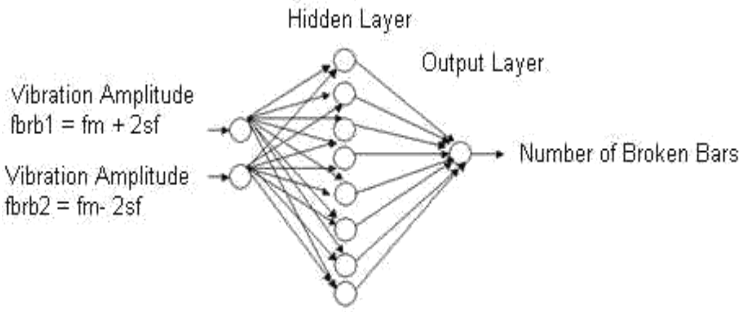


Figure 14: shows the structure of BP Network for Fault Detection

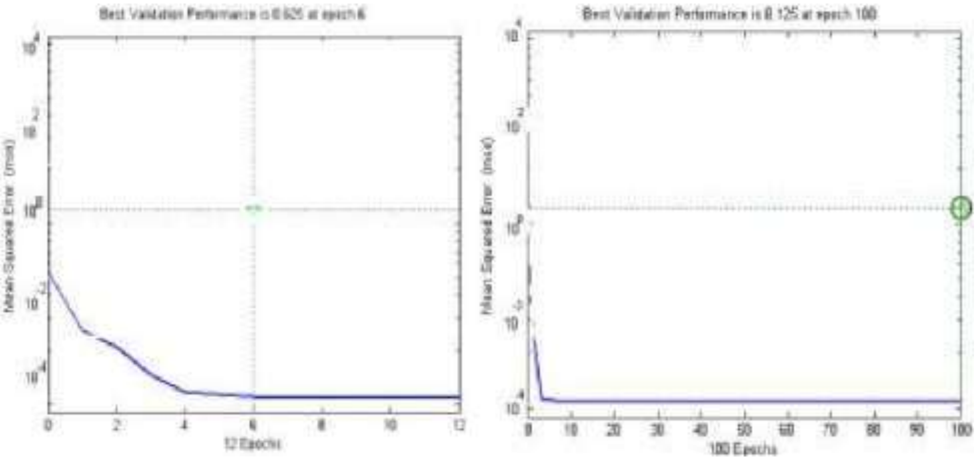


Figure 15: shows the error vs epoch characteristics

Table 2
a) without load

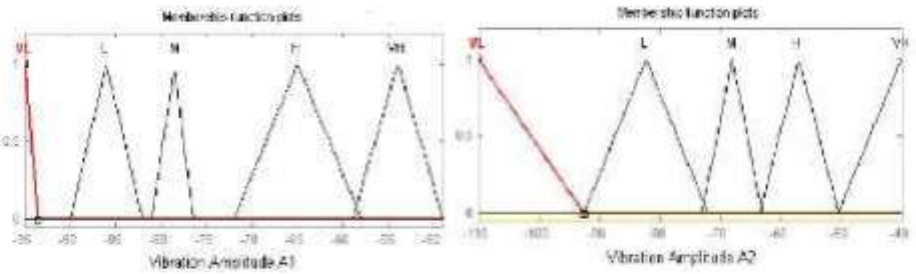
S.N.	A_1 in db	A_2 in db	Target (No of broken bars)	Actual output	Error (%)
1	-95.3	-99.4	0	0.06	0
2	-80.3	-73	1	1.012	0.011
3	-76.4	-70.2	2	2.013	0.006
4	-72.3	-63	3	3.01	0.003
5	-65.4	-57.3	4	4.047	0.011
6	-59.2	-50.4	5	5.0215	0.004
7	-53.3	-46.5	6	6.0114	0.001
8	-50.6	-40.3	7	7.123	0.017
				Average	0.007

b) With load

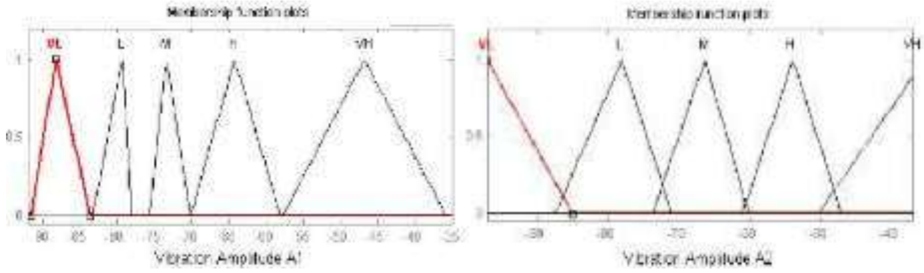
S.N.	A_1 in db	A_2 in db	Target (No of broken bars)	Actual output	Error (%)
1	-95.3	-99.4	0	0.006	0
2	-80.3	-73	1	1.006	0.005
3	-76.4	-70.2	2	2.02	0.009
4	-72.3	-63	3	3.991	0.248
5	-65.4	-57.3	4	4.021	0.005
6	-59.2	-50.4	5	5.111	0.021
7	-53.3	-46.5	6	6.113	0.018
8	-50.6	-40.3	7	7.016	0.002
				Average	0.044

Table 3
Fuzzy rules for broken rotor bar detection

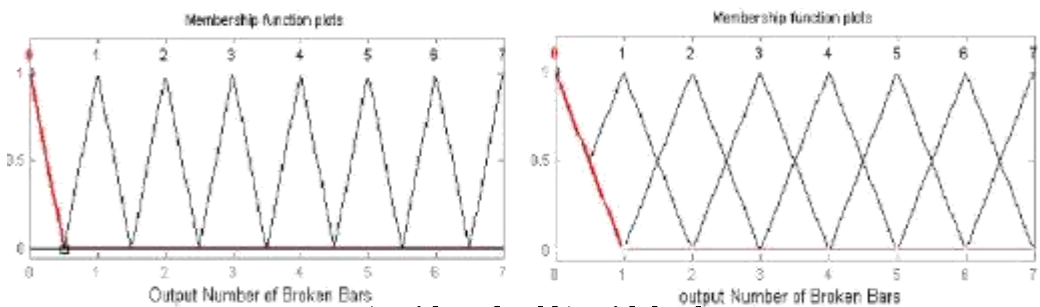
A_2 / A_1	VL	L	M	H	VH
VL	0	IF	1	2	3
L	IF	1	2	3	4
M	1	2	3	4	5
H	2	3	4	5	6
VH	3	4	5	6	7



a) without load



b) With load
Figure 16: input Membership functions



a) Without load b) With load
Figure 17: Output membership functions

Table 4
Simulation results of FL fault diagnosis system for broken bar detection
a) Without load

S.N.	A_1 in db	A_2 in db	Target output (No of broken bars)	Actual output (No of broken bars)	Error (%)
1	-95.3	-99.4	0	0.089	0
2	-80.3	-73	1	1	0
3	-76.4	-70.2	2	2	0
4	-72.3	-63	3	3	0
5	-65.4	-57.3	4	4	0
6	-59.2	-50.4	5	5	0
7	-53.3	-46.5	6	6.01	0.16
8	-50.6	-40.3	7	7	0
				Average	0.02

b) With load

S.N.	A_1 in db	A_2 in db	Target output (No of broken bars)	Actual output (No of broken bars)	Error (%)
1	-95.3	-99.4	0	0.0212	0
2	-80.3	-73	1	1	0
3	-76.4	-70.2	2	2	0
4	-72.3	-63	3	3	0
5	-65.4	-57.3	4	4	0
6	-59.2	-50.4	5	5.01	0.2
7	-53.3	-46.5	6	6	0
8	-50.6	-40.3	7	7	0
				Average	0.025

Conclusion

This paper manages the utilizations of NN as well as Fuzzy Logic for faults detection in 3-phase induction motors. To gather the training samples analyses were directed. The traditional BP algorithm was utilized for network training and testing. To implement the fault detection scheme a model has been created. The broken rotor bar location plan for three phase induction motor had been actualized utilizing Fuzzy Logic. The harmonic components of the vibration spectrum were extracted for fault diagnosis. The Fuzzy Logic has been utilized to analyze faults. The outcomes of the simulations reveal it is construed that the indicative precision of Fuzzy faults determination system decreased error percentages, which extraordinarily diminishes an ideal opportunity to identify the broken rotor bars when contrasted with the past work[13].

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