A Fuzzy Logic Approach for the Diagnosis of Rotor Faults in Squirrel Cage Induction Motors

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Abstract— **This paper presents a practical implementation of a new strategy using the fuzzy logic for the detection and the diagnosis of broken bars in electrical induction machine. Motor Current Signature Analysis (MCSA) was used. The strategy rests on the follow-up (in amplitude and frequency) of the harmonics representing the defects of the broken bars, preparing and thus generating the adequate inputs for the treatment where the decision is made by fuzzy logic. The results obtained are good and it is capable to detect the correct number of broken bar.**

Keywords- fuzzy logic; diagnosi; induction motor.

I. INTRODUCTION

The great diffusion of induction motors for industrial application is mainly due to their simple and robust design as well as their construction. It is indeed, omnipresent in the industrial sectors like aeronautics, the nuclear power, chemistry. In spite of these qualities, stresses of various natures (thermal, electrical, mechanical or environment) can affect the life span of this one by involving the occurrence of stator and/or rotor faults [1]. For instance the stator winding is subject to the failure of insulation, as a consequence of mechanical vibrations. Also the rotor bearings may be subject to wear or damage because of bad lubrication, excessive load or misalignment. Finally, the cast aluminum bars of the squirrel-cage rotor may be subject to faults as a result of internal mechanical stresses. Incipient faults will affect the performance of the machine before major failures occur. A single broken or cracked rotor bar may cause its neighbors to fail dues to increased currents in adjacent bars and consequently increased thermal and mechanical stresses. These faults cause considerable economic losses. However, to obtain a high level of reliability for an electric drive with induction motors, a diagnostic system is necessary.

In the last decades several researches proposed methods to monitor the condition and diagnosis of induction motors. A great number of papers have reported the enormous success of the application of the motor current signature analysis (MCSA) for stator and rotor faults detection [2], [3], [4].

There are a lot of techniques used to detect motor faults with artificial intelligence [5],[6] such as the Artificial Neural Network [7],[8], Fuzzy Logic [9]-[14] and Neuro-Fuzzy[15].

In this paper, we have introduced a technique using fuzzy logic which takes into account the load variation.

Certain work [16] applying the technique of fuzzy logic has considered the case of the full load for the diagnosis. However, in industry the load is variable.

II. ROTOR FAULTS SIGNATURE OF INDUCTION MOTORS

With reference to the electrical and mechanical faults of an induction motors; it is well known that a stator current signal contains potential fault information [17], [18]. The literature reports that each defect is characterized by a harmonic in the stator spectrum of current.

An induction machine rotor asymmetry introduced by broken bars produces spectrum lines at frequencies:

$$f_{rbb} = \left(1 \pm 2ks\right)f \tag{1}$$

Where s is the slip, f is the supply frequency and k an integer equal to 1, 2…

Eccentricity components are caused by many different factors like small misalignment between the motor shaft and the electromagnetic brake used as load for the induction motor, bearing wear, bent rotor shaft and mechanical resonance at critical load. The frequencies for these components can be determined from the following equation:

$$f_e = \left(f \pm kf_r\right) \tag{2}$$

Where f is the supply frequency, f_r rotor mechanical frequency, f_e eccentricity frequency and k = 1, 2 …

III. EXPERIMENTAL RESULTS

A. *Descreption of the Experimental Set-Up.*

A scheme of the experimental set-up is shown in Fig.1. The motor under test is 1.1 kW, 220/380V, 50 Hz, 4 pole, Squirrel-cage induction motor with 28 rotor bars , a DC generator acts as a load. Two types of signals are collected in the experiments: stator current and stator voltage. The signals were interfaced to a PC by A Data acquisition board.

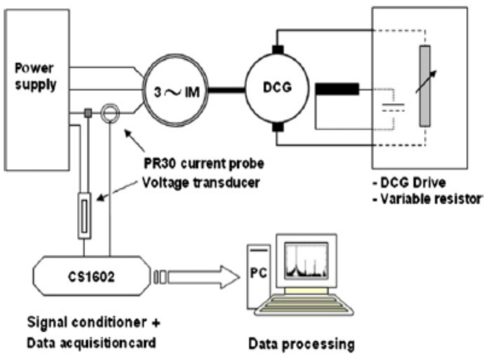

Figure 1. A configuration of the Experimental set-up

B. Steady State Results

At steady state, the stator current is transformed to the frequency domain using a fast Fourier Transform algorithm (FFT).

The practical results shows, Fig. 2, Fig. 3, Fig. 4 that the spectrum of the current in the healthy and faulty state, contains several harmonics, among other the harmonics of eccentricity and the harmonics of broken bars.

The frequencies of the signatures characterizing the defects of bars vary with the load (variation of s) as indicated by equation 1. Their amplitudes are sensitive at the same time to the load and to the severity of defaults (number of broken bars). Thus, by the observation of amplitudes, the state of the rotor can be deduced.

In order to achieve this goal, the treatment is focused in the left side part of the fundamental component of the spectrum. When we followed the component (1-2s) f characterizing the defects of bars, two criterions are considered: the amplitude of this component, and its position in the spectrum.

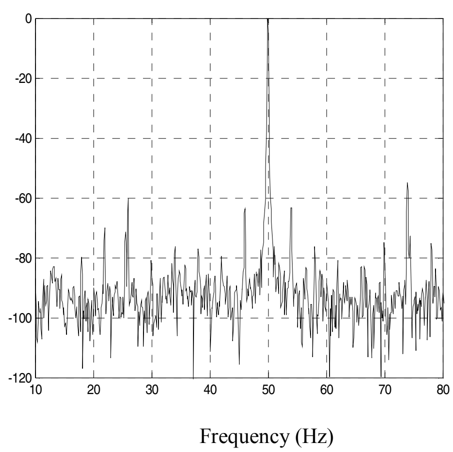

Figure 2. Amplitude of current Spectrum (healthy motor, full load)

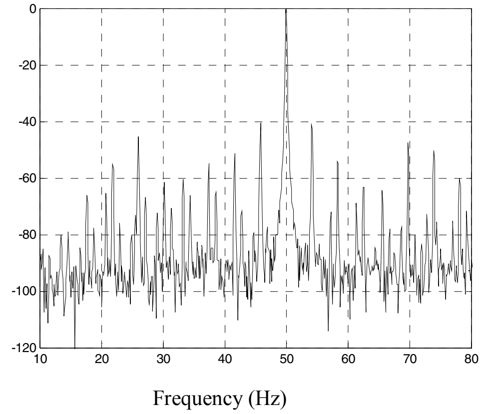

Figure 3. Magnitude of current spectrum (1 Broken Bar, full load)

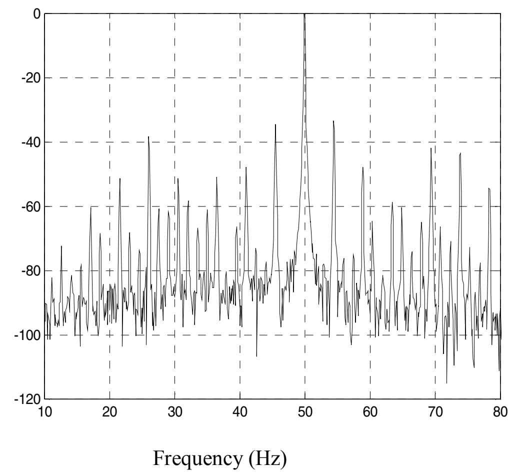

Figure 4. Magnitude of current spectrum (2 Broken Bar, full load)

The analysis of the spectrum shows, that with low loads, the components due to the eccentricity are more significant than that due to the broken of bars. In faulty state, with the increase of the load, the amplitude of the harmonic (1-2s) f increase and become most significant at full loads

To follow the (1-2s) f component, the harmonics in the spectrum, characterized by their peaks are referred to -70 dB and the modules are now A , Fig .5.

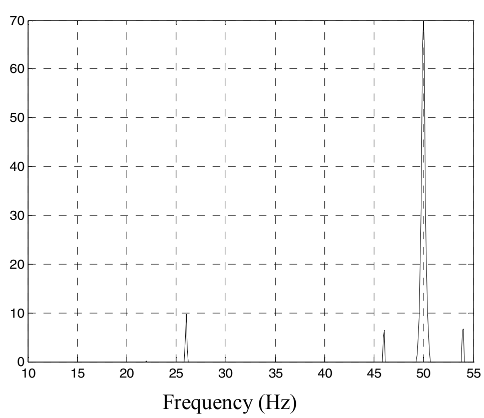

Figure5. Amplitude of current spectrum, Referred to -70 dB (healthy motor, full load)

Tables 1, 2, 3 contain the amplitudes and frequencies of the four significant harmonics for healthy and faulty state under various loads. According to these results, the amplitudes of the harmonic (1-2s)f varies according to two parameters: the load and severity of the defects. Thus, for healthy operation the amplitude of this harmonic is always lower than that due to the eccentricity. In faulty condition, this harmonic can pass from the fourth position (low load) to the first position (full load).

TABLE 1. Amplitudes of current spectrum (Healthy Motor)

		Healthy Motor			
Low load	**f(Hz)**	25.2	24.7	00	00
	A(dB)	30.1	19.0	00	00
Half load	**f(Hz)**	35.1	23.5	25.6	47.9
	A(dB)	15.2	11.8	10.0	7.1
Full load	**f(Hz)**	26.1	46.1	22.0	00
	A(dB)	9.6	6.4	00.0	00

TABLE 2. Amplitudes of current spectrum (1 Broken Bar)

		1 Broken Bar			
Low load	**f(Hz)**	25.2	25.7	49	24.7
	A(dB)	33.6	10.7	9.2	3.4
Half load	**f(Hz)**	25.6	47.9	23.4	34.9
	A(dB)	27.1	25.1	23.5	13.3
Full load	**f(Hz)**	45.9	26.1	341.7	21.9
	A(dB)	29.6	24.2	18.6	14.7

TABLE 3. Amplitudes of current spectrum (2 broken Bar)

		2 Broken Bar			
Low load	**f(Hz)**	24.6	26.2	25.9	48.9
	A(dB)	28.1	24.7	16.9	9.7
Half load	**f(Hz)**	47.4	25.7	23.1	28.4
	A(dB)	33.2	31.8	25.8	16.7
Full load	**f(Hz)**	45.5	26.2	41.2	36.7
	A(dB)	35.3	31.2	21.8	18.6

VI. FUZZY LOGIC APPROACH FOR DIAGNOSIS OF ROTOR FAULTS

A. Fuzzy System Input-Output Variables

The state of the rotor can be deduced by observing the amplitude of certain components in the stator current spectrum. Using fuzzy logic, these amplitudes can be taken as input in Fig. 6.

The numerical input data is converted as linguistic information. By fuzzy inference, using a knowledge base, compressing a rule and data base, the state of the rotor, is then obtained as output.

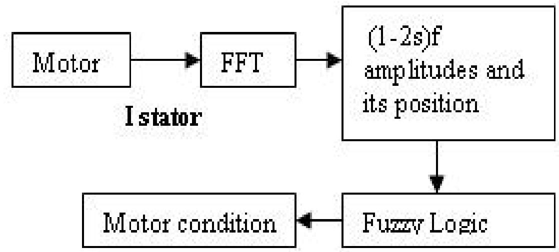

Figure 6. Motor fault diagnosis using fuzzy logic

The result of rotor condition can be deduced by observing the stator current spectrum. The position of the harmonic *(1-2s)f* and its amplitude will be called respectively P and A and will be used as input for the fuzzy system. The rotor condition, CM, is chosen as the output variable.

B. Construction of Membership Function and Fuzzy Inference

Fuzzy rules and membership function are constructed by observing the data set. The available human knowledge and skills on fault diagnosis of induction motors as interpreted as a set of linguistic rules, used to build a knowledge base, comprising a data base and a rule base. The shape of membership functions for input variables is illustrated in Fig.7 and Fig.8. There are five linguistic values for input A which are "Very Small" (VS), "Small" (S), "Medium" (M),"Big" (B) and "VB" (Very Big), five linguistic values for P, which are respectively P1,P2, P3, P4 and P5 for the first Position to the fourth and upper.

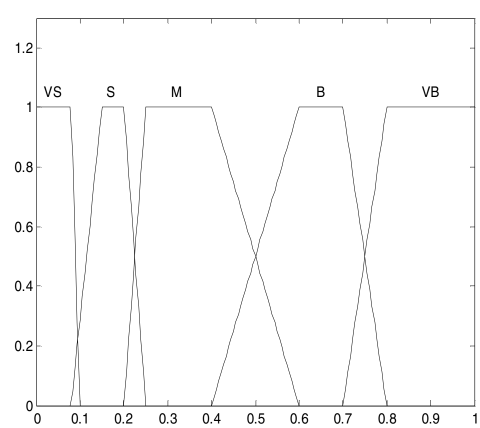

Figure 7. Member ship Functions for A

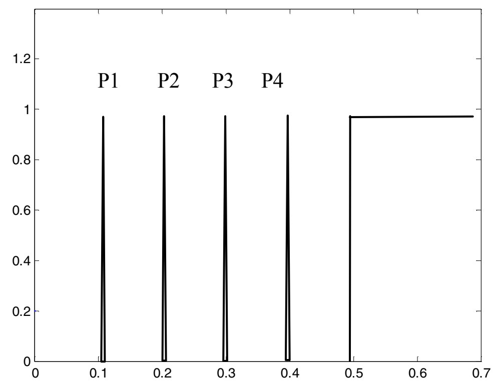

Figure 8. Membership Function for P

The shape of the output CM is chosen as singletons, which have three linguistic values "H" (healthy), "D" (defect), "SD" (severe defect). The Tab.4 described the output range for this variable.

TABLE 4. RANGE OF OUTPUT

Range	Bar Condition	Number of Broken Bar
0≤Output ≤0.4	Healthy(G)	0
0.4≤ Output ≤0.7	Defect (D)	1
0.7≤ Output ≤1	Severe Defect(SD)	2

The rule base is set up as follows:

Rule 1 : if A is VS then CM is G
Rule 2 : if A is S and p is p2 then CM is G
Rule 3 : if A is S and p is p4 then CM is G
Rule 4 : if A is S and p is p3 then CM is D
Rule 5 : if A is M and p is p3 then CM is D
Rule 6 : if A is B and p is p3 then CM is D
Rule 7 : if A is M and p is p4 then CM is SD
Rule 8 : if A is VB then CM is SD

The implementation inference system is of Sugeno type and the centroid method has been used for defuzzification process.

To verify the efficiency of the fuzzy logic system, several tests were carried out. These tests were made under different loads, for the healthy and faulty rotors. In each case, the stator current is transformed to the frequency domain using a fast Fourier Transform algorithm (FFT). After, the component *(1-2s)f* are selected and the amplitude of the harmonic with its position were transferred into the corresponding universes of discourse as the inputs. The fuzzy logic system evaluates the inputs and diagnosis the rotor condition. For instance, for a rotor without faults, the diagnosis obtained should be "G", for healthy, "D" for one broken bar and "SD" for two broken bars. The fuzzy technique was realised by Matlab and the results are presented in Tab.5.

TABLE 5. OUTPUT RELATIONS BETWEEN INPUT AND ROTOR CONDICTION

State of rotor	Input 1 A(db)	Input 1 Normalized	Input 2 P	Output (CM)
Healthy	6.4	0.17	4	0
1 broken bar	29.6	0.74	1	0.5
2 broken bar	35.3	0.90	1	0.99

V. CONCLUSION

A method of diagnosis using fuzzy logic, to determine the state condition of the induction motor rotor was presented. The amplitude of the *(1-2s)f* component of the spectrum of the stator current and its position are described as the input in the fuzzy system witch are converted to variables linguistic by fuzzy subsets and their corresponding membership functions. The output of this system represents the rotor condition. The system was tested for different number of broken bars and under different load. The results obtained with this system are good and it is capable to detect the correct number of broken bar.

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