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# Discrete Wavelet Analysis for the Fault Diagnosis in Induction Motor

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**Abstract:** In this paper, Discrete Wavelet Transform is used to detect the inter-turn fault in the stator winding of an induction motor and a detailed interpretation of the signals resulting from DWT is provided for each case under healthy as well as stator inter-turn faulty operating condition, using wavelet technique has been proposed. The tests were carried out in the laboratory using a three phase squirrel cage induction motor having four poles, 550 turns per phase winding on the stator, and rated 1.5 kW, 415 V, 50 Hz. The phase currents were used as the diagnostic signal using filtering techniques have been also proposed. The results obtained for both healthy and faulty condition for the proper diagnosis of the faulty condition.

**Keywords:** Induction motor interturn fault detection, Discrete Wavelet transform (DWT), Decomposition.

## I. INTRODUCTION

The DWT technique is applied for the diagnosis of the squirrel cage induction motor conditioning, using transient stator currents. This approach is based on the identification of characteristic patterns introduced by fault components in the wavelet signals obtained from the discrete wavelet transform of transient stator currents. A diagnosis of rotor asymmetries in induction motors based on the transient extraction of fault components using filtering techniques have also been proposed. In this paper, the inter-turn fault detection in the stator winding of an induction motor using wavelet technique has been proposed. The results obtained for both healthy and faulty condition for the proper diagnosis of the faulty condition.

## II. DWT METHODOLOGY FOR FAULT IDENTIFICATION

Fig.1 shows the steps that to be followed to apply the discrete wavelet transform (DWT) based methodology for the diagnosis of inter-turn short circuit faults in the stator winding of an induction motor.

### 2.1 CAPTURING THE PHASE CURRENTS UNDER HEALTHY AND FAULTY CONDITIONS:-

The first step for the discrete wavelet based fault diagnosis consists of the capturing of the currents both under healthy as well as inter-turn short circuit condition of an induction motor. When capturing the current signals the sampling frequency $f_s$ plays an important role. Since, most of the important fault components are usually in the low-frequency region. Sampling frequencies of 2 or 5K samples $f_s$ enables good resolution analysis. The sequential Flowchart of DWT-based diagnosis methodology is furnished hereunder for the perusal of the reader for their easy grasp.

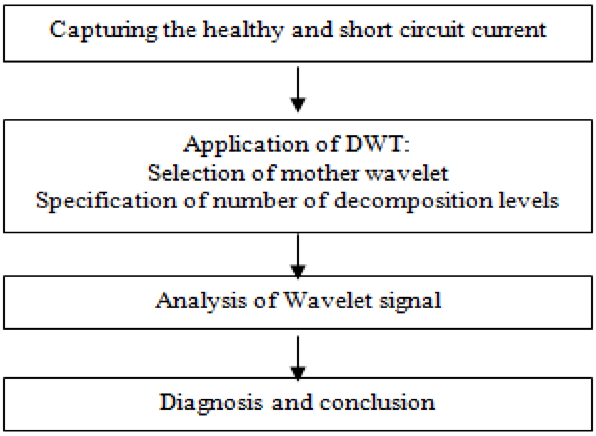

Fig.1. Flowchart of DWT-based diagnosis methodology

It is advisable not to set the limits of the band of the wavelet signal containing the fundamental frequency “f” very close to this frequency. Otherwise, this component could partially be filtered within the adjacent bands, masking the evolution of other components within these bands due to its much higher amplitude. Typically, sampling frequencies of around 40 Hz (for instance, 5000 samples/s) are recommended for the fault diagnosis of an induction motor.

### 2.2 APPLICATION DWT AND SELECTION OF MOTHER WAVELET

Before the application of the DWT, we have to select the type of mother wavelet and the number of decomposition levels. An important step is the selection of the mother wavelet to carry out the analysis. The selected mother wavelet is related to the coefficients of the filters used in the filtering process inherent to the DWT. There are several wavelet families with different mathematical properties have been developed. These wavelets are Infinite supported wavelets (Gaussian, Mexican Hat, Morlet, Meyer, etc.) and wavelets with compact support (orthogonal wavelets such as Daubechies or Coiflet, and bi-orthogonal wavelets) etc. For the fault diagnosis of an induction motor, some families have shown better results for particular applications.

However, it is to emphasis that, in the case of compactly supported wavelets, once the wavelet family is selected, it is advisable to carry out the DWT using a high-order mother wavelet; this is a wavelet with an associated filter with a large number of coefficients. If a low- order wavelet is used, the frequency response gets distorted, and the overlapping between adjacent frequency bands increases. Daubechies wavelet with orders higher than 20 has shown satisfactory results. In our case, we have used Daubechies-44 as the Mother wavelet, for the DWT analysis.

### 2.2.1 SPECIFICATION OF THE NUMBER OF DECOMPOSITION LEVELS

The number of decomposition levels is determined by the low-frequency components to be traced. The extracted frequency band becomes lower if the number of decomposition levels of the DWT becomes higher as shown in Table 1. So, the evolution of these components will be reflected through the high-level signals resulting from the analysis.

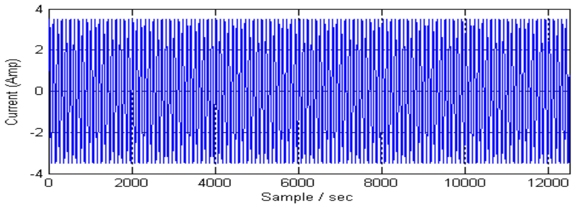

Fig.2.1 Stator Phase current in case of healthy condition

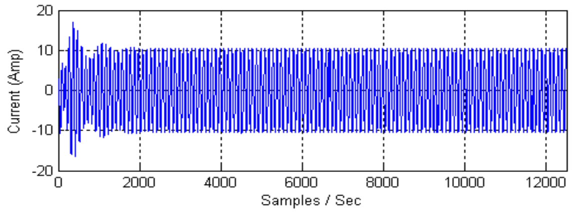

Fig. 2.2 A phase Stator current in case of faulty condition

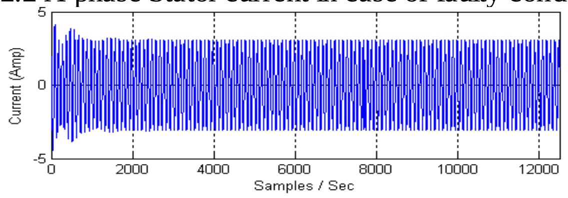

Fig. 2.3 B-Phase Stator current in case of faulty condition

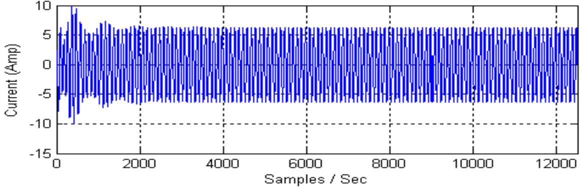

Fig. 2.4 C-Phase Stator current in case of faulty condition

| **Level** | **Signal** | **Frequency band for $f_s$ =5000 samples/Sec** |
|---|---|---|
| $d_1$ | Detail Signal | 1250-2500 Hz |
| $d_2$ | | 625-1250Hz |
| $d_3$ | | 312.5-625 Hz |
| $d_4$ | | 156.25-312.5 Hz |
| $d_5$ | | 78.12-156.25 Hz |
| $d_6$ | | 39.06-78.12 Hz |
| $a_1$ | Approximation Signal | 0-39.06 Hz |

Table-1 Frequency bands for wavelet signal

## III. ANALYSIS OF THE WAVELET SIGNALS.

The next step is to the study of the wavelet signals resulting from the DWT. Two different and complementary types of analyses should be carried out, i.e., a qualitative analysis and a quantitative analysis.

**1) QUALITATIVE ANALYSIS:** The aim of this analysis is to detect the presence of characteristic patterns caused by the evolution of the stator inter-turn fault components during the inter-turn short circuit fault, through the oscillations appearing in the wavelet signals. More specifically, this comprises three phases described as follows.
i) Physical analysis in order to determine the theoretical transient evolution of the fault-related components to be detected. The evolution will be justified in both amplitude and frequency. As an example, Fig. 2.1,2.2,2.3, and 2.4 show the stator phase currents in healthy as well as faulty three phase currents, respectively.
ii) Determination of the frequency bands through which the fault-related component evolves. Each wavelet signal reproduces the evolution of the theoretical signal in the corresponding frequency band associated with that wavelet signal. Therefore, once, knowing the frequency bands through which the component evolves, one can detect the presence of the fault-related component through the oscillations appearing in the wavelet

signals covering those bands. These oscillations will be arranged in a characteristic way, according to the evolution in amplitude and frequency of the fault component during the transient.

iii) Determination of the type of fault, depending on the characteristic pattern arising from the oscillations in the wavelet signals.

**2) QUANTITATIVE ANALYSIS:** Once the condition of the machine has preliminarily been diagnosed, using the qualitative identification of characteristic patterns, it is advisable to compute the quantification parameters defined for the corresponding fault in order to assess the degree of failure in the machine.

These parameters can also be used for generating alert signals in non-supervised systems. Although alerts based on quantitative parameters are not as reliable as the identification of a characteristic pattern, they have the advantage of being much easier to be implemented.

In next Section some non-dimensional parameters will be introduced and computed for the cases qualitatively analyzed.

### 3.1 DIAGNOSIS CONCLUSION

Once the qualitative patterns associated with a particular fault have been detected and the failure severity has been quantified, the diagnosis conclusion can be reached.

### 3.2 RESULTS AND DISCUSSIONS

In this section, discrete wavelet transform is applied for diagnosing induction machine under healthy as well as stator inter-turn faulty operating condition. A detailed interpretation of the signals resulting from DWT is simulated for each case. The tests were performed in the laboratory using a squirrel cage motor with four poles, 550 turns per phase winding on the stator, rated 1.5 kW, 415 V, 50 Hz

### 3.3 DIAGNOSIS OF A HEALTHY INDUCTION MOTOR

Fig 3 shows the sampled healthy phase current (signals, at the top) and the signals resulting from the DWT i.e approximation signal ($a_6$), and detail signals ($d_6$… $d_1$).

The interpretation of these graphs are given below.

i) The approximation signal $a_6$ does not show any relevant pattern once the initial oscillation due to electromagnetic transient is vanished. This transpires that there are no significant low- frequency components (below 39.06 Hz) within the signal.

ii) The detail signal $d_6$ practically reproduces the analyzed healthy current. This is because, for the sampling frequency used, the frequency band corresponding to this signal is [39.06, 78.12] Hz (see Table 1) and so includes the fundamental component of the current, which is more than 30 times greater than the rest of the components.

iii) The detail pattern signal $d_5$ is produced by a component with frequency increasing with time. In the detail pattern $d_5$ at 525 samples per second (t = 0.105 sec) its frequency becomes higher than 78.12 Hz and the component penetrates within the detail pattern signal $d_5$. For the detail signal pattern $d_4$, $d_3$, $d_2$ and $d_1$ which contains very high frequency signals as shown in Fig. 3 From which it can be observed that no oscillations are there after the initial electromagnetic transient. This is due to the fact that the machine is healthy and therefore, no significant patterns exist after the transient condition.

### 3.4 DIAGNOSIS OF A FAULTY INDUCTION MOTOR

The previous test repeated using a machine in which the stator winding turns are artificially shorted in the different phases of an induction motor. Fig. 4, Fig 5 and Fig 6 show the sampled stator inter-turn faulty current (signals, at the top) and the signals resulting from the DWT i.e approximation signal ($a_6$), and detail signals ($d_6$… $d_1$).

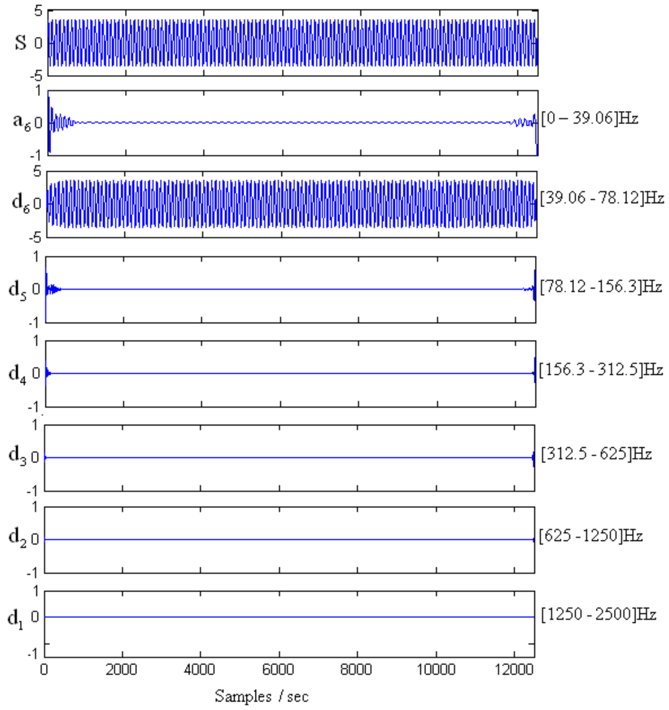

Fig.3 DWT of stator phase current of a healthy I.M.

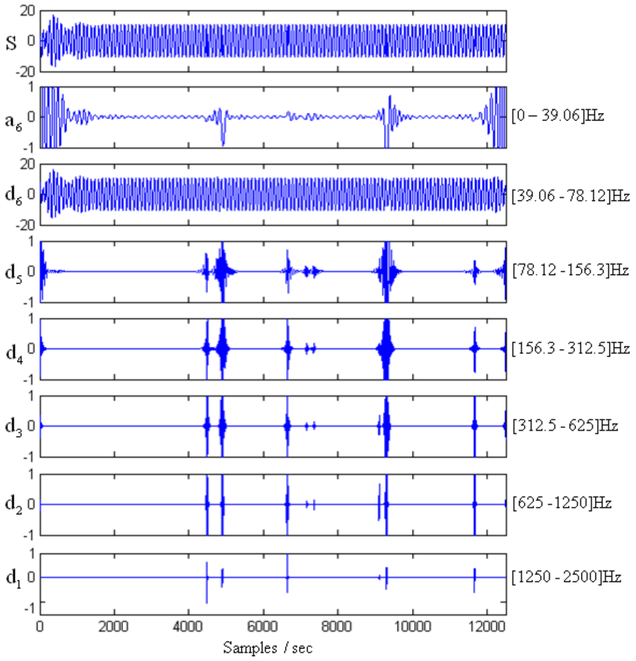

Fig. 4 DWT of A phase stator current of a Faulty I. M.

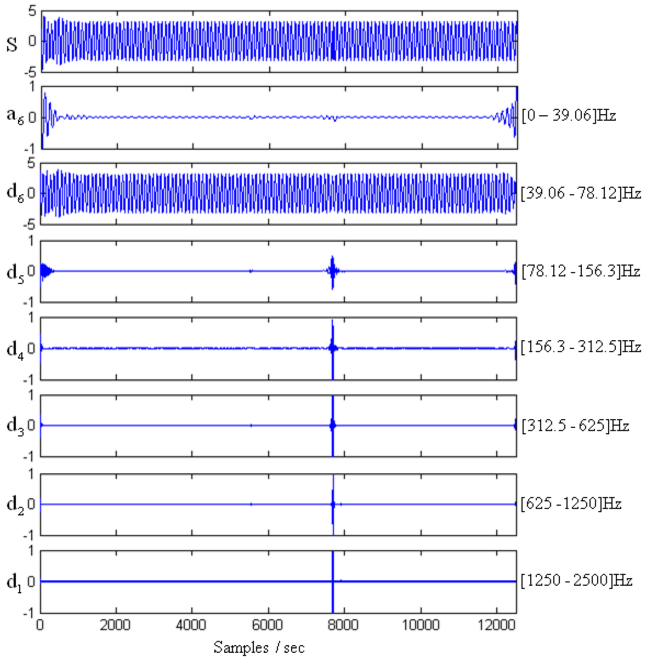

Fig.5. DWT of B phase stator current of a Faulty I. M.

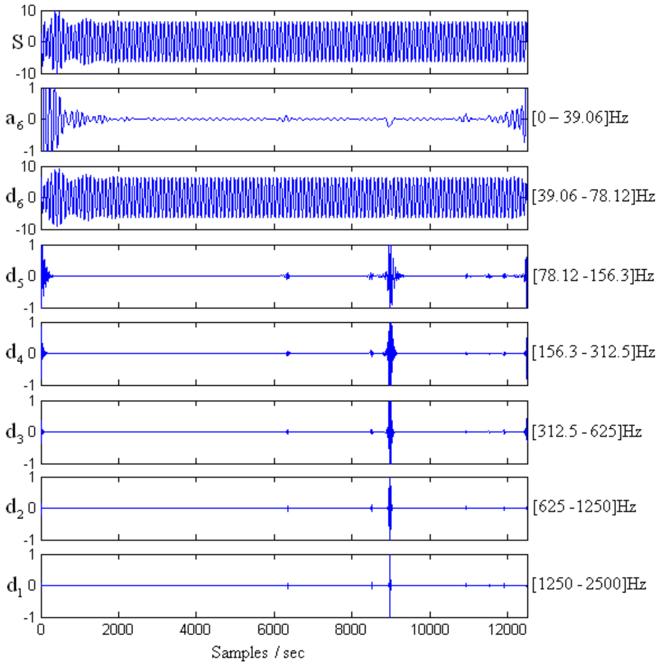

Fig.6 DWT of C phase stator current of a Faulty I.M.

i) From Fig.3, Fig.4, Fig 5 and Fig 6, it is transpires that the inter-turn fault can be detected through the alteration of the approximation signal $a_6$, we get a clear disturbance occurring after the initial electromagnetic transient was vanished.

ii) The detail signal $d_6$ practically reproduces the analyzed induction motor stator inter-turn short circuit fault current. This is because, for the sampling frequency used, the frequency band corresponding to this signal is [39.06, 78.12] Hz (see Table 1.) and so includes the fundamental component of the current, which is more than 30 times greater than the rest of the components.

## IV. QUANTIFICATION OF THE DEGREE OF SEVERITY OF FAULT

The qualitative analysis describes that in faulty conditions, the oscillations, reflecting the evolution of fault components appear in one or several wavelet signals. These oscillations lead to increase in the energy of the involved wavelet signals which can be used as a base for defining the parameters for the quantification of the severity of the fault.

A general expression for calculating the non-dimensional parameters based on the increments of the energy of a wavelet signal is given as

$$\gamma_{nf}\,(\text{in decibels}) = 10\log\left[\frac{\sum_{j=Nb}^{Ns} i_j^2}{\sum_{j=Nb}^{Ns} [A_{nf}(j)]^2}\right]$$

where ij is the value of the $i^{th}$ sample of the current signal, $A_{nf}(j)$ is the $j^{th}$ element of the order of approximation signal. $N_s$ are the number of samples of the signals until a steady state region is reached, and $N_b$ is selected in such a way that the oscillations appearing in the wavelet signal due to the electromagnetic transient phenomena are avoided. The parameters calculated by using above equation represents the ratio between the energy of the tested short circuit current and the energy of the wavelet signal used for the quantification within referred time interval, expressed in decibel.

In this case, for the calculation of the fault parameter $\gamma_{nf}$ , where nf = $d_5$ is selected, because the approximation with level 5 is the signal used for carrying out the diagnosis. The value of $N_b$ and $N_s$ are selected according to the evolution of the signals in healthy state (Fig.3).

The value of $N_b$= 525(0.105 sec) samples have been selected since at this time the initial oscillation caused by the electromagnetic switch on transient are practically extinguished in $d_5$. The selected value of $N_s$=12068(2.4136 sec.) corresponds to the end of the oscillations due to the fault. Table 2 shows the fault parameters for both the healthy and faulty machine. So, we can conclude from the Table 2 that, the proposed parameters suffer significant reductions when an inter-turn short circuit fault occurs in the stator windings of an induction motor.

| **Test** | **Inter-turn S. C. fault** |
|---|---|
| Wavelet Signal | $d_5$ |
| $N_b$ | 525 |
| $N_s$ | 12068 |
| Healthy Machine | 41.66 db |
| Faulty Machine ( A Phase ) | 27.618 db |
| Faulty Machine ( B Phase ) | 36.40 db |
| Faulty Machine ( C Phase ) | 33.10 db |

Table-2 Calculated Quantification Parameters

## V. SUMMARY

The DWT technique is applied to locate the stator inter-turn fault of an induction motor. This technique is based on the analysis of stator phase currents under both, healthy and inter-turn faulty condition. By using the DWT analysis employing Daubechies-44 as the mother wavelet, the approximation signals and detail signals of the fault patterns of the machine are generated. From those generated detail signals the severity of the fault condition can be determined.

From the results presented and analysis made ,it is transpires that the machines subjected to inter-turn short circuit fault can be diagnosed through the characteristic patterns caused by inter-turn short circuit fault components in the DWT analysis by using the stator phase currents. Oscillations after the initial transient are not observed in case of healthy condition, but some oscillations after the initial transient are notified in case of inter-turn faulty condition. In this work by using the fault current patterns we are also able to find out the quantification of the degree of severity of the stator inter-turn fault in an induction motor. Thus the simulation study, analysis and results presented in this work prove the efficacy of discrete wavelet transform technique in induction motor fault diagnosis.

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