Detection of Input Voltage Unbalance in Induction Motors Using Frequency-Domain Discrete Wavelet Transform

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Abstract

Analysis of faults in induction motors has become a major field of research due to importance of loss and damage reduction and maximum online performance of motors. There are several methods to analyze the faults in an induction motor from conventional Fourier transform to modern decision-making neural networks. Considering detectability of fault among all methods, a new fault detection solution has been proposed; it is called as frequency-domain Discrete Wavelet Transform (FD-DWT). In this method, the stator current is decomposed through series of low- and high-pass filters and consequently, the fault characteristics are more visible, because additional components have been reduced. The objective of this paper is early detection of input voltage unbalance in induction motor using wavelet transform in frequency domain. Experimental results show the effectiveness of the proposed method in early detection of faults.

1. Introduction

Induction motor input voltage unbalance can be occurred by a problem in manufacturing such as unequal number of turns in the windings, a misaligned rotor or an asymmetric stator [1]. As per the National Electrical Manufacturers Association (NEMA) guidelines [2], operation of the motor for any length of time above 5% of voltage-unbalance condition “is not recommended”. There it seems necessary to detect the occurrence of unbalance in a motor as early as possible to decrease the possible loss and damages.

To address this issue, most of the research works have mostly focused into detection of input voltage unbalance to induction motors. In other words, late diagnosis of fault is not useful, because it has already cause high amount of loss. In [3-4], a detailed review of voltage unbalance effects on induction motors has been proposed. Usually, the stator current vector has been analyzed and shown the unbalance in input voltage causes an inequality in these vectors. These research works can only detect existence of fault in an offline mode. In other words, calculations and analysis process requires long time that makes the diagnostic method operate very late. Therefore, it seems necessary to offer alternative solutions for detection of faults.

Frequency domain Discrete Wavelet Transform (FD-DWT), as an effective method for detection of faults, uses sets of high- and low-pass filters that reduce level of noise in the analyzed signal. Using frequency domain analysis of DWT, it is possible to detect a fault earlier in order to reduce loss [5]. In this paper, various severities for input voltage unbalance will be examined a test-bed and the resultant stator currents are analyzed using DWT frequency domain analysis method. Also, another objective of this problem will be realized that is minimization of Time to Fault (TTF) [6].

In section 2, the TTF minimization will be discussed; following in the next sections, input voltage unbalance scenarios will be applied and DWT process will be performed to show the characteristics of fault.

2. Minimization of TTF in FD-DWT Process

As FD-DWT process has been introduced extensively in [7], it can be proved that TTF can be minimized due to signal characteristics. A signal with n data-samples as $x[n] = \{x_1, x_2, ..., x_n\}$ is passed through a set of low- and high-pass filter and subsampled by 2, and *G(s)* and *H(s)* are the transfer functions for low- and high-pass filters accordingly. A low pass filter is represented in time domain as follows:

$$\frac{dy}{dt} + f_{cut} y(t) = f_{cut} x(t) \tag{1}$$

Because in our problem, the signal is a discrete signal, therefore the above equation should be discretized:

$$\frac{y_n - y_{n-1}}{T} + f_{cut} y_n = f_{cut} x[n] \tag{2}$$

,where y_n is the low-pass filter output of the current time step, yn-1 is the filter output of the previous time step, x_n is the current filter input and T is the sampling period. Rearranging (2) to solve for y_n yields the equation for the discrete-time, low-pass filter:

$$y_n - y_{n-1} + f_{cut} T y_n + f_{cut} T x[n]$$

$$y_n (1 + f_{cut} T) = y_{n-1} + f_{cut} T x[n]$$

$$y_{n(low)} = \frac{y_{n-1} + f_{cut} T x[n]}{(1 + f_{cut} T)} \tag{3}$$

The same reasoning is used for the high-pass filter, which has the following transfer function:

$$H(s) = \frac{1}{s + f_{cut}} \tag{4}$$

The discretized output is arranged as:

$$y_{n(high)} = \frac{y_{n-1} + T x[n]}{(1 + f_{cut} T)} \tag{5}$$

The matter that wavelet transform creates is because of filtering process where half of the data samples are eliminated; therefore, *x[n]* length becomes half and signal gets more outspread. Considering (3) and (5), by filtering a signal into several levels, the length of *x[n]* becomes smaller and smaller, and same for output. It means some major fault characteristics are eliminated. The idea behind lies in this matter that if we just recognize this level, and do not decompose the signal more than that, because after that level, no fault information exists, the detection process completes earlier and so TTF decreases. This means by detecting this level of decomposition, fault characteristic is recognized, and after this level, no fault information remains and it is inefficient to decompose the fault signal more. By this action, the fault is detected earlier and possible damages to motor are reduced.

3. Input Voltage Unbalance Characteristics

One major characteristics of voltage unbalance are defined as the line voltage unbalance rate (LVUR), which is defined by National Electrical Manufacturers Association (NEMA) and is used by industries to measure the degree of unbalance [7].

$$\text{LVUR} = \frac{\text{max voltage deviation from average line voltage magnitude}}{\text{average line voltage magnitude}}$$

$$= \frac{\max[[v_{ab} - v_{avg}].[v_{bc} - v_{avg}].[v_{ca} - v_{avg}]]}{v_{avg}} \times 100\% \quad (6)$$

where $V_{avg} = \frac{V_{ab} + V_{bc} + V_{ca}}{3}$.

There are six possible voltage unbalance scenarios defined: (1) three phases under-voltage unbalance, (2) two phases under-voltage, (3) single phases under-voltage, (4) three phases over-voltage, (5) two phases over-voltage, (6) single phases over-voltage. Table 1 shows the unbalance cases in detail:

Table1. Input voltage unbalance cases

		$LVUR\%$	V_{ab}	V_{bc}	V_{ca}
Balanced		0	110	110	110
Sc.1	3ph-UV	8.06	95	100	105
Sc.2	2ph-UV	4.76	100	105	110
Sc.3	1ph-UV	3.07	105	110	110
Sc.4	3ph-OV	2.60	118	115	112
Sc.5	2ph-OV	2.65	116	113	110
Sc.6	1ph-OV	2.99	115	110	110

4. Experimental Results

The experimental set up is shown in Fig. 1 that includes of induction motor, and data acquisition system (DAQ) for measuring and analyzing the signal.

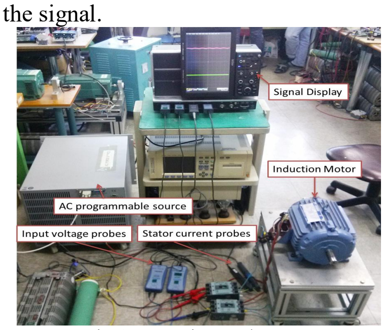
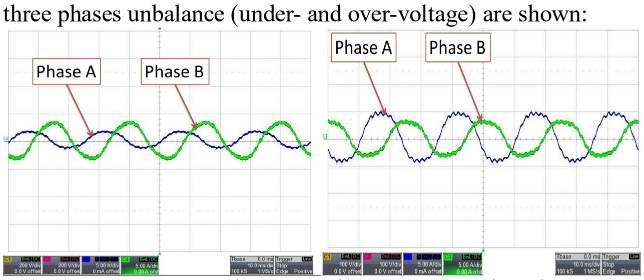


Fig.1. Experimental set-up

In Fig. 2, the waveforms of the worst unbalance cases which are three phases unbalance (under- and over-voltage) are shown:



a) Stator currents are 3 phases UV b) Stator currents in 3 phases OV

Fig.2. Stator currents in two most severe scenarios

The major fault frequency will appear in the third multiple of major frequency. Therefore, the fault will appear at and shown in Fig.3:

$$f_{fault} = 3 \times f_s = 180 \text{ Hz} \quad (7)$$

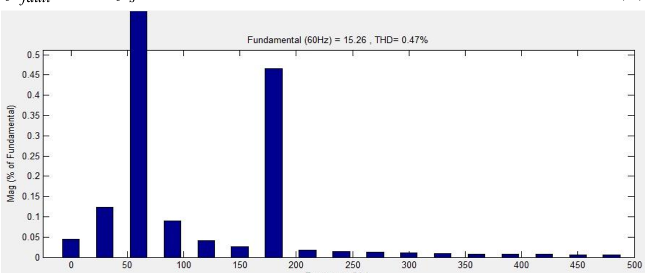
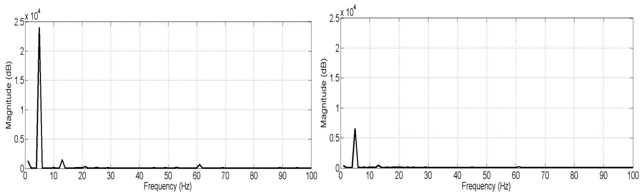


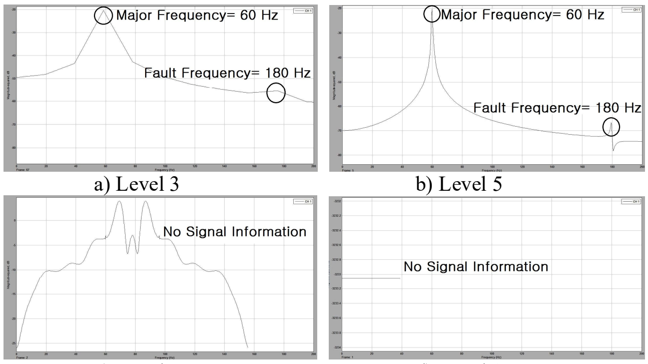
Fig.3. Discrete FFT analysis of stator current phase B in Sc.1



a) Level 3 b) Level 5

Fig.4. Stator current of phase B in Sc. 1 noise reduction

In Fig.4, the stator current of phase B in Sc. 1 has been analyzed and proved that the noise level has considerably reduced. Therefore, the advantage of this method is shown.



a) Level 3 b) Level 5

c) Level 7 d) Level 9

Fig.5. Stator current in phase B FD-DWT analysis

In Fig. 5, the fault information along with major frequency characteristic is observed in level 3 and level 5, whereas no special fault information exists in level 7 and level 9. Therefore, it can be stated based on what mentioned in section 2 that optimal number of decomposition levels is 5 out of maximum 9 for such a fault, because no additional fault information can be derived after level 5.

5. Conclusion

FD-DWT can be used for detection of input voltage unbalance fault in induction motor. Considering input voltage unbalance, it is observed that by decomposing the signal, noise level will be reduced, which makes unbalanced condition detected early as well as more visible.

Acknowledgment

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