ISSN 2229-5518

DC Link Faults Detection in a 3 phase VSI fed Induction Motor Drive using Wavelet Transform

K. Mohanraj, S. Paramasivam, Subhranshu Sekhar Dash

Abstract. The aim of this study is to employ the wavelet technique for the diagnosis of open-circuit and short circuit faults in the dc link of induction motor drive. The symlet wavelet is selected as the wavelet base to perform stator current analysis during faults. In this method, the stator currents are used as an input to the system. The MATLAB software is used to process discrete wavelet transform (DWT) of the signals. The stator current is used for the detection of the fault. When an open-circuit fault or a short circuit fault appears, the signal fault information is included in each frequency region. The time of the spikes in the DWT is correlated with the time of fault. As a result of time & frequency domain studies, a faulty system can be easily discriminated from the healthy system.

Keywords: DC link, Open Circuit and Short Circuit Fault, Wavelet, Induction motor, Discrete wavelet transform, DC link, Friction factor,

1 INTRODUCTION

THE modern day advanced engineering systems have become more complex. As a result, there has been a growing demand for reliable fault detection and identification and diagnosis schemes. A fault is defined to be any deviation of the system outside its designed operation. Fault detection is the process of recognizing when a system has begun to operate outside its original design limit. Fault identification is the process of locating the most likely root cause of the detected failure within the system's components or subsystems. A survey of system fault identification and diagnosis can be found in [1] [2] [3]. Since the field of fault diagnosis has been developed, new techniques have emerged to monitor power systems and give immediate information as a fault occurs. Fault detection and diagnosis for power system is complicated because of the wide variations in power components operating conditions and performance caused by many different constraints. The theory of application of wavelet transforms (WT) to fault detection and classification has been discussed in many papers. The induction motor is widely used in many industries due to their low cost, ruggedness, low maintenance, and operation with an easily available power supply. Since the induction motor current contains harmonics it can be used for the identification of many faults. Many different techniques are employed in fault diagnosis in drives. One such technique is wavelet technique. This technique is new in the field of fault diagnosis due to its ability to extract information in both time and frequency domain as well as it provides a sensitive means to the diagnosis of faults if compared to other signal processing method like Fourier Transform.

- *Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
- *Co-Author name is currently pursuing masters degree program in electric power engineering in University, Country, PH-01123456789. E-mail: author_name@mail.com*
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The fault diagnosis has two main levels:

1) A traditional control level
2) A knowledge based fault diagnosis

One of the most important analysis tools in both frequency and time domain is the wavelet. The multi resolution analysis and good time localization makes wavelet very attractive for research work in fault diagnosis. Wavelets are localized in both the time and frequency domains because wavelets have limited time duration and frequency bandwidth.

2 APPLICATION OF WAVELET IN FAULTS DIAGNOSIS

Fourier analysis techniques provide significant information on frequency components of signals under study, but offer no information regarding where a particular frequency was located in the time axis. In contrast, wavelet transforms offers time-frequency information of signals under study, thereby making wavelet transform methods more comprehensive than Fourier transforms. In signal analysis, wavelet coefficients, at a first level of decomposition, are obtained from a signal under analysis by applying a mother wavelet. The process can be repeated if the mother wavelet is scaled and translated. The mother wavelet function (denoted by $\psi(t)$) and its scaling function (given as $\phi(t)$) describe a family of functions which are required to satisfy a number of criteria. It must have a zero mean denoted in equation below.

$$\int_{-\infty}^{+\infty} \psi(t)dt = 0 \qquad (1)$$

In addition $\Psi(t)$ must have a square norm of one as denoted in equation (2)

$$\int_{-\infty}^{+\infty} |\psi(t)|^2 dt = 1 \qquad (2)$$

ISSN 2229-5518

When a mother wavelet is translated by a factor of 'a' and scaled by a factor of 'b', it can be expressed in a generic form as follows

$$\phi_{a,b}(t) = \frac{1}{\sqrt{a}}\phi\frac{(t-b)}{a} \qquad (3)$$

The use of these wavelet functions provides a robust method of analyzing non-stationary signals to provide both frequency and time information. Wavelet transformation contains many kinds, but in this paper discrete wavelet transform has been discussed.

2.1. Discrete Wavelet Transform (DWT)

The wavelet transformation is the process of determining how well a series of wavelet functions represent the signal being analyzed. The goodness of fitting of the function to the signal is described by the wavelet coefficients.

Considering a signal consisting of 2m data points, where m is an integer, DWT requires 2m wavelet coefficients to fully describe the signal. DWT decomposes the signal into m+1 levels, where the level is denoted as j and the levels are numbered i= -1, 0, 1, 2, 3…m-1. Each level i consists of *j*=2i wavelet translated and equally spaced 2m/*j* intervals apart. The *j*=2i wavelets at level i are dilated such that an individual wavelet spans n-1 of that level interval, where N is the order of the wavelet being applied. The forward wavelet transform determines $(a_{i,j})$ of j wavelet at each level 'i' for the signal f (n), the DWT is

$$a_{i,j} = a_{2^i+j}\sum f(n).\psi_{i,j}(n) \qquad (4)$$

The use of wavelets has been shown to yield satisfactory results for detecting electrical and mechanical faults of induction machine. Wavelet decomposition results in useful data contained in '*details*' and '*approximate*' parts as shown in the simplified block diagram of Figure1. The '*approximation*' signal can be further decomposed in to a new set of '*approximation*' and '*details*' signals and continue until *n* decomposition levels.

The '*details*' signal contains high frequency information whereas the approximate part contains signal data with the low frequency components. For the induction motor signature analysis, the higher frequency wavelet components represent system noise or harmonics due to faults in the dc link of induction motor drive.

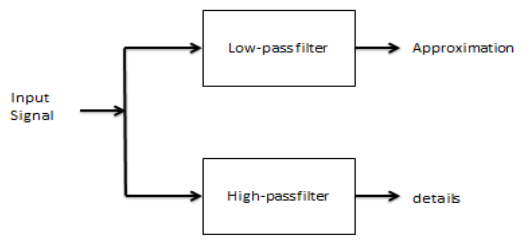

Fig.1. First level decomposition in wavelet

Figure (2) shown below is of reconstructed signal representing decomposition of a signal. Fault patterns are obtained from the information yielded by the *n*-level wavelet decomposition through a variety of strategies, including filter banks and classification algorithms.

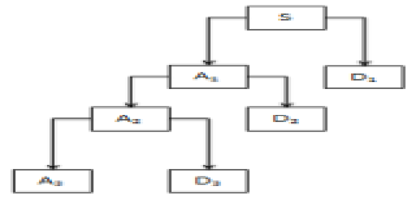

Fig.2. Reconstructed signal components in wavelet

In this study, a statistical analysis of the wavelet '*details*' coefficients is used as the basis for fault detection. From the mean or standard deviation of the wavelet coefficients, it could be inferred that the average magnitude of frequency components are present in the signal under analysis. Each level of the signal detail coefficients provides frequency resolution that allows unique signature characteristics to be deduced. That is if the n level detail coefficients are analyzed then each level represents the spatial information for a small range of frequencies [5], [6], [8].

3 FUNCTIONAL UNITS

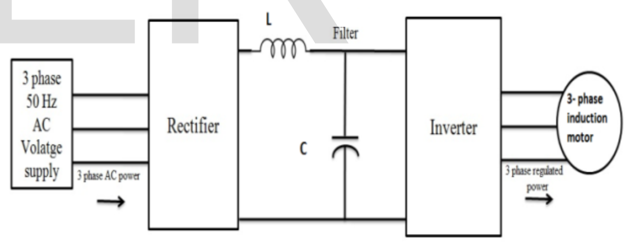

Fig.3. Block diagram of an induction motor drive

Figure (3) describes the functional units present in induction motor drive. A 5.4 HP induction motor is driven by voltage source inverter. The operation of the system is as follows: A 3 phase supply of 50 Hz is given to a rectifier which converts the given ac source to dc. The filter circuitry in the dc link is meant to reduce the harmonic content in the ac input and ripples present in the dc output. The filtered dc output is fed to the inverter which converts dc into ac and the output obtained from the VSI is fed to the induction motor.

Figure (4) shows the introduction of an open circuit fault and a short circuit fault in the dc link of the induction motor drive.

The open circuit fault occurs first for duration of 0.2 seconds followed by a short circuit fault which occurs across the capacitor in dc link which too lasts for 0.2 seconds. The

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switching over of the first breaker starts at 1sec and lasts for 0.2 seconds which forms open circuit fault.

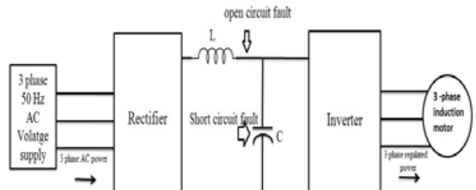

Fig.4. Block diagram of the induction motor drive after introduction of faults in the dc link

The switching over of the second breaker starts at 2 sec and lasts for 0.2 sec and it forms the short circuit fault across the capacitor. The performance of the drive in both the cases is analyzed by wavelet theory. The output stator current signal obtained from the induction motor is used for the detection of faults occurring in the system.

4 Simulation Results

Various simulations are done using MATLAB software for the induction motor drive circuit presented in Fig. (3). The output of the VSI is given to the induction motor. The drive circuit shown in Fig. (5) is the simulation model of the healthy induction motor drive. Fig. (6) Shows the induction motor drive circuit in which two faults are introduced in the dc link before the inverter circuitry. These two faults are open circuit and short circuit faults.

To analyze the change in the operation of the drive after the introduction of faults, the stator current signal of the induction motor is analyzed using the wavelet toolbox which is available in Matlab. The stator current signal is analyzed & decomposed using symlet wavelet at the 6th level of decomposition. It can be clearly seen that by using wavelet transform the exact location & frequency of the signal can be detected at the exact instant where the actual discontinuity takes place which also helps in specifying the fault type.

The wavelet toolbox is able to analyze & detect the open circuit & short circuit faults that occur in the dc link of an induction motor drive. The decomposition at level 6 of symlet wavelet is presented to ensure the best detection of both the faults in the dc link.

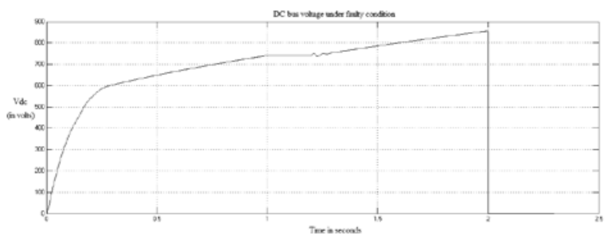

Fig.5. DC output voltage waveform of three-phase VSI under DC bus faults

The peak current in the healthy case is approximately 2 amperes but with little overshoot in the transient region.

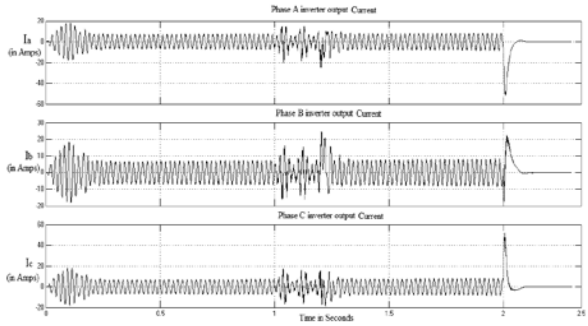

Fig.6.Stator current signal of induction motor drive under dc bus faults

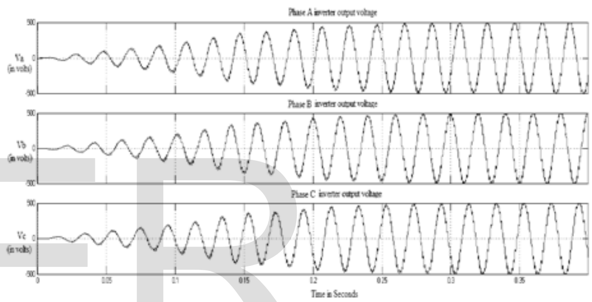

Fig.7.Inverter output voltage under nominal condition

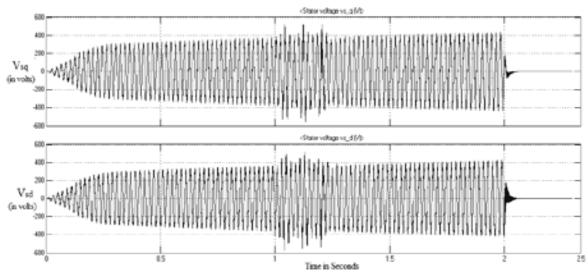

Fig.8.Inverter output voltage under DC bus faults

The amplitude of stator current in the case of short circuit fault in the dc link of the induction motor drive is -50 amperes to +50 amperes in faulty state. The approximation & detail coefficients of the wavelet effectively detect open circuit & short circuit faults in the dc link of induction motor drive.

TABLE 1

THE THRESHOLD OF WAVELET LEVELS IN CASE OF OPEN CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Level	Threshold
6	5.152
5	5.155
4	3.172

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3	0.524
2	1.432
1	1.367

TABLE 2

THE THRESHOLD OF WAVELET LEVELS IN CASE OF SHORT CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Level	Threshold
6	5.019
5	5.019
4	3.204
3	2.189
2	3.783
1	3.493

TABLE 3

THE THRESHOLD OF WAVELET LEVELS IN CASE OF HEALTHY INDUCTION MOTOR DRIVE

Level	Threshold
6	0.177
5	0.032
4	0.066
3	0.004
2	0.007
1	0.006

From the values obtained, it can be inferred that threshold of wavelet levels increases in case of faults & is low in case of healthy induction motor.

TABLE 4

THE APPROXIMATION SIGNAL WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF SHORT CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Approximation signal	Mean energy values
Standard deviation	762.2
Median abs deviation	702.9
Mean abs deviation	3981

Mean energy values show the magnitude of deviation present in the stator current signal indicating presence of fault in the dc link of induction motor drive.

TABLE 5

THE DETAIL SIGNAL WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF SHORT CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Detail signal	Mean energy values
Standard deviation	15.93
Median abs deviation	1.68
Mean abs deviation	1.92

TABLE 6

THE APPROXIMATION SIGNAL WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF OPEN CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Approximation signal	Mean energy values
Standard deviation	1.912e+004
Median abs deviation	8752
Mean abs deviation	1.362e+004

TABLE 7

THE DETAIL SIGNAL WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF OPEN CIRCUIT FAULT IN DC LINK OF INDUCTION MOTOR DRIVE

Detail signal	Mean energy values
Standard deviation	33.87
Median abs deviation	16.13
Mean abs deviation	24.15

TABLE 8

THE APPROXIMATION SIGNAL WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF HEALTHY INDUCTION MOTOR DRIVE

Approximation signal	Mean energy values
Standard deviation	63.23
Median abs deviation	59.21
Mean abs deviation	55.86

TABLE 9

THE DETAIL SIGNAL OF WAVELET DECOMPOSITION MEAN ENERGY VALUES IN CASE OF HEALTHY INDUCTION MOTOR DRIVE

Detail signal	Mean energy values
Standard deviation	0.07151
Median abs deviation	0.05883
Mean abs deviation	0.06228

From the values obtained through the wavelet toolbox for the deviation in the approximation signal & detail signal it can be inferred that there is significant change in the threshold & mean energy values in case of open circuit & short circuit fault in dc link of three phase induction motor drive than the healthy induction motor drive.

5 APPENDIXES

5.1 Induction Motor parameters

Power – 4KW
Line-line voltage – 400V
Frequency – 50Hz
Stator resistance – 1.405ohms
Stator inductance – 0.005839Henry
Rotor resistance – 1.395ohm
Rotor inductance – 0.005839Henry
Mutual inductance – 0.1722Henry
Inertia – 0.0131kg.m^2
Friction factor – 0.002985 Nm.s
Pole pairs – 2

6 Conclusion

This paper presents wavelet techniques for the diagnosis of open circuit & short circuit faults that occur in the dc link of an induction motor drive. The fault detection carried out using wavelet analysis helps to extract fault characteristics. Threshold values & mean energy values obtained from the approximation signal & detail signal show the nature of dc link faults, by indicating deviation taken place in threshold values and mean energy values of the healthy condition of induction motor drive. The result of the symlet wavelet gives advantageous information to decide faulty situation, particularly in case of open circuit & short circuit faults

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