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MONITERING AND DIAGNOSIS OF STATOR INTER TURN FAULTS IN THREE PHASE INDUCTION MOTOR

D.NAGALAKSHMI, SMT.N.RAMADEVI, G.VENUGOPALARAO

Abstract—**Induction motors are one of the commonly used electrical machines in industry because of various technical and economical reasons. Three-phase induction motors are the "workhorses" of industry and are the most widely used electrical machines. In an industrialized nation, they can typically consume between 40 to 50% of all the generated capacity of that country. Stator fault is one of the most commonly occurring faults in ac machines. Early detection of faults in stator winding of induction motor is crucial for reliable and economical operation of induction motor in industries. This paper compares the two fault detection methods for stator inter-turn faults, which are based on FFT and Wavelet transform. The voltage and current signals are captured by using power network analyzer DIP8000(UNIPOWER) with sampling frequency 5.3 kHz .This data is then processed and analyzed using FFT and Wavelet transform. The results show the wavelet transforms is more effective than FFT analysis.**

.Index Terms— Induction motors, Inter turn faults, FFT analysis, Wavelet transform.

I.INTRODUCTION

Induction motors are most commonly used electrical machines in industry because of their low cost, reasonably small size, ruggedness, low maintenance, and operation with an easily available power supply. Although these are very reliable, they are subjected to different modes of failures / faults. These faults may be inherent to the machine itself or due to operating conditions. The inherent faults may be are due to the mechanical or electrical forces acting on the machine enclosure. The Induction motor faults are divided into three main categories: stator winding faults, broken rotor bar problems, and bearing problems. Turn-to-turn and turn-to-earth faults in an IM stator winding lead to asymmetry between the three phases, causing undesirable motor behavior and heat. It can also be seen that a large portion of stator winding-related faults are initiated by insulation failures in several turns of a stator coil within one phase [1]. This is nearly 35–40% of the total motor failures [2]. Generally, stator winding insulation thermal stresses are categorized into three types: aging, overloading and cycling [3]. The lead time between the start of the fault and the complete failure of the machine depends on several factors, namely the initial number of shorted turns, winding configuration, ratedpower, ratedvoltage, environmental condition etc [4].

Wavelet techniques for fault monitoring and diagnosis of induction motor are increasing because these techniques allow performing stator current signal analysis during transients [5]. It is thus a powerful tool for condition monitoring and fault diagnosis. Inter turn fault is detected with the help of absolute peak d1 coefficients of stator currents.

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Almost 90% of induction motors are provided with squirrel cage motor because of its very simple, robust and almost inscrutable construction.

II. FAST FOURIER TRANSFORM

One of the major Signal Processing tools is the Fourier analysis, which has different forms like Fourier series, Fourier Transform, Discrete Fourier Transform, and so on. Fourier analysis methods use orthogonal sets of functions in order to expand a given periodic function into an infinite series. While a large number of orthogonal sets exist, the Fourier analysis form which is commonly utilized makes use of the cosine and sine functions. However, for non-periodic time-varying signals, the above mentioned method has several inconveniences. To a certain extent, these could be overcome by the application of different windowing techniques leading to the Short-Time-Fourier Transforms. But these have also their own limitations. An alternative method is to use wavelets.

A.FOURIER TRANSFORM (FT)

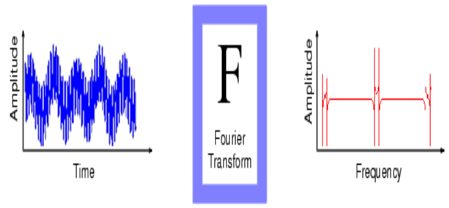

Fig.1.Fourier Transform of a given signal

FT give the frequency information of the signal, which means that it tells us how much of each frequency exists in the signal, but it does not tells us when in tine this frequency components exist. This information is not required when the signal is so called stationary.

B.FFT (Fast Fourier Transform)

The FFT is a faster version of the Discrete Fourier Transform (DFT).To approximates a function by samples, and to approximate the Fourier integral by the discrete transform. The Fourier transform has many applications, in fact any field of physical science that uses sinusoidal signals, such as engineering, physics, applied mathematics, and chemistry, will make use of Fourier series and Fourier transforms. Here are some examples from physics, engineering, andsignalprocessing.Communications, Astronomy, Geology Physics

III. WAVELET TRANSFORM

A. INTRODUCTION TO WAVELETS

Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. They have advantages over traditional Fourier methods in analyzing physical situations where the signal contains discontinuities and sharp spikes. Wavelets were developed independently in the fields of mathematics, quantum physics, electrical engineering, and seismic geology.

"A wavelet is a waveform of effectively limited duration that has an average value of zero"

B. WAVELET TRANSFORM

Wavelet transform (WT) is an efficient means of analyzing transient current and voltages. Wavelet analysis represents the next logical step: a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information.

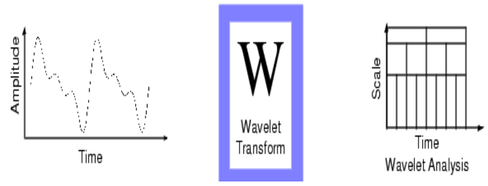

Fig.2.Wavelet Analysis of a given signal

Ingrid Daubechies, one of the brightest stars in the world of wavelet research, invented what are called compactly supported orthonormal wavelets -- thus making discrete wavelet analysis practicable.

The names of the Daubechies family wavelets are written dbN, where N is the order, and db the "surname" of the wavelet. The db1 wavelet, as mentioned above, is the same as Haar wavelet. Here is the wavelet functions psi of the next nine members of the family. Wavelet Transforms are used to compress the fingerprint pictures for storage in their data bank. Data compression can be achieved by discarding these low amplitudes.

IV. Experimental set up

Currently electrical motors are amongst the most useful equipment in the industry. For an experimental purpose 3H.P, 3 phase, 4 pole, 415 volts, 50 Hz squirrel cage induction motor is considered for the analysis of stator inter-turn faults. Experimental setup of the three phase Induction motor is shown in Fig.3.a. Dip 8000 is used to capture the three phase stator currents Stator currents and phase voltages are used to analyze the various inter turn faults with the help of FFT and Wavelet Transforms.

Fig .3.a.Experimental set up of three phase Induction motor Stator inter turn fault detection.

A. Interfacing Device-DIP 8000(Power network analyzer):

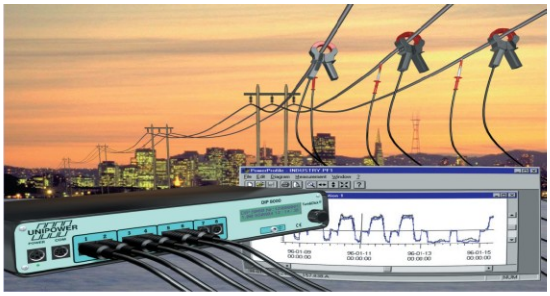

Fig .3.b.Power network analyzer

DIP 8000(UNIPOWER) is specially designed for power distributors, utilities, industries, consultants, hospitals and many other user categories in need of advanced measuring equipment in the power network environment.

V.SIMULATION RESULTS

A. Fault detection by using FFT analysis:

The three phase voltage signals and current signals of a three phase Induction motor is captured by using power network analyzer (DIP8000), and these captured voltage and current signals are analyzed by using FFT analysis. The detection of fault can be obtained by comparing the %THD with threshold1 (18) and product of 3rd and 5th harmonics with threshold2 (38).

FFT results for healthy condition

The captured three phase stator current signals of a three phase induction motor under healthy condition are shown in figure 4.a, b, and c. For R phase, Y phase, and B phases respectively. By using FFT three phase currents are analyzed over a window length of one cycle.

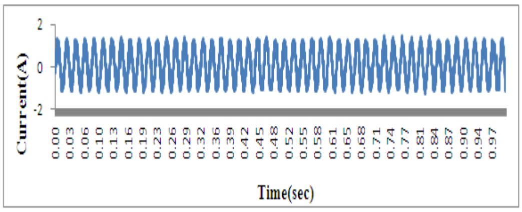

Fig.4.a.R phase current under healthy condition

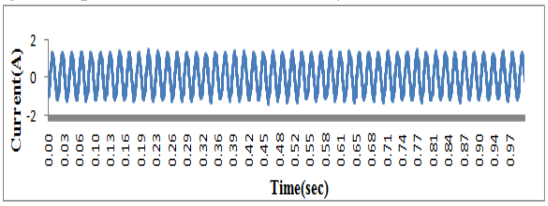

Fig.4.b.Y phase current under healthy condition

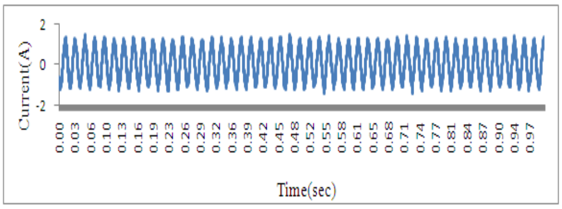

Fig.4.c.B phase current under healthy condition

The calculated %THD and product of 3rd and 5th harmonics for various instants are tabulated as follows. It is observed that all the values of %THD is less than threshold1 or product of 3rd and 5th harmonics is less than threshold2 or both because it is a healthy case.

Table-I: FFT analysis of R phase, Y Phase, B Phase currents under healthy condition

Phases	Start time	%3rd Harmonic w.r.t. fundamental	%5th Harmonic w.r.t. fundamental	%THD w.r.t. fundamental	Fundamental	Multiplication(3rd harmonic*5th harmonic)
R-Phase	0.1	1.087	3.35	2.53	15.44	8.4755
	0.2	1.047	3.49	9.61	20.66	33.5389
	0.3	1.07	1.52	4.54	17.67	6.9008
	0.4	1.059	4.96	6.69	17.51	33.1824
	0.44	1.075	5.25	7.04	19.86	36.96
	0.5	1.055	4.28	7.63	19.83	32.6564
	0.6	1.091	0.51	4.52	17.12	2.3052
	0.7	1.063	4.55	5.82	16.31	26.481
	0.8	1.095	4.42	3.86	15.97	17.0612
	0.9	1.064	3.4	7.5	18.87	25.5
Y-Phase	0.1	1.14	1.42	4.47	10.66	6.347
	0.2	1.137	1.44	5.97	11.90	8.597
	0.3	1.156	1.84	5.82	10.3	10.71
	0.4	1.15	1.92	4.48	12.5	8.602
	0.5	1.15	0.63	5.62	10.49	3.541
	0.6	1.148	1.06	4.44	10.44	4.706
	0.7	1.171	2.46	3.06	10.71	7.528
	0.8	1.161	0.92	5.96	11.76	5.483
	0.9	1.159	2.8	4.59	9.47	12.85
B-Phase	0.1	0.88	3.94	10.52	1.072	3.467
	0.2	1.23	4.84	11.13	1.059	5.953
	0.3	1.86	2.51	11.83	1.087	4.669
	0.34	2.72	5.56	12.10	1.045	67.27
	0.4	1.13	4.3	10.88	1.047	4.859
	0.5	1.65	5.23	14.09	1.055	8.63
	0.6	0.34	2.2	11.85	1.057	0.748
	0.7	2.08	5.14	10.72	1.064	10.69
	0.8	3.16	6.05	12.37	1.069	19.12
	0.9	2.37	5.76	11.79	1.05	13.65

FFT analysis for turn fault

Turn fault in R phase:

The turn fault is creating in R phase with 6turns from the neutral point. Figures .5.a. shows the variation of current in R phase. The signal is analyzed by using FFT analysis.

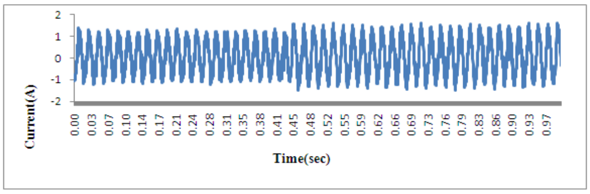

Fig .5.a.Variation of R phase current under R phase turn fault on 3-phase induction motor.

The calculated %THD and product of 3rd and 5th harmonics for various instants are tabulated as follows. By observing the tables II both the %THD and product of 3rd and 5th harmonics are greater than the threshold1 (18) and threshold2 (38) at the fault instant.

Table-II: FFT analysis of R phase Y Phase, B Phase currents for a 3-phase induction motor in R phase turn fault

Phases	Start time	%3rd Harmonic w.r.t. fundamental	%5th Harmonic w.r.t. fundamental	%THD w.r.t. fundamental	Fundamental	Multiplication(3rd harmonic*5th harmonic)
R-Phase	0.1	5.54	7.19	17.51	1.016	39.83
	0.2	2.05	7.50	17.20	1.052	15.37
	0.3	8.62	9.34	21.04	1.085	80.51
	0.4	3.74	6.06	18.22	1.077	22.66
	0.44	**10.74**	**7.11**	**21.70**	**1.193**	**76.36**
	0.5	4.10	7.07	17.51	1.2	28.98
	0.6	2.17	3.34	17.65	1.185	7.24
	0.7	1.28	5.64	17.59	1.227	7.21
Y-Phase	0.1	3.28	6.84	18.64	1.054	22.43
	0.2	2.63	7.34	15.19	1.082	19.30
	0.3	3.40	8.73	17.84	1.055	29.68
	0.4	3.55	6.94	18.21	1.087	24.63
	0.44	**3.40**	**4.35**	**14.92**	**1.147**	**14.79**
	0.5	5.37	9.20	16.30	1.268	49.40
	0.6	3.03	2.66	12.97	1.156	8.05
	0.7	2.33	3.38	13.60	1.186	7.87
B-Phase	0.1	2.82	9.51	14.48	1.035	26.81
	0.2	2.29	8.37	15.34	1.054	19.16
	0.3	1.96	8.95	15.74	1.025	17.54
	0.4	1.02	7.77	16.96	1.019	7.92
	0.44	**6.97**	**7.42**	**15.54**	**0.954**	**51.71**
	0.5	2.63	10.01	16.37	0.966	26.32
	0.6	1.74	7.10	19.41	0.916	12.35
	0.7	1.78	8.72	17.01	0.935	12.52

Turn fault in Y phase:

The turn fault is creating in Y phase with 6turns from the neutral point. Figures 5.b, shows the variation of current in Y phase. The signal is analyzed by using FFT analysis.

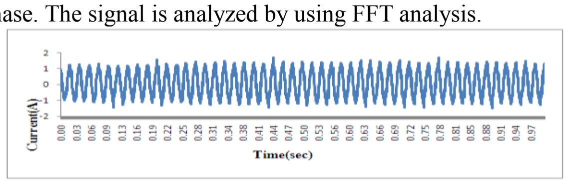

Fig .5.b.Variation of Y phase current under Y phase turn fault on 3-phase induction motor.

The calculated %THD and product of 3rd and 5th harmonics for various instants are tabulated as follows. By observing the tables III both the %THD and product of 3rd and 5th harmonics are greater than the threshold1 (18) and threshold2 (38) at the fault instant.

Table-III: FFT analysis of R phase Y Phase, B Phase currents for a 3-phase induction motor in Y phase turn fault

Phases	Start time	%3rd Harmonic w.r.t. fundamental	%5th Harmonic w.r.t. fundamental	%THD w.r.t. fundamental	Fundamental	Multiplication(3rd harmonic*5th harmonic)
R-Phase	0.1	2.58	3.31	15.91	1.122	8.5398
	0.177	2	4.44	14.87	1.127	8.88
	0.2	**4.33**	**6.2**	**15.03**	**1.118**	**26.846**
	0.3	5.11	6.98	15.45	1.295	35.6678
	0.4	1.34	5.24	15.83	1.267	7.0216
Y-Phase	0.1	2.49	5.9	14.05	1.017	14.691
	0.177	4.47	9.54	17.12	1.02	42.6438
	0.2	**3.16**	**12.22**	**18.63**	**1.077**	**38.6152**
	0.3	3.78	5.73	11.58	1.189	21.6594
	0.4	4.23	9.1	14.72	1.188	38.493
B-Phase	0.1	1.48	2.38	19.56	0.912	3.5224
	0.177	2.72	7.42	20.4	0.97	20.1824
	0.2	**4.91**	**7.42**	**21.38**	**0.953**	**36.4322**
	0.3	6.59	10.41	24.64	0.804	68.6019
	0.4	2.8	3.56	21.31	0.848	9.968

Turn fault in B phase:

The turn fault is creating in B phase with 6turns from the neutral point. Figures .5.c shows the variation of current in B phase. The signal is analyzed by using FFT analysis.

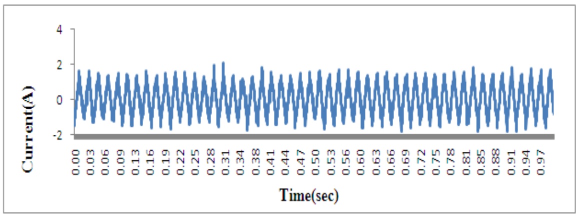

Fig .5.c.Variation of B phase current under B phase turn fault on 3-phase induction motor.

The calculated %THD and product of 3rd and 5th harmonics for various instants are tabulated as follows. By observing the tables IV both the %THD and product of 3rd and 5th harmonics are greater than the threshold1 (18) and threshold2 (38) at the fault instant.

Table-IV: FFT analysis of R phase Y Phase, B Phase currents for a 3-phase induction motor in B phase turn fault

Phases	Start time	%3rd Harmonic w.r.t. fundamental	%5th Harmonic w.r.t. fundamental	%THD w.r.t. fundamental	Fundamental	Multiplication(3rd harmonic*5th harmonic)
R-Phase	0.1	0.61	8.15	20.02	1.08	4.9715
	0.2	2.41	8.55	18.58	1.081	20.606
	0.3	2	5.94	15.39	1.101	11.88
	0.34	**1.84**	**6.84**	**18.63**	**1.075**	**12.586**
	0.4	2.72	3.61	11.6	1.111	9.8192
	0.5	2.66	4.9	13.98	1.005	13.034
Y-Phase	0.1	2.59	5.61	14.11	1.003	14.53
	0.2	1.32	7.5	17.07	1.024	9.9
	0.3	0.45	6.78	13.11	1.028	3.051
	0.34	**1.32**	**5.67**	**13.24**	**0.988**	**7.4844**
	0.4	4.54	5.8	16.63	0.971	26.332
	0.5	2.14	5.82	12.54	1.164	12.455
B-Phase	0.1	3.45	1.48	16.65	1.018	5.106
	0.2	1.58	5.86	18.83	0.938	9.2588
	0.3	2.7	6.89	18.03	1.017	18.603
	0.34	**6.37**	**9.29**	**20.42**	**1.032**	**59.177**
	0.4	3.37	5.21	19.35	0.9592	17.558
	0.5	6.29	8.53	16.8	1.098	53.654

From the above analysis it is clear that the FFT analysis is used to detect the fault, but this analysis will not give the exact location of the turn fault. The above problem can be overcome by using Wavelet analysis. The Wavelet analysis determines the exact location of the fault.

B.Faulty phase detection by using Wavelet analysis based on Energy calculations of the current signals

The current signals are captured by using power network analyzer (DIP8000) with a sampling frequency of 5.3 KHz. These signals are analyzed by using Bior3.3 mother wavelet to obtain the detailed and 5th level coefficients. The detection of faulty phase can be analyzed by comparing the energy value of 5th level detail coefficients of three phase stator currents are compared with a predefined threshold3 to identify the faulty phase.

Energy calculation for healthy condition

Normal three phase currents

The captured current signals are analyzed by Wavelet analysis the three phase normal currents are shown in Fig.5.d.

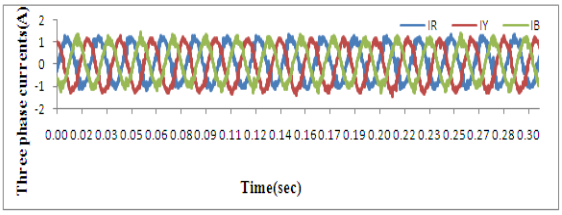

Fig.5.d. Normal three phase currents of 3-ph induction motor

The captured three phase normal currents are shown in Fig.5.d. The energy value of 5th level detail coefficients of three phase stator currents are tabulated as follows.

Table-V: Energy value of 5th level detail coefficients of 3-ph induction motor under healthy condition

Level	Detailed coefficient of current I_R	Detailed coefficient of current I_Y	Detailed coefficient of current I_B
1	0.3385	0.1205	0.1425
2	0.7744	0.2356	0.3164
3	0.8999	0.3167	0.371
4	0.7476	0.3624	0.3248
5	0.7052	0.5128	0.4712

Energy calculations for turn fault

Turn fault in R phase, Y- Phase, B Phase

The turn fault is creating in R phase, Y Phase, B phase with 6 turns from the neutral point. The R,Y,B phases captured current signals of a three phase induction motor in R,Y,B phases faults are analyzed by using wavelet analysis.

Table-VI: Energy value of 5th level detail coefficients of 3-ph induction motor under turn fault in R, Y, and B phases.

Phase	Level	Detailed coefficient of current I_R	Detailed coefficient of current I_Y	Detailed coefficient of current I_B
R-Phase	1	0.39188	0.10941	0.18469
	2	0.73594	0.19081	0.39981
	3	1.33733	0.15649	0.94404
	4	0.72535	0.30005	0.59213
	5	1.38575	0.62567	1.01681
Y-Phase	1	0.39019	0.30984	0.60927
	2	0.71082	0.42794	1.13787
	3	0.50494	0.34539	0.87995
	4	0.88444	0.47255	0.68431
	5	0.99209	1.20649	0.90829
B-Phase	1	0.1532	0.13056	0.28298
	2	1.12369	0.49514	0.60257
	3	1.21331	0.71127	0.91216
	4	0.71403	1.00412	1.07481
	5	0.28842	0.78632	1.48004

From the above analysis the energy value of 5th level detailed coefficients of three phase currents are used to identify the faulty phase.

C.Wavelet analysis for detection and identification of turn faults based on Sum of the absolute values of the detailed coefficient d1 of three phase voltages

The three phase stator voltage (from stator input terminal to tapping point of the stator winding) and current signals are captured by using power network analyzer (DIP8000) with a sampling frequency of 5.3 KHz. These signals are analyzed by using Bior3.3 mother wavelet to obtain the detailed and 5th level coefficients. The detection of fault can be analyzed by comparing the sum of absolute value of detailed level coefficients of three phase stator voltages with a predefined threshold4(1.09).

Wavelet analysis for Healthy condition

The captured three phase normal voltages are shown in Fig.6.a.

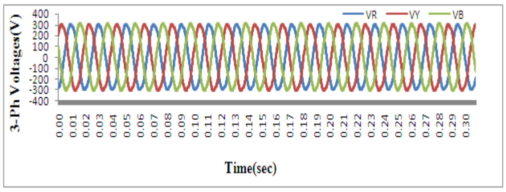

Fig.6.a. Three phase normal voltages of 3-ph induction motor

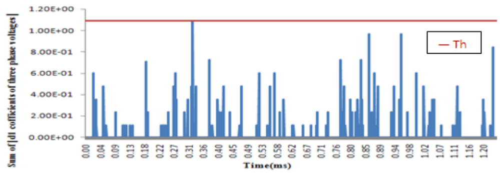

Fig.6.b.Sum of the absolute value of the detailed coefficient d1 of three phase voltages

The fig.6.b. Shows that the variation in sum of absolute magnitude of detailed level coefficient of three phase voltages, which is less than the threshold4 (1.09) because motor is under normal condition.

Fault detection using Wavelet transform

Turn fault in R phase:

The turn fault is creating in R phase with 6turns from the neutral point. The three phase captured voltage signals of a three phase induction motor in R phase fault is shown in Figure 6.c.

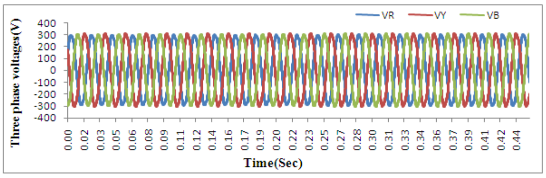

Fig.6.c. Variation of 3-ph voltages under R phase turn fault on 3-phase induction motor.

The voltage signals are analyzed by using bior3.3 mother Wavelet transform the Sum of absolute magnitude of detailed coefficient d1 of 3-ph voltages under R phase turn fault shown in figure.6.d.

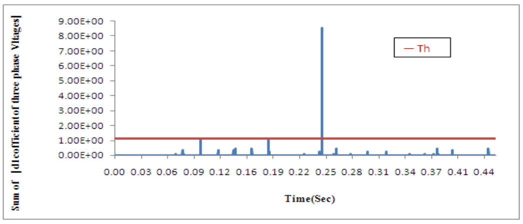

Fig.6.d. Sum of absolute magnitude of detailed coefficient d1 of 3-ph voltages under R phase turn fault

The above fig. 6.d shows that the variation in sum of absolute values of detailed level coefficient of three phase voltages, which is greater than the threshold4(1.09) the threshold value is shown in above fig.6.d with red line. Thus the fault is detected.

Turn fault in Y phase:

The turn fault is creating in Y phase with 6turns from the neutral point. The three phase captured voltage signals of a three phase induction motor in Y phase fault is shown in Fig.6.e.

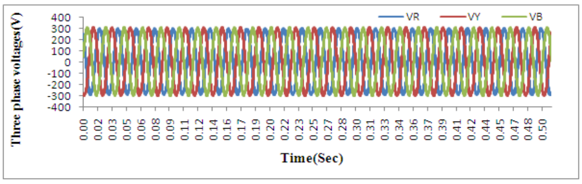

Fig.6.e.Variation of 3-ph voltages under Y phase turn fault on 3-phase induction motor.

The voltage signals are analyzed by using bior3.3 mother Wavelet transform the Sum of absolute magnitude of detailed coefficient d1 of 3-ph voltages under Y phase turn fault shown in figure.6.f.

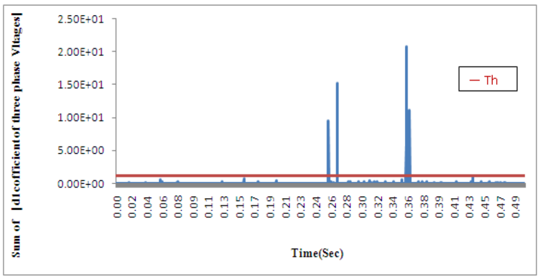

Fig.6.f.Sum of absolute magnitude of detailed coefficient d1 of three phase voltages

Sum of absolute magnitude of detailed coefficient d1 of three phase three phase fault voltages is shown in fig.6.f.the threshold value is shown in above fig.6.f with red line. This Threshold value is greater than the normal threshold4 value.

Turn fault in B phase:

The turn fault is creating in B phase with 6turns from the neutral point. The three phase captured voltage signals of a three phase induction motor in B phase fault is shown in Fig.6.g.

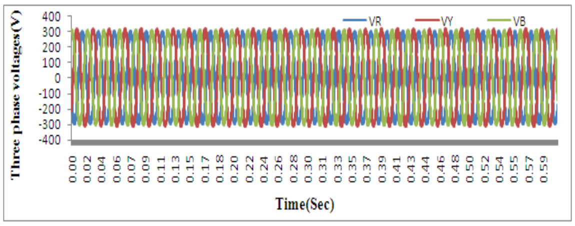

Fig.6.g.Variation of 3-ph voltages under B phase turn fault on3-phase induction motor.

The voltage signals are analyzed by using bior3.3 mother Wavelet transform

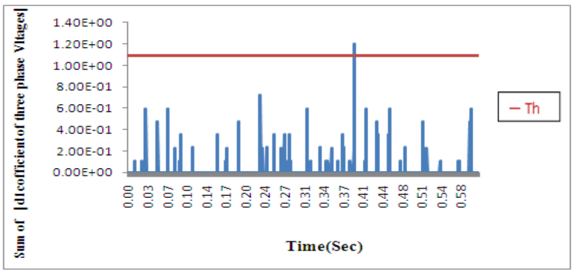

Fig.6.h.Sum of absolute magnitude of detailed coefficient d1 of three phase voltages under B phase turn fault

Sum of absolute magnitude of detailed coefficient d1 of three phase three phase fault voltages is shown in fig.6.h.the threshold value is shown in above fig.6.h. With red line. This threshold value is greater than the normal threshold4 value.

VI. CONCLUSION

Wavelet decomposition is a superior method of signal analysis in time varying situations due to spatial data retention. Analysis using wavelets produces both frequency and spatial information providing a robust solution for motor fault detection. Damage of stator insulation is the most frequent failure in electrical motor. In this paper two techniques are considered which are FFT and Wavelet transform. The voltage and current signals are captured by using DIP8000 and analyzed by using Wavelet analysis and FFT analysis. When the captured voltage and current signals are analyzed by using FFT analysis, FFT analysis is used to detect the fault, but this analysis will not gives the exact location of the fault. This problem is overcome by using wavelet analysis. When the captured voltage signals are analyzed by Wavelet transform, the energy value of 5th level detailed coefficients of three phase currents are used to identify the faulty phase. The sum of absolute values of three phase d1coefficients is used to detect fault and fault instant. Thus the stators in terturn faults are effectively detected and identified the fault location by using wavelet analysis. Hence the Wavelet Transform method is efficient and reliable for detecting and identifying the stator interturn faults.

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