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Fault Identification of BLDC Motor Using Signal Processing Techniques−A Review

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Abstract: ***Now a days the Motor Current Signature Analysis (MCSA) is considered as the most popular fault detection method because it can easily detect the common machine fault such as Rotor faults, Stator faults, Inverter faults , Dynamic eccentricity, Short winding, Bearing & gearbox failure.The present paper discusses the fundamentals of Motor Current Signature Analysis (MCSA) and condition monitoring of the brushless DC motor using MCSA with different signal processing techniques such as FFT, STFT, wavelet transform(WT). Motor current signature analysis (MCSA) can effectively detect abnormal operating conditions in BLDC motor.***

Index Terms: BLDC Motor, MCSA, FFT and WT

I. INTRODUCTION

Brush Less DC motors or electronically commutated motors are electric motors powered by direct current electricity and having electronically commutation systems, rather than mechanical commutators and brushes. A BLDC motor has rotating permanent magnets and a fixed armature. An electronic controller replaces the brush/ commutator assembly of brushed DC motor which continually switches the phase to windings to keep the motor turning. A BLDC motor has trapezoidal waveform back-EMF with 120 electrical- degree wide conducting period .The current is rectangular in shape. At any instant of time during operation, or during one conducting period which is 60 electrical degrees, two of the stator phases are excited as positive and negative terminal while the third phase floats. One of the main features of BLDC motor is that the Back-EMF signals provide information about the rotor position in order to generate commutations patterns and sequence. BLDC machines are being used, often in critical high performance applications. Fault diagnosis and condition monitoring of BLDC machines are assuming a new importance. Early detection of faults and asymmetries could allow preventive maintenance to be performed and provide sufficient time for controlled shutdown of the affected process, thereby reducing the costs of outage time and repairs.

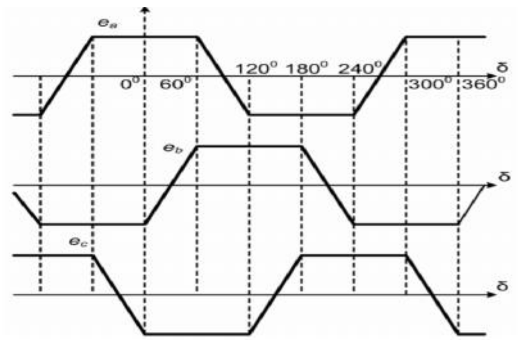

Figure 1: Induced EMF in Three Phases [5]

II. MAJOR FAULTS IN BLDC MOTORS

Major Faults Of BLDC Motors are Broken rotor bar, Static & dynamic air gap irregularities, Dynamic eccentricity, Winding short, Bearing & gearbox failure.

a. Inverter faults: BLDC motors are inverter fed. Many faults can occur in the inverter, such as the loss of one or more of the switches of a phase, the short circuit of a switch, and the opening of one of the lines to the machine.

b. Rotor faults in BLDC machines are eccentricities, damaged rotor magnets, & damaged Hall sensors. All of these rotor faults cause problems such as vibration & noise.

c. Stator Fault is breakdown of the winding insulation. This usually occurs in the region where the end windings enter the stator slots. It is caused by large electrical voltage stresses, electrodynamic forces produced by winding currents, thermal aging from multiple heating & cooling cycles, and mechanical vibrations from internal & external sources.

III. DIAGNOSTIC METHODS TO DETECT FAULTS

Diagnostic Methods to detect faults are Electromagnetic field monitoring, Temperature measurements, RF emission monitoring, Noise & vibration monitoring, Motor Current Signature Analysis (MCSA), AI & NN based techniques. The signal processing tools include DFT, FFT, STFT and Wavelet transform. Artificial intelligence is also used for fault diagnosis .These techniques include the applications of expert systems, genetic algorithm, neural networks and fuzzy logic. Modern techniques are based on application of advanced

DSP tools on stator currents for fault diagnosis i.e. MCSA. Faults can be diagnosed using any one of signal processing techniques. These signal processing techniques cannot be used for diagnosing every type of faults. There is need to compare and analyze various signal processing techniques for diagnosing a particular fault to identify most congruous technique for particular fault.

a. Fault Diagnosis In BLDC Motors

- When the fault happens, the motor can be operated without breakdown, but it is necessary to maintain the motor for continuous working. Several methods have been applied to detect faults. It is important to be able to detect faults while they are still developing. This is called incipient failure detection. Timely warning that can be followed by maintenance can avoid catastrophic failures & costly long down times. The incipient detection of failures also results in a safer operating environment. Faults can occur either in stator, rotor, inverter or in the external systems connected to the motor.
- Vibration monitoring is the most popular choice for condition monitoring but it is preferred for use only in large machines where expensive accelerometers can be afforded.
- Electrical monitoring, which includes current based monitoring, is the most recent of all condition monitoring techniques and is inexpensive as electrical sensors are lower in cost compared to mechanical transducers.
- Condition monitoring is defined as the continuous evaluation of the health of the plant and equipment throughout its service life. It is used to detect various types of faults such as rotor fault, short winding fault, air gap eccentricity fault, bearing fault, load fault etc.
- Current monitoring does not require additional sensors because basic electrical quantities associated with electromechanical plants such as current & voltage are readily measured by tapping into existing voltage & current transformers that are always installed as part of protection system. It is non intrusive & implemented in motor control centre remotely from the motors being monitored.

b. Methods For Current Monitoring

- Methods for current monitoring are MCSA (Motor Current Signature Analysis) & Park Vector approach. MCSA uses the current spectrum of machine for locating characteristic fault frequencies. When a fault is present, the frequency spectrum of the line current becomes different from healthy motor. Such fault modulates air gap & produces rotating frequency harmonics in the self & mutual inductances of machine.

IV. SIGNAL PROCESSING TECHNIQUES

Different algorithms are proposed to track & detect the faults operating under different load conditions: Fast Fourier Transform, Short time Fourier Transform, Wavelet Transform, Gabor Transform, Park's Vector approach, Wigner Ville distribution, Short time Fourier Transform and MCSA. The condition monitoring techniques utilised the spectral analysis of motor current or voltage.

A. Fast Fourier Transform (FFT). FFT is employed for the extraction of frequency contents in signal, in order to detect stator and rotor faults in BLDC motor. A fault in motor by FFT can be detected easily in comparison to time domain analysis. FFT is simply a computationally efficient way to calculate the Discrete Fourier Transform (DFT) which is calculated as

$$X(k) = \frac{1}{n}\sum_{N=0}^{N-1} x(n)e^{-j\frac{2\pi kn}{N}} \qquad K=0,1,2..N-1 \quad (1)$$

Where X(k) − Fourier transform of the signal

k − frequency index

n − time index

N— total length of the signal

The specific characteristic fault frequency can be easily & accurately diagnosed using FFT with the loss of time information.

B. Short Time Fourier Transform (STFT)

STFT is used to analyse signal in both time and frequency domain. In this, original signal is divided into small segments and each segment is multiplied with shifted window function of a chosen width in order to produce short stationary signals. This process is defined by :

$$X(\tau, w) = \int_{-\infty}^{+\infty} i(t)W(t-\tau)e^{-jwt}\,dt \qquad (2)$$

$X(\tau, w)$− short time Fourier transform of the current signal i(t)
w = 2πf, where f is the frequency of the signal
W(t-τ) − window function
t − time
τ − delay parameter

The drawback of this technique is that particular size for time window, is same for all frequencies. But many signals require variable window size.

c. Wavelet analysis

The wavelet analysis confines signals information in the time frequency plane and makes it suitable for the analysis of non- stationary signals. It is a substitute to the STFT analysis. The general Wavelet transform of a signal is defined by:

$$WT(a, \tau) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} i(t)\varphi_{a,\tau}\left(\frac{t-\tau}{a}\right)dt \qquad (3)$$

Where WT – wavelet transform of the current signal, i (t)
$\varphi_{a,\tau}$ – wavelet function
a and τ – scaling and translation respectively
*denotes the complex conjugate of the function

Wavelet analysis allows use of both long time intervals requiring more precise low frequency information and short time intervals requiring high frequency information. But this analysis has disadvantage of using large no of scales for calculations.

c. Park's Vector Approach

The best representation of Park's vector is circular locus cantered at the origin of the I_d and I_q coordinate:

$$I_d = \sqrt{\frac{2}{3}}\, i_a - \frac{1}{\sqrt{6}}\, i_b - \frac{1}{\sqrt{6}}\, i_c \qquad (4)$$

$$I_q = \frac{1}{\sqrt{2}}\, i_b - \frac{1}{\sqrt{2}}\, i_c \qquad (5)$$

In the case of healthy motor, three phase current leads to the Park's vector with the following components:

$$I_d = \frac{\sqrt{6}}{2}\, i_m \sin(wt) \qquad (6)$$

$$I_q = \frac{\sqrt{6}}{2}\, i_m \sin(wt-\pi/2) \qquad (7)$$

Under faulty conditions, I_d and I_q change and shape of pattern of faulty motor is different from healthy motor. In condition monitoring, the Park's vector approach can be used for detection of various faults.

V. DISCUSSIONS

MCSA is condition monitoring technique which uses the current spectrum of a machine for locating characteristic frequencies indifferent from characteristic frequencies of healthy machine. The signal processing can be carried out in either time domain or frequency domain or time – frequency domain. When a signal is analysed in frequency domain, it often provides valuable information of the process operation. The faults can be diagnosed by comparing spectrum of healthy motor with spectrum of faulty motor.

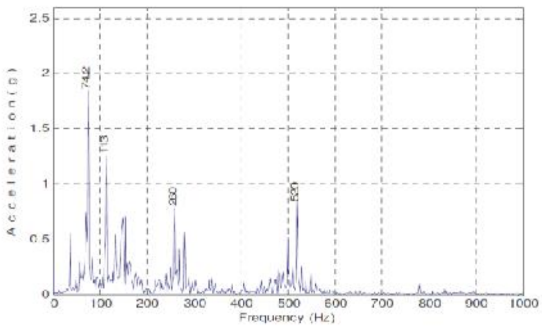

Figure 2: Motor Current Spectrum of a Healthy [6] Motor

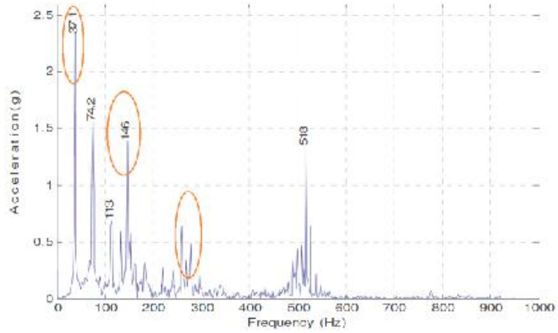

Figure 3: Motor current Spectrum with two broken rotor bars [6]

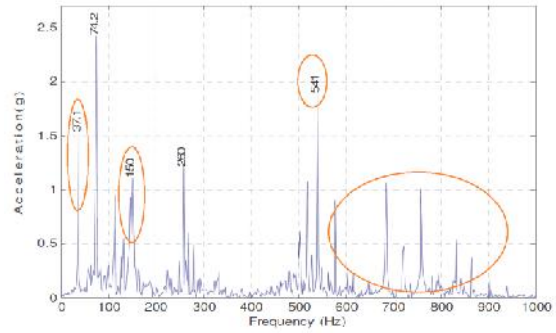

Figure 4: Motor current Spectrum with faulty bearing [6]

VI. MCSA DIAGNOSIS APPROACH

MCSA is an online condition monitoring technique for diagnosis of the faults in motor and thus avoids complete failure of the motor. In MCSA method, the basic procedure involves phase current measurement with the help of Current Transformer after then, signal is fed into signal conditioning unit which converts the measured current into voltage and also provides proper filtering. Finally, output from the signal conditioning unit is connected to the data collector/analyser for detection of fault and resulting output signal is sent to computer for analysis.

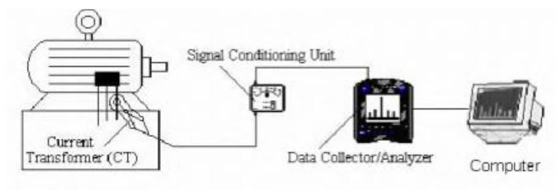

Figure 5: Basic On Line Current Monitoring System

VII. LITERATURE REVIEW

Numerous applications of using MCSA in equipment health monitoring have been published among the nuclear-generation, industrial and defence industries.

Stator current is monitored for diagnosis of different faults of induction motors and BLDC motors.

A. Induction Motors

1. Neelam Mehala [1], has worked on condition monitoring and fault diagnosis of induction motor using MCSA. This study presented comparative analysis of techniques applied for detection of motor faults.
2. Randy R. Schoen [2] et. al. has addressed the application of motor current signature analysis for the detection of rolling-element bearing damage in induction machines. This study had investigated the efficacy of current monitoring for bearing fault detection by correlating the relationship between vibration and current frequencies caused by incipient bearing failures. Randy R. Schoen presented a method for on-line detection of incipient induction motor failures which requires no user interpretation of the motor current signature, even in the presence of unknown load and line conditions.
3. Hamid A. Toliyat et. al. [3] developed a new induction machine model for studying static rotor eccentricity.
4. M.E.H. Benbouzid and H. Nejjari et. al.[4] stated that preventive maintenance of electric drive systems with induction motors involves monitoring of their operation for detection of abnormal electrical and mechanical conditions indicating failure of the system.

B. BLDC Motors

1. Time frequency representations has been presented as a solution for the diagnosis of rotor faults in BLDC motors operating under constantly changing load & speed conditions. Four Time-Frequency Representations (TFR) are considered: STFT, WVD, CWD and ZAM. TFR are implemented in real time & their load computations are compared in order to study their suitability for implementation in commercial system.

2. Wigner Ville family of time frequency distributions has been presented as an alternative to STFT & Wavelets for diagnostics of rotor faults in a BLDC motor. Wigner Ville distributions possess better frequency resolution than STFT & Wavelets.

3. Wavelet transform of stator current signal has been proposed for detecting dynamic eccentricity in BLDC motors operating under rapidly varying speed & load conditions by S.Rajgopalan [5].

4. Faults in aerospace & transportation industries (non-stationary conditions) has been analyzed. Windowed Fourier Ridges is proposed for detection of rotor faults.

5.Hyung-Woo Lee [6] presented a winding function based method to analyze the inter turn fault in stator windings of a BLDC motor. The winding functions & inductance of stator windings are explained in detail & information simulation results based on winding function theory is provided to analyze current abnormalities & torque pulsation under turn to turn short.

6.Awadallah, M.A. [7] studied faulty performance of PM BLDC motor drives under open switch conditions. Wavelet transform was used to extract diagnostic indices from the current waveform of motor dc link. An intelligent agent based on adaptive neuro-fuzzy interference systems (ANFIS) was developed to automate the fault identification & location process. ANFIS was trained offline using simulation results under various healthy & faulty conditions obtained from a lumped parameter and network model. ANFIS testing shows that system could not only detect the open switch fault but also identify faulty switch.

7. Awadallah, M.A. [7] designed a model based diagnostic system for stator winding inter turn faults of PM BLDC motor drives. A transient model of drive system is set up & run under different healthy & faulty conditions. The steady supply current was selected as diagnostic signal to compare the healthy operation to faulty operation under different loads. The supply current signal was transformed to frequency domain using DFT. Appropriate diagnostic indices are extracted from supply current spectrum to differentiate between healthy & different faulty conditions.

VIII. CONCLUSION

BLDC motors are used in industries and home appliances. It is necessary to develop new conditioning methods for BLDC motor so that breakdown time can be reduced to its minimum level. During research, new method(s) will be developed to monitor & diagnose the faults of BLDC motor which will diagnose the faults in more reliable and timely manner resulting into significant reduction in cost of preventive maintenance.

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