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Wavelet Transform Based Fault Diagnosis of BLDC Motor Drive

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Abstract

Due to the development in science and technology tremendous improvement in solid state devices and circuits, so we need to reduce the complexity of control circuits. The Brushless DC Motor (BLDCM) has simple construction, stator consists of winding and rotor consists of permanent magnet. It has higher efficiency and high speed range. In this paper presents the vibration analysis of single phase open circuit fault conditions and the signals are extracted from the Discrete Wavelet Transform (DWT). The Spartan-6 FPGA processor was implemented due to their high performance of the control applications in recent decades. In this process Sinusoidal Pulse Width Modulation (SPWM) techniques were used to control the speed of BLDC Motor. The experimental analysis is carried out in 3phase, BLDCM drive. The vibration signals are measured by using Accelerometer through Lab VIEW software.

Keywords: *brushless DC motor (BLDCM), vibration analysis, discrete wavelet transform (DWT), Lab VIEW*

1. Introduction

A motor that retains the characteristics of a dc motor it eliminates the commutator and brushes is called a Brushless DC Motor (BLDCM). It has stator and rotor,the stator carries the armature and the rotor carries the permanent magnet, it rotor and armature remains static. BLDCM can in many cases replace conventional DC motors. The function of the commutator is to collection of current from the armature conductor and it converts the alternating current induced in the armature conductors into unidirectional current in the external load circuit. A dc current is passing through the brushes because of commutator and brushes action and unidirectional torque is developed in armature conductor. The BLDC motor with windings in delta configuration gives low torque at low rpm but can give higher ranges of rpm. The configuration gives high torque at low rpm but the motor cannot be operated in higher rpm ranges.

BLDCM having rotor position sensor, it converts the information about the rotor position into a suitable electrical signals, hall effect sensor is used in this motor for sense the rotor position.It having more features like, low maintenance because of no brushes, long life, low inertia, high efficiency. In [8], proposed the wavelet theory for developing a sensorless drive for BLDC motors. Wavelet theory is broadly used in an image processing that enables to analyze non stationary signals in frequency and time domain. Reference [14], discussed the over current protection for Permanent Magnet Brushless DC Motor (PMBLDCM) operating under the different operating conditions at no load to full load operation. The measurement of the instant frequency is a significant feature of the anticipated fault detection algorithm [5]. In [9], proposed the Simulation Modeling of BLDCM drive and harmonic analysis of current, speed and acceleration using Discrete Wavelet Transform Technique. DWT is a useful tool to detect the disturbances of instant time varying signals. In [10] mechanical vibration is directly related to the large torque ripple. Methods of effective voltage vector combinations to reduce the torque ripple and thereby reduce the mechanical vibration.

In this main work is to analysis the vibration signals using DWT, accelerometer is placed in BLDCM drive; it will measure the vibration signals by using Lab VIEW. The NIcDAQ card is used to measure the real time signals like voltage, current and vibration. This paper is considered brief about discrete wavelet transform in section 2, Section 3 discussed the

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LabVIEW. Section 4 discussed the block diagram of BLDCM drive. Section 5 discussed Experimental Result and section 6 is concluding comments.

2. Discrete Wavelet Transform

In continuous wavelet transform (CWT), the mother is dilated and translated continuously over a real continuous number system and it can generate substantial redundant information. The discrete Fourier transform (DFT) is obtained from the Fourier transform by replacing the integral with a finite sum. The discrete wavelet transform (DWT) is obtained from the wavelet transform in the same way. There exists a more subtle way to perform the decomposition using wavelets. These signals A and D are interesting but we get 2000 values instead of the 1000 we had then looking carefully at the computation we may keep only one point out of two in each of the two 2000-length samples to get the complete information The process on the right which includes down sampling, produces DWT coefficients. This is the notion of down sampling. We produce two sequences called cA and cD.To gain a better appreciation of this process let's perform a one-stage discrete wavelet transform of a signal. In this signals will be a pure sinusoid with high-frequency noise added to it. Sample DWT coefficient signal developed block is shown in Figure 1.

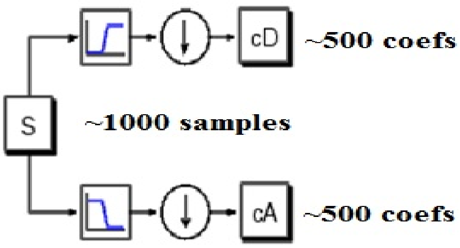

Figure 1. Sample DWT Coefficients Signals

In these signals was generated using MATLAB code needed and the signals were sub divided into lower frequency (cA) and higher frequency (cD).

```
s = sin(20.*linspace(0,pi,1000)) + 0.5.*rand(1,1000);
[cA,cD] = dwt(s,'db2');
```

Here, db2 is the name of the wavelet we want to use for the analysis.

Notice the detail coefficients cD is small and consist mainly of a high-frequency noise, while the approximation coefficients cA contains much less noise than does the original signal.

```
[length (cA) length(cD)]
```

3. Lab VIEW

Lab VIEW (Laboratory Virtual Instrument Engineering Workbench) programs are called virtual instruments because their appearance and operation imitate physical instruments such as multimeters and oscilloscopes. Lab VIEW contains a comprehensive set of tools for displaying, acquiring, analyzing and storing data as well as tools to help you troubleshoot code you write.

Data acquisition is the process of sampling signals that measure real world physical conditions and converting the resulting samples into digital numeric values that can be manipulated by a computer, BLDC motor with vibration sensor using Lab VIEW is shown in the Figure 2.

NI 9234 is analog DAQ which has four channels, 24 bit resolution; it can operate in temperature range from -40.c to 70.c range. The NI 9234 analog input channels are referenced to chassis ground through a 50 Ω resistor. To measure the vibration signals by using this accelerometer and analysis of vibration in different condition. The input signal on each channel is conditioned and buffered then sampled by a 24-bit Delta-Sigma ADC. To minimize ground noise, make sure the chassis ground is connected to earth ground. Each channel has protected from over voltages.

The NI 9227 C Series current input module was designed to measure 5 Arms nominal and up to 14 A peaks on each channel with channel-to-channel isolation.

Figure 2. BLDC motor with vibration sensor using Lab VIEW

4. Block Diagram of BLDCM Drive

The block diagram of BLDC Motor Drive shown in the Figure 3. The 3Φ, 400V, AC supply is fed to Intelligent Power Module (IPM) through auto transformer. It consists of rectifier and inverter circuits. Rectifier is converted AC into DC supply and inverter is converted DC into AC. DC generator was coupled with BLDC shaft, it act as a eddy current load. Hall-effect current and voltage sensors are used to measure the voltage and current signals. The torque is measured by using load cell; it will indicate the torque values in torque indicator. The FPGA controller gives proper commutation to the inverter circuit via buffer IC's. The active filter is connected between rectifier output and inverter input. An accelerometer is mounted on the BLDCM, it was connected through the NI cDAQ card. The real time vibration signals are measured using Lab VIEW software. The whole drive system is controlled by Spartan-6 processor. The Block diagram of BLDCM drive is shown in Figure 3.

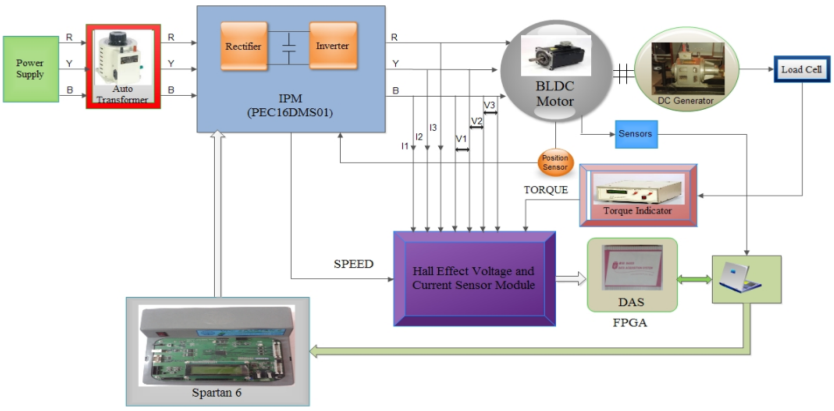

Figure 3. Block Diagram of BLDC Motor Drive

Each phase of voltage and current to be sensed in Hall Effect voltage and current sensor module and speed signals also get in from Intelligent Power Module. Torque indicator is used in this work for indicate the BLDC motor torque when adding load to the motor and fed to

Hall Effect voltage and current sensor module. Data Acquisition System is used to acquire real time current, voltage, speed, torque of the BLDC motor through Hall Effect voltage and current sensor module. Hall sensor is used to senses the rotor position, which is given to FPGA controller. These Spartan-6 FPGA enhanced and combined with advanced process technology deliver more functionality and bandwidth per dollar than was previously possible. The accelerometer is used to perform the measurement of the vibration signals and using current DAQ NI 9227 to measure the current signals by Lab VIEW software. It is placed circumferentially on the BLDC motor body.

5. Experimental Result and Discussion

The experiment setup for BLDC motor drive through SPARTAN-6 FPGA kit and vibration sensor through Lab VIEW is shown in the Figure 4. The development control system is tested on a FPGA based BLDC Motor drive setup in Electrical Drives and Control laboratory at K.S.Rangasamy College of Technology.

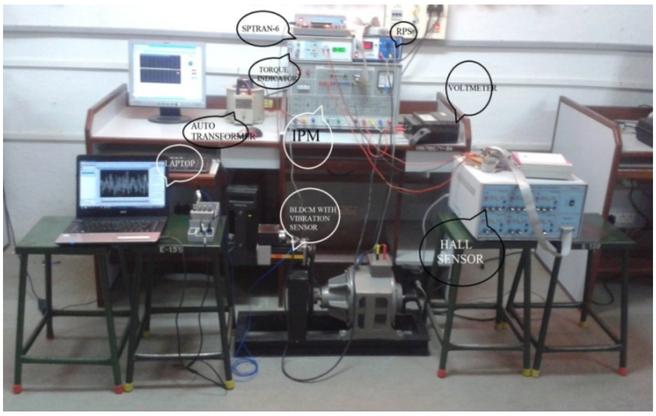

Figure 4. Hardware Setup of BLDC motor

5.1. Time and Frequency Feature of Vibration Signals during Healthy Condition

The discrete wavelet transform features of vibration signals are shown in Figure 5 and Figure 6 shows maximum, minimum, mean and standard deviation signals (SDS) for the healthy phase of vibration of the BLDC motor is taken using the discrete wavelet transforms.

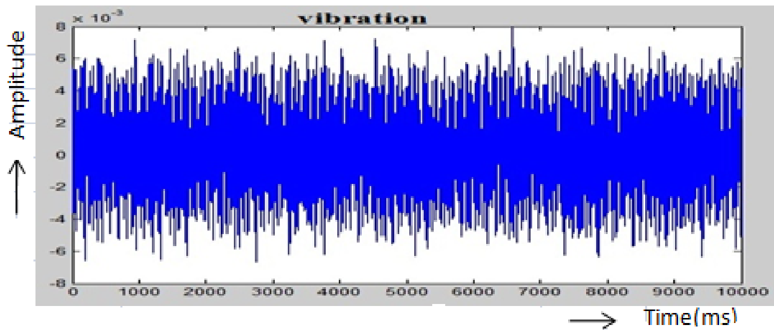

Figure 5. DWT Vibration Signals during Healthy Condition

$$\%DR=std(D2)+std(D3)+std(D4)+std(D5)+std(D6)/std(D1)*100 \quad (1)$$

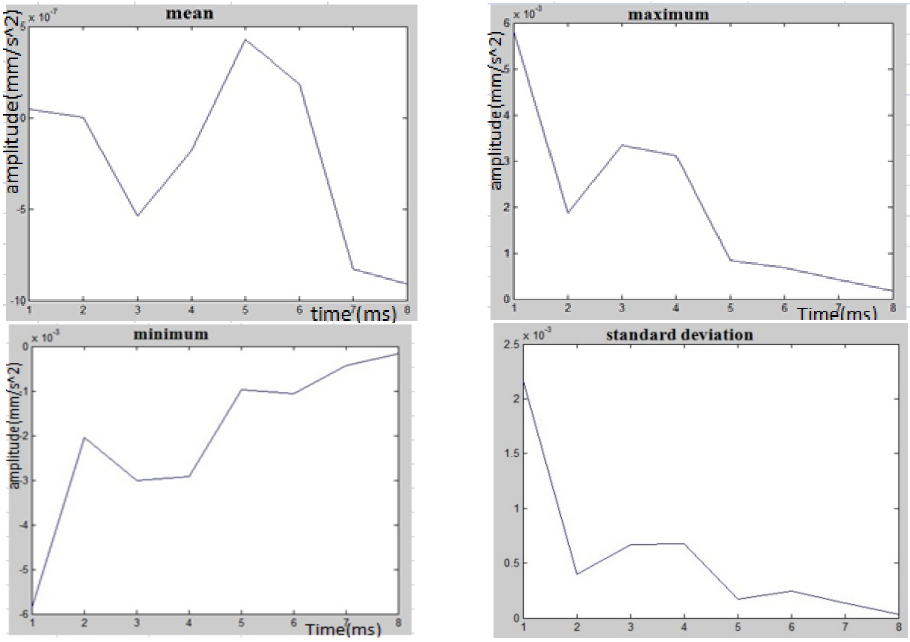

Figure 6. DWT Mean, Maximum, Minimum, SDS of the Healthy Condition

The decomposition value is upto 8 levels and mother wavelet used is “db2” signal. The current value in the first Figure is healthy and the decomposition ratio is about 12.6275. The time and frequency features are extracted in the MATLAB using the mat file program in the command window in which is used find the fault values of the time and frequency of vibration in BLDC motor.

5.2. Time and Frequency Feature during Open Circuit Fault Condition

The extracted time and frequency feature using discrete wavelet transforms during single phase open circuit fault condition is shown in Figure 7. The fault diagnosis vibration, mean, maximum, minimum, standard deviation signals (SDS) for open circuit fault vibration signals of BLDC motor is taken using the discrete wavelet transform shown in Figure 8. The level of decomposition ratio during the open circuit fault is about 34.9682.

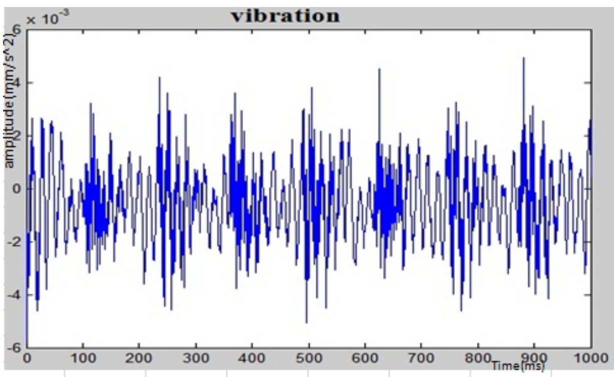

Figure 7. DWT Vibration Signals during Faulty Condition

$$\%DR=std(D2)+std(D3)+std(D4)+std(D5)+std(D6)/std(D1)*100 \quad (2)$$

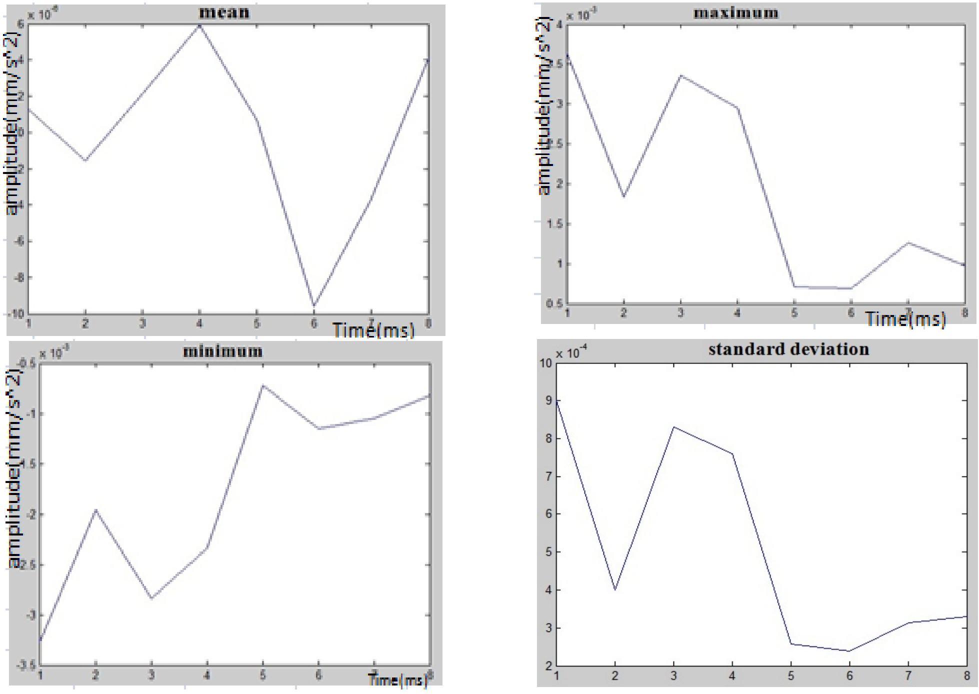

Figure 8. DWT Mean, Maximum, Minimum, SDS of the Faulty Condition

Table 1 gives the details about the extracted features of the BLDC motor vibration for various operating conditions. The mean, minimum, maximum, standard deviation value during the healthy condition and open circuit fault condition are given and it is useful in analyzing the vibration signal which gives the information about fault type and the time of fault.

Table 1. Extracted Features for Different Operating Condition of the BLDC Motor

Data set	Extract features	Wavelet sub band (Hz)							
		D1	D2	D3	D4	D5	D6	D7	D8
Healthy Condition	Maximum	0.0058	0.0019	0.0033	0.0031	8.3e-04	5.7e-04	4.1e-04	1.7e-04
	Minimum	-0.006	-0.002	-0.003	-0.003	-9.7e-04	-0.0011	-4.4e-04	-1.6e-04
	Mean	4.5e-08	1.1e-09	-5.4e-07	-1.8e-07	4.3e-07	1.9e-07	-8.3e-07	-9.1e-07
	Standard Deviation	0.0022	4e-04	5.7e-04	5.8e-04	1.8e-04	2.5e-04	1.4e-04	3.4e-05
	Decomposition Ratio	12.6277							
Open Circuit Fault Condition	Maximum	0.0036	0.0018	0.0033	0.0029	5.1e-04	5.9e-04	0.0012	9.8e-04
	Minimum	-0.0032	-0.0019	-0.0028	-0.0023	-5.3e-04	-0.0012	-0.001	-8.2e-04
	Mean	1.3e-06	-1.6e-06	2.2e-06	5.9e-06	5.9e-07	-9.6e-06	-3.6e-06	4.1e-06
	Standard Deviation	8.9e-04	3.9e-04	8.3e-04	5.6e-04	2.6e-04	2.4e-04	3.1e-04	3.3e-04
	Decomposition Ratio	34.9682							

The frequency sub band value gives the information about the higher order frequency, fundamental frequency and the lower order frequency values in which the fundamental frequency lies at the sixth level of decomposition.

6. Conclusion

In this paper reviewed single phase open circuit fault condition vibration analysis of BLDC Motor and extract the signal features from the Discrete Wavelet Transform (DWT). FPGAs based on speed control of this system reveal the use of reliable and lower cost controller. The speed of BLDCM is controlled by duty cycle and frequency of the simple Pulse Width Modulation (PWM) techniques. In this analysis sinusoidal PWM control techniques is employed. The proposed system is analyzed the vibration in fault condition and healthy condition with speed of 3000rpm. The results are obtained by using Lab VIEW analysis of both time domain and frequency domain. The analyzed signals are extracted in DWT using MATLAB, under the faulty condition vibration to be diagnosis by extracting signal features by wavelet transform to be analyzed in values of maximum, minimum, mean and standard deviation. In these investigations we have to find the distortion ration of both healthy condition (12.6277) and faulty condition (34.9682).

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