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Broken Rotor Bar Diagnosis via Monitoring Current Spectrum Analysis in Micro Wind Turbine Induction Motor

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Abstract:

Micro wind turbines are generally used in remote locations, and it is difficult and expensive to repair faults which forced the need for condition monitoring and fault diagnosis which has not been used extensively for small turbines. The possibility of utilizing Fast Fourier Transform (FFT) for diagnosis the faults of broken rotor bar in squirrel cage induction motor of a micro wind turbine was investigated. Monitoring and analysis the current spectrum can be effective for diagnosis the early stage of faults and avoid complete catastrophic failure in the motor by powerful virtual instruments and LabVIEW software as an integral part of this instrumentation. Combination advanced signal processing technique with computerized signal processing and high accuracy data acquisition offer a new approach for monitoring spectral analysis of rotor bar fault in an induction motor. The theoretical rule of this method was proved by laboratory experiment.

Keywords: Wind Turbine WT, broken rotor bar, FFT, fault diagnosis.

تشخيص شريط الدوار المكسور بواسطة مراقبة التحليل الطيفي للتيار في محرك حثي لتوربين رياح صغير

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الخلاصة

عادة ما تستخدم توربينات الرياح الصغرى في المواقع النائية، ومن الصعب والمكلف إصلاح الأعطال مما يجبر الحاجة إلى مراقبة الحالة وتشخيص الخلل والتي لم تستخدم على نطاق واسع لتوربينات صغيرة. في هذا البحث، تم التحقيق في إمكانية استخدام تحويل فورييه السريع لتشخيص خلل شريط الدوار المكسور في قفص سنجابي لمحرك حثي لتوربين رياح صغير. مراقبة التحليل الطيفي للتيار يمكن أن تكون فعالة لتشخيص المرحلة المبكره من الخلل وتجنب الفشل الكارثي الكامل في المحرك من قبل الأجهزة الافتراضيه الفعاله وبرمجيات (LabVIEW) كجزء تكاملي للاجهزه الافتراضيه . الجمع بين تقنية معالجة الإشارات المتقدمة مع معالجة الإشارات الحاسوبية ودقة استحصال البيانات تقدم نهج جديد لمراقبة التحليل الطيفي لخلل الشريط الدوار في المحرك الحثي. تم إثبات القاعدة النظرية لهذه الطريقة من خلال التجربة المختبرية.

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1. Introduction

Wind turbine (WT) is an electromechanical system. Faults can be occurring often in anywhere in this system. [1,2]. There is a need, therefore, for early warning by using condition monitoring which can be a very important solution for detecting incipient faults and preventing unscheduled downtime costs and troublesome outage of electromechanical systems [3]. Broken Rotor Bars (BRB) is one of the numbers of wind turbine failures due to the gearbox and generator subassemblies has been shown to be significant and can be a serious problem with certain induction motors due to laborious duty cycles. BRB represent serious secondary effects lead to motor failure because of hitting the rotor bar to the end winding or stator core of a high voltage motor at a high velocity [4]. This can cause serious mechanical damage to the insulation and a consequential winding failure may follow, resulting in a costly repair and lost production. Also, it can be caused by thermal, magnetic, environmental or mechanical stresses, residual stresses due to manufacturing problems [5]. Rotor failures now account for around 5%-10% of total induction motor failures [6]. This paper focuses on BRB faults in Micro Wind Turbine (MWT), which have a size of less than 3 kW and we will present an analysis of the compatibility of advanced signal processing technique with computerized data acquisition and processing by the use of spectral analysis.

2. Motor Current Spectrum Analysis

Motor Current Spectrum Analysis **(**MCSA) has simply defined the process by which motor current readings are recorded and analyzed in the frequency domain. Since 1985 it has been around and proven itself well over the years in locating rotor faults and air gap problems in motors [7].The choice of MCSA method because of it can be classified as the most promising fault detection method nowadays and of its ruggedness and low-cost. The electrical signal that has current components can be sensed by MCSA. Current components direct by-product of unique rotating flux components caused by faults such as BRB. The success of MCSA depends upon locating by spectrum analysis with specific harmonic components caused by faults and capable of using it online. An idealized current spectrum is shown in Figure-1.

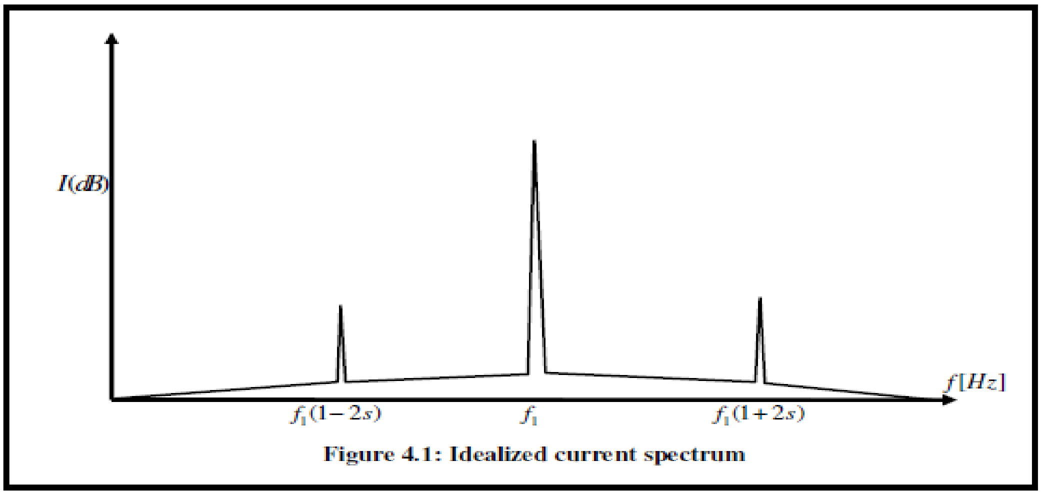

Figure 1- idealized current spectrum [8].

The two slip frequency sidebands due to BRB near the main harmonic can be clearly observed. Usually, a decibel (dB) versus frequency spectrum is used for detecting the unique current signature pattern that is characteristic of different faults [9]. The rotating magnetic field induces rotor voltage and currents at slip frequency, and this produces an effective three phase magnetic field rotating at slip frequency with regard to the rotor. Under the perfect balanced condition, a forwarding rotating magnetic field is produced in induction motor which rotates at synchronous speed.

$$n_1 = 120 \frac{f_1}{p} \quad \text{...(1)}$$

Where

f_1; is the supply frequency

p is the pole.
The slip is the measure of the slipping back of the rotor regarding the rotating field.

$$slip\ (s) = \frac{(n_1 - n)}{n_1} \qquad (2)$$

Where
n is speed of induction motor. The slip speed is the actual difference in between the speed of the rotating magnetic field and the actual speed of the rotor.

$$n_2 = n_1 - n = sn_1 \qquad (3)$$

Putting the value of $n_2 = sn_1$ in eq. 2, we get

$$slip\ (s) = \frac{n_2}{n_1} \qquad (4)$$

Thus,

$$n = n_1(1 - s) \qquad (5)$$

The backward rotating magnetic field speed produced by the rotor due to broken bars and with respect to the rotor is

$$n_b = n - n_2 \qquad (6)$$

$$n_b = n(1 - s) - s.n_1 \qquad (7)$$

$$n_b = n_1 - n_1.s - s.n_1 = n_1 - 2n_1.s \qquad (8)$$

$$n_b = n_1(1 - 2s) \qquad (9)$$

It may be expressed in terms of frequency

$$f_b = f_1.(1 - 2s) \qquad (10)$$

Therefore, twice slip frequency side bands occur at $\mp 2sf_1$, both side of the supply frequency

$$f_b = (1 \mp 2s)f_1 \qquad (11)$$

The lower sideband and upper side bands are specifically due to the broken bar and consequent speed oscillation.

$$f_b = (1 \mp 2ks)f_1 \qquad (12)$$

Where:
$k = 1,2,3 \ldots ..$

Rotor bar analysis fault can be monitored by investigating the compatibility of advanced signal processing technique with computerized data acquisition and processing by the use of spectral analysis [10]. Fast Fourier Transform (FFT) can be used for diagnosis of rotor bar fault [11]. Spectral estimation techniques are widely adopted in machine diagnosis.

3. Experimental Setup

A variable speed controller N50 Hyundai was used to regulate the variable-speed of rotation. One bar broken was created, in order to monitor the output signal and lead to diagnosis the defect in an induction motor. A PC user control interface programmed using LabVIEW software developed for monitoring. National Instruments developed LabVIEW software for the first time in the year 1986 for the Apple Macintosh Company. It was conceptualized as a programming environment for hardware control. The introduction of an interface between the Personnel Computer and the instrument which is to be controlled by software was the main aim. The graphical user interface, which is used to simulate the controlled instrument on the computer, monitors itself with the help of LabVIEW software. LabVIEW software is used to analyze the signals. DAQ NI USB 6205 is used to acquire the current samples from the motor under different loads. The tachometer was used to measure the speed of the motor as shown in Figure- 2.

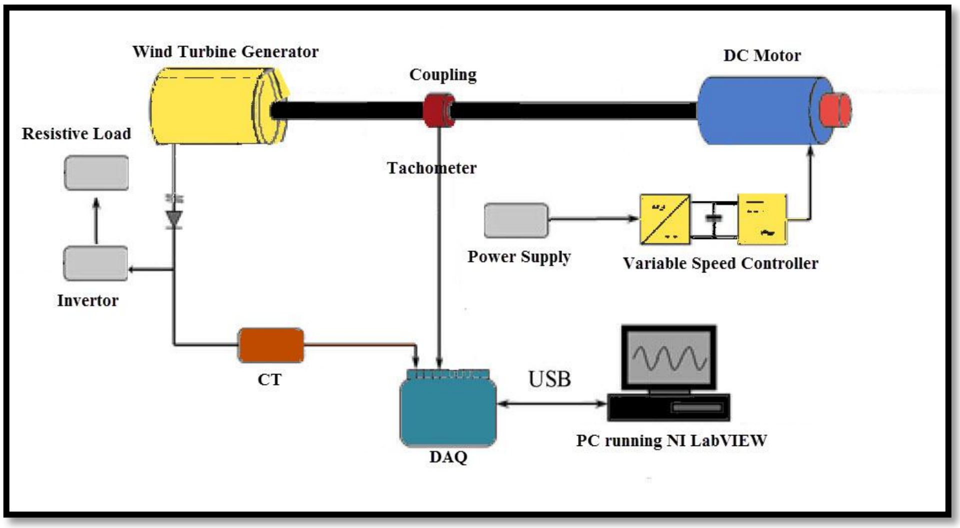

Figure 2- Wind turbine condition monitoring test rig. Schematic presentation of the test rig.

In order to diagnose the fault of induction motor with high accuracy, a modern laboratory test bench was built and setup by authors as shown in Figure- 3.

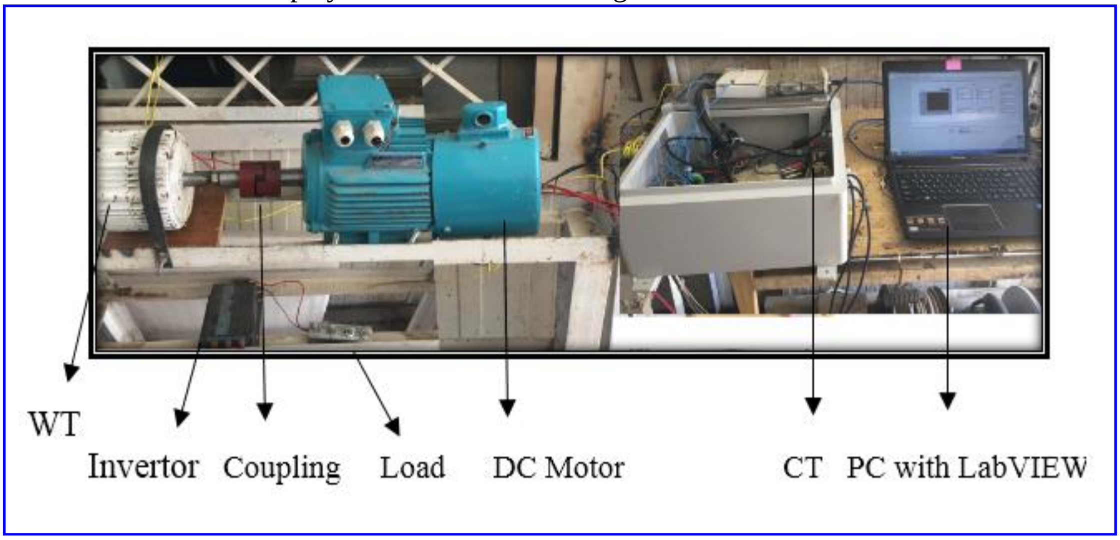

Figure 3- illustrates the test bench was used in the experiment.

It consists of an MWT which has a 3 phase squirrel cage industrial induction motor coupled with DC motor, Current Transducer (CT), Variable speed controller, DAQ NI USB 6205, PC with LabVIEW software. The characteristics of WT induction motor shown in Table- 1.

Table 1- parameters of experimental induction motor

Power	No. of phase	No. of pole pairs	No. of rotor slots
0.4 hp	3	4	36

In the designed system, DAQ was used to acquire the current signal from the WT generator operating under various load condition. No. of samples, frequency resolution, a physical channel, and scan rate were determined. The current signal was processed by FFT based power spectrum. Figure- 4 illustrates the block diagram for obtaining the power spectrum using programming in LabVIEW.

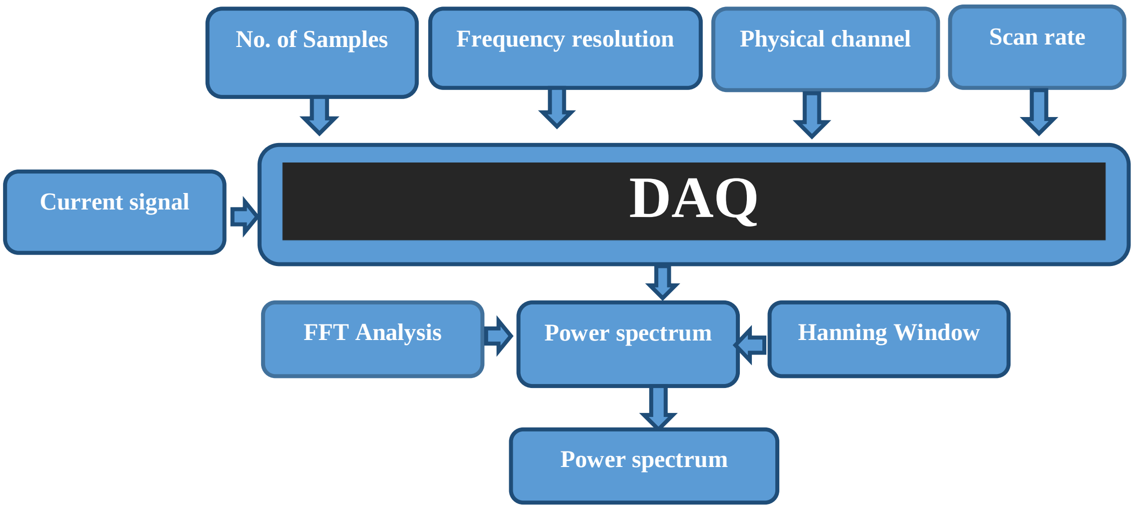

Figure 4- block diagram for obtaining power spectrum using Lab VIEW programming.

4. Observation and discussion

The WT induction motor was tested for healthy working condition and current measurements were done for one BRB under the various loading condition (no load, half load, and full load). The results recorded and observed for the healthy induction motor for no load and those having rotor faults were compared, especially looking for the sideband components having the frequencies given by equations 11 and 12. The rotor faults were created by drilling into the rotor. The power spectrum of the measured phase currents was plotted. The power spectrum of the measured current at healthy is shown in Figure-5. Frequency range is selected from 0 Hz to 100 Hz, as it contains the fundamental frequency and sideband frequencies.

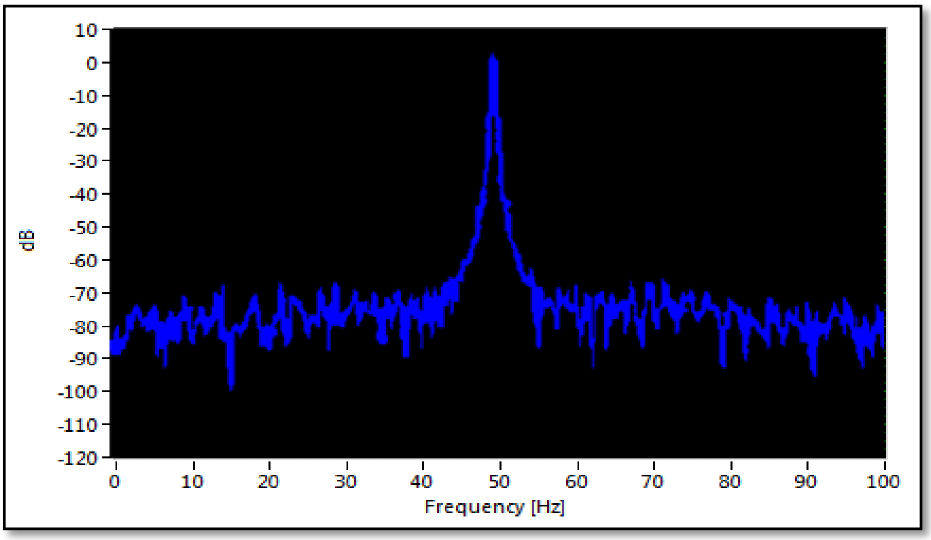

Figure 5- power spectrum of healthy motor at healthy condition.

Figure- 6 shows the power spectrum obtained from the current signal for one BRB at no load condition.

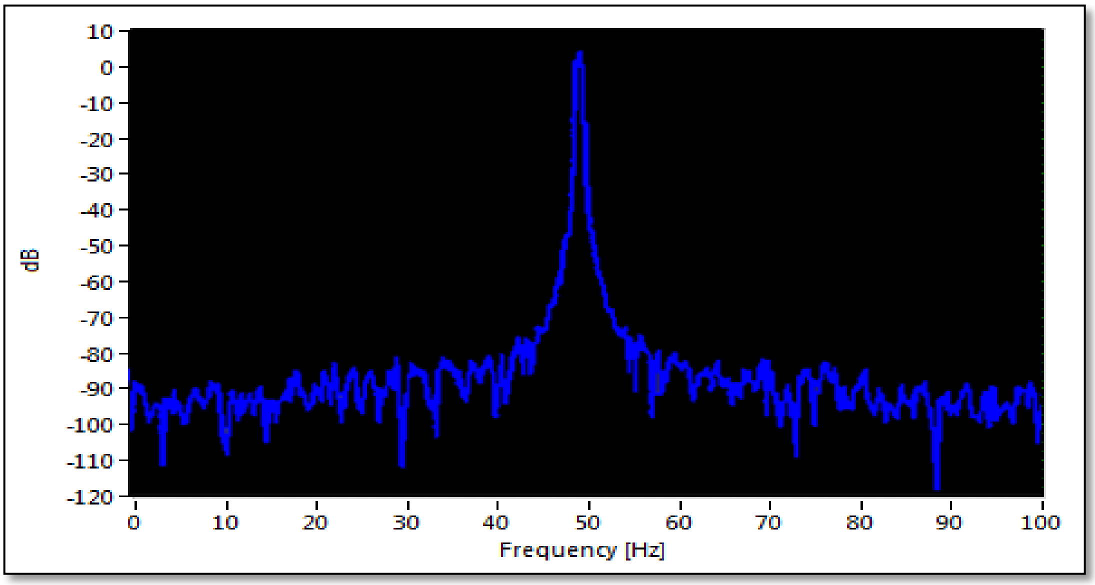

Figure 6- power spectrum of BRB under no load condition.

It can be seen from the Figure- 6 the detection of the searched slip frequency sidebands at no load condition is not visible**.** The Lower Side Band (LSB) and Upper Side Band (USB) frequencies are computed with equation (12) for k=1 and k=2 are (LSB=48 Hz, USB=51 Hz) and (LSB=47 Hz, USB=53 Hz) respectively. At no load, the side bands frequency is very close to the fundamental frequency and the amplitudes of the sidebands of the sidebands are quite smaller or negligible as shown in Figure- 6. The detection of the searched slip frequency sidebands at no load or light load is too difficult. Figure- 7 shows the power spectrum obtained from the current signal for one broken bar at half load.

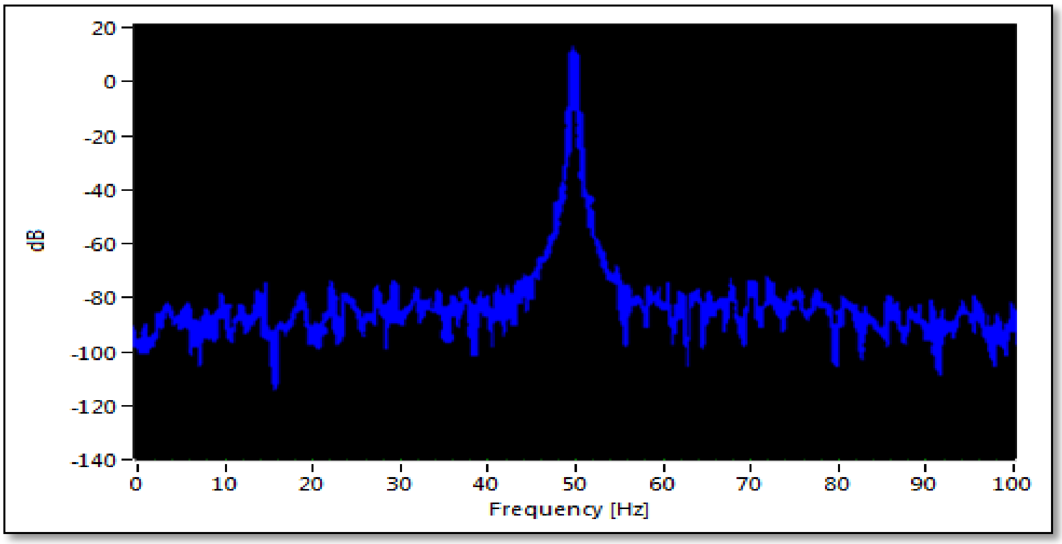

Figure 7-power spectrum of BRB under half load condition.

At the rated half load, the speed is less, which means that the slip is greater. In this case, the computed sideband frequencies for k=1 and k=2 are (LSB=45 Hz, USB=55 Hz) and (LSB=40 Hz, USB=60 Hz). It is observed from Figure- 6 that sideband fault frequencies are not visible at half load condition. Figure- 8 illustrates the power spectrum of the faulty motor with one broken under full load condition.

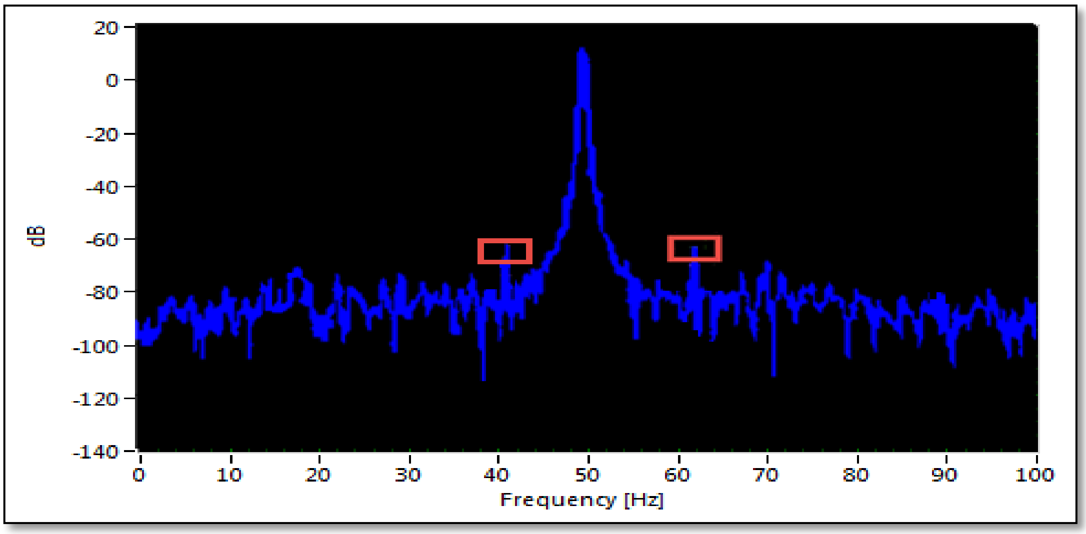

Figure 8- power spectrum of BRB under full load condition.

It is observed from the Figure-8 the fault frequencies at K=1 appear at LSB=41 Hz and USB= 59 Hz in the power spectrum which is an indication of BRB fault. The sidebands frequency components of the power spectrum are marked with red small squares. Table- 2, summarize the expected fault frequencies at various load condition. The complete observation from power spectrum analysis for BRB is given in Table-3.

Table2- summarize the expected fault frequencies at various load condition

Load condition	**Slip**	**K=1**		**K=2**	
		LSB (Hz)	**USB (Hz)**	**LSB (Hz)**	**USB (Hz)**
No load	0.016	48	51	46	53
Half load	0.05	45	55	40	60
Full load	0.09	41	59	23	68

Table 3- Power spectrum analysis of one broken bar at various loading condition

Figure No.	**Load condition**	**Slip**	**K=1**		**observations**
			LSB (Hz)	**USB (Hz)**	
6	No load	0.016	48	51	Not visible
7	Half load	0.05	45	55	Not visible
8	Full load	0.09	41	59	visible

5. Conclusion:

In the condition monitoring technology, there are strengths and weaknesses. And each technology applied will give a complete view of the health of the equipment. It has been shown in this paper the application of Motor Current Signature Analysis (MCSA) utilizing power spectrum estimation method for the BRB fault in MWT induction motor. The results showed that the FFT method gives acceptable results for diagnosis faults, while the FFT spectrum is a great source for identification of rotor bar problems in motors but it proved difficult to analyze in some frequencies. The spectra obtained from test results show no visible fault frequencies appear at no load and half load conditions. The fault frequency can be observed at full load condition so the ability to have baseline data when the machine is in good health is ideal while comparing data to similar machines is also very effective. For different types of equipment, as historical and statistical data is compiled, there will be more alarming guidelines established in the future.

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