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Unbalanced Brushless DC Rotor Diagnosis Using Instantaneous Amplitude Analysis

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Abstract. Cost-effective, predictive, and proactive maintenance of electrical machines, particularly BLDC motors, is becoming increasingly important as the use of these motors grows in many areas of application. A well-known method for assessing imminent problems is to analyze the features of the stator current, thereby detecting both electrical and mechanical faults. This paper describes a method for diagnosing eccentricity faults in brushless DC motors, based on the analysis of the instantaneous current amplitude extracted from the Hilbert transform. The proposed eccentricity detection technique has been validated in MATLAB/SIMULINK. For incipient eccentricity conditions, the proposed method highlights spectral components of the defect in which the amplitude of 1.04×10^{-2} is completely masked in the conventional FFT spectrum by the fundamental peak (amplitude ≈ 0.86).

1. Introduction

BLDC motors are a type of synchronous motor, meaning that the stator magnetic field and the rotor magnetic field rotate at the same frequency. As their name suggests, BLDC motors do not use brushes. Instead, they use an electronic commutator rather than the mechanical commutator used by traditional DC electric machines. This eliminates contact-related wear and tear and increases reliability.

The elimination of brushes also reduces the required maintenance frequency, increases the service life, and extends the operating speed range. In addition, BLDCs offer other advantages such as high power density, which makes them useful in applications where size and weight are critical factors, such as robots, drones, and electric vehicles. [1], [2].

Despite their high efficiency and compact size, brushless DC (BLDC) motors have a number of requirements that must be met to prevent failure. Without proper maintenance, their condition gradually deteriorates, their efficiency tends to decline, and their operational life is reduced [3]. In addition, unaddressed failures can also cause emerging failures, as can accidental or unexpected failures, leading to significant losses such as production stoppages, service interruptions, and failures in critical areas such as maintaining precise temperatures for products in the medical and healthcare sector, the proper functioning of drones or electric vehicles [4]. In this regard, the impacts of machine loss also have a major impact on the companies and users affected (additional time losses and higher expenses, reduced system reliability). It follows that maintenance should not be considered after the fact, but rather as an essential element to be taken into account for the operational safety, security, and reliability of the systems and machines used, as well as the satisfaction of users of BLDC motor-based technological systems. [5].

BLDC motors are vulnerable to three types of faults: electrical, mechanical and magnetic. Electrical faults are considered the most critical, as they have direct effects on operational stability and secondary damage. Typical electrical faults are inter-turn shorts, inter-winding faults, inter-phase faults and open-circuit faults, which generally result from insulation failure, temperature cycling, transients and switching, and mechanical stress. Each fault also produces its own

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symptoms, characterized by abnormal current amplitudes, torque fluctuations and distorted EMF feedback signals. Different electrical faults can produce different fault signatures depending on operational characteristics. For example, a sudden drop to zero of the current in one of the phases may indicate an open circuit fault and that the motor has lost its phase current. A doubling of the phase current and an increase in torque potential may, in this case, indicate a phase-to-phase short-circuit [6].

Mechanical faults attributed to all BLDC motor failures represent up to 50% and include the usual bearing failures as well as misalignments between rotor and stator. One of the most common mechanical faults is air gap eccentricity, which produces asymmetrical magnetic field distribution and parasitic losses. Eccentricity can be classified as static, dynamic or elliptical. Static eccentricity occurs when the axis of rotation is displaced, and usually occurs when the rotor has been incorrectly assembled or the stator is not completely cylindrical. Dynamic eccentricity occurs when the rotor itself, with an offset, rotates around the stator without an offset. Elliptical eccentricity is linked to specific manufacturing tolerances that structurally affect the circular symmetry of rotor or stator components. Eccentricities in excess of 10% of the air gap are considered faults. They create stray currents and unwanted heat in the stator [7].

Magnetic faults are most often associated with demagnetization of the permanent magnet, whether complete or partial. Magnetic faults are generally the result of prolonged overheating, prolonged overloading, short circuits, and particularly phase faults. Demagnetization affects a motor's torque capacity and dynamic response. Corrosion and material degradation over time also contribute to the loss of magnetic properties. As magnetic performance deteriorates, efficiency decreases, thermal stresses increase, and the rate and severity of electrical or mechanical failures increase. Consequently, effective monitoring combined with rapid fault diagnosis is essential to ensure the safe, reliable operation of BLDC motor systems [8].

Among these defects, rotor eccentricity, both static and dynamic, has been the subject of more sophisticated diagnostic methods, as it is less obvious but crucial to engine operation. Advances in signal analysis now allow for more precise identification of these defects. The SAC-DM (Signal Analysis based on Chaos using Density of Maxima) method, including multiresolution wavelet analysis (WMA), allows chaotic components in acoustic signals to be framed and offers 88.34% accuracy in detecting dynamic eccentricity at constant speed [9]. With regard to static eccentricity, recent current-based techniques that exploit both positive and negative sequence components provide a more reliable diagnosis than conventional methods that use only the negative sequence component [10]. Finally, frequency domain methods using finite element modeling and fast Fourier transforms also make it possible to distinguish between different types of faults by identifying stator current spectra [11]. Harmonic extraction methods enhance real-time fault detection by separating out specific eccentricity-related current harmonics, validated by simulation and experimental results [12].

2. Architecture of the proposed approach

2.1 Hilbert transform

The Hilbert transform (HT) method can be used to study the non-stationary motor current waveforms and simplify the analytical development of the signal [13]. The analytical signal defined in (1) consists of the original real signal $a(t)$ and the Hilbert transform as the imaginary component, resulting in a complex-valued signal:

$$\tilde{a}(t) = a(t) + j\hat{a}(t) \qquad (1)$$

In this equation, j is the imaginary unit and $a(t)$ is the Hilbert transform of the signal, which is defined in (2) as the convolution with 1/πt. The definition is simply the integration of the signal, weighted by the function 1/πt, and can be represented as follows:

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$$\hat{a}(t) = \mathcal{H}\{a(t)\} = \frac{1}{\pi}\int_{-\infty}^{+\infty} \frac{a(\tau)}{t-\tau}\, d\tau \qquad (2)$$

The Hilbert transform shifts the phase of the negative frequency components of the signal by +90°, then shifts the positive frequency components by -90°. The instantaneous amplitude of the resulting analytic signal is derived from the modulus of this complex signal and given by equation (3):

$$A(t) = |\tilde{a}(t)| = \sqrt{a^2(t) + \hat{a}^2(t)} \qquad (3)$$

The instantaneous amplitude is also called the "signal envelope"; it highlights low-frequency components by filtering out high-frequency swings. It provides better visibility of slow variations, which is particularly useful for detecting faults in brushless DC motors, such as eccentricity, which manifests itself as a modulation of the current amplitude masked by high-frequency noise.

The analytical signal representation provides an optimal way to identify and distinguish subtle fault signatures, such as harmonic content identified due to eccentricity of motor currents. Once the signal has been analytically characterized, the envelope of the motor current can be clearly isolated, which would support more accurate fault detection because higher frequency disturbances, in particular from the mains supply should be effectively filtered out. As shown in this study, the use of the Hilbert transform for envelope extraction is a reliable pre-processing procedure to use in condition monitoring, which enables the user to identify low-frequency modulations, typically indicative of fault conditions and particularly eccentricity.

2.2 Fast Fourier Transform Analysis

FFT analysis is the primary tool in signal processing. The ultimate goal of signal processing is to improve understanding of a signal by investigating its frequency domain representation. In this case, the FFT of the stator currents will be convoluted with an FFT of the Hanning window [14]. The coefficients of a Hanning window of length L given in (4) can then be derived using the following expressions:

$$\omega(n) = \omega_0.\left(\frac{L}{N}\left(n - \frac{N}{2}\right)\right) \qquad (4)$$

$$\omega_0(x) = \begin{cases} \frac{1}{2}\left(1 + \cos\left(\frac{2\pi x}{L}\right)\right) = \cos\left(\frac{x\pi}{L}\right), |x| \le \frac{L}{2} \\ 0, |x| > \frac{L}{2} \end{cases}$$

$$\omega(n) = \frac{1}{2}\left(1 - \cos\left(\frac{2\pi n}{L}\right)\right) = \sin\left(\frac{n\pi}{L}\right), \qquad 0 \le n \le N$$

Where N + 1 is the size of the window [15].

A Hanning window is then applied to limit the frequency bands of interest and reduce numerical instability at the edges of each component. Without windowing, the affected frequency bands exhibit spectral disturbances in the form of high-magnitude oscillating components, which are typical of linear non-stationary processes. This makes it difficult to develop effective fault diagnosis system implementations.

The presence of eccentricity flaws in a BLDC machine will cause asymmetries in the flux distribution and components of the stator currents. These eccentricity flaws will introduce characteristic spectral lines in the stator current, also most notably as sidebands adjacent to the phase frequency harmonics [13]. In the case of mixed eccentricity, the lines will be at the frequencies f_d defined in (5):

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$$f_d = f_s \pm k.\frac{fs}{p} \qquad (5)$$

Where fs is the stator phase frequency, and p is the number of pole pairs. These components, which can be clearly identified by applying the FFT to the stator current, provide a precise way to diagnose the machine's condition [16][17].

2.3 The proposed approach

The proposed methodology is designed to detect and evaluate faults based on stator current, this methodology is described in the flowchart in the fig. 1.

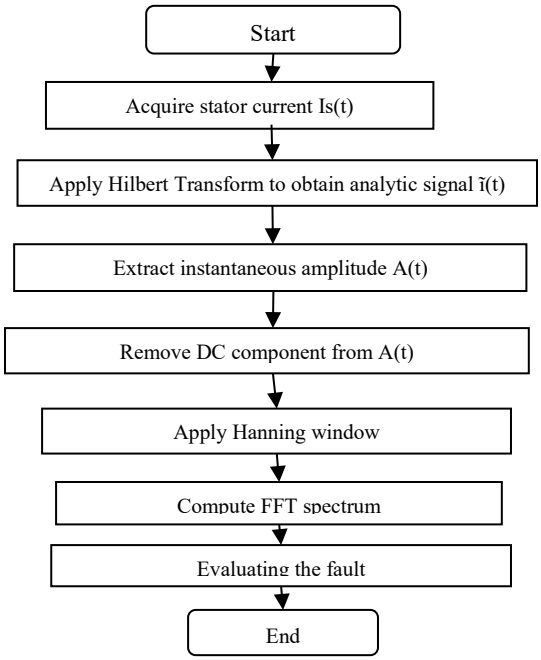


Fig. 1. Flowchart of the proposed methodology

First, the measured signal Is(t) is converted into an analytical signal using the Hilbert transform, allowing the instantaneous amplitude A(t) to be extracted. After removing the DC component, a Hanning window is applied to attenuate spectral leakage effects and improve frequency resolution. The signal spectrum is then obtained by fast Fourier transform (FFT), and the harmonic characteristics of the machine's faults are extracted. Finally, identifying the harmonics characteristic of the fault is the final step in the flowchart, allowing the presence of anomalies to be confirmed and their severity to be measured.

3. Simulation results and validation

The purpose of this section is to evaluate the effectiveness of the proposed method. To this end, a simulation of the different operating conditions of the BLDC machine, as shown in Fig. 2, was carried out in the MATLAB/Simulink environment.

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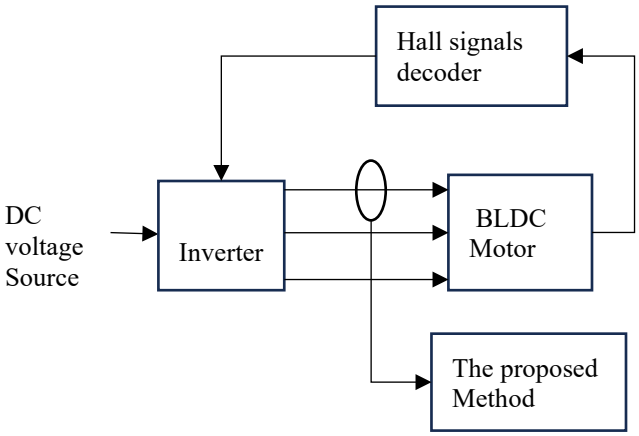


Fig. 2. Simplified block diagram of the BLDCM monitoring process

The scenarios studied include the healthy state of the machine and two levels of eccentricity faults. The principal parameters of the BLDC machine are shown in Table 1. The signals observed, namely the stator current and rotor speed, sampled at a frequency of F = 20 kHz, produce a total number of samples NT = 100000, corresponding to an acquisition time of 5 seconds.

Table 1. *Simulated BLDCm parameters*

Machine Parameters	Values
Voltage	100V
Stator resistance	2.98 Ω
Stator inductance	7 mH
Permanent magnet flux linkage	0.125 Wb
Number of pole pairs	2
Back electromotive force (EMF) constant	0,375
Rotor inertia	$J = 0.47 \times 10^{-4}$ kg·m²

4. The Performance of the proposed method

The simulation is performed on a BLDC motor model under nominal load in three conditions: normal, incipient fault, and severe fault. The stator current waveforms obtained for each operating condition are shown in Figures 3(a), 3(b) and 3(c). A direct comparison of present signals in the time domain does not reveal significant rotor imbalance faults. Thus, time analysis of stator current by itself is insufficient for reliable fault detection, emphasizing the requirement for advanced signal processing techniques.

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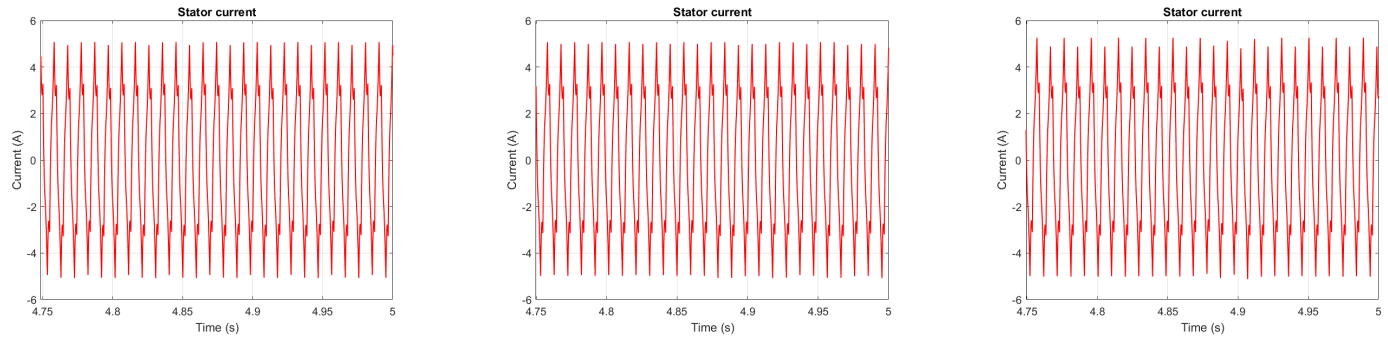


Fig. 3. Stator current signal under healthy (a), incipient fault (b), and severe fault conditions (c)

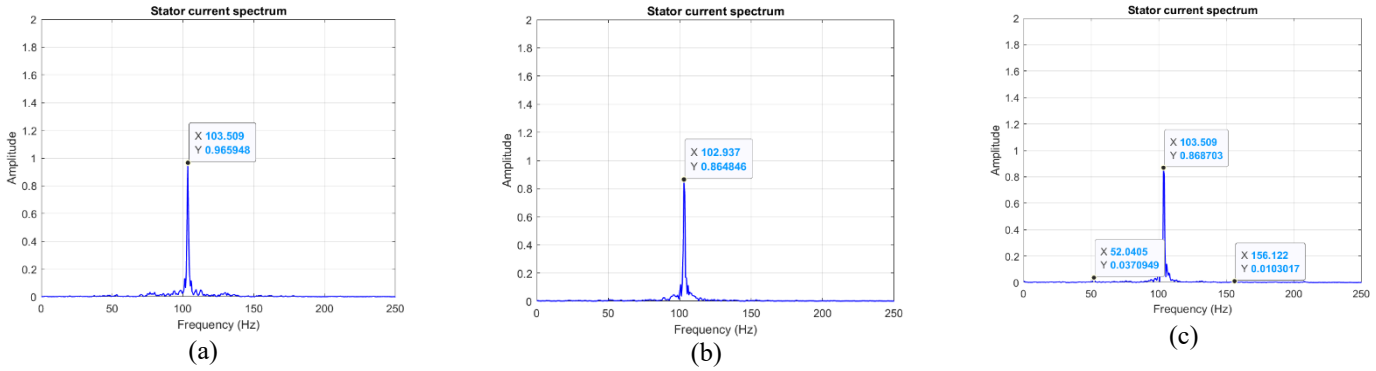


Fig. 4. Current stator spectrum for healthy (a), incipient fault (b), and severe fault conditions (c)

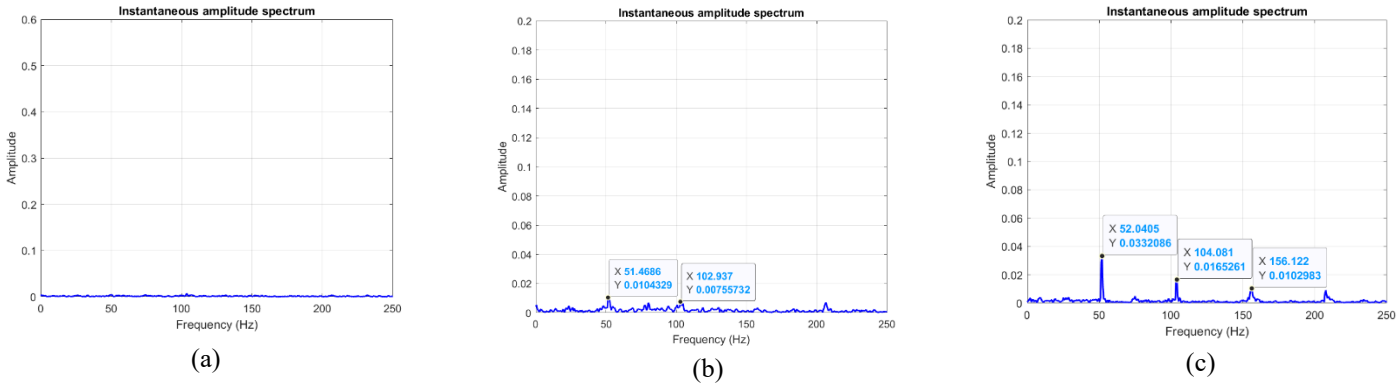


Fig. 5. Frequency spectrum of the extracted envelope for healthy (a), incipient fault (b), and severe fault conditions (c)

In the next step, a spectral analysis of the stator current is performed to expose the eccentricity defects of the BLDC machine. The obtained spectra for the healthy case, incipient, and heavy-defect conditions are shown in Figures 4.a., 4.b., and 4.c, respectively.

The results show that in the case of health, there are no side effects and that the fundamental component dominates the entire spectrum.

On the other hand, if the fault is verified, weak sidebands appear in the spectrum and clearly indicate the imbalance of the rotor. However, for the incipient fault, no sidebands were detected, highlighting the limitation of the fast Fourier transform (FFT), which alone cannot effectively diagnose incipient rotor faults.

In the following, the Hilbert Transform is performed on the stator current in order to obtain the instantaneous amplitude. A fast Fourier transform (FFT) is then performed on the instantaneous amplitude. The obtained spectrum are shown in Figures 5.a, 5.b, and 5.c, respectively, for the healthy, incipient, and severe fault cases. The results clearly indicate that the proposed technique can reveal spectral components of the defect, which are necessarily of low amplitude (1.04×10^{-2}), which remain undetectable using conventional FFT analysis due to the dominance of the fundamental component (≈ 0.86). Therefore, this method allows for highlighting the presence of incipient rotor faults; such faults were not possible to detect using a simple time domain analysis or applying a direct FFT on the
raw current.

Conclusion

The research presented in this paper shows how effective the combination of the Hilbert transform and fast Fourier transform (FFT) is in assessing operating conditions and health status of brushless direct-current (BLDC) motors. The combination is an effective method for identifying early rotor fault conditions such as eccentricity. The combination method is superior to the more commonly used traditional methods of monitoring, which focus only on either the time-based or spectral response of signals. Additionally, this research provides a basis for developing predictive maintenance strategies that enhance the reliability and continuous operation of electric drive systems.

References

[1] Mustafa F. Mohammed, Speed Control for BLDC Motor for Electric Vehicles Applications by Different Kinds of Sliding Mode Control Techniques, SSRG Int. J. Electr. Electron. Eng., 2024. https://doi.org/10.14445/23488379/IJEEE-V11I2P102

[2] Vinay Kumar Awaar, Sravani Bannuru, Arsalan Abbas, Position Sensorless Field-Oriented Control of BLDC Motor for EV Applications, E3S Web Conf., 2023.

[3] Yufeng Gu, Qianqian Zhang, Qingzhe Wang et al., Health management of brushless direct current motor controller, IET Conference Proceedings, 2025,

[4] Rommel S. P. Estacio, Diego A. B. Montenegro, Carlos F. R. Rodas, Machine hearing for predictive maintenance of BLDC motors, Journal of Quality in Maintenance Engineering, 2024,

[5] Enesi Y. Salawu, Olanrewaju O. Awoyemi, Opeyemi E. Akerekan et al., Impact of Maintenance on Machine Reliability: A Review, E3S Web of Conferences, 2023, https://doi.org/10.1051/e3sconf/202343001226

[6] Solís, R.; Torres, L.; Pérez, P. Review of Methods for Diagnosing Faults in the Stators of BLDC Motors. Processes 2023, 11, 82. https://doi.org/10.3390/pr11010082

[7] [K. Kudelina, B. Asad, T. Vaimann, A. Rassõlkin, A. Kallaste and D. V. Lukichev, "Main Faults and Diagnostic Possibilities of BLDC Motors," 2020 27th International Workshop on Electric Drives: MPEI Department of Electric Drives 90th Anniversary (IWED), Moscow, Russia, 2020, pp. 1-6, doi: 10.1109/IWED48848.2020.9069553. https://doi.org/10.1109/IWED48848.2020.9069553

[8] Sardashti, A., & Nazari, J. (2023). A learning-based approach to fault detection and fault-tolerant control of permanent magnet DC motors. Journal of Engineering and Applied Science, 70(1), 109. https://doi.org/10.1186/s44147-023-00279-5

[9] Veras, F. C., Lima, T. L. de V., Souza, J. V. da S., Ramos, J. G. G. S., Lima Filho, A. C., & Brito, A. V. (2019). Eccentricity Failure Detection of Brushless DC Motors From Sound Signals

Based on Density of Maxima. IEEE Access, 7, 150318-150326. https://doi.org/10.1109/ACCESS.2019.2946502

[10] Jiang, C., & Habetler, T. G. (2015). Static eccentricity fault detection of the BLDC motor inside the air handler unit (AHU). International Electric Machines and Drives Conference, 1473-1476. https://doi.org/10.1109/IEMDC.2015.7409256

[11] [Park, J.-K., & Hur, J. (2016). Detection of Inter-Turn and Dynamic Eccentricity Faults Using Stator Current Frequency Pattern in IPM-Type BLDC Motors. IEEE Transactions on Industrial Electronics, 63(3), 1771-1780. https://doi.org/10.1109/TIE.2015.2499162

[12] Jeon, M.-S., Im, J.-H., & Hur, J. (n.d.). Eccentricity Fault Diagnosis Method Using the Harmonic Extractor in BLDC Motor.

[13] Sabir, H., Ouassaid, M., & Ngote, N. (2020, December). Early Severity Assessment of Unbalanced rotor Fault in WRIM using ANN based Hybrid TSA and FFT Approach. In 2020 IEEE 7th International Conference on Engineering Technologies and Applied Sciences (ICETAS) (pp. 1-6). IEEE. https://doi.org/10.1109/ICETAS51660.2020.9484312

[14] Choqueuse, V. V., & Benbouzid, M. (2015). Induction machine diagnosis using stator current advanced signal processing. International Journal on Energy Conversion, 3(3), 76-87.

[15] Sabir, Hamza & Ouassaid, Mohammed & Ngote, Nabil. (2021). Early Fault Estimation of Inter-turn Short-circuit in Rotor Winding of WRIM using ANN-based Combined TSA and MCSA Technique. https://doi.org/10.1109/ISAECT50560.2020.9523697

[16] Cerna, M., & Harvey, A. F. (2000). The fundamentals of FFT-based signal analysis and measurement (pp. 1-20). Application Note 041, National Instruments.

[17] Panagiotou, P. (2020). Reliable Detection of Rotor Electrical Faults in Induction Motors Using Frequency Extraction of Stator Current and Stray Magnetic Flux Signals (Doctoral dissertation, Coventry University)