Analysis for inter turn stator fault with load variation in Induction Motor

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Abstract – This paper investigates the impact of load variation on the diagnosis of inter-turn stator faults in induction machines. The proposed detection technique relies on the analysis of stator current using the discrete wavelet transform (DWT) in both normal and faulty states of the machine. The energy of the approximation and detail signals obtained from DWT provides valuable information about the machine's health and the severity of the inter-turn stator faults. Experimental tests were conducted using a dSpace 1104 signal card-based interface to study the load effects in detecting and diagnosing stator inter-turn short circuit faults in induction motor.

***Keywords**:* Induction Motor, fault detection, diagnosis, Inter Turns Short Circuit Fault (ITSC), Discrete Wavelet Energy (DWE).

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I. Introduction

Induction motors play a crucial role in various industrial applications by converting electrical power into mechanical energy. These electromechanical devices are widely employed globally and are considered the workhorses of industrial operations. Induction motors are known for their robustness, making them suitable for a wide range of applications, including hazardous environments and challenging operating conditions.

Induction motors can experience failures due to various environmental or internal factors. These faults often exhibit subtle symptoms but can lead to increased energy consumption, reduced efficiency, and diminished performance. Even minor faults can result in losses and elevated temperatures, leading to insulation deterioration in the windings and potentially reducing bearing lifespan due to increased vibration levels. The history of fault diagnosis and protection for electrical machines dates back to the early stages of their development. Initially, manufacturers and users relied on basic protections such as overcurrent, overvoltage, and earth-fault protection to ensure safe and reliable operation. However, as the tasks performed by these machines became more complex, there was a need for improvements in fault diagnosis techniques. Nowadays, diagnosing faults when they occur has become crucial, as unscheduled downtime of machines can disrupt deadlines and result in significant financial losses [1]. Hence, it is imperative to diagnose the health of induction motors to minimize maintenance costs. Published surveys have indicated that induction motor failures encompass various types of faults. The most common failures include bearing-related faults, accounting for 40% of failures, followed by short circuits in stator windings at 38%. Rotor faults constitute approximately 10% of failures, while other types of faults, such as end ring faults, make up the remaining 12% [2].

Research indicates that stator winding faults are the second most common type of failures in induction machines, following bearing faults. However, detecting bearing faults is comparatively easier through physical examination. In small motors, abnormal noise produced by the machine can be a telltale sign of bearing faults, while large motors are equipped with temperature sensors for online monitoring, where a rise in temperature indicates a fault. Stator faults typically originate as minor inter-turn short circuits (ITSC) within a coil. These short circuits arise due to hotspots forming in the winding. ITSC can progress into more severe faults, such as phase-to-earth or phase-to-phase short circuits. The high current resulting from these short circuits further elevates the winding temperature, leading to insulation deterioration and eventual failure. Detecting and diagnosing ITSC faults at an early stage is crucial in preventing significant damage to the stator core. By identifying inter-turn short circuits before insulation failure occurs, the motor can be rewound, averting a complete machine failure. Typically, the rewinding process is faster and more cost-effective than replacing the entire motor [3,4] .

Several offline and online techniques are available for the detection and diagnosis of stator winding faults. In this context, non-intrusive methods that rely solely on voltage and current measurements from motor terminals, without requiring additional sensors, are generally preferred [5]. One such non-invasive method is motor current signature analysis (MCSA), which has demonstrated its efficiency in identifying stator winding faults [6]. Recently, various stator winding fault detection techniques have been extensively discussed in the literature, including analysis of axial flux [7], vibration monitoring, Extended Park's Vector Approach (EPVA) [5], detection of negative sequence current [8], negative sequence impedance [9], residual saturation harmonics [10], and multiple reference frame theory [11]. To extract fault-related information from stator current signals, signal processing tools such as Fast Fourier Transform (FFT), Short-time Fourier Transform (STFT), Wavelet transform (WT) [4,16], and Power Spectral Density (PSD) estimation have been introduced [12-17].

This paper explores the utilization of energy derived from the analysis of stator current using Discrete Wavelet Transform (DWT) to diagnose inter-turn short circuit faults in induction motors under varying load conditions. By harnessing the multi-resolution analysis capabilities of DWT, the proposed approach enhances fault diagnosis accuracy and reliability. The study validates the effectiveness through experimental investigations, offering valuable insights for real-world implementation. This research contributes to improved motor diagnostics, leading to enhanced reliability and operational efficiency.

II. Materials and Methods

II.1. Experimental setup

Experimental data were obtained from a squirrel-cage induction motor with the following specifications: three-phase, 50 Hz frequency, Y connection, 4 poles, 46 bars, and a power rating of 1.1 kW. The motor was directly supplied by the network with a voltage of 400V (Un). It was specially rewound to allow for the external manipulation of the number of turns in each phase winding, enabling easy creation of inter-turn short circuit (ITSC) faults. Stator current data was recorded using current sensors connected to the interface of a dSpace card 1104, and the data was stored on a PC **(**Figure 1**).** The data acquisition process utilized a sampling frequency of 10 kilo samples per second for all experimental tests conducted.

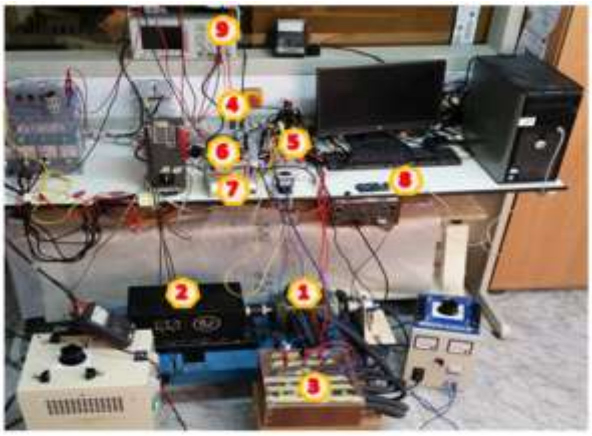

Figure 1. Workbench used in tests

1	A squirrel-cage IM 1.1 Kw
2	Magnetic powders break with load control unit
3	External box for enables introducing ITSC with different number of turns in different phases
4	dSpace DS 1104 with 5 control desk software plugged in personnel computer.
5	Current sensors
6	Voltage sensors
7	Circuit for controlled the time of the fault
8	Arduino card 'UNO'
9	GW-INSTEK numerical oscilloscope

To modify the stator of the motor, an alteration was made by incorporating five additional connections that were linked to the stator coils of the three phases. This modification can be observed in the schematic winding diagram provided in Figure 2**.**

The opposite ends of these external wires were connected to a motor terminal box, which facilitated the introduction of inter-turn short circuits (ITSC) with varying numbers of turns across different phases, as depicted in Figure 2.

The duration of the fault was controlled through the utilization of a specialized circuit, comprising a relay contactor that was controlled by an 'Mega2560' Arduino card, as illustrated in Figure 3.

This setup allowed for the application of the fault for a specified duration, typically a few seconds, to protect the machine from potential damage

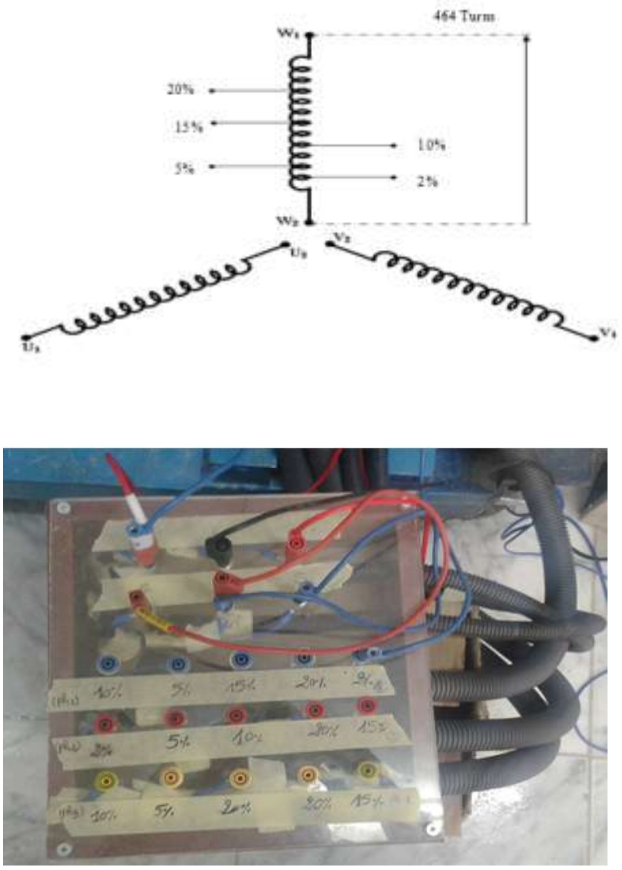

Figure 2. Tappings connected to the stator coils of the stator phase W1-W2

Figure 3. Circuit to control the time of the ITSC fault by 'Arduino card'

Table 1. Frequency bands for the wavelet signal

Level	Frequency Bands (Hz)
D1	2500-5000
D2	1250-2500
D3	625-1250
D4	312.5-625
D5	156.25-312.5
D6	78.125-156.25
D7	39.0625-78.125
D8	19.531-39.0625
D9	9.765-19.531

This study focuses on detecting inter-turn short circuit (ITSC) faults under various load conditions. The detection process is accomplished by calculating the energy of the detail coefficients derived from the discrete wavelet transform (DWT) of the stator current. The analysis considers different scenarios, including healthy operation and ITSC faults occurring under different load conditions. Detailed explanations of the methodology and findings related to this detection approach will be provided in the upcoming sections.

II.2. Algorithm for fault detection

Figure 5 illustrates the sequential steps required to implement the discrete wavelet energy (DWE) based methodology for diagnosing inter-turn short circuit (ITSC) faults.

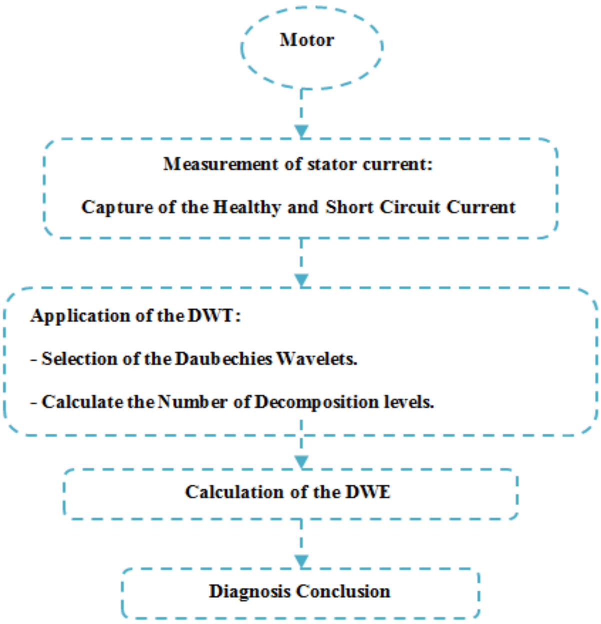

Figure 5. Flowchart for the DWE-based diagnosis methodology

The proposed methodology utilizes the application of the discrete wavelet transform (DWT) to the stator current signal under healthy and inter-turn short circuit (ITSC) fault conditions with varying loads. By employing this method, the sideband harmonics generated during the fault can be extracted, and the energy of the detail coefficient is calculated. This approach enables the diagnosis of the fault by comparing the values of the detail coefficient energy between the healthy and ITSC fault states under different load conditions. The discrete wavelet energy (DWE) serves as a reliable indicator for detecting and diagnosing ITSC faults, while also considering the effects of varying loads on the fault diagnosis process.

III. EXPREMENTAL RESULT

III.1. Validation

To validate the proposed method, a series of tests were conducted using a specialized of 4-pole 1.1 kW industrial induction motor that was rewound for the purpose. This motor was equipped with an external connection box (refer to Figure 2 and Figure 3) which allowed for the external creation of an ITSC fault. To vary the load, the motor was coupled with a powder brake. The experiments were carried out at a supply frequency of 50 Hz.

Figure 6 and Figure 7 depict the stator current of the A-phase while the induction machine operates in both healthy and ITSC fault conditions at various loads. The motor was initially started with no load after charging, and then the ITSC fault was applied with a load for a duration of 2 seconds using the time control circuit (refer to Figure 3). This allowed us to observe the impact of the fault under different load conditions. The short duration of the ITSC fault enabled multiple uses of the machine in the tests.

This section presents the current behavior of the A-phase in both healthy and ITSC states (with 2% and 5% turns shorted) under different load levels (25%, 50%, 75%, and full load). It is worth noting that:

- **healthy stat**

As the load increases, there is an observed increase in the A-phase current in different states.

- **ITSC fault stats**

The stator current of the A-phase shows a significant increase, particularly in the 5% ITSC fault state, where the current value surpasses the nominal value of the motor, especially under a load of 75%. In the case of the 2% ITSC fault, the current increase is comparatively lower since the number of turns shorted is negligible in comparison to the total turns of the winding.

III.2. Analyses the results by DWE

The evaluation of the forecasted causes of the defect cannot be directly assessed in the temporal space. However, by analyzing the stator current using Discrete Wavelet Transform (DWT), the energy obtained from different harmonic components can provide valuable information about the effect of load on the fault. The impact of load variation on the "short circuit" defect becomes evident through the energy stored at certain levels.

Energy Analyzing the results, it is observed that the energy stored in level d7, corresponding to the frequency band [78.125-39.0625Hz], depends on the degree of the fault and the load. The energy increases with higher loads and an increased percentage of inter-turn short circuit.

Fig 8 Illustrates the results of the energy variation, represented by the discrete wavelet detail coefficient in level 7 (Ed7) of the stator current (A-phase), for the motor in healthy and ITSC fault states (2% and 5%) with different load conditions. Ed7 serves as a clear indicator of the effect of both load and ITSC fault, particularly when the number of turns shorted is small (2%). Therefore, studying the behavior of Ed7 values allows for the diagnosis of the induction motor in ITSC fault under different load conditions.

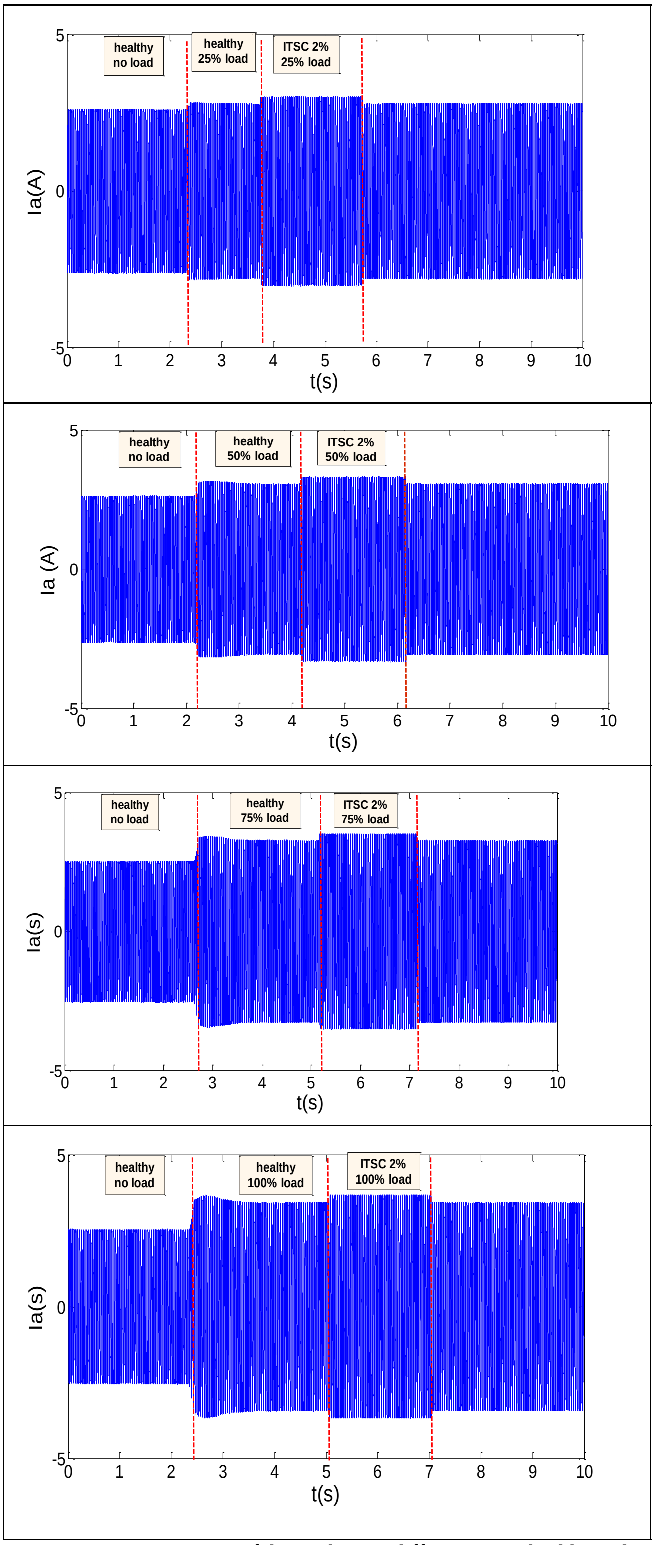

Figure 6. Stator current of the A-phase in different cases: healthy and ITSC 2% under different load (no load, 25%, 50%, 75%, full load)

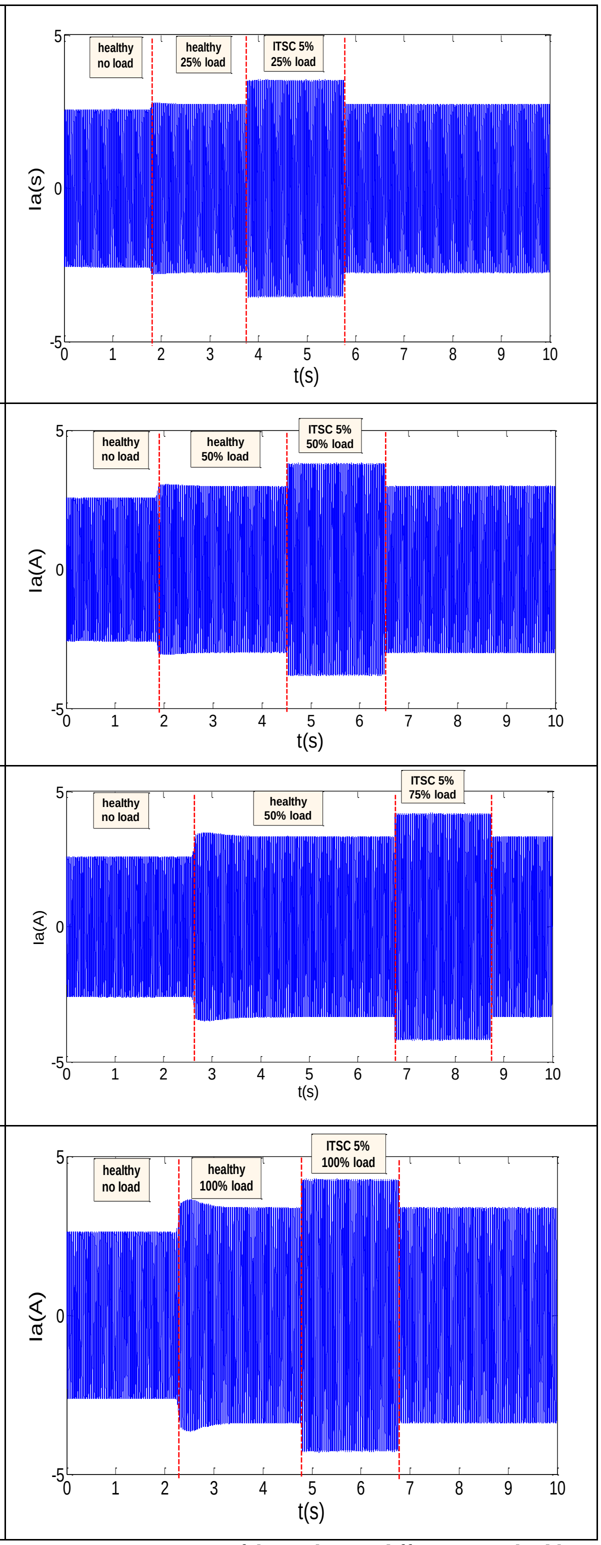

Figure 7. Stator current of the A-phase in different cases: healthy and ITSC 5% under different load (no load, 25%, 50%, 75%, full load).

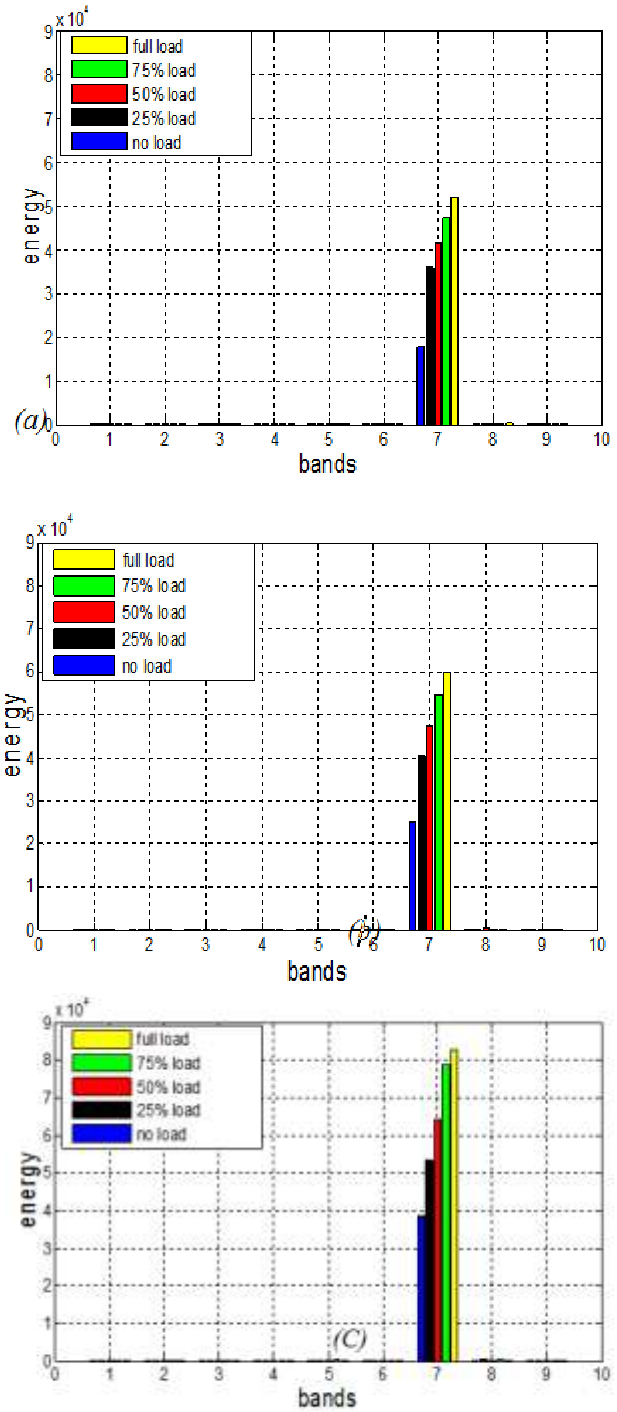

Fig.8.The energy variation in frequency bands for different cases

(a): Healthy with deferent load (no load , 25%,50% ,75% and full load)
(b): ITSC fault 2% with deferent load (no load , 25%,50% ,75% and full load)
(c): ITSC fault 5% with deferent load (no load , 25%,50% ,75% and full load)

Fig. 9 illustrates the relationship between the energy stored at level 7 (Ed7) and the different loads applied on motor. It can be observed that the energy Ed7 rises with an increase in load for the normal operating condition (healthy) of the machine. However, the energy increase is more pronounced in the faulty cases (ITSC) of the motor

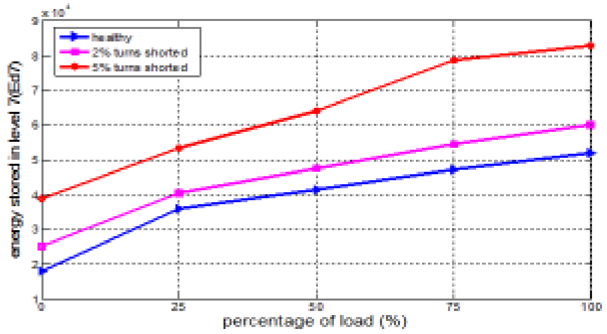

Figure 9. Comparison of energy variation for three cases (health and faulty state: 2% and 5% ITSC) at different load: no load, 25%, 50%, 75% and full load respectively.

IV. Conclusions

An essential aspect to consider during the detection of faults is the behavior of primary faults in a motor operating under various loads. Detecting faults becomes difficult due to large variations in load .The amplitude and frequency of the spectral components associated with the faults also change with loads. Thus, evaluating the amplitudes of the fault components requires a load calculation. Next, it can be seen that motor faults, specifically ITSC faults are depend on the torque applied to the motor.

This study investigates the impact of load on the detection and diagnosis of stator inter-turn short circuits fault. The diagnostic approach employed in this research focuses on analyzing the energy of the stator current using Discrete Wavelet Transform (DWT). The proposed wavelet-based energy technique successfully captures valuable characteristics from the stator current, particularly in non-stationary conditions, within an induction motor.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.
- The authors confirmed that the paper was free of plagiarism.

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