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Comparison of Fault Detection Techniques for Induction Motors

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ABSTRACT
In the era of twenty-first century, induction motor plays a dominant role in industrial processes and essentially run out 40 to 50 % of total energy demand. Accordingly, their safety, durability, and efficiency are of major concern. Faults developing in induction motor necessitates significant consideration as they eradicate its operation and reduce the mean life. In this research, the most widely used MCSA that captures stator current signatures and acceleration-based vibration diagnosis techniques are practically investigated employing low-cost sensors. Moreover,the comparative analysis is performed to find an effective method for detection of faults, efficiently and persuade motor safety and reliable operation.

General Terms
Condition Monitoring of Induction Motor.

Keywords
Motor Current Signature Analysis (MSCA), Fast Fourier Transform (FFT), Condition Monitoring (CM).

1. INTRODUCTION
With the escalating evolution in industrial processes, IMs have replaced 90% of the actuators altogether exercised in the production line and were surveyed to be more fault-tolerant [1, 2]. Pre-diagnosis of faults occurring in induction motors can increase, its durability. In consequence, the practical investigation is crucial to execute condition monitoring techniques of an IM.

Manufacturing imperfections, installation, maintenance schedule, and inadequate lubrication are the reported factors of faults in IMs [3]. The engineers are confronting challenges for providing adequate protection to electric motors. Origin of failures in IMs bifurcated as internal and external and subdivided into electrical, environmental, and mechanical defects in Fig.1.

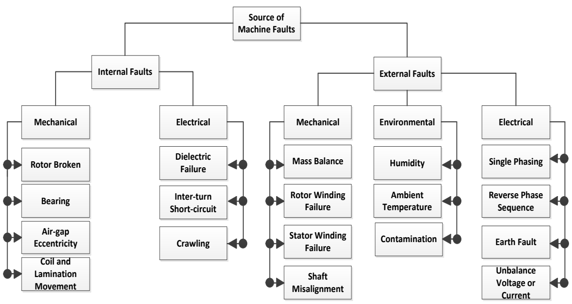

Fig1:Faults classification in IM

Numerous types of faults along with their sources are tabulated in Table 1.

Table I. Faults and their causes in IM

Fault	Causes
Bearing	Fabrication Faults, overstress, Inappropriate oiling, debris due to friction
Rotor Misalignment	Untrue coupling, inadequate installation, deterioration of bearing, overload
Air gap Eccentricity	Irregular magnetic pull, rotor misalignment, bearing defects
Broken Bars (rotor)	Considerable transient, thermic stress, Fabrication faults, Unbalance magnetic pull, negative sequence in supply,
Stator Winding	Installation deficiency, Supply Surges, lessen of coil

ASEA Brown Boveri (ABB), Electric Power Research Institute (EPRI), and Institution of Electrical and Electronic Engineers (IEEE) carried out studies on faults occurring in motors as shown in Table 2.

Table 2. Statistics of IM faults

Faults	Percentage of Occurrence (%)		
	ABB	EPRI	IEEE
Shaft coupling	2		
Stator	16	28	36
Rotor bar	5	9	8
Bearing	51	41	42
Other	10	22	14
External conditions	16		

Several CM techniques are reported in the literature. On-line CM for double cage rotor [4], bearing and stator winding faults frequently encountered in IM [5, 6], acoustic emissions and vibration-based CM [7-8], bearing faults and diagnostic methods are outlined in [9, 10]. In [11] and [12], bearing fault was detected using vibrations and stator current respectively. The image-based algorithm for allocation of faults with different classifiers presented in [13], [14] discussed IRT-based thermal image segmentation to recognize end rings and broken rotor problems. In [15], authors have reviewed fault detection techniques to identify broken rotor bar faults in IM. A review divulged to identify eccentricity problems [16]. In [17], the author addressed vibration analysis based on

DWT for the identification of rotor incipient broken bar faults. Acoustic emission integrating with vibration signals are discussed to properly point out the failure in IM [18]. It is proposed to use MCSA for achieving better reliability of operation of IM [19, 20]. Researchers have used thermal images to identify the roller-bearing fault in IM [21, 22]. CM techniques are mapped against faults in Table 3.

Table3. IMs faults mapping with monitoring techniques

Fault	MCSA	Vibration Analysis	Temperature Monitoring	Acoustic Emission
Bearing	✓	✓	✓	✓
Inter-turn		✓	✓	
Broken Rotor	✓	✓	✓	
Air gap Eccentricity	✓			
Mass Misalignmen t	✓			
Mass Unbalance			✓	

Comparative analysis has shown, Motor Square Current Signature Analysis (MSCSA) provides significant signatures among Principle Component Analysis (PCA) and MCSA techniques to identify broken rotor bars faults [23]. Current signature-based approaches are compared to diagnose gearbox faults [24]. Researchers have investigated different measurement techniques to determine the bearing faults [25]. In [26], authors have presented a review on machine learning algorithms-based fault detection techniques for IM. MCSA is reported to be an effective method for electrical fault detection in IM [27].

Although authors have presented various studies in literature, despite that very few work published relative analysis among MCSA and accelerometer-based vibration analysis for revealing faults of a squirrel cage IM. In this research, MCSA and vibration analysis techniques are experimentally investigated to find an efficient method to identify fault developing in squirrel cage IM.

In this paper introduction & related studies reported in the literature are presented in Section I. Section II includes methodology adopted for the implementation of MSCA and vibration technique. Experimental results are shown in Section III. Section IV deals with the conclusion made from acquired results. Furthermore, future recommendations summarized the research paper in Section V.

2. MATERIAL & METHODS

Thephysical system is divided into two parts. At first,the dedicated setup has been developed to characterize both current and vibration sensors. In the second phase sensors are interfaced with the arduino mega 2560 controller to acquire serial data, which is processed to properly diagnose the health of IM.

The circuit diagrams, in Fig.2 and Fig.4 were implemented to calibrate the current sensor and accelerometer respectively. Hall effect based current sensor module has very low input impedance thus an external resistor of value 32R2 ohms were connected in series to limit the current in safe operating range. A set of voltages were applied at input circuit of current sensor and resulting output in millivolts was serially monitored using arduino microcontroller to find equation relating input current and output voltage.

In Fig.3, the output voltage of current sensor is plotted against the input current flowing through the load and internal resistance of the current sensor. The statistical value of R^2 relates the dependent and independent variable using a regression line. R square value closer to unity shows strong relationship b/w the data points and linear trend line.

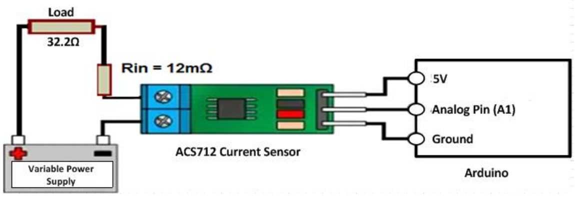

Fig 2: Current sensor characterization circuit

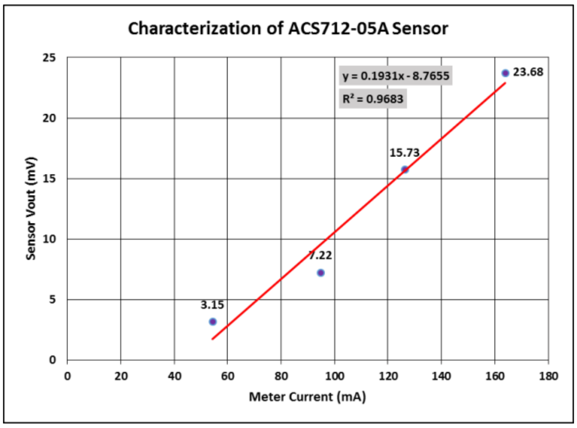

Fig 3: Characteristic curve of ACS712 current sensor

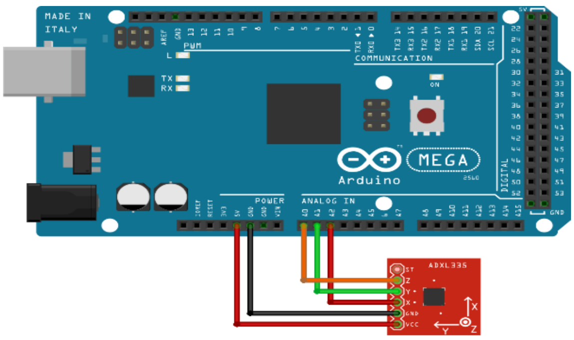

Fig 4: Interfacing of adxl335 with arduinomega2560

Furthermore, the practical setup for accelerometer characterization was developedas shown in Fig.5. The test setup were comprises of sensor block and calibrated scale block. The accelerometer was successively characterized in both x and y direction as delineated in Fig.6 and Fig.7 respectively.At first, accelerometer was placed on sensor block to measure the value of g in x direction while y and z remains constant. The sensor block was rotated in steps of 5 degrees over a calibrated scale block. The value of g in x direction saturates after 75 degrees as shown in Fig.6. Secondly, the adxl345 was attached on sensor block in y direction taking x and z axis values of g constant and minor changes was detected in value of g after 75 degrees of rotation of sensor block. The regression line have been drawn as displayed in Fig.6, initially till the first ten degrees the value of g deviates from the trend line, thus do not follow linear relation,the data points from 15 to 65 degrees obeys linearity whereas g gets saturatedafter 75 degree of rotation.

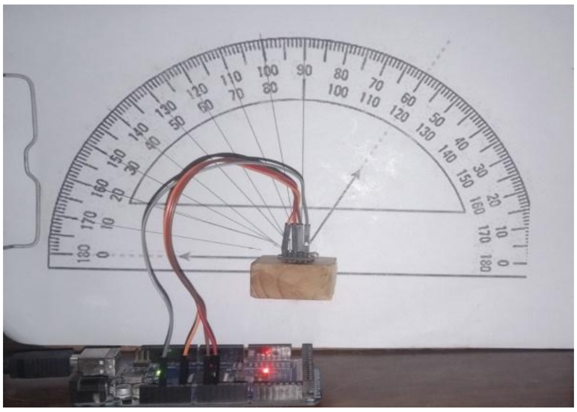

Fig 5: Adxl335 characterization system

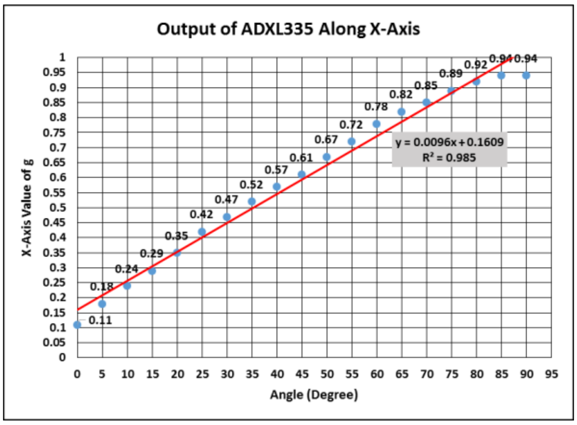

Fig 6: Characterization of Adxl335 along x-axis

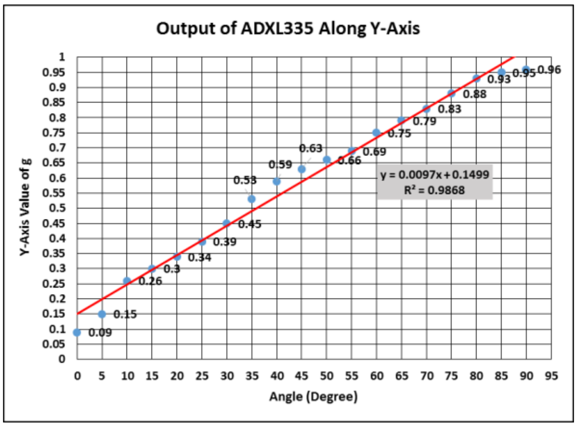

Fig 7: Characterization of Adxl335 along y-axis

The statistical line was drawn as seen in Fig.7; at first, the value of g differs significantly from the trend line until the first 5 degrees, hence the data sets do not follow strong correlation; however, the statistics point from 10 to 30 degrees comply strong linearity, whereas g diverges from the regression line again between 35 and 50 degree and becomes saturated after 75 degrees of rotation.After characterization, both the current sensor and the accelerometer are used to implement MCSA and vibration analysis techniques for IM health detection. The proposed system's block diagram is shown in Fig.8.

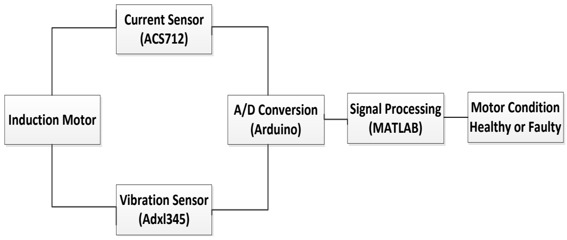

Fig8: Block diagram of test setup

2.1 Motor Current Signature Analysis

The stator current of IM is accomplished employing ACS712-05B-T sensor and digitized using arduino microcontroller ADC. Subsequently, the finite number of current samples were transmitted serially and analyzed using the FFT tool in MATLAB. Besides the fundamental harmonic at 50Hz supply frequency) all leftover frequencies in the stator current reflect the unhealthy condition of an induction motor.

2.2 Vibration Analysis

MEMS-based tri-axis Adxl335-accelerometer was utilized for vibration measurement. Arduino controller provides the mean for ADC conversion of vibration data that in pursuit transmitted over serial port to perform FFT n MATLAB. The spectrum of serial data was acquired in both healthy and faulty conditions of IMs at low, medium, and high speed respectively. The newly developed frequency components the FFT of vibration data identify the faulty condition of an IM.

3. RESULTS & DISCUSSIONS

Due to timely degradation of motor performance, the difference in speed between new and old IM may also appear at even no or light loads. MCSA and accelerometer-based fault diagnosis techniques were investigated at scenarios listed in Table 4.

Table 4. Experimental Design

Method	Scenarios #	Speed	Motor (125 W)
MCSA	1	Low	New
			Old
	2	Medium	New
			Old
	3	High	New
			Old
Accelerometer (X-Axis)	4	Low	New
			Old
	5	Medium	New
			Old
	6	High	New
			Old
Accelerometer (Y-Axis)	7	Low	New
			Old
	8	Medium	New
			Old
	9	High	New
			Old

In Fig.9, Fig.10, and Fig.11 significant bands resulting from FFT of stator current of both motors at speed of approximately 490, 980 and 1072 rpms is plotted.

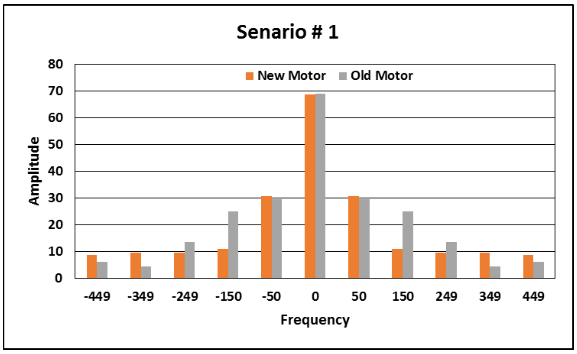

Fig9: Comparison of FFT of both motors using MCSA at low speed

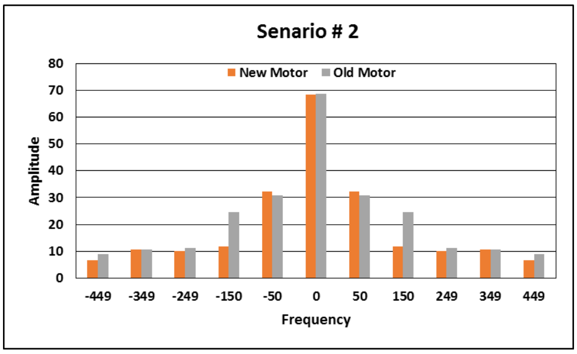

Fig10: Comparison of FFT of both motors using MCSA at medium speed

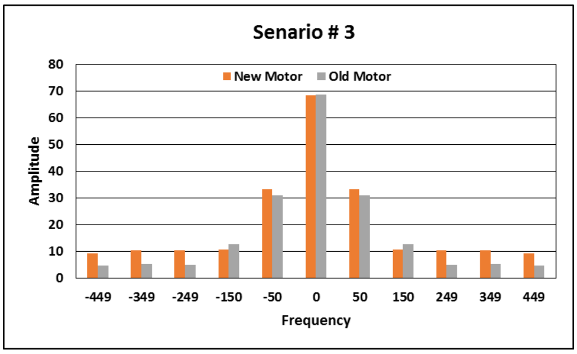

Fig11: Comparison of FFT of both motors using MCSA high speed

Table.5 summarizes the data collected using MCSA at both new and old motors. It can be deduced from the listed data that both IMs produce various frequency components that are multiples of the fundamental frequency (50Hz), but the amplitudes of harmonics produced in the old motor at 150, 249, 349, and 449 are significantly larger than those produced in the new IM, which in result depicts the faulty condition of and old IM.

Table 5.Comparison of MSCA data for both new and old motor

MCSA						
Frequency	Low Speed		Medium Speed		High Speed	
	New Motor	Old Motor	New Motor	Old Motor	New Motor	Old Motor
-449	8.67	6.25	6.47	8.99	9.42	4.73
-349	9.51	4.31	10.44	10.48	10.6	5.51
-249	9.5	13.6	9.87	11.07	10.4	4.96
-150	11.06	25	11.83	24.68	10.9	12.7
-50	30.66	29.6	32.25	30.74	33.4	31.1
0	68.62	68.9	68.51	68.81	68.5	68.8
50	30.66	29.6	32.25	30.74	33.4	31.1
150	11.06	25	11.83	24.68	10.9	12.7
249	9.5	13.6	9.87	11.07	10.4	4.96
349	9.51	4.31	10.44	10.48	10.6	5.51
449	8.67	6.25	6.47	8.99	9.42	4.73

The results accomplished, affirms the healthy condition of the new motor as no sidebands with distinct amplitudes are produced except at dc level and fundamental component at 50 Hz, unlike the case of an old motor. Comparison of vibration data collected at three discussed speeds along the x-axis is shown in Fig.12, Fig.13, and Fig.14. Various distinct frequencies at 33 and 58 Hz, along with the significant change in amplitude of some components at 8, 42, 50, 67, 100 and 141 Hz observed in Fig.12. The discrepancy in characteristics of experimental outcomes evidenced distinct conditions of both motors.

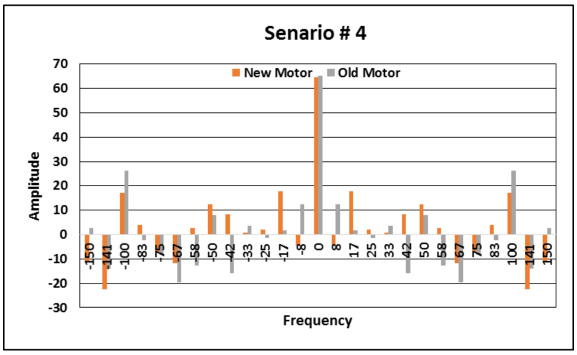

Fig12: Comparison of vibrations along the x-axis of both motors at low speed

Furthermore, Fig.13 and Fig.14 unveiled the dissimilar state of IMs both together, highlighting the conflicting harmonics at 33, 50, 83, and 67 Hz, whereas the remarkable change can also be observed in co-efficient of 100 Hz and 17, 25, 58, 100 Hz respectively.

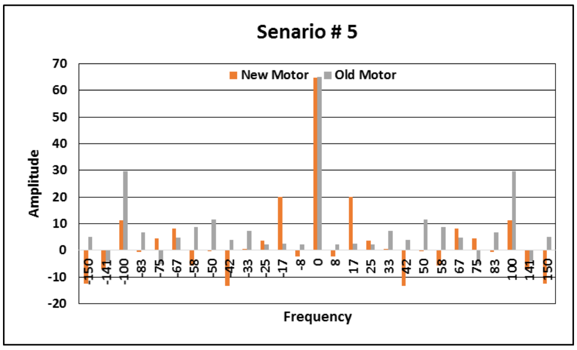

Fig13: Comparison of vibrations along x-axis of both motors at medium speed

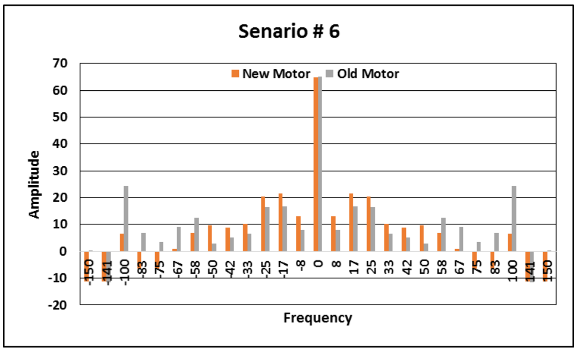

Fig14: Comparison of vibrations along the x-axis of both motors at high speed

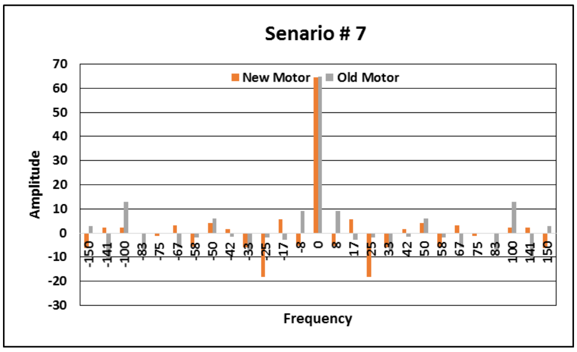

Fig15: Comparison of vibrations along y-axis of both motors at low speed

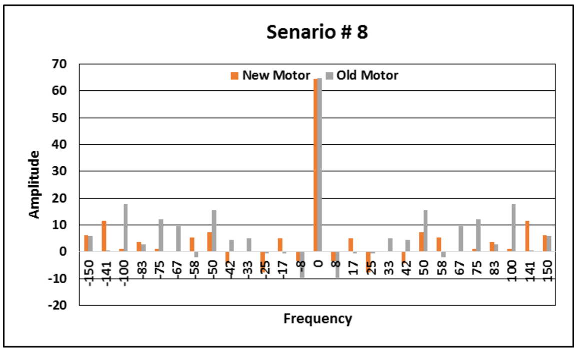

Fig16: Comparison of vibrations along y-axis of both motors at medium speed

Subsequently, the analogy between the outcomes of vibrations produced along the y-axis of accelerometer mounted on either motor was evaluated as shown in Fig.15, Fig.16, and Fig.17. The comparative investigation has conceivably differentiated among conditions of both motors.

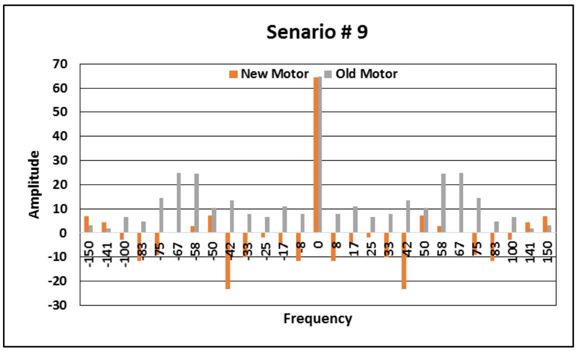

Fig17: Comparison of vibrations along y-axis of both motors at high speed

4. CONCLUSION

This research employed low-cost sensors for the implementation of both MCSA and vibration analysis techniques for tracking the condition of electric motors. Both techniques were examined on numerous scenarios where acquired results have shown notabledifferences among FFT of new and old motor data at low medium and high speed.

The experimental data of old motor acquired using MCSA, evident the presence of odd harmonics with significant amplitudes at low, medium,and high speed. Unlike MCSA the change in amplitudes of harmonics at 8, 17, 25, 33, 50, 58, 67, 75, and 100Hz measured along x and the y axis of accelerometer can be observed from the FFT of an old motor to the new motor which depicts the faulty condition of old IM.

Ithas been derived from the above experiments that MCSA produces distinguishable frequency components evenly spaced by the fundamental frequency of ac supply and no dedicated placement of the current sensor is required whereas sophisticated placement of sensor required in case of accelerometer-based approach and non-uniform pattern of harmonics produced with lessor amplitudes in contrast to sidebands frequencies developed in MCSA. Consequently, comparative analysis has shown MSCA to be a better approach for diagnosing and condition monitoring of an IM.

MCSA and vibration methods were correlated and analysis unveiled MCSA to be more apparent as noticeable differences were observed in harmonic components of current and vibration data of old motor.

5. FUTURE RECOMMENDATION

In the proposed research, the health of single-phase IMs was investigated at no load condition whereas the same scenarios can be developed at various load conditions that will change the slip of an induction motor and hence results.Moreover, research can also be extended to diagnose fault using the integration of both MCSA and accelerometer techniques.

Furthermore, the FFT tool was only considered, while discrete wavelet transform and other neural network algorithms can be employed and comparative study can be proposed. Also, the proposed topology was not aimed to detect any particular faults rather research context was general. The Relative study can be carried out to monitor both electrical and mechanical faults and find the most apparent method for proper health monitoring of IM.

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