Near Infrared Sensor-Based Condition Monitoring and Fault Diagnosis of Induction Motors using machine learning algorithms

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Abstract
Induction motors are extensively used in industrial applications because of their rugged construction, reliability, and low maintenance requirements. However, stator winding faults, rotor defects, insulation degradation, and bearing failures can significantly affect motor performance and operational reliability. Early fault detection is essential to reduce downtime and maintenance costs. Conventional monitoring methods utilize current, vibration, acoustic, and thermal measurements for fault diagnosis. Recent advances in optical sensing technologies have introduced Near Infrared (NIR) sensors as an effective non-contact solution for induction motor condition monitoring. This review presents a comprehensive study of induction motor fault diagnosis techniques with particular emphasis on NIR sensor-based monitoring systems. Signal processing methods including Discrete Wavelet Transform (DWT), Dyadic Wavelet Transform (DyWT), Rational Dilation Wavelet Transform (RADWT), and Tunable Q-Factor Wavelet Transform (TQWT) are reviewed and compared. The advantages, limitations, and future research opportunities of NIR-based monitoring systems are discussed. The study concludes that NIR sensor-based monitoring provides a promising alternative for online diagnosis of winding and insulation faults in induction motors.

Keywords: Induction Motor, Near Infrared Sensor, Condition Monitoring, Fault Diagnosis, Wavelet Transform, Predictive Maintenance.

1. Introduction

Induction motors are the backbone of industrial automation and account for a major portion of electrical energy consumption in industrial facilities. Their reliability and efficiency make them suitable for pumps, compressors, conveyors, fans, and manufacturing equipment. Despite their robustness, induction motors are vulnerable to faults arising from thermal stress, electrical overloads, mechanical vibrations, insulation ageing, and environmental conditions.

Motor failures often begin as minor insulation degradation or winding defects and gradually progress into severe failures. Therefore, continuous monitoring of motor health is essential for improving system reliability and reducing maintenance costs. Traditional monitoring systems employ current signature analysis, vibration analysis, thermal imaging, and acoustic emission monitoring. Although these techniques are effective, sensor placement limitations and signal interference often reduce diagnostic accuracy.

Near Infrared (NIR) sensing has emerged as a promising non-contact technique for monitoring magnetic flux variations associated with motor faults. NIR sensors can detect subtle changes in flux distribution and provide valuable information regarding winding and insulation deterioration.

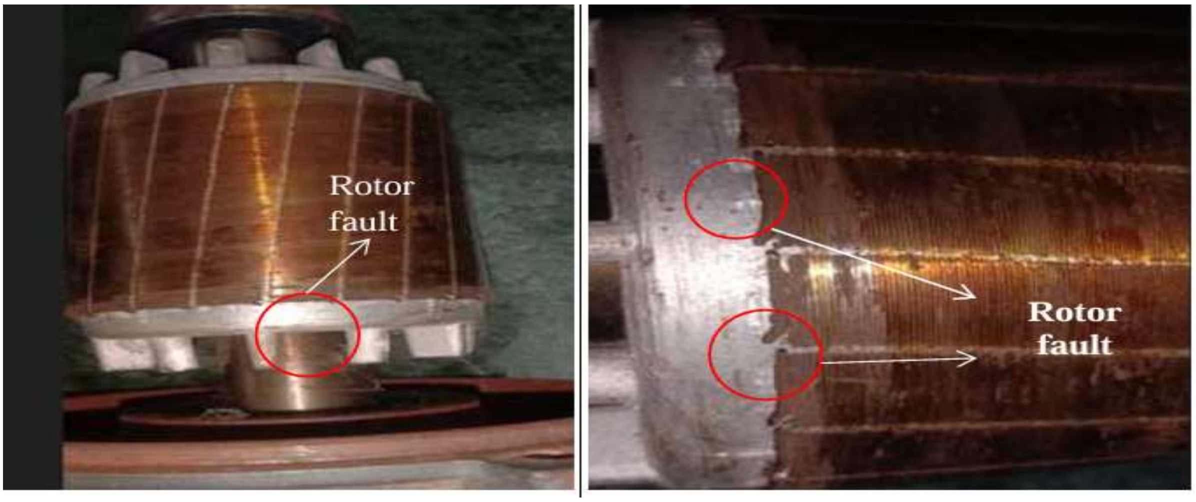

Fig 1. shows Overview of induction motor insulation and winding fault detection in using NIR Sensor

2. Induction Motor Faults

Induction motor faults can generally be categorized into:

2.1 Stator Faults

- Inter-turn short circuits
- Phase-to-phase faults
- Phase-to-ground faults
- Insulation degradation

2.2 Rotor Faults

- Broken rotor bars
- End ring defects
- Rotor eccentricity
- Rotor winding deterioration

2.3 Bearing Faults

- Inner race defects
- Outer race defects
- Lubrication failure
- Shaft misalignment

2.4 Electrical Faults

- Voltage imbalance
- Overvoltage
- Harmonics
- Transient conditions

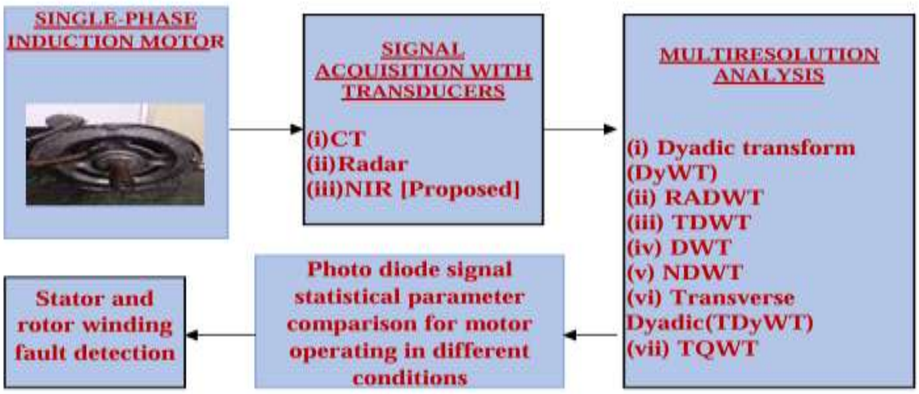

Fig 2. shows Overview of induction motor insulation and winding fault detection in using NIR Sensor.

INDUCTION MOTOR

↓

Stator and Rotor Magnetic Flux

↓

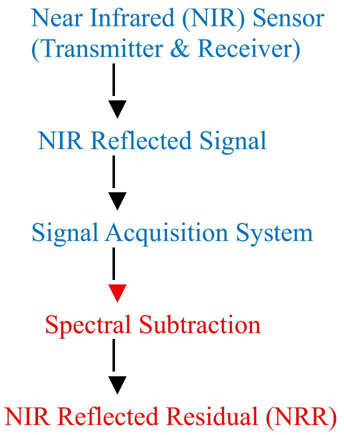

Fig 3 shows flow chart for various Methods in induction motor.

3. Conventional Fault Diagnosis Techniques

3.1 Motor Current Signature Analysis (MCSA)

Motor Current Signature Analysis is one of the most widely adopted techniques for induction motor fault diagnosis. The method identifies fault-related frequency components in stator current signals. Although effective, its performance is affected by load variations and electrical noise.

3.2 Vibration Analysis

Vibration monitoring detects mechanical faults such as bearing defects and rotor imbalance. Accelerometers are typically mounted on motor housings to acquire vibration signals.

3.3 Thermal Imaging

Infrared thermal imaging identifies abnormal temperature distributions caused by winding faults and insulation degradation. However, environmental conditions can affect measurement accuracy.

3.4 Acoustic Emission Monitoring

Acoustic sensors detect sound patterns generated by defective motor components. Signal interpretation becomes difficult in noisy industrial environments.

4. Near Infrared Sensor-Based Monitoring

Near Infrared sensing is a non-contact technique that monitors variations in magnetic flux generated within the air-gap region of induction motors.

The operating principle involves:

1. Emission of NIR radiation toward the motor air gap.
2. Interaction of NIR radiation with magnetic flux.
3. Reflection and detection by photodiode receivers.
4. Signal acquisition and processing.
5. Fault classification using statistical and signal processing techniques.

NIR sensors provide several advantages:

- Non-contact operation
- Reduced sensor installation complexity
- Early fault detection capability
- High sensitivity to insulation degradation
- Online monitoring capability

5. Signal Processing Techniques

5.1 Discrete Wavelet Transform (DWT)

DWT decomposes signals into multiple frequency bands and provides time-frequency analysis. It effectively identifies transient fault signatures and insulation degradation.

5.2 Dyadic Wavelet Transform (DyWT)

DyWT improves fault feature extraction by eliminating shift variance. It enhances fault detection accuracy under varying operating conditions.

5.3 Rational Dilation Wavelet Transform (RADWT)

RADWT provides flexible frequency resolution and improved extraction of resonance components. It is particularly useful for rotor and stator fault analysis.

5.4 Tunable Q-Factor Wavelet Transform (TQWT)

TQWT enables adaptive adjustment of the quality factor and facilitates accurate separation of oscillatory fault components. It offers excellent performance in identifying winding and insulation deterioration.

6. Comparative Analysis

Technique	Advantages	Limitations
MCSA	Simple implementation	Sensitive to load variations
Vibration Analysis	Effective for mechanical faults	Requires sensor mounting

Thermal Imaging	Visual fault localization	Environmental influence
Acoustic Monitoring	Non-invasive	Noise sensitive
NIR Monitoring	Non-contact, early detection	Requires signal processing

The comparison indicates that NIR-based approaches provide superior performance for early-stage fault detection when combined with advanced wavelet analysis methods.

Table 1 RADWT processed signal statistical values

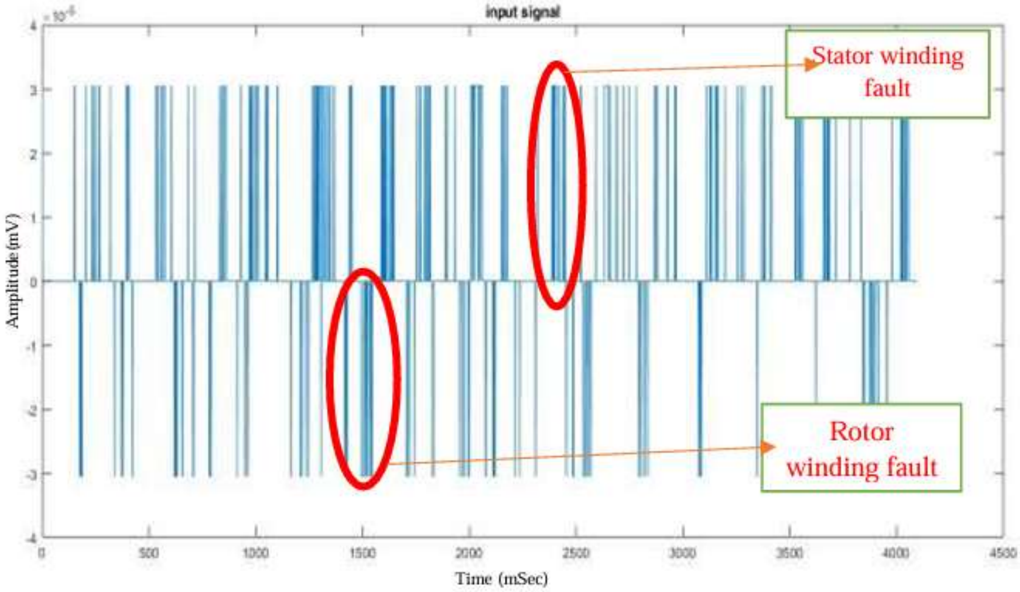

Fig 3 Raw input signal with stator & rotor wind fault (Burt-5x7 X Haar-detalp)

7. Future Research Directions

Future investigations may focus on:

- Artificial Intelligence based fault classification
- Deep learning assisted NIR signal analysis
- IoT enabled remote monitoring
- Digital twin models for predictive maintenance
- Hybrid sensor fusion approaches
- Real-time cloud-based diagnostics

These developments can significantly improve industrial predictive maintenance systems.

8. Result and Discussion

RADWT based winging fault in induction motor is analysed and inefficient due to certain operations such as the Hilbert transform, envelope detection, instantaneous frequency estimation, never suits for oscillatory signal processing.

TQWT accurately detects low and high frequency NRR signal components. NIR-based winding and insulation fault diagnosis are compared with current signatures and radar signals. NIR sensor-based NRR signals classify insulation and winding faults 92% accurately compared to current signal signatures from 50 motors. NRR-TQWT signal Kurtosis and SD range identifies the winding and insulation faults.

NIR signal-SUB BAND STATSTICAL VALUES						
Motor condition	**Fault free**	**Motor operated at loaded condition**	**Stator winding insulation fault**	**Stator winding fault**	**Rotor winding insulation faulty**	**Rotor winding fault**
Mean	19.6335	18.1118	-0.578583	2.65274	-0.842193	0.0233102
SD	**534.637**	**306.068**	**148.367**	**339.385**	**273.705**	**139.527**
Variance	198910	41464	24080.2	10994	80288.6	21361.4
Skewness	0.35557	2.59574	-0.510743	29.3117	29.4383	-0.476705
Kurtosis	**4.16748**	**49.5488**	**20.691**	**5783.95**	**6877.32**	**22.1657**

Table 2 RADWT processed signal statistical values

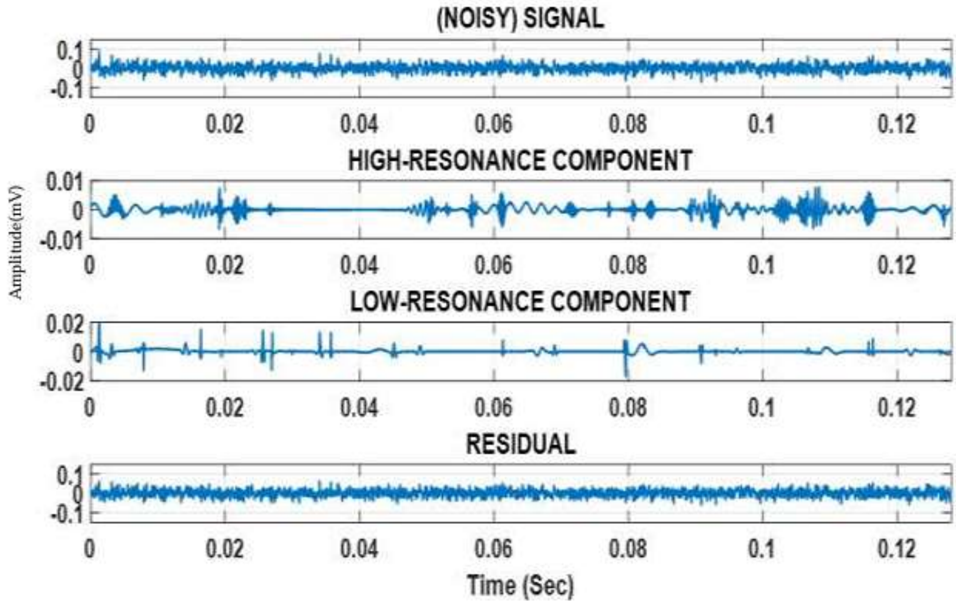

Fig 4 Stator winding Fault shows the noisy signal, high resonance component and low resonance component – RADWT

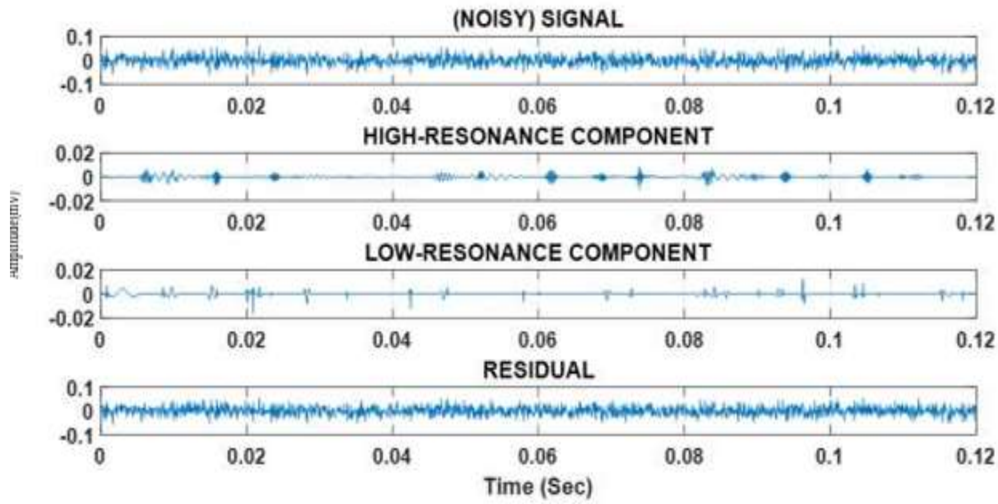

Fig 5 Rotor winding faults -RADWT

9. Conclusion

Condition monitoring plays a crucial role in improving induction motor reliability and reducing maintenance costs. Traditional monitoring methods provide valuable information but often suffer from sensor placement constraints and signal interference. Near Infrared sensor-based monitoring offers a promising non-contact alternative capable of detecting stator, rotor, and insulation faults during motor operation. The integration of NIR sensing with advanced signal processing techniques such as DWT, DyWT, RADWT, and TQWT enhances fault detection accuracy and supports predictive maintenance strategies. Future integration with artificial intelligence and IoT technologies will further expand the capabilities of NIR-based motor monitoring systems.

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