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Advanced Techniques of Health Monitoring of Single-Phase Induction Motors: Overview

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Abstract: *SPIMs require reliability because they have extensive use in different kinds of industrial and domestic applications; lately, in the case of SPIMs, over several decades, the scenario has built an immense concern with respect to them. As in the past decades, various techniques of health monitoring together with diagnoses research studies have been formulated in order to guarantee a healthy lifetime with the efficiency of SPIM. This chapter will provide a comprehensive overview of health monitoring techniques that ranges from vibration analysis, acoustic noise monitoring, thermal imaging, advanced signal processing, to IoT-based systems. Further, automation of fault diagnosis by introducing artificial intelligence and fuzzy logic, problems encountered such as environmental interference, cost, and data security, and some future research avenues toward developing the robust and scalable solution are discussed*

Keywords: health monitoring system

I. INTRODUCTION

SPIMs are the most abundant usage motors in industries, homes, and agricultural sectors because of their simple structure, higher reliability, and easy maintenance. However, recurring mechanical stress, electrical imbalances, and environmental conditions give birth to mysterious failures. Effective health monitoring systems are a critical requirement for improving motor reliability, minimizing downtime, and cutting down maintenance costs. This paper provides an all-inclusive overview of conventional and modern health monitoring techniques with advantages, disadvantages, and possible implementations.

II. CONVENTIONAL MONITORING TECHNIQUES

2.1 Vibration Monitoring

The most used technique for fault diagnosis is vibration monitoring. This technique can be used to detect bearing faults, rotor imbalance, and misalignments. Vibration signals are captured by accelerometers; the signals are analyzed in time and frequency domains for the extraction of fault signatures [1, 2]. It is based on tracking periodic vibrations that are due to some particular defects or faults, including wear and tear of the bearings and misalignment in the rotor. Advanced techniques include fast Fourier transforms or envelope analysis of vibration, with increased diagnostic capability. Because the method relies on interference from unwanted external noise, it is an extremely significant challenge to acquire an accurate perception of data at industrial locations. Additionally, vibration sensors are very expensive and not widely applied in low-cost applications.

2.2 Acoustic Noise Monitoring

It makes use of acoustic noise patterns generated when motors are operating in the monitoring of defects. The increase in air gap eccentricity or looseness in the parts, due to mechanical misalignment, is associated with the change in noise amplitude and frequency [2, 3]. It catches the wave of the produced sound wave and later uses it along with other high order filtering to enhance this extracted noise-based fault signal from it. It is a place-specific method about faults, mainly in inaccessible space within the motor. However, it cannot practically be used in such noisy environments of industrial plants due to domination of background sounds above noise which seems to result from faults. Though these technologies have some limitation, acoustic noise monitoring technologies have been improved much due to sophisticated noise-canceling algorithms and machine learning.

2.3 Thermal Monitoring

Thermal scanning is determining temperature in the motor so that the cause of heat generation due to electrical mis-match, friction overheating, and insulation failures can be detected. Infrared thermography records hotspots and unusual thermal activity by scanning without any contact [4]. Temperature sensors fitted at pivotal component parts of motors can monitor the temperature generated continuously so that thermal faults can be detected even before they erupt. This has been very useful in overloads, bad ventilation, and the abnormalities of friction in bearings. But for small faults which are generating minute heat and so on, such as misalignments, electrical noise, thermal monitoring is not an effective idea. Calibration of the sensors is an important prerequisite to obtain viable output.

III. ADVANCED TECHNIQUES OF MONITORING

3.1 Advanced Signal Conditioning

Advanced techniques of sophisticated signal processing for fine faults detection and classification are wavelet transforms, Hilbert-Huang transforms, and Fourier analysis. This technique decomposes the sophisticated signal into its different frequency components. This property may detect transient faults, such as short electrical disturbances or swift mechanical impacts [5]. For example, the wavelet transform is very helpful in detecting the non-stationary signals occurring due to start-up of motors or sudden alteration in load. The above mentioned techniques can even further increase the accuracy and dependability of fault classification, if used in combination with the machine learning algorithm. Moreover, the real-time signal processing system offers immediate feed back. Consequently, appropriate correcting actions can be taken in advance.

3.2 IoT-Based Monitoring Systems

IoT has made SPIM health monitoring a real-time system because of data acquisition, remote diagnostics, and predictive maintenance. The IoT-based monitoring system uses sensors for the detection of vital parameters such as current, voltage, vibration, and temperature. After detection, data are transferred to cloud-based platforms for further analysis [6, 7]. These systems use high-order algorithms that may recognize anomalies and possible failure which could be applied to avoid system failure. In IoT systems, it also reduces field visits and enables distant control where many motors can be checked using centralized control. With IoT systems implementation comes challenges that face data security and reliability in the network setting, plus integration of installed infrastructure already available.

3.3 AI and Fuzzy Logic Implementation

With the aid of AI and fuzzy logic designs, fault diagnosis is entirely automated and now fully dependent on human data interpretation. SVM, ANN, and deep learning models train fault pattern on historical data so that the health of a motor could be predicted [8]. The fuzzy logic approach is more suited to uncertainties and imprecise inputs. It is more appropriate for real-world applications. For instance, a motor's health can be classified as "good," "moderate fault," or "severe fault" depending upon the input parameters by developing a system with fuzzy logic-based on the condition. These AI-based techniques do not only increase the accuracy of diagnosis but also allow the design of self-learning systems that learn new fault conditions over time.

IV. KEY CHALLENGES

Despite all this progress, problems are still attached to SPIM health monitoring. These are:

- Sensor Cost: The high-end sensors for vibration, thermal, and acoustic monitoring are still very costly, making it not viable for low-budget applications.
- Environmental Noise: In the industrial environment, the noise of the external noise and the background noise will generate false positives or simply ignore the fault altogether.

- Data Security: The IoT based systems are vulnerable to cyber attacks, so there should be strong encryption and authentication. Data-related sensitive information should be protected.
- Scalability: Monitoring systems for mass operations with numerous motors require technical and financial investments.
- Energy Efficiency: Because it continuously monitors and transfers data, it may use more energy. So, energy-efficient systems low-powered are needed.

V. FUTURE RESEARCH SCOPE

Future scopes of SPIM health monitoring include:

- Cost savings: Sensor technologies which are low-cost for sensing and an open-source tool to evaluate the data in this aspect.
- Edge Computing: It applies local processing by an edge computing unit that reduces latency and depends less on cloud infrastructure.
- Advanced AI Models: Hybrid models of machine learning, deep learning, and fuzzy logic that ensure effective fault diagnosis.
- Cybersecurity: The data security is ensured through improved encryption methods, intrusion detection systems, and secure communication protocols.
- Energy Optimization: Efficiency of IoT devices and systems is developed in an energy-consuming manner.
- Environmental Robustness: Noisy algorithms and sensors developed that can protect IoT in harsh industrial environments.

VI. CONCLUSION

With modern technological advancement, health monitoring of single-phase induction motors have been enforced to understand in a highly drastic revolution. From olden days traditional vibration and thermal monitoring to a new age IoT-based and AI-based approaches for SPIM, reliability and accuracy have improved greatly in fault diagnosis. However, some of the issues such as the cost being quite high, environment causing interference, and the security of data can pose a significant challenge. Hence, further research work will aim to design these types of monitoring systems so that the long-term efficient use of SPIM will be ensured.

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