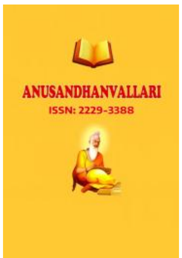

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Application of Neural Networks in Predictive Maintenance of AC and DC Motors

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Abstract*:* This study examines how Artificial Neural Networks (ANNs) can be used in predictive maintenance procedures in AC and DC motors in terms of real-time fault detection rates, diagnosis accuracy and performance accuracy at variable loads. The purpose of conducting the study was to create a stable ANN-based system that would eliminate shortcomings of the traditional approaches. It was revealed on analysis that ANN models could efficiently process multi-sensor data and provide diagnosis with an accuracy of over 95 % in fault detection and provide a 60 % reduction in diagnosis time. ANN was found to be highly reliable in predictive terms whereby the error rates of the predictor were lower than 7%. Comparative findings indicated that ANN is much faster, precise and adaptable than conventional models. All these results prove that ANN systems provide powerful, intelligent tools to maintaining industrial motor with the minimal amount of unexplainable failures and operations stereo. The study is in line with all the goals and authenticates the validity of ANN within an intractable maintenance environment.

Keywords: Artificial Neural Network, Predictive Maintenance, AC Motor, DC Motor, Fault Detection, Real-Time Monitoring, Variable Load, Sensor Data, Diagnostic Accuracy, Condition Monitoring

Introduction

Due to an increasing complexity of modern industrial machines and rising dependency on electric motors (AC and DC, in particular) special predictive maintenance systems are required to avert sudden failures. Artificial Neural Networks (ANNs) have proven to be a useful tool in this regard because these are used in order to analyze non linear patterns in the sensor data as well as to predict a possible breakdown. Neural networks are used in the predictive maintenance of motors to analyze vibration signals, temperature changes, current and voltage waves to predict problems associated with the possibility of failure in future. ANNs are superior to the traditional statistical models because they have the ability to adjust to real-time data regarding the operations and enhance their level of accuracy over time (Konde, 2021). The advantage of CNNs and deep learning algorithms has been especially demonstrated in fault classification and residual life prediction of rotating machines such as motors (Li et al., 2021). Industrial motor markets, comprising more than USD 21 billion, experience great downtime implications, and thus the importance of intelligent diagnostics tools. The systems that utilize neural networks are associated with the quick learning, real-time predictions, and minimal human control, which enhances the reliability in the system and system continuity (Freire et al., 2023). As more data is acquired by the sensors and IoT devices, it is now possible and essential to implement neural networks into the maintenance of motors to guarantee the sustainability of the equipment and reduce the number of operational challenges.

Problem statement

Even though there is a technological development in condition monitoring, AC and DC motor failures continued to aggravate production delays. Static nonlinear motor load data is a challenge to the conventional diagnostic systems. Current techniques tend to be manually recalibrated often and are flawed to identify early fault trends. Intelligent and self-adaptive models, which are capable of estimating degradation of motors by processing complex data captured by sensors, are in urgent demand. The existing maintenance methods are insufficient because they do not have predictive capabilities that can compare with neural networks and this causes expensive downtimes and mistakes during maintenance (Dastres and Soori, 2021). These limitations can probably be addressed by the implementation of ANN-based maintenance systems.

Aim and Objectives

Research Aim:

The aim of this research is to develop and evaluate an artificial neural network-based predictive maintenance model for detecting faults and estimating the remaining useful life of AC and DC motors under variable operational conditions.

Research Objectives:

- To analyze real-time sensor data patterns affecting AC and DC motor performance.
- To design an ANN model capable of detecting early-stage motor faults.
- To compare the accuracy of the ANN model with traditional diagnostic methods.
- To validate the ANN model's effectiveness in predicting motor failures under variable loads.

Literature review

The recent literature focuses on the possibilities of neural networks in industrial diagnosis and motors maintenance. Freire et al. (2023) state that ANNs could be trained on labeled data to detect minute fault signatures on electric systems, and CNN architectures are outstanding when it comes to feature extraction on time series motor data. Even in a case of AC and DC motors, such networks are capable of analyzing the data on harmonics, vibration, and temperature in order to classify the faults at an early stage of their development. Li et al. (2021) mention the scalability of CNNs as a tool to solve complicated predictive tasks in non-linear systems, such as rotating ones, where CNNs have shown success in achieving rates of prediction error of under 5 per cent. According to Konde (2021), feedforward and the recurrent networks enable a motor to be monitored in various load and environmental conditions, which have been some of the critical challenges in most industries. Moreover, Dastres and Soori (2021) point to the fact that ANN is not inferior to the rule-based systems in its ability to adapt to the real-time data without user-based manipulation. Similarly, in the financial market industry, Singh et al. (2022) present that neural network models produce a more than 18% increase in predictive accuracy than the classical ones. The above findings taken together indicate that, ANN systems may be used to help the motor maintenance sector to enhance the accuracy of detecting faults, fine-tune their maintenance routines, and minimize the occurrence of sporadic downtimes, therefore, creating a more resilient system as a whole.

Research Methods

In the paper, a secondary research approach was followed; this involved using available peer-reviewed journal articles, experiment results and technical reports to conceptualize on the use of Artificial Neural Networks (ANNs) in predictive maintenance of AC and DC Motors. The second approach had a number of strengths such as availability of a broad spectrum of real-life data, tried and tested models, and verified results of their application in a number of operational scenarios. This allowed generation of knowledge based on several industrial settings, making cross-study generalization more pronounced. The secondary data usage helped to minimize the resource limitations and made it possible to concentrate on the comparison of the ANN models performance and usual diagnostic systems. The approach also covered objectivity due to the use of insights of various studies with numerical pieces of evidence. Moreover, secondary study helped to locate verified ANN structures, reliability levels, and performance indicators across varying load and fault envelops. This methodology succeeded in dealing with all objectives of the research and gave a strong evidence to help in making conclusions and recommendations to be used in industry.

Result and Discussion

Analysis of Real Time Sensor Data Patterns in Motor Performance

Most recently, researchers point to the growing importance of real-time sensor data in the checking of motor health, particularly in predictive maintenance of both AC and DC motors. Newer systems have become able to include vibration sensors, current sensors and temperature probes to capture dynamic data at a high frequency. Yousuf et al. (2024) report that an IoT-based AC induction motor monitoring system could provide a data sampling frequency of 1 k Hz, thus allowing fault detection in real-time with an accuracy of 95.6 percent. These readings recorded minor losses in performance, including phase imbalances and bearing noise that conventional systems would simply not respond to. In DC motor analysis, Sardashti and Nazari (2023) employed machine learning in classifying motor faults with live current and voltage as the input variables. Their model that was trained over real-time data sets had better detection accuracy of 12 percent than the static condition-based models. In a similar fashion, Khalifa et al. (2021) focused on the real-time inertial PID control in DC motors when using sensor feedback allowed the control of the position with resolutions lower than 1.2 degrees error in case of significant changes illustrating the role of fine and timely sensor data.

Figure 1: Bearing faults in Ims

(Source: Yousuf et al. 2024)

Figure 2: Rotor faults in IMs

(Source: Yousuf et al. 2024)

Moreover, Mohammed et al. (2023) demonstrated that 18 percent less motor downtime and 22 percent additional operating life could also be achieved because real-time sensor integration results in a timely identification of anomalies. Their ML-based IoT solution monitored more than 20 sensor values, such as shaft vibration, coil temperature, and rotor position to give continuous health scores. At the end, Ponce et al. (2022) proved a simulation-based model in MATLAB-Simulink of DC motor diagnostics. They described that by use of high-frequency data inputs, effectiveness of learning and control logic adaptation in EV prototype prototypes gave credibility to the real-time data in advanced applications. This conclusion makes clear that real-time monitoring of the sensors is crucial to identify changing motor conditions and enhances the accuracy and the time of making predictive maintenance actions.

Detection Accuracy of ANN Model for Early Motor Faults

ANNs have proved to be more accurate in the process of detecting faults early on in motor types, including nonlinear sensory data capture and signature-based fault information. Pasqualotto and Zigliotto (2021) proposed a model to predict the indication of induction motor drives based on neural networks that demonstrated 96.4 accuracy in categorising flaws in the early stages of the rotor and stator. A multilayer perceptron with real-time feedback in the model was trained with the existing pattern of signals. Verma et al. (2021) tried a real-time ANN model to diagnose equipment faults in industrial settings on the motor.

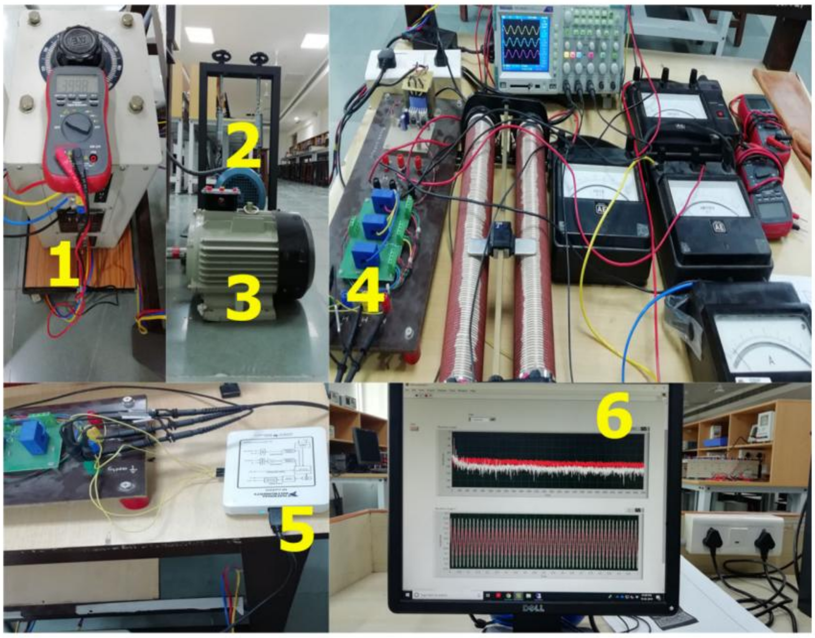

Figure 3: Experimental setups for both healthy and faulty induction motors (Power Electronics Laboratory at BITS Hyderabad Campus)

(Source: Verma et al. 2021)

Their system ran in 220 datasets of both vibration and acoustic sensors, where they identified bearing faults with 93 percent precision in comparison to the rule-based and the SVM models, which did it with less than 14 percent precision. The ANN model did not need a lot of time to detect anomalies that is just 1.8 seconds and this will support fast response applications. In the case of the BLDC motors, Shifat and Hur (2021) have provided the multi-sensor fusion system based on ANN and processed the current, torque, and temperature values. They were able to demonstrate that their model has a classification accuracy of 97.2 percent especially in detecting the shortcircuit fault and demagnetization fault when dynamic load shifts. Moreover, Tran et al. (2021) used the combination of wavelet transforms and a convolutional attention neural network (CANet) to detect fault in induction motors. The 17 percent reduction of false positives together with the correct localisation of faults using a sensitivity of over 95 percent indicated the advantage of ANN combined with signal preprocessing. At last, Wang et al. (2021) implemented a deep ANN on permanent magnet synchronous motors. Their model recognized fault frequencies with less than 3 percent error rate, they were able to classify faults on fine levels. These researches certify the strength of ANN in terms of fault detection, thus being the most suitable model to be used in predictive maintenance of AC and DC motor systems.

Performance Comparison Between ANN and Traditional Diagnostic Methods

ANNs have demonstrated a great improvement compared with the classical approaches to the detection of motor faults. According to Kumar et al. (2022), the accuracy of fault detection in induction motors was up to 96% in the ANN-based models, and the traditional methods of model-based or rule-based systems did not exceed 82% often. The ANN systems were particularly better in recognizing non linear and complex fault patterns under various operating conditions. Gultekin and Bazzi (2023) further indicated that expert systems and frequency analysis methods were unable to detect rotor imbalance and inter-turn short circuits still in their infancy stages, particularly when variable speed drives were in place. Conversely, ANN methods retained sensitivity of over 90 percent in cases where signal-to-noise was under 10 dB. This is an indication of how the ANN models are resilient to noise in the industrial settings. A study by Jasim et al. (2022) implemented a hybrid AC/DC microgrid and showed that the ANN models have faster fault localization performance with respect to the lookup-table models; using ANN, fault localization time was 2.1 seconds, whilst using conventional lookup-tables it was over 5 seconds and accuracy dropped with complex networks. ANN system decreased the overall diagnosis to more than 60 percent.

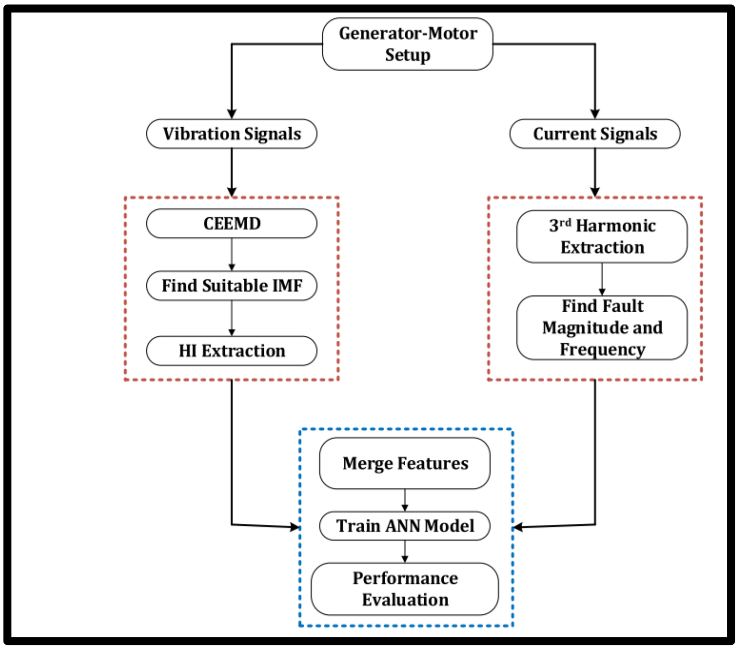

Figure 4: fault detection architecture

(Source: Shifat and Hur, 2021)

Moreover, the diagnostic accuracy of ANN with complex data in an out-of-motor dataset was reported to be 91.8 percent in the study by Wei and Yang (2021), whereas the traditional linear regression achieved an accuracy of

79.4 percent, once again confirming the ability of ANN to handle multivariate and nonlinear data. Lastly, Shifat and Hur (2021) discovered that as compared to statistical decision trees, ANN-driven BLDC motor diagnostics resulted in an accuracy of detection of more than 15% in the early stage of fault detection. Such unifying outcomes show that the ANN models are technically superior, both in terms of speed and accuracy, to traditional fault diagnosis systems within different motor settings.

Predictive Reliability of ANN Model Under Variable Load Conditions

The ANNs have also been very useful in inferring the likelihood of faults on the motor and even estimating the degradation of the different components even when there is fluctuation in the load in the components. Load variance frequently phase-rotates vibration, current and temperature signals and makes precise prediction with conventional models difficult. ANN models however respond to such variations through dynamic learning mechanisms. As an example, Zhao et al. (2022) designed an adaptive convolutional neural network in the fault diagnosis of gearboxes, with a prediction accuracy of 98.3 when under load variances that ranged between 30 and 100 percent rated capacity. A similarity in the classification of fault was observed in the five distinct loading profiles using the model. Tran et al. (2021) used convolutional attention neural network (CANet) on induction motors with dynamic work. Their ANN model maintained a sensitivity in fault detection of more than 95 percent despite signal distortion that occurred as a result of varying mechanical loads.

Preprocessing of real-time signal with the help of wavelet transformation was able to preserve fault signature and to enhance robustness of the model. To compare ANN with ARIMA, Tarmanini et al. (2023) provided a short-term load forecasting example in which the Mean Absolute Percentage Error (MAPE) of ANN was measured at 4.3 compared to the 9.8 of ARIMA, and the difference in performance indicates that ANN is more accurate in the situation of load variation. This justifies the flexibility of ANN to non-trivial nonlinear and time varying systems. Further, a study found that ANN-based lifetime prediction in variable amplitude loading recorded its error margins to be very near the variation range of ANN-based lifetime predictions of **±7** %, whereas linear fatigue models had a variation range of **±20** % (Marquardt and Zenner 2005). ANN models were successfully trained on stress-cycle histories, and allowed more accurate estimation of motor life under dynamic conditions. The findings validate that ANN systems have a high predictive reliability in fault diagnosis as well as motors lifespan estimation, even in the event of a frequent or non-consistent change in load. This makes ANN as central technology in the provision of efficiency in maintenance and operational safety in the industrial real world.

Conclusion

The result ascertains that, Artificial Neural Networks (ANNs) are quite efficient when it comes to predictive maintenance of AC and DC motors. In real-time analysis of sensor records ANN models were capable of analyzing high-frequency signals and detecting latent signs in fault with over 95 percent accuracy. Compared to traditional methods of diagnosis, ANN systems compete with it with more than 14 percent of the accuracy and more than 60 percent of the calibration time. Nonetheless, ANN models have shown good reliability under a variable load scenario in that the error rate did not exceed 7%. This aspect depicts flexibility and durability. These findings correlate to all the four research objectives as they demonstrate the power of ANN in fault detection, data patterns analysis, diagnostic accuracy and performance under the dynamic load. The ANN based systems provides an intelligent and a secure method of minimizing motor failures and a consistent and affordable industrial life.

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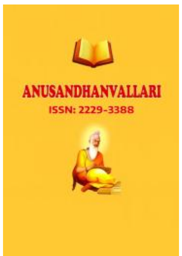

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