WIP: SCIM 의 저부하 조건에서 고장 감지를 위한 에너지 유도 오토인코더 기반 비지도 진단 프레임워크

Chibuzo Nwabufo Okwuosa, 허장욱*

국립금오공과대학교 기계시스템공학과, *국립금오공과대학교 기계시스템공학과

okwuosachibuzo3@kumoh.ac.kr, *hhjw88@kumoh.ac.kr

WIP: An Energy-Guided Autoencoder−Based Unsupervised Diagnostic Framework for Low-Load Fault Detection in SCIM

Chibuzo Nwabufo Okwuosa, Jang-Wook Hur*

Department of Mechanical Engineering, Kumoh National Institute of Technology,
* Department of Mechanical Engineering, Kumoh National Institute of Technology
okwuosachibuzo3@kumoh.ac.kr, hhjw88@kumoh.ac.kr*

Abstract

This work proposes an Energy-Guided Transformer Autoencoder (EGT-AE) for unsupervised outlier detection in stator winding faults of a three-phase induction motor at low-load. The model is trained exclusively on healthy operating data to learn normal system behavior and detect fault-induced deviations through reconstruction error analysis. Signal energy information is embedded into the transformer attention mechanism to enhance sensitivity to fault-related temporal patterns. Performance is compared against Bi-LSTM, Bi-GRU, GNN and lightweight transformer models using reconstruction error statistics obtained from healthy data, while four stator winding fault severity cases are employed to validate outlier detectability. The learned representations provide a foundation for future fault severity classification and real-time implementation.

I. Introduction

Induction motors are critical assets in industrial manufacturing, where failures can result in significant downtime and economic loss. Ensuring early and reliable fault detection is therefore essential for maintaining operational efficiency [1]. This work adopts an unsupervised learning framework for stator winding fault detection in a three-phase induction motor using multivariate time-series data at low-load conditions. An Energy-Guided Transformer Autoencoder (EGT-AE) is trained exclusively on healthy operating data to model normal system behavior and identify anomalies through reconstruction error analysis. By integrating signal energy information into the transformer attention mechanism, the proposed approach enhances sensitivity to fault-induced deviations and provides a robust foundation for intelligent condition monitoring and predictive maintenance applications.

II. Method

Our proposed framework consists of three core stages: data collection, offline model training, and real-time fault detection and classification. The collected data are first subjected to magnitude envelope analysis [2], which enhances fault-relevant characteristics in the signals. The proposed model is then trained exclusively on healthy operating data to achieve accurate signal reconstruction and to establish a baseline reconstruction error. Based on this healthy reference, an unsupervised outlier detection model is developed and evaluated using four stator winding fault severity conditions, corresponding to severity levels 1-4, as illustrated in Fig. 1. Furthermore, the learned latent representations and reconstruction error features are extended to a lightweight classification model for fault severity identification. The complete framework is subsequently validated under real-time data streaming conditions using ZeroMQ, enabling online fault detection and severity classification.

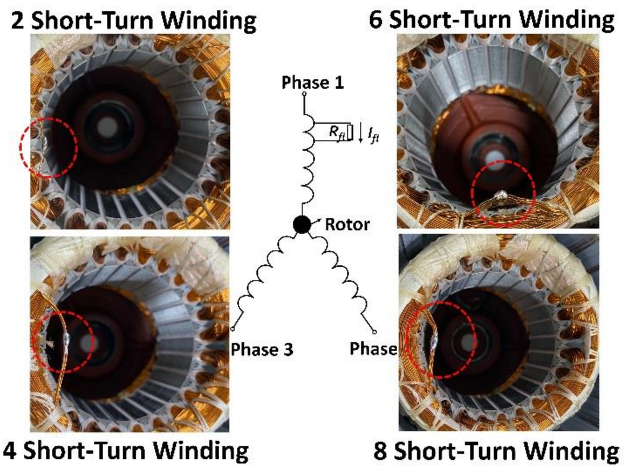

Fig. 1. Induced Fault Severity.

III. Conclusion

In summary, this work introduces an energy-guided diagnostic framework for unsupervised detection of stator winding faults in a three-phase induction motor using a transformer-based autoencoder. The proposed Energy-Guided Transformer Autoencoder, trained exclusively on healthy operating data, demonstrates promising capability for identifying fault-induced deviations across multiple severity levels under low-load conditions. By embedding signal energy information into the attention mechanism, the framework provides an effective representation of normal system behavior and a foundation for outlier-based fault analysis. Ongoing work focuses on extending the framework toward robust fault severity classification and real-time deployment, with the aim of improving the reliability and operational lifespan of induction motor systems.

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