Journal of Applied Science and Engineering Innovation, Vol.12, 2025, pp.5-10
ISSN (Print):
ISSN (Online):

Overview of Research on Fault Diagnosis Techniques in Electric Vehicle Motor Drive System

Lin Zheng, Mingkai Gao, Hailin Zhu, Lei Tian, Yuankun Zhou
College of Electromechanical Engineering, Dalian Minzu University, Dalian Liaoning 116605, China

Abstract: As a core component of electric vehicles, motor drive systems are prone to severe faults in motors and motor controllers under prolonged operation and complex working conditions, compromising the safety and stability of the vehicle. This paper systematically reviews the state-of-the-art research on fault diagnosis for electric vehicle motor drive systems. Firstly, it analyzes the primary fault types and their underlying causes in motor drive systems. Secondly, categorized by components, the paper summarizes existing fault diagnosis techniques, examining their developmental progress and application-specific characteristics. Building upon this analysis, the study also identifies challenges to be addressed in future development and prospects for future research directions, aiming to provide insights for enhancing the efficiency and reliability of motor drive systems.

Keywords: Electric vehicle; Motor drive system; Fault diagnosis

INTRODUCTION

The depletion of fossil fuels and the worsening problem of environmental pollution have prompted governments around the world to place great emphasis on the development of electric vehicles (Kuang, et. al.,2024). Compared with traditional fuel-powered vehicles, electric vehicles significantly reduce carbon emissions (Zhang, et. al.,2025). As the core component of electric vehicles, the motor drive system serves as the primary source of power, and its operating condition directly affects the vehicle's dynamic performance, energy consumption, and safety (Lei,2023). The electric vehicle motor drive system mainly consists of a drive motor and a motor controller. Due to its complex structure and the need for coordinated operation among components, various types of faults can easily occur during operation (Feng,2020). Typical faults include stator inter-turn short circuits, permanent magnet demagnetization, and controller IGBT open-circuit faults (Shi, et. al.,2025). Therefore, early fault warning of the motor drive system is a key factor in ensuring the safety and reliability of electric vehicles.

This paper focuses on the drive motor and motor controller within the motor drive system, systematically analyzing the classification and failure mechanisms of typical faults. It then reviews the current fault diagnosis techniques and finally presents prospects for future developments in fault diagnosis technologies for motor drive systems. The goal is to promote the advancement of these technologies toward greater intelligence and real-time capabilities.

COMMON FAULTS IN ELECTRIC VEHICLE MOTOR DRIVE SYSTEMS

As the core power unit of electric vehicles, the motor drive system plays a crucial role in ensuring overall vehicle operational safety due to its structural precision and high degree of functional integration. The system primarily consists of two key components: the drive motor and the motor controller. The structural diagram of the electric vehicle motor drive system is shown in Figure 1.

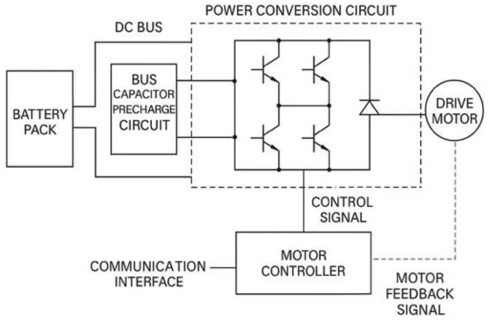

Figure 1. Schematic Diagram of Electric Vehicle Motor Drive System

In the electric vehicle motor drive system, the drive motor and motor controller achieve energy conversion through complex electrical and mechanical coupling. This high degree of functional dependency significantly increases the risk of faults. Anomalies in any component within the system can not only cause localized functional failures but may also lead to system-level faults through cascading effects, potentially compromising the overall vehicle safety. To establish a systematic fault diagnosis

Corresponding Author: Mingkai Gao, College of Electromechanical Engineering, Dalian Minzu University, Da1ian Liaoning 116605, China

framework, this section organizes typical fault modes based on component classification, focusing on fault types, causes, and possible consequences. The detailed information is presented in Table 1.

Table 1. Faults in Electric Vehicle Motor Drive Systems

Fault Component	Fault Type	Underlying Causes	Possible Consequences
Drive Motor Faults	Stator inter-turn short circuit	Voltage overload Overheating mechanical vibration	Efficiency reduction Local overheating Fire hazard
	Sensor fault	Material aging Mechanical wear Temperature and vibration	Failure of electronic control system functions Educed power performance
	Demagnetization fault	Poor heat dissipation High load operation prolonged vibration	Reduced output torque Temperature rise Further demagnetization
	Rotor eccentricity fault	Bearing wear or failure Rotor imbalance	Shortened bearing life Contact between stator and rotor Potential motor burnout
	Bearing fault	Lubrication failure Solid contaminants Mechanical wear	Power output decline Anormal noise Motor seizure
Motor Controller Faults	IGBT fault	Welding fatigue Thermal aging Abnormal control signals Voltage anomalies	Performance degradation Increases system losses
	CAN communication fault	Line faults Electromagnetic interference CAN transceiver damage	Motor unable to operate Vehicle loss of control
	DC bus short circuit fault	Capacitor aging Overvoltage insulation breakdown Conductive debris intrusion	Motor controller damage Thermal runaway Vehicle loses power

RESEARCH STATUS OF FAULT DIAGNOSIS TECHNOLOGIES FOR ELECTRIC VEHICLE MOTOR DRIVE SYSTEMS

Fault diagnosis technologies for electric vehicle motor drive systems are developing in a diversified manner, with signal analysis-based and intelligent diagnosis-based methods emerging as current research hotspots. As automotive motor systems evolve toward higher power density and greater intelligence, modern diagnostic frameworks increasingly rely on advanced signal processing techniques and intelligent diagnostic models to establish closed-loop mechanisms that integrate multi-dimensional feature extraction with adaptive decision-making.

Signal Analysis-Based Fault Diagnosis Technology

Signal analysis-based fault diagnosis technology first collects signals such as current and vibration, then performs filtering and normalization on the acquired data. Next, time-domain and frequency-domain features are extracted to identify faults. Finally, multi-signal analysis is used to locate the specific fault location.

Faults in Permanent Magnet Synchronous Motors

Wang, et. al. (2020) proposed a stator inter-turn short circuit fault diagnosis method for electrical faults in Permanent Magnet Synchronous Motors, based on the fusion of electromechanical signals. By combining heterogeneous signals such as negative sequence current difference and double-frequency components of stator vibration and integrating Support Vector Machines (SVM) with Dempster–Shafer evidence theory, high-precision fault diagnosis was achieved. Xu (2022) proposed a diagnostic method based on high-frequency signal injection. The method utilizes non-zero vector injection to stabilize the injected voltage amplitude, making it unaffected by fundamental modulation depth. The approach was validated to effectively distinguish stator inter-turn short circuit faults.

Ge, et. al. (2024) conducted co-simulation experiments by injecting square wave signals into both healthy and faulty motors and analyzed the waveform differences between them. Experimental results demonstrated the method’s effectiveness in identifying demagnetization faults. Ding, et. al. (2024) proposed the construction of an equivalent magnetic circuit model along the d-axis of the motor. After extracting and normalizing the characteristic signals, radar charts were drawn. By comparing the average radial air-gap flux density at each level between normal and faulty motors, demagnetization faults could be diagnosed.

Regarding mechanical faults in PMSMs, Zhang, et. al. (2024) collected stator current and vibration signals, performed wavelet packet decomposition to obtain corresponding energy distributions, and compared them with those of a healthy motor to determine the occurrence of rotor faults. The method was validated through simulation experiments. Bórnea, et. al. (2025) proposed a novel method for identifying early-stage distributed bearing faults by extracting specific acoustic features from the motor. Acoustic signals were collected, filtered through similarity testing to select effective sensor data, and conditioned. Key acoustic features were then extracted using recursive feature extraction and random forest algorithms. A model was built based on these features to achieve fault identification.

Faults in Motor Controllers

For power device faults in motor controllers, Zou, et. al. (2021) collected the three-phase currents during insulated gate bipolar transistor (IGBT) faults. After applying short-time Fourier transform to obtain the real-frequency images of the current fault signals, convolutional neural networks were used to locate and diagnose the time-frequency images. The results demonstrate that this method can accurately identify IGBT open-circuit faults. Zhao, et. al. (2023) proposed an open-circuit fault diagnosis method based on information fusion and a Deep Residual Shrinkage Network. By converting the time series of key signals into fused images using recurrence plots, the images are then input into the DRSN for fault diagnosis. Experiments showed an average accuracy of 98.44%.

To address CAN communication timeout faults, Zhang (2025) proposed a method that collects data from the CAN bus and reconstructs the signal using a segmented cubic Hermite interpolation algorithm. Anomalous states are identified by comparing the gradient of the fitted curve with a preset threshold. Experimental results showed an average fault recognition accuracy of 95.56%, with a false alarm rate controlled within 2.58%, demonstrating strong diagnostic reliability. Liu (2023) addressed noise issues in CAN communication signals by proposing a filtering method based on wavelet transform and Wiener filtering. The method applies wavelet threshold denoising to extract low-frequency wavelet coefficients, which are then processed with Wiener filtering. The reconstructed signal from these coefficients effectively suppresses noise while minimizing information loss. Simulation results confirmed the method’s high precision in denoising.

Tang, et. al. (2021) addressed DC bus capacitor aging by using a genetic algorithm to optimize the parameters for Variational Mode Decomposition (VMD) of line voltage signals. The voltage fault signals of the DC bus are decomposed into multiple intrinsic mode functions using both VMD and Complementary Ensemble Empirical Mode Decomposition (CEEMD), followed by wavelet decomposition. A Support Vector Machine diagnostic model is then built. Experimental results demonstrated that the VMD method optimized by a genetic algorithm significantly improved fault analysis accuracy compared to CEEMD. To suppress the significant harmonic distortion during motor drive system operation, Song, et. al. (2024) proposed an active damping control method based on impedance reshaping. The method first extracts the bus harmonic voltage signals and then applies optimal voltage compensation in a feedback loop to reshape the equivalent impedance at specific frequencies within the drive system, thereby reducing grid-side current harmonics.

Intelligent Diagnosis-Based Fault Diagnosis Technology

Intelligent diagnosis-based fault diagnosis technology is founded on data-driven approaches and self-learning mechanisms for feature extraction. It collects multi-dimensional signals such as current and vibration via sensors and then transforms these signals into feature images or vectors using techniques like Short-Time Fourier Transform and time-frequency analysis. Deep learning models are subsequently employed to automatically extract fault patterns and perform classification or prediction.

Compared to traditional methods, the key distinction lies in its independence from manual expertise or fixed physical models. Intelligent approaches dynamically optimize diagnostic logic through self-learning from data, enabling adaptability to previously unseen fault types.

Faults in Permanent Magnet Synchronous Motors

Niu (2022) proposed an intelligent classification and diagnosis method for stator inter-turn short circuit faults by accurately modeling the winding inter-turn short circuit fault using finite element modeling. The method combines spectral analysis and negative sequence current extraction for frequency-domain feature extraction and integrates operating condition parameters with a BP neural network. Validation results show that the online dynamic diagnosis error is less than 2%, providing high-precision, real-time fault diagnosis assurance for safe motor operation under harsh conditions. Wang, et. al. (2024) proposed a stator inter-turn short circuit diagnosis method for asynchronous motors based on d-q transformation combined with the whale optimization algorithm and Long Short-Term Memory networks. The d-q transformation is used to extract fault characteristic spectra from stator current, while the whale algorithm optimizes LSTM network parameters to build an efficient classification model. Experiments demonstrate a comprehensive accuracy of 98.3%, reliably identifying faults of varying severity.

For permanent magnet demagnetization faults, Walch, et. al. (2024) applied Fast Fourier Transform to motor phase current and constructed an anomaly detection algorithm by combining feature dimensionality reduction with one-class Support Vector Machine. To ensure proper initialization of the machine learning model, training was performed solely on healthy motor spectral data. Experimental optimization of harmonic selection strategies and metric parameters resulted in a fault detection accuracy of 99%. Li, et. al. (2022) proposed a CNN- and image recognition-based method for diagnosing demagnetization faults in built-in permanent magnet synchronous motors. The method converts stator current into grayscale images via autocorrelation matrices and uses CNN to extract features for diagnosis.

Chen, et. al. (2024) developed an improved end-to-end CNN-based intelligent fault model for bearing faults. By converting raw vibration signals into two-dimensional matrices for end-to-end training, the model achieves direct classification of bearing faults even under noisy conditions. Huang, et. al. (2022) proposed a method to construct a normalized indicator set for PMSM bearing faults and developed a bearing fault detection method based on Variational Mode Decomposition and multilayer perceptron. The method achieved an average accuracy of 95.4%, validating its advancement and effectiveness.

Faults in Motor Controllers

Wang (2024) proposed a rapid fault location method for IGBT short-circuit faults in electric vehicles by detecting the DC bus current combined with switching logic or bridge arm voltage. The fault-tolerant control adopts either a fault three-phase short circuit compensation or normal three-phase compensation strategy to suppress torque fluctuations. Validation shows this method effectively improves motor operational reliability under fault conditions. Jie, et. al. (2022) introduced a fuzzy genetic algorithm for IGBT fault detection, analyzing the DC measurement current in the frequency domain to determine IGBT open-circuit faults.

Li, et. al. (2020) addressed CAN communication anomalies in motor controllers by monitoring CAN communication status of components via a life signal sent by the motor controller. The method calculates the CAN frame loss rate and grades components based on severity, applying different handling measures accordingly. Yu (2024) proposed an intelligent fault detection technique for automotive CAN bus systems using data acquisition and feature extraction combined with an LSTM model to build a diagnostic system. Compared to traditional methods, this approach achieves higher detection accuracy, shorter processing time, and lower false alarm and missed detection rates, significantly improving fault diagnosis efficiency.

Zhao, et. al. (2023) presented an online monitoring scheme for DC bus capacitors in digitally controlled boost power factor correction converters, which requires no additional sampling devices. The single-test estimation error is less than 3.5%, and the average error across multiple tests is below 1.5%.

Yuan (2024) proposed a DC bus current estimation algorithm for motor drive systems based on the power conservation law. By compensating for non-ideal factors such as digital control delay and inverter dead-time, combined with stator current sampling correction and first-order low-pass filtering, the method achieves high-precision current estimation. Wang, et. al. (2024) proposed an online monitoring method to estimate the equivalent series capacitor of the motor drive converter's DC bus capacitor using long-period transient signal analysis. The method estimates the ESC by analyzing the long-period charge-discharge transient trajectory caused by load switching. Data comparison, simulations, and experiments verified the effectiveness and superiority of the proposed method.

DIAGNOSTIC TECHNOLOGY RESEARCH CONCLUSIONS

Fault diagnosis methods based on signal analysis have the advantages of strong real-time capability, directly analyzing the spectrum or time-frequency features of sensor signals, low computational resource requirements, clear physical meaning, and ease of expert interpretation of fault mechanisms. However, they rely on manually set thresholds based on experience, making it difficult to adapt to complex dynamic conditions or unknown fault types, and they have poor anti-interference ability. Intelligent fault diagnosis methods, on the other hand, automatically extract features through deep learning, adapting to complex nonlinear relationships and unknown faults, supporting high-precision diagnosis and predictive maintenance. However, they require a large amount of labeled data to train models, have high computational costs, and suffer from poor model interpretability, which affects the reliability of fault traceability.

In summary, signal analysis is suitable for simple real-time detection, while intelligent diagnosis excels in complex scenario prediction. When performing fault diagnosis of electric vehicle motor drive systems, methods can be flexibly selected according to the specific fault requirements to improve diagnostic efficiency and accuracy.

CHALLENGES AND OUTLOOK FOR FUTURE TECHNOLOGIES

Challenges

1) Current research on fault detection of motor controllers remains insufficient. Existing studies mainly focus on describing fault phenomena and analyzing failure mechanisms, while systematic exploration of diagnostic methods is relatively lacking. Due to the complex structure of motor controllers and the diversity of fault causes, the difficulty of diagnosis is significantly increased. Especially in complex scenarios such as multiple fault coupling and dynamic operating conditions, the accuracy and adaptability of existing diagnostic methods still need improvement. Therefore, the field of motor controller fault diagnosis continues to face numerous challenges and requires further in-depth research.
2) When electric vehicles operate during start-up, acceleration, braking, and various complex working conditions, system parameters continuously change, requiring the fault diagnosis system to possess high real-time performance and robustness. A major technical challenge lies in how to quickly capture, separate, and identify fault signals under non-steady state operating conditions, avoiding misjudgments caused by data acquisition delays or the inadequacy of analysis algorithms.
3) The motor drive system of electric vehicles involves multiple subsystems, including the motor, inverter, controller, and sensors, each of which may experience electrical and mechanical faults. A common issue in current research is the lack of clear fault localization, as these faults often occur simultaneously or alternately, increasing the difficulty of fault detection in the motor drive system.

Outlook for Future Technologies

1) Robustness Optimization for Coupled Faults. Coupled faults often involve noise and various interferences. By simultaneously analyzing the time-domain and frequency-domain features of current and vibration signals, fault-sensitive frequency bands can be automatically identified and enhanced, while non-essential signal fluctuations and interferences are suppressed. This enables the model to accurately distinguish overlapping fault characteristics under dynamic operating conditions, thereby improving diagnostic stability and anti-interference capability.
2) Applications of Artificial Intelligence. AI technologies are evolving toward multi-algorithm collaboration, adaptive learning, and practical implementation. By leveraging intelligent data generation techniques to expand the sample size, diagnostic results can become more transparent and trustworthy.
3) Multi-Source Data Fusion. With the increasing variety of sensors, future developments will focus on better integration of different types of data such as vibration, current, and temperature. By leveraging the correlations among these diverse data sources, the symbiotic relationships between faults in the motor drive system can be more effectively analyzed.

REFERENCES

Bórnea P Y, Vitor L A, Goedtel A, et al., 2025, "A novel method for detecting bearing faults in induction motors using acoustic sensors and feature engineering", Applied Acoustics, pp 234110627-110627.

Chen Y, Li G, Li A, et al., 2024, "End-to-End Intelligent Fault Diagnosis of Transmission Bearings in Electric Vehicles Based on CNN", Lubricants, vol. 12, no. 11, pp 364.

Ding S, He W, Hang J, et al., 2024, "Uniform demagnetization fault diagnosis for PMSM based on radial air-gap flux density and stator current", Proceedings of the CSEE, vol. 44, no. 1, pp 332-341.

Feng X, 2020, "Research on Development of Permanent Magnet Synchronous Motor Controllers for Battery Electric Vehicles", South China University of Technology.

Ge C, Dai B, Wang R, et al., 2024, "Signal injection-based diagnosis of demagnetization faults of Prius permanent magnet synchronous motors", Electrical Engineering, vol. 1, no. 1, pp 52-54.

Huang X, He Q, Chen W, 2022, "Bearing fault detection method of PMSM based on VMD and MLP", Journal of Mechanical & Electrical Engineering, vol. 39, no. 7, pp 911-918.

Jie W, 2022, "Fault Diagnosis of IGBT Single-Phase Bridge Arm Based on Fuzzy Logic Genetic Algorithm", Tehnički vjesnik, vol. 29, no. 2, pp 395-400.

Kuang X, Leng C, 2024, "Carbon Reduction Role of Green Technology Innovation in the Yangtze River Economic Belt: Effect and Mechanism", Jianghan Tribune, vol. 11, no. 11, pp 15-22.

Lei Y, 2023, "Research on model predictive control of new consequent-pole hybrid excitation motor for electric vehicle", Southeast University.

Li W, Wang J, 2020, "Fault handling method for CAN communication loss of pure electric vehicle motor controller", Beijing Automotive Engineering, vol. 1, pp 35-38.

Li Z, Wu Q, Yang S, et al., 2022, "Diagnosis of rotor demagnetization and eccentricity faults for IPMSM based on deep CNN and image recognition", Complex & Intelligent Systems, vol. 8, no. 6, pp 5469-5488.

Liu K, 2023, "CAN communication signal filtering method based on wavelet transform and Wiener filtering", Telecom Power Technology, vol. 40, no. 17, pp 120-122.

Niu X, 2022, "Research on stator winding fault diagnosis strategy of permanent magnet synchronous machine for electric vehicles", Master's thesis, Harbin Institute of Technology.

Shi T, Liu B, Yan Y, et al.,2025, "Opportunities and challenges of industrial application of fault diagnosis technology for motor drive systems", Proceedings of the CSEE, vol. 1, no. 15,pp 1-15.

Song J, Song W, Zhang Q, 2024, "Harmonic suppression strategy of grid-side current for small DC bus capacitor permanent magnet synchronous motor drive system", Transactions of China Electrotechnical Society, vol. 39, no. 18, pp 5668-5679.

Tang J, Pazilai Mahemuti, 2021, "Early fault diagnosis of DC bus capacitor in three-level inverter", Modern Electronics Technology, vol. 44, no. 24, pp 112-118.

Walch D, Blechinger C, Schellenberger M, et al., 2024, "Detection of Demagnetization Faults in Electric Motors by Analyzing Inverter Based Current Data Using Machine Learning Techniques", Machines, vol. 12, no. 7, pp 468.

Wang D, Gu H, Wei S, et al., 2020, "Inter-turn short circuit fault diagnosis of DFIG stator winding based on electromechanical signal fusion", Automation of Electric Power Systems, vol. 44, no. 9, pp 171-178.

Wang K, 2024, "Research on fault diagnosis and fault tolerant control for inverter IGBT of double-three-phase permanent magnet synchronous motor", Harbin Institute of Technology.

Wang X, Qin J, Geng M, 2024, " Asynchronous motor stator turn-to-turn short circuit fault diagnosis based on d-q transform and WOA-LSTM ", Electric Machines and Control, vol. 28, no. 6, pp 56-65.

Wang Y, Li R, Chen T, et al., 2024, "Online monitoring of a DC-link capacitor for a motor drive converter based on long period transient signal analysis", Power System Protection and Control, vol. 52, no. 16, pp 120-131.

Xu Z, 2022, "Fault diagnosis of permanent magnet synchronous machine with high frequency signal injection", Southeast University.

Yu Z, 2024, "Research on intelligent fault detection technology for automobiles based on CAN bus", Car Test Report, vol. 20, pp 5-7.

Yuan B, 2024, "Research on the estimation method of DC-bus current in permanent magnet synchronous motor drive system for electric vehicles", Huazhong University of Science and Technology.

Zhang H, 2025, "Fault detection method of CAN bus communication timeout for new energy vehicle", Telecom Power Technology, vol. 42, no. 4, pp 203-205.

Zhang S, Guo X, Wen D, et al., 2025, "Research on electric vehicle charging guidance strategies adapted to renewable energy consumption", Electric Age, vol. 1, no. 1, pp 154-157.

Zhang Y, Yang K, Yang F, 2024, "Rotor fault diagnosis of induction motor based on wavelet packet energy analysis and signal fusion", Electrical Measurement & Instrumentation, vol. 61, no. 4, pp 161-168.

Zhao Y, Davari P, Lu W, et al., 2023, "Online DC-Link capacitance monitoring for digital-controlled boost PFC converters without additional sampling devices", IEEE Transactions on Industrial Electronics, vol. 70, no. 1, pp 907-920.

Zhao Y, He Y, Xing Z, et al., 2023, "Open-circuit fault diagnosis method of DAB converter based on information fusion and deep residual shrinkage network", Electric Power Automation Equipment, vol. 43, no. 2, pp 112-118.

Zou S, Zhu J, 2021, "Fault diagnosis of brushless DC motor controller", Computer Knowledge and Technology, vol. 17, no. 30, pp 148-150.