A Bionic Visual Perception Optimization Method Adapted to Multiple Signal Intensities Within GIS

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ABSTRACT

Bionic visual perception technology captures optical signals from gas insulated metal enclosed switchgear (GIS) partial discharge by mimicking the biological visual system, achieving real-time detection and recognition of partial discharge phenomena under complex electromagnetic environments. However, existing technologies often consider only a single spectrum and do not account for differentiated thresholds for various discharge phenomena, affecting imaging accuracy. This paper proposes a multi-spectral bionic visual perception optimization method for GIS. First, a multi-spectral bionic visual perception framework is constructed. Second, an optimization problem is formulated to maximize the average imaging accuracy of all GIS discharge phenomena. Next, a two-stage event-driven deep Q-network (DQN) optimization method is proposed, learning the optimal light intensity change threshold through two-stage closed-loop feedback, including offline and online learning. Finally, the superior performance of the proposed method is validated through simulations.

KEYWORDS

Bionic Visual Sensing, GIS, Multi-Spectral, Discharge Phenomenon Sensing, Offline Learning, Online Learning

INTRODUCTION

Due to the iterative development of new power systems and the rapid expansion of power grid scale, increasingly stringent requirements are being placed on the reliability and safety of electrical equipment, especially high-voltage switchgear. Gas insulated metal enclosed switchgear (GIS), as a core component of the power grid, has been widely adopted in power systems due to its advantages of compact size and high reliability (Liu et al., 2019; Wen et al., 2019). However, due to issues such as insulation material aging, power system overload, and insulation defects, various discharge phenomena, including partial discharge, corona discharge, surface discharge, and breakdown discharge, can occur within GIS. These discharges can easily lead to insulation breakdown, equipment failure and fire, and electromagnetic interference, posing significant threats to the stable operation of the power system (Ren et al., 2021; Sun et al., 2024). Different types of discharge phenomena generate signals of varying intensities. For instance, partial discharge typically produces low-intensity signals, while breakdown discharge generates high-intensity signals (Bassma & Tayeb, 2018; Behrmann & Smajic, 2016; Jangra et al., 2023; Ma et al., 2024; Song et al., 2022). Therefore, to ensure the safe

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and reliable operation of GIS equipment, it is imperative to explore high-accuracy discharge detection methods for discharge phenomena with varying signal intensities.

Traditional internal discharge detection methods for GIS based on acoustics and electronics are vulnerable to issues such as signal attenuation and high complexity of data collection and analysis, leading to lower accuracy and sensitivity of discharge detection (Kawakami et al., 2021; Li et al., 2018; Liu et al., 2014; Zhang et al., 2024). Bionic visual perception technology, by mimicking the function and principles of the biological visual system, can capture the optical signals radiated from GIS partial discharge (Zheng & Wu, 2021). Based on image processing and pattern recognition algorithms, it analyzes the characteristics and states of these signals, enabling real-time detection and identification of GIS internal partial discharge phenomena in complex electromagnetic environments (Yuwei et al., 2023). In the field of GIS internal discharge detection, bionic visual perception methods have been extensively studied due to their strong anti-interference capability, high sensitivity and accuracy, and adaptability to GIS internal environments. Li et al. (2023x) proposed a bionic visual perception method for GIS discharge signal detection with optical fiber rod, whereby a fault diagnosis model was established for GIS discharge optical signals by analyzing the temporal signal characteristics of partial discharge optical signals. This improved the effectiveness and diagnostic reliability of GIS partial discharge detection. Ren et al. (2021) proposed a bionic visual perception method for GIS by using an ultra-sensitive three-band optical local discharge sensor, which achieved efficient clustering of multiple discharges and accurate identification of discharge phenomena without the need for signal intensity and phase resolution statistics. Song et al. (2022) proposed a multi-scale fusion bionic visual perception method for simulating GIS discharge signals, whereby micro-scale optical simulation was combined with macro-scale circuit simulation models to improve the accuracy of GIS partial discharge signals perception under temperature effects. Lu et al. (2022) proposed a bionic visual sensing method for detecting GIS discharge signals, whereby sensors based on bionic visual perception were employed to enable comprehensive acquisition of information of discharge pulse signals and enhance the sensitivity of GIS discharge detection. However, due to factors such as reflections and obstructions inside GIS equipment, these detection methods face challenges including long detection times and susceptibility to environmental changes, leading to lower accuracy in imaging GIS internal discharge phenomena.

In response to the above-mentioned challenges, scholars in relevant fields have optimized existing bionic visual perception methods. Common methods include multi-sensor fusion and artificial intelligence-based algorithm optimization (Sun et al., 2022). The multi-sensor fusion method improves the detection accuracy and reliability of GIS discharge signals by integrating different types of sensors. Zhao et al. (2023) proposed a damping alternating current voltage optimization method for GIS partial discharge bionic visual perception, which enhanced the effectiveness of insulation defect detection in GIS. Wu and Zheng (2021) proposed a bionic visual perception optimization method for GIS partial discharge based on fluorescent fiber optics, which significantly reduced electromagnetic signal interference and improved the accuracy of GIS discharge perception by connecting couplers to transmission fiber optics and converted light signals into electrical signals for display with an optoelectronic multiplier tube. On the other hand, artificial intelligence-based algorithm optimization uses advanced algorithms such as machine learning and deep learning to perform finer analysis and recognition of GIS discharge signals, thereby improving the accuracy and real-time capabilities of GIS detection. Tuyet-Doan et al. (2021) proposed a bionic visual perception optimization method based on deep neural networks (DNNs) to assess the discharge states in GIS, where an integrated model was designed to obtain confidence levels and thresholds for unknown faults within GIS equipment. Wang et al. (2023) proposed a bionic visual perception optimization method for GIS partial discharge based on semantic correction discriminative generative adversarial networks, significantly enhancing the accuracy of GIS partial discharge diagnosis with feature generation and classification modules. Nevertheless, the above methods fail to consider the variability in light intensity threshold changes for GIS discharge phenomena across different signal intensities, resulting in inadequate imaging