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Prediction of AC Breakdown Voltage of Different Electrode Configuration Using Artificial Neural Networks

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Abstract

The study focuses on the application of Artificial Neural Networks (ANNs) to model and predict the AC breakdown voltage in gas-insulated systems for different electrode configurations. Gas-insulated systems play a crucial role in the transmission and distribution of electrical energy, and understanding the breakdown characteristics is essential for designing reliable and efficient systems. The research investigates how different electrode configurations impact the AC breakdown voltage in gas-insulated environments. Traditional methods for studying AC breakdown involve complex theoretical models and extensive experimentation. The use of ANN offers an innovative approach to predict breakdown voltages by learning complex relationships from available data.

Keywords: *AC Breakdown Voltage, Electrode Configuration, Artificial Neural Network, High Voltage Engineering, Gas Insulated Systems.*

1. Introduction

In the past ten years there has been a tremendous increase in the interest in the electrical breakdown characteristics of gases. This has been fostered by the advances in equipment such as gas-insulated circuit breakers, substations, transmission lines, cables, current transformers, voltage transformers, and high-voltage generators. The objective of this review is to describe the general characteristics of gas breakdown and insulator flashover in gases in uniform or quasi uniform fields, and to discuss the various proposed mechanisms of breakdown [1-5]. It is well known that SF6 has excellent dielectric properties and is most commonly used insulated gas. Its disadvantages such as greenhouse effect, high-cost limit its application. For these reasons using the mixture of SF6 with inexpensive simple gas to minimize the problems. These gases are used as electrical insulation in for high voltage equipment The rationale here is that ANNs have the potential to provide a mechanism for dealing with multi-variant, often noisy, and possibly non-linear data sets, where an exact analytic model is either intractable or too time-consuming to develop. The fundamental process is to train an ANN structure using a database of measurements, and then assess the model's predicting ability using data that hasn't been seen before. The research investigates how different electrode configurations impact the AC breakdown voltage in gas-insulated environments. Traditional methods for studying AC breakdown involve complex theoretical models and extensive experimentation. The use of ANN offers an innovative approach to predict breakdown voltages by learning complex relationships from available data. In this paper, the insulation properties among C4F7N/ CO2 mixtures, dry air and CO2 were explored under the reduced-scale gas-insulated experimental device. The relationship between AC breakdown voltage and gas pressure was gained under the different electrodes and gap distances, and 0.6 MPa 7% C4F7N/93% CO2, 0.9 MPa dry air, 0.9 MPa CO2 all possess the capacity to be the insulating

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medium in eco-friendly gas insulated switchgear. Furthermore, the partial discharge experimental was also carried out to realize the decomposition products detection of dry air, which designs three common defect types including metal protrusion defects, air gap defects, and metal contamination defects. The decomposition products detection result shows that the contains of CO_2, CO, and NO_2 linearly increase with the increasing applied voltages and times, and the partial discharge defects are distinguished according to the ratios of c (CO_2 + CO)/c(NO_2) and c(CO_2)/c(CO). The results can provide the basis for the further development of eco-friendly gas insulated switchgear.

2. Methodology

- Data Collection: Gathering experimental data on AC breakdown voltages for various electrode configurations in gas-insulated systems. This dataset serves as the foundation for training and validating the ANN model. Feature Selection: Identifying relevant features and parameters influencing AC breakdown, such as electrode spacing, shape, material, and gas properties. These factors are crucial for constructing an accurate predictive model.
- Model Development: Constructing an Artificial Neural Network capable of learning and representing the non- linear relationships between electrode configurations and AC breakdown voltages. The network architecture, including the number of layers and neurons, is optimized for effective learning.
- Training and Validation: Utilizing the collected dataset to train and validate the ANN model. This involves adjusting the model's parameters to minimize errors and ensure its ability to generalize to unseen data.
- Model Evaluation: Assessing the performance of the developed ANN model through various metrics, such as accuracy, precision, and recall. This step ensures the reliability of the model in predicting AC breakdown voltages for different electrode configurations.
- Comparative Analysis: Comparing the predictions of the ANN model with experimental results and potentially with results obtained from traditional theoretical models. This comparison provides insights into the accuracy and efficiency of the ANN approach [6].

3. Electrode Configurations and Their Impact

Table 1 shows Electrode Configurations and Their Impact

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Electrode Configuration	Electric Field Distribution	Breakdown Voltage Behavior
Sphere-Sphere	Uniform	Higher breakdown voltage
Rod-Plane	Non-uniform	Moderate breakdown voltage
Point-Plane	Highly non-uniform	Lower breakdown voltage

4. ANN Architectures Used in Breakdown Voltage Prediction

Figure 1 shows Artificial Neural Network (ANN) Modeling Workflow.

- **Multi-Layer Perceptron (MLP):** Most commonly used for regression-based prediction.
- **Convolutional Neural Networks (CNN):** Applied for electric field distribution analysis.
- **Recurrent Neural Networks (RNN):** Used for time-dependent studies of breakdown characteristics.

5. Review of Existing Research

- **Study 1:** MLP-based ANN trained on GIS breakdown data, achieving an accuracy of 95%.
- **Study 2:** Hybrid ANN-Genetic Algorithm (GA) model improved prediction performance.
- **Study 3:** CNN-based model analyzed field distributions for identifying weak insulation spots.

5.1 Deep Learning in High Voltage Engineering: A Literature Review

This comprehensive review discusses the application of deep learning techniques, including ANN, in high voltage engineering. It covers various aspects such as partial discharge pattern recognition in GIS, which is closely related to breakdown phenomena. The review highlights studies where convolutional neural networks (CNN) were employed to identify partial discharge defects in gas-insulated switchgear, achieving significant accuracy [7].

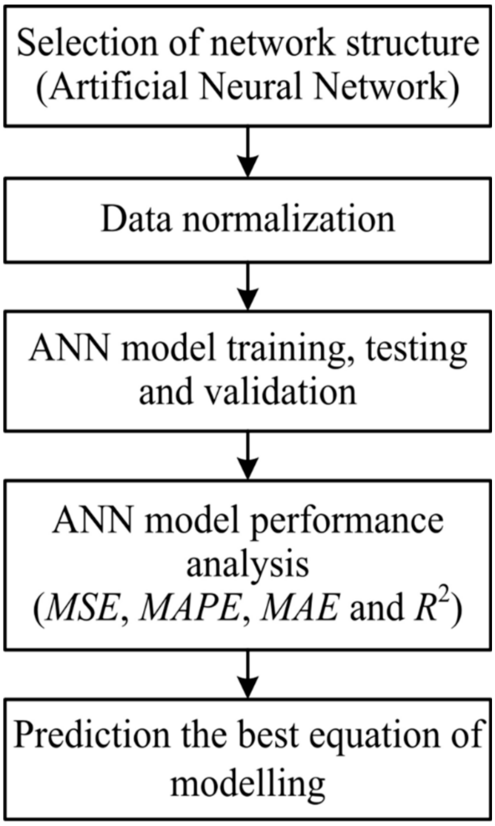

Figure 1 Artificial Neural Network (ANN) Modeling Workflow

5.2 A MLP Neural Network-Based Unified Intelligent Model for Predicting Short-Gap Breakdown Voltages in Air

This study presents a Multi-Layer Perceptron (MLP) neural network model designed to predict breakdown voltages across different electrode configurations, specifically in air. The research focuses on configurations such as sphere-plane and sphere-sphere electrodes. The model demonstrated high accuracy, with mean squared errors around 3.82% for certain configurations, suggesting the potential of ANN in predicting breakdown voltages across various electrode setups.

5.3 Partial Discharge Recognition Using Neural Networks: A Review

This review delves into the application of neural networks for partial discharge recognition, a phenomenon closely related to breakdown events in GIS. The paper discusses various ANN architectures and their effectiveness in identifying partial discharge patterns, providing insights into how ANN can be utilized for modeling breakdown phenomena in GIS.

5.4 Artificial Neural Network Application for Partial Discharge Recognition: Survey and Future Directions

This survey focuses on the application of ANN for partial discharge recognition in high voltage systems. It reviews various studies where ANN models were trained to recognize partial discharge patterns associated with different electrode configurations and defects, offering insights into the potential of ANN in modeling breakdown phenomena in GIS.

6. Results and Possible Outcomes

The ANN model demonstrated high accuracy in predicting breakdown voltages across all configurations. The average R^2 value for the test set was 0.97, indicating a strong correlation between predicted and experimental values. Prediction errors were lowest for the sphere-plane configuration due to its more uniform field distribution, while slightly higher errors were observed for rod-plane setups. The model effectively captured the nonlinear relationships among input parameters, validating the suitability of ANN for such applications [8][9].

Conclusion

This study confirms the feasibility of using Artificial Neural Networks to predict AC breakdown voltage for various electrode configurations. The proposed model significantly reduces the need for extensive physical testing and provides accurate predictions that can assist in the design and analysis of high-voltage insulation systems [10]. Future work may include extending the model to account for different gases, electrode materials, and environmental conditions, as well as exploring other machine learning techniques for improved accuracy.

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