

PhD offer

Deep learning for advanced physical models to predict breakdown voltage in complex industrial configurations

Context: The proposed PhD subject focuses on developing an AI-based engineering tool for breakdown voltage prediction in medium-voltage switchgear using pressurized pure air as the insulating medium. The motivation stems from the urgent need to replace SF₆, a potent greenhouse gas, with environmentally friendly alternatives. Pressurized air at 1 to 3 bar absolute pressure, with a focus on 3 bar, is considered a promising candidate. However, its lower dielectric strength compared to SF₆ requires optimized designs and accurate prediction tools to ensure reliability under severe electrical stresses, including lightning impulse conditions.

Current insulation design practices rely on IEC 62271 and IEC 60060 standards for testing, on finite element (FEM) electrostatic simulations to estimate the background electrical field, and on breakdown voltage limit estimation with criteria, such as the “Raether–Meek streamer criterion”, corrected with empirical factors based on experimental breakdown data. While this method is relatively accurate at pressure up to 2 bars, they are some lacks for complex geometries, and higher-pressure cases, and it does not take into account many of the design parameters.

Proposed PhD subject:

The proposed research aims to overcome these limitations by developing a physics-informed, AI model capable of predicting breakdown voltage based on electrostatic field simulation outputs, design and test parameters (“as features”), and advanced streamer inception criteria. An improved Raether–Meek criterion, which describes the conditions for streamer initiation, will be integrated into the model to provide a strong physical foundation and will serve as a key feature for training the AI system.

A major scientific challenge lies in adapting streamer theory to short-duration impulses, such as those used in Basic Insulation Level (BIL) tests with a 1.2/50 μ s waveform. Unlike AC or DC stresses, impulse conditions involve rapid voltage rise and transient field distributions, which significantly influence electron avalanche growth and time-to-breakdown. The research will address this by incorporating time-dependent avalanche models and correction factors into the physics-informed learning process. This adaptation will enable accurate prediction of breakdown voltage under lightning impulse conditions, validated against IEC 60060 and IEC 62271 dielectric test data.

The methodology will involve generating a comprehensive dataset through high-fidelity FEM electrostatic simulations of various electrodes geometries filled with pressurized air, combined with experimental breakdown measurements. During the PhD, there will be no limitation on computation time for data generation and model training, allowing the use of complex architectures such as convolutional neural networks for field maps, graph neural networks for geometry encoding, and physics-informed neural networks to embed fundamental laws.



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Multi-task learning approaches will be explored to jointly predict breakdown voltage and streamer inception thresholds, while maintaining a strong focus on model explainability and mathematical robustness. Particular attention will be paid to understanding what the models actually learn, ensuring proper convergence, and guaranteeing stability and robustness, especially in the context of physics-informed AI.

A dedicated part of the work will address Explainable AI methods to verify learned representations, along with an analysis of desired mathematical properties (output bounds, behavior under noise, probabilistic predictions, ...). Multi-instance methods for physics-informed neural networks, as well as transfer-learning approaches, will also be explored to improve generalization while maintaining interpretability. The final objective is to deliver an engineering-ready AI predictive tool with very short calculation times, suitable for integration into switchgear design workflows. This will require transitioning from high-fidelity models to lightweight implementations through techniques such as, surrogate modeling, and feature compression. The target performance is fast prediction, with accuracy within $\pm 5-10\%$ compared to IEC BIL test results. Such a tool will enable rapid design optimization for eco-friendly MV switchgear, reducing reliance on SF₆ while maintaining safety and reliability.

Environment of the PhD:

This three-year PhD project, proposed by Schneider Electric and the Grenoble Electrical Engineering Laboratory (G2ELAB), will be carried out jointly at G2ELAB and at the Schneider Electric Technopole R&D center, both located in Grenoble, France.

The PhD student will benefit from the experimental facilities and expertise available at both institutions, which are geographically very close to each other. The project will also involve close interactions with Schneider Electric design teams in Grenoble and Germany.

The expected starting date is September 2026.

Required candidate background:

The project is mainly experimental and will involve numerical calculations and the development of simplified physical models to interpret the observations and understand the underlying mechanisms. The candidate should therefore have a solid background in Electrical Engineering or Applied Physics, with an interest in both experimental work and modeling. The ability to analyze physical phenomena and translate them into numerical or conceptual models will be appreciated. Good communication skills and the ability to work within multidisciplinary research teams in both academic and industrial environments are also expected.

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