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Air Breakdown Voltage Prediction in Post-arcing Conditions for Compact Circuit Breakers

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Abstract : The air breakdown voltage in compact circuit breakers is a critical factor in the design and reliability of electrical distribution systems. This voltage determines the threshold at which the air insulation between conductors will fail or 'break down,' leading to an arc. This phenomenon is highly sensitive to the conditions within the breaker, such as the temperature and the distance between electrodes. Typically, air breakdown voltage models have been reliable for predicting failure under standard operational temperatures. However, in conditions post-arcing, where temperatures can soar above 2000K, these models face challenges due to the complex physics of ionization and electron behaviour at such high-energy states. Building upon the foundational understanding that the breakdown mechanism is initiated by free electrons and propelled by electric fields, which lead to ionization and, potentially, to avalanche or streamer formation, we acknowledge the complexity introduced by high-temperature environments. Recognizing the limitations of existing experimental data, a notable research gap exists in the accurate prediction of breakdown voltage at elevated temperatures, typically observed post-arcing, where temperatures exceed 2000K.To bridge this knowledge gap, we present a method that integrates gap distance and high-temperature effects into air breakdown voltage assessment. The proposed model is grounded in the physics of ionization, accounting for the dynamic behaviour of free electrons which, under intense electric fields at elevated temperatures, lead to thermal ionization and potentially reach the threshold for streamer formation as Meek's criterion. Employing the Saha equation, our model calculates equilibrium electron densities, adapting to the atmospheric pressure and the hot temperature regions indicative of post-arc temperature conditions. Our model is rigorously validated against established experimental data, demonstrating substantial improvements in predicting air breakdown voltage in the high-temperature regime. This work significantly improves the predictive power for air breakdown voltage under conditions that closely mimic operational stressors in compact circuit breakers. Looking ahead, the proposed methods are poised for further exploration in alternative insulating media, like SF6, enhancing the model's utility for a broader range of insulation technologies and contributing to the future of high-temperature electrical insulation research.

Keywords : air breakdown voltage, high-temperature insulation, compact circuit breakers, electrical discharge, saha equation
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