Different Stages for the Creation of Electric Arc Plasma through Slow Rate Current Injection to Single Exploding Wire, by Simulation and Experiment

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Abstract : This work simulates the voltage drop and resistance of the explosion of copper wires of diameters 25, 40, and 100 µm surrounded by 1 bar nitrogen exposed to a 150 A current and before plasma formation. The absorption of electrical energy in an exploding wire is greatly diminished when the plasma is formed. This study shows the importance of considering radiation and heat conductivity in the accuracy of the circuit simulations. The radiation of the dense plasma formed on the wire surface is modeled with the Net Emission Coefficient (NEC) and is mixed with heat conductivity through PLASIMO® software. A time-transient code for analyzing wire explosions driven by a slow current rise rate is developed. It solves a circuit equation coupled with one-dimensional (1D) equations for the copper electrical conductivity as a function of its physical state and Net Emission Coefficient (NEC) radiation. At first, an initial voltage drop over the copper wire, current, and temperature distribution at the time of expansion is derived. The experiments have demonstrated that wires remain rather uniform lengthwise during the explosion and can be simulated utilizing 1D simulations. Data from the first stage are then used as the initial conditions of the second stage, in which a simplified 1D model for high-Mach-number flows is adopted to describe the expansion of the core. The current was carried by the vaporized wire material before it was dispersed in nitrogen by the shock wave. In the third stage, using a three-dimensional model of the test bench, the streamer threshold is estimated. Electrical breakdown voltage is calculated without solving a full-blown plasma model by integrating Townsend growth coefficients (TdGC) along electric field lines. BOLSIG$^+$ and LAPLACE databases are used to calculate the TdGC at different mixture ratios of nitrogen/copper vapor. The simulations show both radiation and heat conductivity should be considered for an adequate description of wire resistance, and gaseous discharges start at lower voltages than expected due to ultraviolet radiation and the exploding shocks, which may have ionized the nitrogen.

Keywords : exploding wire, Townsend breakdown mechanism, streamer, metal vapor, shock waves
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