Thermal-Electrical Study of an Ultra-fast Disconnect Switch with a Piezoelectric Actuator

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Abstract

With increased adoption of intermittent sources of power generation and the need for dynamic and reconfigurable power grids, there has been a paradigm shift in power system design towards systems based on power electronic devices. This has created a need for a new kind of circuit breaker, since due to the fault current limiting, design requirements will focus on ultra-fast breaker operation to handle dynamic grid changes, rather than breaking large magnitude fault currents, as is the focus of conventional breakers. The last several years has seen the emergence of hybrid breaker designs which combine the speed and current breaking capabilities of high power semiconductors with the low losses of a fast mechanical disconnect switch ([1], [2]).

A research team at FSU CAPS is developing a novel disconnect switch based on a piezoelectric actuator to support the FREEDM System Center's development of a 15 kVAC, 200 A hybrid breaker based on SiC semiconductors. The piezoelectric actuator is expected to provide ultra-fast operation in the sub-millisecond range, however, use of the piezoelectric actuator limits contact force and contact travel to the range of a few hundred Newtons and less than a millimeter respectively. Therefore, contact design is critical to limiting resistance during the closed state and improving voltage withstand capability during the open state. The piezoelectric actuator is integrated in a vacuum switching chamber (Figure 1). Two ceramic feedthroughs provide power leads and a multi-pin feedthrough allows for actuator drive and feedback signals. The piezoelectric actuator's elliptical shell is housed in an insulator frame, which also holds the fixed and moving contacts.

COMSOL Multiphysics® software was used to optimize geometry and material selection of the disconnect switch. The requirements were low voltage drop, minimum temperature rise (Figure 2), mechanical stress levels well below the limit of the chosen materials (Figure 3), and electrostatic fields well below the critical breakdown field in vacuum (Figure 4). Besides the bulk copper conductor resistance, both contact resistance and solder resistance were taken into account for the thermal analysis, calculating the effects of Joule heating. The model for the contact resistance consists of both bulk resistance and constriction resistance without any contamination resistance. The thermal field is calculated in a transient model, which allows for studying the effect of temporary over-current. The structural analysis helped determine optimum thickness of the insulator strips holding the moving contact elements, thus keeping von Mises stresses to a safe level. The electrostatic field calculation confirmed that the chosen hemispherical contact geometry results in minimum field enhancement in the gap.

The use of COMSOL Multiphysics® proved to be essential in the design and optimization process of this novel disconnect switch. By adapting the geometry and cycling through materials with different properties, all design requirements were met. Parts for the first prototype are currently being machined and a subsequent phase of experiments is expected to start in a few months. Patents pending [3].

Reference

[1] J. Häfner, B. Jacobson, "Proactive Hybrid HVDC Breakers - A key innovation for reliable HVDC grids," Proc. of Cigré Bologna, Paper 0264 (2011).
[2] Y. Wu, M. Rong, Y. Wu, F. Yang, M. Li, Y. Li, "Development of a new topology of dc hybrid circuit breaker," Proc. of the 2nd International Conference on Electric Power Equipment - Switching Technology (ICEPE-ST), pp.1,4, 20-23 (Oct 2013).
[3] L. Graber, C. Widener, S. Smith, M. Steurer, "Fast Electromechanical Disconnect Switching Chamber with Integrated Drive Mechanism," U.S. provisional patent filed on 23 Jan 2014 under 61/930,755.

Figures used in the abstract

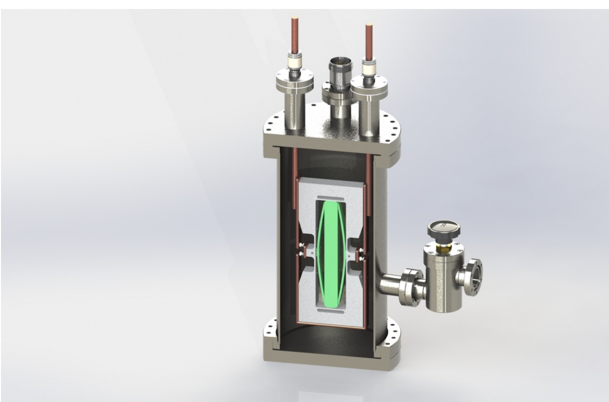

Figure 1: CAD rendering of the disconnect switch in the vacuum chamber (Patents pending [3]).

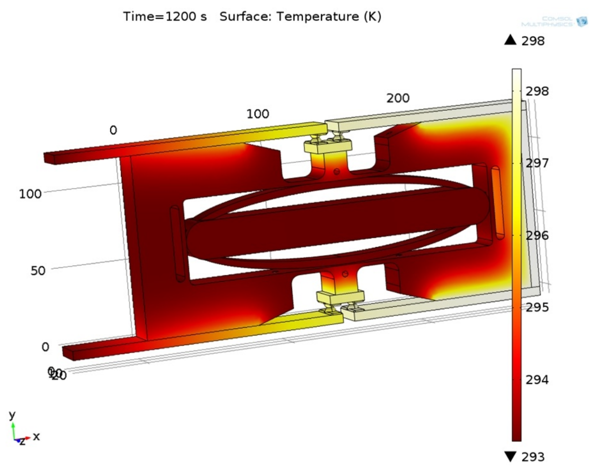

Figure 2: Thermal field of the switch assembly in vacuum after 20 minutes at a current of 200 A.

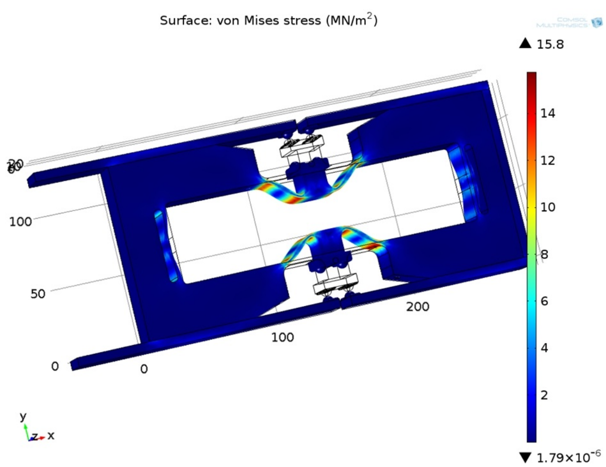

Figure 3: Von Mises stress at a contact displacement of 500 µm (actuator suppressed in the rendering).

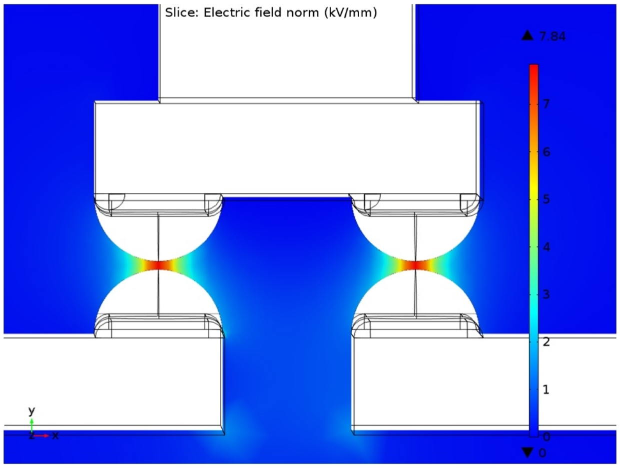

Figure 4: Electrostatic field around the open contact elements.